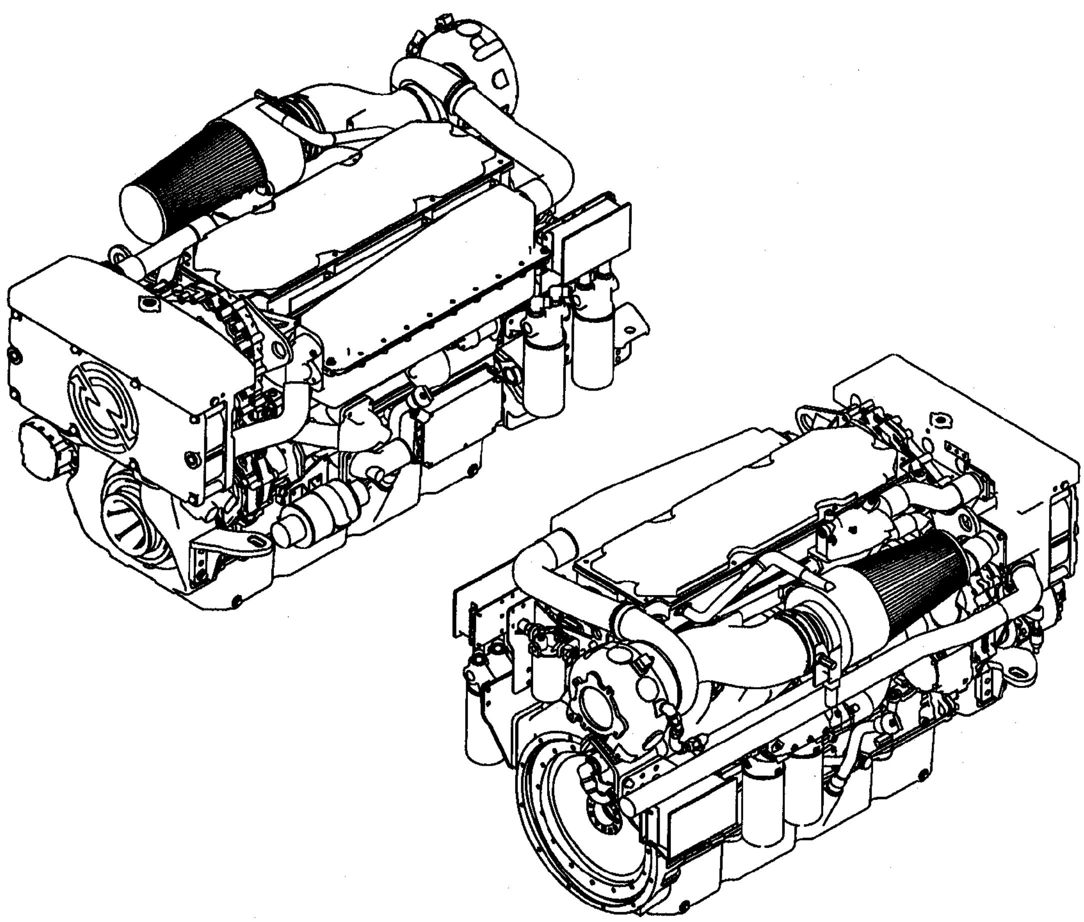
TM 55-1945-222-14&P-1

TECHNICAL MANUAL

OPERATOR, UNIT, DIRECT SUPPORT AND
GENERAL SUPPORT MAINTENANCE MANUAL
FOR

DIESEL ENGINE (DETROIT DIESEL)
DDC MODEL 60 SERIES

NSN 2815-01-505-2025



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Dates of issue for original and changed pages are:

Original ....0 .....15 JUNE 2005

TOTAL NUMBER OF PAGES FOR FRONT AND REAR MATTER IS 42 AND TOTAL NUMBER OF PAGES IN CHAPTERS IS 1000 CONSISTING OF THE FOLLOWING:

Page No.	*Change No.	Page No.	Change No
Front Cover	0	1-11/1-12	0
List of Effective Pages (A-F)	0	1-13/1-14	0
Publication Sheet (I/II blank)	0	1-15/1-16	0
Title Block Page	0	1-17/1-18	0
Table of Contents (i-xv/xvi blank)	0	1-19/1-20	0
Chapter 1	0	1-21/1-22	0
Registration	0	1-23/1-24	0
Maintenance Manual Cover	0	1-25/1-26	0
i/ii	0	1-27/1-28	0
iii/iv	0	1-29/1-30	0
v/vi	0	1-31/1-32	0
vii/viii	0	1-33/1-34	0
ix/x	0	1-35/1-36	0
xi/xii	0	1-37/1-38	0
xiii/xiv	0	1-39/1-40	0
1/2	0	1-41/1-42	0
3/4	0	1-43/1-44	0
5/6	0	1-45/1-46	0
7/8	0	1-47/1-48	0
9/10	0	1-49/1-50	0
11/12	0	1-51/1-52	0
13/14	0	1-53/1-54	0
15/16	0	1-55/1-56	0
17/18	0	1-57/1-58	0
19/20	0	1-59/1-60	0
21/22	0	1-61/1-62	0
23/24	0	1-63/1-64	0
25/26	0	1-65/1-66	0
27/28	0	1-67/1-68	0
29/30	0	1-69/1-70	0
31/32	0	1-71/1-72	0
33/34	0	1-73/1-74	0
35/36	0	1-75/1-76	0
37/38	0	1-77/1-78	0
39/40	0	1-79/1-80	0
41/42	0	1-81/1-82	0
43/44	0	1-83/1-84	0
45/46	0	1-85/1-86	0
1-1/1-2 blank	0	1-87/1-88	0
1-3/1-4	0	1-89/1-90	0
1-5/1-6	0	1-91/1-92	0
1-7/1-8	0	1-93/1-94	0
1-9/1-10	0	1-95/1-96	0

Page No.	*Change No.	Page No.	*Change No.
1-97/1-98	0	1-201/1-202	0
1-99/1-100	0	1-203/1-204	0
1-101/1-102	0	1-205/1-206	0
1-103/1-104	0	1-207/1-208	0
1-105/1-106	0	1-209/1-210	0
1-107/1-108	0	1-211/1-212	0
1-109/1-110	0	1-213/1-214	0
1-111/1-112	0	1-215/1-216	0
1-113/1-114	0	1-217/1-218	0
1-115/1-116	0	1-219/1-220	0
1-117/1-118	0	1-221/1-222	0
1-119/1-120	0	1-223/1-224	0
1-121/1-122	0	1-225/1-226	0
1-123/1-124	0	1-227/1-228	0
1-125/1-126	0	1-229/1-230	0
1-127/1-128	0	1-231/1-232	0
1-129/1-130	0	1-233/1-234	0
1-131/1-132	0	1-235/1-236	0
1-133/1-134	0	1-237/1-238	0
1-135/1-136	0	1-239/1-240	0
1-137/1-138	0	1-241/1-242	0
1-139/1-140	0	1-243/1-244	0
1-141/1-142	0	1-245/1-246	0
1-143/1-144	0	1-247/1-248	0
1-145/1-146	0	1-249/1-250	0
1-147/1-148	0	1-251/1-252	0
1-149/1-150	0	1-253/1-254	0
1-151/1-152	0	1-255/1-256	0
1-153/1-154	0	1-257/1-258	0
1-155/1-156	0	1-259/1-260	0
1-157/1-158	0	1-261/1-262	0
1-159/1-160	0	1-263/1-264	0
1-161/1-162	0	1-265/1-266	0
1-163/1-164	0	1-267/1-268	0
1-165/1-166	0	1-269/1-270	0
1-167/1-168	0	1-271/1-272	0
1-169/1-170	0	1-273/1-274	0
1-171/1-172	0	1-275/1-276	0
1-173/1-174	0	1-277/1-278	0
1-175/1-176	0	1-279/1-280	0
1-177/1-178	0	1-281/1-282	0
1-179/1-180	0	1-283/1-284	0
1-181/1-182	0	1-285/1-286	0
1-183/1-184	0	1-287/1-288	0
1-185/1-186	0	1-289/1-290	0
1-187/1-188	0	1-291/1-292	0
1-189/1-190	0	1-293/1-294	0
1-191/1-192	0	1-295/1-296	0
1-193/1-194	0	1-297/1-298	0
1-195/1-196	0	1-299/1-300	0
1-197/1-198	0	1-301/1-302	0
1-199/1-200	0	1-303/1-304	0

Page No.	*Change No.	Page No.	*Change No.
1-305/1-306	0	1-409/1-410	0
1-307/1-308	0	1-411/1-412	0
1-309/1-310	0	1-413/1-414	0
1-311/1-312	0	1-415/1-416	0
1-313/1-314	0	1-417/1-418	0
1-315/1-316	0	1-419/1-420	0
1-317/1-318	0	1-421/1-422	0
1-319/1-320	0	1-423/1-424	0
1-321/1-322	0	1-425/1-426	0
1-323/1-324	0	1-427/1-428	0
1-325/1-326	0	1-429/1-430	0
1-327/1-328	0	1-431/1-432	0
1-329/1-330	0	1-433/1-434	0
1-331/1-332	0	1-435/1-436	0
1-333/1-334	0	1-437/1-438	0
1-335/1-336	0	1-439/1-440	0
1-337/1-338	0	1-441/1-442	0
1-339/1-340	0	1-443/1-444	0
1-341/1-342	0	1-445/1-446	0
1-343/1-344	0	1-447/1-448	0
1-345/1-346	0	1-449/1-450	0
1-347/1-348	0	1-451/1-452	0
1-349/1-350	0	1-453/1-454	0
1-351/1-352	0	1-455/1-456	0
1-353/1-354	0	1-457/1-458	0
1-355/1-356	0	1-459/1-460	0
1-357/1-358	0	1-461/1-462	0
1-359/1-360	0	1-463/1-464	0
1-361/1-362	0	1-465/1-466	0
1-363/1-364	0	1-467/1-468	0
1-365/1-366	0	1-469/1-470	0
1-367/1-368	0	1-471/1-472	0
1-369/1-370	0	1-473/1-474	0
1-371/1-372	0	1-475/1-476	0
1-373/1-374	0	1-477/1-478	0
1-375/1-376	0	1-479/1-480	0
1-377/1-378	0	1-481/1-482	0
1-379/1-380	0	1-483/1-484	0
1-381/1-382	0	1-485/1-486	0
1-383/1-384	0	1-487/1-488	0
1-385/1-386	0	1-489/1-490	0
1-387/1-388	0	1-491/1-492	0
1-389/1-390	0	1-493/1-494	0
1-391/1-392	0	1-495/1-496	0
1-393/1-394	0	1-497/1-498	0
1-395/1-396	0	1-499/1-500	0
1-397/1-398	0	1-501/1-502	0
1-399/1-400	0	1-503/1-504	0
1-401/1-402	0	1-505/1-506	0
1-403/1-404	0	1-507/1-508	0
1-405/1-406	0	1-509/1-510	0
1-407/1-408	0	1-511/1-512	0

Page No.	*Change No.	Page No.	*Change No.
1-513/1-514	0	1-617/1-618	0
1-515/1-516	0	1-619/1-620	0
1-517/1-518	0	1-621/1-622	0
1-519/1-520	0	1-623/1-624	0
1-521/1-522	0	1-625/1-626	0
1-523/1-524	0	1-627/1-628	0
1-525/1-526	0	1-629/1-630	0
1-527/1-528	0	2-1/2-2	0
1-529/1-530	0	2-3/2-4	0
1-531/1-532	0	2-5/2-6	0
1-533/1-534	0	2-7/2-8	0
1-535/1-536	0	2-9/2-10	0
1-537/1-538	0	2-11/2-12	0
1-539/1-540	0	2-13/2-14	0
1-541/1-542	0	2-15/2-16	0
1-543/1-544	0	2-17/2-18	0
1-545/1-546	0	2-19/2-20	0
1-547/1-548	0	2-21/2-22	0
1-549/1-550	0	2-23/2-24	0
1-551/1-552	0	2-25/2-26	0
1-553/1-554	0	2-27/2-28	0
1-555/1-556	0	2-29/2-30	0
1-557/1-558	0	2-31/2-32	0
1-559/1-560	0	2-33/2-34	0
1-561/1-562	0	2-35/2-36	0
1-563/1-654	0	2-37/2-38	0
1-565/1-566	0	2-39/2-40	0
1-567/1-568	0	2-41/2-42	0
1-569/1-570	0	2-43/2-44	0
1-571/1-572	0	2-45/2-46	0
1-573/1-574	0	2-47/2-48	0
1-575/1-576	0	2-49/2-50	0
1-577/1-578	0	2-51/2-52	0
1-579/1-580	0	2-53/2-54	0
1-581/1-582	0	2-55/2-56	0
1-583/1-584	0	2-57/2-58	0
1-585/1-586	0	2-59/2-60	0
1-587/1-588	0	2-61/2-62	0
1-589/1-590	0	2-63/2-64	0
1-591/1-592	0	2-65/2-66	0
1-593/1-594	0	2-67/2-68	0
1-595/1-596	0	2-69/2-70	0
1-597/1-598	0	2-71/2-72	0
1-599/1-600	0	2-73/2-74	0
1-601/1-602	0	2-75/2-76	0
1-603/1-604	0	2-77/2-78	0
1-605/1-606	0	2-79/2-80	0
1-607/1-608	0	2-81/2-82	0
1-609/1-610	0	2-83/2-84	0
1-611/1-612	0	2-85/2-86	0
1-613/1-614	0	2-87/2-88	0
1-615/1-616	0	2-89/2-90	0

Page No.	*Change No.
2-91/2-92	0
2-93/2-94	0
2-95/2-96	0
2-97/2-98	0
2-99/2-100	0
2-101/2-102	0
2-103/2-104	0
2-105/2-106	0
2-107/2-108	0
2-109/2-110	0
2-111/2-112	0
2-113/2-114	0
2-115/2-116	0
2-117/2-118	0
2-119/2-120	0
2-121/2-122	0
2-123/2-124	0
2-125/2-126	0
2-127/2-128	0
2-129/2-130	0
2-131/2-132	0
2-133/2-134	0
2-135/2-136	0
2-137/2-138	0
2-139/2-140	0
2-141/2-142	0
2-143/2-144	0
2-145/2-146	0
2-147/2-148	0
2-149/2-150	0
2-151/2-152	0
2-153/2-154	0
2-155/2-156	0
2-157/2-158	0
2-159/2-160	0
2-161/2-162	0
2-163/2-164	0
2-165/2-166	0
2-167/2-168	0
2-169/2-170	0
2-171/2-172	0
2-173/2-174	0
2-175/2-176	0
2-177/2-178	0
2-179/2-180	0
2-181/2-182	0
2-183/2-184	0
2-185/2-186	0
2-187/2-188	0
2-189/2-190	0
2-191/2-192	0
2-193/2-194	0
2-195/2-196	0
2-197/2-198	0
2-199/2-200	0
2-201/2-202	0
2-203/2-204	0
2-205/2-206	0
2-207/2-208	0
2-209/2-210	0
2-211/2-212	0
2-213/2-214	0
2-215/2-216	0
2-217/2-218	0
2-219/2-220	0
2-221/2-222	0
2-223/2-224	0
2-225/2-226	0
2-227/2-228	0
2-229/2-230	0
2-231/2-232	0
2-233/2-234	0
2-235/2-236	0
2-237/2-238	0
2-239/2-240	0
2-241/2-242	0
2-243/2-244	0
2-245/2-246	0
2-247/2-248	0
2-249/2-250	0
2-251/2-252	0
2-253/2-254	0
2-255/2-256	0
2-257/2-258	0
2-259/2-260	0
2-261/2-262	0
2-263/2-264	0
DA Form 2028 (10 pgs)	0
Authentication Page (2 pgs)	0
Back Cover (2 pgs)	0

* Zero in this column indicates an original page

LIST OF EFFECTIVE PAGES (CONT'D)

ERRATA SHEET

The Warping Tug (WT) Engine is a Detroit Diesel DDC model 6062TK02.

The following pages do not apply to the Detroit Diesel engine installed on the Warping Tug (WT) engine.

Chapter 1

- 38 to 40
- 1-533 to 1-582

Chapter 2

- 2-7 to 2-10
- 2-102 to 2-127
- 2-141 to 2-161
- 2-176
- 2-220 to 2-260

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   PURCHASE ORDER OR CONTRACT NUMBER: DAAE 07-01-D-T026
   EQUIPMENT: Engine, Diesel, DDC Model 60 Series
   TITLE: Operator, Unit, Direct Support and General Support Maintenance Manual (Including Repair Parts and Special Tool List)
   DATE: 15 May 2004

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   a. Identifying Technical Publication Sheet.
   b. Front Manual Cover.
   c. Title Block Page.
   d. List of Effective Pages.
   e. Table of Contents.
   f. Chapter Identification Pages.
   g. Maintenance Allocation Chart (MAC) Introduction.
   h. Maintenance Allocation Chart (MAC).
   i. Maintenance Allocation Chart (MAC) Remarks.
   j. Maintenance Allocation Chart (MAC) Tools and Test Equipment.
   k. Repair Parts List.
   l. DA Form 2028.
   m. Metric Conversion Chart.

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WASHINGTON, D.C. 15 JUNE 2005

TECHNICAL MANUAL

OPERATOR, UNIT, DIRECT SUPPORT AND GENERAL SUPPORT MAINTENANCE MANUAL FOR

DIESEL ENGINE (DETROIT DIESEL) DDC MODEL 60 SERIES NSN 2815-01-505-2025

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TABLE OF CONTENTS

Chapter No./Page No.

NOTE - THIS MANUAL IS PRINTED IN THREE VOLUMES AS FOLLOWS:

TM 55-1945-222-14&P-1, consisting of: Table of Contents and Maintenance Sections 1 and 2.

TM 55-1945-222-14&P-2, consisting of: Table of Contents, Maintenance Sections 3 through 29, and Supplemental Maintenance Information.

TM 55-1945-222-14&P-3, consisting of: Table of Contents, Repair Parts and Special Tools Lists, Custom Parts Catalog, Drawings, and Supplemental Parts Data.

TABLE OF CONTENTS (CONT'D)

Chapter No./Page No.

TABLE OF CONTENTS (CONT'D)

Chapter No./Page No.

TABLE OF CONTENTS (CONT'D)

Chapter No./Page No.

TABLE OF CONTENTS (CONT'D)

Chapter No./Page No.

TABLE OF CONTENTS (CONT'D)

Chapter No./Page No.

TABLE OF CONTENTS (CONT'D)

Chapter No./Page No.

TABLE OF CONTENTS (CONT'D)

Chapter No./Page No.

TABLE OF CONTENTS (CONT'D)

Chapter No./Page No.

TABLE OF CONTENTS (CONT'D)

Chapter No./Page No.

TABLE OF CONTENTS (CONT'D)

TABLE OF CONTENTS (CONT'D)

Chapter No./Page No.

GENERAL INFORMATION (CONT'D)

SECTION 2 - CUSTOM PARTS CATALOG, VOL 3.

CUSTOM PARTS CATALOG, VOL 3.

TABLE OF CONTENTS (CONT'D)

Chapter No./Page No.

CUSTOM PARTS CATALOG, VOL 3. (CONT'D)

SECTION 3 - ENGINEERING DRAWINGS, VOL 3.

TABLE OF CONTENTS (CONT'D)

Chapter No./Page No.

TABLE OF CONTENTS (CONT'D)

CHAPTER 1

MAINTENANCE MANUAL
FOR
DIESEL ENGINE (DETROIT DIESEL)

DETROIT DIESEL
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Detroit Diesel® Series 60 Diesel, Natural Gas-Fueled, and Diesel Marine Engines

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CALIFORNIA
Proposition 65 Warning

Diesel engine exhaust and some of its constituents are known to the State of California to cause cancer, birth defects, and other reproductive harm.

ABSTRACT

This manual provides instruction for servicing on-highway, construction and industrial, generator set, and marine applications of the Detroit Diesel Series 60 Diesel and Natural Gas-Fueled Engines.

Specifically a basic overview of each major component and system along with recommendations for removal, cleaning, inspection, criteria for replacement, repair and installation and mechanical troubleshooting are contained in this manual.

DDEC III/IV troubleshooting concerns are contained in the DDEC III/IV Single ECM Troubleshooting Guide, 6SE497.

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ENGINE EXHAUST

Consider the following before servicing engines:

CAUTION:

Diesel engine exhaust and some of its constituents are known to the State of California to cause cancer, birth defects, and other reproductive harm.

- ☐ **Always start and operate an engine in a well ventilated area.**
- ☐ **If operating an engine in an enclosed area, vent the exhaust to the outside.**
- ☐ **Do not modify or tamper with the exhaust system or emission control system.**

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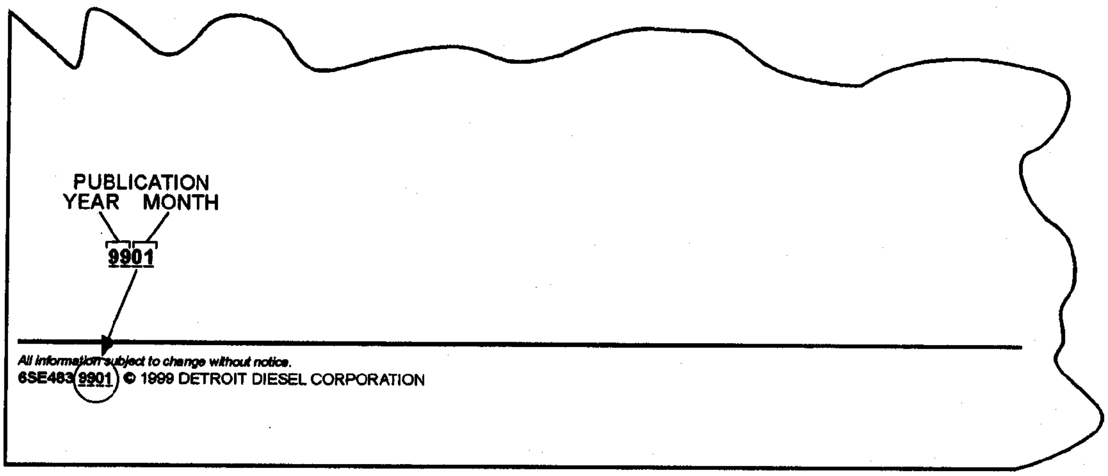
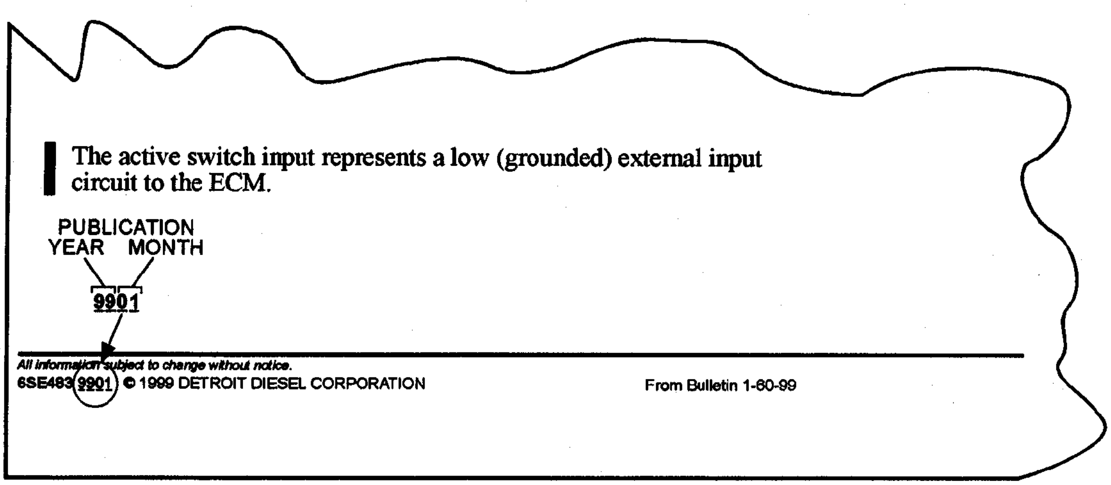
REVISION NOTIFICATION

Modifications to this manual are announced in the form of Service Information Bulletins. The bulletins include attachment pages and are posted on the World Wide Web (www.detroitdiesel.com/svc/sibindex.htm).

Revisions to this manual will be sent marked with a revision bar (see Example 2). Sections containing revisions will have a third line in the page footer (compare Examples 1 and 2).



Example 1 - Unchanged Pages



Example 2 - Changed Pages

TABLE OF CONTENTS

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GENERAL INFORMATION

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SCOPE AND USE OF THIS MANUAL

This manual contains complete instructions on operation, adjustment (tune-up), preventive maintenance, and repair (including complete overhaul) for the Series 60 Inline Diesel Engines. This manual was written primarily for persons servicing and overhauling the engine. In addition, this manual contains all of the instructions essential to the operators and users. Basic maintenance and overhaul procedures are common to all Series 60 Engines, and apply to all engine models.

This manual is divided into numbered sections. Section one covers the engine (less major assemblies). The following sections cover a complete system such as the fuel system, lubrication system, or air system. Each section is divided into subsections which contain complete maintenance and operating instructions for a specific engine subassembly. Each section begins with a table of contents. Pages and illustrations are numbered consecutively within each section.

Information can be located by using the table of contents at the front of the manual or the table of contents at the beginning of each section. Information on specific subassemblies or accessories within the major section is listed immediately following the section title.

CLEARANCE OF NEW PARTS AND WEAR LIMITS

New parts clearances apply only when all new parts are used at the point where the various specifications apply. This also applies to references within the text of the manual. The column entitled "Limits" must be qualified by the judgement of personnel responsible for installing new parts. For additional information, refer to the section entitled "Inspection" within this section. Refer to section ADDITIONAL INFORMATION, "Table of Specifications, New Clearances, and Wear Limits" under "Specifications", for a listing of clearances of new parts and wear limits on used parts.

THE FOUR CYCLE PRINCIPLE FOR DIESEL ENGINES

The diesel engine is an internal combustion engine, in which the energy of burning fuel is converted into energy to work the cylinder of the engine. In the diesel engine, air alone is compressed in the cylinder, raising its temperature significantly. After the air has been compressed, a charge of fuel is sprayed into the cylinder and ignition is accomplished by the heat of compression. The four piston strokes of the cycle occur in the following order: intake, compression, power and exhaust. See Figure 1.

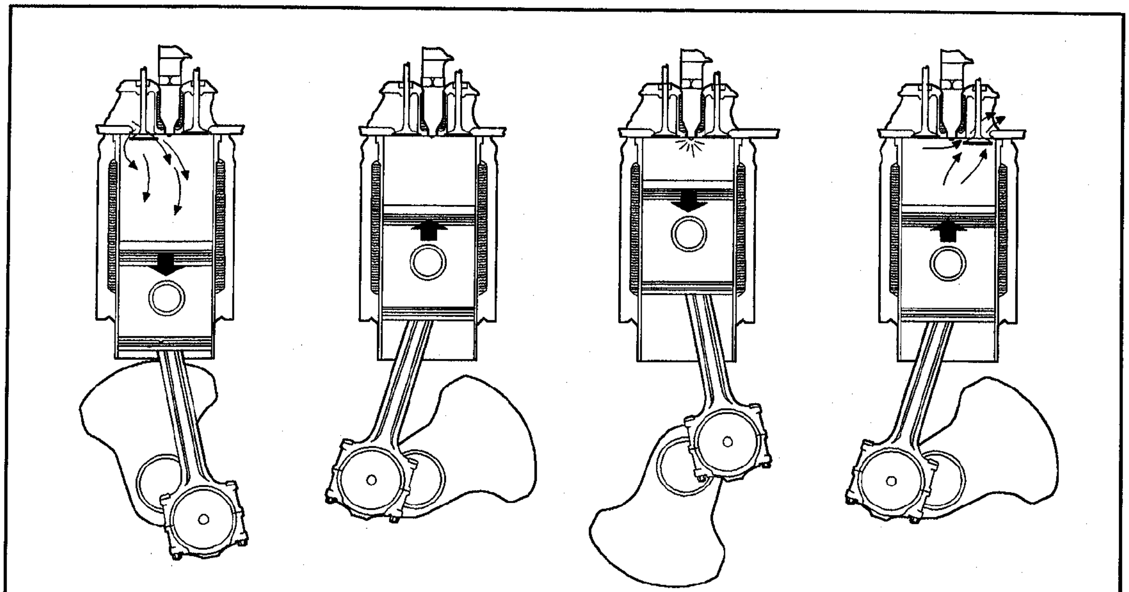

Figure 1 The Four Stroke Cycle (Diesel)

Intake Stroke

During the intake stroke, the piston travels downward, the intake valves are open, and the exhaust valves are closed. The down stroke of the piston facilitates air from the intake manifold to enter the cylinder through the open intake valve. The turbocharger, by increasing the air pressure in the engine intake manifold, assures a full charge of air is available for the cylinder.

The intake charge consists of air only with no fuel mixture.

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Compression Stroke

At the end of the intake stroke, the intake valves close and the piston starts upward on the compression stroke. The exhaust valves remain closed.

At the end of the compression stroke, the air in the combustion chamber has been compressed by the piston to occupy a space about one-fifteenth as great in volume as it occupied at the beginning of the stroke. Thus, the compression ratio is 15:1.

Compressing the air into a small space causes the temperature of that air to rise. Near the end of the compression stroke, the pressure of the air above the piston is approximately 3445 to 4134 kPa (500 to 600 lb/in.^{2}) and the temperature of that air is approximately 538°C (1000°F). During the last part of the compression stroke and the early part of the power stroke, a small metered charge of fuel is injected into the combustion chamber.

Almost immediately after the fuel charge is injected into the combustion chamber, the fuel is ignited by the hot air and starts to burn, beginning the power stroke.

Power Stroke

During the power stroke, the piston travels downward and all intake and exhaust valves are closed.

As the fuel is added and burns, the gases get hotter, the pressure increases, pushing the piston downward and adding to crankshaft rotation.

Exhaust Stroke

During the exhaust stroke, the intake valves are closed; the exhaust valves are open, and the piston is on its up stroke.

The burned gases are forced out of the combustion chamber through the open exhaust valve port by the upward travel of the piston.

From the preceding description, it is apparent that the proper operation of the engine depends upon the two separate functions: first, compression for ignition, and second, that fuel be measured and injected into the compressed air in the cylinder in the proper quantity and at the proper time.

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FOUR CYCLE PRINCIPLE FOR NATURAL GAS ENGINES

This engine is a four cycle internal combustion engine, in which the energy of burning fuel is converted into energy to work the cylinder of the engine. However, unlike the diesel engine, a combustible air and fuel mixture is introduced to the cylinder during the intake stroke. Upon compression, the temperature of this mixture is increased to a temperature below its auto-ignition threshold. Combustion occurs through means of a spark plug which ignites the mixture. See Figure 2 for the four stroke cycle utilized on the natural gas engine.

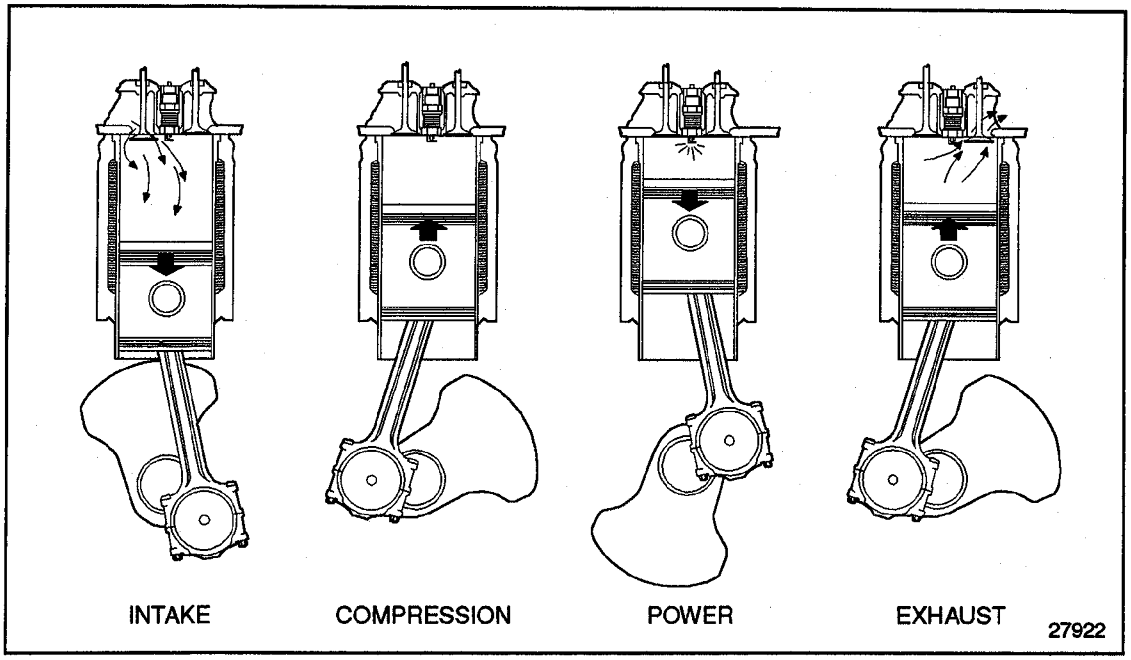

Figure 2 The Four Stroke Cycle (Series 60G Engine)

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Intake Stroke

During the intake stroke, the piston travels downward, the intake valves are open, and the exhaust valve are closed. The downward stroke of the piston increases the volume in the cylinder and draws in a fresh air and fuel mixture through the intake valves.

Compression Stroke

At the end of the intake stroke, the intake valves close and the piston starts upward on the compression stroke. The exhaust valves remain closed.

At the end of the compression stroke, the air-fuel mixture in the combustion chamber has been compressed by the piston to occupy a space about one-tenth as great in volume as it occupied at the beginning the stroke. Thus, the compression ratio is 10:1. This act of compression dramatically increases the temperature of the air-fuel mixture, to a temperature below its auto-ignition threshold. It is a timed, externally supplied ignition through the spark plug that actually causes ignition to the mixture. The timed spark is introduced to the cylinder near the end of the compression stroke, which initiates combustion and begins the power stroke.

Power Stroke

During the power stroke, the piston travels downward and all intake and exhaust valves are closed.

As the throttle is opened to introduce a greater charge of air-fuel mixture to the cylinders, the increasing pressure of combustion against the pistons adds to crankshaft rotation.

Exhaust Stroke

During the exhaust stroke, the intake valves are closed, the exhaust valves are open, and the piston is on its up stroke.

The burning gases are forced out of the combustion chamber through the open exhaust valve port by the upward travel of the piston.

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GENERAL DESCRIPTION

The Series 60® Diesel Engine described in this manual is a four-stroke cycle, high speed, diesel engine.

It uses an inline cast iron block and has a cast iron cylinder head that contains a single overhead camshaft. The camshaft actuates all the valves (two intake, two exhaust per cylinder), and operates the fuel injectors. The vertically aligned gear train, located at the front end of the engine in a gear case, contains drive gears for the lubricating oil pump, crankshaft, camshaft, air compressor drive, fuel pump drive, water pump and alternator accessory drives.

Each current engine is equipped with dual full-flow oil filters, an oil cooler, one or two fuel oil filters, a turbocharger and an electronic engine control system.

Full pressure lubrication is supplied to all main, connecting, camshaft and rocker assembly bearings and to other moving parts. A gear-type pump draws oil from the oil pan through a screen and delivers it to the oil filters. From the filter, a small portion of the oil is delivered directly to the turbocharger by an external oil line. The remainder of the oil flows to the oil cooler, or bypasses the cooler, and then enters a longitudinal oil gallery in the cylinder block where the supply divides. Part of the oil goes to the cylinder head where it feeds the camshaft bearings and rocker assemblies. The remainder of the oil goes to the main bearings and connecting rod bearings via the drilled oil passages in the crankshaft. Drilled passages in the connecting rod feed oil to the piston pin and the inner surface of the piston crown.

Coolant is circulated through the engine by a centrifugal-type water pump. The cooling system, including the radiator, is a closed system. Heat is removed from the coolant by the radiator. Control of the engine temperature is accomplished by thermostats that regulate the flow of the coolant within the cooling system.

Fuel is drawn from the supply tank through the primary fuel filter by a gear-type fuel pump. From there, the fuel is forced through the secondary fuel filter and into the fuel inlet in the cylinder head and to the injectors. Excess fuel is returned, through a restricted fitting, to the supply tank through the outlet connecting line. Since the fuel is constantly circulating through the injectors, it serves to cool the injectors and to carry off any air in the fuel system. Air separators are available, as optional equipment.

Air is supplied by the turbocharger to the intake manifold and into the engine cylinders after passing through an air-to-air charge air cooler mounted ahead of the cooling system radiator. The charge air cooler cools the pressurized intake air charge coming from the turbocharger before it enters the intake manifold.

Engine starting may be provided by an electric or air starting motor energized by a storage battery or air pressure storage system. A battery charging alternator, with a suitable voltage regulator, serves to keep the battery charged.

The Series 60 diesel engine was designed to be electronically controlled. The Detroit Diesel Electronic Control (DDEC) system has evolved with the product.

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DDEC I

DDEC I controls the timing and amount of fuel injected into each cylinder. The system also monitors several engine functions using various sensors that send electrical signals to the main Electronic Control Module (ECM). See Figure 3. The ECM uses this information to send a command pulse to the Electronic Distributor Unit (EDU). The EDU functions as the high current switching unit for actuation of the Electronic Unit Injector (EUI) solenoids. The ECM also has the ability to limit or shut down the engine completely (depending on option selection) in the case of damaging engine conditions, such as low oil pressure, low coolant level, or high oil temperature.

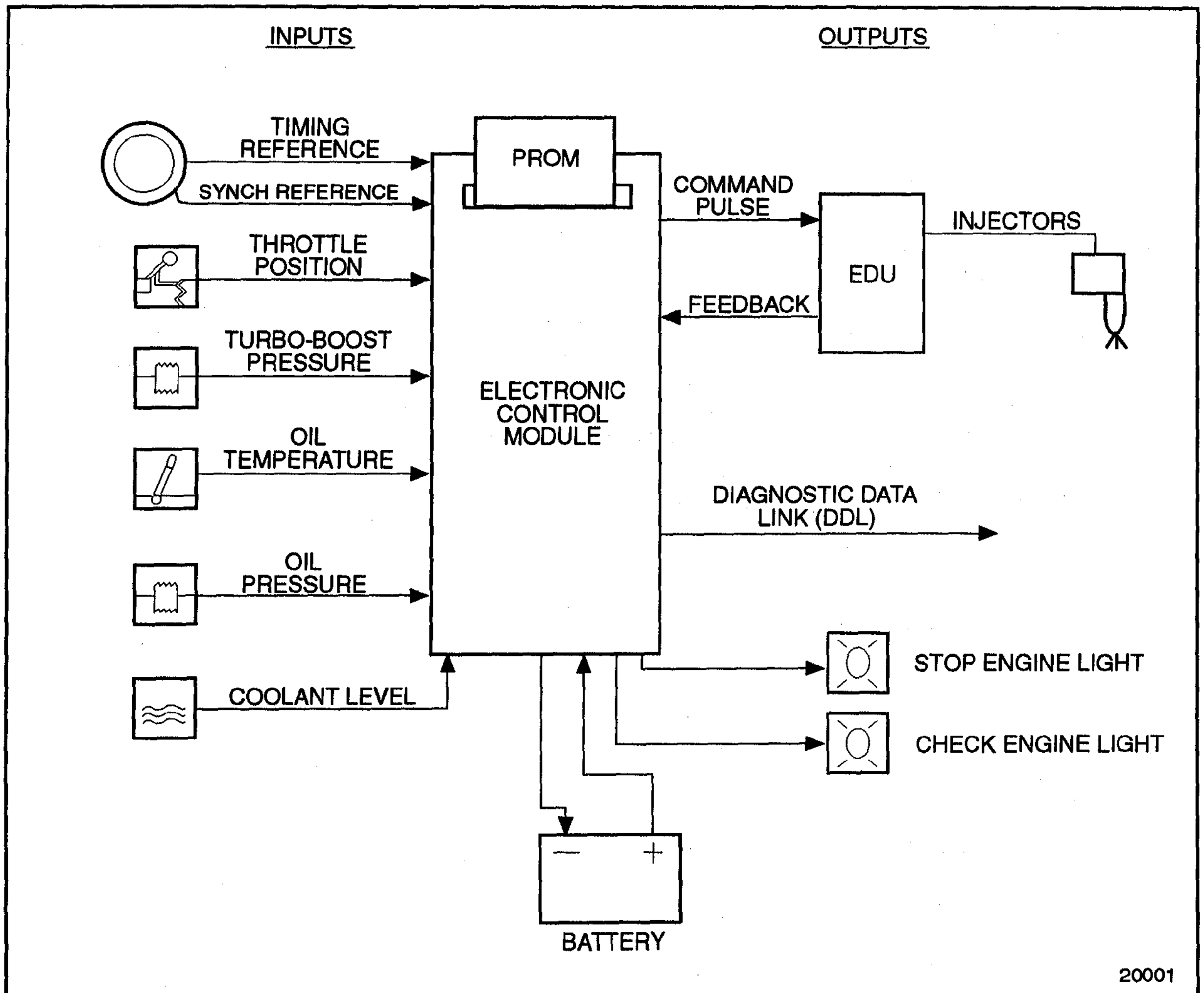

Figure 3 Schematic Diagram of DDEC I

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DDEC II

DDEC II also controls the timing and amount of fuel injected into each cylinder. The system also monitors several engine sensors that send electrical signals to the main ECM. See Figure 4. Unlike DDEC I, the DDEC II ECM uses this information to actuate the EUI solenoids. DDEC II incorporates all of the control electronics into one engine mounted ECM instead of the ECM and EDU that are required in DDEC I. The ECM also has the ability to limit or shut down the engine completely (depending on option selection) in the case of damaging engine conditions, such as low oil pressure, low coolant level, or high oil temperature.

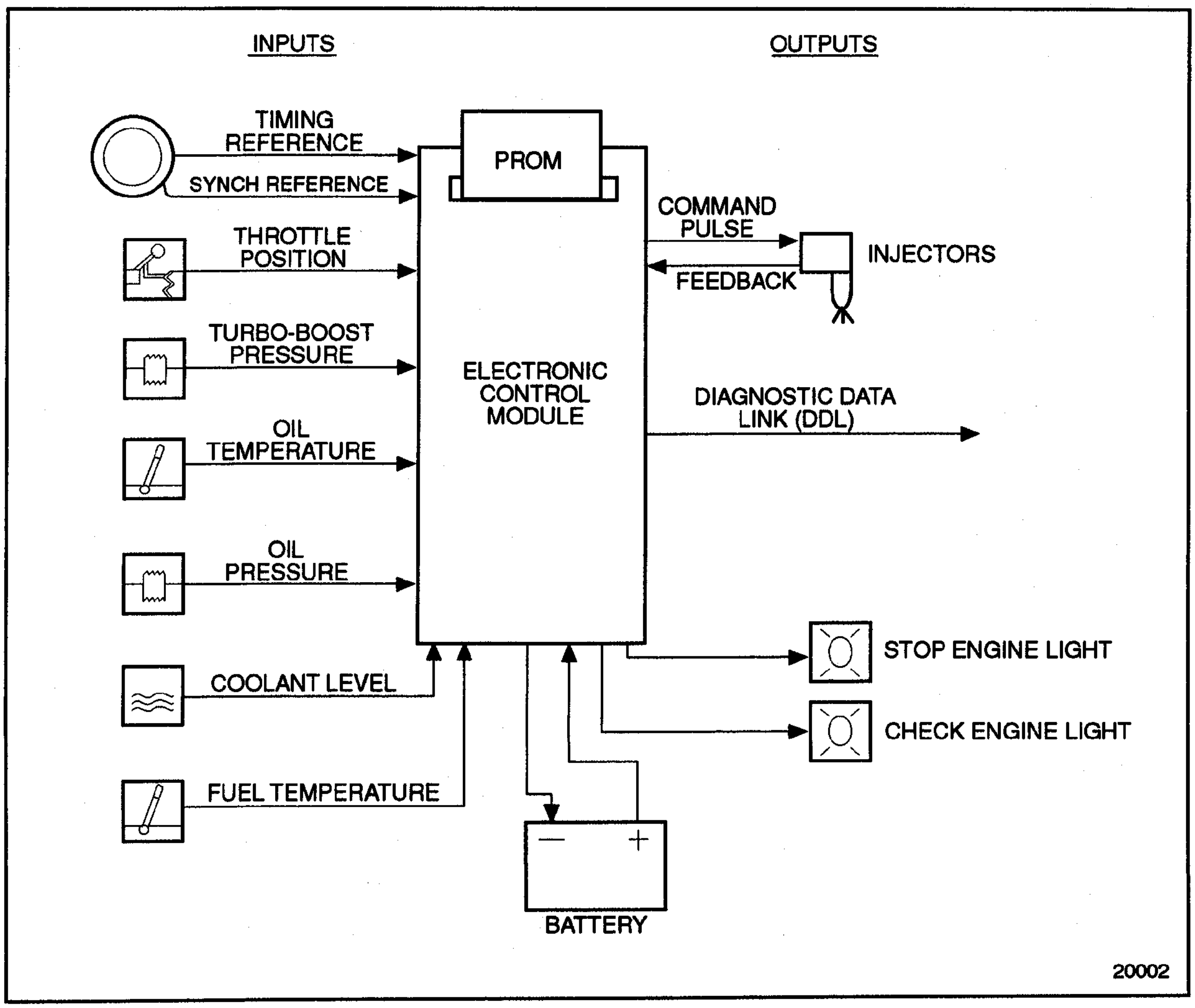

Figure 4 Schematic Diagram of DDEC II

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DDEC III/IV

The DDEC III/IV ECM receives electronic inputs from sensors on the engine and vehicle, and uses the information to control engine operation. It computes fuel timing and fuel quantity based upon predetermined calibration tables in its memory.

Fuel is delivered to the cylinders by the EUIs, which are cam-driven to provide the mechanical input for pressurization of the fuel. The ECM controls solenoid operated valves in the EUIs to provide precise fuel delivery. See Figure 5.

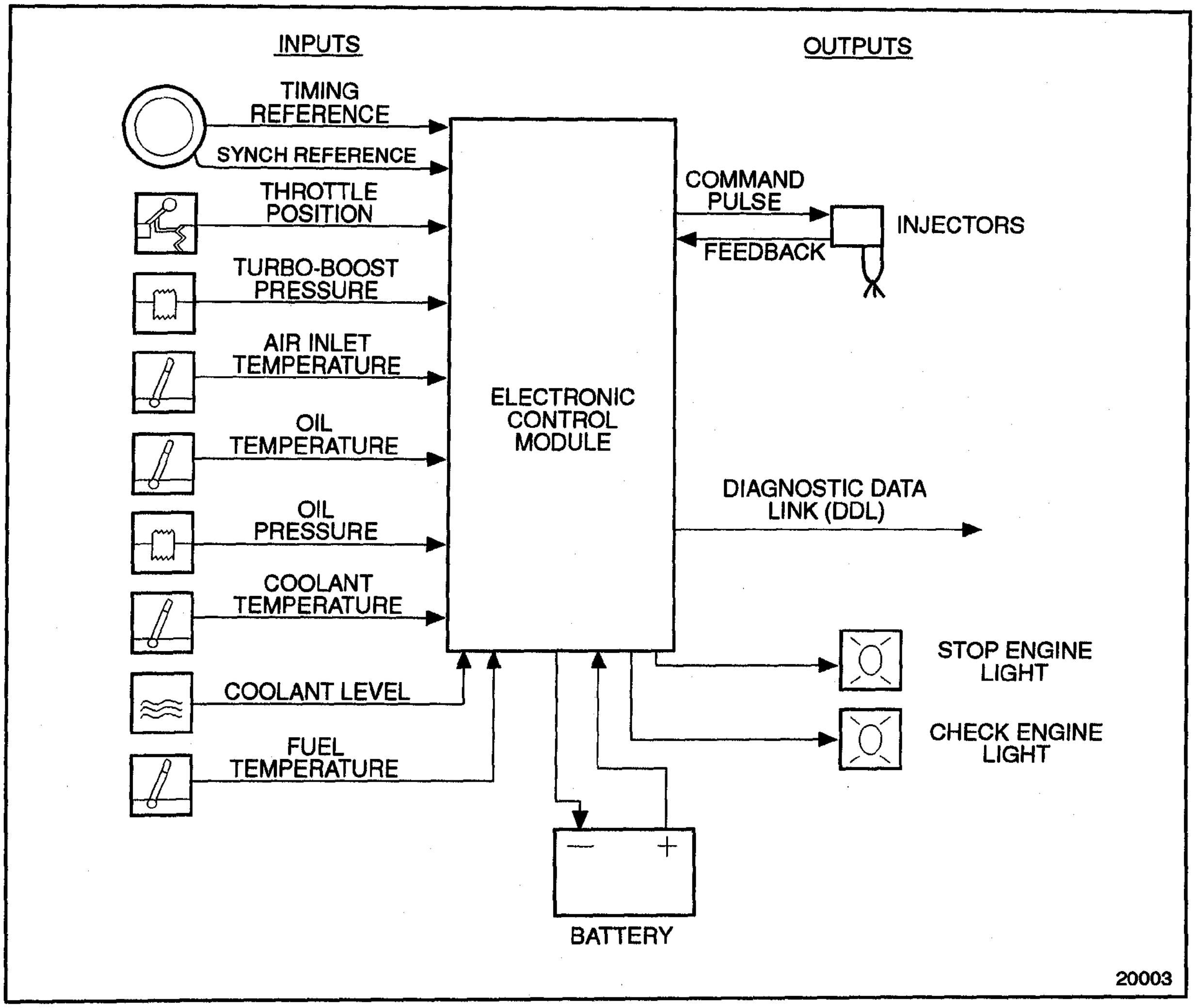

Figure 5 Schematic Diagram of DDEC III/IV

Portable equipment facilitates access to diagnostic capabilities of DDEC III/IV's. The Diagnostic Data Reader (DDR) requests and receives engine data and diagnostic codes. This equipment provides many unique capabilities including cylinder cutout, printer output, and data snapshot. The DDR also provides limited programming capability.

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DDEC III/IV (Series 60G Engine)

The DDEC III/IV ECM receives electronic inputs from sensors on the engine and vehicle, and uses the information to control engine operation.

Fuel is controlled by DDEC. See Figure 6.

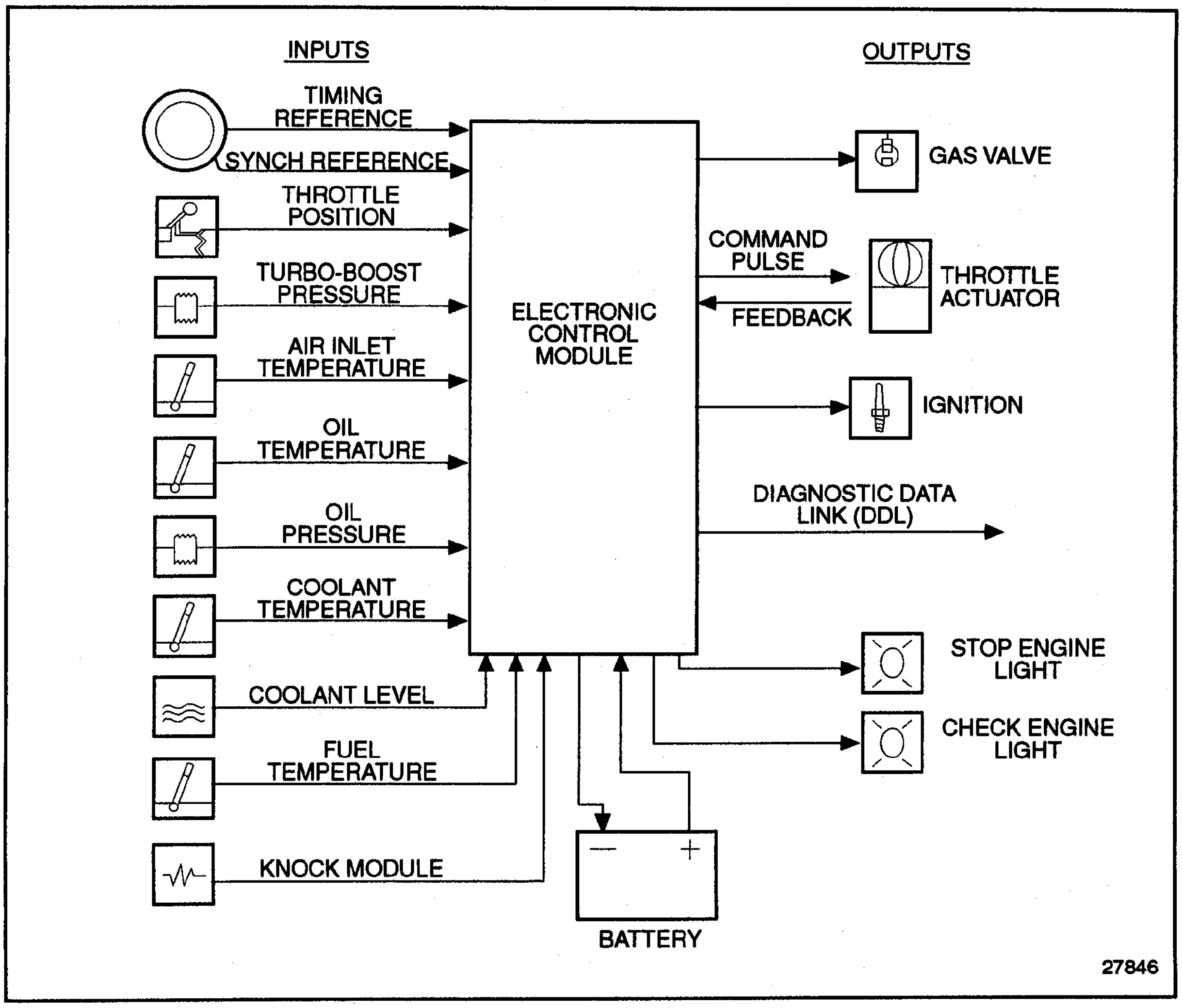

Figure 6 Schematic Diagram of DDEC III/IV (Series 60G Engine)

Portable equipment facilitates access to diagnostic capabilities of DDEC III/IV's. The Diagnostic Data Reader (DDR) requests and receives engine data and diagnostic codes. This equipment provides many unique capabilities including cylinder cutout, printer output, and data snapshot. The DDR also provides limited programming capability.

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GENERAL SPECIFICATIONS

The general specifications for the Series 60 Engine are listed in Table 1. See Figure 7 for the cylinder designation and firing order.

General Specifications	11.1L Family	12.7L Family	14L Family
Total Displacement (L)	11.1	12.7	14.0
Total Displacement (in.^{3})	677	775	855
Type	4-cycle	4-cycle	4-cycle
Number of Cylinders	6	6	6
Bore (in.)	5.12	5.12	5.24
Bore (mm)	130	130	133
Stroke (in.)	5.47	6.30	6.61
Stroke (mm)	139	160	168
Compression Ratio	16.0:1	15.0:1 or 16.5:1	15.0:1 or 16.5:1
Number of Main Bearings	7	7	7

Table 1 Specifications for the Series 60 Engine

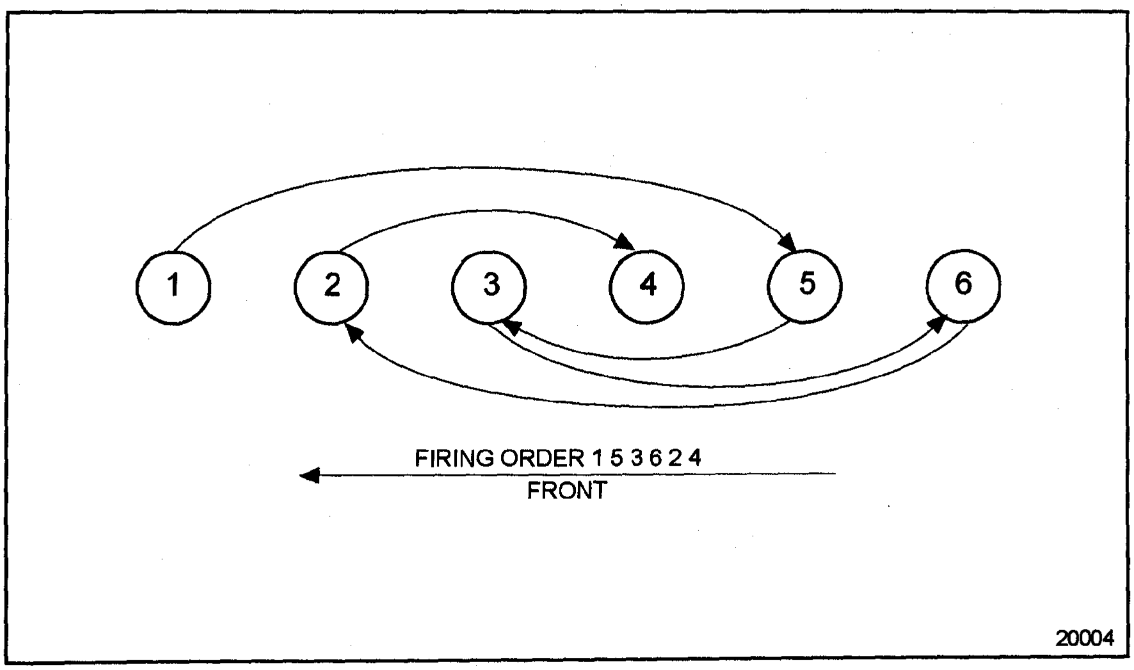

Figure 7 Cylinder Designation and Firing Order

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GENERAL SPECIFICATIONS FOR THE SERIES 60G ENGINE

The general specifications for the Series 60G Engine are listed in Table 2. See Figure 8 for cylinder designation and firing order.

General Description	Specification
Total Displacement (L)	12.7
Total Displacement (in.^{3})	775
Type	Four-cycle
Number of Cylinders	6
Bore (in.)	5.12
Bore (mm)	130
Stroke (in.)	6.30
Stroke (mm)	160
Compression Ratio	10:1
Number of Main Bearings	7

Table 2 General Specifications for the Series 60G Engine

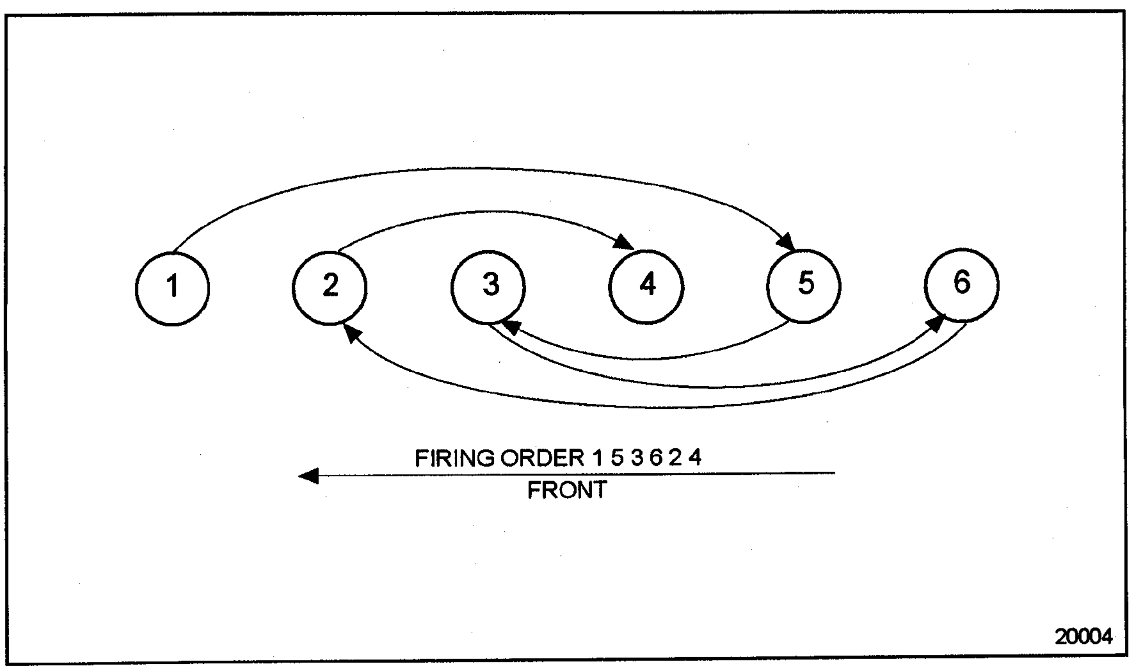

Figure 8 Cylinder Designation and Firing Order for the Series 60G Engine

ENGINE MODEL, SERIAL NUMBER AND OPTION LABEL

The engine serial and model numbers are stamped on the cylinder block. See Figure 9. A guide to the meaning of the model number digits is listed in Table 3.

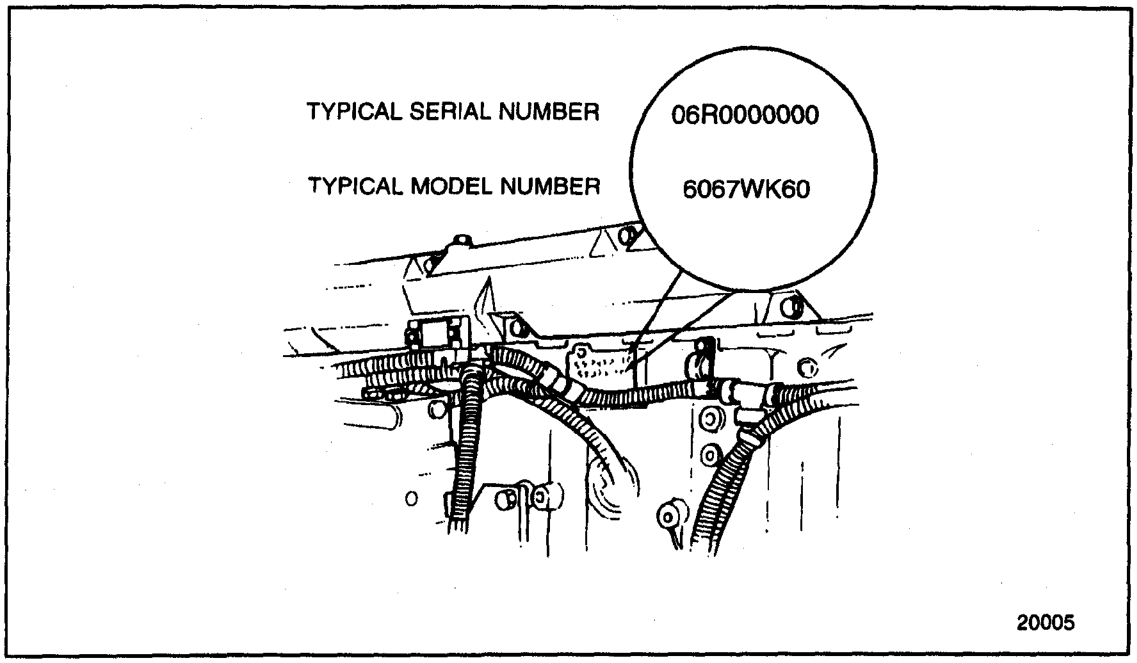

Figure 9 Location of Engine Serial and Model Number on Block

Digit	Value	Meaning
1	6	Series 60 Engine
2 & 3	06	Six Cylinders
4	2	Marine Application
4	3	Industrial Application
4	5	Generator Application
4	7	Automotive Application
5	W, S, E, L	11.1 L Displacement
5	G, T, M	12.7 L - Standard
5	P, B	12.7 L - Premium
5	F, H	14 L Displacement
6	T	DDEC I Engine Control
6	U	DDEC II Engine Control
6	K	DDEC III/IV Engine Control
7 & 8	28	1991 and later Coach
7 & 8	32	Underground Mining
7 & 8	40	Pre-1991 Engine
7 & 8	60	1991 and later On-Highway Truck

Table 3 Model Number Description for Series 60 Engine

For example, 6067-WK60 represents an 11.1 liter Series 60 engine that is controlled with DDEC III/IV electronics to be used in a 1991 or later truck.

Option labels attached to the valve rocker cover contain the engine serial and model numbers and list any optional equipment used on the engine. See Figure 10.

With any order for parts, the engine model number with serial number should be given. In addition, if a type number is shown on the option plate covering the equipment required, this number should also be included on the parts order.

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All groups or parts used on a unit are standard for the engine model unless otherwise listed on the option plate.

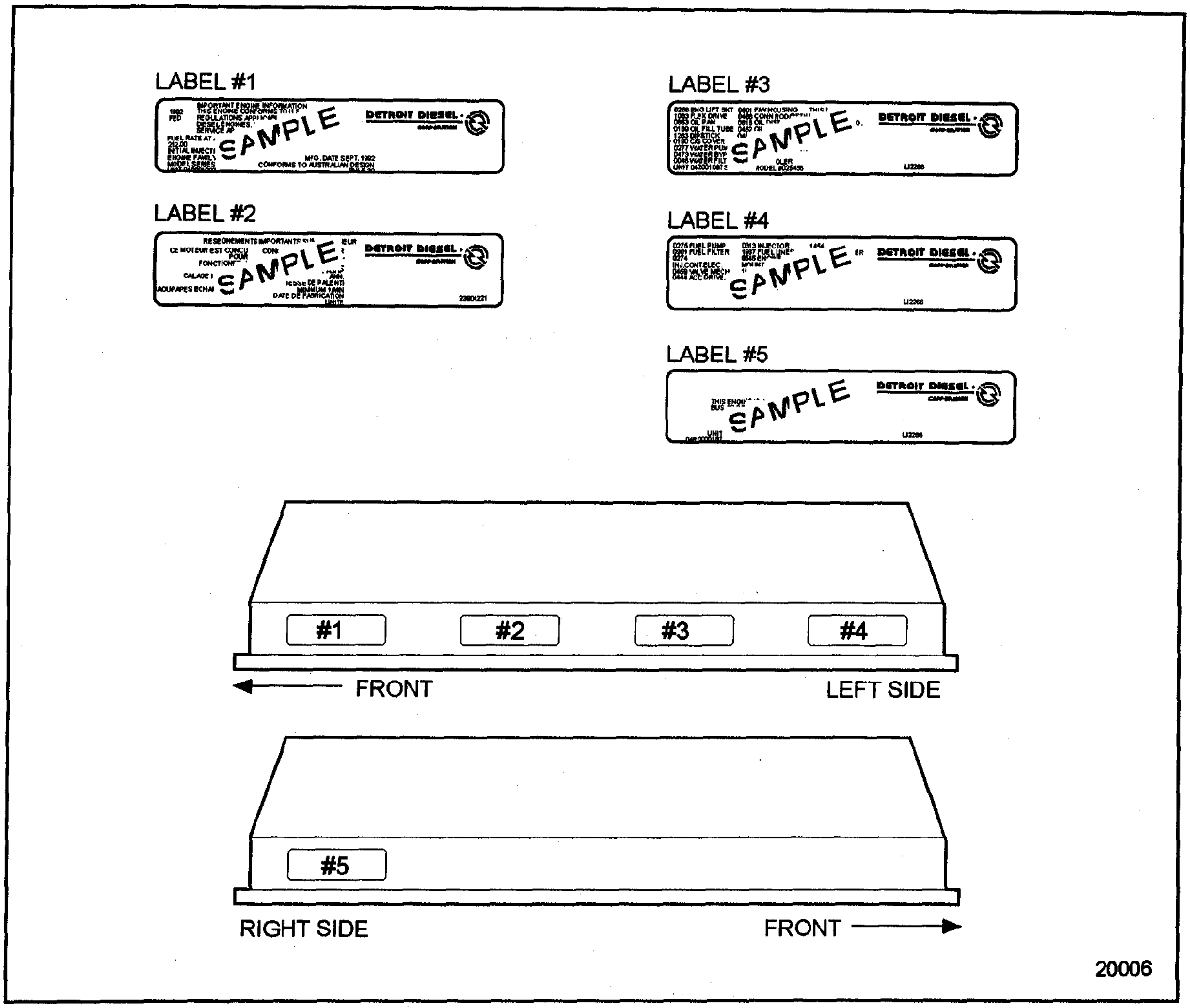

Figure 10 Rocker Cover with Option Label

ENGINE MODEL, SERIAL NUMBER AND OPTION LABEL (SERIES 60G ENGINE)

The engine serial and model numbers are stamped on the cylinder block. See Figure 11. A guide to the meaning of the serial number digits is listed in Table 4.

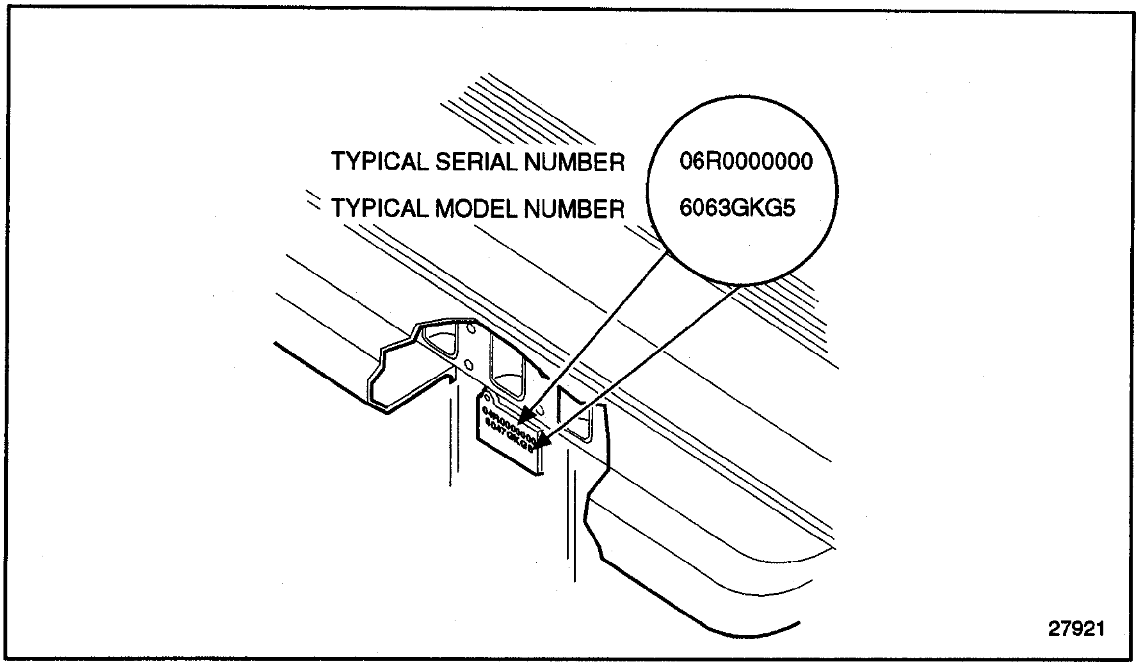

Figure 11 Location of Engine Serial and Model Number on Block (Series 60G Engine)

Digit	Value	Meaning
1	6	Series 60 Engine
2 & 3	06	Six Cylinders
4	3 / 7	Generator Application / Automotive
5	G / T	12.7 L Displacement
6	K	DDEC III / DDEC IV
7	G	Alternate Fuel Engine
8	5 / 8	Customer Designation

Table 4 Model Number Description for Series 60G Engine

REPLACING AND REPAIRING

In many cases, a technician is justified in replacing parts with new material rather than attempting repair. However, there are times when a slight amount of reworking or reconditioning may save a customer considerable added expense. Exchange assemblies such as injectors, fuel pumps, water pumps and turbochargers are desirable service items.

Various factors such as the type of operation of the engine, hours in service and the next overhaul period must be considered when determining whether new parts are installed or used parts are reconditioned to provide trouble-free operation.

For convenience and logical order in disassembly and assembly, the various subassemblies and other related parts mounted on the cylinder block will be treated as separate items in the various sections of the manual.

DISASSEMBLY

A technician can be severely injured if caught in pulleys, belts or the fan of an engine that is accidentally started. To avoid such a misfortune, take the following precautions before starting to work on an engine.

CAUTION:

To avoid injury from accidental engine startup while servicing the engine, disconnect/disable the starting system.

CAUTION:

To avoid injury from the sudden release of a high-pressure hose connection, wear a face shield or goggles.
Bleed the air from the air starter system before disconnecting the air supply hose.

Before any major disassembly, the engine must be drained of lubricating oil, coolant and fuel.

To perform a major overhaul or other extensive repairs, the complete engine assembly, after removal from the engine base and drive mechanism, should be mounted on an engine overhaul stand; then the various subassemblies should be removed from the engine. When only a few items need replacement, it is not always necessary to mount the engine on an overhaul stand.

Parts removed from an individual engine should be kept together so they will be available for inspection and assembly. Those items having machined faces, which might be easily damaged by steel or concrete, should be stored on suitable wooden racks or blocks, or a parts dolly.

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CLEANING

Before removing any of the subassemblies from the engine (but after removal of the electrical equipment), the exterior of the engine should be thoroughly cleaned.

NOTICE:
The Series 60 engine is equipped with various sensors and other electronic components which may be damaged if subjected to the high temperatures in a solvent tank. Do not immerse any electrical components in a solvent tank. Care should be taken to ensure that all electronic components are removed from the various engine assemblies before they are immersed in a solvent tank. Refer to section 8for a description of these components.

Then, after each subassembly is removed and disassembled, the individual parts should be cleaned. Thorough cleaning of each part is absolutely necessary before it can be satisfactorily inspected. Various items of equipment needed for general cleaning are listed below.

The cleaning procedure used for all ordinary cast iron parts is the same as the following cylinder block cleaning procedure. Any special cleaning procedures will be mentioned when required.

Remove cylinder liners before putting the block in cleaning or descaling baths, to avoid trapping cleaning agents in block liner seating bores.

After stripping and before removing the cylinder block from the overhaul stand for cleaning and inspection, install the two metric eye bolts into head bolt holes at each end of the cylinder block.

Remove all oil and water gallery and weep hole plugs to allow the cleaning solution to enter the inside of the oil and water passages.

1. Using two metric eye bolts installed in the head bolt holes at opposite ends of the block, and with a suitable lifting device and spreader bar, immerse and agitate the block in a hot bath of a commercial, heavy-duty alkaline solution.
2. Wash the block in hot water or steam clean it to remove the alkaline solution.
3. If the water jackets are heavily scaled, proceed as follows:
   - [a] Agitate the block in a bath of inhibited phosphoric acid.
   - [b] Allow the block to remain in the acid bath until the bubbling action stops (approximately 30 minutes).
   - [c] Lift the block, drain it and immerse it again in the same acid solution for 10 more minutes. Repeat until all scale is removed from the water jacket area.
   - [d] Rinse the block in clear, hot water to remove the acid solution.
   - [e] Neutralize the acid that may cling to the casting by immersing the block in an alkaline bath.

[f] Wash the block in clean water or steam clean it.

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

4. Dry the cylinder block with compressed air.

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

5. Blow out all of the bolt holes and passages with compressed air.

NOTE:
The above cleaning procedure may be used on all ordinary cast iron and steel parts for the engine. Aluminum parts, such as flywheel housing, air intake manifold, oil filter adaptor and the camshaft gear access cover should NOT be cleaned in this manner. Mention will be made of special procedures when necessary.

6. Be certain that all water passages and oil galleries have been thoroughly cleaned. After the cylinder block has been thoroughly cleaned and dried, install weep hole plugs and precoated pipe plugs. Install new cup plugs using a coating of good grade non-hardening sealant such as Loctite® 620 or equivalent.

Loctite® is a registered trademark of The Loctite Corporation.

Steam Cleaning

A steam cleaner is a necessary item in a large shop and is useful for removing heavy accumulations of grease and dirt from the exterior of the engine and its subassemblies.

Solvent Tank Cleaner

Chlorinated solvents such as 1,1,1 trichloroethane have been identified by the EPA (Environmental Protection Agency) as possessing ozone-depleting properties. Special procedures have been developed for the handling and proper disposal of these chemicals. For environmental considerations, Detroit Diesel has replaced 1,1,1 trichloroethane with Tech Solv 340 branded solvent.

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Tech Solv 340 is a petroleum-based solvent that contains no chlorinated or fluorinated compounds, has a controlled evaporation rate, leaves no residue, is odorless, has a high flash point, and provides outstanding cleaning. To enhance its cleaning and drying properties, it may be heated to 52°C (125°F). Spills can be cleaned up with commercially available oil absorbents, and conventional waste treatment methods for petroleum-based products can be used when disposing of this product.

Detroit Diesel believes that a prudent environmental approach to the use of 1,1,1 trichloroethane should be taken. Therefore, Detroit Diesel recommends replacing 1,1,1 trichloroethane with Tech Solv 340 branded solvent wherever the former solvent was used.

Tech Solv 340 is manufactured by and available from the following supplier:

Chemical Technologies, Inc.

1610 Clara Street

Jackson, MI 49203

Telephone: 800-688-8262

FAX: 517-782-2448

We believe this source and their Tech Solv 340 solvent to be reliable. There may be other manufacturers of solvents that replace 1,1,1 trichloroethane. Detroit Diesel does not endorse, indicate any preference for, or assume any responsibility for the solvents from these firms or for any such products that may be available from other sources.

Solvent Tank Cleaning

A tank of sufficient size to accommodate the largest part that will require cleaning (usually the cylinder block) should be provided and provisions made for heating the cleaning solution.

CAUTION:

To avoid injury, wear a face shield or goggles.

Fill the tank with a commercial heavy-duty solvent, such as Tech Solv 340, that is heated to 52°C (125°F). Lower large parts directly into the tank with a hoist. Place small parts in a wire mesh basket and lower them into the tank. Immerse the parts long enough to loosen all of the grease and dirt.

Aluminum or plastic parts such as the flywheel housing, fuel pump drive, air intake manifold, oil filter adaptor, camshaft gear access cover, oil pan or rocker covers, should not be cleaned in this manner.

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Rinsing Bath

Provide another tank of similar size containing hot water for rinsing the parts.

Drying

Parts may be dried with compressed air.

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

The heat from the hot tanks will quite frequently complete drying of the parts without the use of compressed air.

Rust Preventive

If parts are not to be used immediately after cleaning, dip them in a suitable rust preventive compound. The rust preventive compound should be removed before installing the parts in an engine.

Gasket Eliminator Removal

The gasket eliminator used on numerous mating surface joints in the Series 60 engine results in a very thin film that must be removed from both surfaces prior to reassembly. As many of the surfaces are aluminum and/or dimensionally critical, conventional scraping methods, or the use of emery cloth for removing gasket eliminator is not recommended.

Four-inch, 3M Scotch-Brite® Surface Conditioning Discs, used with an electric or air powered hand drill (with a speed of 15,000-18,000 r/min), have proven successful in removing the gasket eliminator without damaging the mating surfaces of engine parts. See Figure 12.

Scotch-Brite® is a registered trademark of the 3M Corporation.

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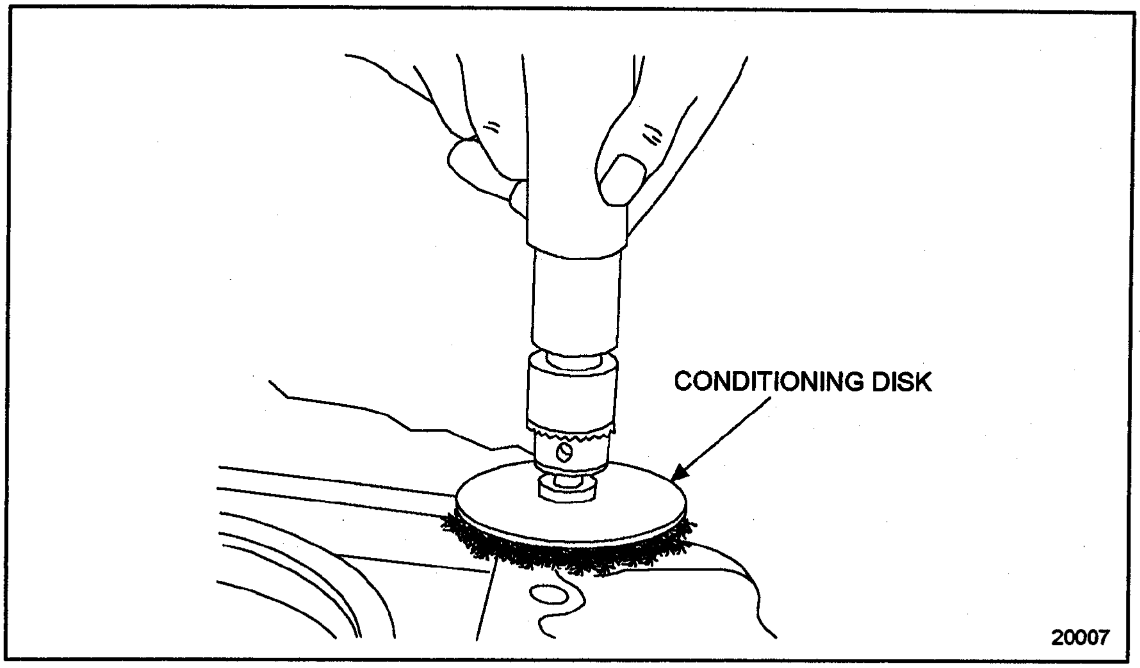

Figure 12 Gasket Eliminator Removal

A coarse pad, is suitable for steel surfaces. A medium pad is recommended for aluminum surfaces. The pads are easily interchangeable. See Figure 13.

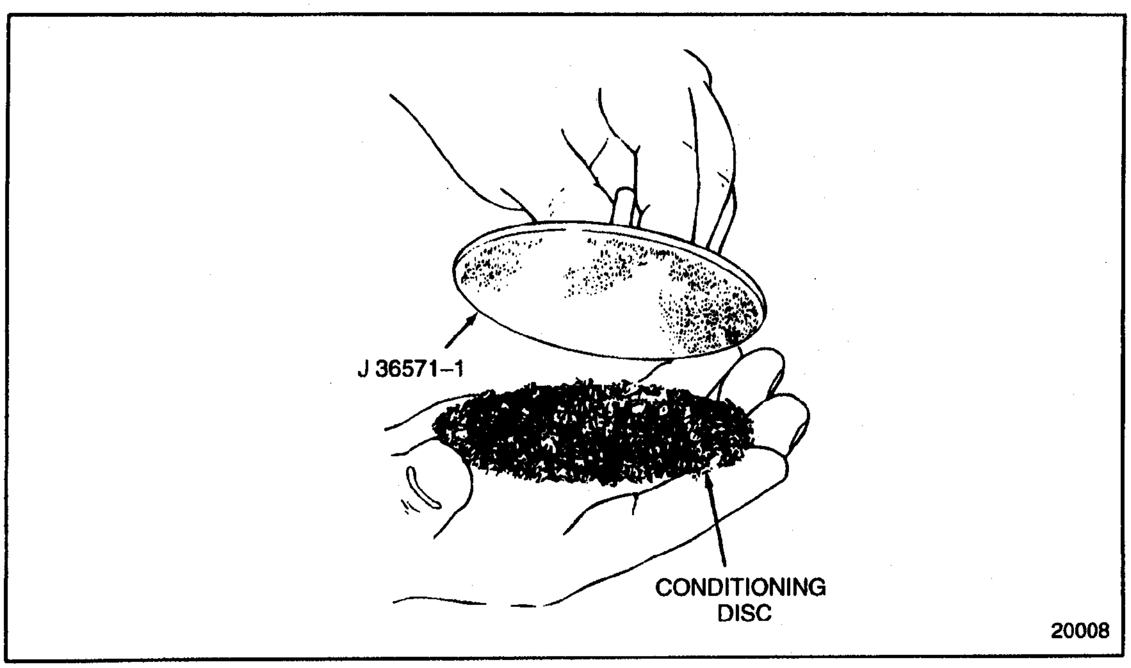

Figure 13 Scotch-Brite Surface Conditioning Disc Installation

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Inspection

The purpose of parts inspection is to determine which parts can be used and which must be replaced. Although the engine overhaul specifications given throughout the text will aid in determining which parts should be replaced, considerable judgment must be exercised by the inspector. The guiding factors in determining the usability of worn parts, that are otherwise in good condition, is the clearance between the mating parts and the rate of wear on each of the parts. If it is determined that the rate of wear will maintain the clearances within the specified maximum allowable until the next overhaul period, the reinstallation of used parts may be justified. Rate of wear of a part is determined by dividing the amount the part has worn by the hours it has operated

Many service replacement parts are available in various undersize or oversize as well as standard sizes. Also, service kits for reconditioning certain parts and service sets that include all of the parts necessary to complete a particular repair job are available.

A complete discussion of the proper methods of precision measuring and inspection are outside the scope of this manual. However, every shop should be equipped with standard gages, such as dial bore gages, dial indicators, and inside and outside micrometers.

In addition to measuring the used parts after cleaning, the parts should be carefully inspected for cracks, scoring, chipping and other detrimental conditions.

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SAFETY PRECAUTIONS

The following safety measures are essential when working on the Series 60 engine.

Exhaust (Start/Run Engine)

Before starting and running an engine, adhere to the following safety precautions:

CAUTION:

To avoid injury before starting and running the engine, ensure the vehicle is parked on a level surface, parking brake is set, and the wheels are blocked.

CAUTION:

Diesel engine exhaust and some of its constituents are known to the State of California to cause cancer, birth defects, and other reproductive harm.

- **Always start and operate an engine in a well ventilated area.**
- **If operating an engine in an enclosed area, vent the exhaust to the outside.**
- **Do not modify or tamper with the exhaust system or emission control system.**

Stands

Safety stands are required in conjunction with hydraulic jacks or hoists. Do not rely on either the jack or the hoist to carry the load. When lifting an engine, ensure the lifting device is fastened securely. Ensure the item to be lifted does not exceed the capacity of the lifting device.

Glasses

Select appropriate safety glasses for the job. It is especially important to wear safety glasses when using tools such as hammers, chisels, pullers or punches.

CAUTION:

To avoid injury, wear a face shield or goggles.

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Welding

Wear welding goggles and gloves when welding or using an acetylene torch.

CAUTION:

To avoid injury from arc welding, gas welding, or cutting, wear required safety equipment such as an arc welder's face plate or gas welder's goggles, welding gloves, protective apron, long sleeve shirt, head protection, and safety shoes. Always perform welding or cutting operations in a well-ventilated area. The gas in oxygen/acetylene cylinders used in gas welding and cutting is under high pressure. If a cylinder should fall due to careless handling, the gage end could strike an obstruction and fracture, resulting in a gas leak leading to fire or an explosion. If a cylinder should fall resulting in the gage end breaking off, the sudden release of cylinder pressure will turn the cylinder into a dangerous projectile.Observe the following precautions when using oxygen/acetylene gas cylinders:

- **Always wear required safety shoes.**
- **Do not handle tanks in a careless manner or with greasy gloves or slippery hands.**
- **Use a chain, bracket, or other restraining device at all times to prevent gas cylinders from falling.**
- **Do not place gas cylinders on their sides, but stand them upright when in use.**
- **Do not drop, drag, roll, or strike a cylinder forcefully.**
- **Always close valves completely when finished welding or cutting.**

CAUTION:

To avoid injury from fire, check for fuel or oil leaks before welding or carrying an open flame near the engine.

NOTICE:

Use proper shielding around hydraulic lines when welding to prevent hydraulic line damage.

Ensure that a metal shield separates the acetylene and oxygen that must be chained to a cart.

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Work Place

Organize your work area and keep it clean. A fall could result in a serious injury. Eliminate the possibility of a fall by:

- ☐ Wiping up oil spills
- ☐ Keeping tools and parts off the floor

After servicing or adjusting the engine:

- ☐ Reinstall all safety devices, guards or shields
- ☐ Ensure that all tools and servicing equipment are removed from the engine

Clothing

Safe work clothing fits and is in good repair. Work shoes are sturdy and rough-soled. Bare feet, sandals or sneakers are not acceptable foot wear when adjusting and/or servicing an engine. Do not wear the following when working on an engine:

CAUTION:

To avoid injury when working on or near an operating engine, wear protective clothing, eye protection, and hearing protection.

- ☐ Rings
- ☐ Wrist watches
- ☐ Loose fitting clothing

Any of these items could catch on moving parts causing serious injury.

Power Tools

Do not use defective portable power tools.

CAUTION:

To avoid injury from electrical shock, follow OEM furnished operating instructions prior to usage.

Check for frayed cords prior to using the tool. Be sure all electric tools are grounded. Defective electrical equipment can cause severe injury. Improper use of electrical equipment can cause severe injury.

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Air

Recommendations regarding the use of compressed air are indicated throughout the manual.

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

Fuel Lines

Remove fuel lines as an assembly. Do not remove fuel lines individually. Avoid getting fuel injection lines mixed up.

Fluids and Pressure

Be extremely careful when dealing with fluids under pressure.

CAUTION:

To avoid injury from penetrating fluids, do not put your hands in front of fluid under pressure. Fluids under pressure can penetrate skin and clothing.

Fluids under pressure can have enough force to penetrate the skin. These fluids can infect a minor cut or opening in the skin. If injured by escaping fluid, see a doctor at once. Serious infection or reaction can result without immediate medical treatment.

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Fuel

Keep the hose and nozzle or the funnel and container in contact with the metal of the fuel tank when refueling to avoid the possibility of an electric spark igniting the fuel.

CAUTION:

To avoid injury from fire caused by heated diesel-fuel vapors:

- **Keep those people who are not directly involved in servicing away from the engine.**
- **Stop the engine immediately if a fuel leak is detected.**
- **Do not allow open flames or smoke when working on an operating engine.**
- **Wear adequate protective clothing (face shield, insulated gloves and apron, etc.).**
- **To prevent a buildup of potentially volatile vapors, keep the engine area well ventilated during operation.**

Diesel fuel is relatively harmless at ambient temperatures.

CAUTION:

To avoid injury from possible fuel vapor ignition when refueling, keep the hose, nozzle, funnel, or container in contact with the metal opening of the fuel tank. This will reduce the likelihood of a dangerous spark.This caution applies to gasoline engines.

The following cautions should be followed when filling a fuel tank:

CAUTION:

To avoid injury from fire, do not overfill the fuel tank.

CAUTION:

To avoid injury from fire, keep all potential ignition sources away from diesel fuel, open flames, sparks, and electrical resistance heating elements. Do not smoke when refueling.

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Batteries

Electrical storage batteries emit highly flammable hydrogen gas when charging and continue to do so for some time after receiving a steady charge.

CAUTION:

To avoid injury from battery explosion or contact with battery acid, work in a well-ventilated area, wear protective clothing, and avoid sparks or flames near the battery. Always establish correct polarity before connecting cables to the battery or battery circuit. If you come in contact with battery acid:

- **Flush your skin with water.**
- **Apply baking soda or lime to help neutralize the acid.**
- **Flush your eyes with water.**
- **Get medical attention immediately.**

Always disconnect the battery cable before working on the electrical system.

CAUTION:

To avoid injury from accidental engine startup while servicing the engine, disconnect/disable the starting system.

Disconnect the batteries or disable an air starter when working on the engine (except DDEC) to prevent accidental starting.

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Fire

Keep a charged fire extinguisher within reach. Be sure you have the correct type of extinguisher for the situation.

Cleaning Agent

Avoid the use of carbon tetrachloride as a cleaning agent because of the harmful vapors that it releases. Ensure the work area is adequately ventilated. Use protective gloves, goggles or face shield, and apron.

CAUTION:

To avoid injury from harmful vapors or skin contact, do not use carbon tetrachloride as a cleaning agent.

Exercise caution against burns when using oxalic acid to clean the cooling passages of the engine.

Working on a Running Engine

When working on an engine that is running, accidental contact with the hot exhaust manifold can cause severe burns.

CAUTION:

To avoid injury from unguarded rotating and moving engine components, check that all protective devices have been reinstalled after working on the engine.

CAUTION:

To avoid injury, use care when working around moving belts and rotating parts on the engine.

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Start Attempts

Avoid excessive injection of ether into the engine during start attempts.

CAUTION:

To avoid injury from an explosion of natural gas, the following precautions must be taken:

- **Do not smoke when installing or servicing the engine or fuel system.**
- **Installation or servicing of natural-gas equipment must only be conducted in well-ventilated, natural gas compatible areas. Do not install or service equipment in an enclosed area where ignition sources are present without first ensuring that an undetected gas leak may be safely vented without being ignited.**
- **Bleed natural gas lines before installing or servicing any component connected to the fuel lines.**
- **Natural gas fuel systems are pressurized. Relieve pressure from any fuel system component prior to installation or service of that component.**
- **Use a combustible-gas detector. Liquefied natural gas (LNG) is odorless and cannot be detected by smell. Compressed Natural gas (CNG) may be odorless and may not be detected by smell.**
- **Equipment fuel systems are the responsibility of the Original Equipment Manufacturer (OEM). Equipment fuel system guidelines must be closely adhered to when installing or servicing equipment. Refer to OEM guidelines specifying which maintenance procedures require venting of fuel lines and fuel tanks.**
- **LNG systems are pressurized and contain extremely cold (-260°F [-162°C]) fluids. Contact the fuel supplier or OEM for LNG safety requirements. Contact with LNG may cause personal injury (freezing).**
- **Vent systems on the equipment should be ducted to a safe area whenever equipment is in an enclosed area.**

Natural gas is highly flammable and explosive and may be extremely cold (-260°F [-162°C]).

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NOTICE:
Avoid excessive injection of ether into the engine during start attempts. Injection of excessive ether may result in an uncontrolled internal engine explosion that could cause engine damage. Follow the manufacturer's instructions on proper product use.

Follow the instructions on the container or by the manufacturer of the starting aid.

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Turbocharger Compressor Inlet Shield

A turbocharger compressor inlet shield, J 26554-A, is available and must be used anytime the engine is operated with the air inlet piping removed. See Figure 14. The shield helps to prevent foreign objects from entering and damaging the turbocharger and will prevent the mechanic from accidentally touching the turbocharger impeller. The use of this shield does NOT preclude any other safety practices contained in this manual. See Figure 15 for Series 60G engine.

CAUTION:

To avoid injury from contact with rotating parts when an engine is operating with the air inlet piping removed, install an air inlet screen shield over the turbocharger air inlet. The shield prevents contact with rotating parts.

Use of this shield does NOT preclude any other safety practices contained in this manual.

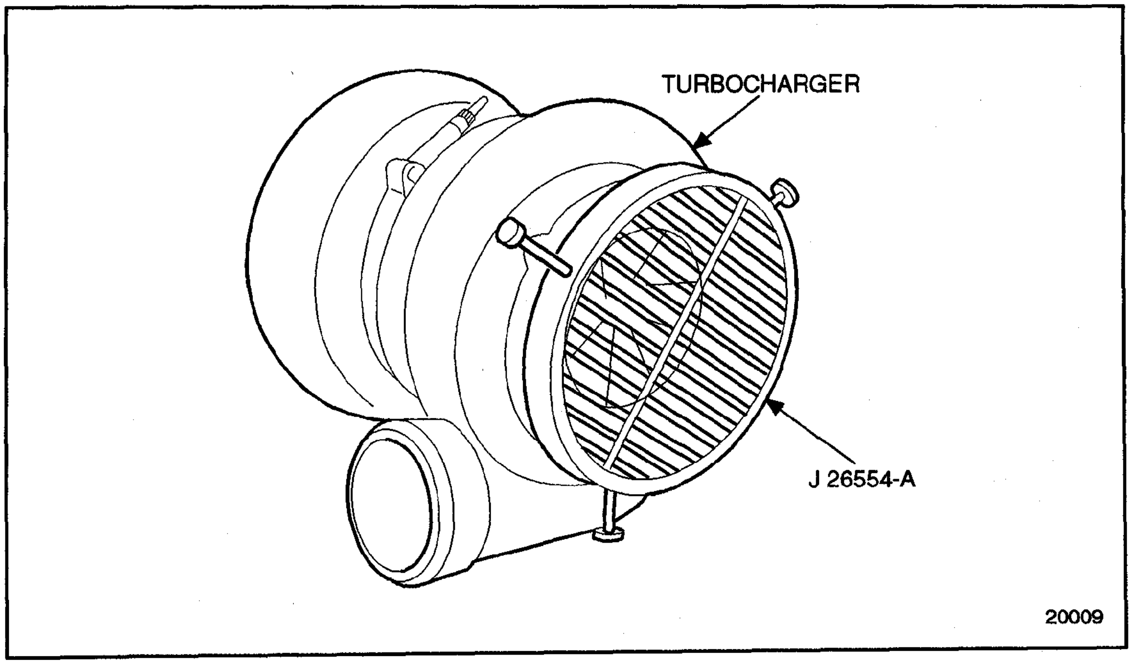

Figure 14 Turbocharger Compressor Inlet Shield

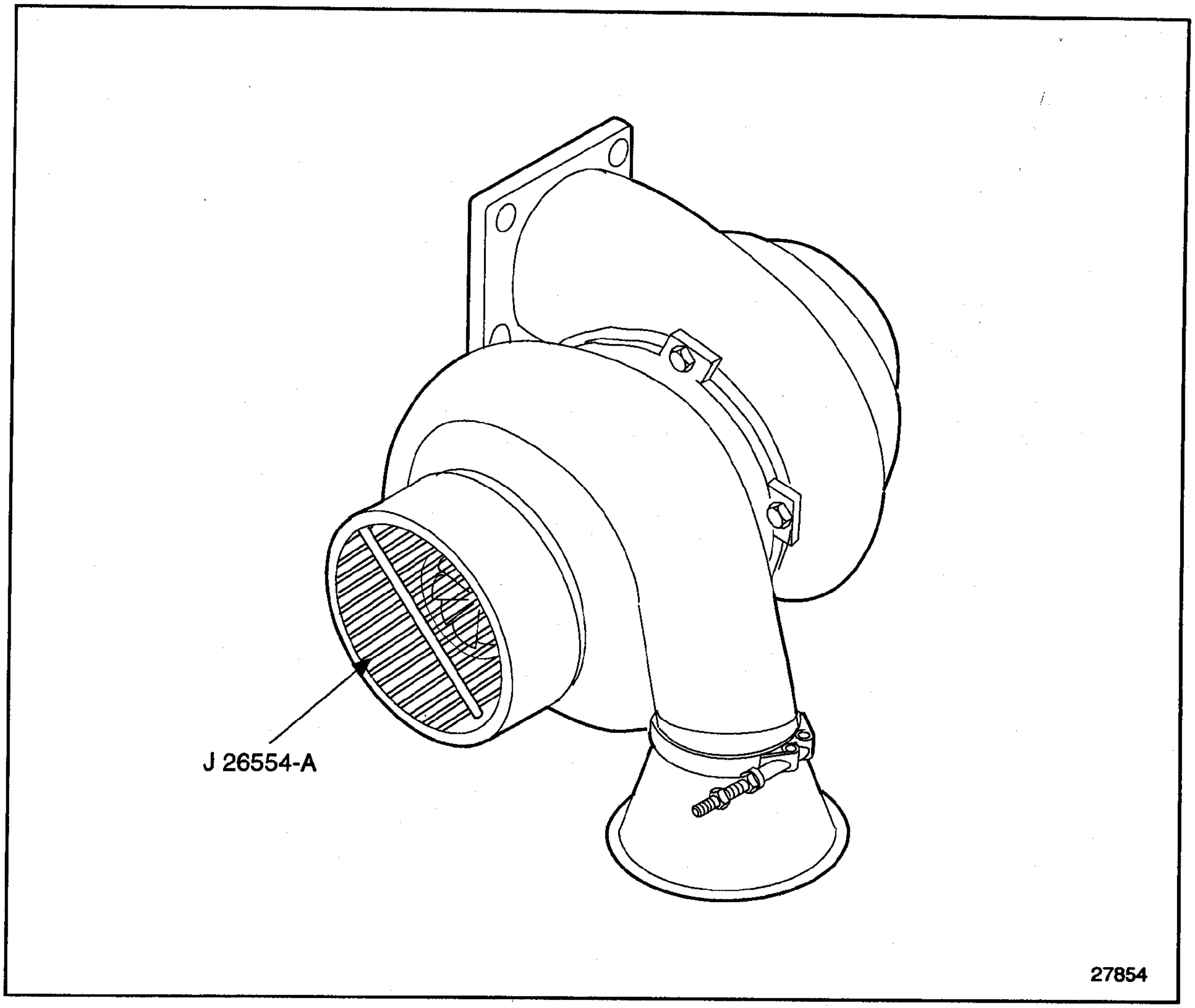

Figure 15 Turbocharger Compressor Inlet Shield, Series 60G Engine

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FLUOROELASTOMER (VITON) CAUTION

Under normal design conditions, fluoroelastomer (VITON) parts, such as O-rings and seals, are perfectly safe to handle.

CAUTION:

To avoid injury from chemical burns, wear a face shield and neoprene or PVC gloves when handling fluoroelastomer O-rings or seals that have been degraded by excessive heat. Discard gloves after handling degraded fluoroelastomer parts.

However, a potential hazard may occur if these components are raised to a temperature above 316°C (600°F), such as during a cylinder failure or engine fire. At temperatures above 316°C (600°F) fluoroelastomer will decompose (indicated by charring or the appearance of a black, sticky mass) and produce hydrofluoric acid. This is extremely corrosive and, if touched by bare skin, may cause severe burns, sometimes with symptoms delayed for several hours.

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ENGINE VIEWS

The engine views show the pre-1991 engine and 1991 and later engine as well as DDEC II and DDEC III/IV. See Figure 16. For Series 60G engine views see Figure 17, see Figure 18and see Figure 19.

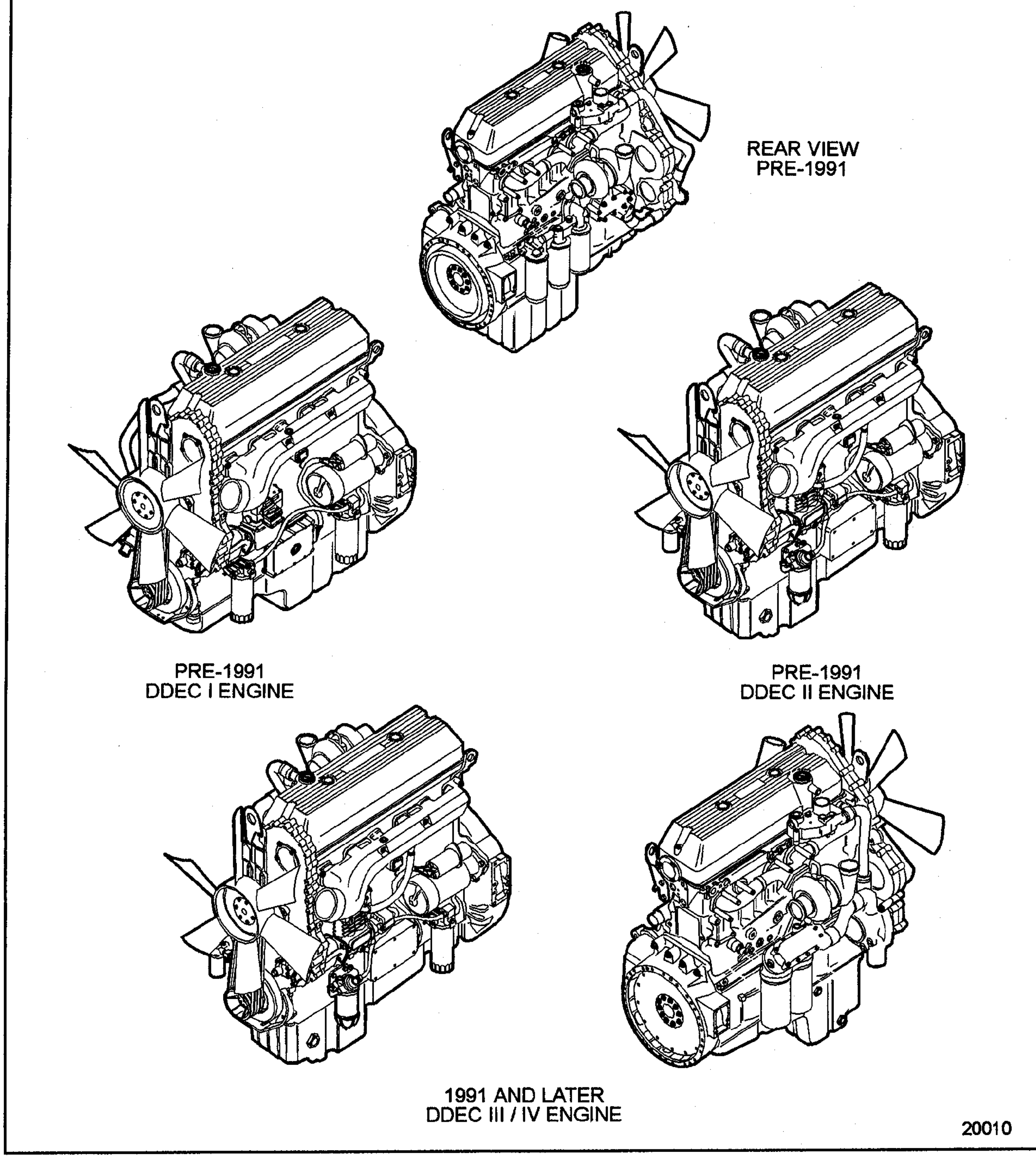

Figure 16 Engine Views

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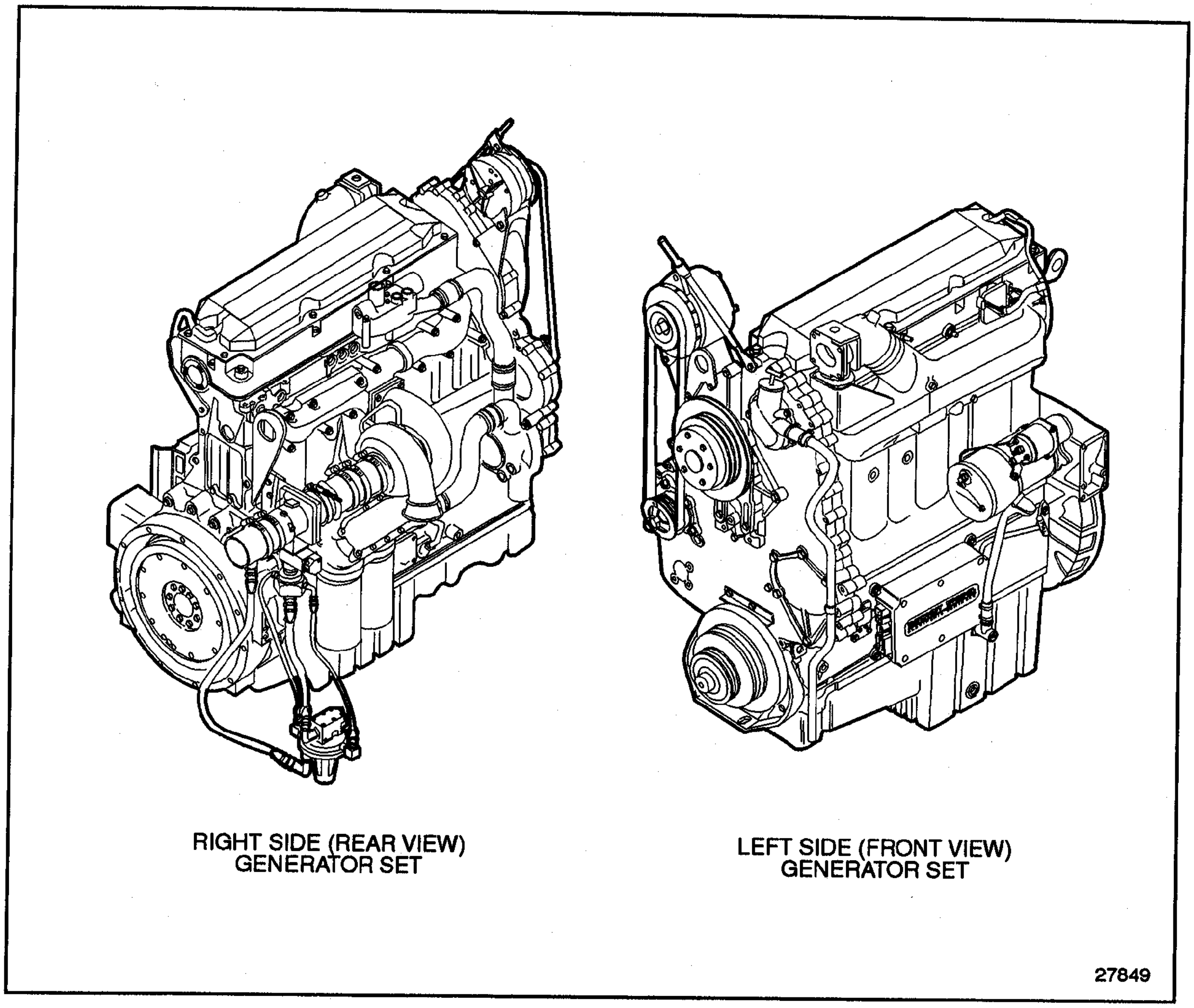

Figure 17 Engine Views (60G Genset Engine)

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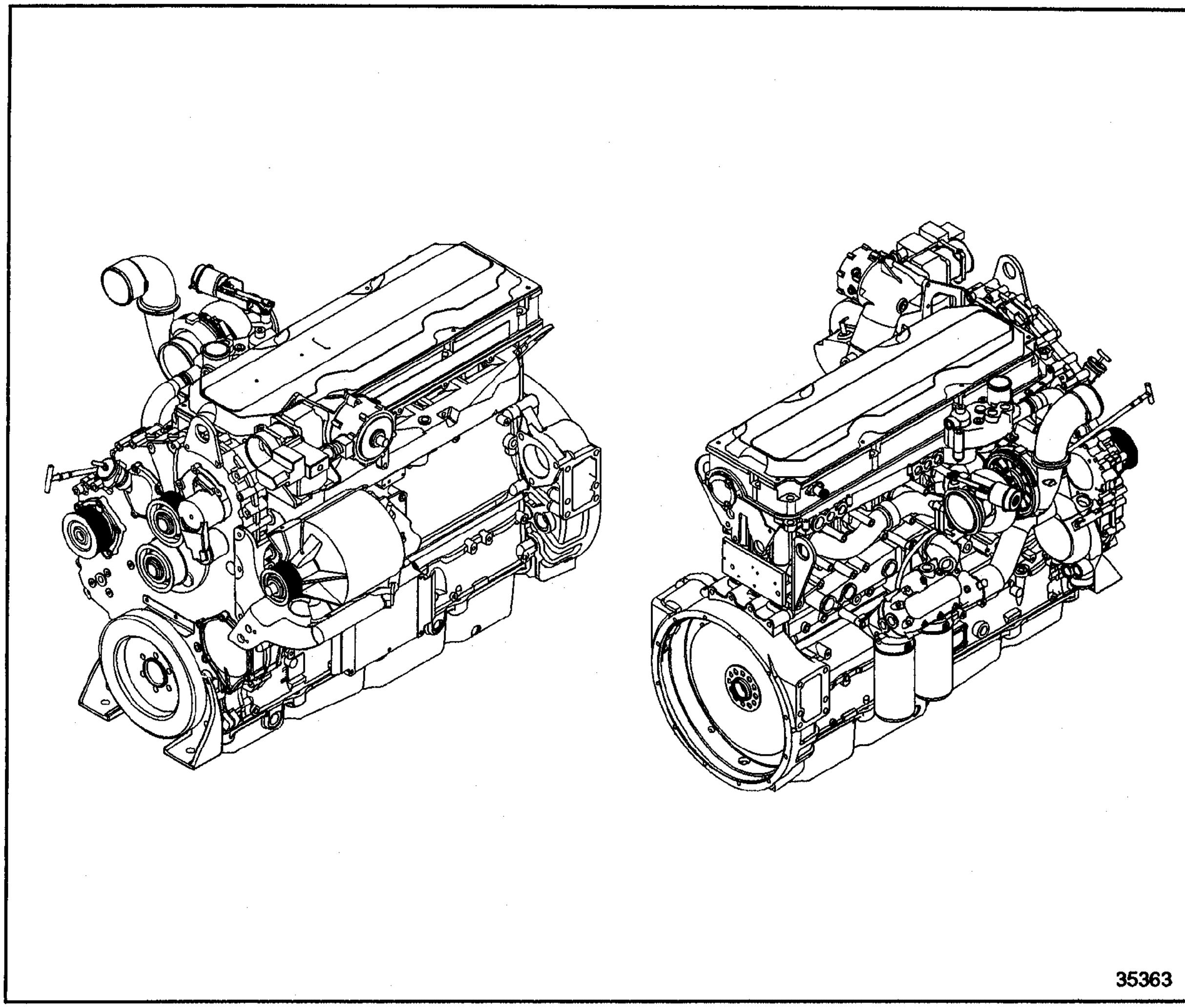

Figure 18 Engine Views (60G Automotive Engine)

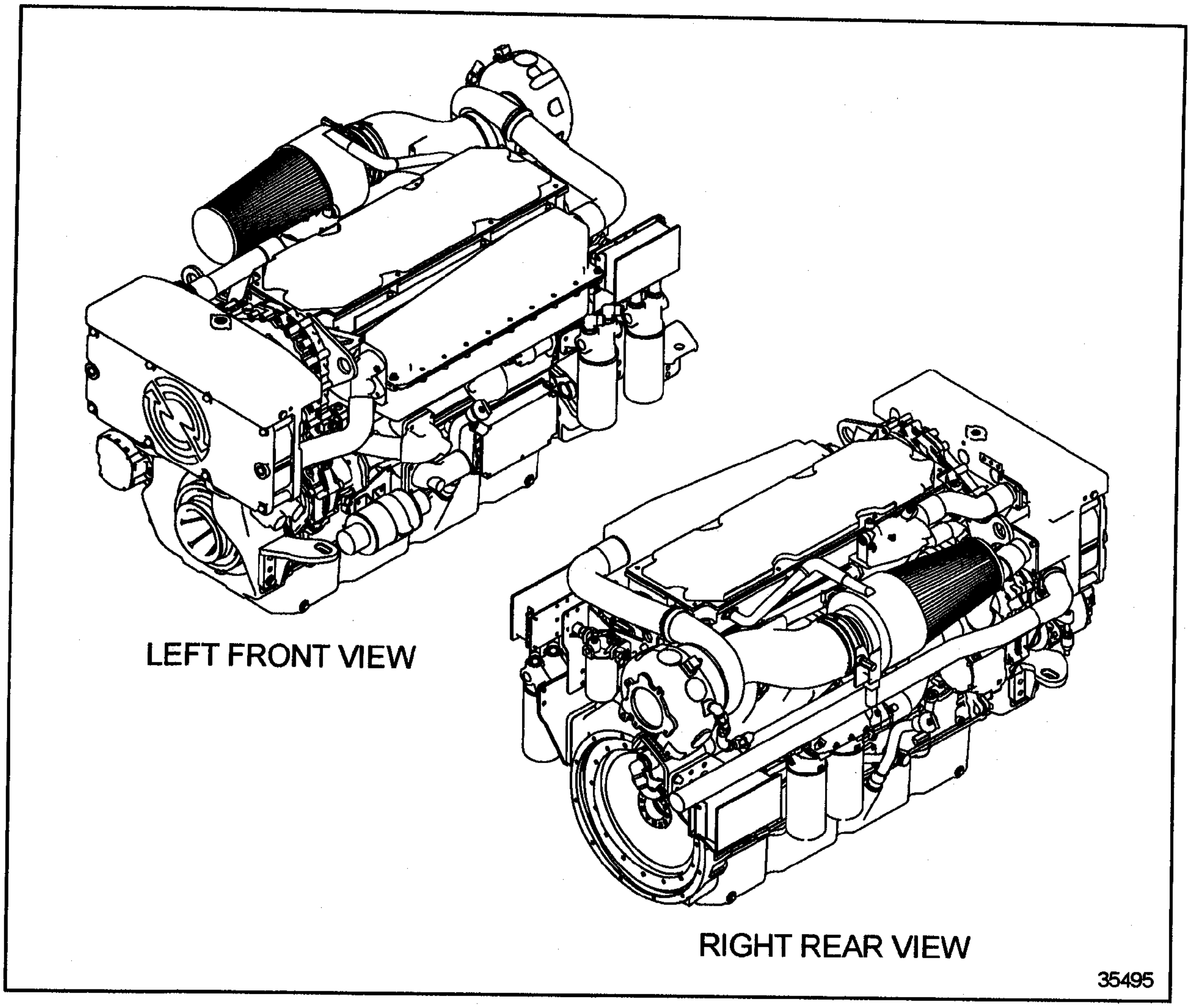

Figure 19 Engine Views (Heat-Exchanger-Cooled Marine Engine)

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ENGLISH TO METRIC CONVERSION

Listed in Table 5 are the English to metric conversions.

Multiply Length	By	To get equivalent number of:
Inch (in.)	25.4	Millimeters (mm)
Foot (ft)	0.3048	Meters (m)
Yard (yd)	0.9144	Meters (m)
Mile (mile)	1.609	Kilometers (km)
Multiply Area	**By**	**To get equivalent number of:**
$Inch^2$ ($in.^2$)	645.2	$Millimeters^2$ (mm^2)
$Inch^2$ ($in.^2$)	6.45	$Centimeters^2$ (cm^2)
$Foot^2$ (ft^2)	0.0929	$Meters^2$ (m^2)
$Yard^2$ (yd^2)	0.8361	$Meters^2$ (m^2)
Multiply Volume	**By**	**To get equivalent number of:**
$Inch^3$ ($in.^3$)	16387	$Millimeters^3$ (mm^3)
$Inch^3$ ($in.^3$)	16.387	$Centimeters^3$ (cm^3)
$Inch^3$ ($in.^3$)	0.0164	Liters (L)
Quart (qt)	0.9464	Liters (L)
Gallon (gal)	3.785	Liters (L)
$Yard^3$ (yd^3)	0.7646	$Meters^3$ (m^3)
Multiply Mass	**By**	**To get equivalent number of:**
Pound (lb)	0.4536	Kilograms (kg)
Ton (ton)	907.18	Kilograms (kg)
Ton (ton)	0.907	Tonne (t)
Multiply Force	**By**	**To get equivalent number of:**
Kilogram (kg)	9.807	Newtons (N)
Ounce (oz)	0.2780	Newtons (N)
Pound (lb)	4.448	Newtons (N)
Multiply Temperature	**By**	**To get equivalent number of:**
Degree Fahrenheit (°F)	(°F-32) ÷ 1.8	Degree Celsius (°C)
Multiply Acceleration	**By**	**To get equivalent number of:**
$Foot/second^2$ (ft/sec^2)	0.3048	$Meter/second^2$ (m/s^2)
$Inch/second^2$ ($in./sec^2$)	0.0254	$Meter/second^2$ (m/s^2)
Multiply Torque	**By**	**To get equivalent number of:**
Pound-inch (lb·in.)	0.11298	Newton-meters (N·m)
Pound-foot (lb·ft)	1.3558	Newton-meters (N·m)
Multiply Power	**By**	**To get equivalent number of:**

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Multiply Length	By	To get equivalent number of:
Horsepower (hp)	0.746	Kilowatts (kW)
Multiply Power	**By**	**To get equivalent number of:**
Inches of water (in. H_2O)	0.2491	Kilopascals (kPa)
Pounds/square in. (lb/in.^{2})	6.895	Kilopascals (kPa)
Multiply Energy or Work	**By**	**To get equivalent number of:**
British Thermal Unit (Btu)	1055	Joules (J)
Foot-pound (ft·lb)	1.3558	Joules (J)
kilowatt-hour (kW·hr)	3,600,000. or 3.6×10^6	Joules (J = one W/s)
Multiply Light	**By**	**To get equivalent number of:**
Foot candle (fc)	10.764	Lumens/meter^2 (lm/m^2)
Multiply Fuel Performance	**By**	**To get equivalent number of:**
Miles/gal (mile/gal)	0.4251	Kilometers/liter (km/L)
Gallons/mile (gal/mile)	2.3527	Liter/kilometer (L/km)
Multiply Velocity	**By**	**To get equivalent number of:**
Miles/hour (mile/hr)	1.6093	Kilometers/hour (km/hr)

Table 5 English to Metric Conversion Table

DECIMAL AND METRIC EQUIVALENTS

Listed in Table 6 are the decimal and metric equivalents:

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Fractions of an inch	Decimal (in.)	Metric (mm)	Fractions of an inch	Decimal (in.)	Metric (mm)
1/64	0.015625	0.39688	33/64	0.515625	13.09687
1/32	0.03125	0.79375	17/32	0.53125	13.49375
3/64	0.046875	1.19062	35/64	0.546875	13.89062
1/16	0.0625	1.58750	9/16	0.5625	14.28750
5/64	0.078125	1.98437	37/64	0.578125	14.68437
3/32	0.09375	2.38125	19/32	0.59375	15.08125
7/64	0.109375	2.77812	39/64	0.609375	15.47812
1/8	0.125	3.175	5/8	0.625	15.87500
9/64	0.140625	3.57187	41/64	0.640625	16.27187
5/32	0.15625	3.96875	21/32	0.65625	16.66875
11/64	0.171875	4.36562	43/64	0.671875	17.06562
3/16	0.1875	4.76250	11/16	0.6875	17.46250
13/64	0.203125	5.15937	45/64	0.703125	17.85937
7/32	0.21875	5.55625	23/32	0.71875	18.25625
15/64	0.234375	5.95312	47/64	0.734375	18.65312
1/4	0.250	6.35000	3/4	0.750	19.05000
17/64	0.265625	6.74687	49/64	0.765625	19.44687
9/32	0.28125	7.14375	25/32	0.78125	19.84375
19/64	0.296875	7.54062	51/64	0.796875	20.24062
5/16	0.3125	7.93750	13/16	0.8125	20.63750
21/64	0.328125	8.33437	53/64	0.828125	21.03437
11/32	0.34375	8.73125	27/32	0.84375	21.43125
23/64	0.359375	9.12812	55/64	0.859375	21.82812
3/8	0.375	9.52500	7/8	0.875	22.22500
25/64	0.390625	9.92187	57/64	0.890625	22.62187
13/32	0.40625	10.31875	29/32	0.90625	23.01875
27/64	0.421875	10.71562	59/64	0.921875	23.41562
7/16	0.4375	11.11250	15/16	0.9375	23.81250
29/64	0.453125	11.50937	61/64	0.953125	24.20937
15/32	0.46875	11.90625	31/32	0.96875	24.60625
31/64	0.484375	12.30312	63/64	0.984375	25.00312
1/2	0.500	12.70000	1	1.00	25.40000

Table 6 Conversion Chart-Customary and Metric Units

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SPECIFICATIONS

This section contains fastener torque specifications and pipe plug torque specifications.

Torque Specifications - Fasteners

The proper bolt and nut torque is dependent on its size. Standard (non-metric) nut and bolt torque specifications are listed in Table 7. The proper torque specifications for metric nuts and bolts are listed in Table 8.

Nut and Bolt Size, mm	280M or Better Torque, N·m	280M or Better Torque, lb·ft
No.10-24	5-7	4-5
1/4 in.-20	9-12	7-9
1/4 in.-28	11-14	8-10
5/16 in.-18	18-23	13-17
5/16 in.-24	20-26	15-19
3/8 in.-16	41-47	30-35
3/8 in.-24	47-53	35-39
7/16 in.-14	62-68	46-50
7/16 in.-20	77-83	57-61
1/2 in.-13	96-102	71-75
1/2 in.-20	112-126	83-93
9/16 in.-12	122-136	90-100
9/16 in.-18	145-159	107-117
5/8 in.-11	186-199	137-147
5/8 in.-18	228-241	168-178
3/4 in.-10	325-339	240-250
3/4 in.-16	393-407	290-300
7/8 in.-9	556-569	410-420
7/8 in.-14	644-657	475-485
1 in.-8	789-799	580-590
1 in.-14	928-942	685-695

Table 7 Standard (Non-metric) Fastener Torque Specifications

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Nut and Bolt Size, mm	Property Class 10.9 Torque, N·m	Property Class 10.9 Torque, lb·ft
M6 X 1.0	13-16	10-12
M8 X 1.25	30-38	22-28
M10 X 1.5	58-73	43-54
M12 X 1.75	101-126	75-93
M14 X 2.0	160-200	118-148
M16 X 2.0	245-306	181-226
M20 X 2.5	478-598	353-441

Table 8 Class 10.9 Torque Specifications for Metric Fasteners

Torque Specification - Pipe Plugs

Standard pipe plug torque specifications supporting the Series 60 engine are listed in Table 9.

*Pipe Plug Size, NPTF	Torque Specifications, N·m	Torque Specifications, lb·ft
1/8 in.	14-18	10-13
1/4 in.	19-24	14-18
3/8 in.	24-31	18-23
1/2 in.	31-39	23-29
3/4 in.	45-56	33-41
1 in.	101-126	75-93
1-1/4 in.	129-161	95-119
1-1/2 in.	149-187	110-138

*Use sealant such as Pipe Plug Sealant with Teflon®, PT-7271 (Loctite® 592), or equivalent on all uncoated pipe plugs.

Table 9 Standard Pipe Plug Torque Specifications

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1 ENGINE

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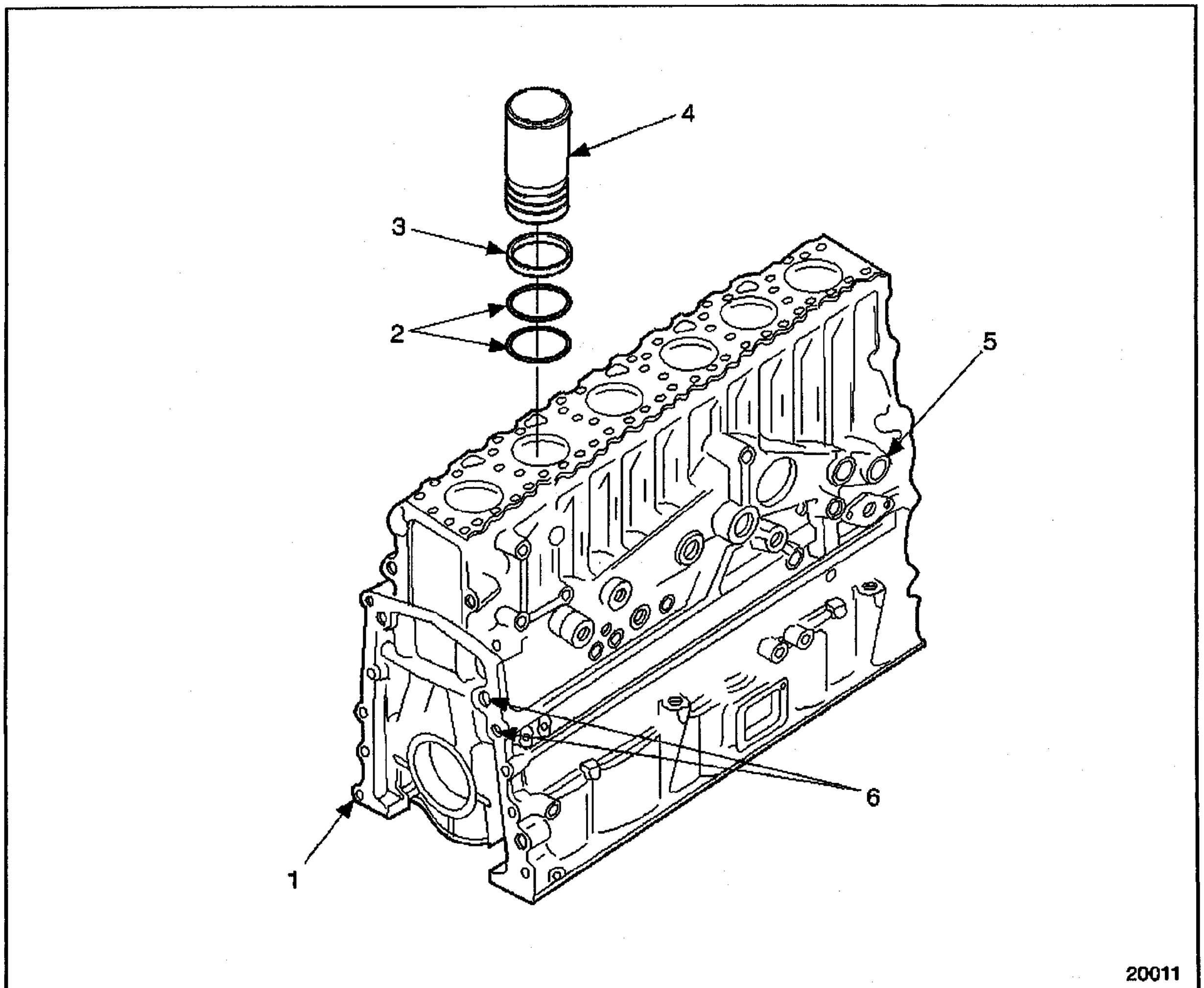
1.1 CYLINDER BLOCK AND CYLINDER LINER

The cylinder block is the basic engine structure, establishing and maintaining the alignment of all engine working parts. In the Series 60 Engine, the cylinder bores are not an integral part of the block casting, but are in the form of replaceable, wet type cylinder liners. See Figure 1-1.

Flanges at the liner upper ends seat in counterbores in the block deck, and project slightly above the deck to compress the head gasket for a good compression seal. Below the water jacket the lower end of the cylinder liner has two D-shaped seal rings and a lipped crevice seal to prevent leakage between the water jacket and crankcase.



1. Cylinder Block
2. D-rings
3. Crevice Seal
4. Cylinder Liner
5. Integral Coolant Inlet Manifold
6. Oil Galleries

Figure 1-1 Series 60 Cylinder Block and Liner

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An integral coolant inlet manifold is cored into the right side of the block. It distributes the water pump output along the length of the block. Oil galleries are machined into the cooler side of the block. See Figure 1-1.

The integral oil galleries direct the oil pump output through the external oil cooler and filters, to the main oil gallery and to drilled passages in the crankcase webs which supply oil under pressure to each main bearing. In the crankcase, five integral webs plus front and rear bulkheads support the crankshaft in seven main bearings. See Figure 1-2.

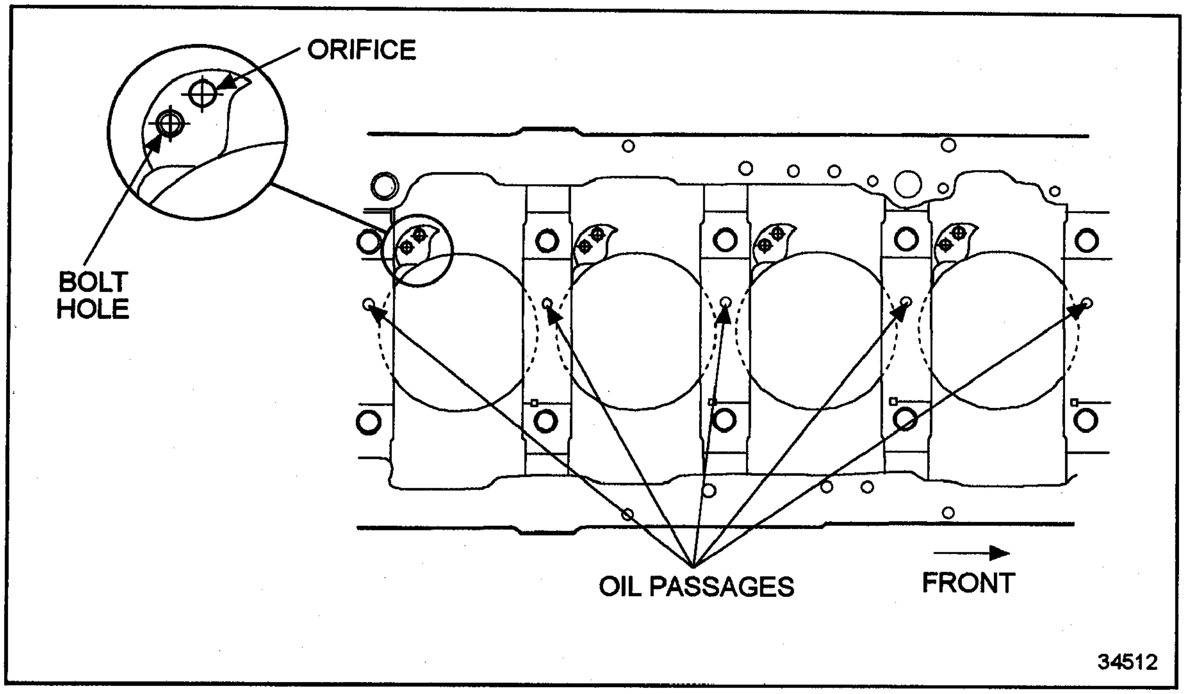

Figure 1-2 Series 60 Cylinder Block Crankcase

An improved cylinder block has replaced the former block on all Series 60 engines. This change took effect with unit serial number 6R210293, built November 30, 1994. The former cylinder block was used on engines built prior to this serial number.

The Series 60 cylinder block was further improved by the addition of a drilled lubrication orifice and bolt hole at the base of each cylinder bore. See Figure 1-2. The orifices are drilled into the main oil gallery and are required for installation of bolt-on oil spray nozzles used with forged steel pistons on premium engines. When blocks are used for non-premium engines with cast-iron pistons, the lubrication orifices are closed with bolt-on steel plates. First usage of the drilled block was on May 2, 1998, effective with engine serial number 6R408505.

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The improved block permits installation of adaptorless Bendix and Midland air compressors onto the gear case. The improved block is similar to the former block, except that it has a slightly modified sidewall configuration that eliminates interference between the block and the adaptorless compressor. To compensate for the elimination of the adaptor, air compressor mounting bracket bolt holes have been moved forward 130.3 mm (5.13 in.) on the block. See Figure 1-3. Since these holes have a different spacing than the former holes, an improved compressor mounting bracket is required. A new air compressor coolant supply port has also been added forward of the former supply port. The former port is plugged when the adaptorless compressor is installed.

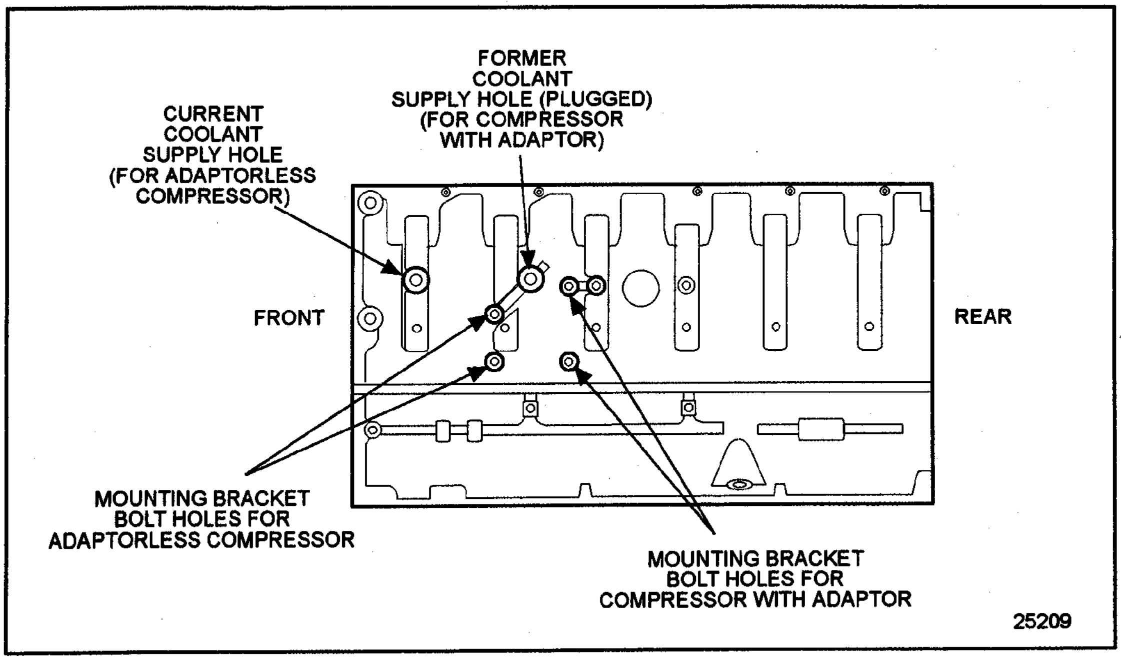

Figure 1-3 Cylinder Block Showing Current Modifications

When replacing a former block with an improved block, it is recommended (but not necessary) that an adaptorless air compressor, improved compressor mounting bracket, and improved compressor coolant supply hose be installed. Refer to section 10.1.3, of this manual for information on installing the adaptorless air compressor.

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1.1.1 Repair or Replacement of Cylinder Block

To determine if repair is possible or replacement is necessary, perform the following procedure. See Figure 1-4.

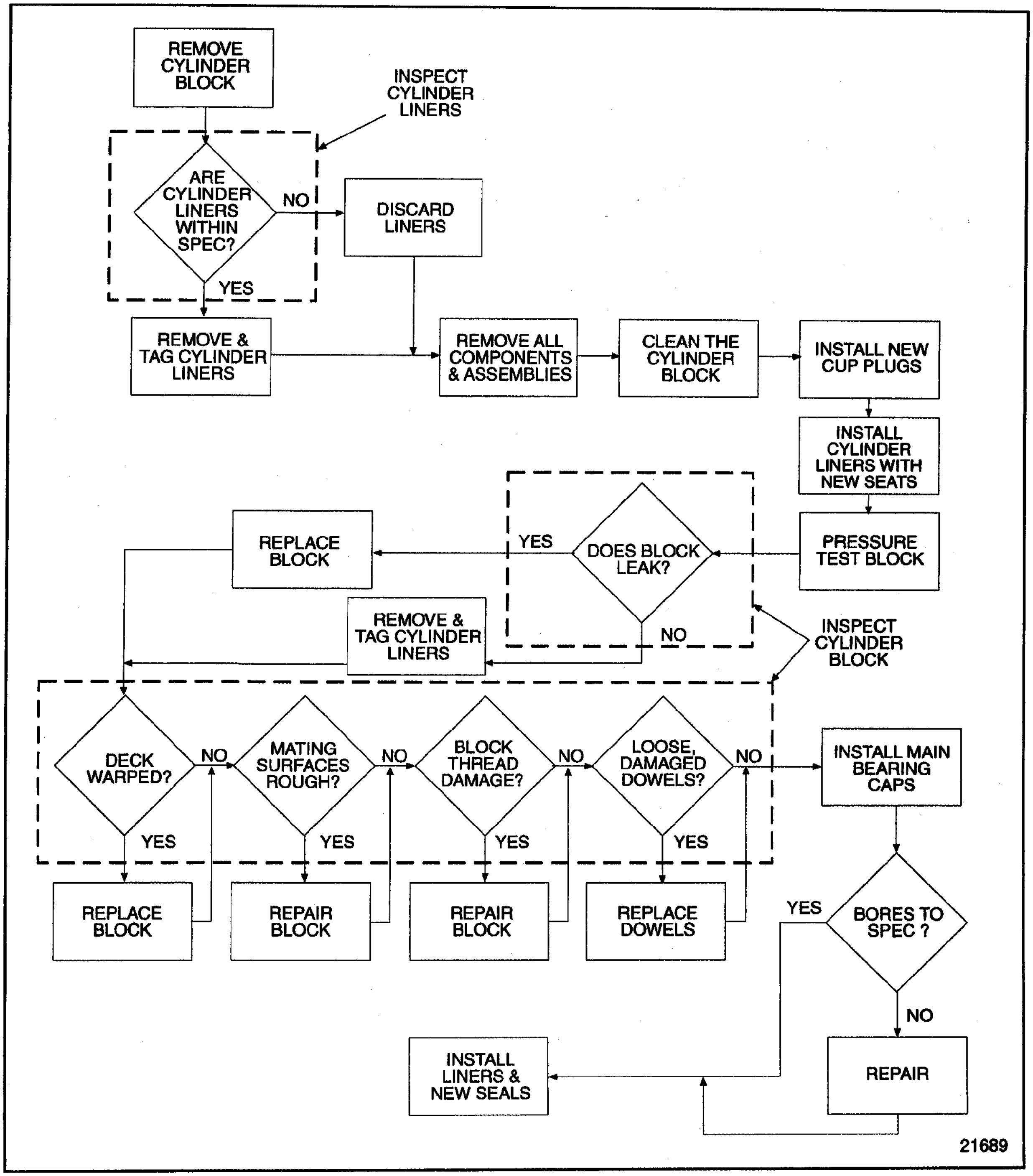

Figure 1-4 Flowchart for Repair or Replacement of Cylinder Block

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1.1.2 Removal and Disassembly of Engine from the Vehicle or Vessel

Before mounting an engine on an overhaul stand, it must be disconnected from the transmission. Details for removing an engine will vary from one application to another. However, the following steps will be necessary, regardless of application:

1. Disconnect the battery cable(s) from the battery(s).
2. Drain the cooling system completely by removing the drain plug in the oil cooler and opening the drain cocks in the cylinder block, thermostat housing and water pump housing. Refer to section 13.13.4.

NOTE:
On marine engines, drain the heat exchanger, charge air cooler and water-cooled intake manifold, if installed.

3. Drain the lubricating oil. Refer to section 13.13.1.
4. Disconnect the inlet fuel line from the primary fuel filter and the outlet line from the upper fitting at the rear of the cylinder head. Refer to section 2.8.1.
5. Remove the air cleaner ducting as necessary for engine removal. Refer to OEM guidelines.
6. Remove the charge air cooler ducting from the turbocharger and intake manifold. Refer to section 6.10.2.
7. Disconnect the exhaust piping from the turbocharger. Refer to section 6.6.2.
8. Disconnect DDEC:
   [a] For DDEC I, disconnect the 22-pin DDEC electrical connector. Refer to section 2.18.2.
   [b] For DDEC II or III, disconnect the 30-pin DDEC vehicle electrical connector and the six-pin DDEC II power connector or DDEC III/IV five pin power connector. Refer to section 2.16.2, or refer to section 2.17.3.
9. Disconnect and remove the cranking motor. Refer to section 8.4.2.
10. Remove the alternator and other electrical equipment, as necessary. Refer to section 8.2.2.
11. Remove the air compressor and any air lines, as necessary. Refer to section 10.1.5.
12. Disconnect and remove the coolant hoses.
13. On marine engines, remove the raw water pump.Refer to section 4.4.2.
14. Remove the charge air cooler, radiator, fan guard and other cooling system related parts as necessary to remove the engine. Refer to section 6.10.2.

NOTE:
On certain keel cooled marine engines, remove the front-mounted charge air cooler and mounting, if installed. Refer to section 4.4.2.

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15. Connect a suitable lifting device to the engine using all three lifting brackets (two at the rear and one at the front).
16. Separate the engine from the transmission or marine gear.
17. Remove the engine mounting bolts.

CAUTION:

To avoid injury from a falling engine, an adequate lifting device with a spreader bar and sling should be used to lift the engine. The sling and spreader bar should be adjusted so the lifting hooks are vertical to prevent bending the lifter brackets. To ensure proper weight distribution, all provided lifter brackets must be used.

18. Lift the engine from its mounts using a suitable lifting device. See Figure 1-5.

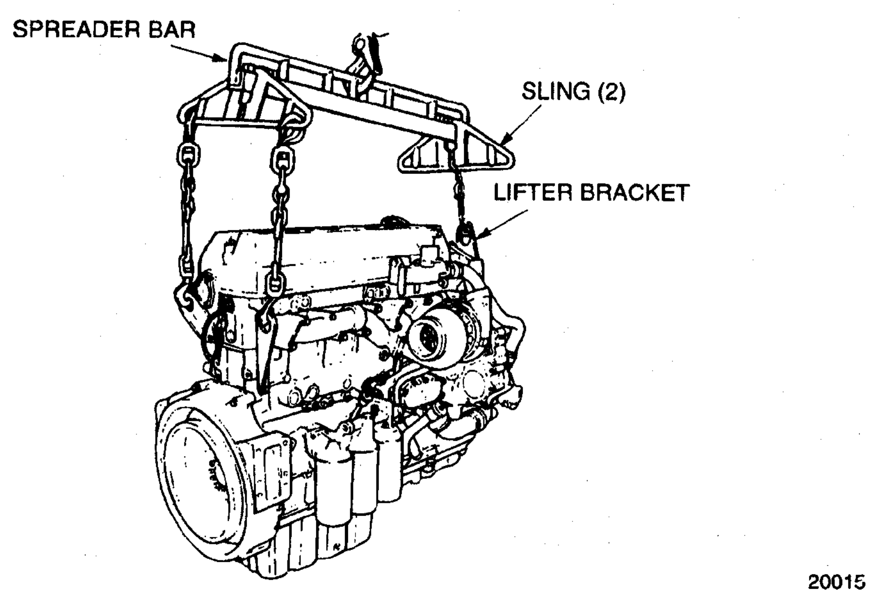

Figure 1-5 Lifting Engine

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CAUTION:

To avoid injury from a falling engine, ensure the engine is securely attached to the engine overhaul stand before releasing the lifting sling.

19. Use engine overhaul stand, J 29109, with stand adaptor plate, J 35635-1 part of J 35635–A for support when stripping a Series 60 engine cylinder block. See Figure 1-6.

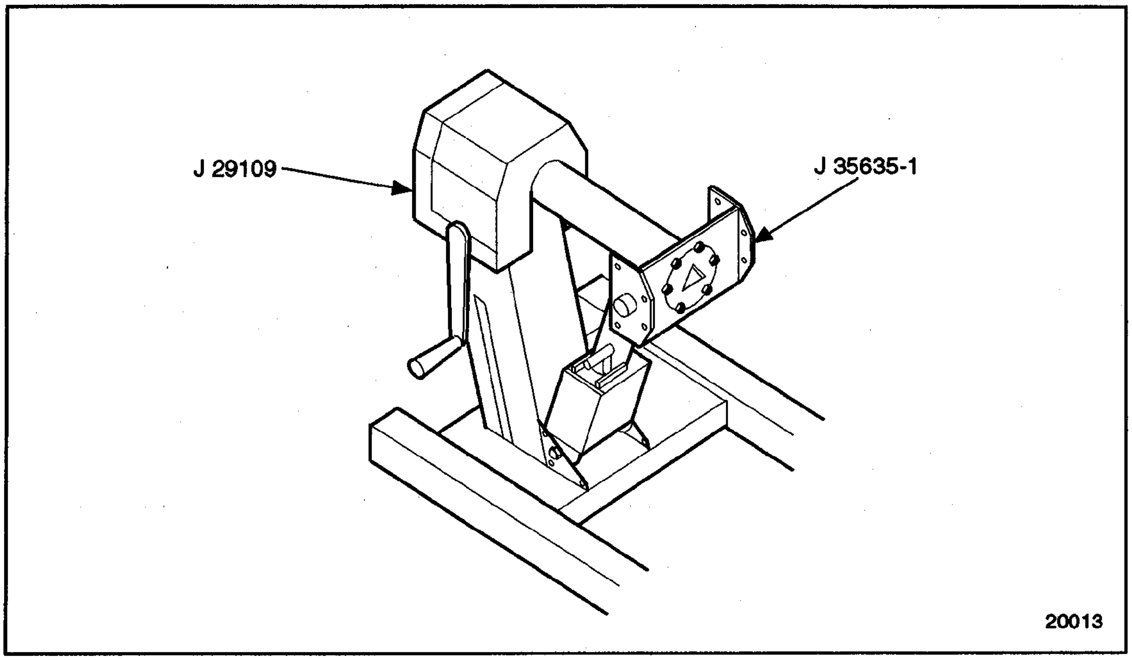

Figure 1-6 Engine Overhaul Stand and Adaptor

20. Bolt cylinder block adaptor, J 35635-2 part of J 35635–A, to the cylinder block and mate it with the stand adaptor, J 35635-1 part of J 35635–A. See Figure 1-7.

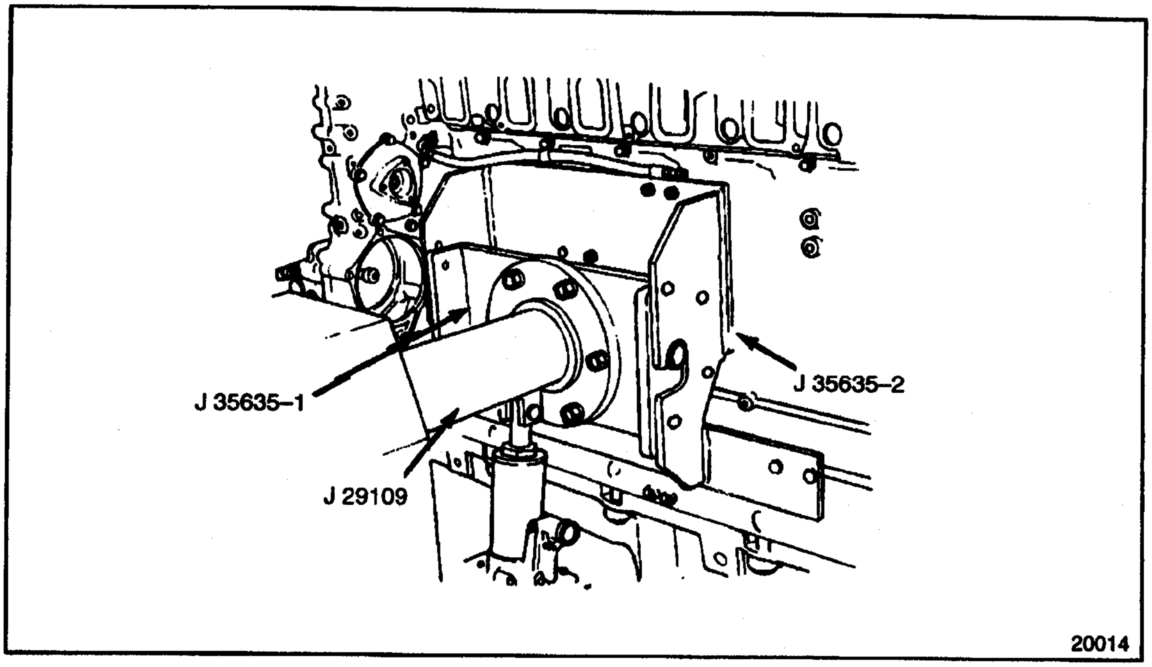

Figure 1-7 Cylinder Block Adaptor

21. The engine is left-side mounted in an upright position. Rotate it in either direction and lock it into position.
22. Remove the fuel filters and adaptor.
    [a] For DDEC I engines, remove the inlet and outlet fuel lines connected to the Electronic Distributor Unit (EDU) cold plate, the EDU mounting bolts, and the EDU. Refer to section 2.18.2.
    [b] For DDEC II engines, remove the inlet and outlet fuel lines connected to the Electronic Control Module (ECM) cold plate, the ECM mounting bolts, and the ECM. Refer to section 2.17.3.

NOTE:
DDC has discontinued the use of the ECM cold plate on all Series 60 automotive engine models, effective with unit serial number 06R0008950. In place of the ECM cold plate, a No. 6 x 37.92 in. (963 mm) long hose assembly (23504785) is now routed from the fuel pump discharge fitting to the inlet of the secondary fuel filter.

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[c] Current DDEC III/IV Series 60 vehicle, industrial and generator set engines do not have a cold plate.

NOTE:
Series 60 marine engines DO have a cold plate.

23. Disconnect the harness connector (gray) from the timing reference sensor (TRS) at the lower left corner of the gear case. Remove the TRS from the gear case. Refer to section 2.30.2.
24. Disconnect the harness (black) connector from the synchronous reference sensor (SRS) at the left rear wall of the gear case. Remove the SRS from the gear case. Refer to section 2.29.2.
25. Remove any electrical components, connectors or wiring looms from the engine.
26. With the engine mounted on the overhaul stand, remove all of any remaining subassemblies and parts from the cylinder block.

    [a] To remove the one piece valve rocker cover, refer to section 1.6.2.

    [b] To remove the two piece valve rocker cover, refer to section 1.6.3.

    [c] To remove the three piece valve rocker cover. Refer to section 1.6.5.

    [d] Remove the engine lifter brackets, refer to section 1.5.2.

    [e] Remove the crankshaft pulley, refer to section 1.13.2.

    [f] Remove the crankshaft vibration damper, refer to section 1.12.2.

    [g] Remove the accessory drive, refer to section 1.28.2.

    [h] Remove the gear case cover, refer to section 1.10.2.

    [i] Remove the camshaft drive gear, refer to section 1.24.2.

    [j] Remove the bull gear and camshaft idler gear assembly, refer to section 1.26.2.

    [k] Remove the adjustable idler gear assembly, refer to section 1.25.2.

    [l] Remove the crankshaft timing gear and timing wheel, refer to section 1.27.2.

    [m] Remove the gear case, refer to section 1.11.2.

    [n] Remove the camshaft, refer to section 1.23.2.

    [o] Remove the cylinder head, refer to section 1.2.2.

    [p] Remove the flywheel, refer to section 1.14.2.

    [q] Remove the flywheel housing, refer to section 1.16.2.

    [r] Remove the oil pan, refer to section 3.11.2.

    [s] Remove the piston and connecting rod assembly, refer to section 1.18.2.

    [t] Remove the crankshaft, refer to section 1.7.2.

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NOTICE:
Before removing main bearing caps, be sure each is stamped or punch-marked in numerical order, beginning with No. 1 at the front, to ensure installation in their original position. Mark all caps on the oil cooler side (right side) of the engine to prevent reversal at assembly. Failure to mark numerical order may result in the caps being put back in incorrect order, improper crankshaft support and severe crankshaft or bearing damage or both.

[u] Remove the crankshaft main bearings, refer to section 1.9.2.

1.1.3 Cleaning the Cylinder Block

Before removing cylinder liners for block cleaning, the liner bores should be gaged to determine whether liner replacement is necessary. Refer to section 1.20.2.2.

Remove cylinder liners with the cylinder liner removal tool, J 35791, before putting the block in cleaning or descaling baths, to avoid trapping cleaning agents in block liner seating bores. See Figure 1-8.

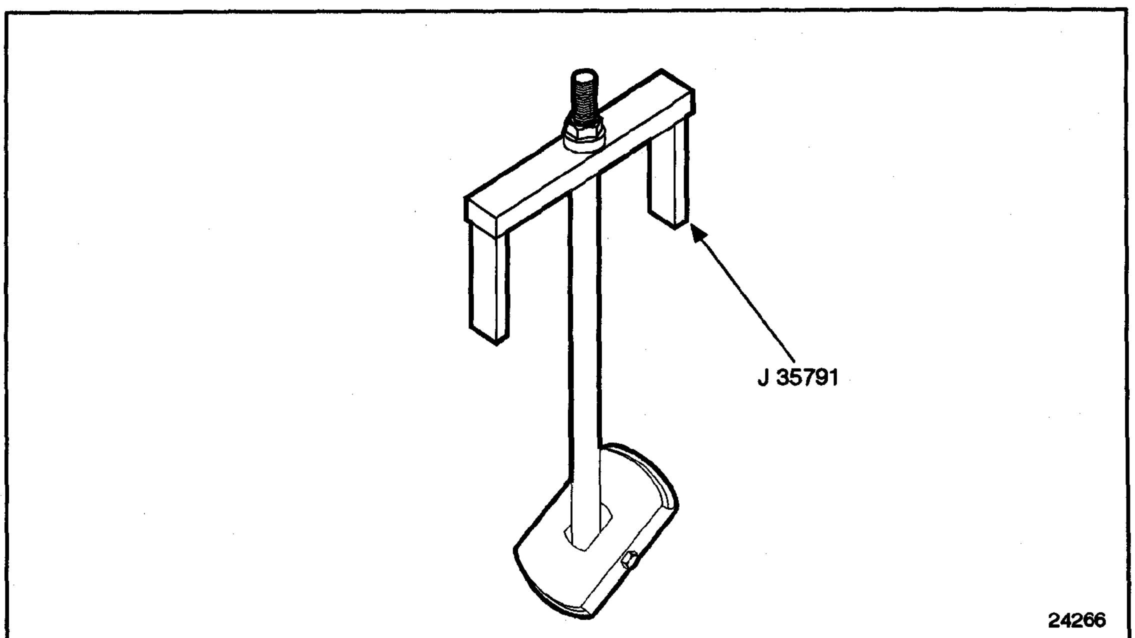

Figure 1-8 Cylinder Liner Removal Tool

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After disassembling and before removing the cylinder block from the overhaul stand for cleaning and inspection, install the two metric eye bolts J 35595 to the cylinder block. See Figure 1-9.

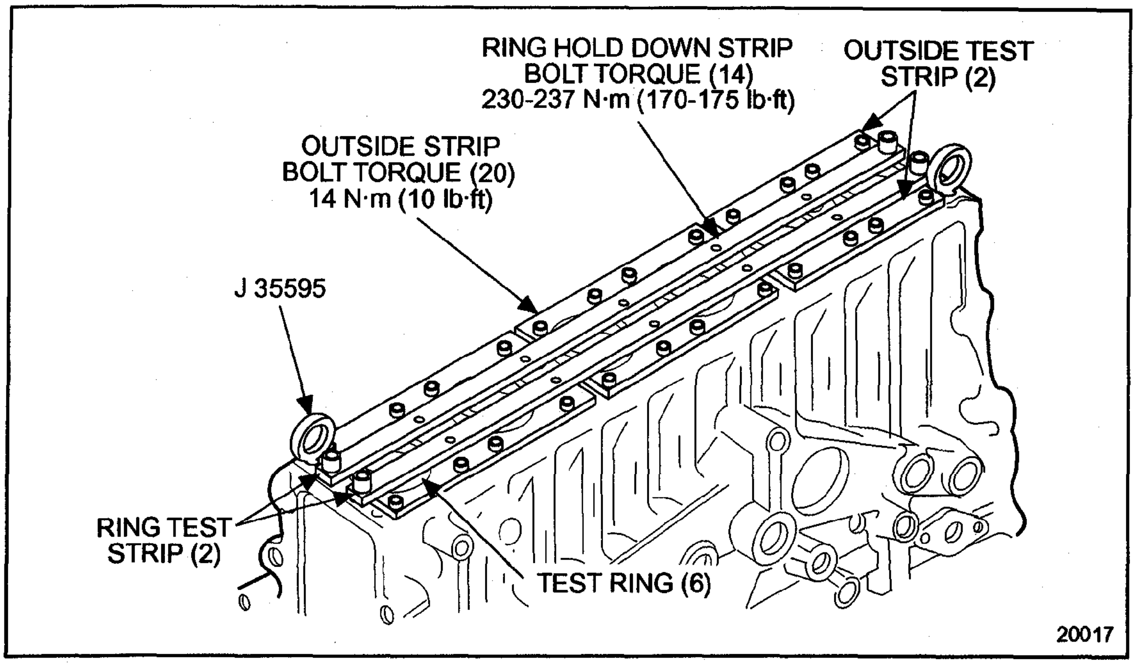

Figure 1-9 Cylinder Block Test Deck Plate Installation

Clean the cylinder block as follows:

1. Remove all oil and water gallery and weep hole plugs to allow the cleaning solution to enter the inside of the oil and water passages. On current block, remove bolt-on plate or piston-cooling oil spray nozzle at the base of each cylinder bore.
2. Immerse and agitate the block in a hot bath of a commercial, heavy-duty alkaline solution.
3. Wash the block in hot water or steam clean it to remove the alkaline solution.
4. If the water jackets are heavily scaled, proceed as follows:
   [a] Immerse and agitate the block in a bath of inhibited phosphoric acid.
   [b] Allow the block to remain in the acid bath until the bubbling action stops (approximately 30 minutes).
   [c] Lift the block, drain it and immerse it again in the same acid solution for 10 more minutes. Repeat until all scale is removed from the water jacket area.
   [d] Rinse the block in clear, hot water to remove the acid solution.
   [e] Neutralize the acid that may cling to the casting by immersing the block in an alkaline bath.

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[f] Wash the block in clean water or steam clean it.

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

5. Dry the cylinder block with compressed air. Blow out all of the bolt holes and passages with compressed air.

NOTE:
The above cleaning procedure may be used on all ordinary cast iron and steel parts for the engine. Aluminum parts, such as flywheel housing, air intake manifold, oil filter adaptor and the camshaft gear access cover should NOT be cleaned in this manner. Mention will be made of special procedures when necessary.

6. Be certain that all water passages and oil galleries have been thoroughly cleaned and dried. Install weep hole plugs and precoated pipe plugs. Install new cup plugs using a coating of good grade non-hardening sealant such as Loctite® 620 or equivalent. Refer to section ADDITIONAL INFORMATION 1.A, "Engine Plug and Dowel Chart."
7. Pressure test the cylinder block. Two methods of cylinder block pressure testing may be used depending on the test facilities available:

   [a] Immersion method; refer to section 1.1.3.1.

   [b] Leak-marker method; refer to section 1.1.3.2.

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1.1.3.1 Testing the Cylinder Block (Immersion Pressure Method)

Use cylinder block pressure test kit, J 36223–D, for immersion method pressure testing as follows:

1. Install cylinder liners with new seal rings and crevice seals. Refer to section 1.20.3. Seat the liners firmly in the block counterbores with cylinder liner installation tool, J 35597.
2. Install two metric eye bolts, J 35595, in the head bolt holes at opposite ends of the block. See Figure 1-10.

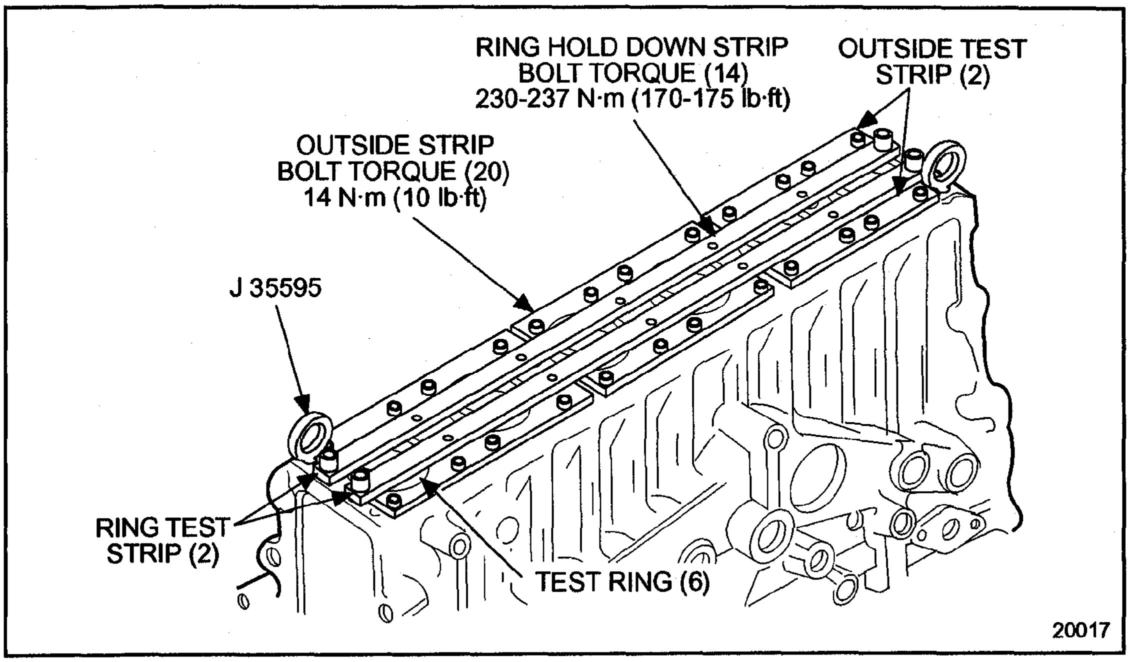

Figure 1-10 Cylinder Block Test Deck Plate Installation

3. Install the cylinder block test strips and rings. See Figure 1-10.
4. Install the bolts through the strips and into the cylinder block. Torque the bolts on the ring strips to 230-237 N·m (170-175 lb·ft). Torque the bolts on the outside strips to 14 N·m (10 lb·ft).

NOTE:
Because of a design change to the 1991 cylinder block, the water inlet cover plate tool has changed. Refer to section ADDITIONAL INFORMATION 1.A, for instructions on modifying the former tool, J 36223-7, part of J 36223–D.

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5. Install the water inlet cover plate, J 36223-7A, part of J 36223–D. See Figure 1-11. Use the bolt supplied with the tool to secure it to the cylinder block.

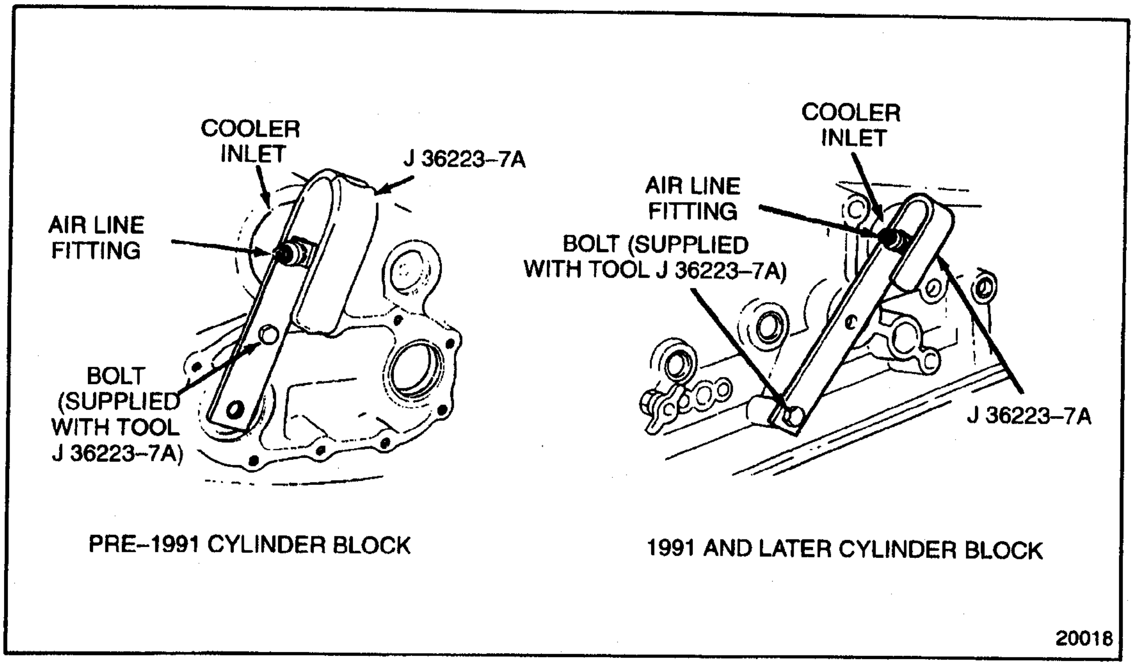

Figure 1-11 Water Inlet Cover Plate Installation

NOTE:
At the base of each liner, the space between upper and lower liner seals is vented to the block surface on the left side. Any coolant leakage past the upper seal is drained to the outside rather than into the crankcase, and is easily detected by a visual inspection.

6. With a suitable lifting device and spreadable bars, immerse the cylinder block for twenty minutes in a tank of water heated to 82-93°C (180-200°F).
7. Attach an air line to the water inlet cover plate and apply 138 kPa (20 lb/in.^{2}) air pressure to the water jacket. Observe the water in the tank for bubbles that will indicate cracks or leaks. A cracked cylinder block must be replaced by a new block.

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CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

8. Remove the block from the water tank. Remove the plates and gaskets and blow out all of the passages in the block with compressed air.
9. Remount the cylinder block to the engine overhaul stand, J 29109. See Figure 1-6.

1.1.3.2 Testing the Cylinder Block (Leak-Marker Pressure)

When a large water tank is not available, or when it is desired to check the block for cracks without removing the engine from the vehicle cylinder block, leak-marker pressure testing may be used. However, it is necessary to remove the cylinder head, oil cooler, and oil pan.

1. Install cylinder liners with new seal rings and crevice seals. Refer to section 1.20.3. Seat the liners firmly in the block counterbores with cylinder liner installation tool, J 35597.
2. Install two metric eye bolts, J 35595, in the head bolt holes at opposite ends of the block. See Figure 1-10.
3. Fill the water jacket with a mixture of water and 3.8 liters (1 U.S. gallon) of permanent-type antifreeze. The antifreeze will penetrate small cracks and its color will aid in detecting their presence.
4. Install the cylinder block test strips and rings. See Figure 1-10.
5. Install the bolts through the strips and into the cylinder block. Torque the bolts on the ring strips to 230-237 N·m (170-175 lb·ft). Torque the bolts on the outside strips to 14 N·m (10 lb·ft).
6. Install the water inlet cover plate, J 36223-7A part of J 36223–D. See Figure 1-11. Use the bolt supplied with the tool to secure it to the cylinder block.

NOTE:
At the base of each liner, the space between upper and lower liner seals is vented to the block surface, on the left side. Any coolant leakage past the upper seal is drained to the outside rather than into the crankcase, and is easily detected by a visual inspection.

NOTE:
Because of a design change to the 1991 cylinder block, the water inlet cover plate tool has changed. Refer to section ADDITIONAL INFORMATION 1.A, for instructions on modifying the former tool, J 36223-7 part of J 36223–D.

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7. Apply 138 kPa (20 lb/in.^{2}) air pressure to the water jacket and maintain this pressure for at least two hours to give the water and antifreeze mixture ample time to work its way through any cracks which may exist.
8. At the end of this test period, examine the outside diameter area of the liner flanges, oil passages, crankcase and exterior of the block for presence of the water and antifreeze mixture, which will indicate the presence of cracks. A cracked cylinder block must be replaced with a new block.

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

9. After the pressure test is completed, remove the test deck plate and gasket and the water inlet cover plate. Drain the water jacket. Then blow out all of the passages in the cylinder block with compressed air.
10. Remount the cylinder block to the engine overhaul stand, J 29109. See Figure 1-6.

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1.1.3.3 Inspection of the Cylinder Block

Perform the following for cylinder block inspection:

1. Remove the cylinder liners and regage to determine whether liner replacement is necessary. Refer to section 1.20.2.
2. Measure the bore of each cylinder with cylinder bore gage, J 5347-B, which has a dial indicator calibrated in 0.0001 in. increments. See Figure 1-12.

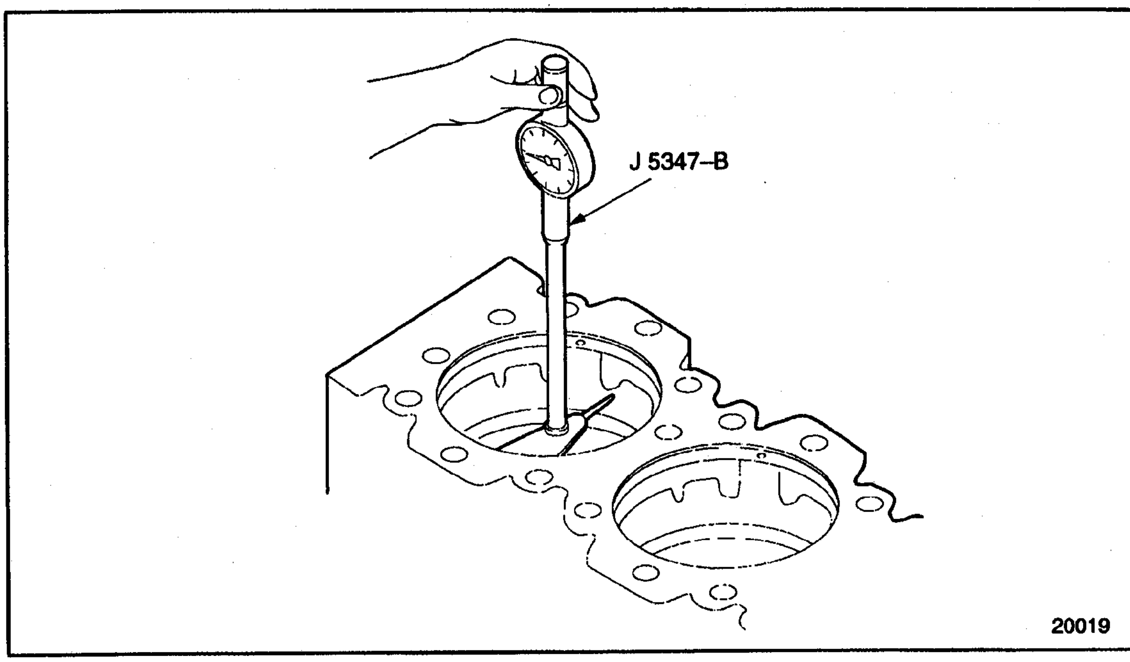

Figure 1-12 Gaging Cylinder Bores

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3. Measure cylinder block bore, at the positions on axis 90 degrees apart. See Figure 1-13. If the diameter does not exceed the dimensions listed in Table 1-1, the block may be reused.

NOTE:
The above measurements are average gage readings at each position. Also, the out-of-round must not exceed 0.0254 mm (0.001 in.).

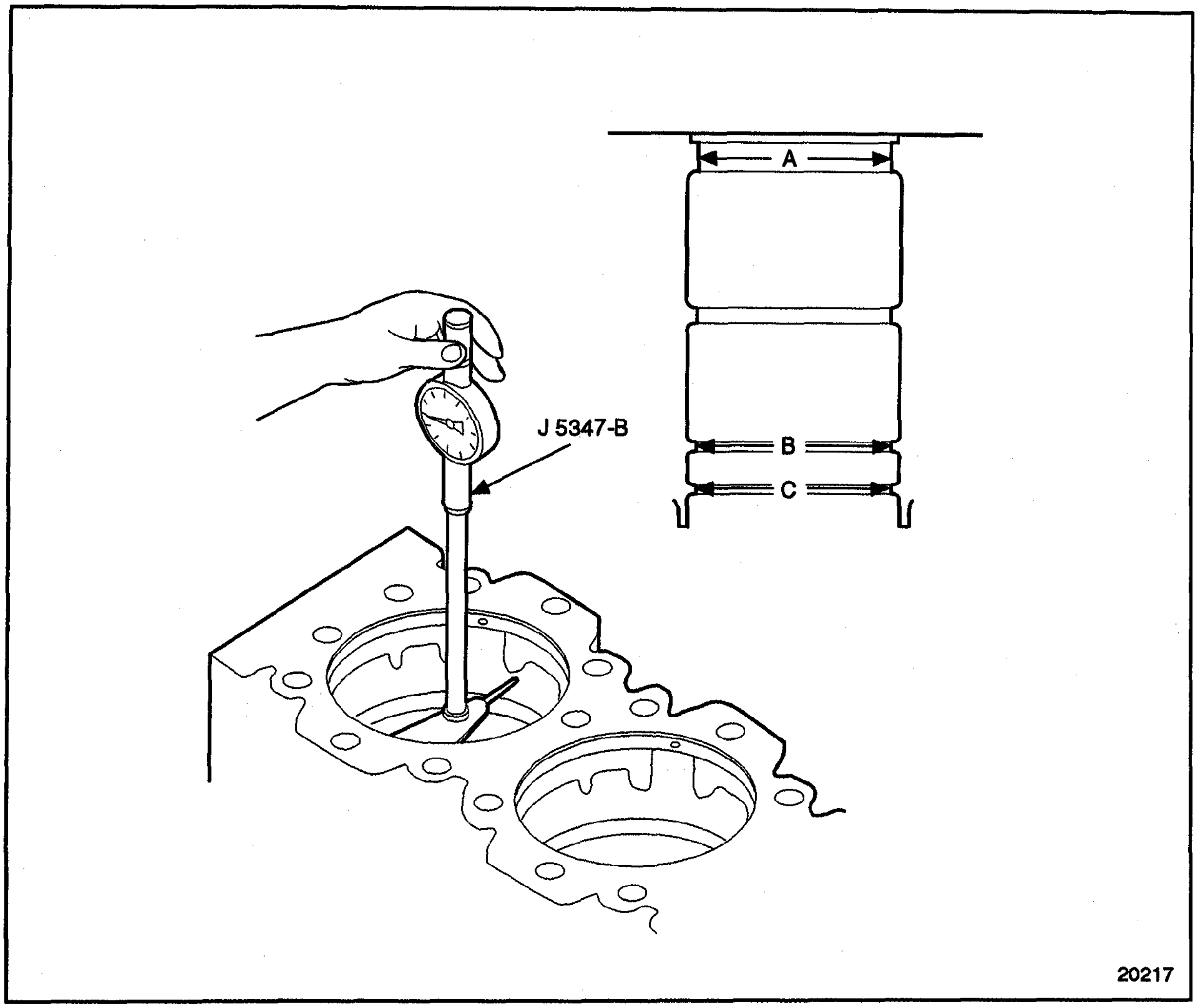

Figure 1-13 Maximum Cylinder Block Bore Diameters by Location (After Clean-up)

Location	Diameter, mm	Diameter, in.
A	149.050 - 149.120	5.868 - 5.871
B	146.050 - 146.120	5.750 - 5.753
C	146.050 - 146.120	5.750 - 5.753

Table 1-1 Acceptable Cylinder Bore Diameters

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1.1.3.4 Inspection of Deck Flatness

Check the cylinder block deck for flatness with an accurate straightedge and feeler gage. See Figure 1-14.

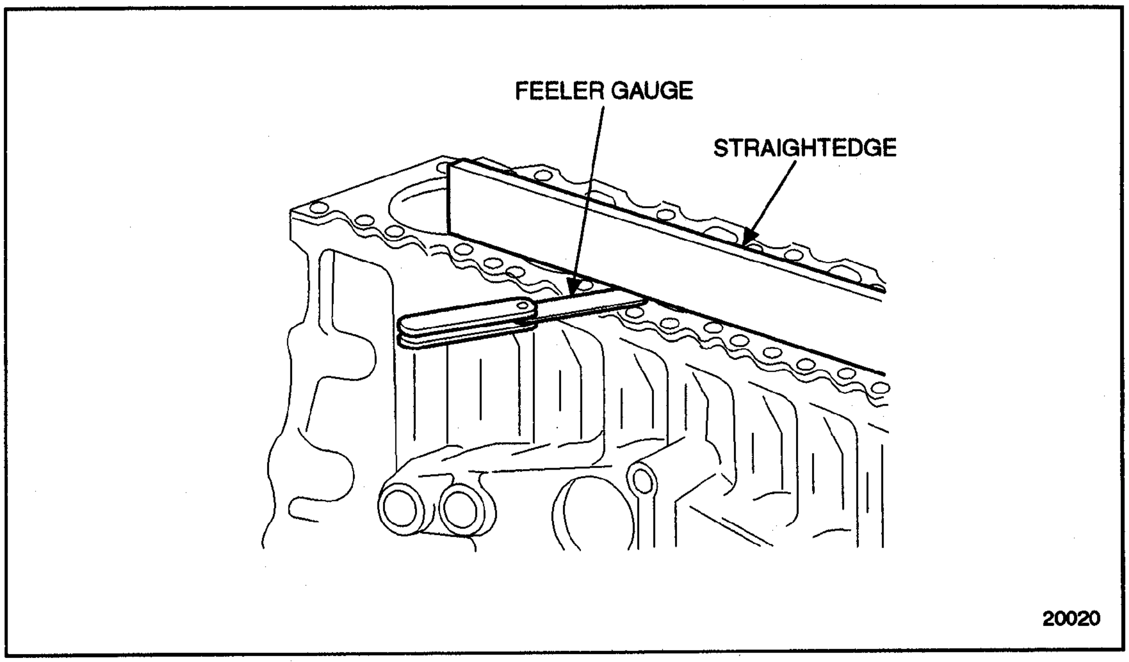

Figure 1-14 Checking Block Deck for Flatness

Check front-to-rear flatness next to the cylinder liner flanges on both sides, and side-to-side flatness between the liner flanges. The deck must be flat within 0.127 mm (0.005 in.) front-to-rear, and flat within 0.076 mm (0.003 in.) side-to-side. If not, the deck must be resurfaced.

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NOTICE:
The camshaft is mounted in the cylinder head so resurfacing of the block affects the position of the camshaft in relation to the adjustable idler gear and gear train.

Record the amount of stock removed from the cylinder block by stamping the amount removed on the cylinder block pad. See Figure 1-15.

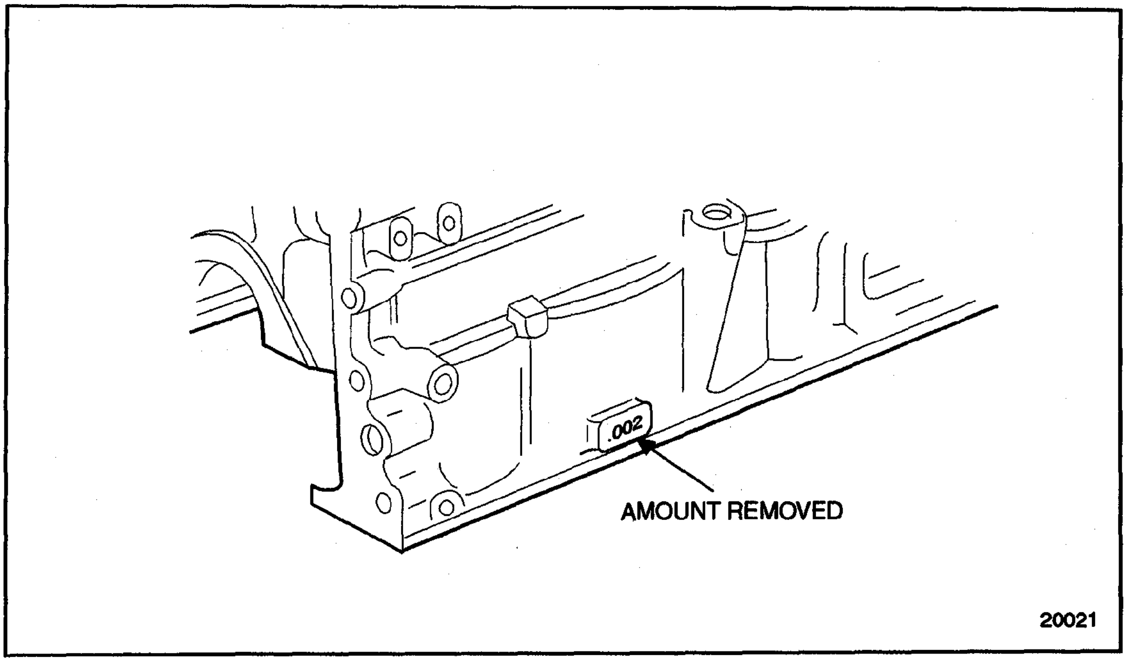

Figure 1-15 Recording Stock Removal on Cylinder Block Pad

1.1.3.5 Inspection of Main Bearing Bores

Perform the following steps for main bearing bore inspection:

1. Install the main bearing caps in their original positions. Lubricate the cap bolt threads and head contact surfaces with a small quantity of International Compound #2®.
   International Compound #2® is a registered trademark of IRMCO.
2. Install the main cap bolts and torque to 470-530 N·m (347-391 lb·ft).
3. Measure the main bearing bores using dial bore gage which has a dial indicator calibrated in 0.0001 in. increments. Set the cylinder bore gage on zero in master setting fixture. See Figure 1-16.

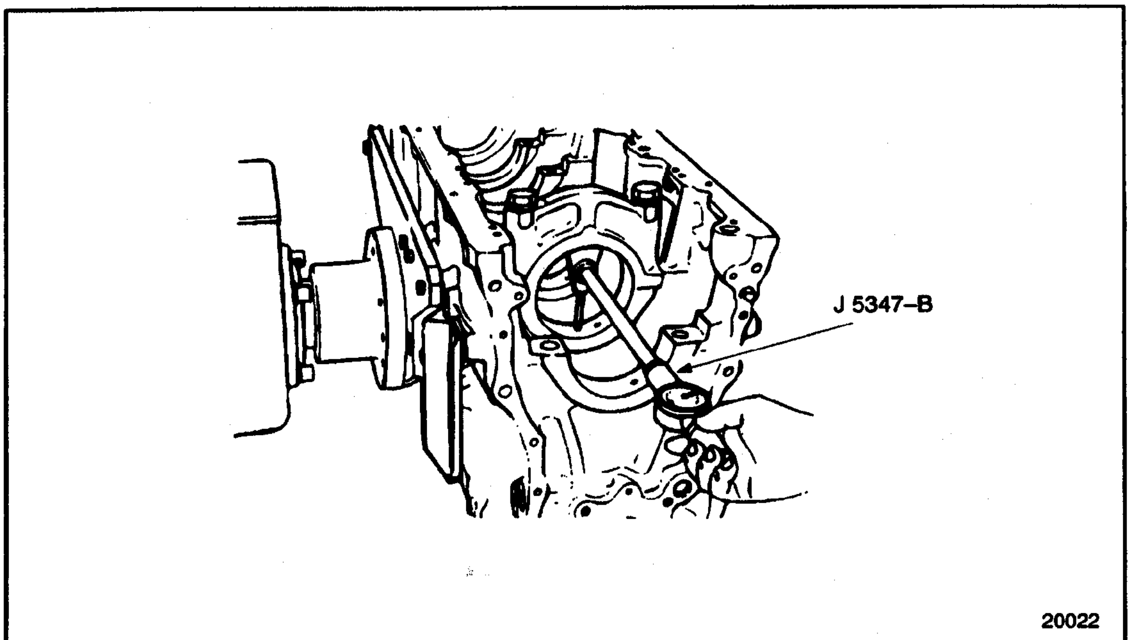

Figure 1-16 Gaging Main Bearing Bores

The bore diameter specifications is 133.00-133.025 mm (5.236-5.237 in.). Line boring is also necessary when a bearing cap must be replaced due to breakage or spun-bearing damage. Refer to section ADDITIONAL INFORMATION1.A, for line bore specifications which are listed in Table 1-15.

NOTE:
Dial bore master setting fixture should be used to zero the cylinder bore gage.

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1.1.3.6 General Inspection

Check all machined surfaces for nicks or burrs that could affect the fit of mating parts. Clean up as necessary by stoning. Also inspect all tapped holes for thread damage and retap or install helical thread inserts as necessary. Replace any loose or damaged dowel pins. Refer to section ADDITIONAL INFORMATION 1.A, "Engine Plug and Dowel Charts" for specifications.

1.1.3.7 Rust Prevention

After inspection, if the cylinder block is not to be used immediately, spray the machined surfaces with engine oil.

NOTICE:
Castings free of grease or oil will rust when exposed to the atmosphere. Rust on machined surfaces may result in leakage.

If the block is to be stored for an extended period of time, spray or dip it in a polar-type rust preventive such as "Tectyl® 502-C" from Valvoline Oil Company (or equivalent).

Tectyl® is a registered trademark of Ashland Oil, Inc.

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1.1.4 Reassembly of Cylinder Block

After the cylinder block has been cleaned and inspected, assemble the engine as follows:

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

1. Before a reconditioned or new service replacement cylinder block is used, steam clean it to remove the rust preventive and blow out the oil galleries with compressed air.
2. If a new service replacement block is used, stamp the engine serial number and model number on the pad provided on the left side of the block, just below the deck. See Figure 1-17.

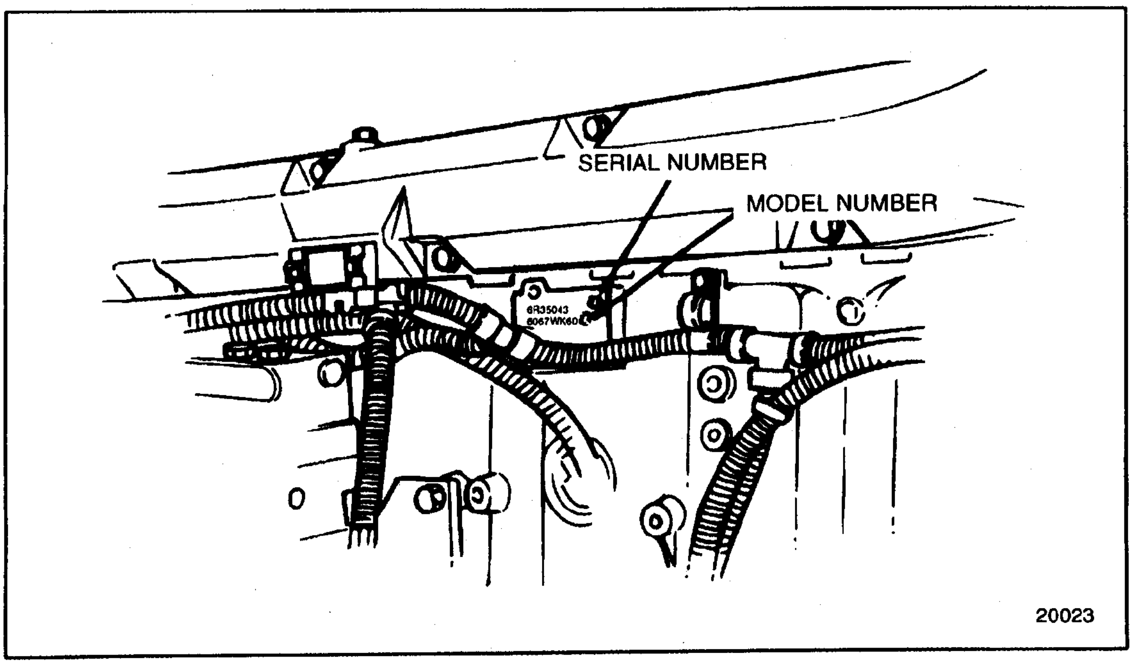

Figure 1-17 Location of Engine Serial and Model Numbers

3. Also stamp the position numbers on the main bearing caps and the position of the No. 1 bearing on the cooler side of the oil pan mounting flange of the block.
4. Install the main bearing caps in their original positions; refer to section 1.9.3.

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NOTICE:

Always check to make sure cooling nozzles are open and aligned after piston installation. An obstructed, misaligned, bent, or damaged nozzle may not provide proper piston cooling. A loosened nozzle may cause a loss of main gallery oil pressure. In either case, piston overheating or lack of adequate lubrication may result in severe engine damage.

5. On current non-premium engines with cast iron pistons, install the bolt-on plate over the oil gallery orifice at the base of each cylinder bore. On premium engines with closed-end rods and forged steel pistons, install oil spray nozzles into these openings. See Figure 1-18 for location of nozzle. Torque plate nozzle retaining bolts to 30–38 N·m (22–28 lb·ft).

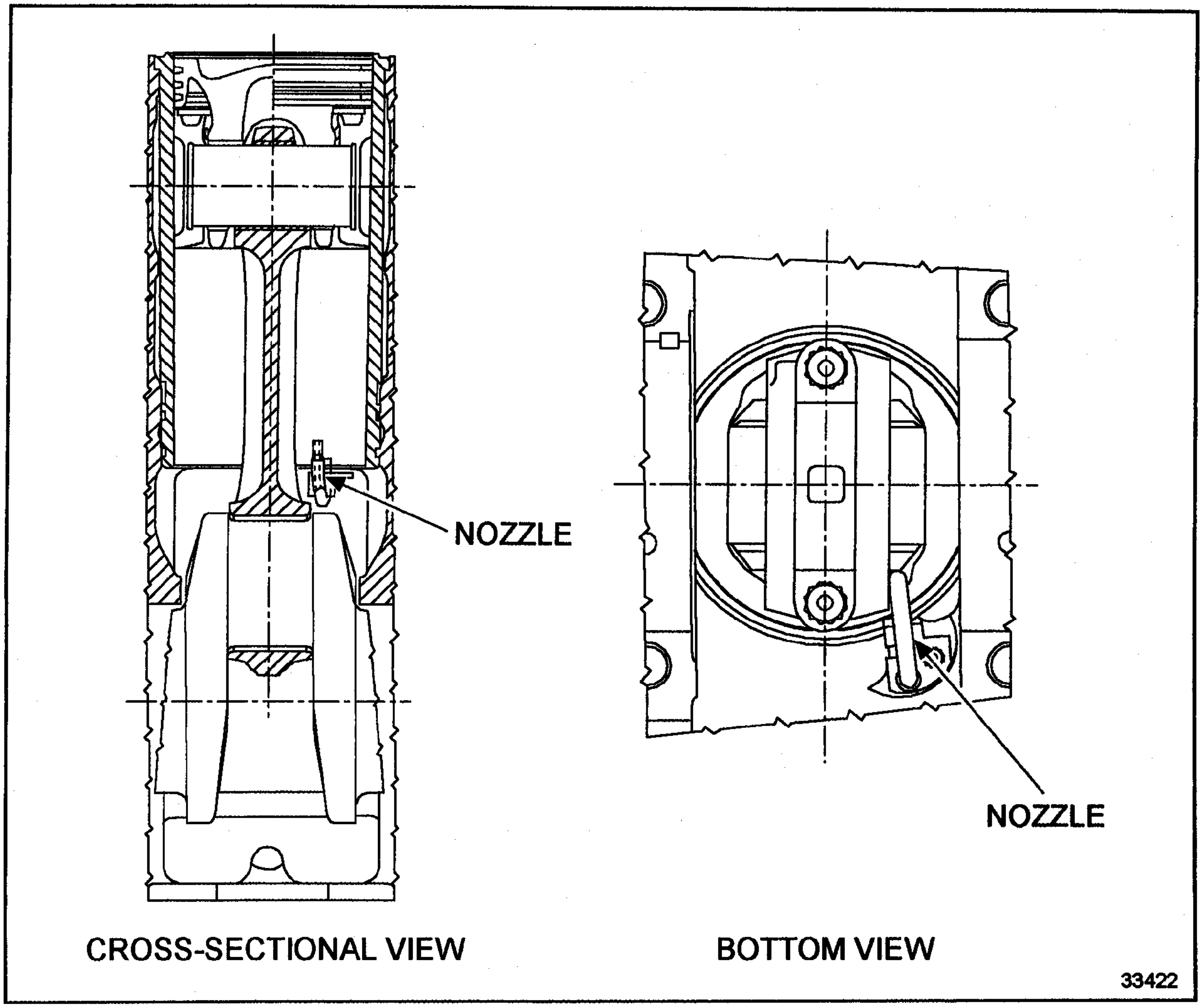

Figure 1-18 Oil Spray Nozzle Location

6. Install all of the required cup plugs. Use a good grade of non-hardening sealant such as Loctite® 620 (or equivalent). Apply a thin coat of sealant just inside the chamfer where the plug is to be installed and install using cup plug installation tool set, J 35653. See Figure 1-19.

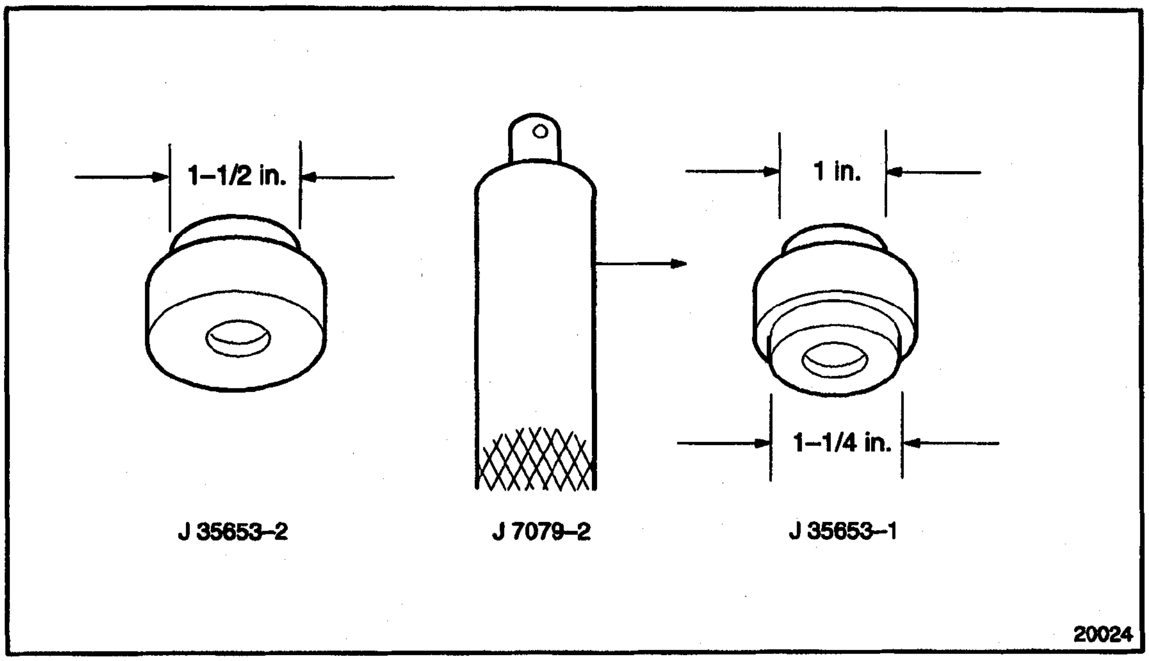

Figure 1-19 Cup Plug Installation Tool Set

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7. Install all of the required pipe plugs. Refer to section ADDITIONAL INFORMATION 1.A, "Engine Plug and Dowel Charts".

NOTE:
Whenever a pipe plug is removed from the cylinder block, the threads must be coated with Loctite®, PT-7260, pipe sealant with Teflon, or equivalent, before reassembly. Certain plugs available from the parts depot already have a sealer applied to the threads. Although unnecessary, this pre-coating will not be affected if pipe sealer with Teflon is also applied.

8. With the engine mounted on the overhaul stand, install all of any remaining subassemblies and parts on the cylinder block.
   [a] To install the crankshaft main bearings, refer to section 1.9.3.
   [b] To install the crankshaft, refer to section 1.7.3.
   [c] To install the piston and connecting rod assembly, refer to section 1.18.5.
   [d] To install the oil pan, refer to section 3.11.4.
   [e] To install the flywheel housing, refer to section 1.16.3.
   [f] To install the flywheel, refer to section 1.14.3.
   [g] To install the cylinder head, refer to section 1.2.5.
   [h] To install the camshaft, refer to section 1.23.6.
   [i] To install the gear case, refer to section 1.11.3.
   [j] To install the crankshaft timing gear and timing wheel, refer to section 1.27.3.
   [k] To install the adjustable idler gear assembly, refer to section 1.25.3.
   [l] To install the bull gear and camshaft idler gear assembly, refer to section 1.26.3.
   [m] To install the camshaft drive gear, refer to section 1.24.4.
   [n] To install the gear case cover, refer to section 1.10.3.
   [o] To install the accessory drive, refer to section 1.28.5.
   [p] To install the crankshaft vibration damper, refer to section 1.12.3.
   [q] To install the crankshaft pulley, refer to section 1.13.3.
   [r] To install the engine lifter brackets, refer to section 1.5.3.
   [s] To install the valve rocker cover, refer to section 1.6.8 (one piece) and refer to section 1.6.9 (two piece and three piece).
   [t] Install any electrical components, connectors or wiring looms that were removed during disassembly.
   [u] Install the SRS, refer to section 2.29.3.
   [v] Install the TRS, refer to section 2.30.3.

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[w] Install the ECM, refer to section 2.18.3for DDEC I, refer to section 2.17.4for DDEC II, refer to section 2.16.3for DDEC III/IV, and cold plate if required, refer to section 2.16.3.

[x] Install a suitable lifting device to the engine. See Figure 1-5.

CAUTION:

To avoid injury from a falling engine, ensure the engine is securely attached to the engine overhaul stand before releasing the lifting sling.

[y] Remove the engine from the overhaul stand. See Figure 1-6.

Transfer the engine to a suitable engine dynamometer test stand. Operate the engine on a dynamometer following the Run-in procedure; refer to section 11.8.3.2.

Install the engine in the equipment from which it was removed.

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1.2 CYLINDER HEAD

The Series 60 cylinder head combines intake and exhaust valve porting and fuel injector seats with water jacketing to cool the ports, injectors and combustion chamber area. See Figure 1-20.

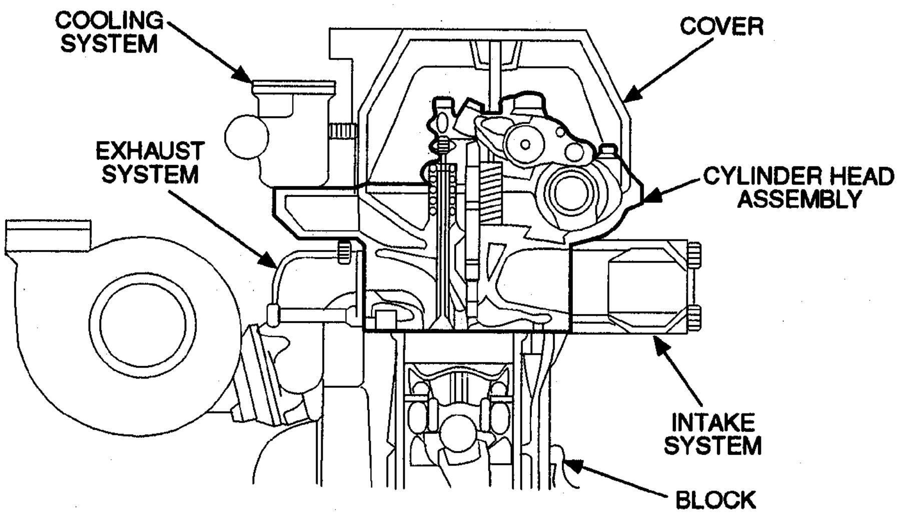

Figure 1-20 Cylinder Head Assembly and Mating Components

With the overhead camshaft design, the cylinder head assembly includes:

- ☐ Cylinder head
- ☐ Valve and injector operating mechanism
- ☐ Injector, valve guide and related parts
- ☐ Camshaft and camshaft bearings

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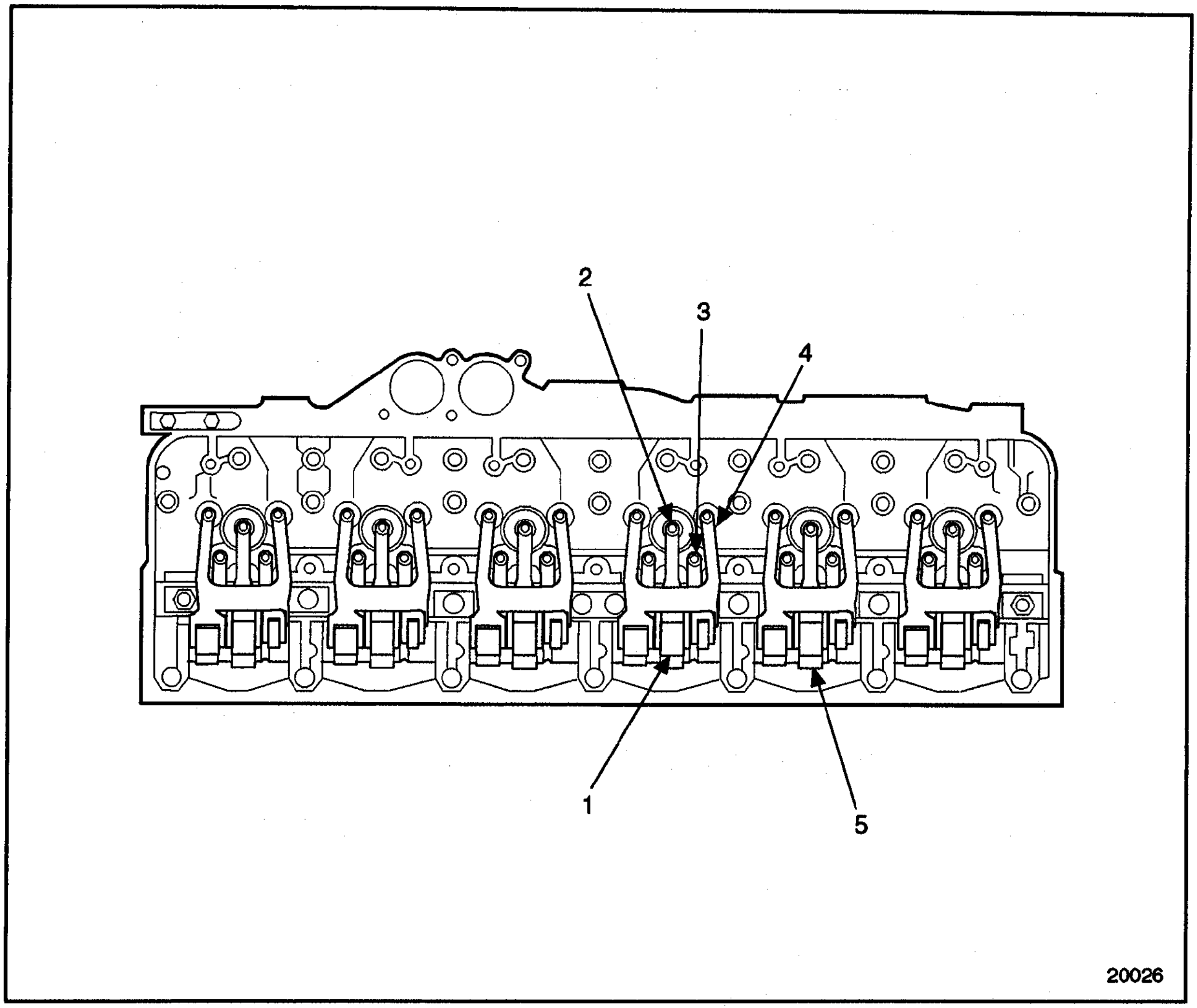
The nested roller follower type rocker arms transmit camshaft motion directly to the valves and injectors. See Figure 1-21.



1. Roller Follower
2. Injector Rocker Arm
3. Intake Valve Rocker Arm
4. Exhaust Valve Rocker Arm
5. Camshaft

Figure 1-21 Cylinder Head Assembly

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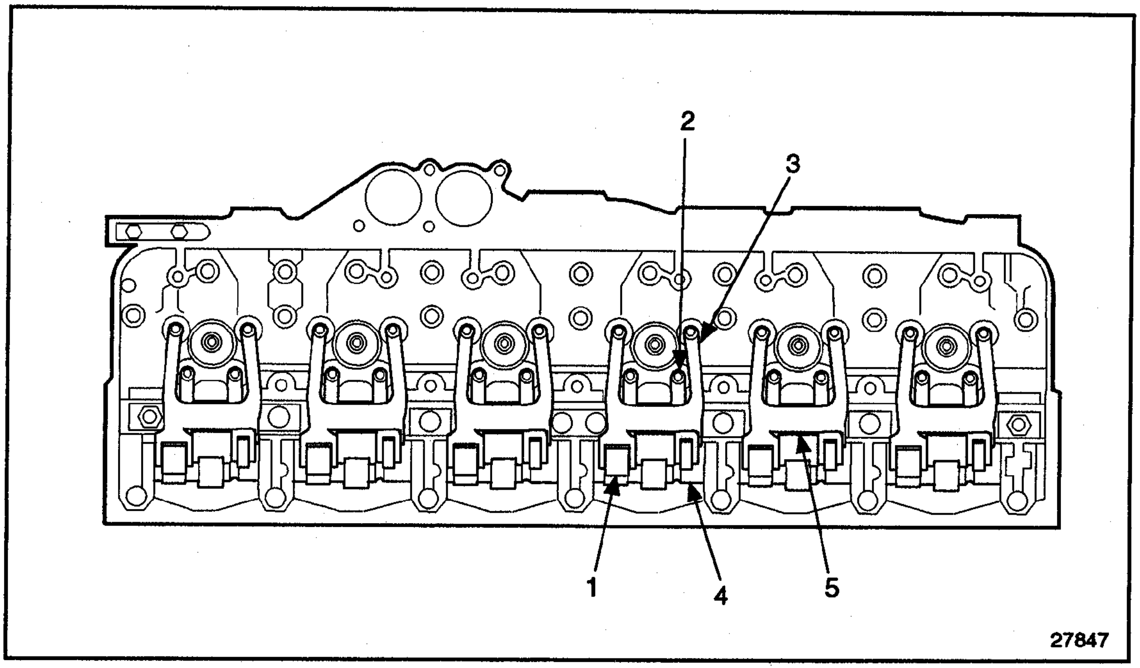
The nested roller follower type rocker arms transmit cam motion directly to the valves. See Figure 1-22.



1. Roller Follower
2. Intake Valve Rocker Arm
3. Exhaust Valve Rocker Arm
4. Camshaft
5. Spacer

Figure 1-22 Cylinder Head Assembly (Series 60G Engine)

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The porting within the cylinder head is cross-flow, with intake and exhaust ports on opposite sides for minimum restriction and maximum exposure to coolant flow. Four valves are used per cylinder, two intake and two exhaust. See Figure 1-23.

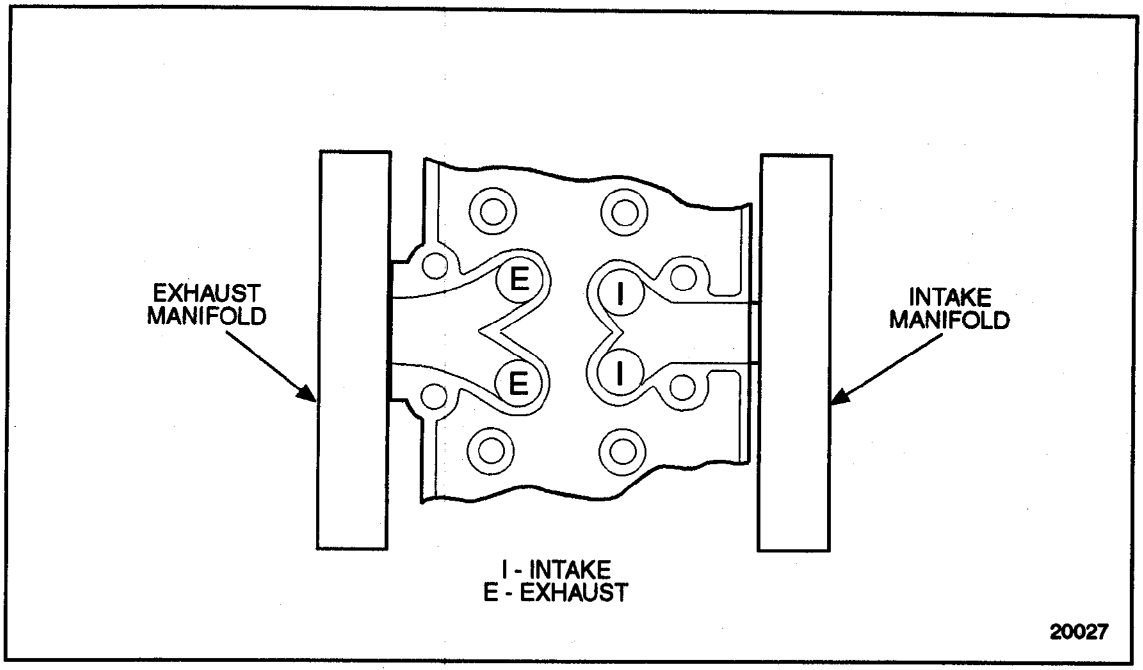

Figure 1-23 Intake and Exhaust Valve Porting

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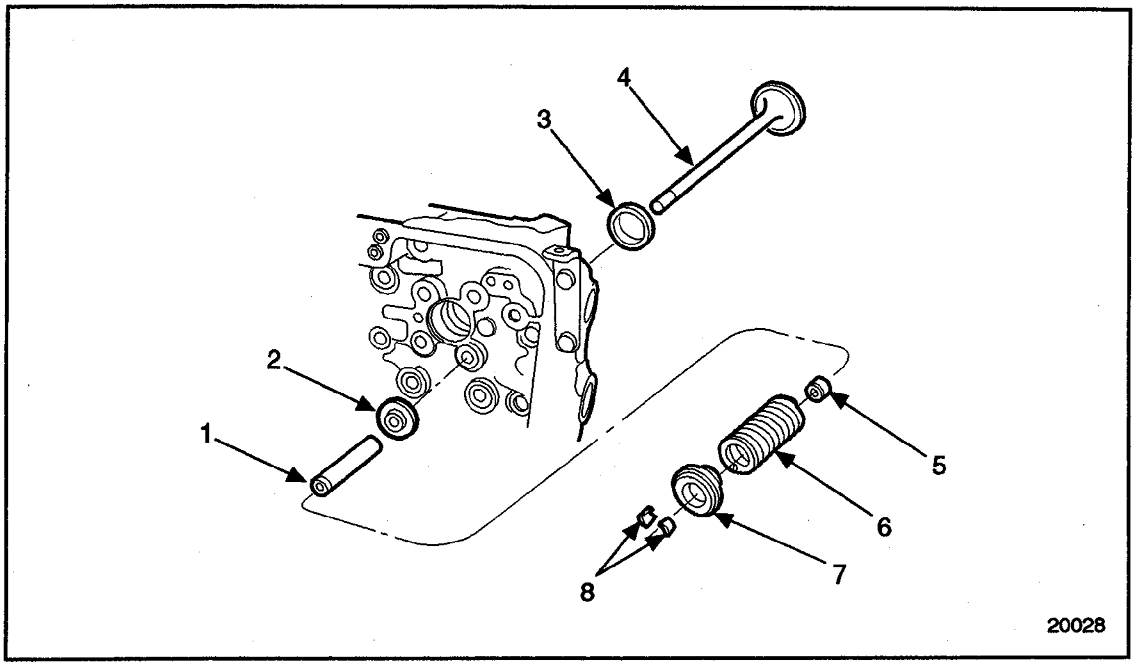
Replaceable valve guides, valve spring seats, valve stem seals, valve rotators and valve seat inserts are used on all valves. See Figure 1-24.



1. Valve Guide
2. Valve Spring Seat
3. Valve Seat Insert
4. Valve
5. Valve Stem Oil Seal
6. Valve Spring
7. Valve Rotator
8. Valve Keepers

Figure 1-24 Valve Guides and Related Parts

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Copper injector tubes extending through the cylinder head water jacket are required for the fuel injectors. The tubes are directly exposed to the coolant. An O-ring seals the injector tube upper end in the recess. The lower end of the injector tube must be expanded and flared during the installation process to contain a tight fit in the firedeck bore. A beveled seat machined in the tube provides a compression-tight seal when the injector is seated, as well as affording effective heat transfer facilitating injector cooling. Refer to section 2.4.

Fuel galleries machined into the head supply fuel under fuel pump pressure to all injectors, and excess fuel is returned to the fuel tank. The fuel gallery outlet (restricted) fitting is installed in the rear of the cylinder head. See Figure 1-25.

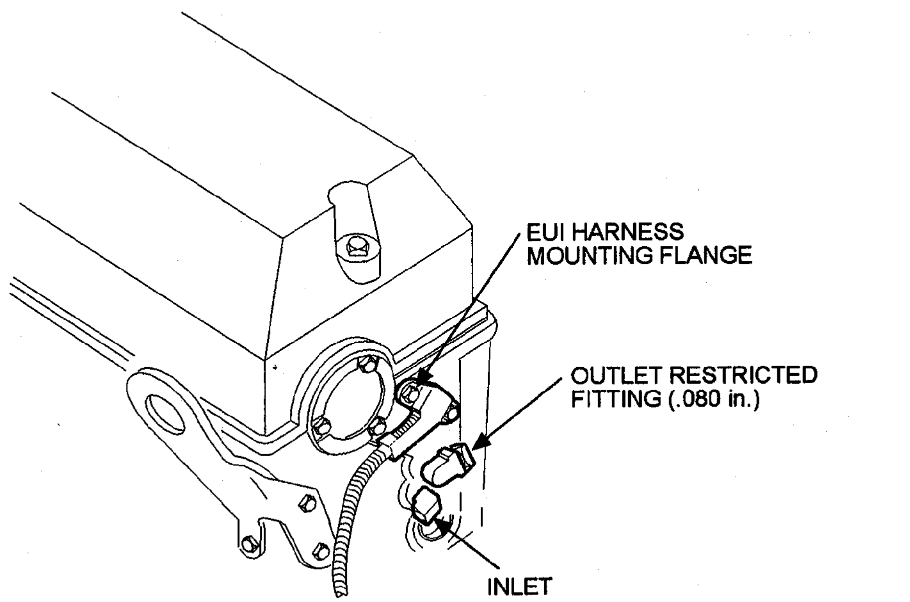

Figure 1-25 Fuel Gallery Inlet and Outlet Fittings

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1.2.1 Repair or Replacement of Cylinder Head

To determine if repair is possible or replacement is necessary, perform the following procedure. See Figure 1-26.

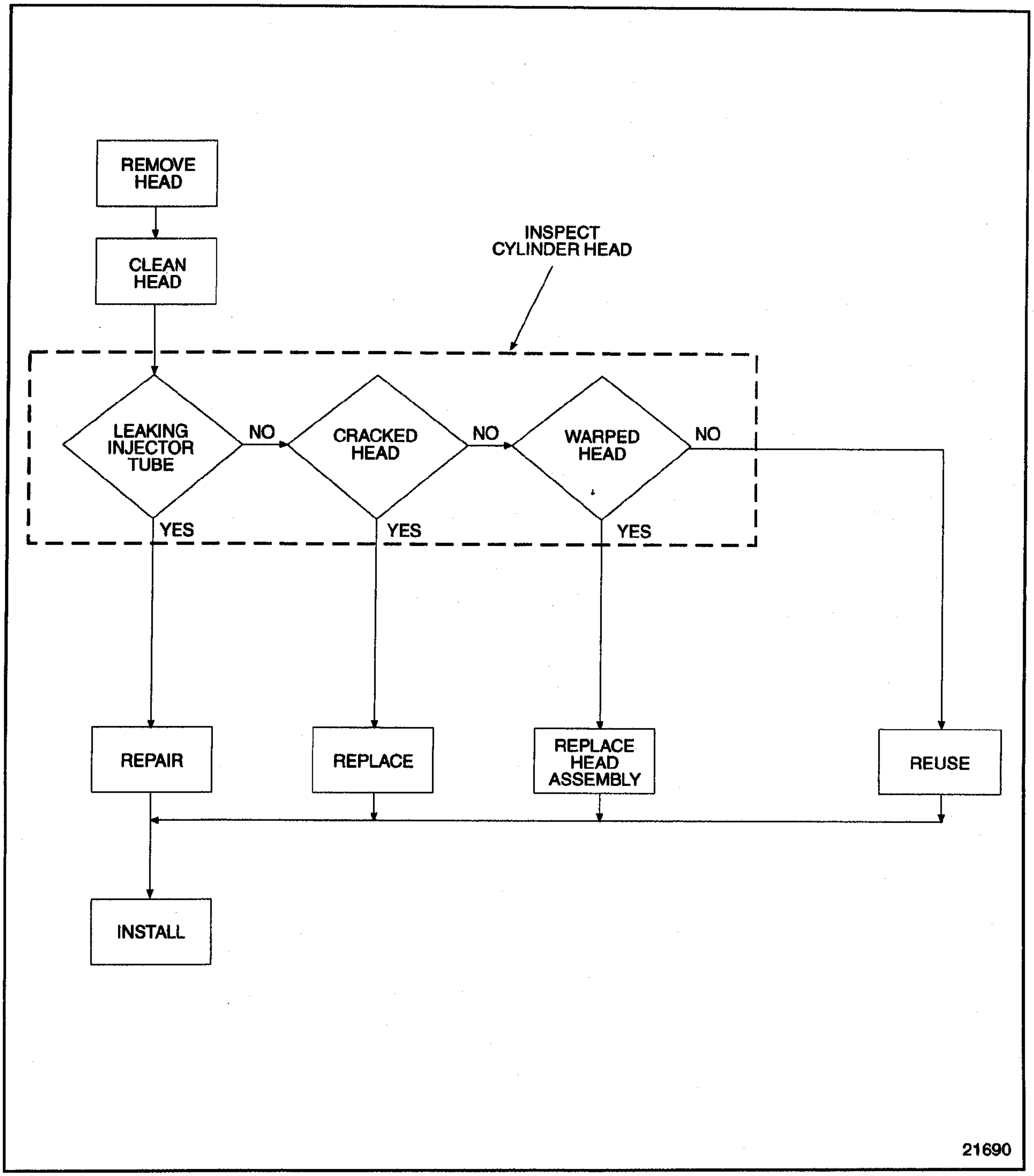

Figure 1-26 Flowchart for Repair or Replacement of Cylinder Head

1.2.2 Removal and Cleaning of Cylinder Head

Because optional and accessory equipment varies with the engine application, this procedure covers only the basic engine. If the engine is equipped with accessories that affect cylinder head removal, note the mounting details of each to assure correct installation at reassembly.

Remove the cylinder head as follows:

1. Drain the cooling system. Refer to section 13.13.4.
2. Disconnect the exhaust pipe at the turbocharger. Refer to section 6.6.2.
3. Remove the air cleaner and charge air cooler ducting from turbocharger and intake manifold. Refer to section 6.2.2and refer to section 6.4.2.

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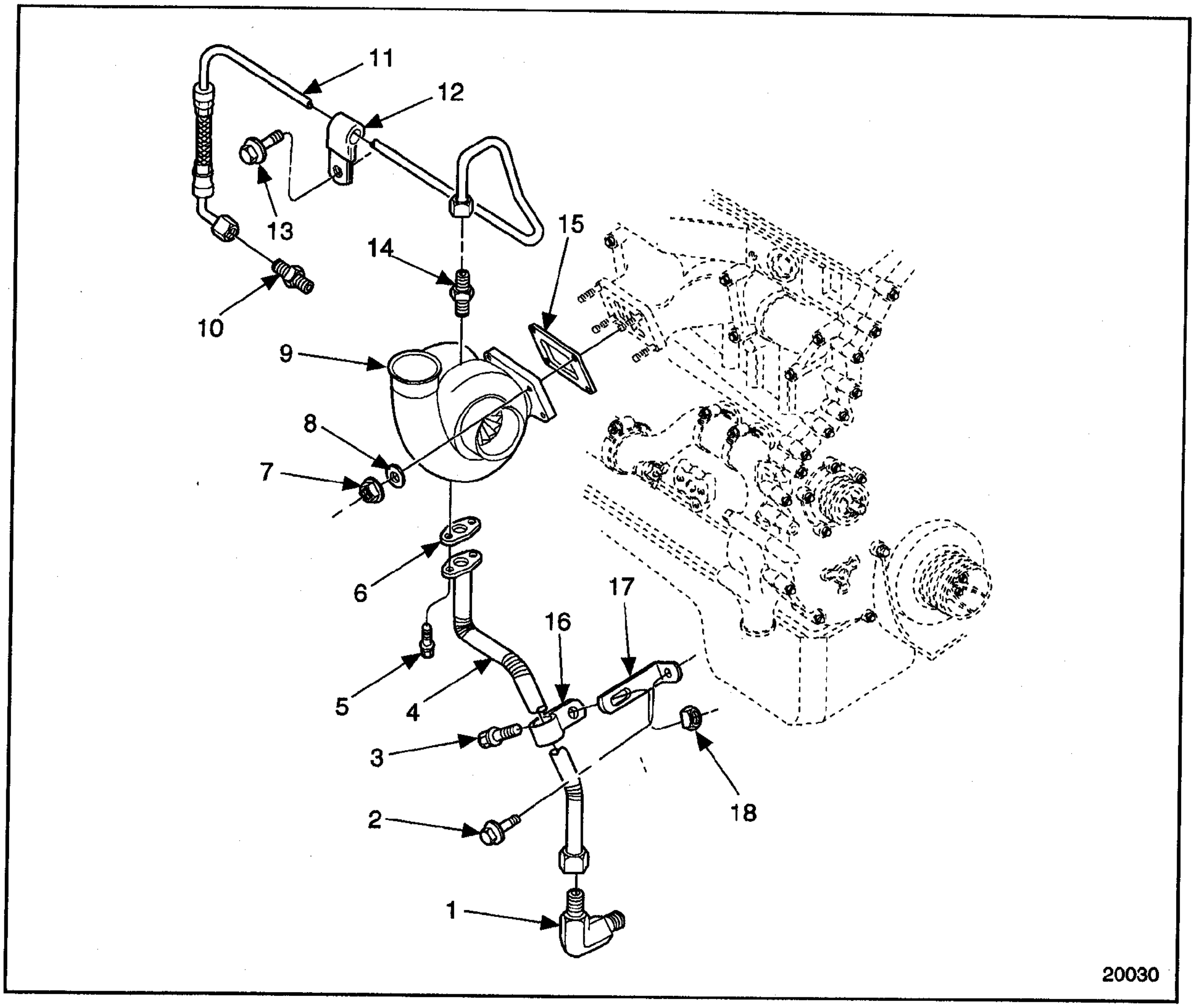
4. Disconnect the turbocharger coolant supply (if water-cooled), oil supply and drain lines, and remove the turbocharger if necessary. See Figure 1-27.



1. Elbow, Oil Drain Tube
2. Bolt, Mounting Bracket
3. Bolt, Oil Drain Tube Clip
4. Tube, Turbo Oil Drain
5. Bolt, Oil Drain Tube Mounting
6. Gasket, Turbo Oil Drain Tube
7. Nut, Turbo Mounting
8. Washer, Turbo Mounting
9. Turbocharger Assembly
10. Connector, Oil Supply Tube
11. Tube Assembly, Turbo Oil Supply
12. Clip, Oil Supply Tube
13. Bolt, Oil Supply Tube Clip
14. Connector, Oil Supply Tube (to turbocharger)
15. Gasket, Turbo Exhaust Inlet
16. Clip, Oil Drain Tube
17. Bracket, Oil Drain Tube Clip Mounting
18. Nut, Oil Drain Tube Clip

Figure 1-27 Turbocharger Oil Lines

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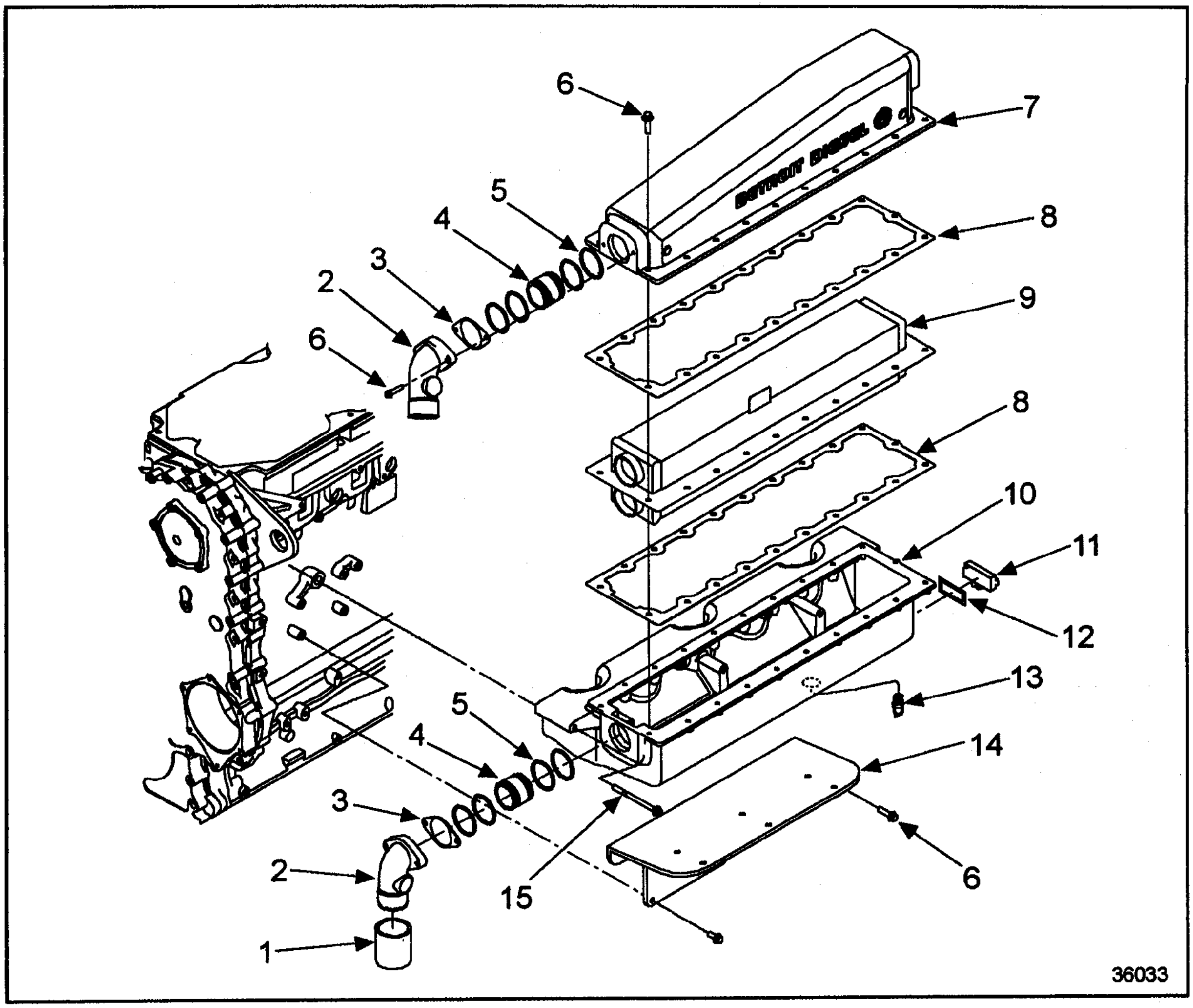
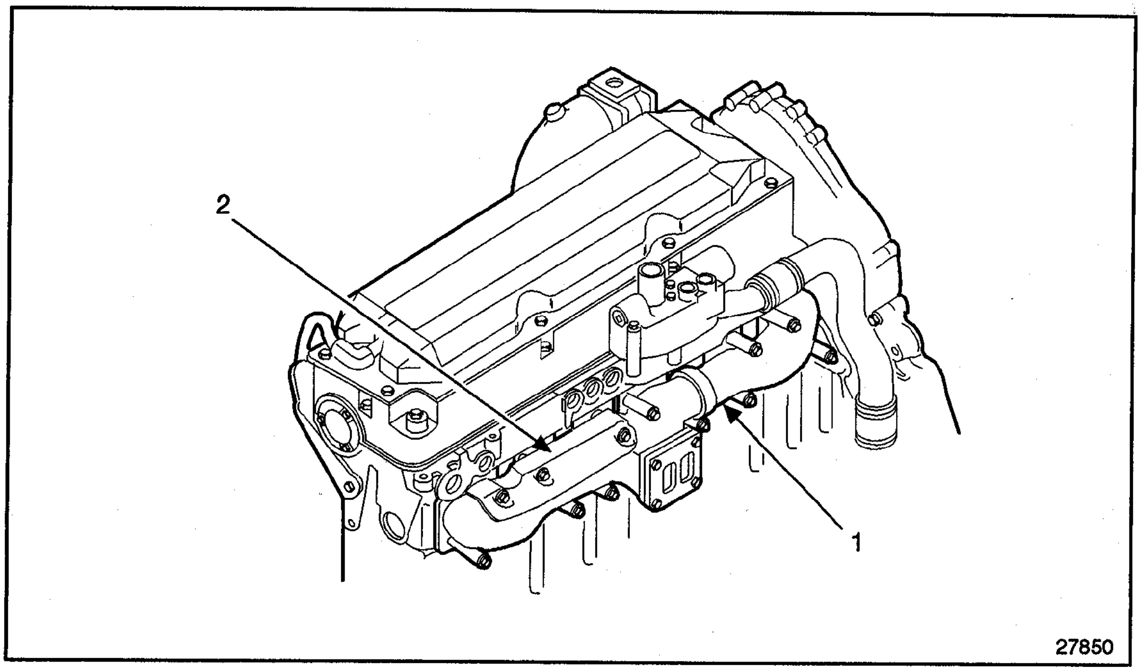
5. On pleasure craft marine engines, remove water-cooled charge air cooler from cylinder head. See Figure 1-28



1. Hose	8. Gasket
2. Elbow	9. CAC Mixer
3. Gasket	10. Housing Lower
4. Sleeve	11. Sensor
5. Seal Ring	12. Seal Ring
6. Bolt	13. Air Temperature Sensor
7. Housing Upper	14. Bracket
	15. Bolt

Figure 1-28 **Intake Manifold and Related Parts (Series 60 Heat Exchanger-Cooled Pleasure Craft Marine Engine)**

6. Seal the turbocharger compressor inlet and discharge with covers or masking tape. Plug the oil supply fitting in the turbocharger housing.
7. Remove and inspect the exhaust manifold if necessary. Refer to section 7.2.2 and refer to section 7.2.3.1. See Figure 1-29, and see Figure 1-30.



1. Exhaust Manifold
2. Heat Shield

Figure 1-29 Exhaust Manifold (Series 60G Engine)

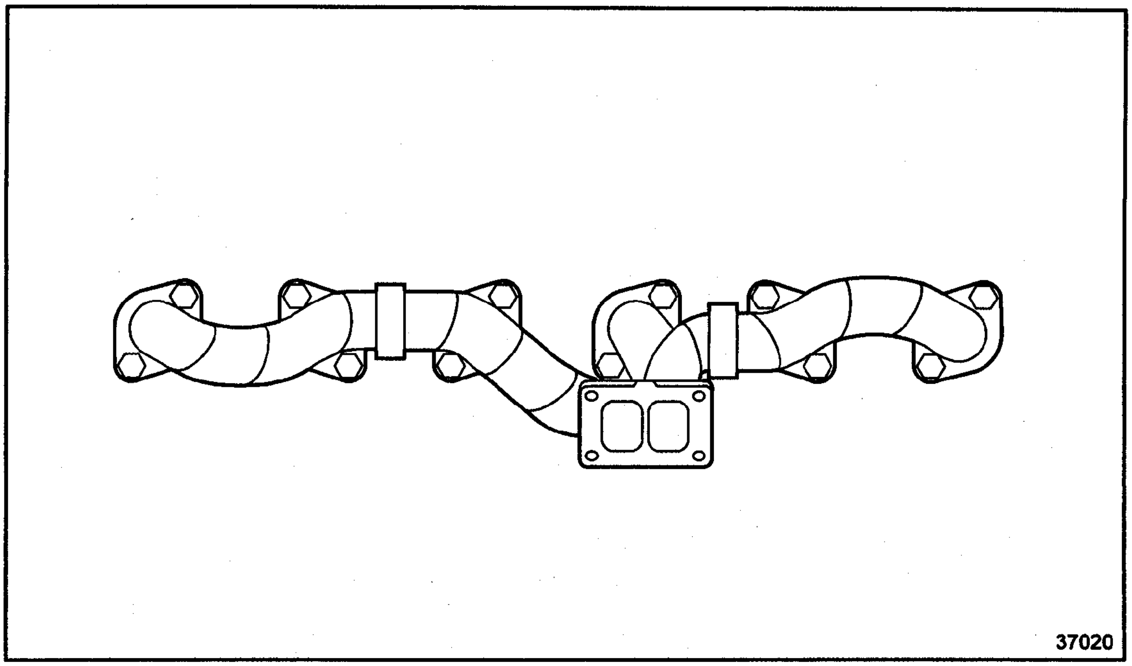


Figure 1-30 Exhaust Manifold (Series 60 Commercial Marine Engine)

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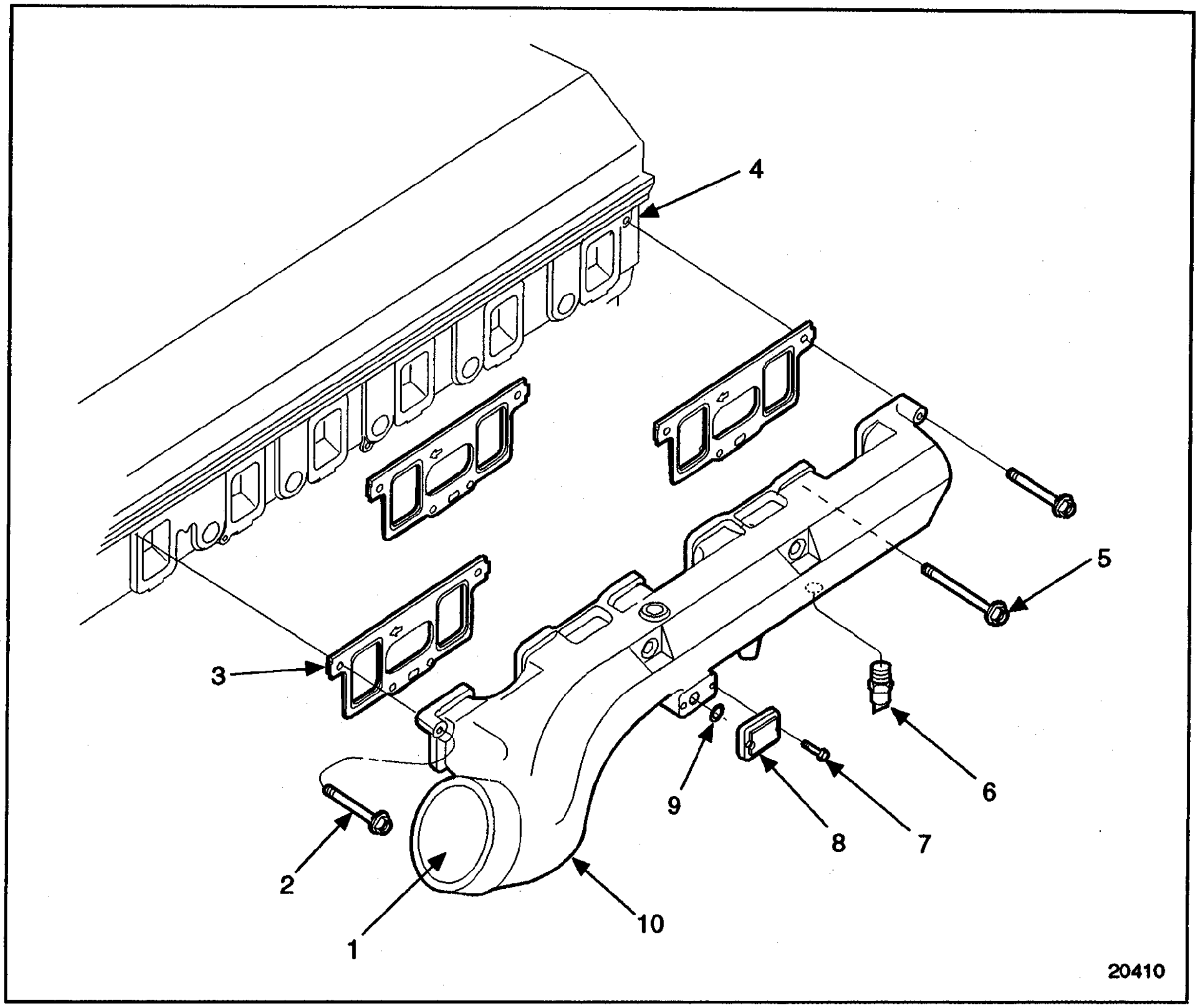
8. Remove and inspect the intake manifold. Refer to section 6.4.2and refer to section 6.4.3.1. See Figure 1-31for all diesel except pleasure craft marine. See Figure 1-28 for pleasure craft marine and see Figure 1-32 for natural gas.



1. Air Inlet
2. Short Bolt (2)
3. Intake Manifold Gasket (3)
4. Cylinder Head
5. Manifold Bolt (7)
6. Air Temperature Sensor
7. Turbo Boost Pressure Sensor Bolt (2)
8. Turbo Boost Pressure Sensor
9. O-ring
10. Intake Manifold

Figure 1-31 Intake Manifold and Related Parts (All Diesel Except Heat Exchanger-Cooled Pleasure Craft Marine)

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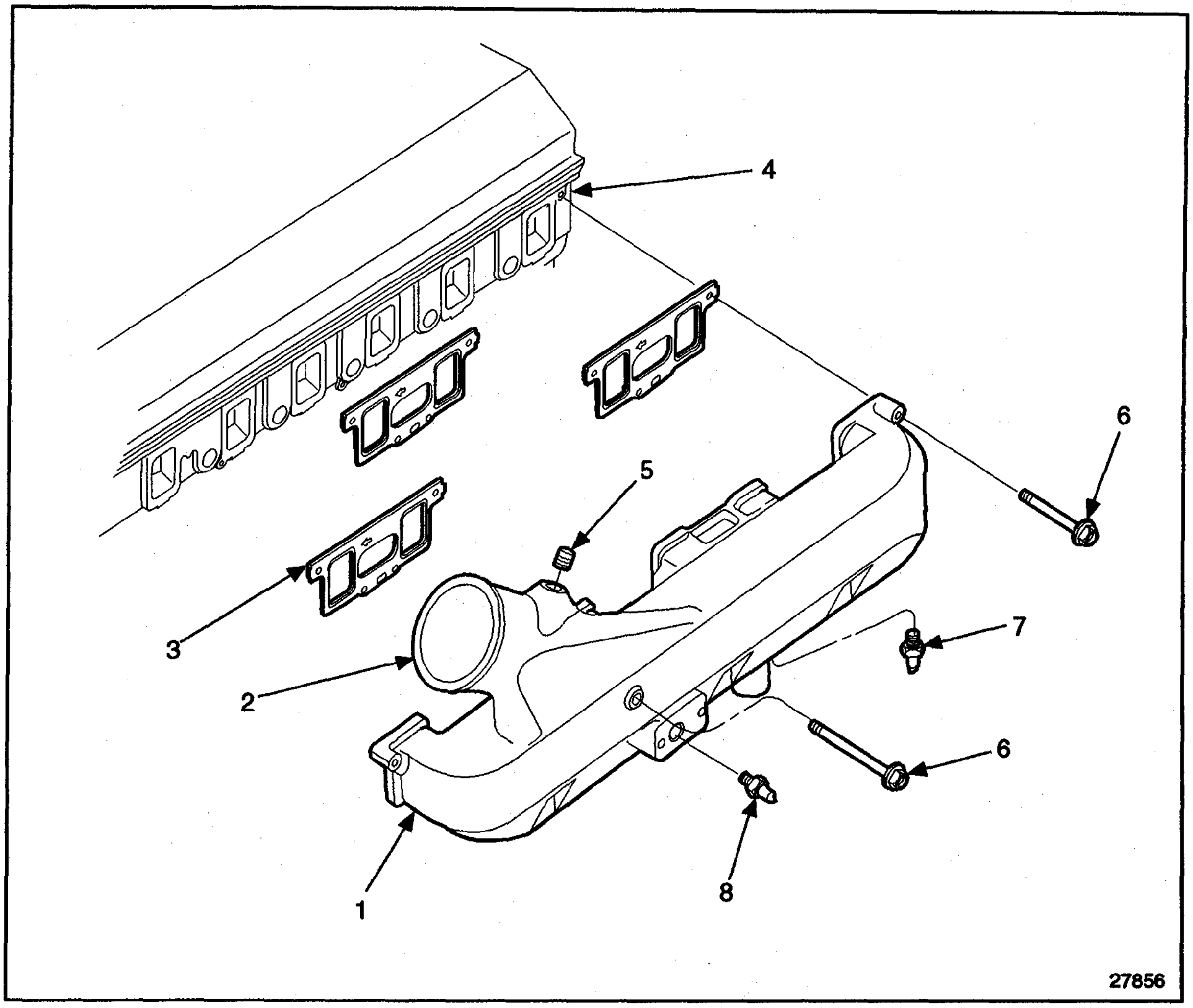

1. Intake Manifold
2. Intake Manifold Inlet
3. Intake Manifold Gasket
4. Cylinder Head
5. Pipe Plug
6. Bolt
7. Air Temperature Sensor
8. Turbo Boost Pressure Sensor

Figure 1-32 Intake Manifold and Related Parts (Natural Gas)

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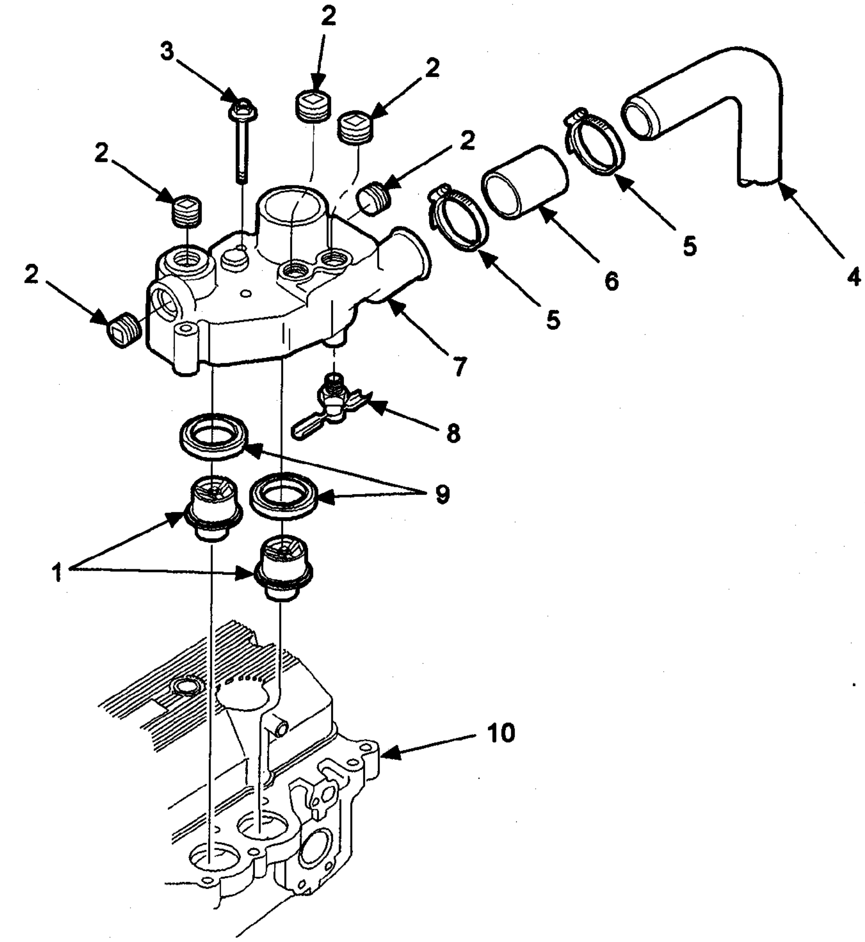
9. Open the drain cock location at the bottom of the thermostat housing to allow the coolant in the housing to drain.
10. Disconnect radiator or heat exchanger, bypass pipe and hose clamps, and remove the thermostat housing. Refer to section 4.5.2 and see Figure 1-33.



1. Thermostat (2)
2. Pipe Plug
3. Bolts, Thermostat Housing-to-Cylinder Head (4)
4. Hose, Coolant
5. Hose Clamps (2)
6. Bypass Tube
7. Thermostat Housing
8. Drain Cock
9. Seals, Thermostat Housing (2)
10. Cylinder Head

Figure 1-33 Thermostat Housing Removal

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11. Remove, disassemble, and inspect the valve rocker cover. Refer to section 1.6.2, (one-piece), refer to section 1.6.3, (two-piece), refer to section 1.6.5, (three-piece) for removal. Refer to section 1.6.6 for disassembly, and refer to section 1.6.2.1for inspection.
12. Remove Jake Brakes®, if equipped. Refer to section 1.29.2.
    Jake Brake® is a registered trademark of Jacobs Vehicle Systems.
13. Remove rocker arm assemblies. Refer to section 1.3.2.

NOTE:
On heat exchanger-cooled pleasure craft marine engines the heat exchanger must be removed before the camshaft can be disassembled from the engine. Refer to section 4.12.2.

14. Remove the camshaft. Refer to section 1.23.2.

NOTE:
Using the camshaft gear pilot tool, J 35906, pull the camshaft gear and thrust plate forward in the gear case until there is approximately a 6.35 mm (1/4 in.) gap between the cylinder head and the diamond-shaped camshaft thrust plate seal when removing the cylinder head. See Figure 1-34.

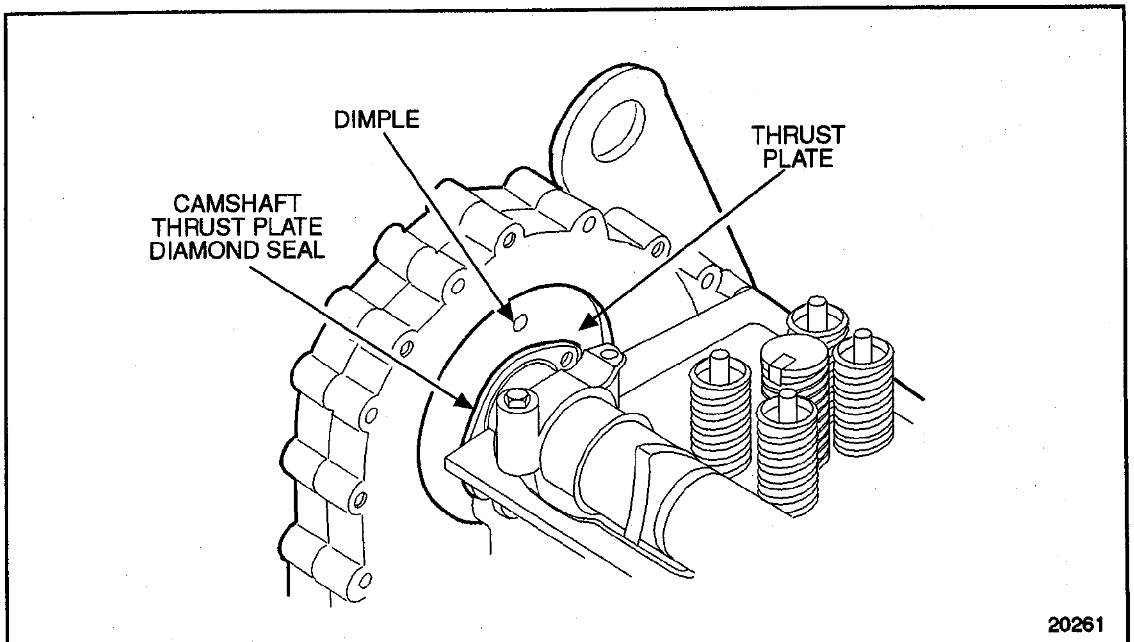

Figure 1-34 Positioning Camshaft Thrust Plate

15. Inspect the rocker arm assemblies and camshaft lobes. Refer to section 1.3.2.2, and refer to section 1.23.3.1.

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16. Disconnect the fuel inlet and outlet lines at the rear of the cylinder head. See Figure 1-35.

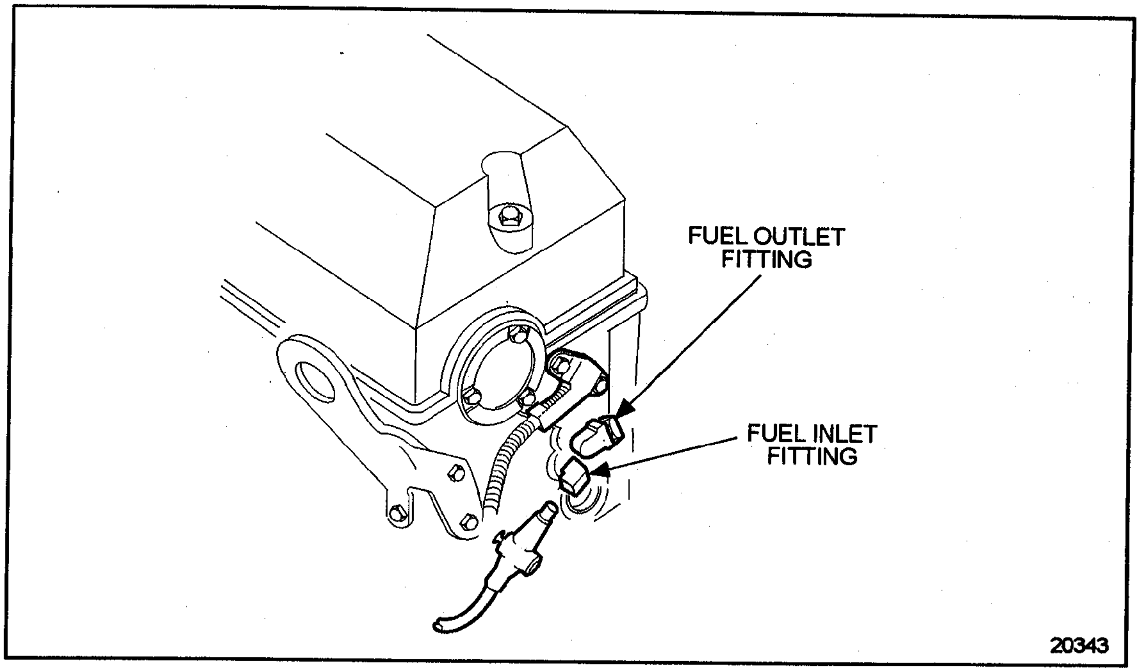

Figure 1-35 Removing Fuel from Cylinder Head Internal Passages

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

17. Blow low pressure compressed air into the inlet fitting for 20 to 30 seconds or until all of the fuel is purged from the cylinder head.
18. Disconnect the injector wire harness at each injector. Refer to section 2.3.2.
19. Remove the harness mounting flange from the rear of the cylinder head and carefully remove the harness from the head by pulling the harness through the hole in the cylinder head. See Figure 1-25.

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NOTICE:

To avoid possible damage to the injector spray tips, remove the injectors before lifting the head from the block. If the injectors are not removed, handle the head carefully when it is off the block and support the head fire deck on wooden blocks.

20. Remove the fuel injectors. Refer to section 2.3.2.

NOTE:
Fuel must be removed from the cylinder head fuel galleries prior to removing the injectors.

21. Remove the gear case stabilizer bracket at the right front corner of the head.
22. Remove the head bolts, refer to section 1.2.2, and install the cylinder head lifter bracket, J 35641-A, using the bolt hole at the inboard center, No. 3 cam cap and two tapped Jake Brake® bolt holes. See Figure 1-36.

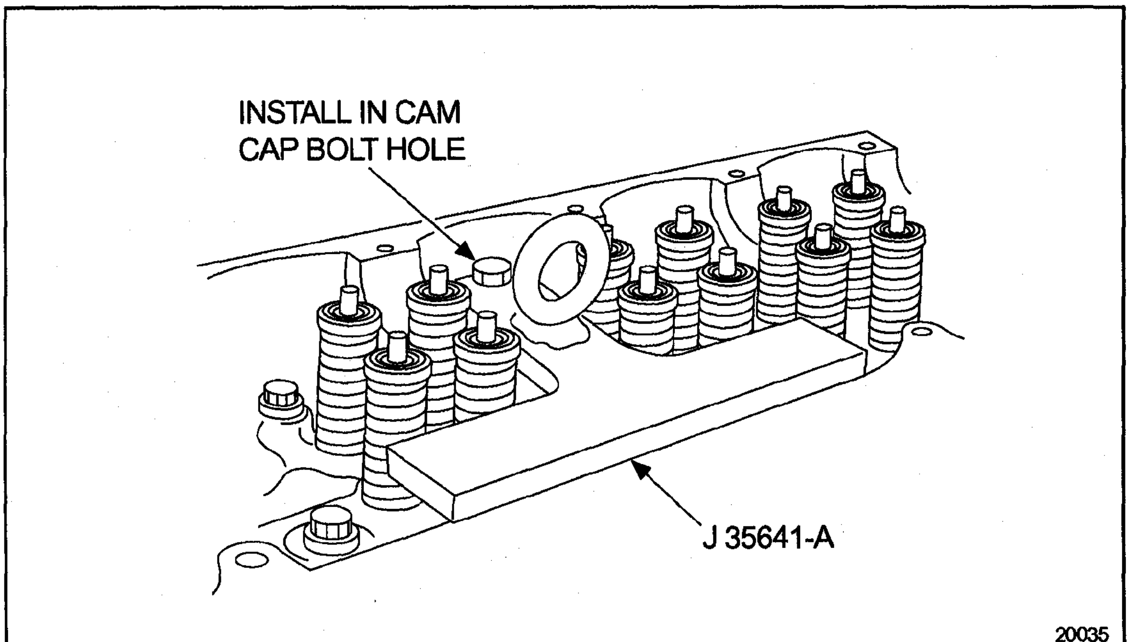

Figure 1-36 Cylinder Head Lift Bracket Removal

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23. Attach a suitable lifting hook to the eyelet in the lift bracket, and lifter the cylinder head off the engine. See Figure 1-37.

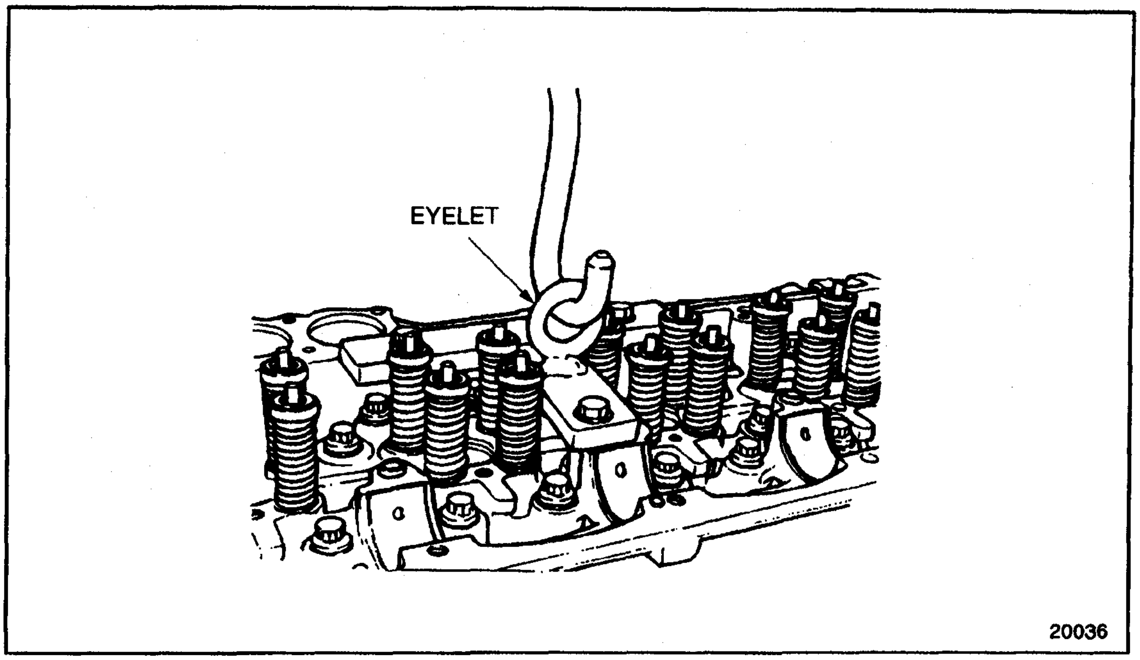

Figure 1-37 Cylinder Head Removal

24. Drain the engine lubricating oil, refer to section 13.13.1, to remove any coolant that may have drained into the oil pan when the water jacket was opened. Remove any coolant from the cylinder bores.

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1.2.3 Cleaning of Cylinder Head

Clean the cylinder head as follows:

1. Keep parts segregated according to original position to assure proper reassembly, if parts are to be reused.
2. Remove all threaded plugs.
3. Steam clean the cylinder head once it has been stripped.
4. If coolant passages are heavily coated with scale, remove the injector tubes and cup plugs, refer to section 2.4.2. Clean the head in a descaling bath, refer to section 1.2.2.

CAUTION:
To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

5. Clean the camshaft and camshaft bearings, valves, springs, valve rotators and rocker shafts in fuel oil and blow dry with compressed air.
6. Clean the rocker arm assemblies.

1.2.3.1 Inspection of Cylinder Head

The following steps must be performed before inspecting the cylinder head:

1. Replace the plugs removed for cleaning. If the old plugs are reused, coat the plugs with Loctite® PT-7260 , pipe sealant with Teflon, or equivalent.

NOTE:
If both front fuel galley plugs have been removed, it will be necessary to replace both plugs.

2. If injector tubes have been removed, install new injector tubes. Refer to section 2.4.1.
3. Install new cup plugs using a good grade non-hardening sealant such as Loctite® 620 or equivalent.
4. Perform the following tests for cylinder head inspection.
   [a] Pressure test, refer to section 1.2.3.2.
   [b] Firedeck straightness test, refer to section 1.2.3.3.

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1.2.3.2 Pressure Testing of Cylinder Head

Perform the following steps to pressure test the cylinder head:

1. Install the test strips (part of cylinder block pressure test kit, J 36223) to the firedeck on the cylinder head. See Figure 1-38.

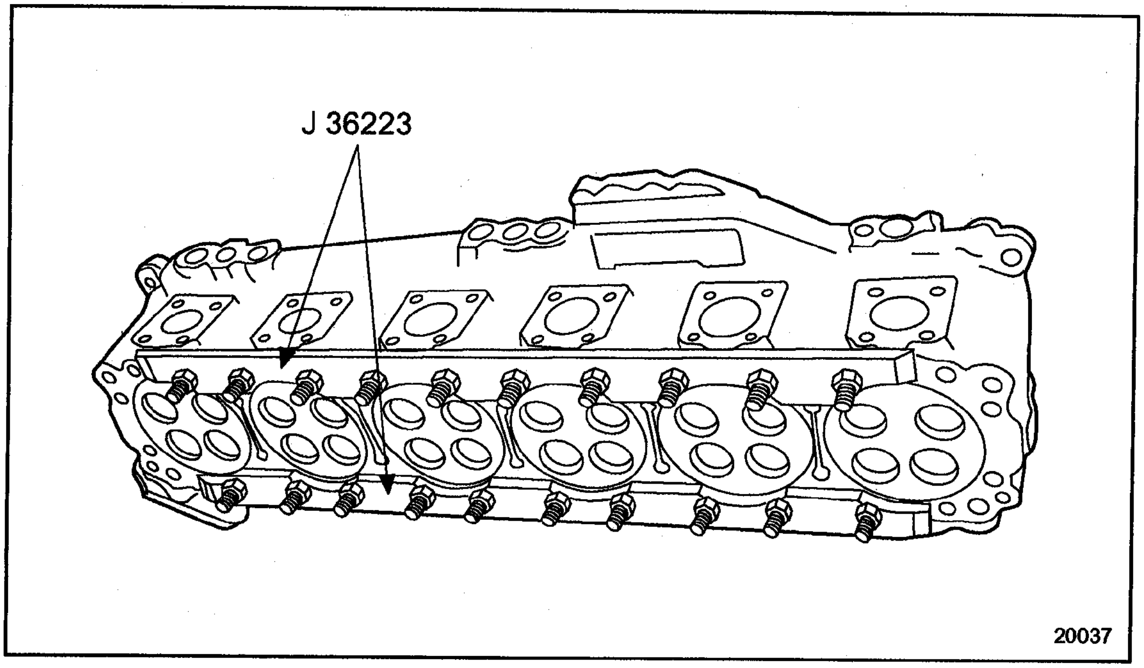

Figure 1-38 Cylinder Head Pressure Test Equipment Installation

2. Insert the cylinder head bolts through the cylinder head and test strips. Attach and torque the nuts (supplied in J 36223) to 14 N·m (10 lb·ft).

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3. Install the thermostat opening cover plate, and gasket to the cylinder head using the bolts provided with the cover plate. See Figure 1-39.

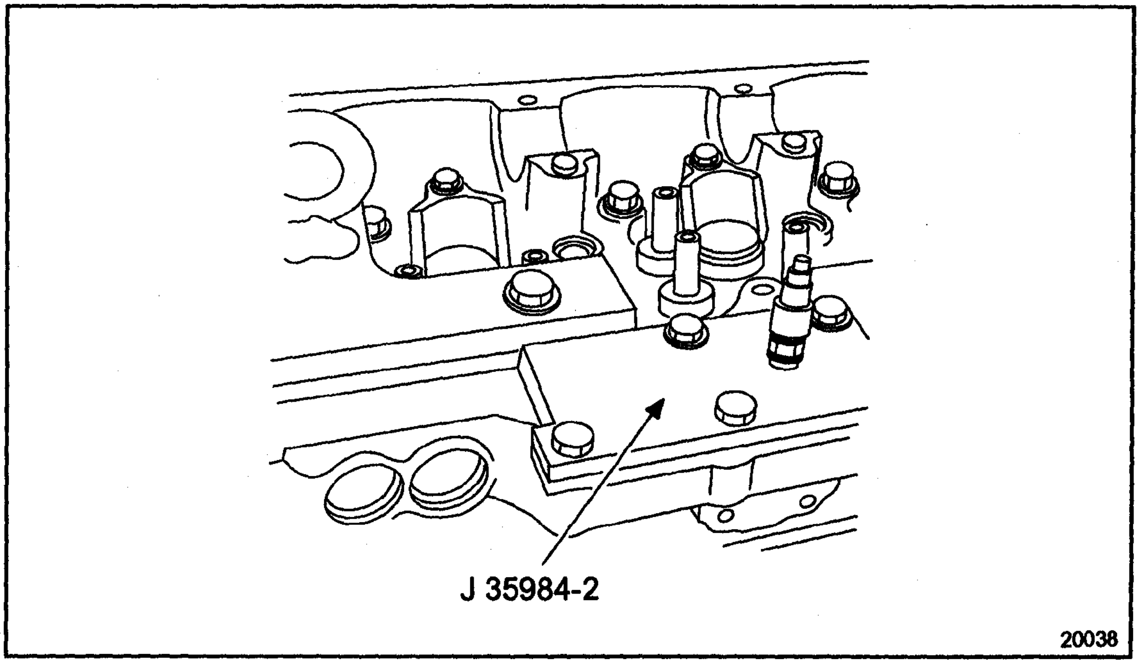

Figure 1-39 Thermostat Opening Cover Plate Installation

4. Install dummy fuel injectors, to the injector bores to assure proper seating of the fuel injector tubes. See Figure 1-40.

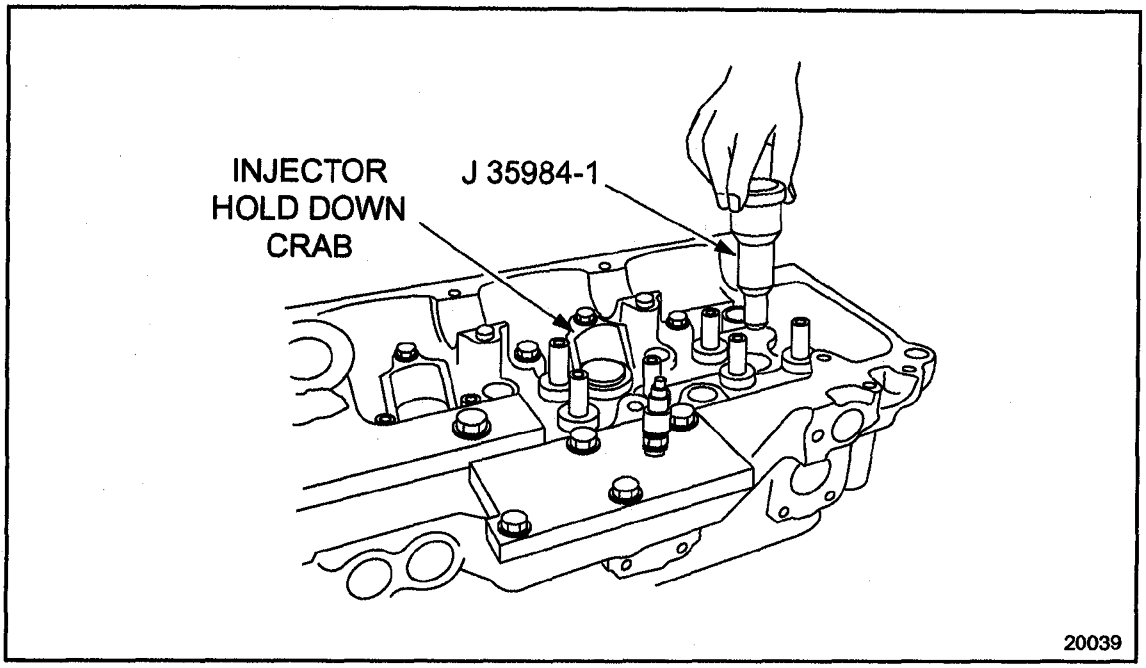

Figure 1-40 Dummy Fuel Injector Installation

5. Install the fuel injector crabs and hold-down bolts. Torque the bolts to 58-66 N·m (43-49 lb·ft). See Figure 1-40.
6. Attach an air hose to the fitting on the thermostat opening cover plate.
7. Apply 207 kPa (30 lb/in.^{2}) air pressure to the cylinder head and immerse the head in a water bath heated to 82-93°C (180-200°F).
8. Leave the head in the bath for at least 20 minutes to heat thoroughly, while watching for bubbles indicating a crack or leak.
   [a] If an injector tube leaks, replace tube(s). Refer to section 2.4.1for removal and refer to section 2.4.5 for installation of new injector tube.
   [b] If a cracked cylinder head is detected, replace the cylinder head. Refer to section 1.2.5.

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1.2.3.3 Inspection and Rework for Firedeck Straightness

The large mass and length of the head casting may contain longitudinal warp after it is unbolted and removed from the engine block. At the time of factory manufacture, the longitudinal warp is normalized by using a fixture and clamping the casting during machining. The casting is placed in a fixture and clamped from its locating surfaces (datums). When unclamped, the head casting resumes its original shape until it is bolted and tightened to the engine block.

Inspect the bottom (firedeck) of the cylinder head for straightness as follows:

1. Use a heavy, accurate straight-edge and feeler gages to check for transverse and longitudinal warpage. See Figure 1-41.

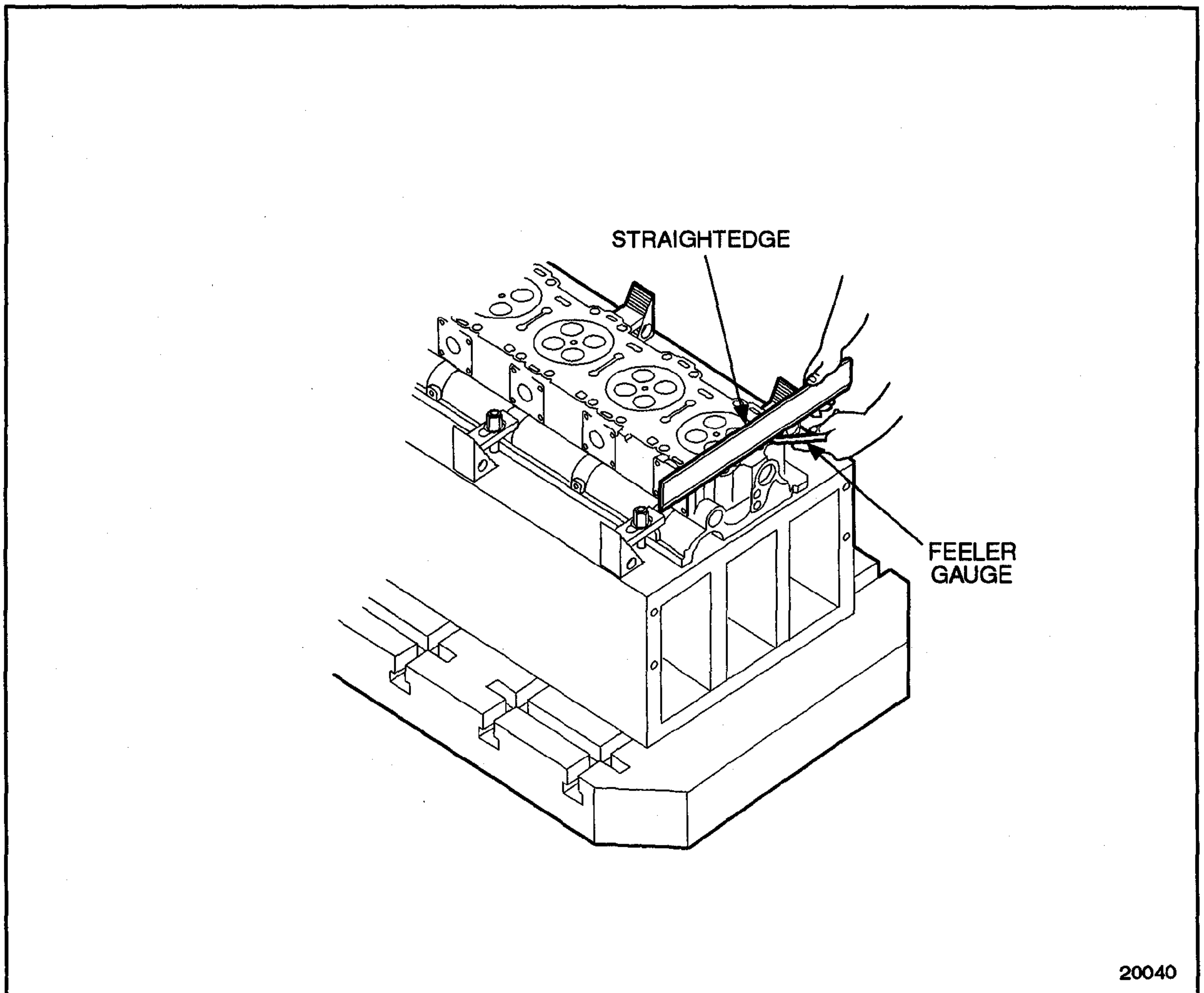

Figure 1-41 Checking Firedeck Straightness

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2. Also, check for longitudinal warpage in five places and transverse warpage in 12 places, indicated as A through L in the next illustration. See Figure 1-42.

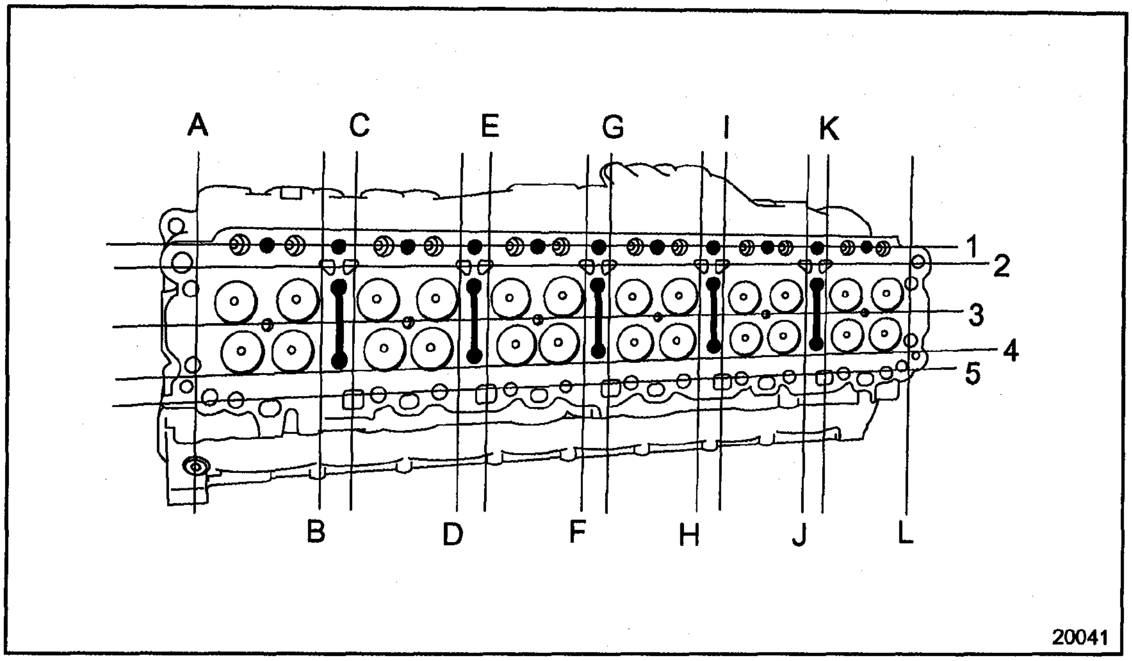

Figure 1-42 Cylinder Head Measurement Locations

3. The natural warp contained in the casting must be considered when inspecting firedeck straightness with the head unbolted and unclamped. Natural warpage is not a cause for correction. The firedeck (unclamped) must be straight within 0.279 mm (0.011 in.) front-to-rear and 0.076 mm (0.003 in.) side-to-side. Cylinder head specifications are listed in Table 1-31.

If the cylinder head flatness is outside of the specifications, Detroit Diesel Corporation recommends replacing the cylinder head.

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1.2.3.4 Verification of Countersink Geometry

To verify countersink geometry, perform the following steps.

1. Install new injector tubes. Refer to section 2.4.5.
2. Place valves into proper location and check to be sure that valve heads are recessed from the firedeck surface by at least 1.4-1.8 mm (0.055 -0.071 in.). Listed in Table 1-31. See Figure 1-43. If not, reduced-thickness valve seat inserts must be installed. Refer to section 1.4.6.

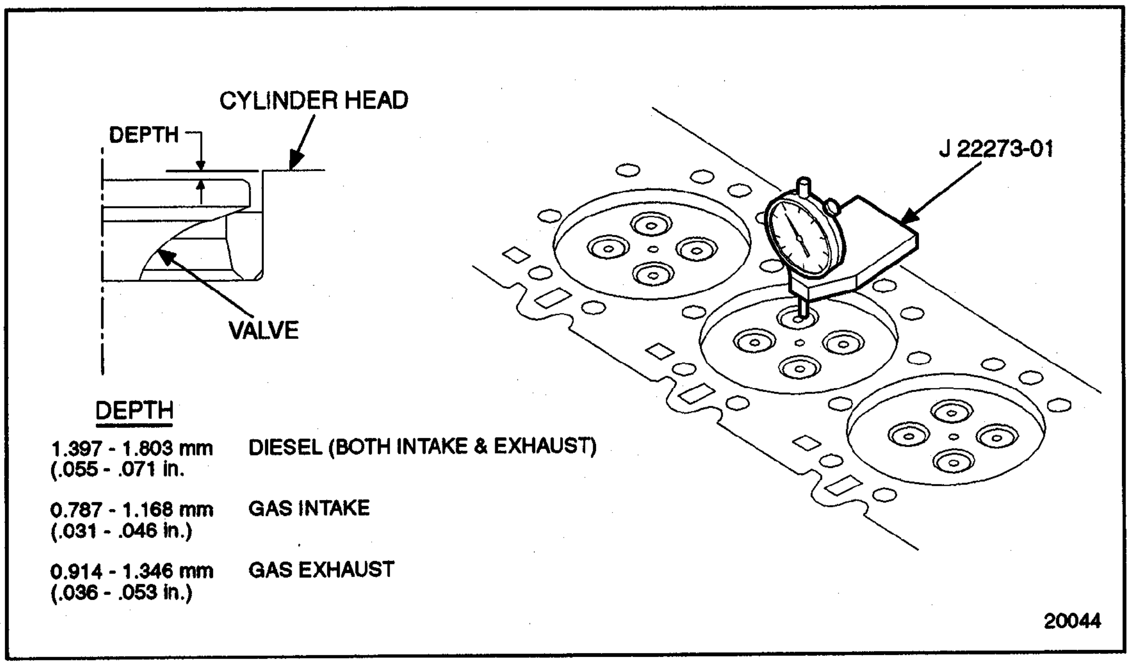

Figure 1-43 Valve Head-to-Cylinder Head Measurement

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1.2.3.5 Inspection and Reworking of Head Bolt Counterbore

To assure clean and non-brinnelled cylinder head bolt counterbores, use J 38189 to resurface the head bolt washer area.

The procedure and steps for proper use of the tool are as follows:

NOTICE:
There must be no space between the bottom of the cylinder head and the table top to properly resurface the counterbores.

1. Place the cylinder head on a solid flat surface (preferably a steel table top) that completely covers the bottom of head.

NOTICE:
Proper use of the J 38189 is important. Failure to use J 38189 properly may result in an incorrect counterbore depth.

2. Protect the valve springs and injector counterbore to keep any loose metal shavings from getting into valve springs and counterbore during cutting operation.
3. With cylinder head on a flat surface using the 1/8 in. hex wrench supplied with tool, loosen the stop collar and cutter to permit sliding on pilot.
4. Starting at the front of the cylinder head, place the pilot of the cutter into a cylinder head bolt hole until the pilot contacts the flat surface beneath the cylinder head.
5. Allow the cutter to contact the counterbore surface. Lock the stop collar while against the cutter. The cutter now will resurface the counterbore 0.508 mm (0.020 in.).
6. Remove the tool and place a 0.020 in. feeler gage between the cutter and the locked stop collar.
7. With feeler gage in place, lock the set screw of the cutter, then remove the feeler gage and loosen the set screw on the stop collar and slide it down tight against the cutter and retighten.

Perform the following steps to resurface the counterbore 0.508 (0.020 in.):

1. Using a drill motor with a 1/2 in. chuck and a **maximum** of 450 r/min and a suitable cutting oil to prolong the life of the cutter and to lubricate the pilot turning in bolt hole,
2. Apply a moderate pressure on the drill motor, continue cutting operation until pilot bottoms on flat surface and then do not stop drill motor until after being lifted from cutting surface. This is to eliminate surface marks.

NOTE:
The J 38189 tool pilot has a shoulder stop that will not allow the cutter to remove material in excess of the Detroit Diesel Corporation specifications.

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3. If some of the bolt holes do not clean up completely, continue resurfacing remaining holes, repeating the operation in. 0.005 in. increments. This will clean up any holes that may not have cleaned up completely during the first cut.
4. After all counterbores have been resurfaced, remove any loose cutting chips.
5. Steam clean the complete cylinder head.
6. After steam cleaning, inspect the cylinder head for any remaining chips.
7. Reinstall the cylinder head assembly, using 38 of the new ground head bolt washers.

1.2.4 Assembly of Cylinder Head

Perform the following steps for cylinder head assembly:

CAUTION:
To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

NOTICE:
If the cylinder head is to be replaced, the new head must be thoroughly cleaned before installation to remove all rust and preventive compound, especially from the fuel and oil galleries. This can be done by immersion in a bath of fuel oil or mineral-spirits-based solvent and scrubbing out all openings with a soft bristle brush. When clean, blow the head dry with compressed air.

1. Install new precoated pipe plugs or coat the used plugs with pipe sealant with Teflon, PT-7260 , or equivalent. Refer to section ADDITIONAL INFORMATION 1.A, "Engine Plug and Dowel Charts" for specifications.
2. Install all of the required cup plugs using a good grade of non-hardening sealant, such as Loctite® 620 or equivalent, on the cup plugs. Use cup plug installation tool set, J 35653. Refer to section ADDITIONAL INFORMATION 1.A, "Engine Plug and Dowel Charts" for specifications.
3. Ensure that all cup and pipe plugs on the front face of the cylinder head are flush or below the surface.
4. Install valve guides and seats, valves, valve stem seals, valve springs and rotators. Refer to section 1.4.8and refer to section 1.4.7.

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1.2.5 Installation of Cylinder Head

Perform the following steps for cylinder head installation:

1. Ensure piston domes and the cylinder head and cylinder block firedeck surfaces are clean and free of foreign matter. Inspect the head bolt holes in both block and head for the presence of oil, water, dirt, or damaged threads, clean or retap as necessary.
2. Position the head gasket on the block and install cylinder head guide studs, J 35784, at front and rear of the block. See Figure 1-44.

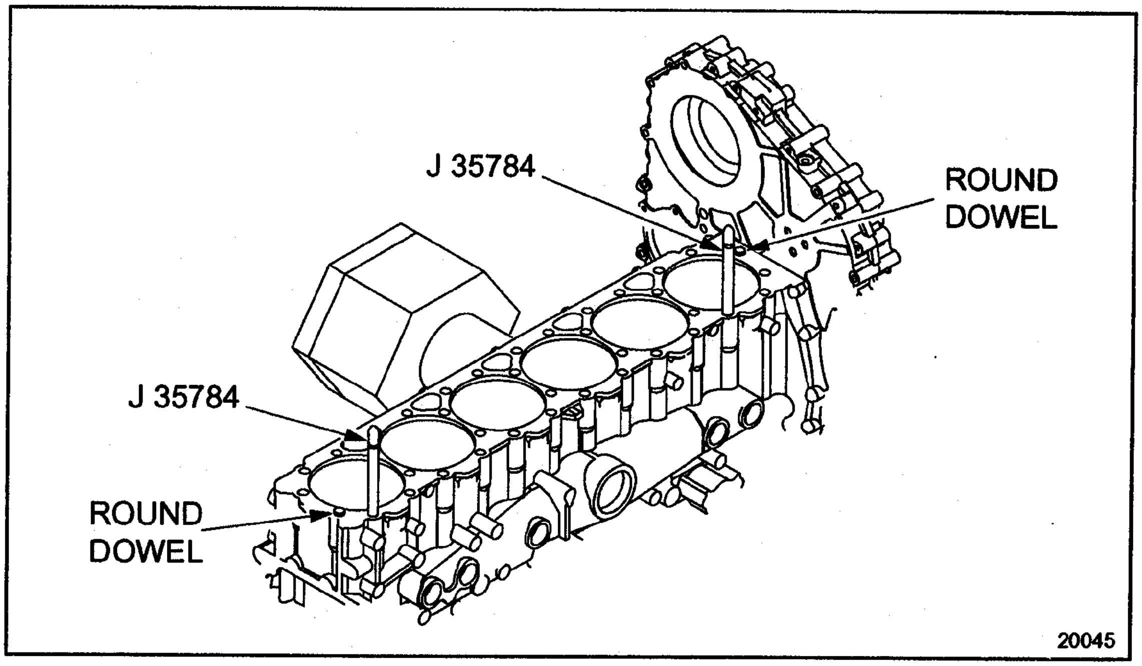

Figure 1-44 Cylinder Head Guide Studs

3. Lift the head into position with lift bracket, J 35641. See Figure 1-45. Lower it into place over the guide studs, J 35784, until it seats on the block deck dowels. See Figure 1-44.

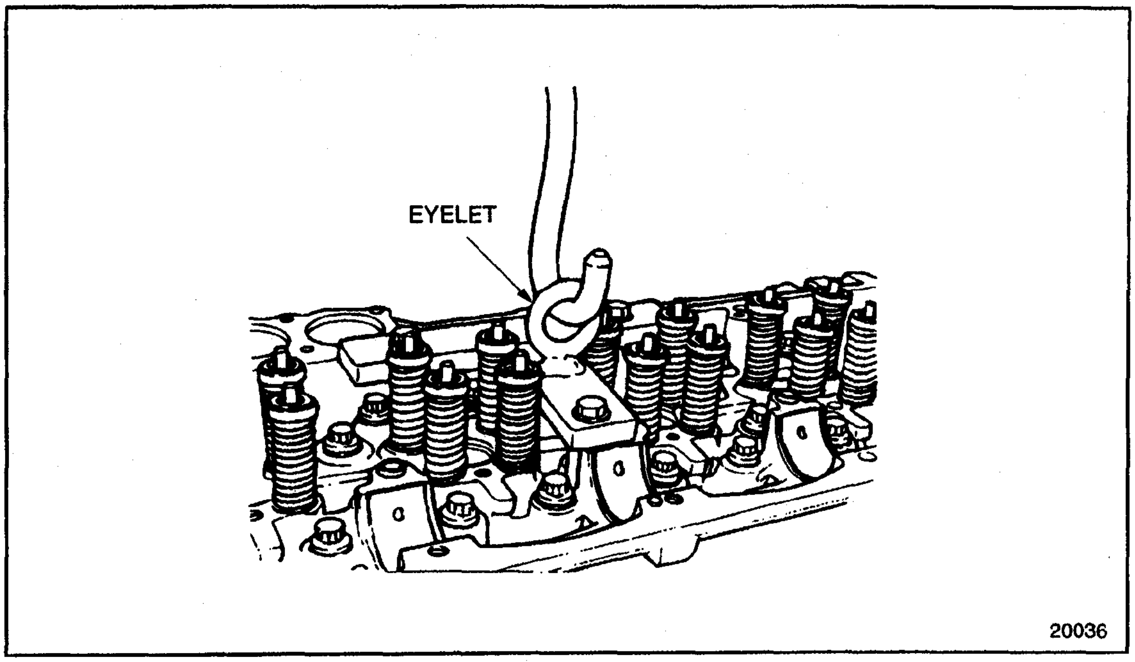

Figure 1-45 Cylinder Head Installation

4. Remove the guide studs.
5. Install the head bolts with special hardened washers, lubricating the threads and bolt-head contact areas with a small amount of International Compound #2®, or equivalent.

6. Torque the head bolts to 250-285 N·m (185-210 lb·ft) in the following sequence. See Figure 1-46.

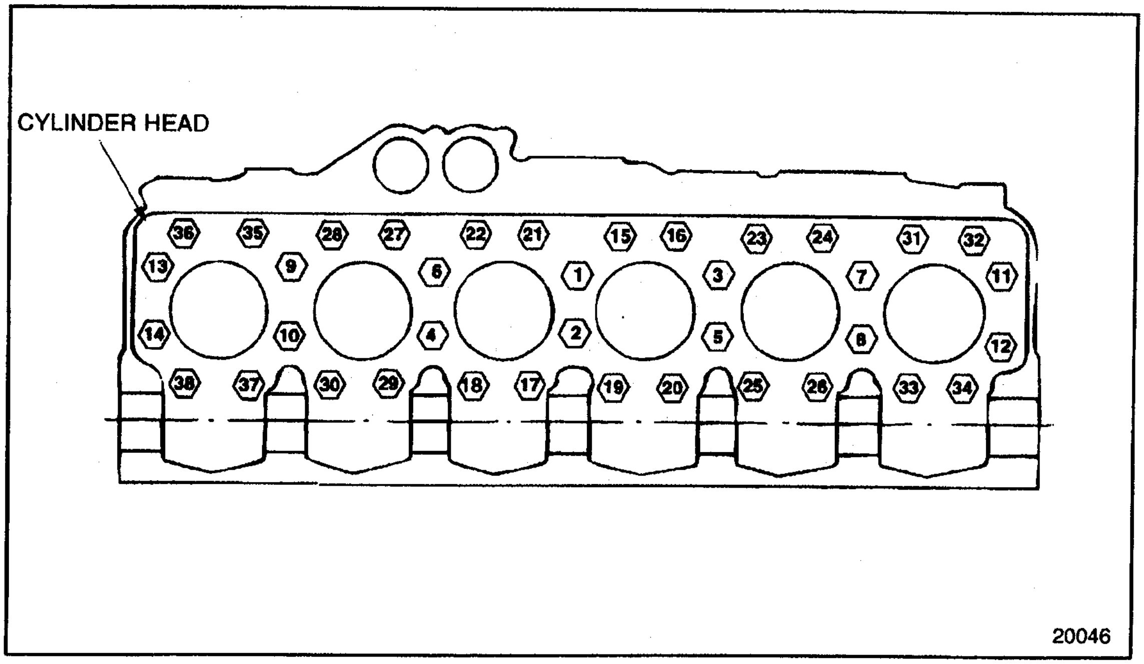

Figure 1-46 Cylinder Head Bolt Tightening Sequence

NOTICE:
Failure to repeat the cylinder head bolt torque tightening sequence can result in some head bolts losing their torque when others are tightened resulting in insufficient clamp load.

7. Repeat the torque sequence to verify all of the head bolts are torqued to specification.

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NOTICE:

The hemispherical portion of the injector hold-down crab washers must be installed facing the crab (pointing down) in order to prevent damage to the washers. See Figure 1-47.

8. Visually inspect each injector hole tube to ensure they are clean. Install the fuel injectors. Refer to section 2.3.5. Be sure the injector hold-down crabs are clear of the valve and injector springs.

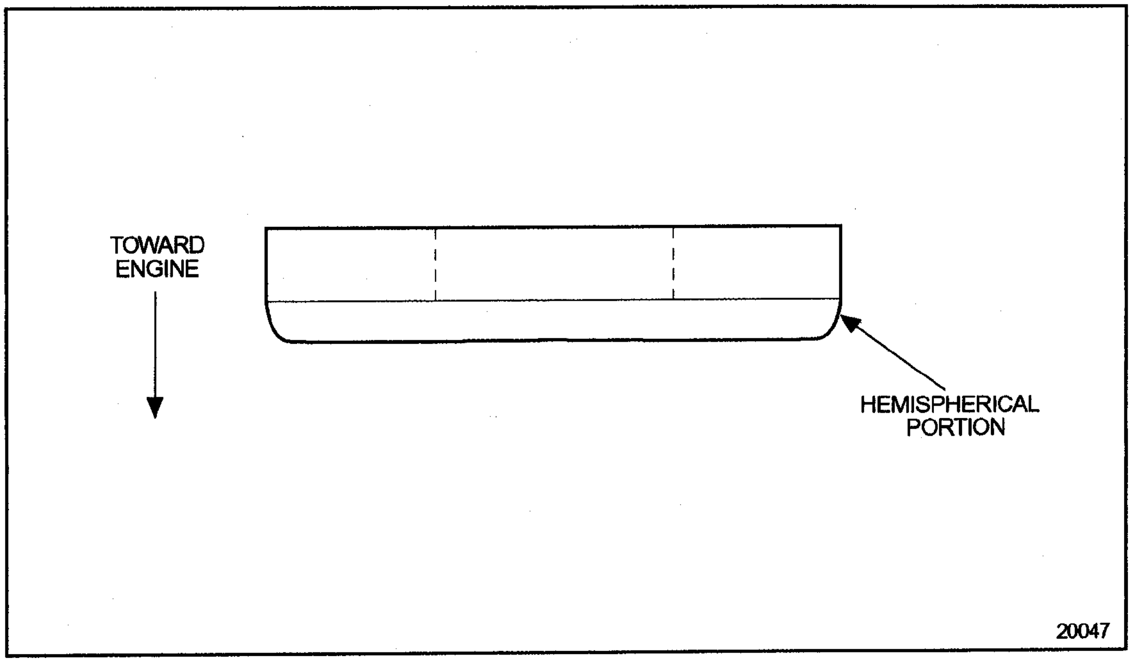

Figure 1-47 Injector Hold-Down Crab Washer Installation

9. Install the clamp bolts with hemispherical washers, torque to 58-66 N·m (43-49 lb·ft).
10. Install the camshaft. Refer to section 1.23.6.

NOTE:

If a cylinder head other than the one removed from the engine, or if a resurfaced cylinder head is being installed, the three nuts retaining the adjustable idler gear must be loosened before installing and torquing the camshaft drive gear retaining bolt.

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NOTICE:
The camshaft drive gear-to-adjustable idler gear lash must be measured/adjusted before the rocker arm shaft assemblies are installed.

11. Measure and adjust the camshaft drive gear-to-adjustable idler gear lash. Refer to section 1.21.2.1.
12. Install the rocker arm shaft assemblies. Refer to section 1.3.3.
13. Install Jacob's Brake assemblies (if equipped). Refer to section 1.29.5.
14. Feed the injector harness wires through the opening at the rear of the cylinder head. Secure the harness mounting flange to the cylinder head by torque the bolts to 10-15 N·m (7-11 lb·ft).
15. Connect the injector harness wires to their respective injectors. Refer to section 2.3.5.
16. Install the gear case stabilizer bracket at the right front corner of the head. Tighten the stabilizer to gear case bolt first and then the two bolts to the head. Torque the three bolts to 58-73 N·m (43-54 lb·ft).
17. Install the thermostats and seals to the thermostat housing. Refer to section 4.5.5.
18. Clean the coolant outlet surfaces of the head and thermostat housing.
19. With the thermostats seated in the housing counterbores, install the housing to the cylinder head, torque the housing bolts to 58-73 N·m (43-54 lb·ft). Connect the radiator or heat exchanger and bypass hose couplings and vent line.
20. Remove all traces of the old gasket from the cylinder head and exhaust manifold joint surfaces. Install the exhaust manifold with new gaskets. Refer to section 7.2.4.
21. Clean the exhaust manifold and turbocharger joint surfaces and install the turbocharger with a new gasket. Refer to section 6.6.7. If turbocharger is water cooled, connect coolant supply and return lines.
22. Fill and vent the cooling system. Refer to section 13.13.4. Fill the engine lubrication system. Refer to section 13.13.1.
23. Connect the exhaust and air-to-air cooler air ducting and install the air cleaner or air separator.
24. Install any other components that were removed and fill with the required fluids, as recommended. Refer to OEM guidelines.

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CAUTION:

Diesel engine exhaust and some of its constituents are known to the State of California to cause cancer, birth defects, and other reproductive harm.

- **Always start and operate an engine in a well ventilated area.**
- **If operating an engine in an enclosed area, vent the exhaust to the outside.**
- **Do not modify or tamper with the exhaust system or emission control system.**

25. Start the engine and check for fuel, coolant or oil leaks. Keep the engine running while you check.
26. Shut down the engine.

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1.3 VALVE AND INJECTOR OPERATING MECHANISM

The valve and injector operating mechanism is located entirely in the cylinder head.

The Series 60 overhead camshaft design eliminates the need for push rods. Separate camshaft followers are not needed, since the rocker arms incorporate follower rollers riding directly on the camshaft lobes, transmitting camshaft motion to the valves and injectors. See Figure 1-48.

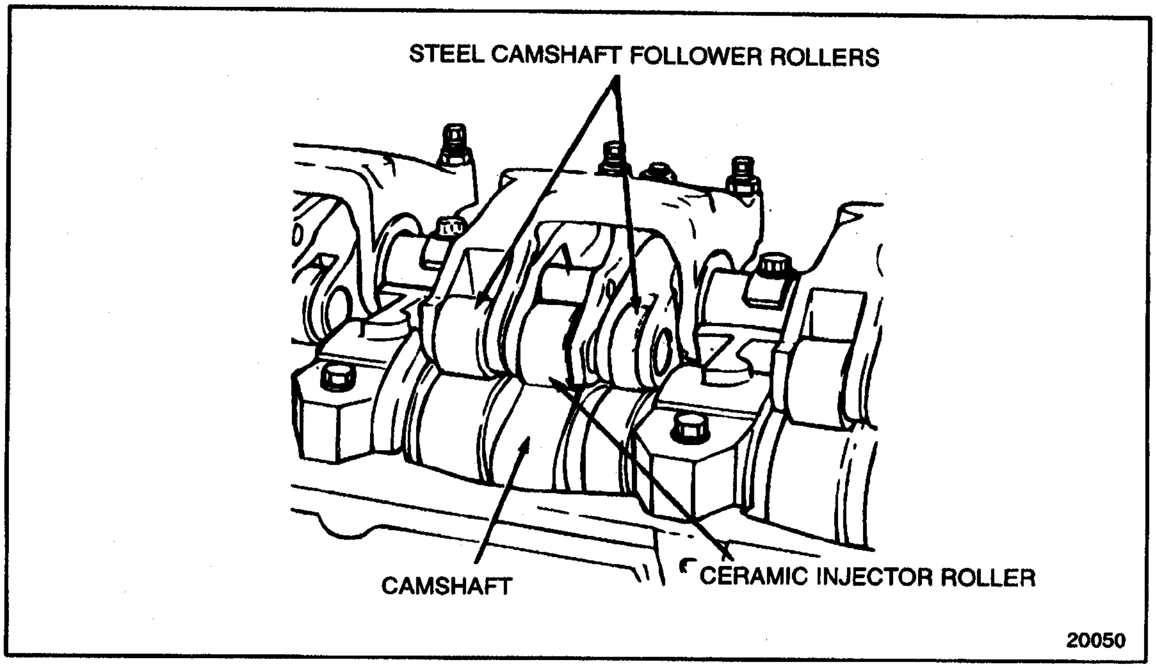

Figure 1-48 Camshaft and Related Parts

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Each of the three rocker arm assemblies contain bushings where the rocker arms are supported on the rocker arm shafts. These bushings are not serviced separately. Each intake rocker arm assembly operates two intake or valves in each cylinder. Each exhaust rocker arm assembly operates two exhaust valves in each cylinder. In each set of rocker arm assemblies, the exhaust rocker assembly is the widest, straddling the intake and fuel injector rocker arm assembly. The center rocker operates the fuel injector follower. See Figure 1-49.

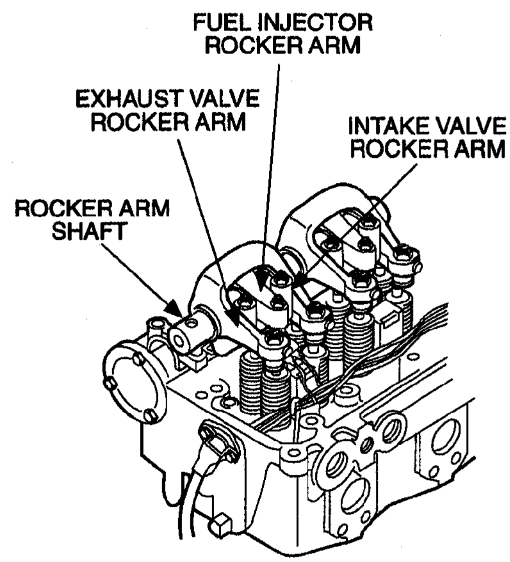

Figure 1-49 Rocker Arm Identification

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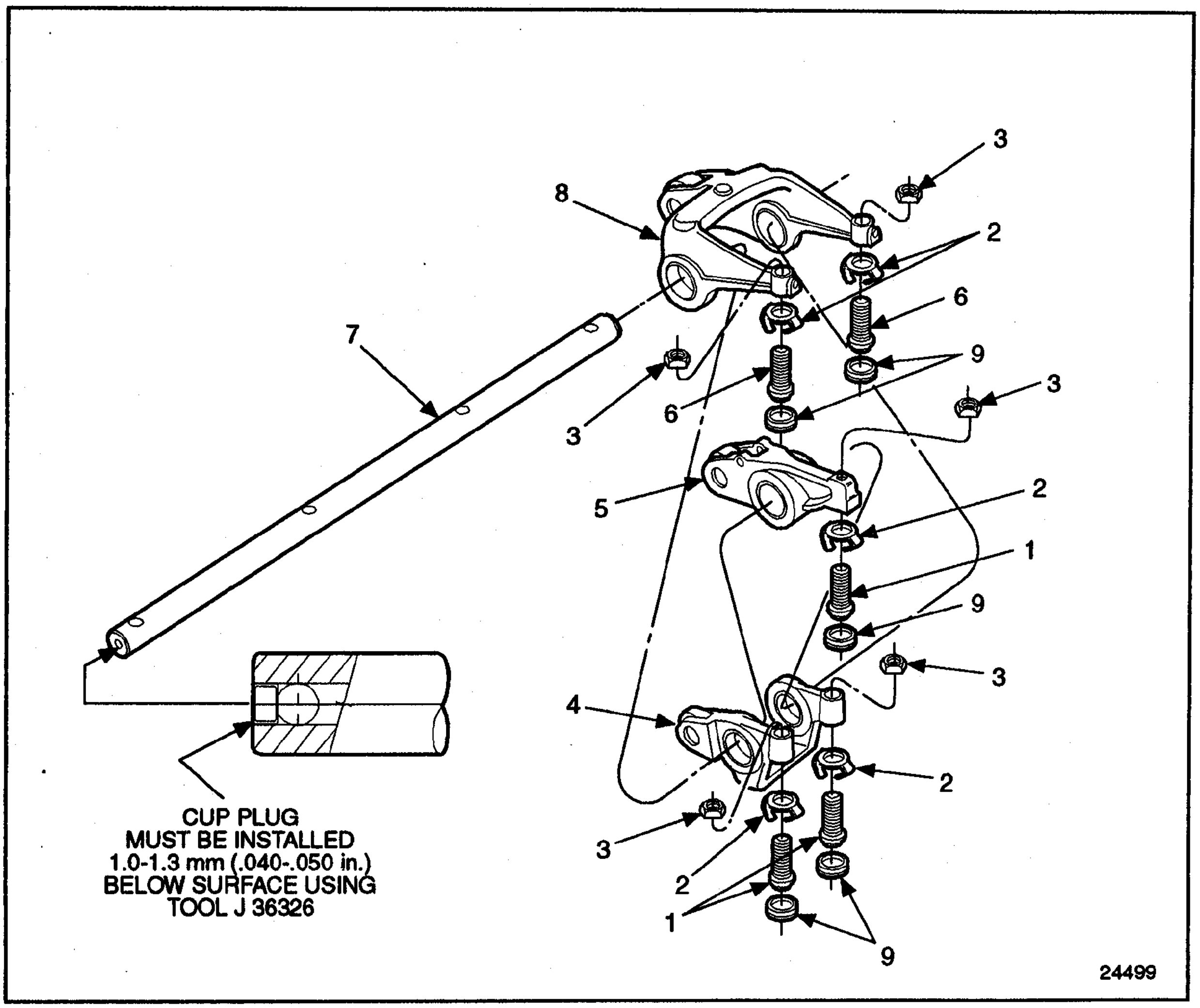
The fuel injector rocker arm assembly is located between the intake and exhaust rocker arm assemblies and has a single, bushing (not serviced separately). A rocker arm shaft carries three sets of rocker arm assemblies and is mounted in seats machined into the camshaft bearing caps. See Figure 1-50 and See Figure 1-51.



1. Intake Valve Adjusting Screw (Used in injector position also)
2. Clip
3. Locknut
4. Intake Rocker Arm Assembly
5. Fuel Injector Rocker Arm Assembly
6. Exhaust Valve Adjusting Screw
7. Rocker Arm Shaft
8. Exhaust Rocker Arm Assembly
9. Valve Button

Figure 1-50 Rocker Arm and Related Parts

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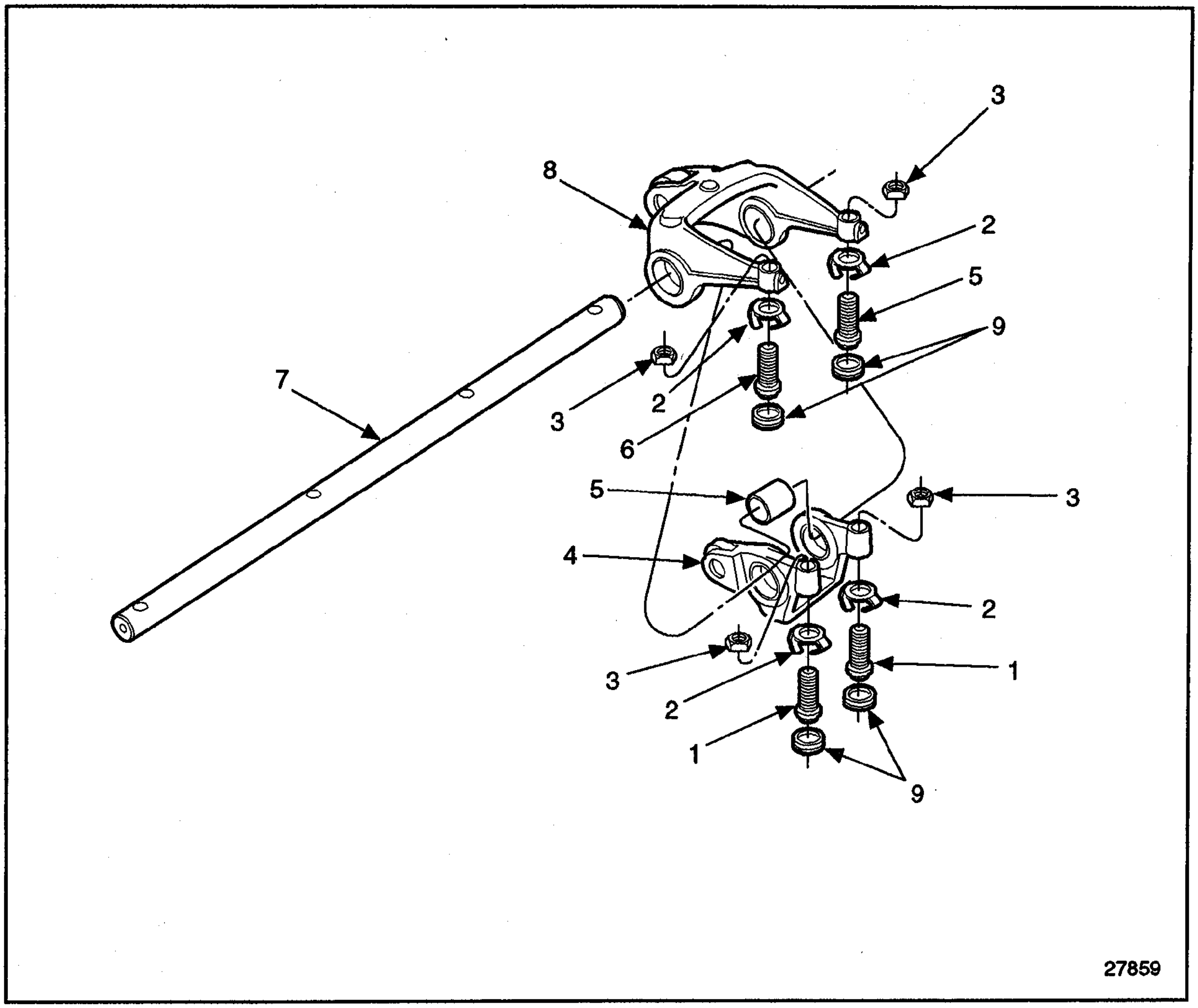

1. Intake Valve Adjusting Screw
2. Clip
3. Locknut
4. Intake Rocker Arm Assembly
5. Spacer
6. Exhaust Valve Adjusting Screw
7. Rocker Arm Shaft
8. Exhaust Rocker Arm Assembly
9. Valve Button

Figure 1-51 Rocker Arm and Related Parts (Series 60G Engine)

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A new injector rocker arm assembly replaced the former injector rocker arm assembly on all model 6067-GK60 engines beginning with serial number 06R0133091, and on all model 6067-GU60 and 6067-WU60 engines beginning with serial number 06R0157655.

NOTE:
When the current rocker is installed on a phosphated shaft, the shaft should be turned 180° to present a fresh phosphated area to the loaded region of the bushing.

The current assembly has a honed rocker arm shaft bushing, a ceramic cam follower and a new phosphated (black in color) rocker arm shaft which provides improved wear characteristics. The phosphated surface is required for the proper break-in of the steel rocker arm shaft bushings.

Current Series 60 engines have rocker arm shafts without flats at the mounting bolt locations. For these engines, a spacer is installed between the rocker arm shaft and the mounting bolts or nuts rather than a washer. This allows the rocker arm shaft to be rotated when installing new rocker arms. When reusing rocker arm assemblies, the rocker arm shaft should not be rotated so that the same surfaces of the rocker arm assemblies and rocker shafts are in contact with each other.

Vertical oil passages at the front and rear of the cylinder head deliver oil from the cylinder block front and rear oil galleries to the No. 1 and 7 lower camshaft bearing saddles. >From there, the oil is directed upward (through the enlarged stud hole) to the No. 1 and 7 upper bearing caps. A drilled passage in each of these caps exits at the rocker arm shaft seat area, where it indexes with a hole in each rocker arm shaft.

The rocker arm shafts have internal oil passages that deliver oil to the rocker arm bushings and intermediate upper camshaft bearings. Some of the oil supplied to the rocker arm bushings passes through the oil hole in the bushing to the rocker arm assemblies. The rocker arm assemblies contained drilled passages that supply oil to the camshaft roller follower, the roller pin and the bushing. The rocker arm assemblies also contain drilled passages that supply oil to the valve adjusting screw, valve button, retainer clip, intake and exhaust valve stems and the fuel injector follower.

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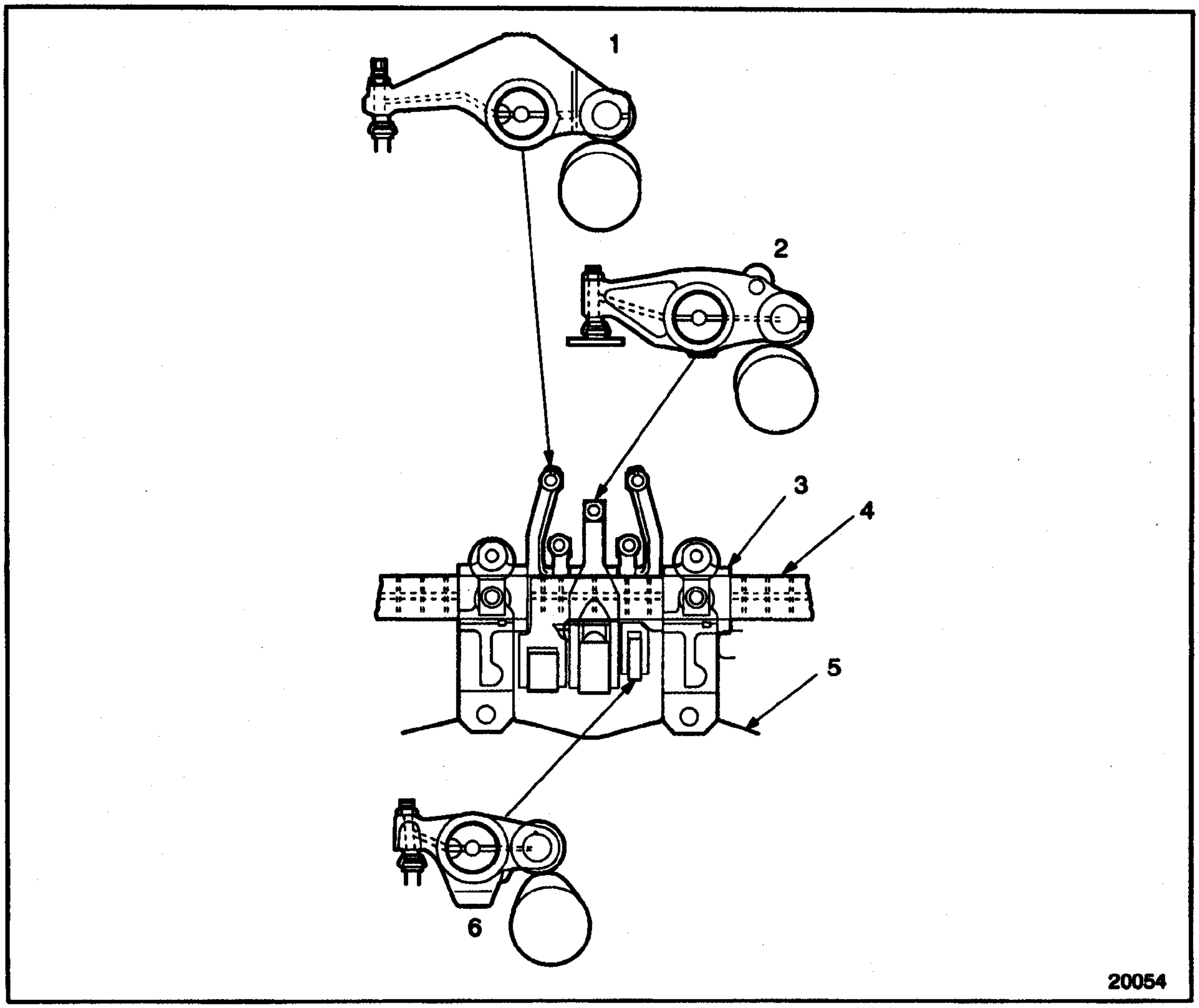
The No. 4 camshaft cap is "Y" drilled, forming an oil path connection between the front and rear rocker arm shafts, to ensure complete lubrication. The oil passage within one rocker arm cylinder set is shown. See Figure 1-52.



1. Exhaust Rocker Arm Assembly
2. Fuel Injector Rocker Arm Assembly
3. Camshaft Cap
4. Rocker Arm Shaft
5. Cylinder Head
6. Intake Rocker Arm Assembly

Figure 1-52 Rocker Arm Assembly Lubrication Schematic

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1.3.1 Repair or Replacement of Valve and Injector Operating Mechanism

To determine if repair is possible or replacement is necessary, perform the following procedure. See Figure 1-53.

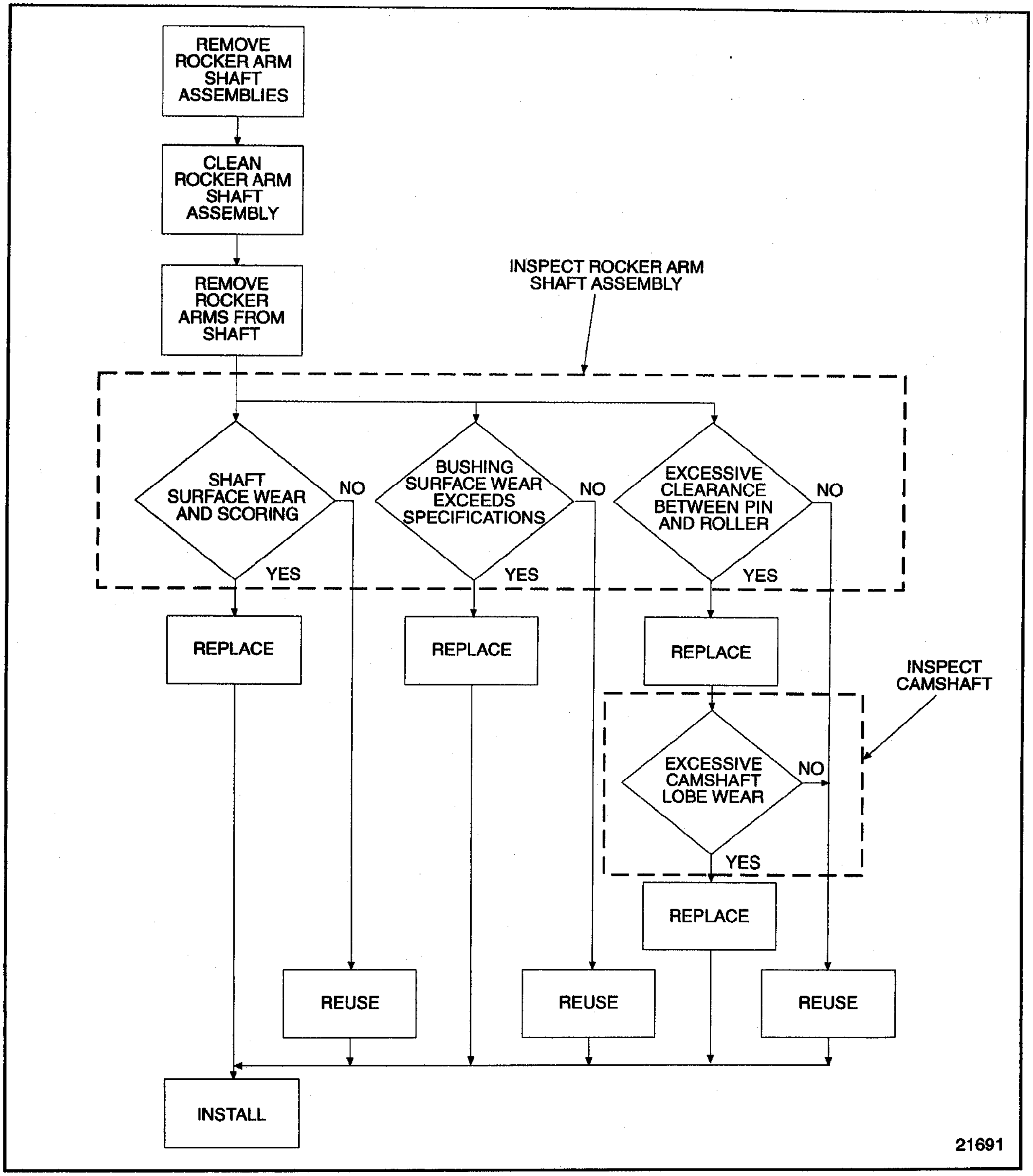

Figure 1-53 Flowchart for Repair or Replacement of Valve and Injector Operating Mechanism and Camshaft

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1.3.2 Removal of Rocker Arm Assembly

Perform the following steps for rocker arm assembly removal:

NOTE:
If unit is equipped with Jake brakes®, remove brake. Refer to section 1.29.2.

NOTE:
Jake Brakes® are not used on the Series 60G engine.

1. If necessary, steam clean the engine around the valve rocker cover and cylinder head mating area.
2. Remove the valve rocker cover. Refer to section 1.6.2 (one-piece), refer to section 1.6.3(two piece), and refer to section 1.6.5 (three-piece).
3. Remove the rocker arm shaft bolts (No. 2, 3, 4 or 5, 6, 7) and nuts (No. 1 or 8) that retain the rocker arm shaft assembly to the cylinder head. See Figure 1-54for Series 60 diesel engine and see Figure 1-55for Series 60 gas engine. For camshaft or cylinder head removal, both rocker arm shaft assemblies must be removed.

NOTE:
Whenever nuts No. 1 or 8 are loosened or removed, the torque on the corresponding rocker shaft stud must be checked. Torque to 126–146 N·m (93–108 lb·ft).

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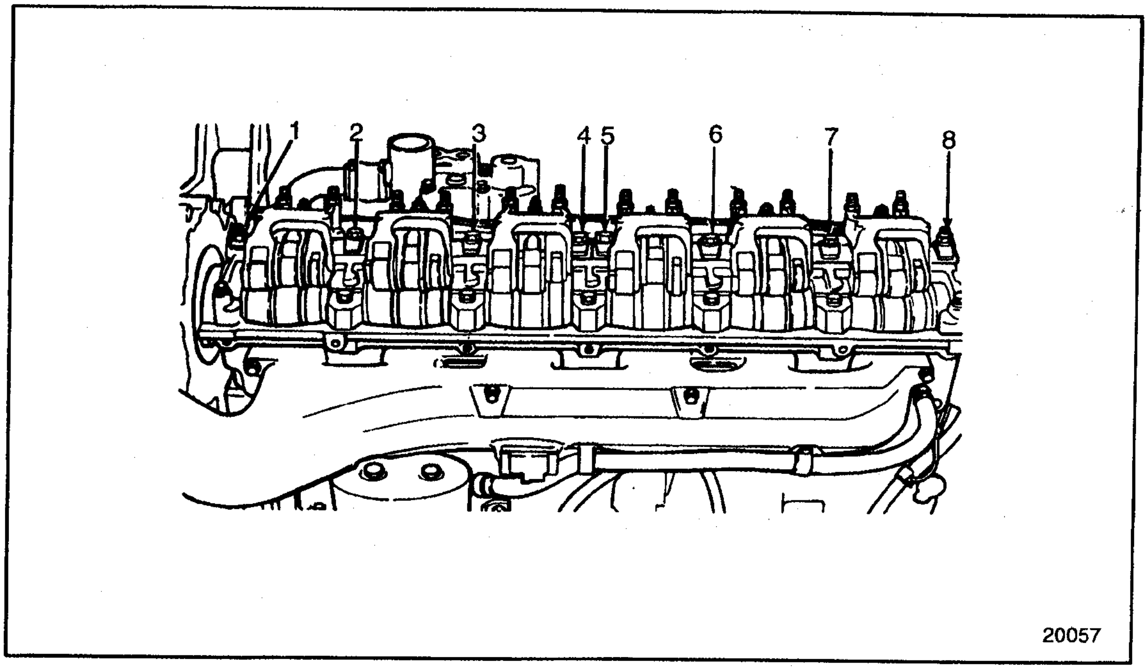

Figure 1-54 **Rocker Arm Shaft Bolts and Nut Identification Numbers**

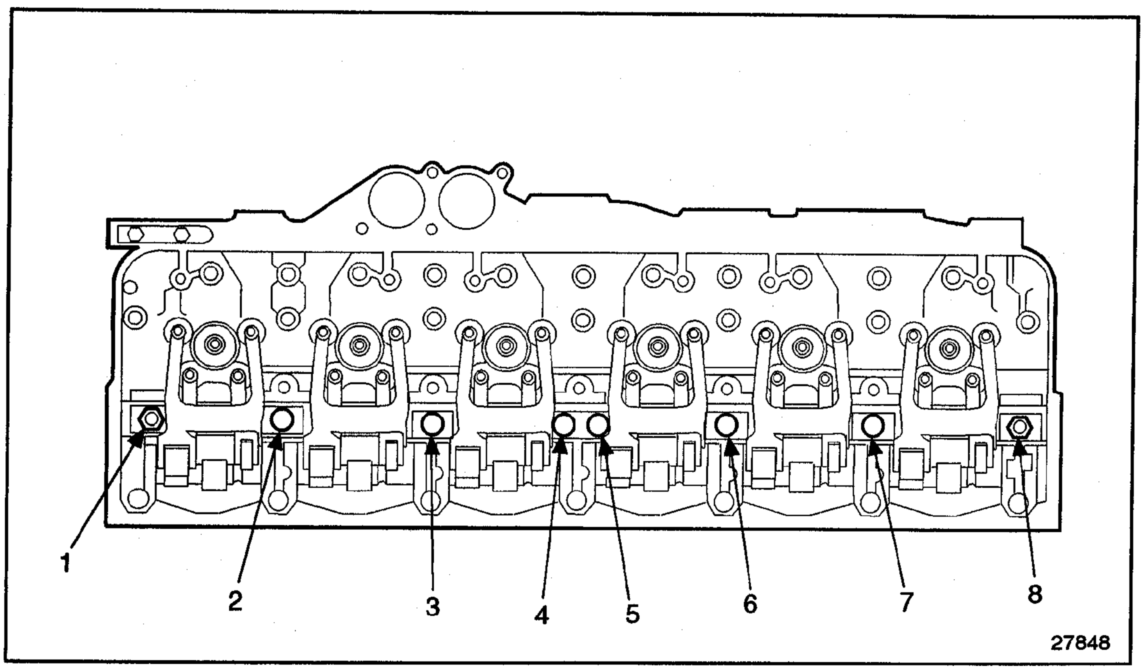

Figure 1-55 **Rocker Arm Shaft Bolts and Nut Identification Numbers (Series 60G Engine)**

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4. Use rocker arm and shaft assembly removal tool, J 35996-A to remove the rocker arm shafts, with rocker arm assemblies in place. See Figure 1-56.

NOTE:
Some engines may be equipped with ceramic injector rollers. Use extra caution while removing and handling.

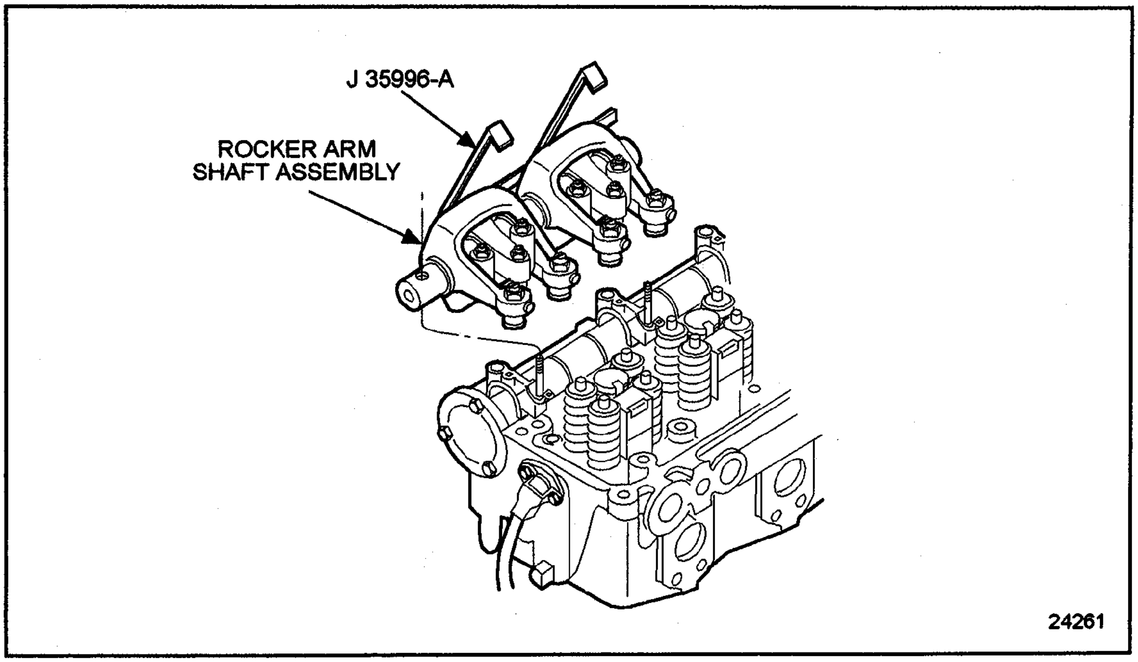

Figure 1-56 Rocker Arm Shaft Assembly Removal

5. To replace the valve button or valve button retaining clip, the valve adjusting screw must be removed from the rocker arm as follows:

NOTICE:
To avoid possible component damage, the valve button retainer MUST NOT be expanded more than 15.5 mm (0.610 in.). An adjusting screw is provided on the expander tool to limit the amount of travel.

[a] Spread the retaining clip with expander and remove the button. See Figure 1-57.

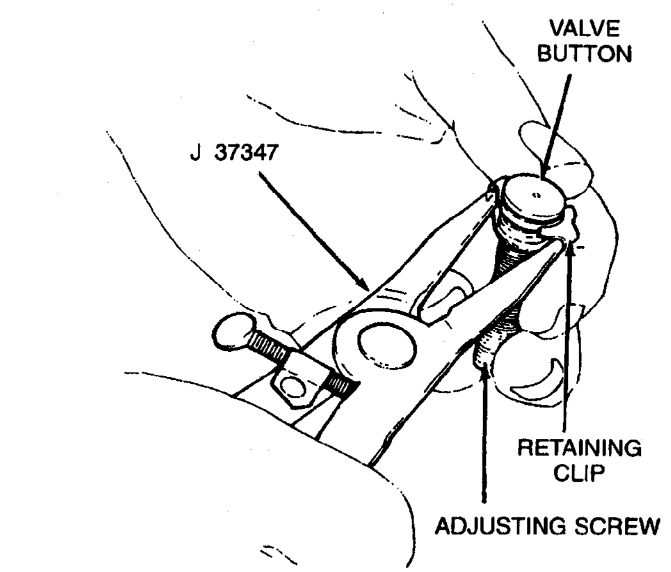

Figure 1-57 Valve Button Retainer Clip Removal and Installation

[b] Slide the retaining clip, open end first, down the adjusting screw. It is necessary to spread the clip slightly so that the open end can pass over the ball head of the adjusting screw.

[c] Insert the tips of the expander, J 36347, between the legs of the retaining clip and expand the clip.

[d] Insert the groove on the valve button into the legs of the retaining clip.

[e] Remove the expander and hold the legs of the retainer with the thumb and index finger.

[f] Press the valve button towards the screw to seat both legs of the retainer completely in the groove.

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6. If further disassembly is necessary, slide the rockers off the shafts, marking or segregating the parts so that they may be reinstalled in the same position from which they were removed.

NOTE:
Front and rear rocker arm shaft sections look identical, but must not be reversed, and must be installed as removed, due to bolt hole center line distances. The DDC logo is stamped on the outboard end of each rocker shaft to ensure correct assembly and installation. See Figure 1-58.

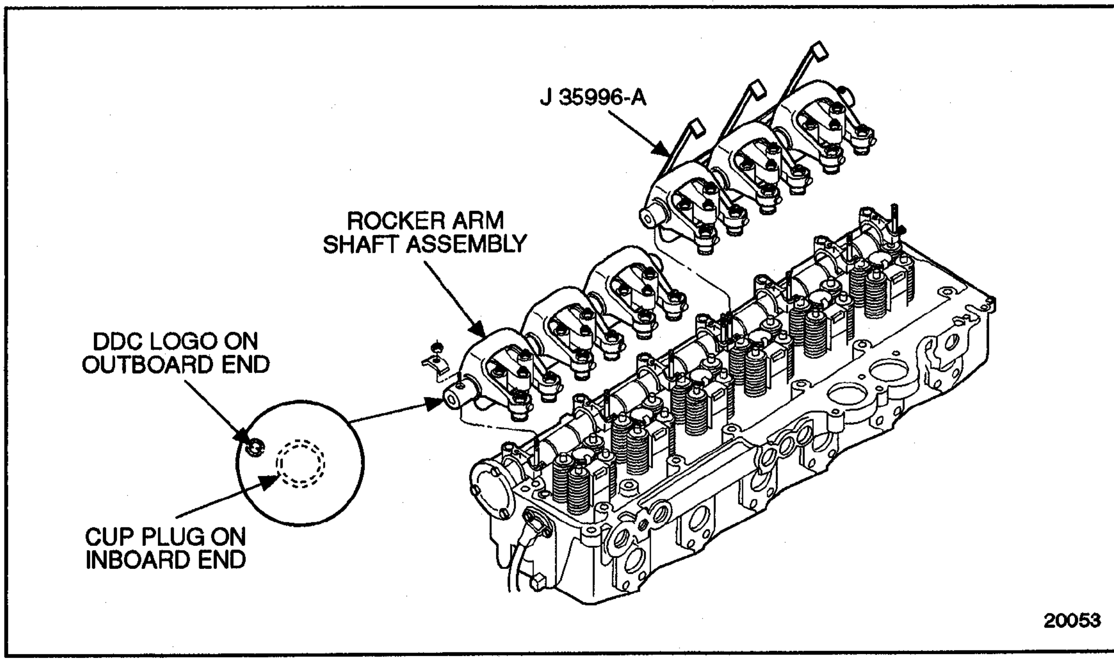

Figure 1-58 Rocker Arm Shaft Identification Mark

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1.3.2.1 Cleaning of Rocker Arm Assemblies

Clean the rocker arm assemblies as follows:

1. Remove the cup plug at one end of the rocker arm shafts to facilitate the removal of any foreign material lodged behind the plug.

NOTICE:
Do not soak the rocker arms in solvent because this will remove the lubricant from the cam follower roller bushings.

2. Clean the exterior of the rocker arms only.

CAUTION:
To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

3. Blow dry with compressed air.
4. Soak the rocker shaft in clean fuel oil.
5. Run a wire brush through the oil passage to remove any foreign material or sludge.

CAUTION:
To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

6. Clean the exterior of the shaft and blow out the passages and oil holes and dry with compressed air. See Figure 1-58.

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1.3.2.2 Inspection of Rocker Arm Assemblies and Camshaft Lobes

Prior to inspection:

1. Install new cup plugs with tool J 36326 until they are 1.0-1.3 mm (0.040-0.050 in.) below the surface of the shaft. See Figure 1-58.
2. Remove all of the old gasket sealer from the joint face of the No. 1 and 7 camshaft bearing caps and the cylinder head. Refer to "Gasket Eliminator Removal" in the "General Information" section.

Inspect the rocker arm assemblies and camshaft lobes as follows:

1. Inspect the rocker arm shaft bushing surfaces and rocker arm bushing bores for wear or scoring.
2. Check the cam follower rollers for scoring, pitting, or flat spots.
3. Check to be sure they turn freely on the roller pins.
   - [a] Clearance between the rollers and pins should not be more than 0.08 mm (0.003 in.).
   - [b] Replace as necessary.
4. Inspect the camshaft lobes and journals for scoring, pitting, or flat spots.
   - [a] If there is doubt as to the acceptability of the camshaft for further service, determine the extent of camshaft lobe wear. Refer to section 1.23.3.1.

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1.3.3 Installation of Rocker Arm Shaft Assembly

Perform the following for rocker arm shaft assembly installation:

1. Make sure the cup plugs are properly installed to each end of the rocker arm shafts before the shafts are installed to the engine. See Figure 1-50. Refer to section 1.3.2.2, step 1.
2. Check the torque on the rocker shaft studs to be sure they were not loosened when the nuts were removed. Torque the studs to 101-116 N·m (75-86 lb·ft).
3. Install the adjusting screws, valve buttons and clips to the rocker arm assemblies. See Figure 1-50.
4. Install the rocker arm assemblies to the rocker arm shafts in their original positions. Use the rocker arm identification marks to ensure correct component assembly. If the rocker arm shaft does not have flats, decide on the position of the worn surfaces and rotate the rocker shaft accordingly.
5. Using care to locate the valve buttons to their respective valve stems and injector followers, install the rocker arm shaft assemblies to the cylinder head. See Figure 1-59.

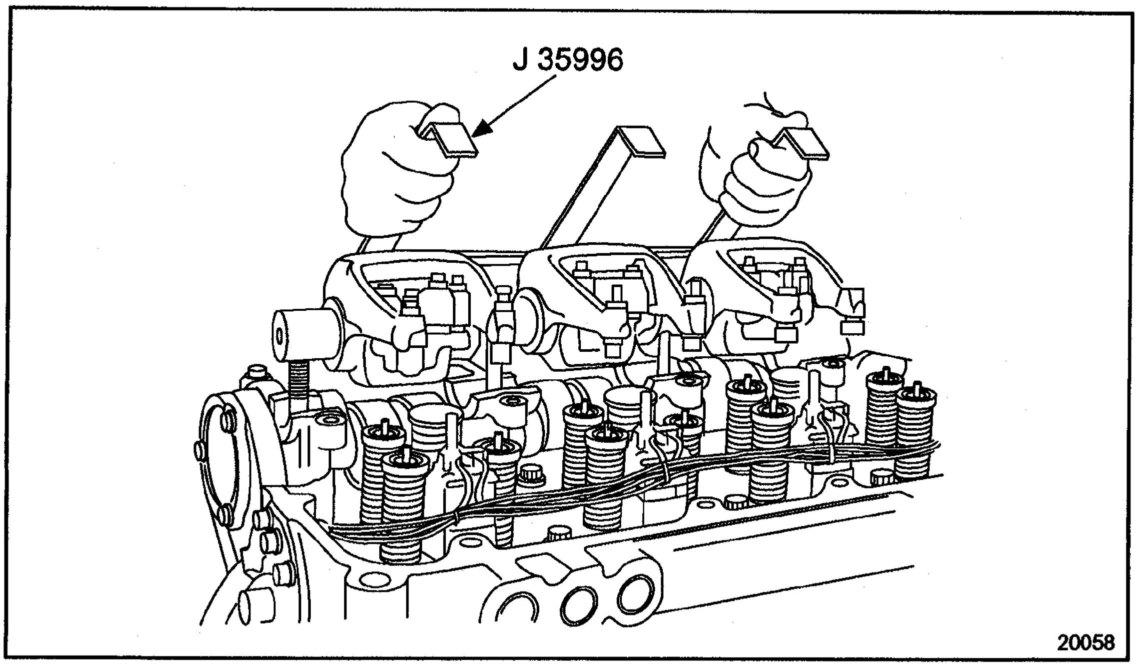

Figure 1-59 Rocker Arm Shaft Assembly Installation

6. If the rocker arm shafts do not have flats in the bolt hole locations, rocker shaft spacers are required.
   [a] If the rocker shafts do not have flats in the bolt hole locations, install the rocker shaft spacers on the cap bolts and studs.
   [b] If the rocker shafts do have flats in the bolt hole locations, rocker shaft spacers are not required.

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7. Install the inboard camshaft cap bolts for each rocker arm assembly, through the rocker arm shaft and camshaft cap and into the cylinder head.
8. Install the nuts to the No. 7 and 8 cap studs.

NOTE:
If new rocker arm components are installed, engine oil should be poured over the rocker arms, rocker shaft, and camshaft as a pre-lubricant.

9. Tighten the rocker arm shaft nuts to 101-116 N·m (75-86 lb·ft) torque using the sequence. See Figure 1-60.

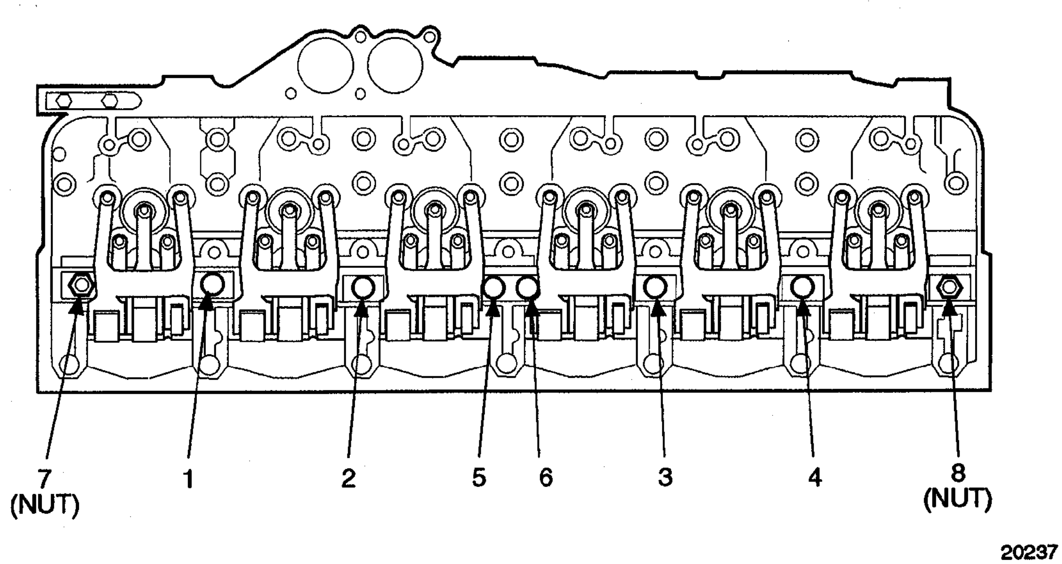

Figure 1-60 Rocker Arm Shaft Retaining Bolt and Nut Tightening Sequence

10. Adjust the intake and exhaust valve clearances and set the injector heights. Refer to section 12.2.
11. Install the valve rocker cover. Refer to section 1.6.8 (one-piece), refer to section 1.6.9 (two-piece), refer to section 1.6.9 (three-piece) for removal.
12. Install any other components that were removed for this procedure.

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CAUTION:

Diesel engine exhaust and some of its constituents are known to the State of California to cause cancer, birth defects, and other reproductive harm.

- **Always start and operate an engine in a well ventilated area.**
- **If operating an engine in an enclosed area, vent the exhaust to the outside.**
- **Do not modify or tamper with the exhaust system or emission control system.**

13. Start the engine and check for leaks.
14. Shut down the engine when completed.

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1.4 VALVES, SPRINGS, GUIDES, INSERTS, SEALS AND ROTATORS

Four valves per cylinder, two each intake and exhaust, give the Series 60 engine excellent breathing and cooling characteristics. See Figure 1-61.

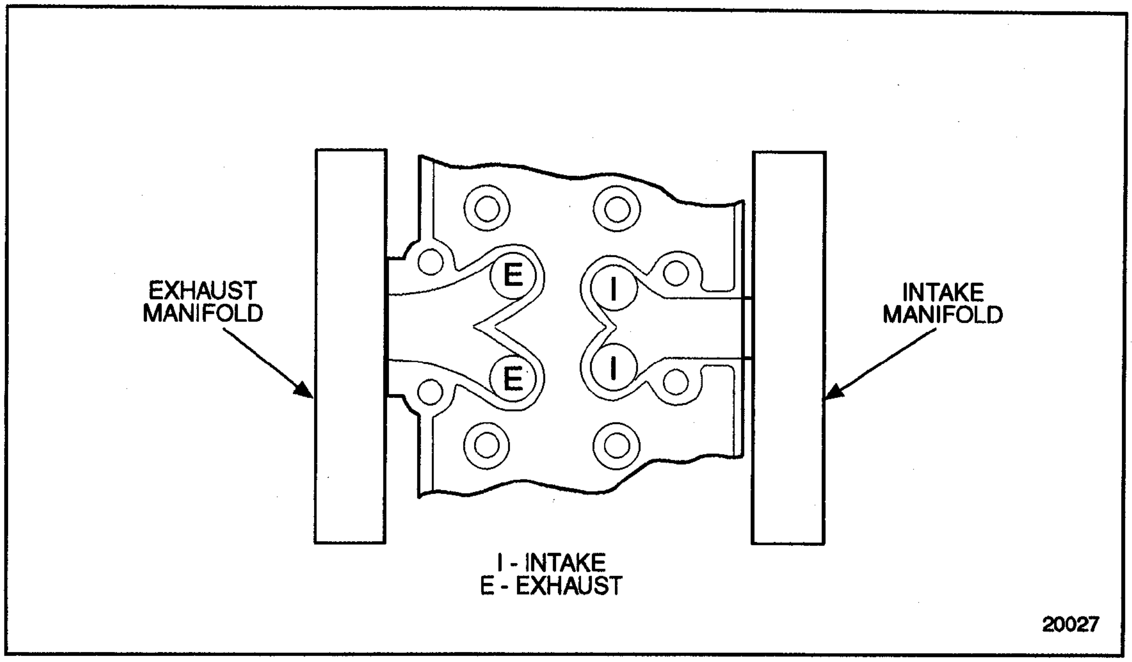

Figure 1-61 Intake and Exhaust Valve Arrangements

Valves are made of heat-treated alloys, with heads and stems precision ground. Stem ends are hardened to minimize wear in contact with the valve rocker buttons.

Hard-alloy valve seat inserts, pressed into both intake and exhaust ports, can be replaced when worn to restore new engine performance.

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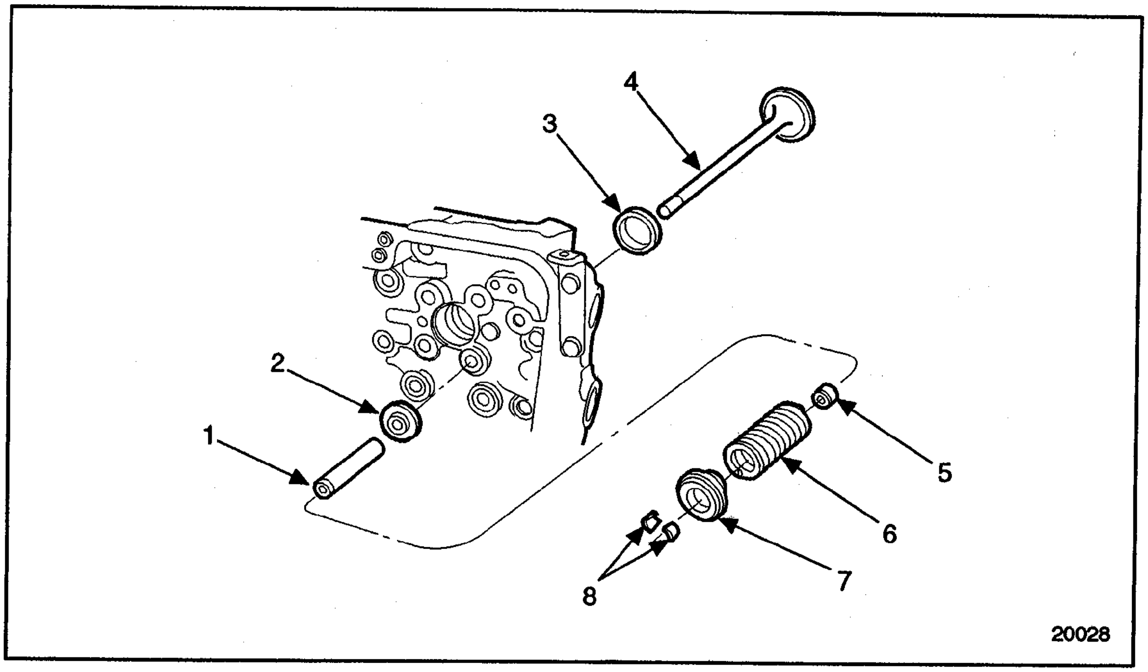
Valves are positioned and aligned by replaceable valve guides pressed into the cylinder head. See Figure 1-62.



1. Valve Guide
2. Valve Spring Seat
3. Valve Insert
4. Valve
5. Valve Stem Oil Seal
6. Valve Spring
7. Valve Rotator
8. Valve Keepers

Figure 1-62 Valve Guide and Related Parts

Replacement guides are reamed to close tolerances, and do not require reaming after installation. All valves are retained by valve rotator spring caps and two-piece tapered valve locks.

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Valve stem oil seals, installed on both intake and exhaust valves, provide controlled valve stem lubrication while limiting oil consumption.

NOTE:

New valve seat inserts are pre-ground and only need to be checked for concentricity after installation. Do not grind a new seat insert unless concentricity exceeds 0.05 mm (0.002 in.). Before grinding, be sure the valve guide is not excessively worn or bent, which could cause an erroneous concentricity reading. If the firedeck has been resurfaced, the valves will have to be seated deeper to restore the valve head recess depth to specification limits. Do not grind seat inserts for this purpose. Reduced thickness inserts are available that are 0.2540, 0.5080 and 0.7620 mm (0.010, 0.020 and 0.030 in.) shallower than standard. When a reduced thickness valve seat insert is used, a correspondingly thicker valve spring seat must be used. See Figure 1-63, and see Figure 1-64.

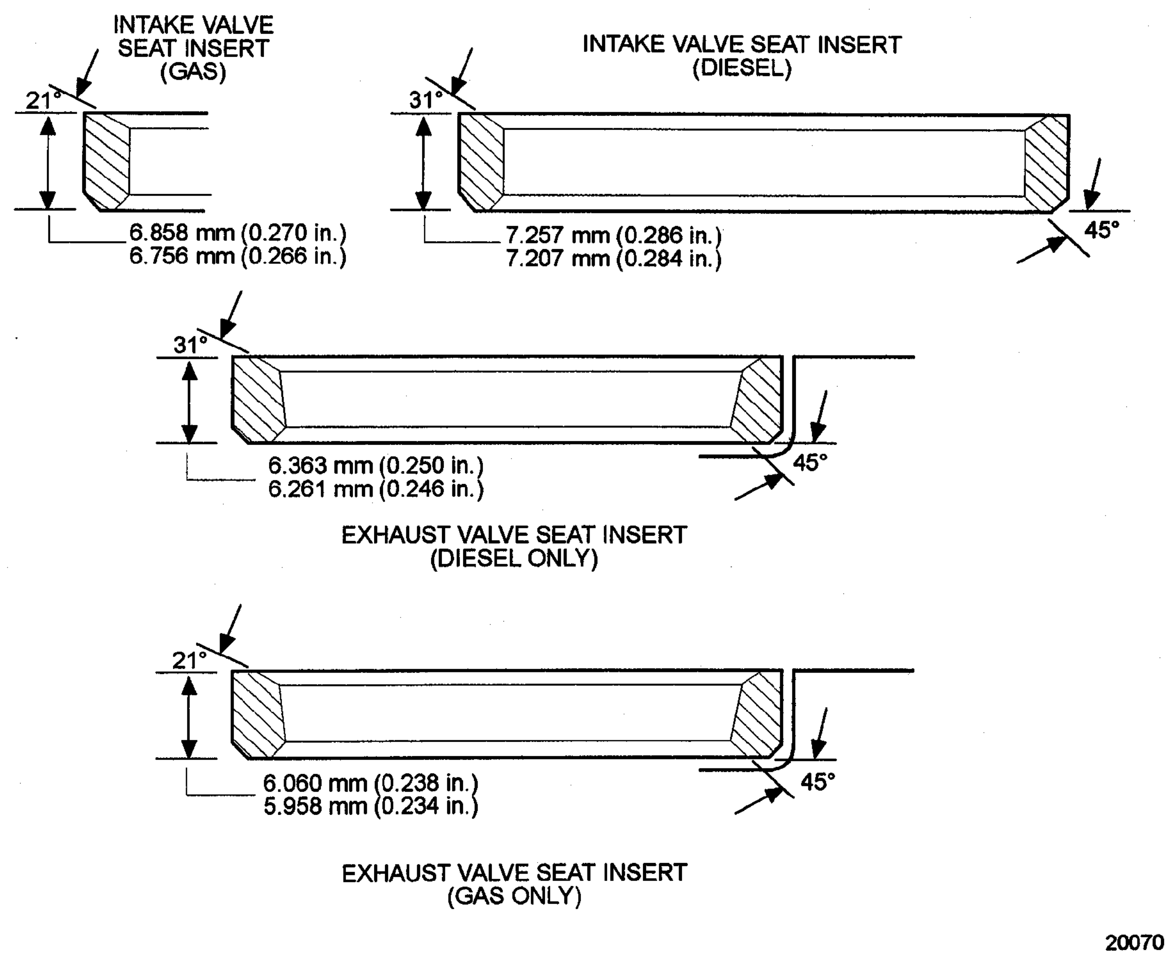

Figure 1-63 **Standard Valve Seat Insert Thickness**

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When servicing exhaust valves, determine which type of exhaust valve is contained in the engine. If an exhaust valve must be replaced, use the same type that was removed. Do not mix exhaust valve types within an engine. Both exhaust valves are available from service stock for this purpose. Exhaust valve lash settings are affected by the type of exhaust valve that is contained in the engine. The valve lash settings and injector timing height are listed on the valve rocker cover. Refer to section 12.2.

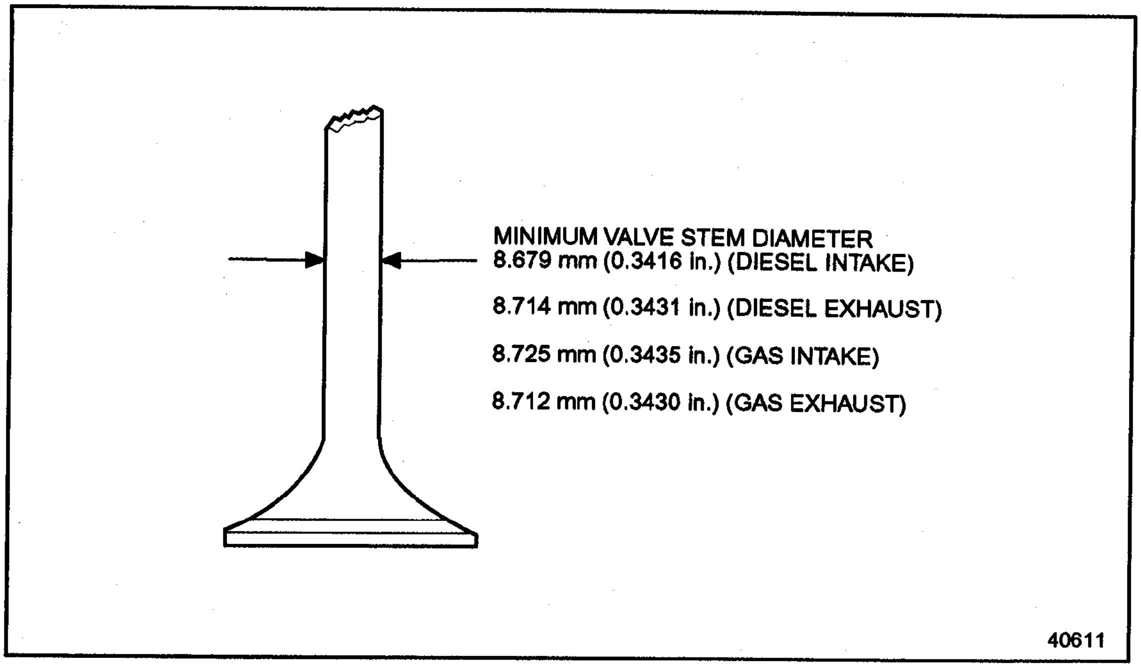

Figure 1-64 Minimum Valve Stem Diameter

Two types of exhaust valves are used on Series 60 engines. Pre-1991 model engines use a nickel-based alloy which can be identified by a forged "U" on the combustion face. 1991 model and beyond engines use an austenitic based alloy which can be identified by a forged "H" on the combustion face, and by a machined identification ring above the valve lock groove. See Figure 1-65. The identification ring can be seen from the right side of the engine with rocker cover removed.

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Series 60G exhaust valves for automotive engines are an inconnel based material. They are marked with a "J" on the face of the valve and a "J6-E-5" and a green dot on the top of the stem of the valve.

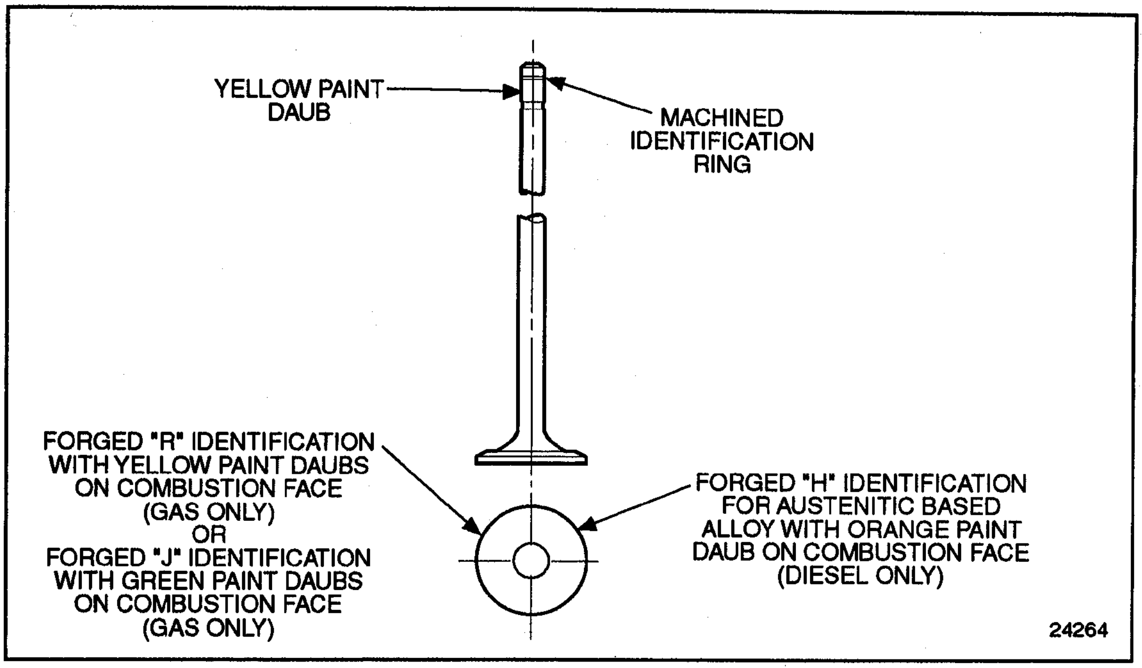

Figure 1-65 Exhaust Valve Identification

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1.4.1 Repair or Replacement of Valves

To determine if repair is possible or replacement is necessary, perform the following procedure. See Figure 1-66.

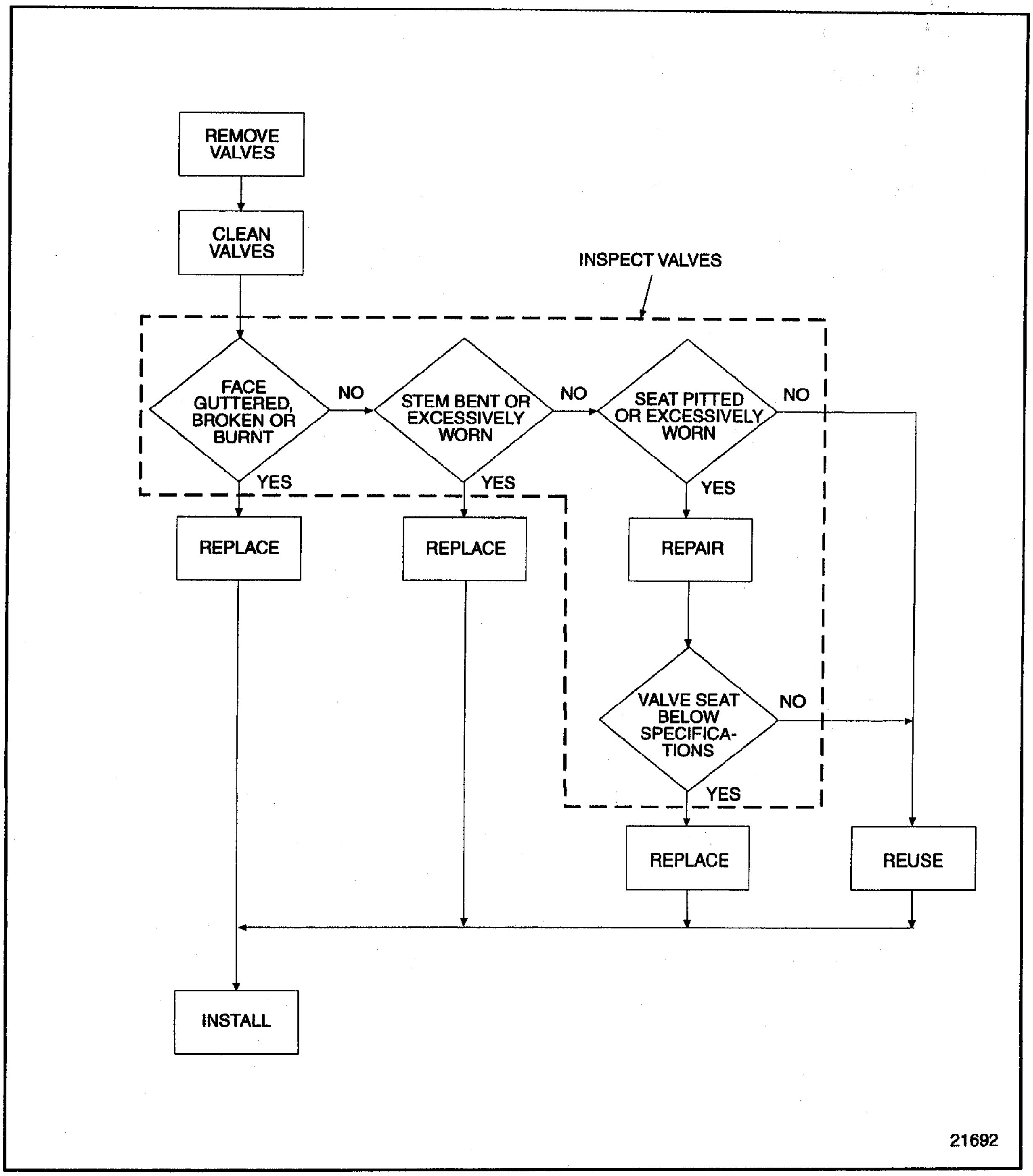

Figure 1-66 Flowchart for Repair or Replacement of Valves

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1.4.2 Removal and Cleaning of Valve Spring (Cylinder Head Installed)

Perform the following steps for valve spring removal:

1. Clean any dirt and debris from the valve rocker cover joint area around the top of the cylinder head. Remove the valve rocker cover. Refer to section 1.6.2 (one-piece), refer to section 1.6.3 (two-piece), refer to section 1.6.5 (three-piece).
2. If the engine has a Jake Brake®, remove the Jake Brake® housings that cover the rocker arm and shaft assembly for the valve to be serviced refer to section 1.29.2.
3. Remove the rocker arm shaft assembly, refer to section 1.3.2.
4. Remove the injector from the appropriate cylinder. Refer to section 2.3.2.

NOTE:
Fuel must be removed from the cylinder head fuel galleries prior to removing the injectors. Refer to section 2.3.2.

5. Bar the engine over until the cylinder is at top-dead-center (TDC).
6. Insert the threaded portion of the valve spring compressor, J 35580 into the threaded inboard camshaft cap hole adjacent to the valve being worked on. See Figure 1-67.

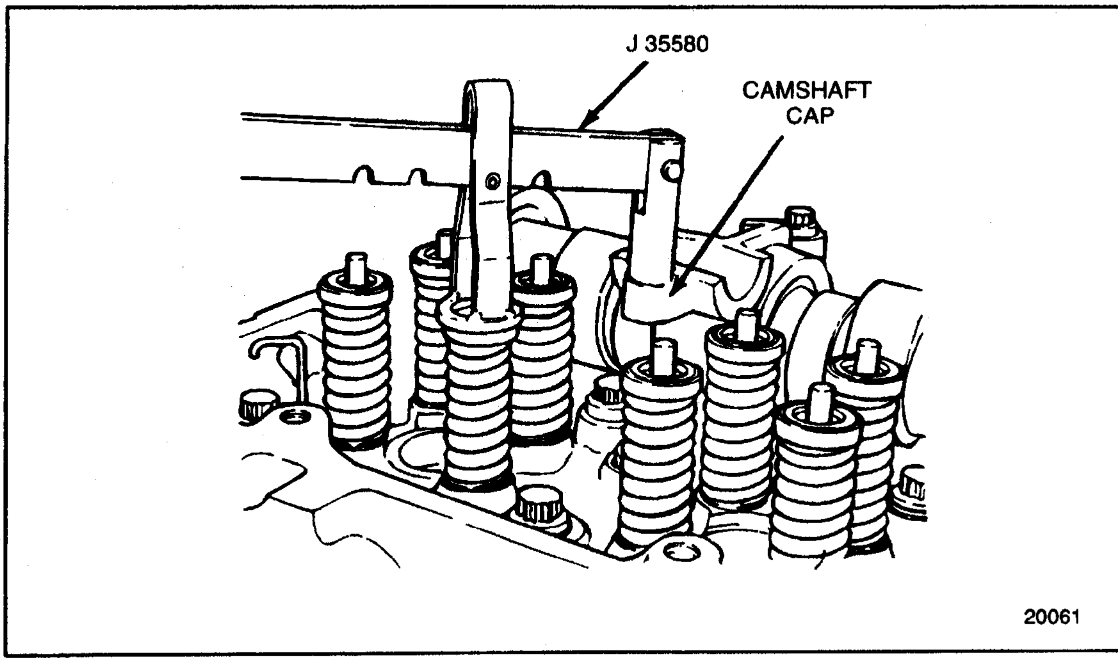

Figure 1-67 Installing Valve Spring Compressor

7. Position the spring compressor cage portion of the valve spring compressor directly over the valve spring to be compressed. Engage the dowel of the cage in the closest slot of the valve spring compressor handle.

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NOTICE:
Do not contact the valve with the compressor tool.

8. Compress the valve spring and remove the valve locks using a small magnet to prevent the locks from falling into the cylinder head oil return galleries.
9. Release the spring and remove the valve rotator and valve spring. If the valve stem oil seal is to be replaced, remove the seal and discard it.
10. On the other three valves it may be necessary to repeat these steps for cylinders being worked on. Refer to step 1and the following steps. Last, refer to step 9.

NOTE:
All valve spring or seal removal and replacement must be completed for each cylinder being serviced while the piston is at top-dead-center, before turning the crankshaft to work on another cylinder.

1.4.3 Removal and Cleaning of the Valve Spring (Cylinder Head Removed)

With the cylinder head assembly removed from the engine, remove the valve springs as follows:

1. Bolt the engine overhaul stand adaptor, J 35635-A, to the engine overhaul stand, J 29109, using the hardware provided with the adaptor. See Figure 1-68.

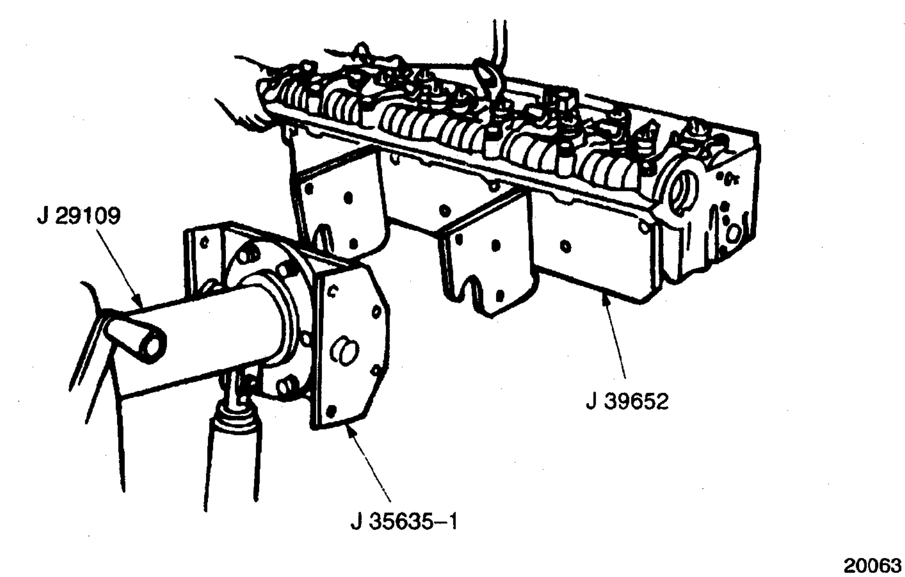

Figure 1-68 Engine Overhaul Stand

2. Bolt the cylinder head adaptor plate, J 35636-A, to the cylinder head using the bolts provided with the adaptor. See Figure 1-68.
3. Mount the cylinder head and adaptor plate to the overhaul stand adaptor by engaging the slots in the cylinder head adaptor plate to the dowels on the overhaul stand adaptor.
4. Install the six nut and bolt assemblies that secure the cylinder head adaptor plate to the overhaul stand adaptor.
5. Remove the cylinder head lifting hardware.
6. Turn the crank of the engine overhaul stand to position the cylinder head in an upright position.
7. Remove the valve locks using valve spring compressor, J 8062, with jaws, J 8062–3 installed, to compress each valve spring. See Figure 1-69.

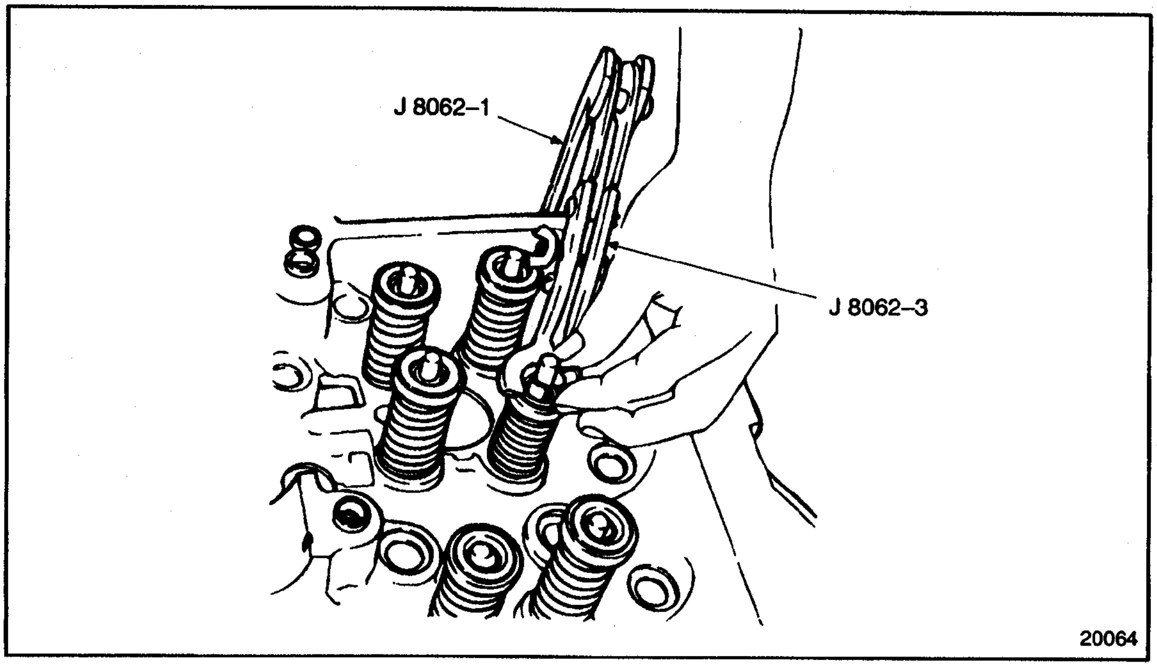

Figure 1-69 Compressing Valve Spring

8. Release the spring and remove the valve, valve rotator and valve spring.
9. Remove the valve stem oil seal and discard the seal.
10. Remove the valve spring seat.
11. As parts are removed, mark or segregate them according to their original position for possible reuse.

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1.4.3.1 Cleaning of Valves and Related Parts

Clean the valves and parts as follows:

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

1. Using proper eye protection, clean all of the disassembled parts with fuel oil and dry with compressed air.
2. Clean the carbon from the valve stems and wash the valves with fuel oil.
3. Clean the valve guide bore to remove all gum and carbon deposits.
   [a] For diesel engines; use bore brush, J 5437 (or equivalent) for this procedure.
   [b] For natural gas engines; a cloth or soft nylon brush is recommended for this procedure.

NOTE:
Do not use bore brush (wire) on natural gas powdered metal guides.

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1.4.4 Removal of Valve Guide

Perform the following steps for valve guide removal:

NOTE:
Valve guides are not replaceable on natural gas or heat exchanger-cooled pleasure craft marine engines.

1. Assemble the valve guide remover, J 34696-B, to an air chisel. See Figure 1-70.

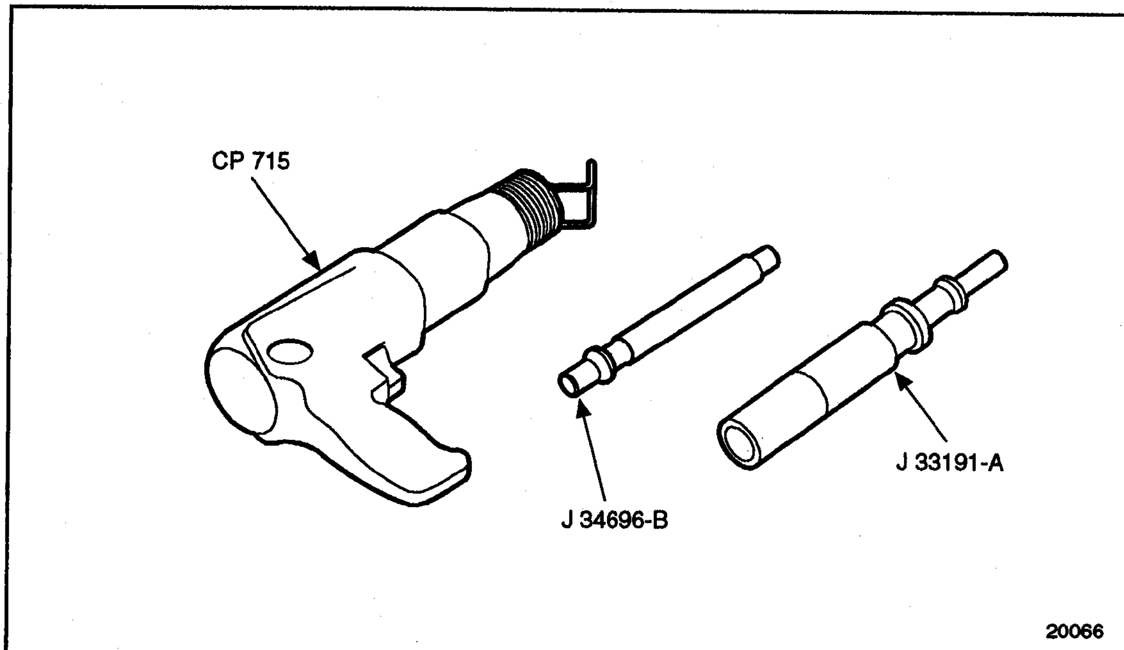

Figure 1-70 Valve Guide Removal Tools

2. Position the cylinder head, firedeck side up, on a turn over stand or supported on 102 x 102 mm (4 x 4 in.) wooden blocks on a workbench.

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3. Insert the tool into valve guide from the firedeck side of the cylinder head. See Figure 1-71.

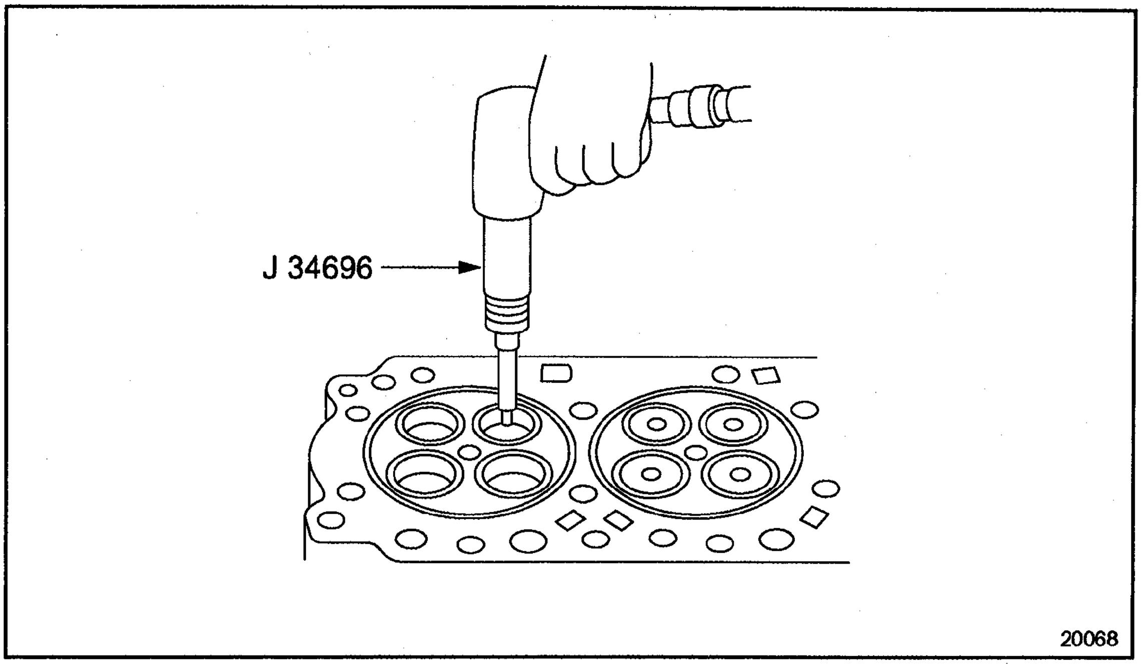

Figure 1-71 Valve Guide Removal

4. Hold the tool vertical to the cylinder head and drive the valve guide until it is free of the cylinder head.
5. Clean the valve guide bore with bore brush, J 5437 (or equivalent), to remove all gum and carbon deposits.

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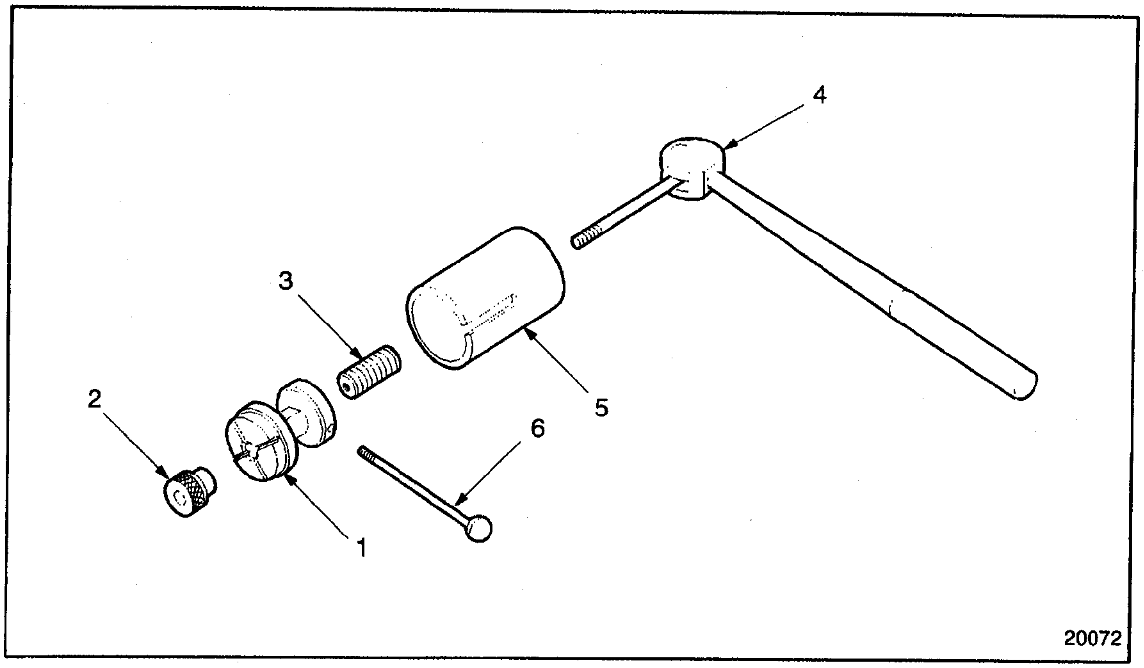
1.4.5 Removal of Intake and Exhaust Valve Seat Insert

As the intake and exhaust valve seats are different in size, two different tools are required for removal. Use the cam-operated valve seat remover, J 23479-460A, with collet, J 23479-100–A, to remove the larger intake valve seat insert. Use valve seat remover, J 23479-271, with collet J 23479-29 to remove the smaller exhaust valve seat insert. See Figure 1-72.



1. Collet
2. Knurled Knob
3. Spring
4. Valve Seat Insert Puller
5. Collar
6. Collet Lever

Figure 1-72 Valve Seat Insert Removal Tools

Remove the intake and exhaust valve seats as follows:

1. Place the cylinder head in a horizontal position with the valve seats facing up.

NOTICE:
Follow instructions supplied with tools J 23479-460A, J 23479-100, J 23479-271, and J 23479-29 to ensure longer tool life and unnecessary collet damage.

2. Using a new valve seat insert as a guide, turn the knurled knob on the end of the shaft to tighten and expand the collet until the valve seat insert will just slip off the collet. Refer to instructions supplied with the valve seat remover tool for correct tool operation.

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1.4.5.1 Inspection of Valve

The valve stems must be free from scratches or scuff marks, and, the valve faces must be free from ridges or cracks. Some pitting of the valve face is normal, and is acceptable as long as no leak paths are evident. If leak paths exist, reface the valves or install new valves. If the valve heads are warped or the valve stem is bent, replace the valves.

If suitable for reuse, a valve may be refaced as long as the valve rim width, after refacing, is not less than 2.0 mm (0.078 in.) for intake valves and 2.2 mm (0.086 in.) for exhaust valves. Refer to section ADDITIONAL INFORMATION 1.A, for "Intake and Exhaust Valve" specifications which are listed in Table 1-36 and listed in Table 1-38. See Figure 1-73.

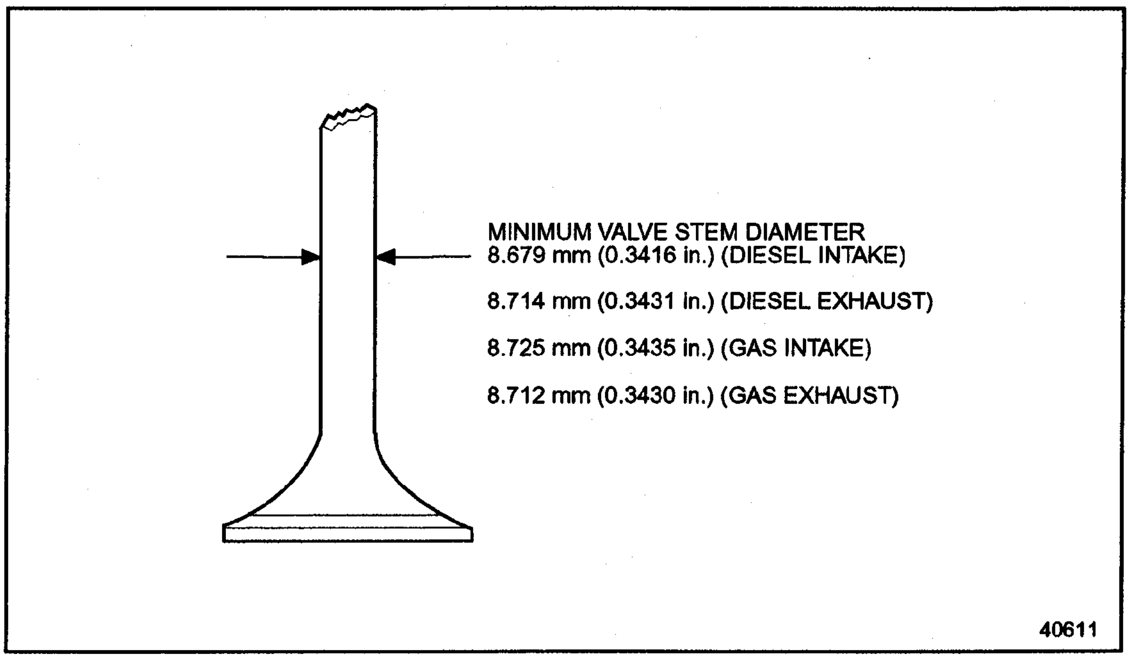

Figure 1-73 Intake and Exhaust Valve Face Refacing and Rim Width

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1.4.5.2 Inspection of Valve Springs

Inspect the valve springs and replace any that are pitted or cracked. The entire spring should be inspected. When a broken spring is replaced, the rotator and valve locks for that valve and spring should also be replaced.

Use valve spring tester, J 22738-02, to test the springs. See Figure 1-74.

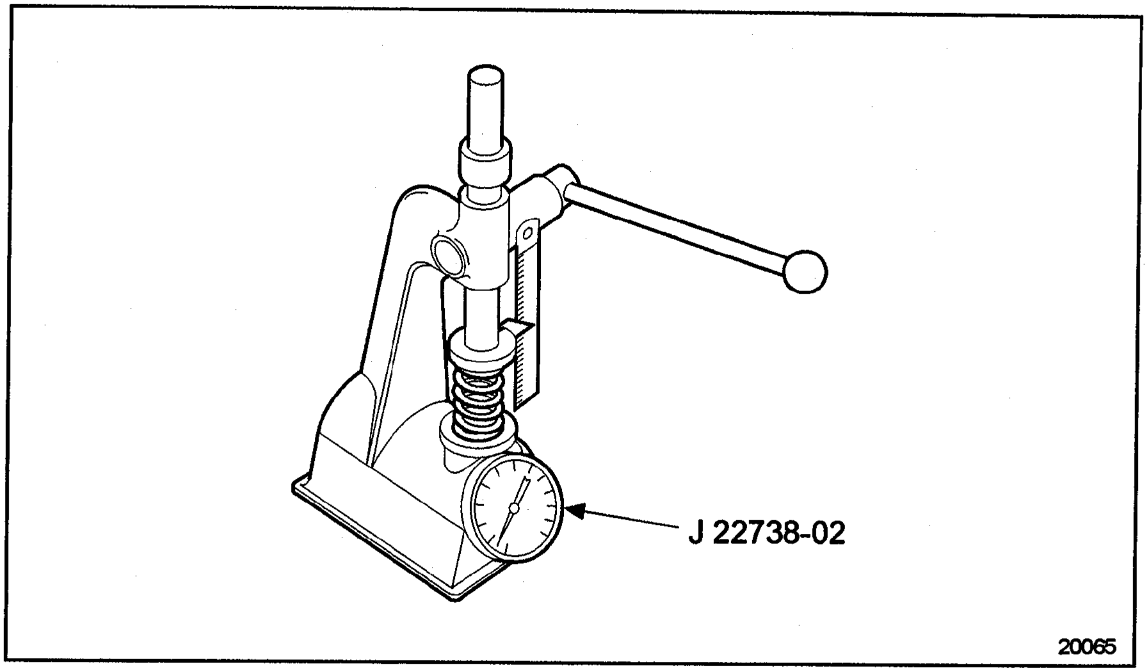

Figure 1-74 Testing Valve Spring

If the spring load is less than 280 N (63 lb) at a compressed length of 67.25 mm (2.648 in.), the spring should be replaced and the valve locks should be discarded.

1.4.5.3 Inspection of Valve Guides

Inspect the guides for cracks, chipping, scoring or excessive wear.

Measure the valve guide bore with a small hole gage or gage pin, and measure the valve stem diameter with a micrometer. Compare the measurements to determine valve stem clearance. If the clearance is greater than 0.152 mm (0.006 in.), the valve guide must be replaced.

1.4.5.4 Inspection of Valve Seat Inserts

Inspect valve seat inserts for wear, cracking or incorrect seat angle, which should be 31 degrees, standard valve seat insert thickness. See Figure 1-63.

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1.4.6 Installation of Intake and Exhaust Valve Seat Insert

Perform the following steps for intake and exhaust valve seat insert installation:

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

1. Clean the seat insert counterbores and the new seat inserts with a suitable solvent and blow dry with compressed air.
2. Use valve seat insert installers, J 33190 (intake) and J 34983 (exhaust), to install new inserts. See Figure 1-75.

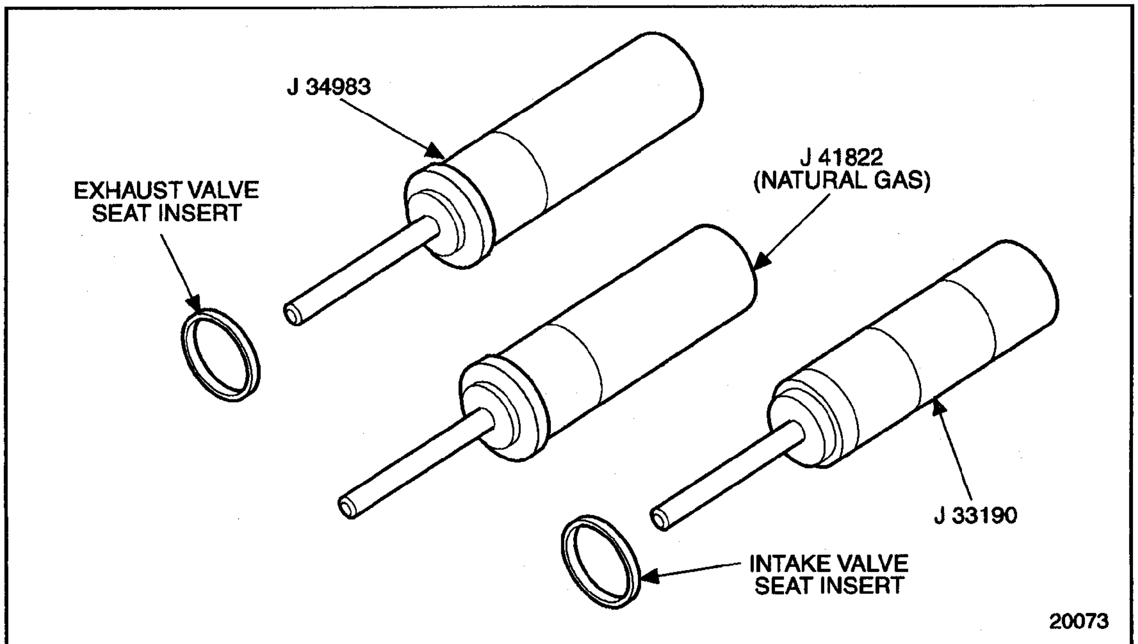

Figure 1-75 Valve Seat Insert Installation Tools

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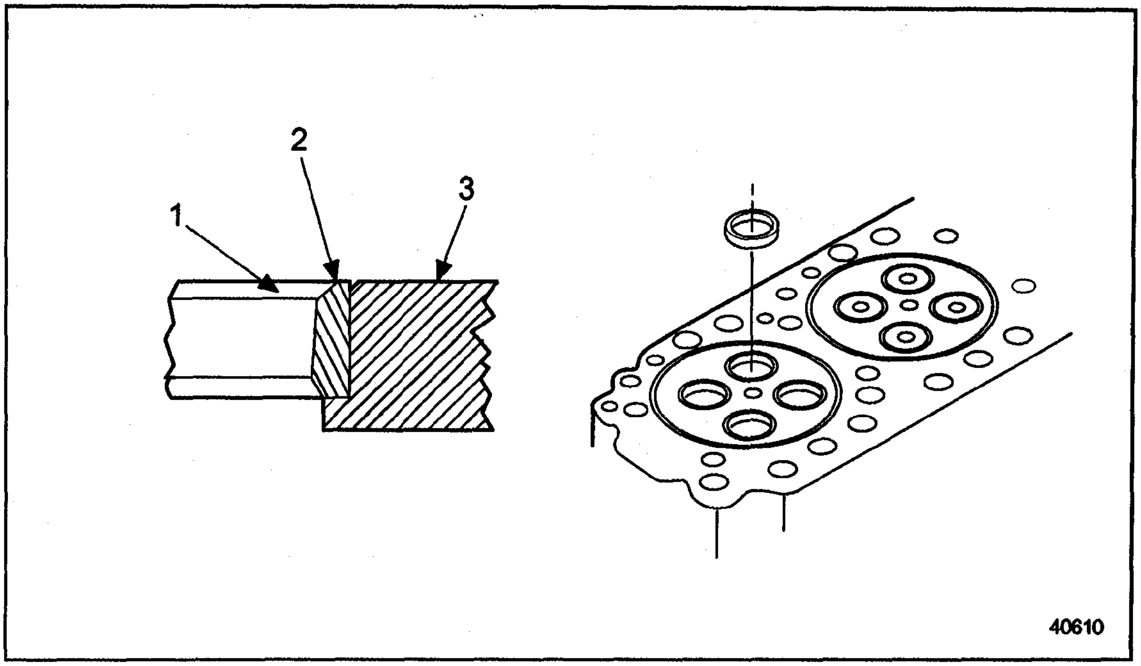
3. Start the insert squarely into its counterbore with the seat facing up. See Figure 1-76.



1. Seat
2. Valve Seat Insert
3. Cylinder Fire Deck

Figure 1-76 Valve Seat Insert Insertion

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4. Pilot the installer into the valve guide from the firedeck surface. See Figure 1-77.

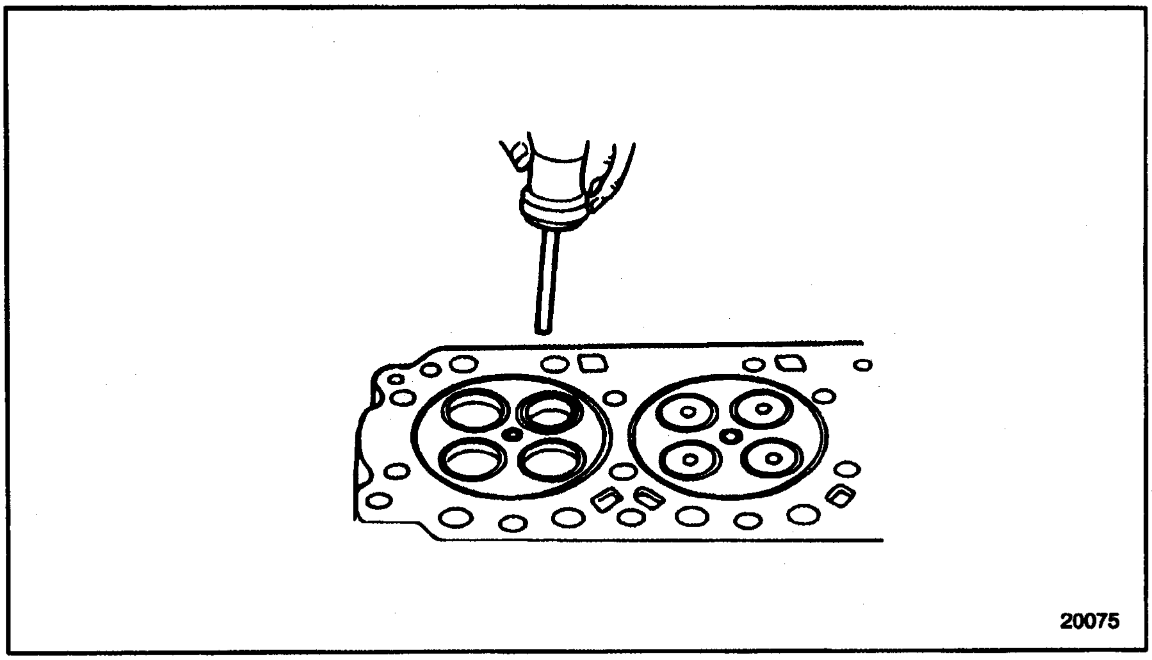

Figure 1-77 Valve Seat Insert Installation

5. Drive the insert solidly into its seat in the cylinder head. See Figure 1-78.

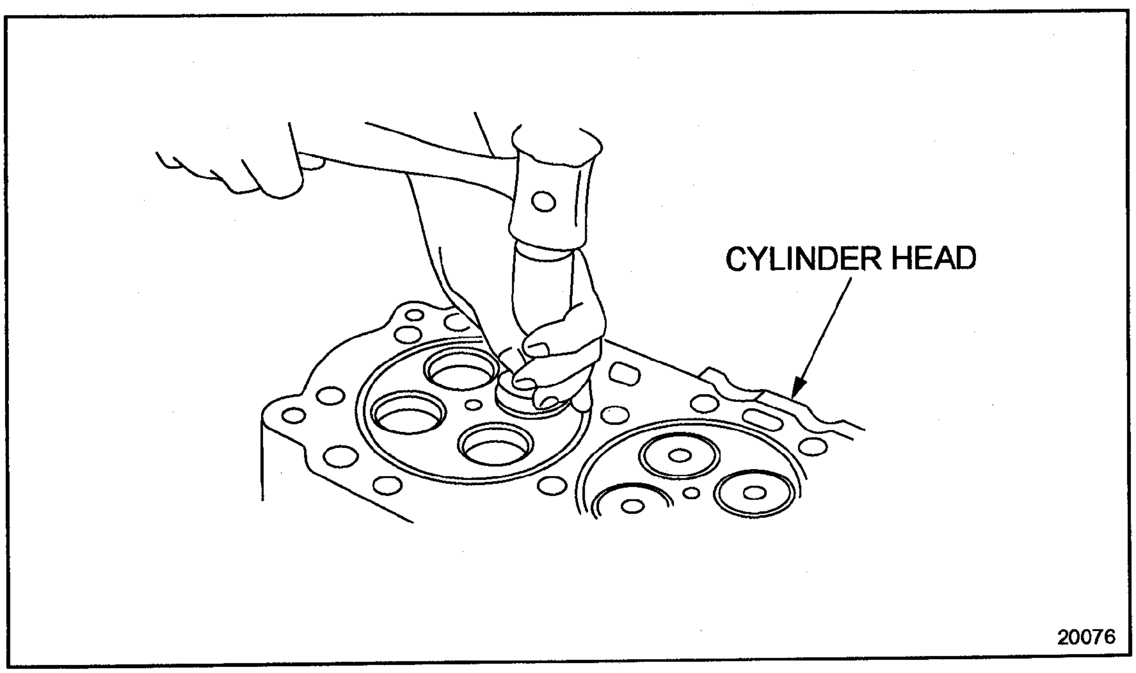

Figure 1-78 Seating Valve Seat Insert

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6. Check the concentricity of valve seat with the valve guide using dial indicator, J 8165-2, and pilot, J 35623-A. See Figure 1-79.

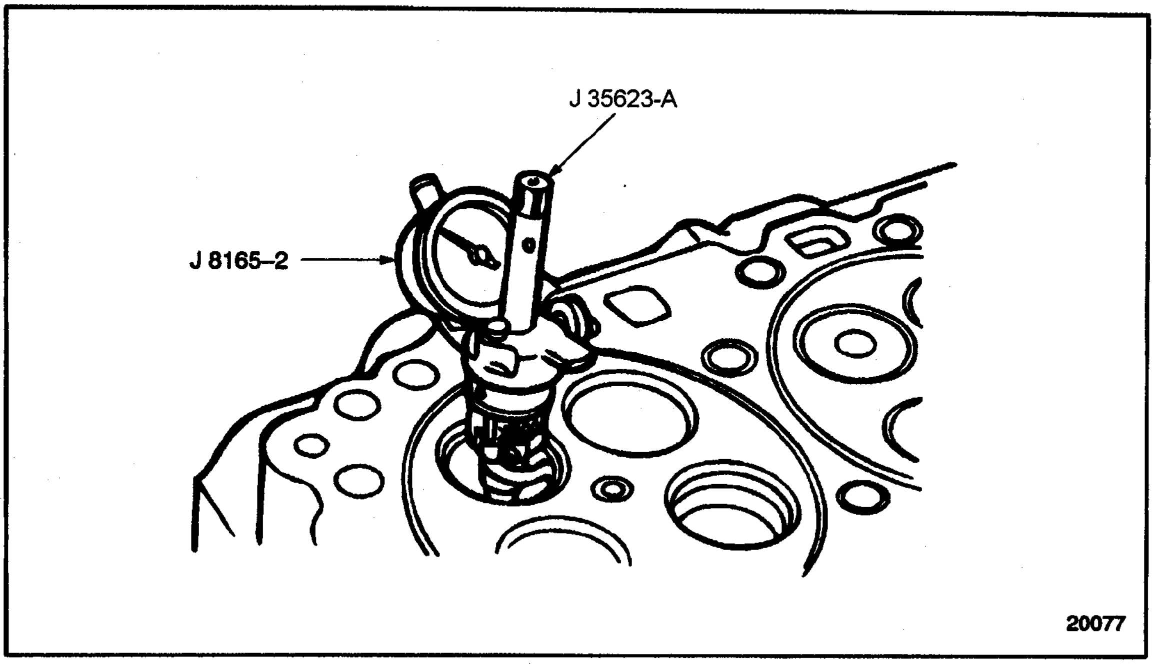

Figure 1-79 Check Valve Seat Concentricity

[a] If the concentricity is within 0.05 mm (0.002 in.), no grinding is required.

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[b] If the concentricity is not within 0.05 mm (0.002 in.), grind the seat only enough to true it up, being sure to lightly grind a full 360 degrees.

NOTE:
Valve seat insert grinding should be limited to light clean-up or concentricity truing. For a fine, accurate finish, the eccentric grinding method using tool J 7040-A is recommended, because the grinding wheel contacts the insert at only one point at any time, and a micrometer feed permits controlled fine adjustment. See Figure 1-80. Seats must be ground to a 31 degree angle.

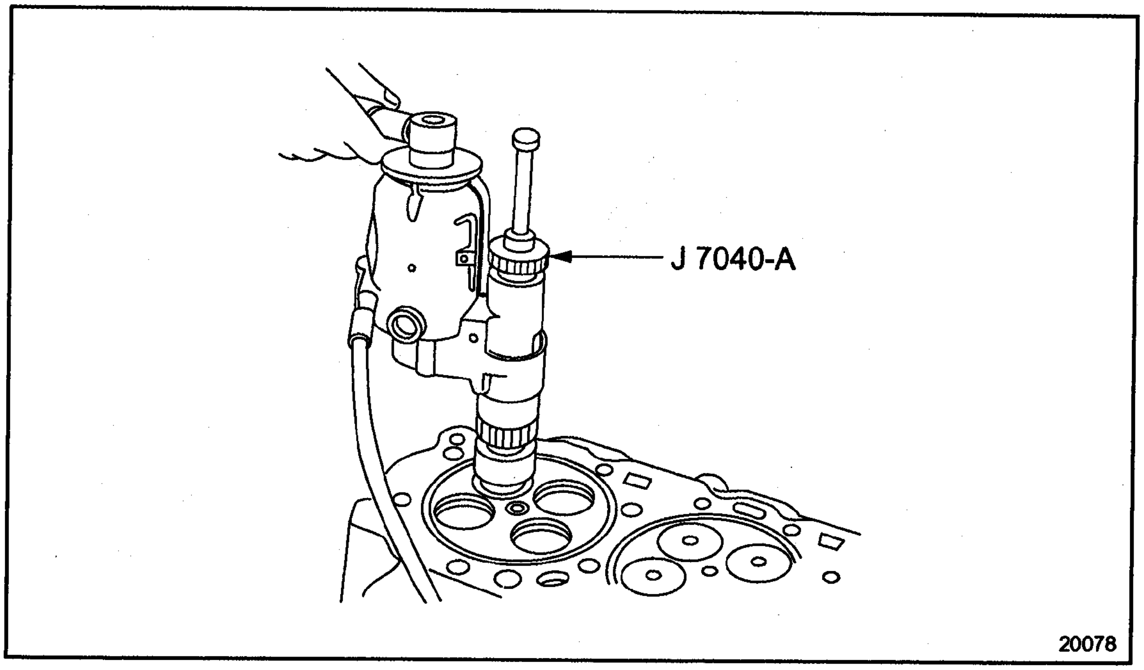

Figure 1-80 Grinding Valve Seat Insert

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7. The valve head recess depth from the firedeck is increased by valve and/or insert grinding. It should be checked with a sled gage, J 22273-01 (or equivalent). See Figure 1-81.

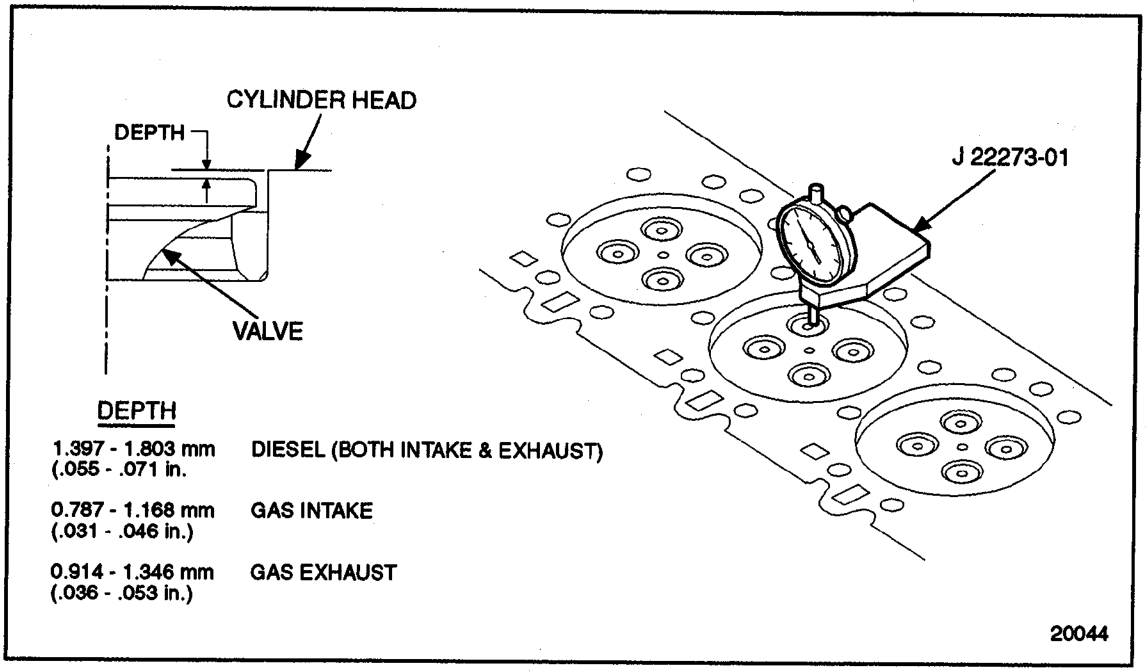

Figure 1-81 Measuring Valve Head Recess Depth

[a] If the diesel intake exhaust valve head recess depth is not between 1.4 to 1.8 mm (0.055-0.071 in.), the valve and seat must be replaced.

[b] If the gas intake valve head recess depth is between 0.79 to 1.17 mm (0.031-0.046 in.), the valve and seat are correctly installed.

[c] If the gas exhaust valve head recess depth is not between 0.976-1.4 mm (0.030-0.053 in.), the intake 0.79-1.17 mm (0.031 -0.046 in.) valve and seat must be replaced for the Series 60G engine.

8. After light clean-up, thoroughly clean the valve seat with fuel oil and blow dry with compressed air. Check seat-to-valve face contact by applying a light coat of Prussian Blue (or equivalent) to the valve seat land. Insert the valve in the guide and "bounce" the valve head on the seat insert without rotating the valve. A full 360° contact line should appear approximately centered on the valve face.

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1.4.7 Installation of Valve Guide

Perform the following steps for valve guide installation:

NOTE:
Valve guides are not replaceable on natural gas or heat exchanger-cooled pleasure craft marine engines.

1. Start the chamfered end of the valve guide into the cylinder head from the top. See Figure 1-82.

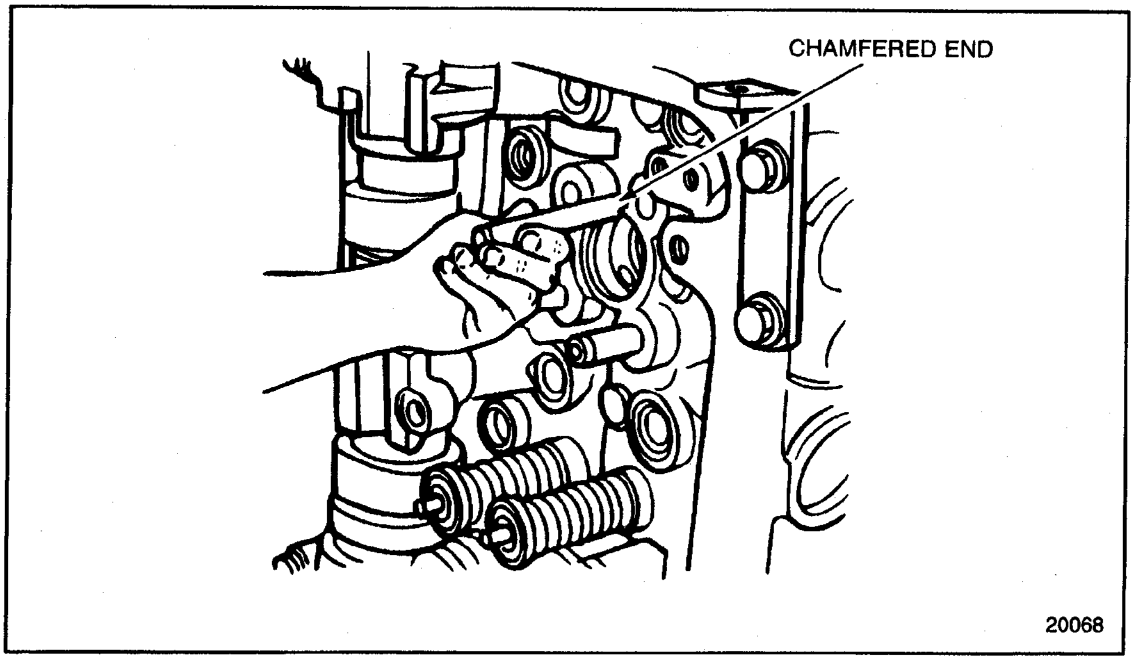

Figure 1-82 Valve Guide Installation

2. Insert the driver into an air chisel. Insert the driver into the valve guide limiting sleeve J 33191-A and install this assembly over the valve guide. Drive the guide into the cylinder head until the driver bottoms in the limiting sleeve. See Figure 1-83.

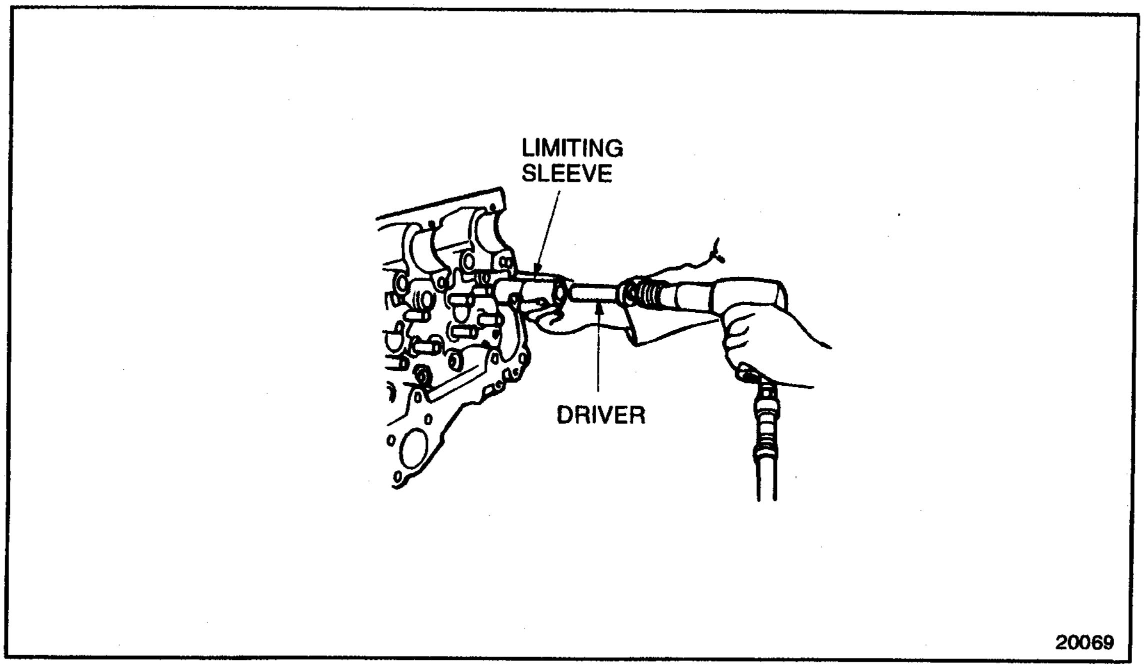

Figure 1-83 Valve Guide Installation

3. Properly used, the installer ensures the correct protrusion of the valve guide from the cylinder head of 37.75 mm (1.486 in.).

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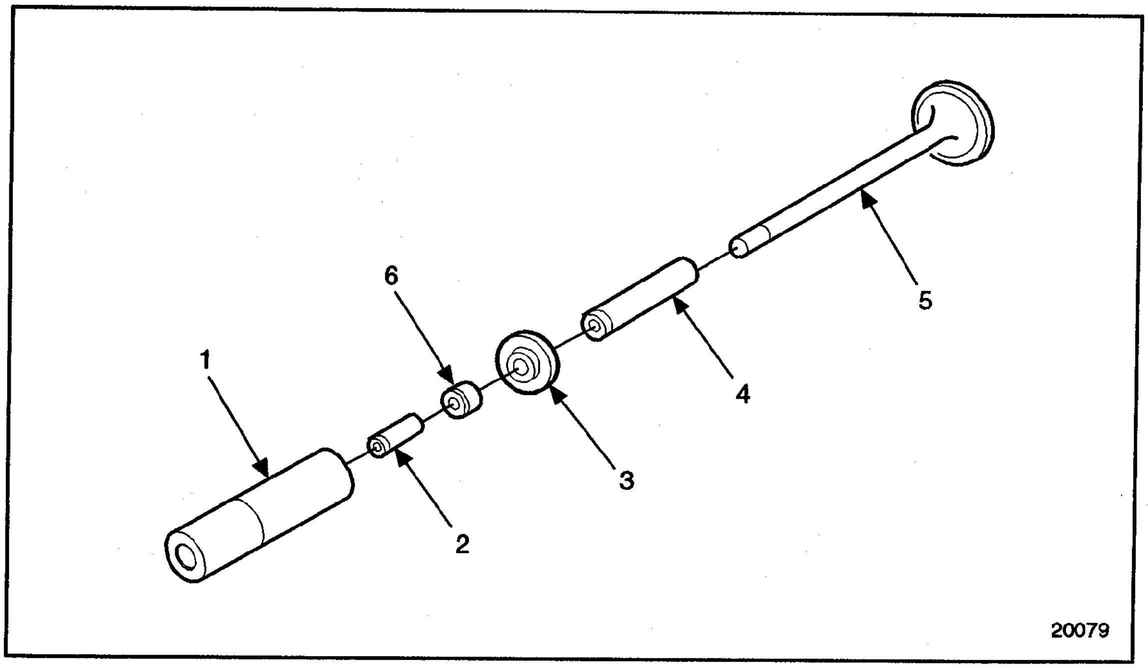
1.4.8 Installation of Valve, Spring, Seal and Rotator

Perform the following steps for valve installation:

1. Position the cylinder head vertically on the overhaul stand. Lubricate the valve stems with clean engine lubricating oil and slide them into their respective valve guides and against the valve seats. If reusing valves, install them to their original positions.
2. Install the valve spring seat over the valve guide. Install the valve stem oil seals using valve stem oil seal installation tools. See Figure 1-84.



1. Valve Stem Seal Installer
2. Oil Seal Protector Cap
3. Valve Spring Seat
4. Valve Guide
5. Valve
6. Valve Stem Oil Seal

Figure 1-84 Valve Stem Oil Seal Installation Tools

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3. Check the length of the plastic seal protector cap relative to the lock groove on the valve stem. If the seal protector cap extends more than 1.6 mm (1/16 in.) beyond the groove, trim off the excess length of the cap. See Figure 1-85.

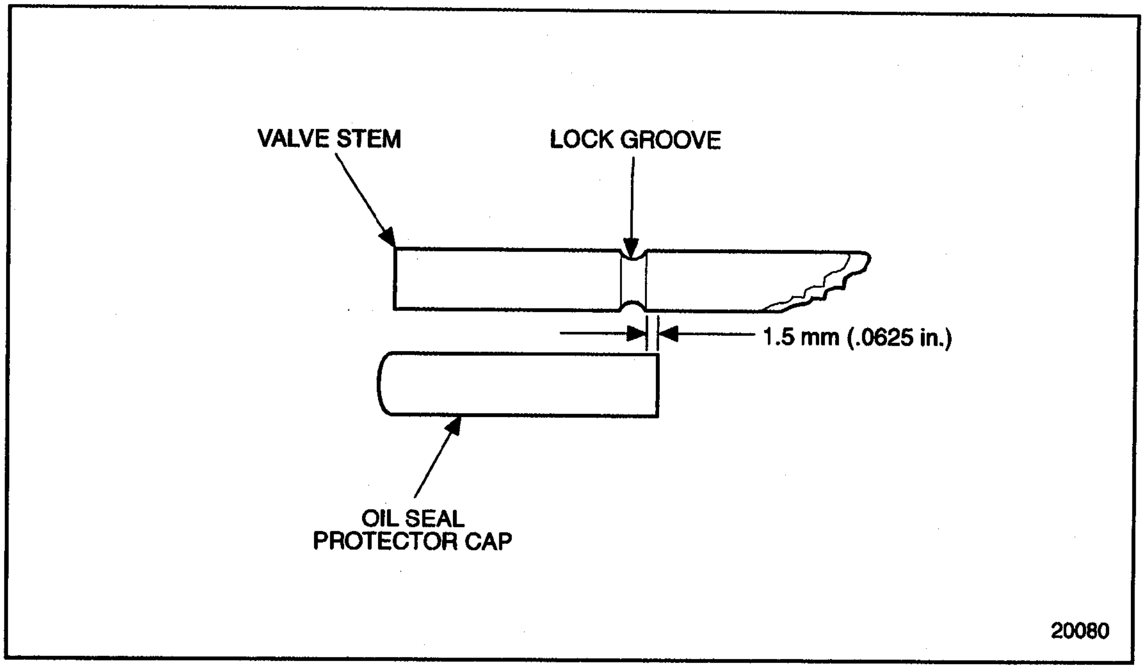

Figure 1-85 Oil Seal Protection Cap Sizing

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4. Install the cap over the valve stem. See Figure 1-86.

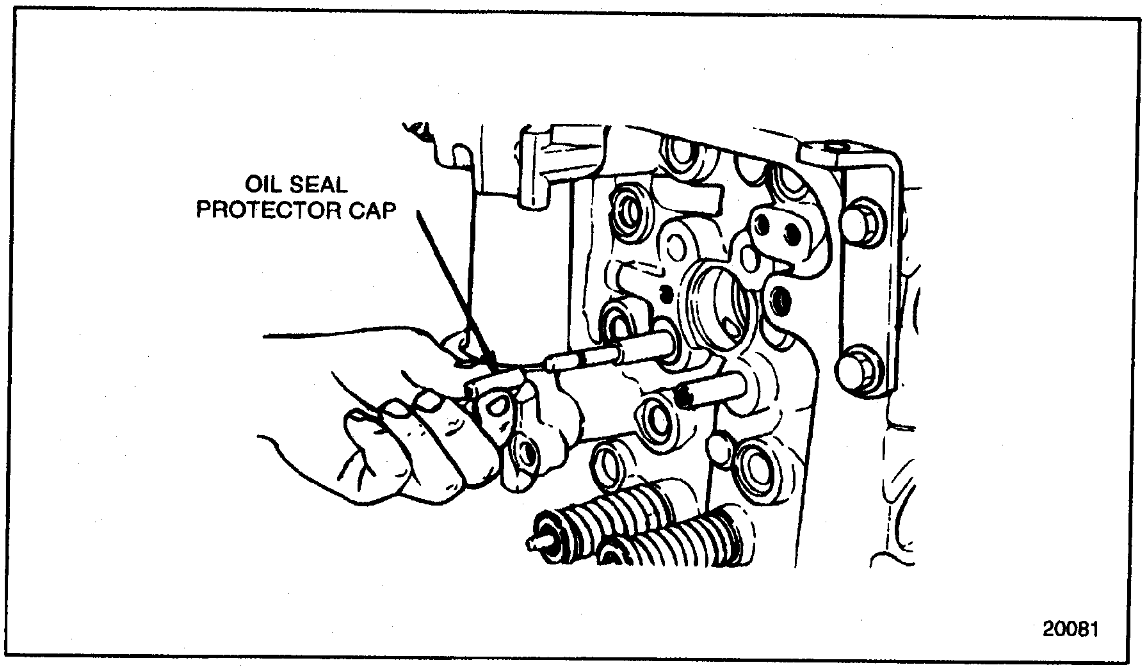

Figure 1-86 Oil Seal Protection Cap Installation

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NOTICE:

Ensure all valve spring seats have been installed before the valve stem seal is installed.

5. The valve stem oil seal may be installed with or without oil. Push the seal over the protector. See Figure 1-87.

NOTE:

The valve stem oil seal on the natural gas engine has a larger inside diameter than the diesel engine. The seal portion of the natural gas oil seal is black in color.

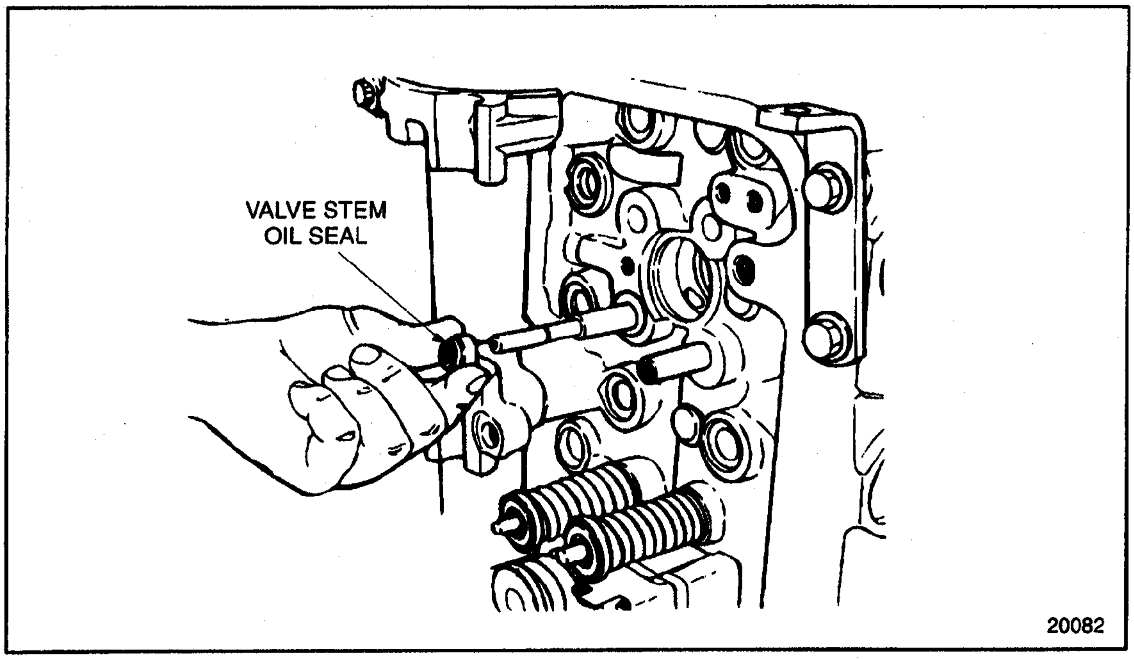

Figure 1-87 Valve Stem Oil Seal Installation

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6. Push the seal down on the valve stem using the seal installer, J 39109, while holding the valve head against the seal. See Figure 1-88.

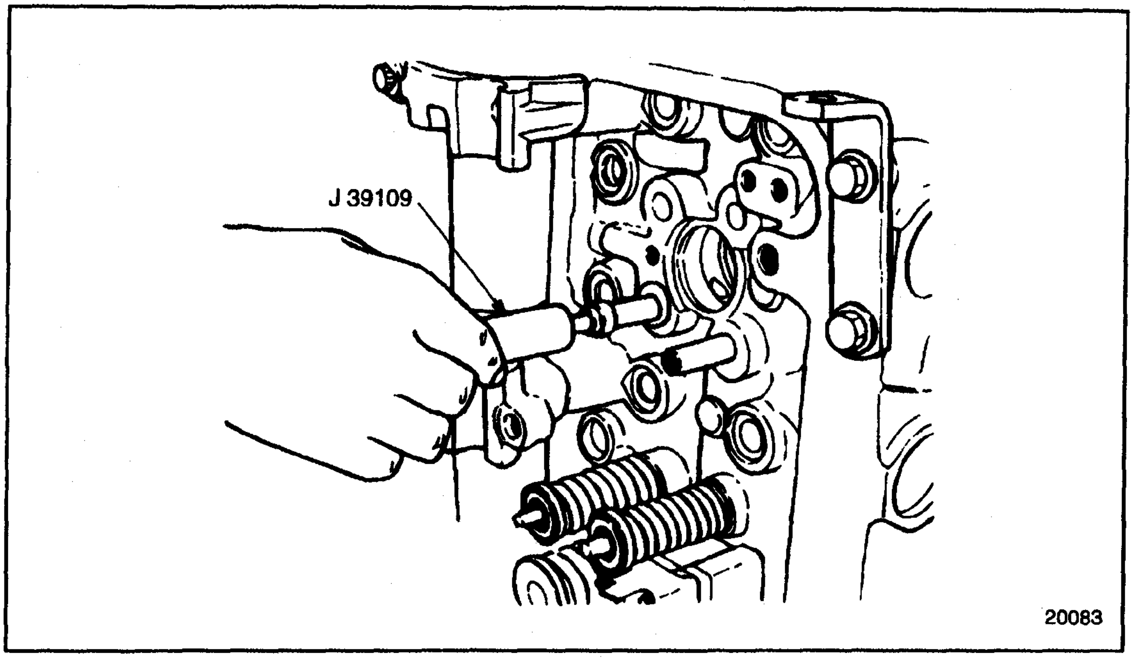

Figure 1-88 Valve Stem Oil Seal Installer

7. When the installer tool contacts the cylinder head, the seal is correctly positioned. Be sure the installer is square against the cylinder head. Remove the seal installer and protector cap.

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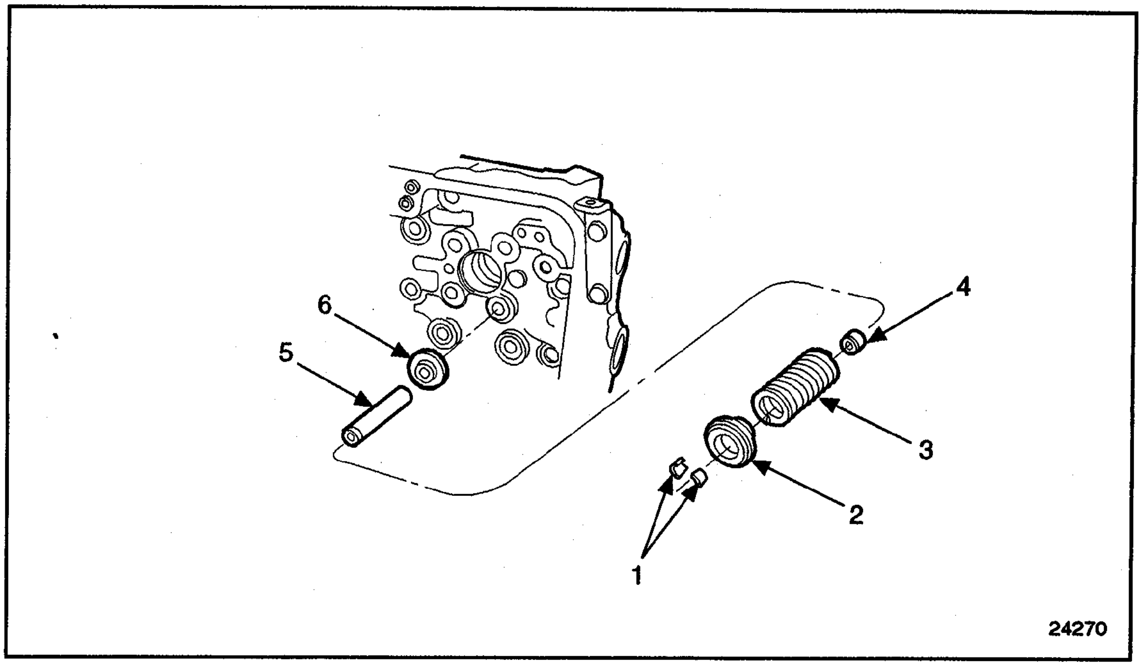
8. Install the valve spring and rotator. See Figure 1-89. If reusing parts, install them to their original positions.



1. Valve Locks
2. Valve Rotator
3. Valve Spring
4. Valve Stem Oil Seal
5. Valve Guide
6. Valve Spring Seat

Figure 1-89 Valve Spring and Related Parts

9. Using the valve spring compressor tool, J 8062, compress the valve spring only as much as required to install the valve locks. After installing the valve locks, rap the end of the valve stem sharply with a plastic mallet to seat the valve locks.

NOTE:
Always install new valve stem locks when installing valves.

NOTE:
Be sure the valve rotator is properly centered and aligned to avoid scoring the valve stem. Do not compress the spring any more than necessary to install the locks, to avoid damaging the oil seal.

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10. After all of the valves are installed, check the spring opening pressure on each valve using spring load gage. See Figure 1-90.

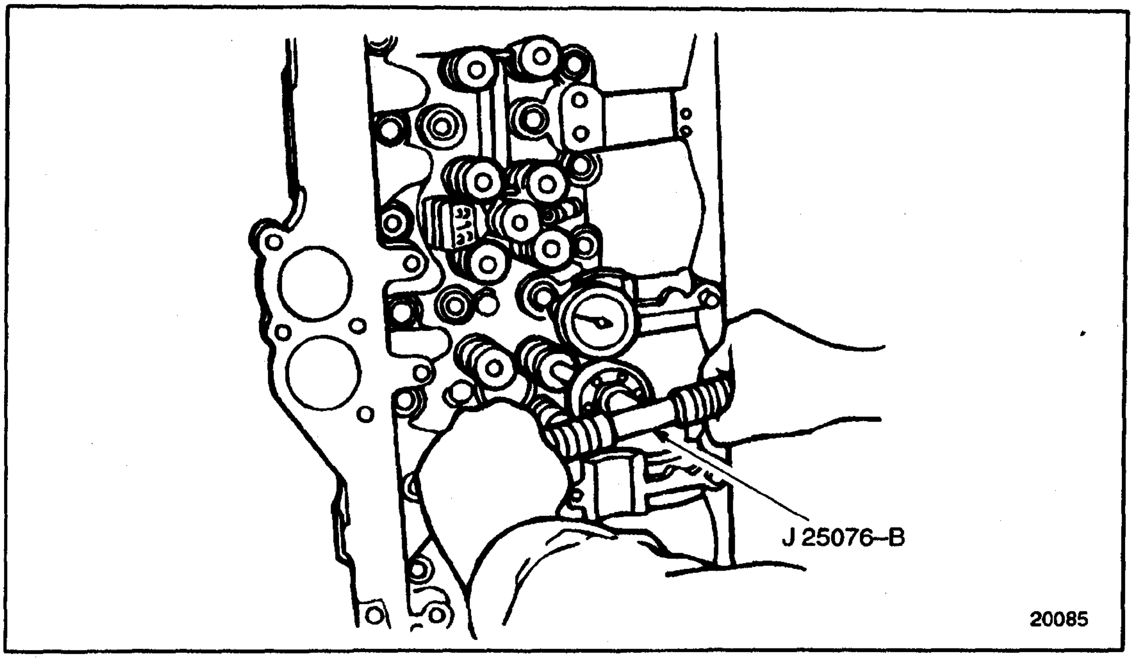

Figure 1-90 Checking Valve Spring Load

11. Note the gage reading when the valve just starts to unseat. The force required to unseat the valve must not be less than 280 N (63 lb).
12. Remove the cylinder head from the overhaul stand and install it on the engine. Refer to section 1.2.5.
13. Install the camshaft and rocker arm assemblies. Lightly lubricate the overhead assemblies with clean engine oil. Refer to section 1.23.5.
14. If the engine is equipped with a Jake Brake®, install the brake. Refer to section 1.29.5.
15. Adjust the valve clearance and injector timing. Refer to section 12.2.
16. If the engine is equipped with a Jake Brake®, lash the brake. Refer to section 12.2.
17. Install any other components that were removed.
18. Fill the engine crankcase (refer to section 13.13.1) with the proper lubricant. Refer to section 5.2.1.
19. Close any drain cocks that were opened and fill the cooling system. Refer to section 13.13.4. Purge the air from the system using the vent in the thermostat housing. Complete filling of the cooling system is essential for proper engine operation.

CAUTION:

Diesel engine exhaust and some of its constituents are known to the State of California to cause cancer, birth defects, and other reproductive harm.

- **Always start and operate an engine in a well ventilated area.**
- **If operating an engine in an enclosed area, vent the exhaust to the outside.**
- **Do not modify or tamper with the exhaust system or emission control system.**

20. Start the engine and check for leaks.

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1.5 ENGINE LIFTER BRACKETS

A total of three engine lifter brackets are installed on each Series 60 engine and are utilized when removing and replacing the engine.See Figure 1-91 and see Figure 1-92.

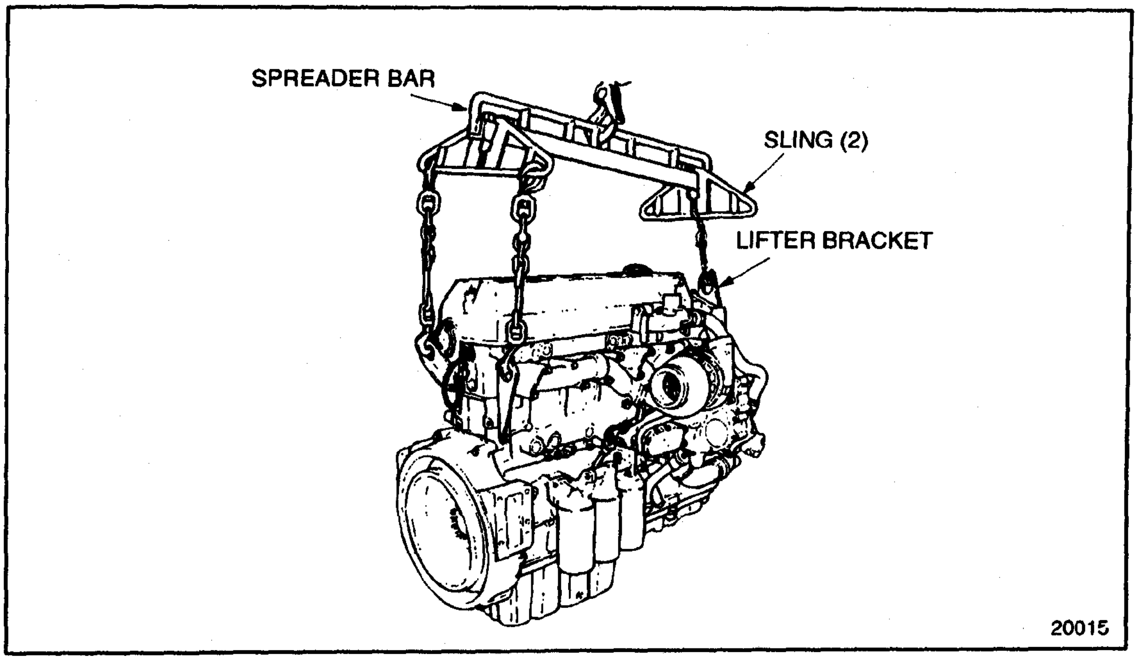

Figure 1-91 Lifting Engine

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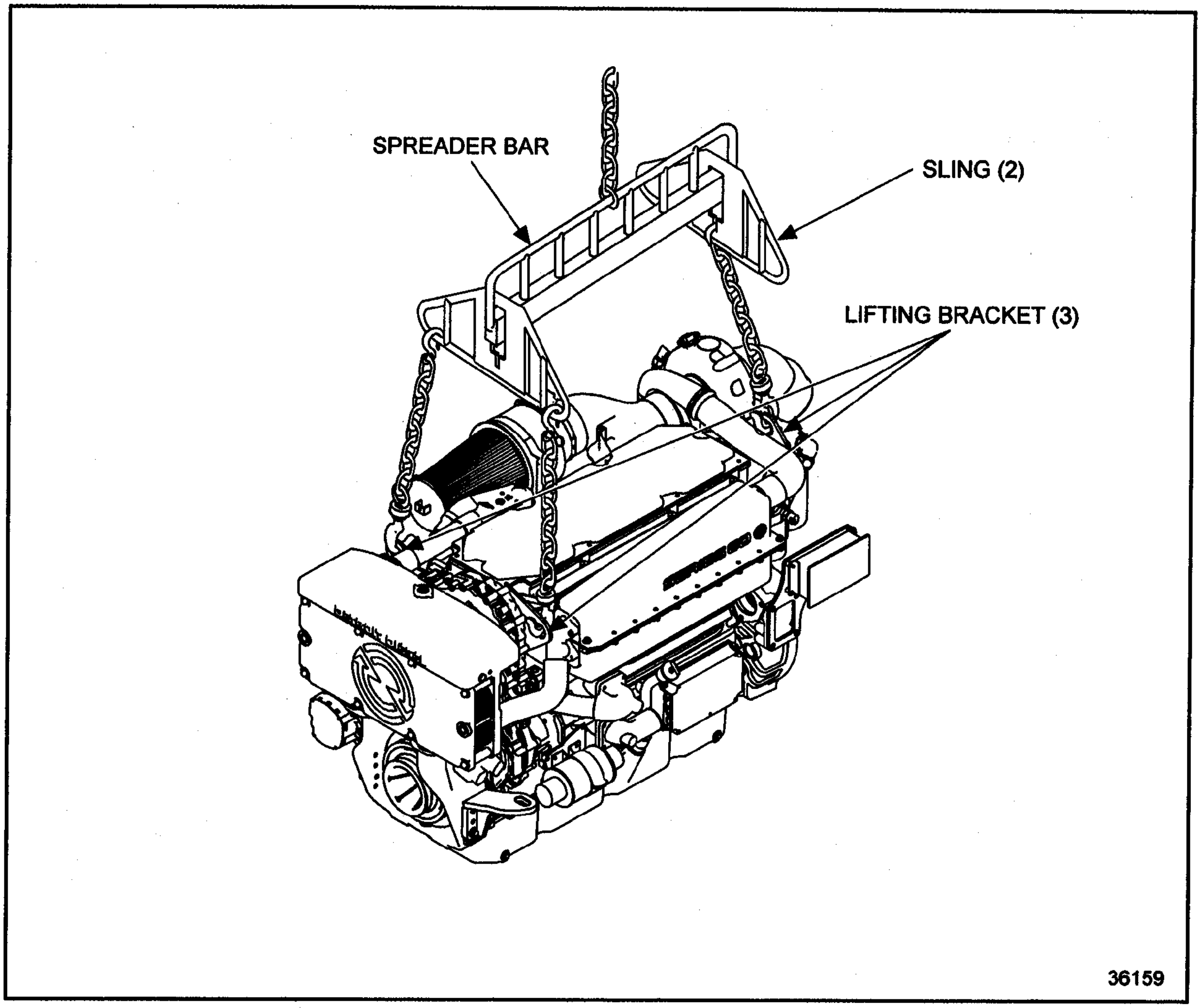

Figure 1-92 Lifting Heat Exchanger-Cooled Pleasure Craft Marine Engine

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CAUTION:

To avoid injury from a falling engine, do not use the front lifter bracket alone when lifting the engine with a marine gear attached. The front engine lifter bracket is designed to lift the engine only.

NOTICE:

To lift the engine, use a suitable lifting device. See Figure 1-91. A spreader bar should be used with a sling and adequate chain hoist when lifting any engine. The lifting device should be adjusted so the lifting hooks are vertical to prevent bending the engine lift brackets. To ensure proper weight distribution, all three engine lift brackets provided must be used in lifting the engine. Be sure the spreader bar is adequate to prevent lifter brackets from contacting the engine rocker cover and causing damage.

A lifter bracket should always be reinstalled whenever removal is necessary. See Figure 1-93and see Figure 1-94.

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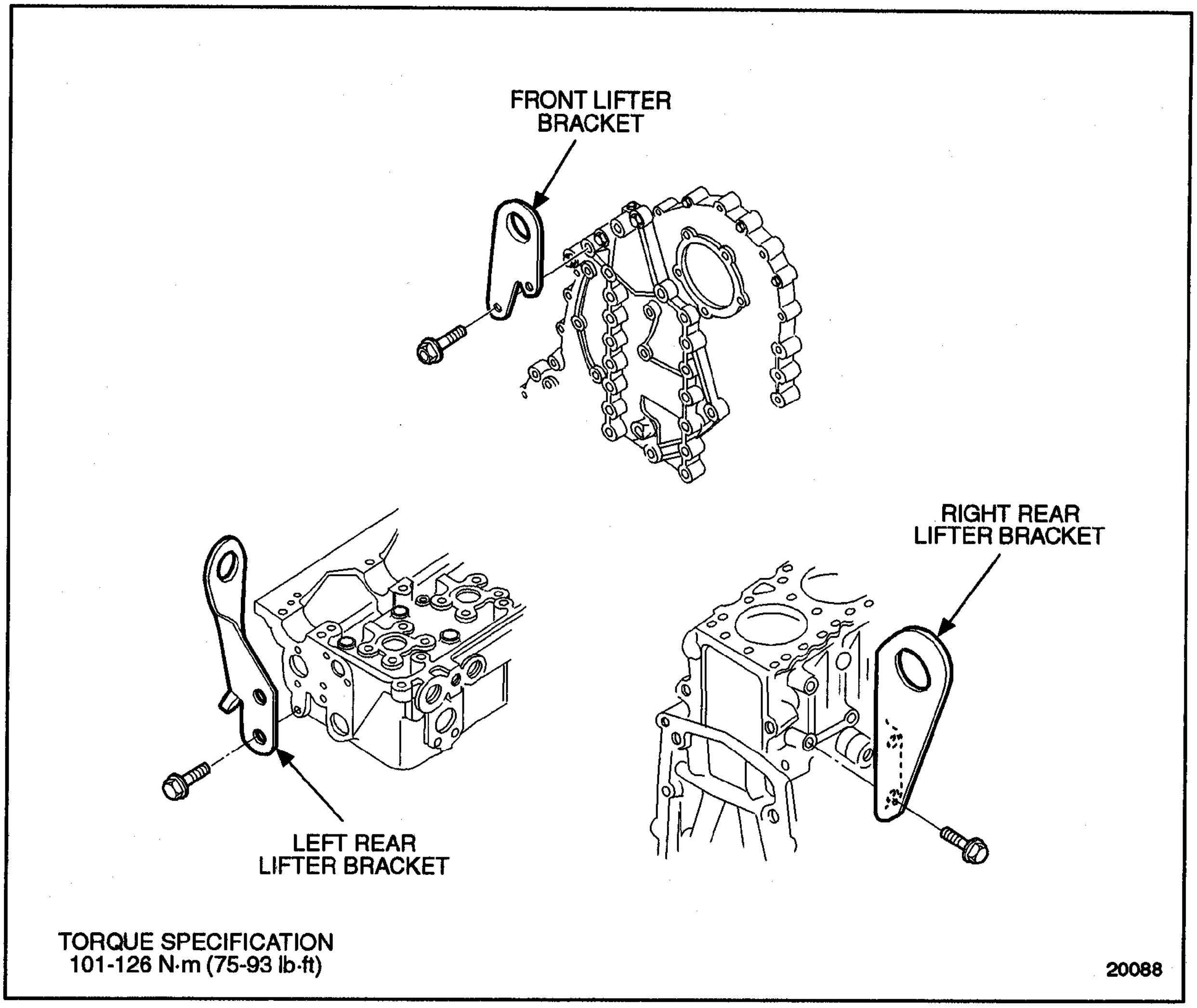

Figure 1-93 Engine Lifter Brackets

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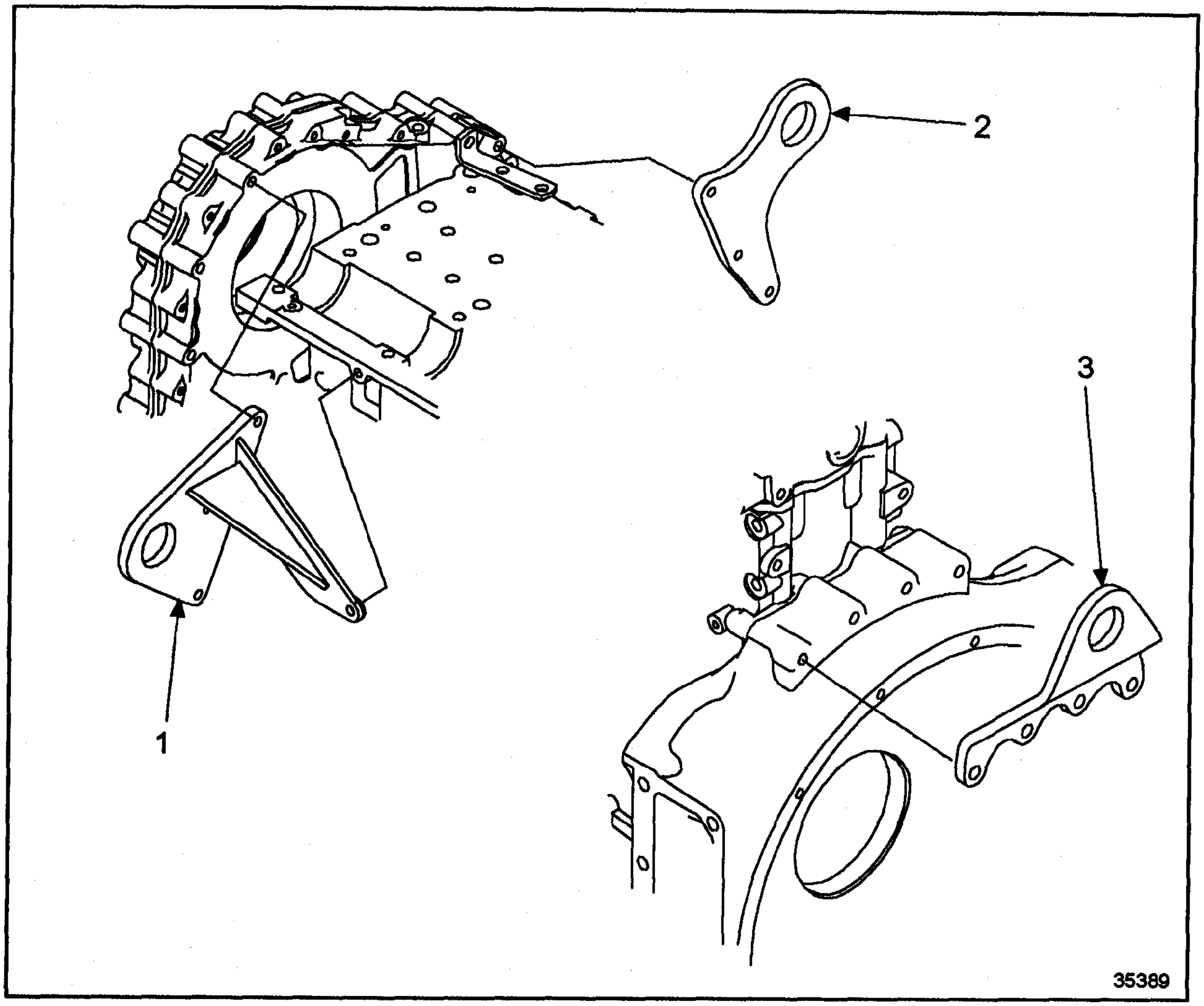

1. Left Front Lifter Bracket
2. Right Front Lifter Bracket
3. Rear Lifter Bracket

Figure 1-94 Pleasure Craft Marine Engine Lifter Brackets

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On some older installations, the front engine lifter bracket may be integral with the fan support bracket. See Figure 1-95.

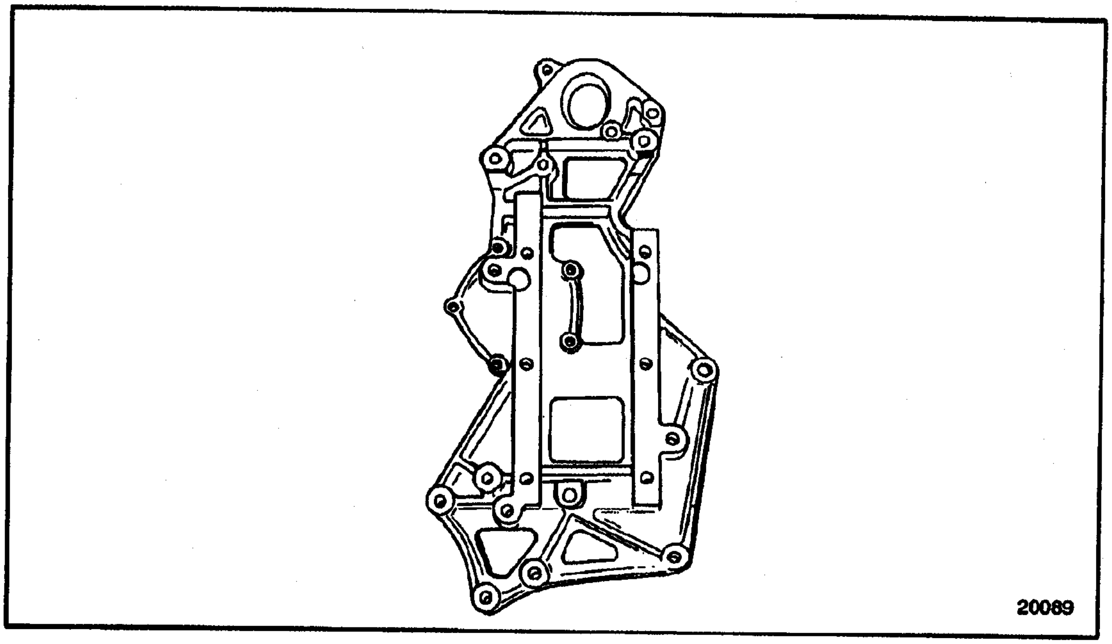

Figure 1-95 Fan Support and Engine Lifter Bracket

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1.5.1 Repair or Replacement of the Lifter Bracket

To determine if repair is possible or replacement is necessary, perform the following procedure. See Figure 1-96.

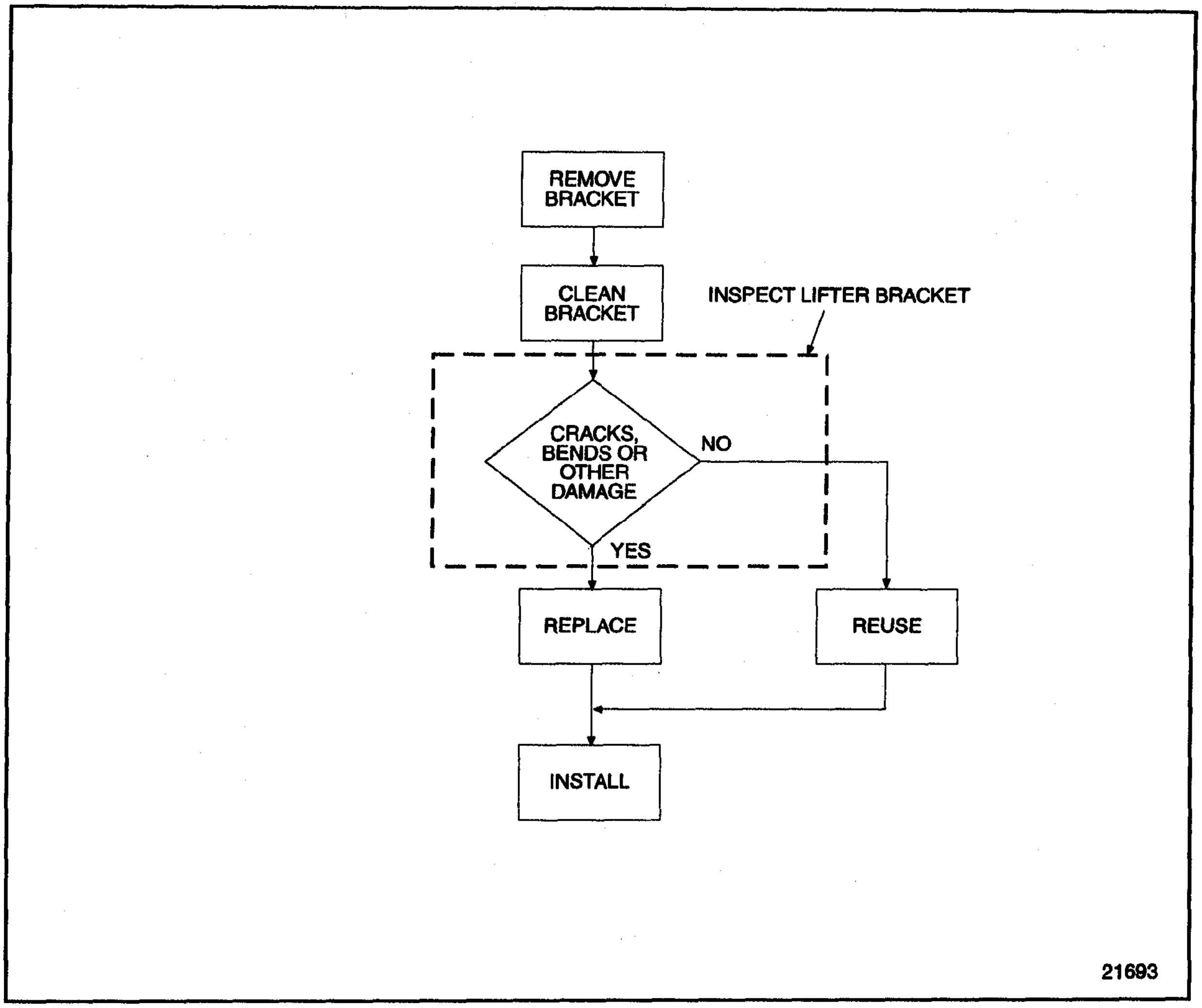

Figure 1-96 Flowchart for Repair or Replacement of Lifter Bracket

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1.5.2 Removal and Cleaning of Lifter Bracket

Perform the following steps for lifter bracket removal:

1. Remove the bolts securing the lifter bracket to the engine.
2. On applications with the integral fan support and engine lifter bracket, remove the fan. Refer to section 1.10.2.

1.5.2.1 Inspection of Lifter Bracket

Perform the following for lifter bracket inspection:

CAUTION:

To avoid injury from a falling engine, do not use a damaged lifter bracket when lifting the engine.

1. Inspect the lifter brackets for cracks, bending or other damage.
2. Replace the bracket if any of these conditions exist.

1.5.3 Installation of Lifter Bracket

Perform the following steps for lifter bracket installation:

1. Install the bracket to the engine. Torque the mounting bolts to 101-126 N·m (75-93 lb·ft).
2. Install the fan support, heat exchanger support, or charge air cooler support bracket, refer to section 1.10.3.

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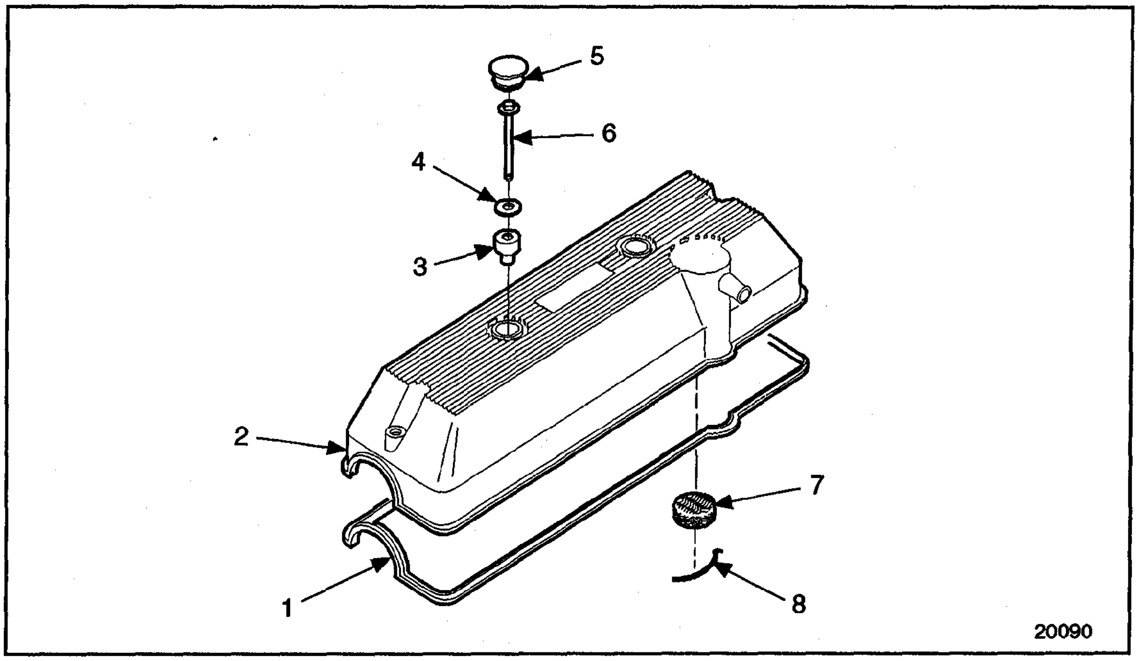
1.6 ROCKER COVER

The rocker cover completely encloses the valve and injector operating mechanism on top of the cylinder head (and in some cases an engine brake), including the overhead camshaft.

Depending on the installation, the rocker cover may be a one-piece, two-piece or three-piece design. See Figure 1-98, see Figure 1-99, and see Figure 1-100.

The one-piece rocker cover is molded of a sound-dampening, fiberglass-reinforced, synthetic material. It is internally ribbed to distribute the hold-down bolt clamp load for effective, full perimeter sealing. See Figure 1-97.

Effective July 1993, a breather baffle is installed on the low-profile aluminum rocker cover.



1. Gasket
2. Rocker Cover
3. Isolator
4. Washer
5. Cover Plug
6. Bolt
7. Element
8. Clip

Figure 1-97 One-piece Rocker Cover - Series 60 Diesel Engine

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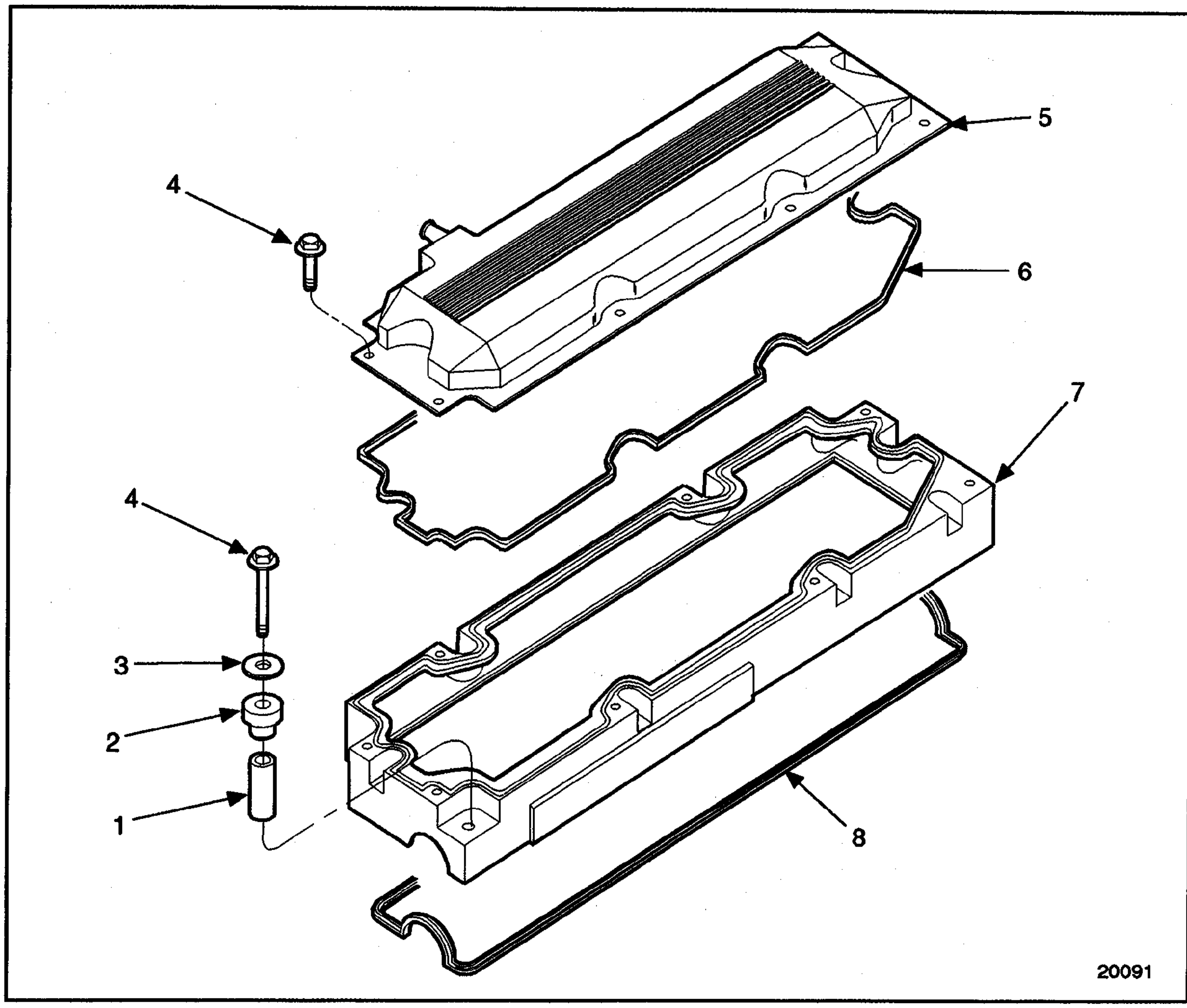

1. Limiting Sleeve
2. Isolator
3. Washer
4. Bolt
5. Rocker Cover Cap
6. Diamond-Shaped Seal
7. Rocker Cover Base
8. Isolator Rim Seal

Figure 1-98 Two-piece Rocker Cover - Series 60 Diesel Engine

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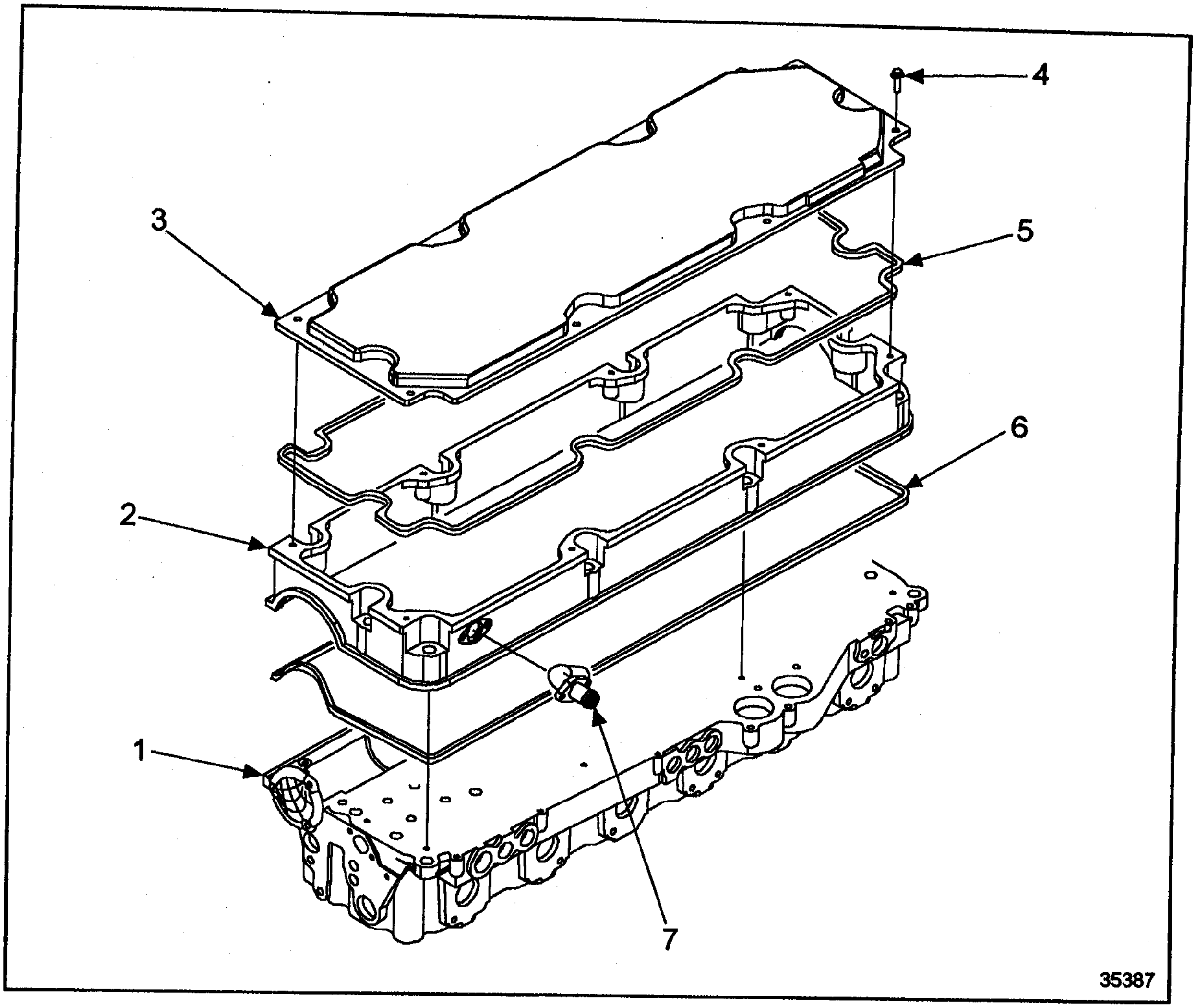

1. Cylinder Head
2. Rocker Cover Base
3. Rocker Cover Cap
4. Bolt
5. Gasket
6. Isolator Rim Seal
7. Ventilation Fitting

Figure 1-99 Three-piece Rocker Cover - (Heat Exchanger-Cooled Marine Engine)

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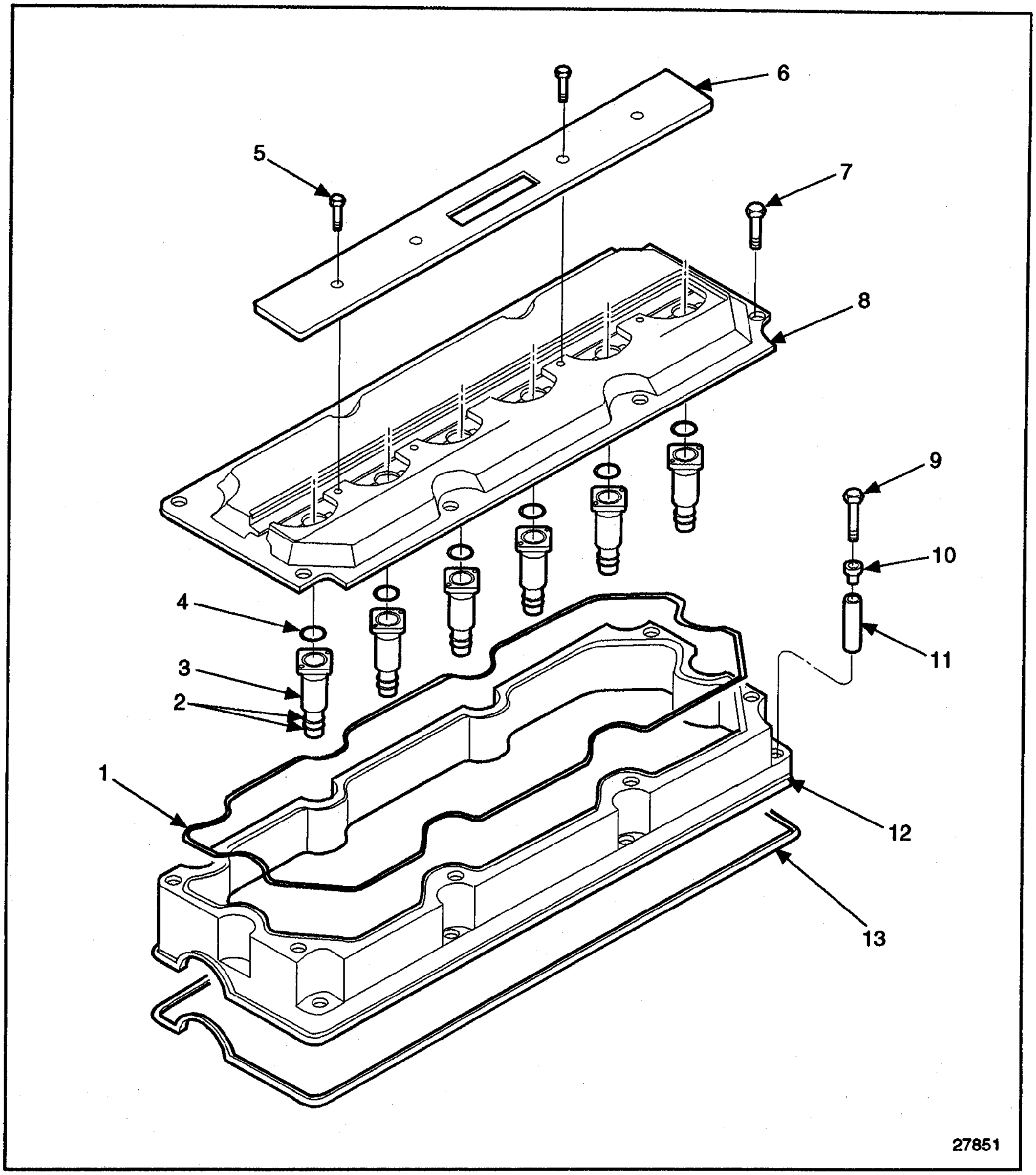

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1. Gasket
2. Seal Ring
3. Tube
4. Seal Ring
5. Screw
6. Cover
7. Bolt
8. Cover
9. Bolt
10. Isolator
11. Spacer
12. Rocker Cover Base
13. Gasket

Figure 1-100 Two Piece Rocker Cover - Series 60G Engine with Coil Over Plug Ignition

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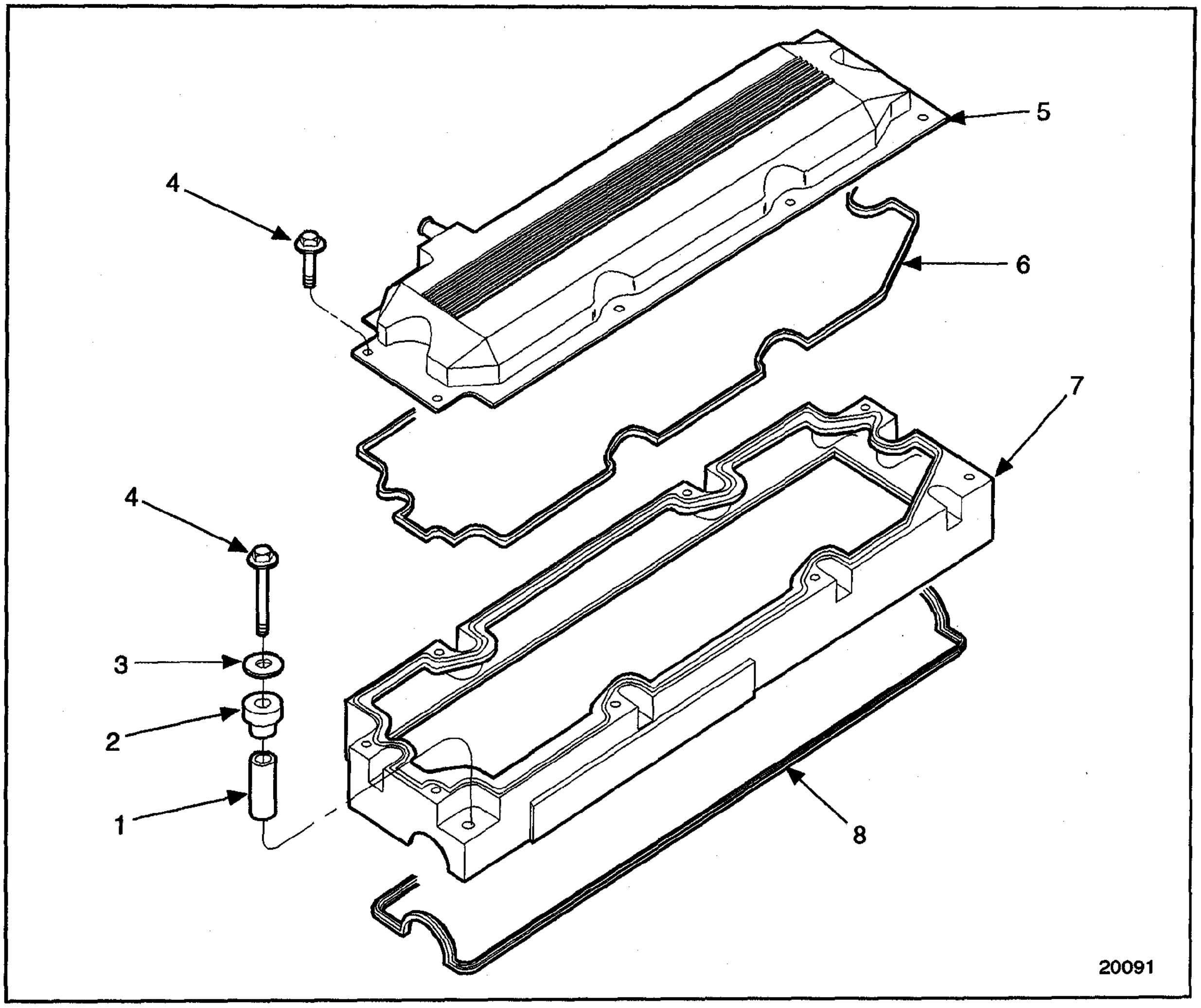
The two-piece rocker cover is constructed of cast aluminum. The top piece or cap is held in place by eight bolts and is removable for access to the valve, engine brake and fuel injector adjusting mechanisms. A one-piece diamond shaped perimeter seal is located in a groove in the rocker cover base and seals the cap to the base. See Figure 1-101.



1. Limiting Sleeve
2. Isolator
3. Washer
4. Bolt
5. Rocker Cover Cap
6. Diamond-Shaped Seal
7. Rocker Cover Base
8. Isolator Rim Seal

Figure 1-101 Two-piece Rocker Cover

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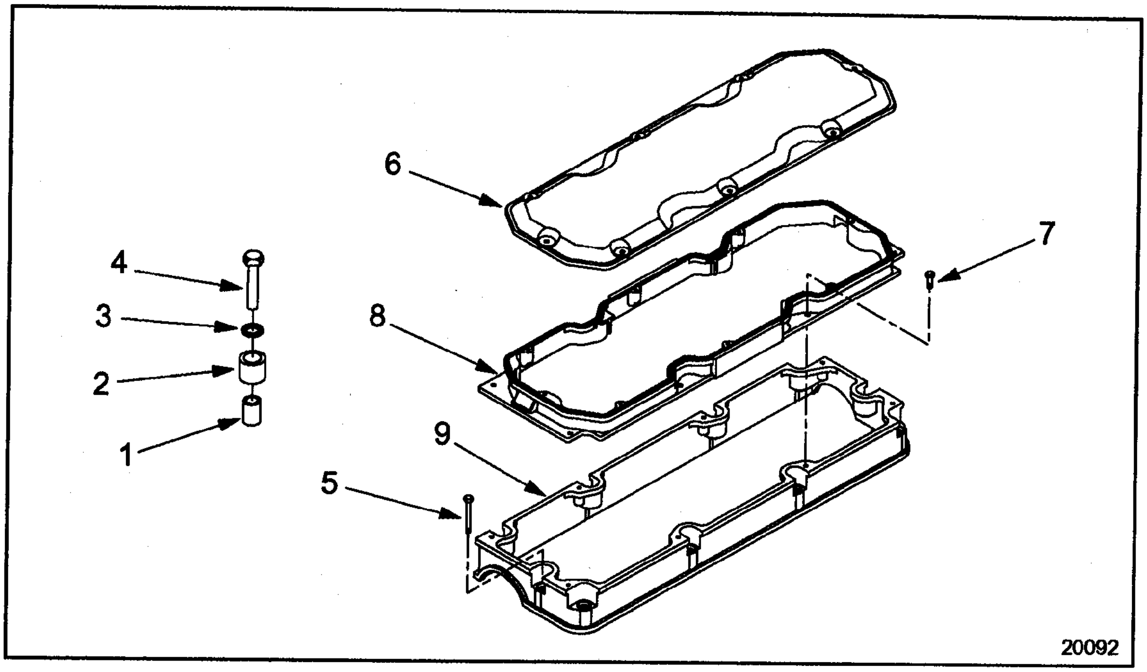
The three-piece rocker cover is similar to the two-piece cover but with an additional intermediate cover and diamond seal and new cover cap. See Figure 1-102.



1. Limiting Sleeve
2. Isolator
3. Washer
4. Bolt
5. Bolt
6. Rocker Cover Cap
7. Bolt
8. Intermediate Cover
9. Rocker Cover Base

Figure 1-102 Three-piece Rocker Cover

Two caps are available with the Series 60 diesel engines. One is for use with a Jake Brake®, and one without a Jake Brake®.

Only one cap is available with the Series 60G engines.

The rocker cover base is attached to the cylinder head using ten assemblies consisting of a bolt, limiter sleeve, isolator and flat washer. All rocker covers use a silicone rim seal, seated in a groove around the bottom edge of the rocker cover base to provide an effective oil seal. The one-piece and two-piece design rocker covers incorporate a crankcase ventilation breather outlet. The three-piece design and the Series 60G cap incorporate a combination filler/breather at the camshaft cover (gear case cover) position.

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1.6.1 Repair or Replacement of Rocker Cover

To determine if repair is possible or replacement is necessary, perform the following procedure. See Figure 1-103.

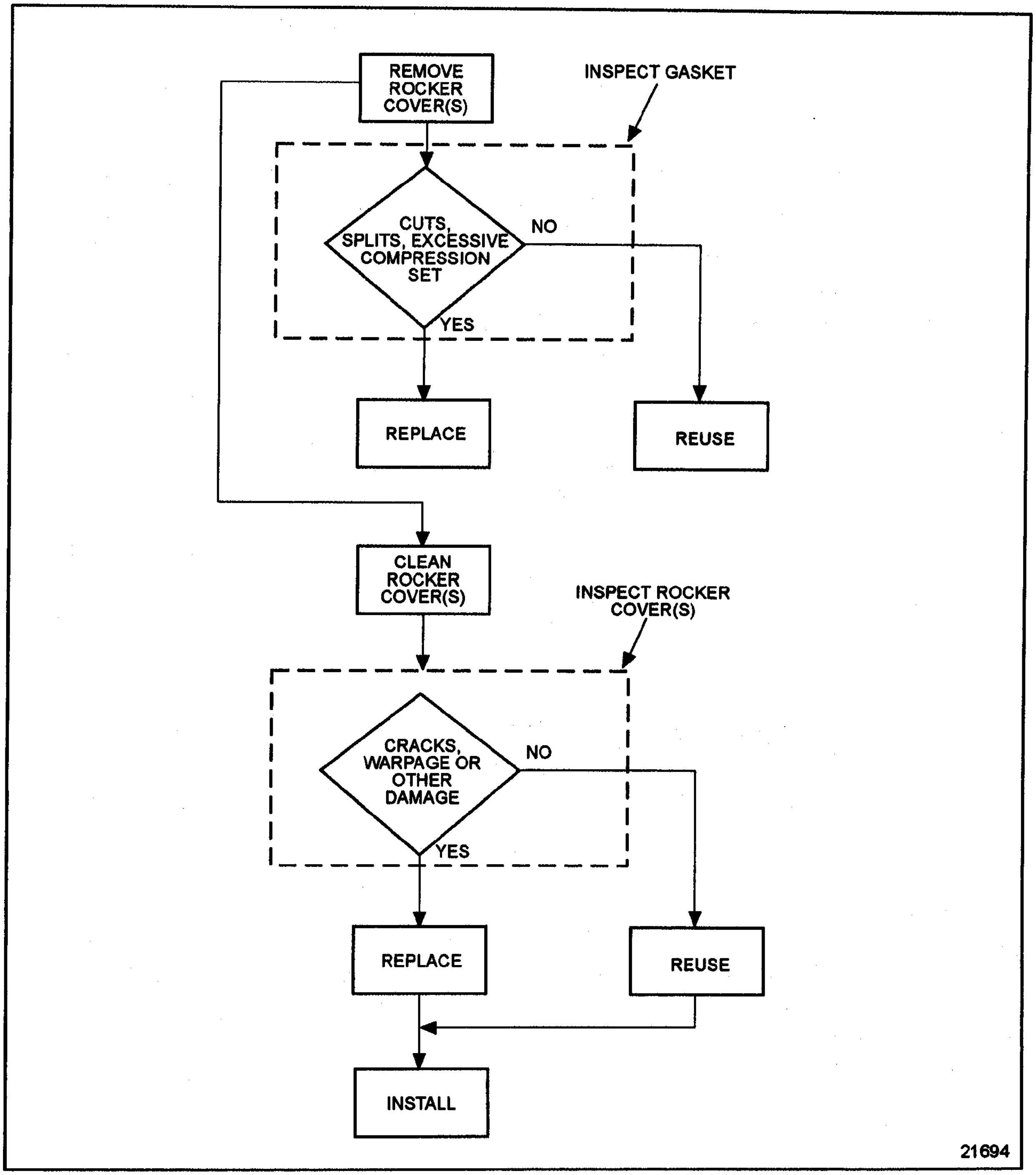

Figure 1-103 Flowchart for Repair or Replacement of Rocker Cover

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1.6.2 Removal and Cleaning of One-piece Rocker Cover For Diesel Engines Only

Preclean the rocker cover, especially around its seat on the head, and in the attaching bolt recesses, to keep dirt and debris out of the valve gear chamber.

Perform the following steps to remove the one-piece rocker cover:

1. Remove the center plugs, hold-down bolts, washers and isolators.
2. Lift the rocker cover straight up off the engine.

1.6.2.1 Cleaning and Inspection of the One-piece Rocker Cover For Diesel Engines Only

Inspect the rocker cover as follows:

1. Remove the breather element and retainer clip.
2. Wash the components in clean fuel oil.

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

3. Blow dry with compressed air.
4. Clean the breather recess in the rocker cover.
5. Check for damage. Replace as necessary.
6. Reinstall the breather element and retainer clip.

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1.6.3 Removal and Cleaning of Two-piece Rocker Cover For Diesel Engines Only

Preclean the two piece rocker cover, especially around its seat on the head, and in the attaching bolt recesses, to keep dirt and debris out of the valve gear chamber.

Perform the following steps to remove the two-piece rocker cover:

1. Remove the eight screws that attach the rocker cover cap to the base.
2. Lift the cap off the base.
3. Loosen and remove the ten bolt and isolator assemblies that attach the base to the cylinder head.
4. Lift the base straight up off the cylinder head.

1.6.3.1 Inspection of Two-piece Rocker Cover

Perform the following steps to inspect the two-piece valve rocker cover which has a removable breather housing:

1. Remove the three screws and retainer that retains the breather housing.
2. Remove the breather housing, seal, and wire mesh element.
3. Wash the components in clean fuel oil.

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

4. Blow dry with compressed air.

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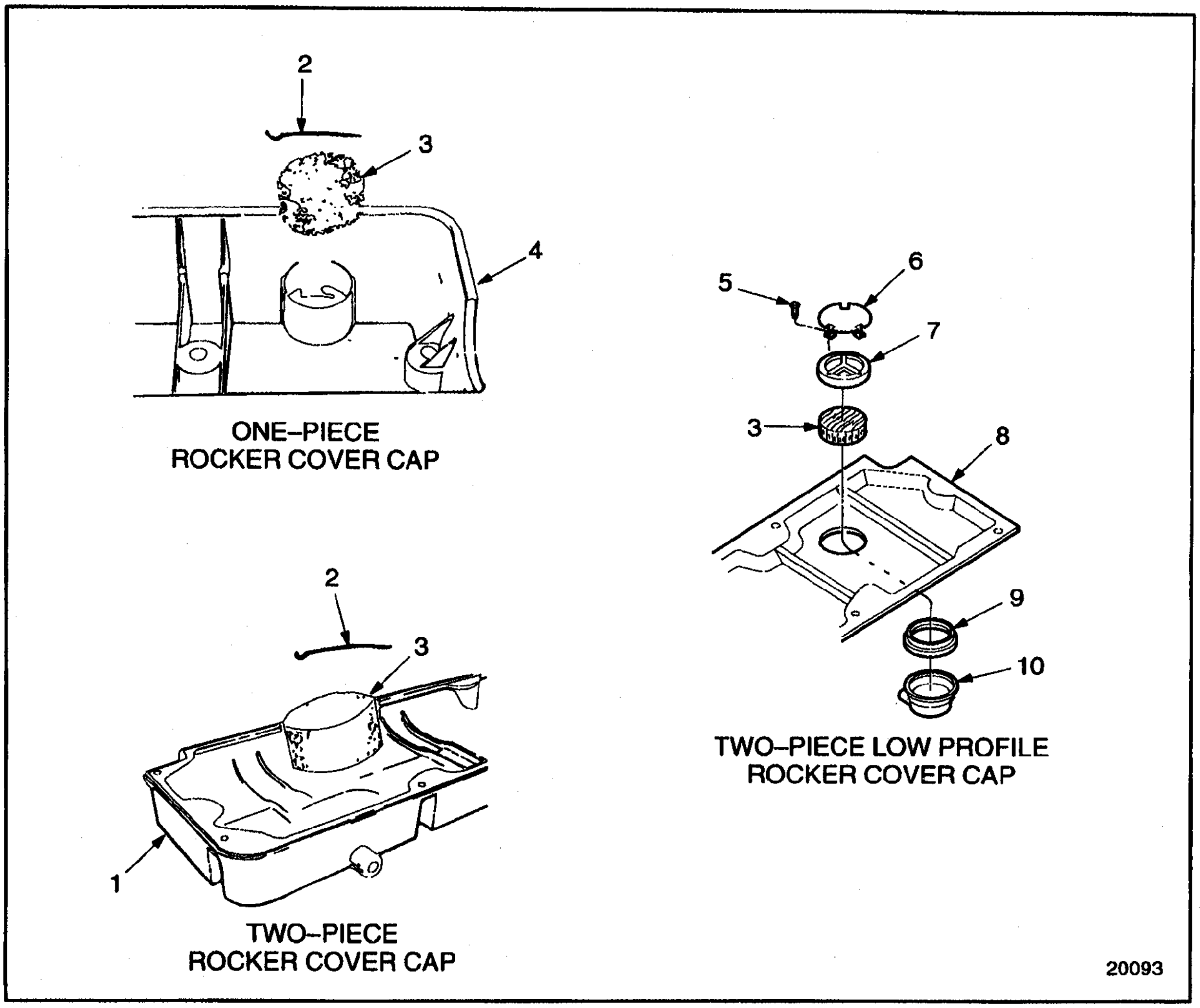
5. Reassemble breather housing to valve cover cap. See Figure 1-104. Torque the screws to 2.5 N·m (22 lb·in.).



1. Two-Piece Rocker Cover
2. Retainer Clip
3. Wire Mesh Element
4. Screw
5. Retainer Cover
6. Retainer
7. Two-piece Low Profile Rocker Cover Cap
8. Seal
9. Breather Housing

Figure 1-104 Two-piece Rocker Cover Assembly

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1.6.4 Removal and Precleaning of Two-Piece Rocker Cover-Gas Engines with Coil Over Plug Ignition System Only

Preclean the rocker cover, especially around its base on the cylinder head and in the attaching bolt recesses to keep dirt and debris out of the valve gear chamber.

To remove the two-piece rocker cover:

1. Remove the ignition boots from the spark plug wells. Refer to section 15.3.1.
2. Lift the cap off the base leaving the six extensions tubes in the cylinder head.
3. Blow any excess oil from the outside of the extension tube so that the oil will not enter the spark plug well when the extensions tubes are removed.
4. Pull the six extension tubes from the cylinder head.
5. Loosen and remove the ten bolt/isolator assemblies that attach the base to the cylinder head.
6. Lift the base straight up off the cylinder head.

1.6.5 Removal and Cleaning of Three-piece Rocker Cover

Preclean the three-piece rocker cover, especially around its seat on the head, and in the attaching bolt recesses, to keep dirt and debris out of the valve gear chamber.

Perform the following steps to remove the three-piece rocker cover:

1. Remove the eight screws that attach the rocker cover cap to the intermediate cover. See Figure 1-102.
2. Lift the cap off the intermediate cover.
3. Loosen and remove the eight bolts that attach the intermediate rail to the base.
4. Lift intermediate off the base.
5. Loosen and remove the ten bolt/isolator assemblies that attach the base to the cylinder head.
6. Lift the base straight up off the cylinder head.

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Before inspecting the rocker cover, clean the isolators as follows:

NOTICE:
To avoid damaging isolators, do not use solvents of any kind, or any petroleum distillates to clean them. The isolators can be cleaned with mild soap and water if necessary. Install new seals and isolators clean and dry.

1. Wash isolators with mild soap and water.

CAUTION:
To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

2. Be sure to completely dry seal grooves in the rocker cover with compressed air.
3. Use new seals (do not reuse old seals).

1.6.5.1 Inspection of Three-piece Rocker Cover

Inspect the three-piece valve cover as follows:

1. Wash the components in clean fuel oil.

CAUTION:
To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

2. Blow dry with compressed air.
3. Clean the breather recess in the rocker cover.
4. Check for damage. Replace as necessary.

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1.6.6 Disassembly of Rocker Cover

Disassemble the rocker cover as follows:

1. Disengage the clip that holds the crankcase vent breather element in the valve cover by pressing the center of the spring steel retaining clip outward and removing the straight end.
2. Rotate the clip upward to remove the curved end.
3. Remove the wire mesh element.

1.6.7 Pre-installation of Rocker Cover

Preform the following steps prior to installing the rocker cover:

1. Install the rocker cover seal in corners of the camshaft cap section (arch at each end of the valve cover) first.

NOTE:
Be sure the rocker cover grooves and the seals are clean, free of oil and dry.

2. Install the cam cap section, starting in the center, by pushing the seal into the groove at the top of the arch. Then install each section at its halfway point. Seat the seal completely around the arch. Be sure the corners are still firmly seated after the arch is completed. They should present a square corner parallel to the rocker cover rail. Repeat this procedure for the cam cap section on the other end. See Figure 1-105.

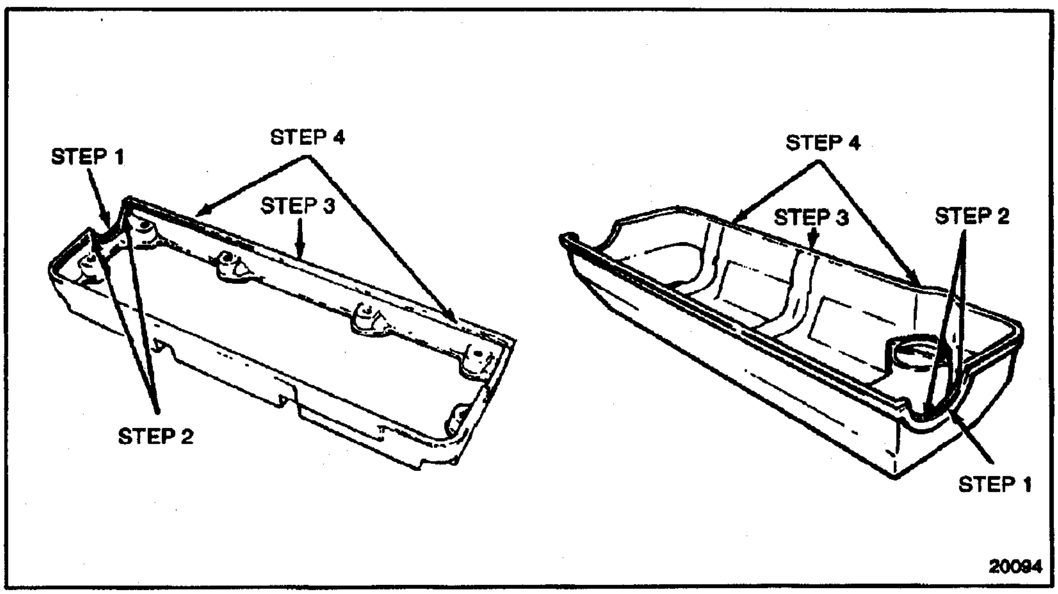

Figure 1-105 Rocker Cover Gasket Installation

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3. Install the long runs of the gasket starting in the center, by pushing the seal into the groove.
4. Then install the rail portion at each halfway point. Repeat this procedure for the other rail portion. Make sure the seal is completely seated all the way around the valve cover.

NOTE:
The corners must be cleaned prior to RTV installation for best results.

5. Apply a small 4.75 mm (3/16 in.) fillet of RTV in the corners formed by the rear camshaft cap and the head, where the cover seal contacts. Repeat this procedure for the corners formed by the front camshaft cap and the head. See Figure 1-106.

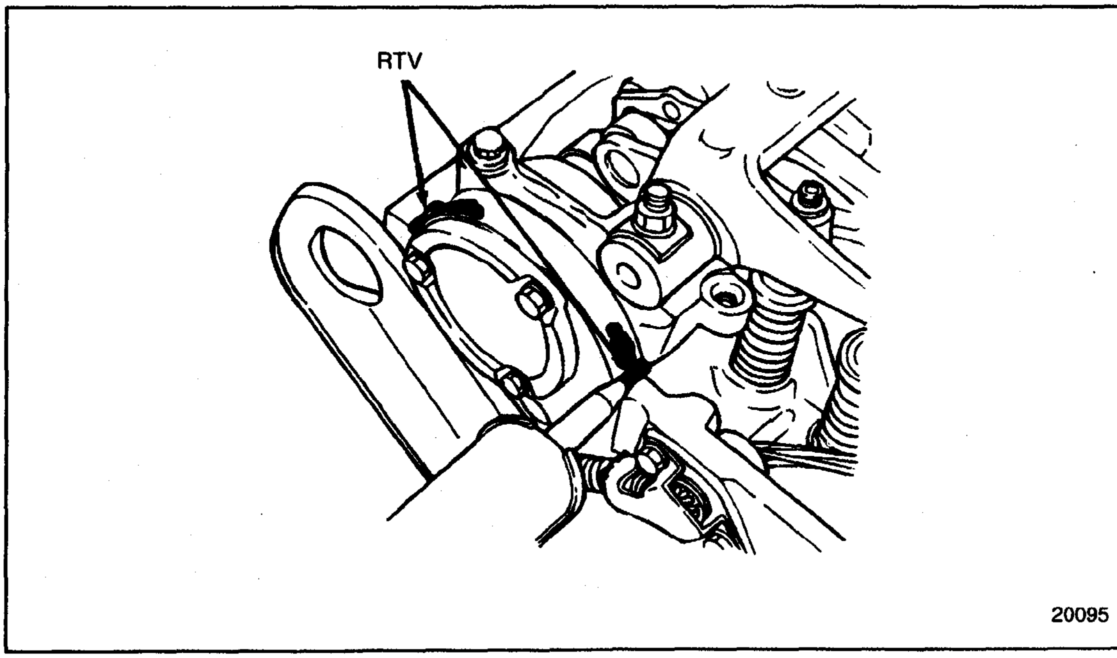

Figure 1-106 RTV Installation

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1.6.8 Installation of One-Piece Rocker Cover

Perform the following steps to install a one-piece rocker cover:

1. Position the rocker cover on the cylinder head.
2. Install the two bolts, with isolators and washers installed, into their recesses in the one-piece rocker cover.
3. Torque the two bolts, starting with the center bolts and working out, to 20-25 N·m (15-18 lb·ft).
4. Press the two protective plugs into the two center holes until they are firmly seated.
5. Install any other components that were removed for their procedure.

CAUTION:

Diesel engine exhaust and some of its constituents are known to the State of California to cause cancer, birth defects, and other reproductive harm.

- **Always start and operate an engine in a well ventilated area.**
- **If operating an engine in an enclosed area, vent the exhaust to the outside.**
- **Do not modify or tamper with the exhaust system or emission control system.**

6. Start the engine and check for leaks.

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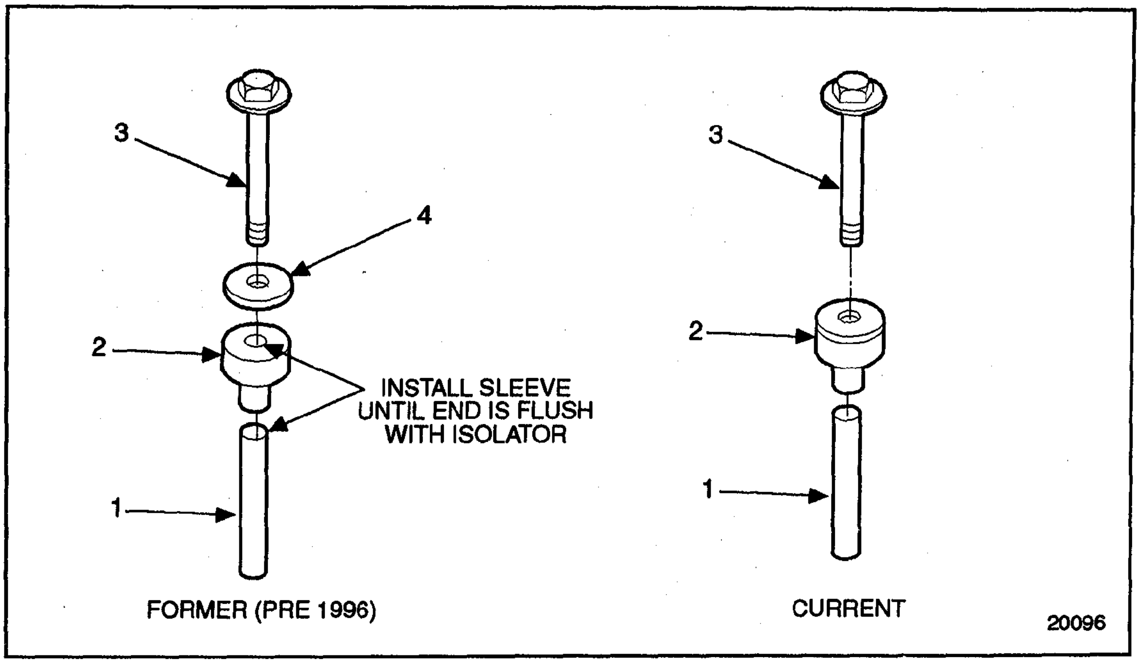
1.6.9 Installation of Two-Piece and Three-Piece Rocker Covers

Perform the following steps to install a two or three-piece rocker cover:

1. Position the rocker cover base on the cylinder head.
2. Lubricate the valve cover limiting sleeves with clean silicone spray. Insert the sleeves into the isolators until the end of the sleeve is flush with the isolator. See Figure 1-107.



1. Limiting Sleeve
2. Isolator
3. Bolt
4. Flat Washer

Figure 1-107 Rocker Cover Base Hold Down Hardware

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3. Install the hold-down bolts, with washers installed, to the limiting sleeves.
4. Install the hold-down assemblies to the rocker cover base, and thread the bolts two to three threads into the cylinder head.

NOTE:
Use care when tightening the rocker cover base hold-down bolts that the injector wires do not get caught between the limiting sleeve and the cylinder head. See Figure 1-108.

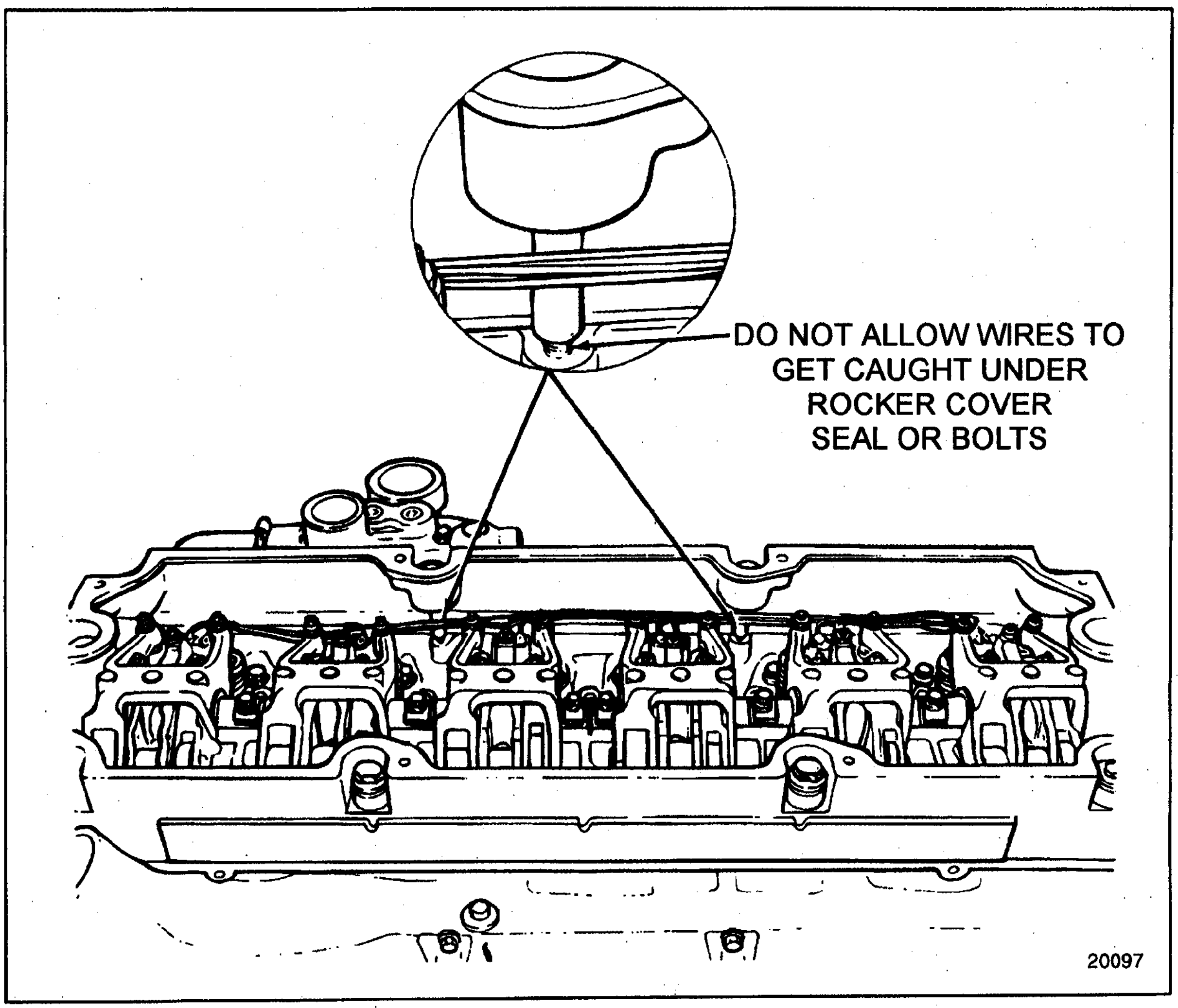

Figure 1-108 Rocker Cover Base Hold-down Bolt Installation

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5. Torque the ten rocker cover base hold-down bolts to 30-38 N·m (22-28 lb·ft). See Figure 1-109.

NOTE:
Torque the bolts in two stages, using half-torque values first.

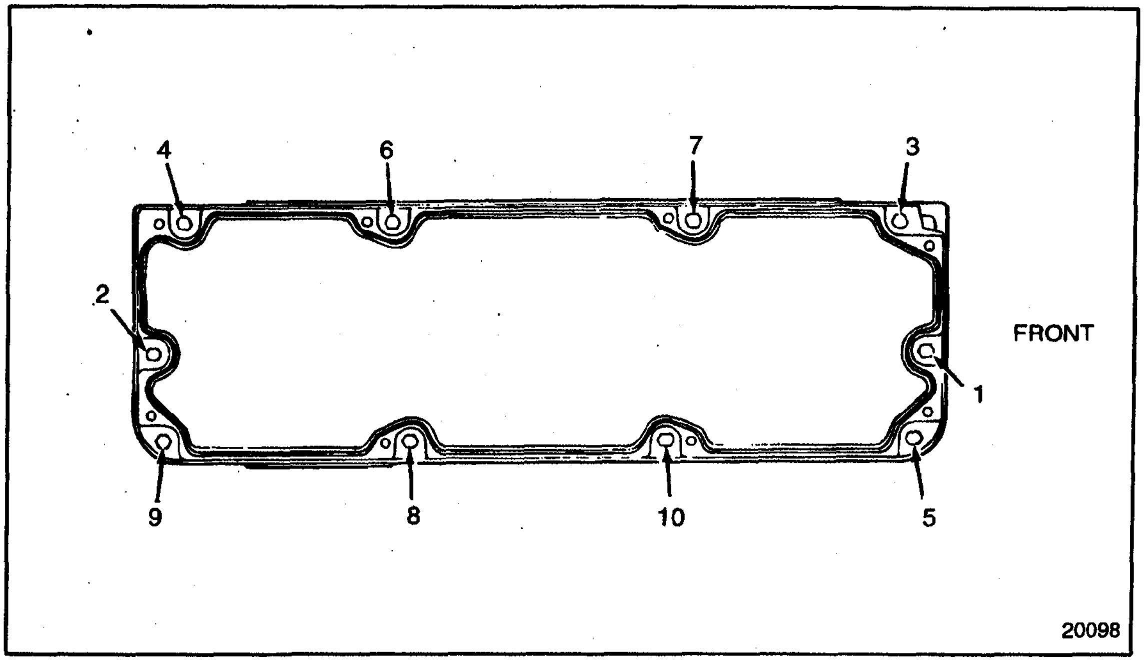

Figure 1-109 Rocker Cover Base Bolt Tightening Sequence

6. Be sure the groove in the top of the rocker cover base, and its mating, diamond-shaped seal are clean and dry. Install the diamond-shaped seal to the groove by pressing the seal into the groove. Use care not to stretch or twist the seal. The seal has a definite shape, and should be installed exactly as removed from the base. If the seal cannot be installed to its groove without bunching or looping, the seal is stretched and must be replaced. The same procedure applies to the intermediate cover diamond seal installation.

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7. Install the rocker cover cap to the base. Install the eight screws that attach the cap to the base, and torque to 22-25 N·m (16-18 lb·ft) using the torque sequence. See Figure 1-110. Tighten the bolts in two stages, using half-torque value first. The same procedure applies to the intermediate cover installation.

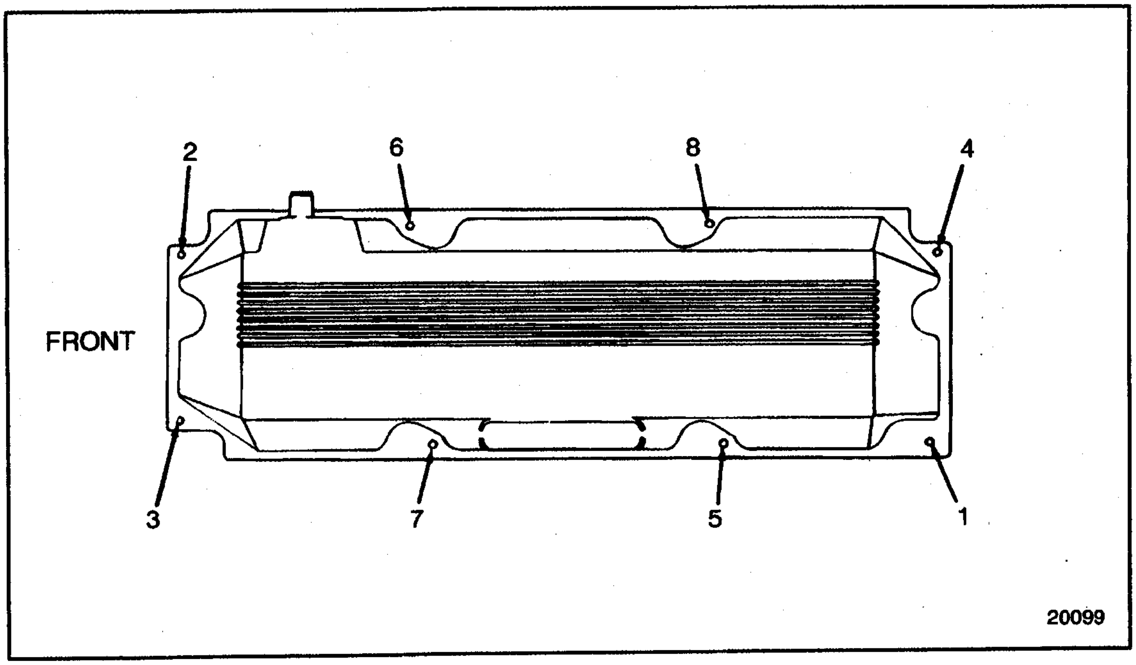

Figure 1-110 Rocker Cover Bolt Tightening Sequence

8. Install any other parts that were removed for this procedure.
9. Refer to section 1.6.8 for the exhaust caution before preceeding. Start the engine and check for leaks. Shutdown engine after checking for leaks.

1.6.10 Installation of the Two-Piece Rocker Cover Cap - Diesel Engines Only

Install the two-piece rocker cover as follows:

1. Be sure the groove in the bottom of the rocker cover base, and its mating, diamond-shaped seal are clean and dry. Install the diamond-shaped seal to the groove by pressing the seal into the groove. Use care not to stretch or twist the seal. The seal has a definite shape, and should be installed exactly as removed from the base. If the seal cannot be installed to its groove without bunching or looping, the seal is stretched and must be replaced. The same procedure applies to the intermediate cover diamond seal installation.
2. Install the rocker cover cap to the base. Install the eight bolts that attach the cap to the base, and torque to 22-25 N·m (16-18 lb·ft) using the torque sequence. See Figure 1-111. Tighten the bolts in two stages, using half-torque value first. The same procedure applies to the intermediate cover installation.

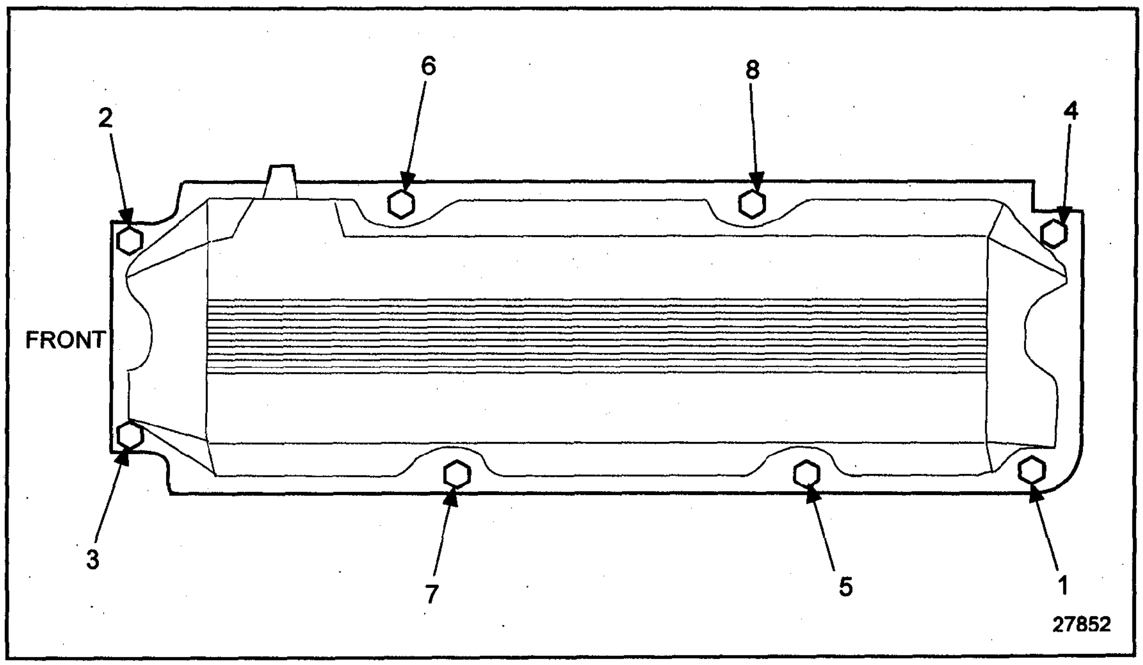

Figure 1-111 Rocker Cover Bolt Cap Tightening Sequence

3. Install any other parts that were removed for this procedure.
4. Refer to section 1.6.8 for the exhaust caution before preceeding. Start the engine and check for leaks. Refer to section 11.8.

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1.6.11 Installation of the Two-Piece Rocker Cover Cap (Gas Engines with Coil Over Plug Ignition System Only)

Install the two-piece rocker cover cap as follows:

1. Clean any oil or dirt from the spark plug wells.
2. Insert the six extension tubes with O-rings in the cylinder head.
3. Orient the extension tubes so that twelve threaded holes are in a straight line. This will allow the coil mounting bolts to engage these holes after the rocker cover cap is installed.
4. Place the rocker cover cap on base without disturbing the extension tube seals. Loosely install the eight bolts that attach the cap to the base.
5. Insert the coils into the spark plug wells. Engage the coil mounting bolts into the extension tubes. Torque the bolts 13-16 N·m (10-12 lb·ft).
6. Torque the eight rocker cover cap mounting bolts to 22-25 N·m (16-18 lb·ft).
7. Install the remaining ignition system parts. Refer to section 15.2.
8. Apply antiseize compound to the coil cover mounting screw holes to aid removal of these parts in the future.
9. Install any other parts that were removed for this procedure.
10. Refer to section 1.6.8 for the exhaust caution before preceeding. Start the engine and check for leaks. Refer to section 11.8.

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1.7 CRANKSHAFT

The crankshaft is a one-piece forging of chrome-alloy steel, heat-treated to ensure strength and durability. See Figure 1-112.

NOTE:
The natural gas crankshaft has machined counter weights to allow for shorter rods.

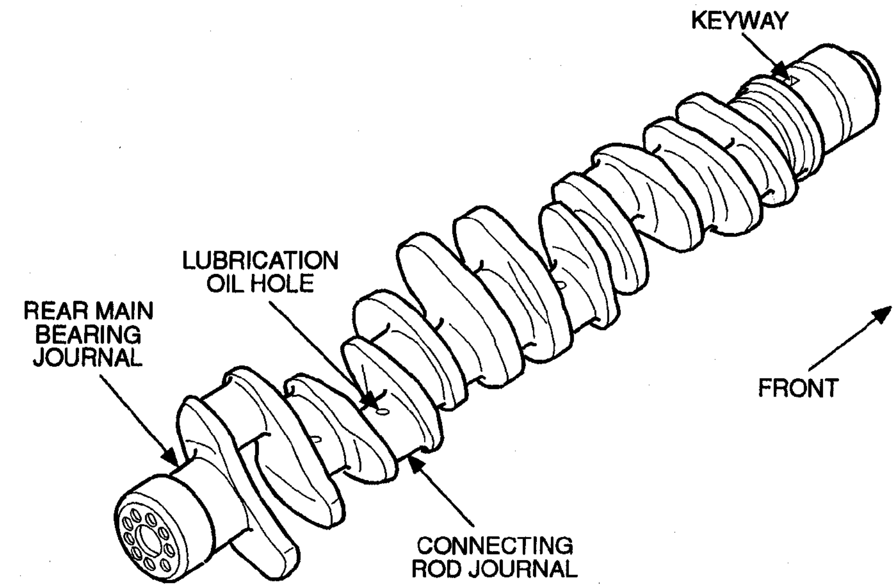

Figure 1-112 Crankshaft

The main and connecting rod bearing journal surfaces and fillets are induction hardened.

Complete static and dynamic balance of the crankshaft has been achieved by counterweights incorporated in the crankshaft.

Current crankshafts may have a six-bolt or twelve-bolt mounting pattern on the front.

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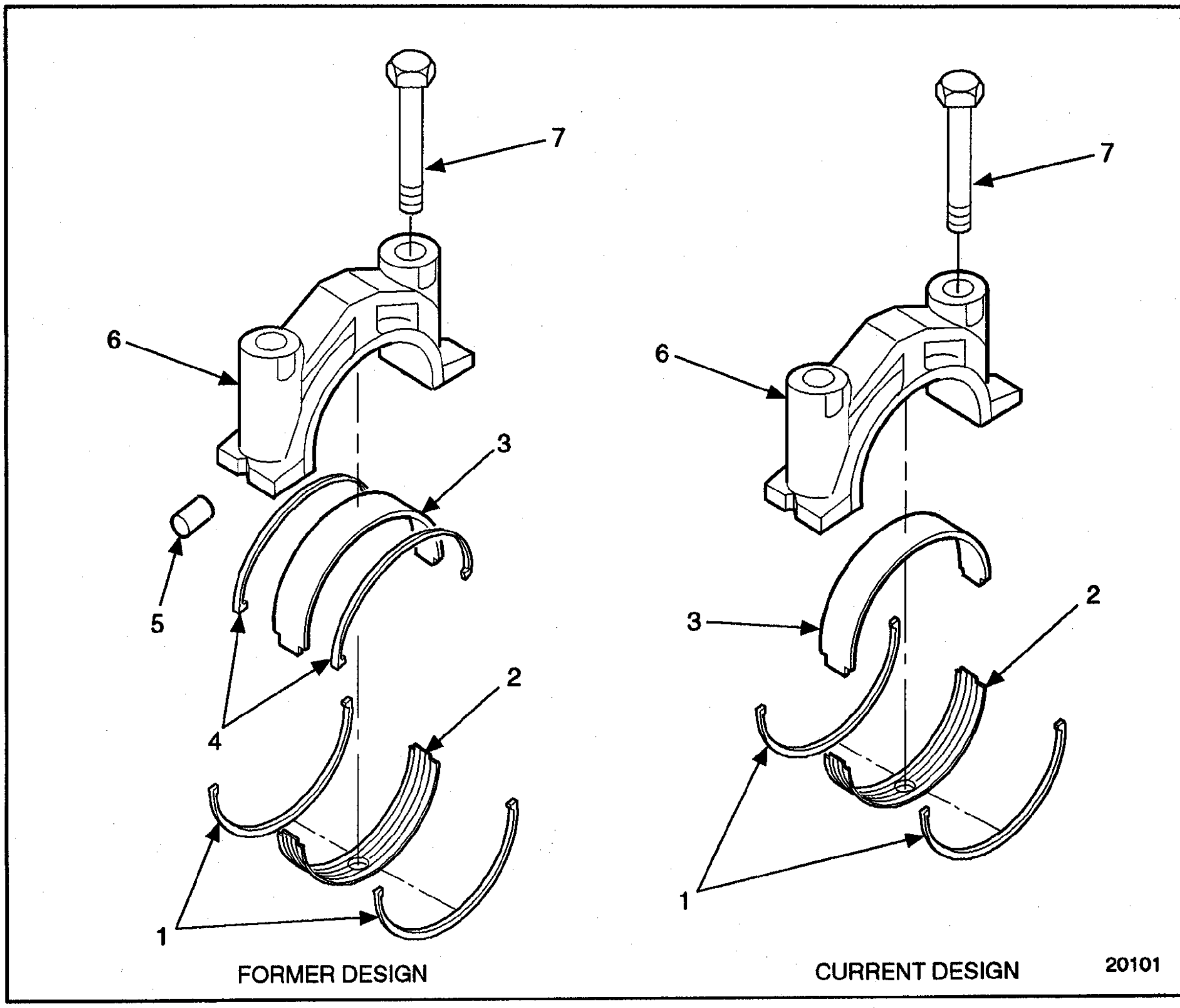
The crankshaft end play is controlled by thrust washers located at the No. 6 main bearing cap and saddle of the engine. See Figure 1-113.



1. Upper Thrust Washer (2)
2. Upper No. 6 Bearing Shell
3. Lower Bearing Shell (No. 1 through 7)
4. Lower Thrust Washer (former design only)
5. Dowel
6. No. 6 Main Bearing Cap
7. Main Bearing Cap Bolt

Figure 1-113 Crankshaft Thrust Bearing Detail

The current design makes use of thrust washers in the upper positions only.

Oversize thrust washers are available to correct for excessive end play.

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On some engines, the No. 6 main bearing cap is indexed to the cylinder block by two slots in the cap which register with dowels in the cylinder block. See Figure 1-114.

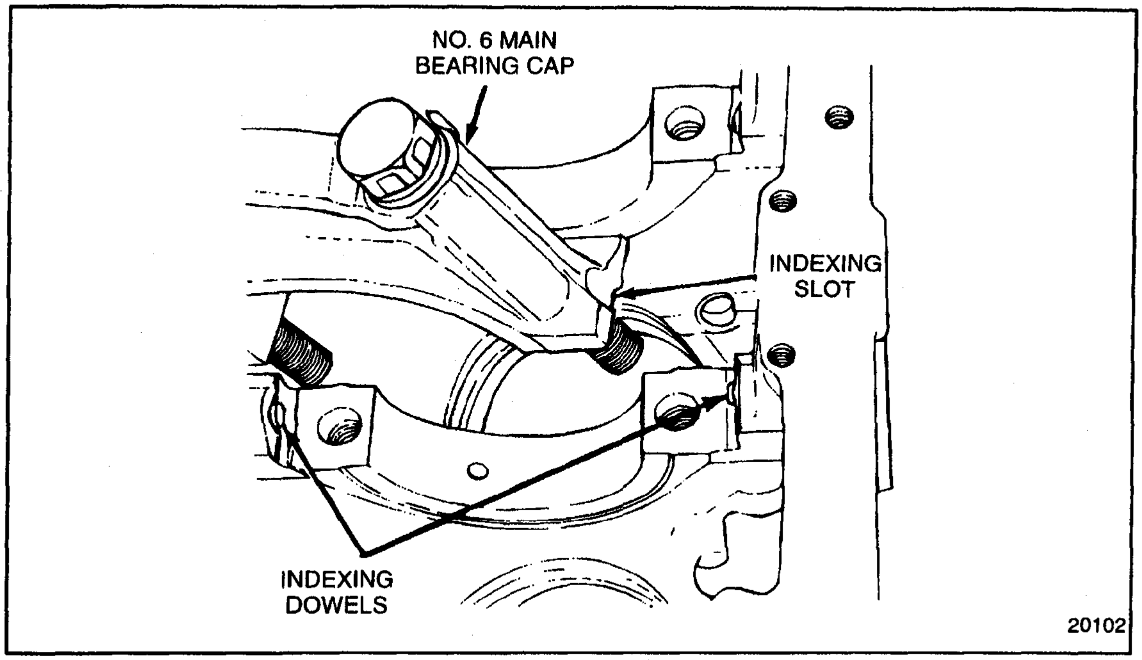

Figure 1-114 Former No. 6 Main Bearing Cap

The current design does not use the indexing dowels. See Figure 1-115.

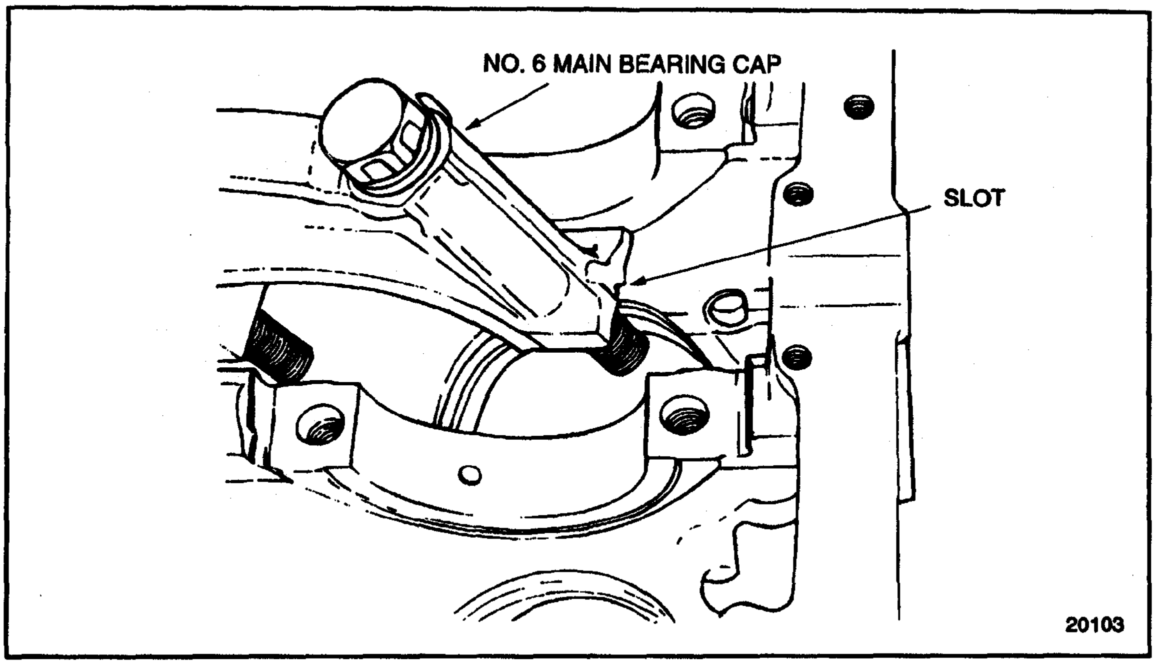

Figure 1-115 Current No. 6 Main Bearing Cap

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Full pressure lubrication to all connecting rod and main bearings is provided by drilled passages within the crankshaft and cylinder block. See Figure 1-116.

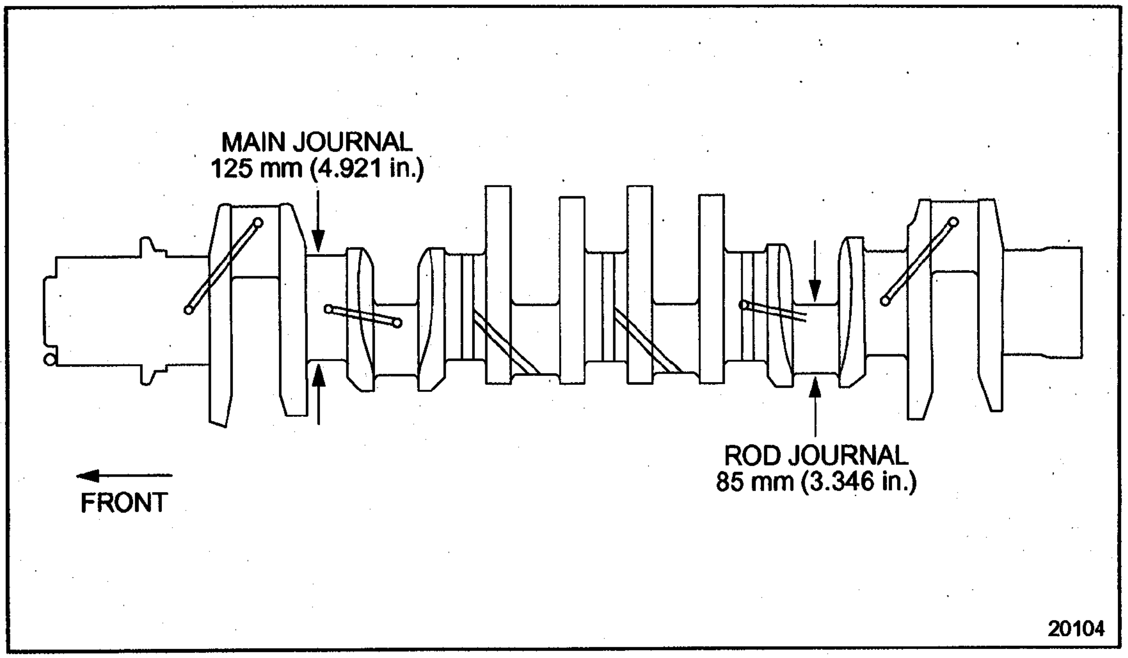

Figure 1-116 Crankshaft Lubricating Oil Holes

Six or twelve tapped holes, equally spaced, are provided on the rear butt for attaching the flywheel. There are six or twelve equally spaced tapped holes on the front butt of the crankshaft for attaching the crankshaft pulley and vibration damper. No locating dowels are provided at either end.

Each standard main bearing journal is 125.000-124.968 mm (4.921-4.920 in.) in diameter and each standard connecting rod journal is 85.000-84.975 mm (3.346-3.345 in.) in diameter.

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New crankshafts with smaller radii fillets (listed in Table 1-2) replaced the former crankshafts, effective with the following engine serial numbers:

Engine Model	Engine Serial Number
6067WK60 (11.1 L)	6R184522
6067GK60 (12.7 L)	6R188251

Table 1-2 New Crankshafts with Smaller Radii Fillets

This change was made to permit installation of new, wider connecting rod bearings that increase rod bearing oil film thickness and reduce bearing pressures. The fillets on the new crankshafts have a radius of 4.0-3.5 mm (0.157 -0.138 in.). The fillets on the former crankshafts had a radius of 6.0-5.5 mm (0.236 -0.216 in.). To conform with this change, new connecting rods with smaller rod chamfers were also released. Refer to section 1.19for information on the new connecting rods and bearings.

The new crankshafts, bearings, and connecting rods must be used together to ensure interchangeability. Former parts cannot be mixed with new parts in the same engine. The former crankshafts will no longer be available.

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1.7.1 Repair or Replacement of Crankshaft

To determine if repair is possible or replacement is necessary, perform the following procedure. See Figure 1-117.

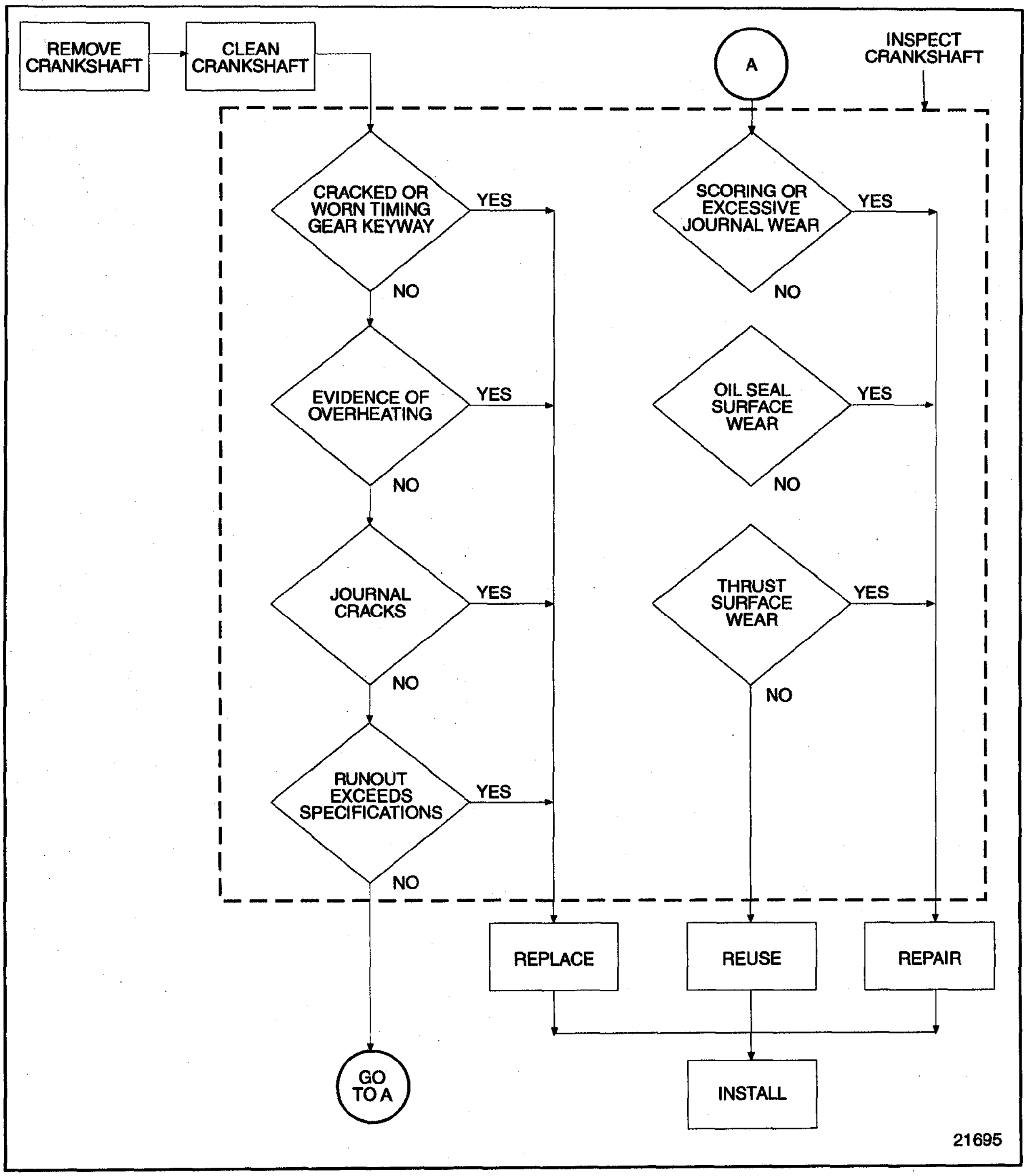

Figure 1-117 Flowchart for Repair or Replacement of Crankshaft

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1.7.2 Removal and Cleaning of Crankshaft

When removal of the crankshaft becomes necessary, first remove the transmission, then proceed as follows:

1. Steam clean the exterior of the engine. Refer to section 1.1.3.
2. Drain the cooling system. Refer to section 13.13.4.
3. Drain the lubricating oil. Refer to section 13.13.1.
4. Attach suitable chain hoist and spreader bar with hooks to the three lifter brackets (one at the front and two at the rear). Remove all engine to base attaching bolts and remove the engine from its base. Refer to section 1.1.2. See Figure 1-5.

CAUTION:
To avoid injury from a falling engine, ensure the engine is securely attached to the engine overhaul stand before releasing the lifting sling.

5. Remove and inspect all of the accessories and assemblies with their attaching parts as necessary to permit the engine block adaptor, to be bolted to the intake (left) side of the cylinder block. Mount the engine to the overhaul stand, J 29109 with adaptor, J 35635-A attached. Refer to section 1.1.2.
6. Remove the oil pan, refer to section 3.11.2.
7. Inspect the oil pan, refer to section 3.11.3.1.
8. Remove the lubricating oil pump, refer to section 3.2.2.
9. Inspect the lubricating oil pump, refer to section 3.2.3.1.
10. Remove the flywheel, refer to section 1.14.2.
11. Inspect the flywheel, refer to section 1.14.2.1.
12. Remove flywheel housing, refer to section 1.16.2.
13. Inspect the flywheel housing, refer to section 1.16.2.1.

NOTICE:
Use care when removing the crankshaft pulley as the vibration damper may come off. If the damper is allowed to fall, damage to the internal components of the damper may result.

14. Loosen and remove two of the crankshaft pulley retaining bolts and hardened washers 180 degrees apart and install two flywheel guide studs, J 36235, in their place. Then loosen and remove the remaining four pulley retaining bolts and hardened washers. Refer to section 1.13.2.

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15. Remove and inspect the viscous vibration damper. Refer to section 1.12.2, and refer to section 1.12.2.1, for inspection.
16. Remove and inspect the engine front support and gear case cover. Refer to section 1.10.2, for removal and refer to section 1.10.2.1, for inspection.
17. Remove the cylinder head, refer to section 1.2.2.
18. Inspect the cylinder head, refer to section 1.2.3.1.
19. Loosen and remove the main bearing cap bolts. Remove the main bearing caps for inspection. Refer to section 1.9.2.

NOTE:
The connecting rod caps must be reinstalled to their respective connecting rods. The main bearing caps should be kept in sequence, so that they may be installed to their original positions.

20. Remove and inspect the piston and connecting rod assemblies. Refer to section 1.18.2 for removal and refer to section 1.18.3.1.
21. Remove and inspect the thrust washers from each side of the No. 6 main bearing cap, if they exist. (Engines with a serial number greater than 6R-6287 do not have thrust washers on the No. 6 main bearing cap.) Refer to section 1.9.2.2 for inspection.
22. Remove and inspect the crankshaft, including the crankshaft gear and timing wheel. Refer to section 1.7.2and refer to section 1.7.2.1.
23. Remove the timing gear and timing wheel, refer to section 1.21.2and inspect it, refer to section 1.21.3.
24. Remove the Woodruff key from the slot in the front crankshaft hub.

1.7.2.1 Inspection of Crankshaft

Perform the following steps for crankshaft inspection:

CAUTION:
To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

1. Clean out the oil passages thoroughly with a stiff wire brush. Clean the crankshaft with fuel oil and dry it with compressed air.
2. Inspect the crankshaft timing gear keyway for evidence of cracks or wear. Replace the crankshaft if these conditions are evident.
3. If the crankshaft shows evidence of excessive overheating, replace the crankshaft since the heat treatment has probably been destroyed.

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4. Check the crankshaft journal surfaces for score marks and other imperfections. If excessively scored, the journal surfaces must be reground. Refer to section ADDITIONAL INFORMATION 1.A, "Main and Connecting Rod Journals".
5. Carefully, inspect the front and rear end of the crankshaft in the area of the oil seal contact surface for evidence of a rough or grooved condition. Any imperfections of the oil seal contact surfaces will result in oil leakage at these points.
6. If the crankshaft oil seal contact surfaces are grooved, the seal surfaces must be sleeved and an oversized seal used. Refer to section 1.8.2.
7. Check the crankshaft thrust surfaces for excessive wear or grooving. If excessively worn, the thrust surfaces must be reground. Refer to section ADDITIONAL INFORMATION 1.A, "Machining Operations".
8. Check the crankshaft timing gear for worn or chipped teeth. Inspect the timing wheel for bent or otherwise damaged teeth. Replace as necessary. Refer to section 1.27.2.1.
9. Check the crankshaft journal run-out. Refer to section 1.7.2.4.
10. Check the journal alignment. Refer to section 1.7.2.3.
11. Check the journal measurements. Refer to section 1.7.2.4.
12. Inspect the crankshaft for cracks. Refer to section 1.7.2.1.

1.7.2.2 Crankshaft Journal Run-out Measurements

Support the crankshaft on its front and rear journals on V-blocks or the inverted engine block with only the front and rear upper bearing shells in place. Check the intermediate main journals with a dial indicator for run-out when the crankshaft is rotated.

When checking the crankshaft bow, if the run-out is greater than that listed in Table 1-3, the crankshaft must be replaced.

Journals Supported On	Journals Measured	Maximum Run-out (Total Indicator Reading)
No. 1 and No. 7	No. 2 and No. 6	0.076 mm (0.003 in.)
No. 1 and No. 7	No. 3 and No. 5	0.127 mm (0.005 in.)
No. 1 and No. 7	No. 4	0.152 mm (0.006 in.)

Table 1-3 Crankshaft Bow

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1.7.2.3 Adjacent Journal Alignment

When run-out on the adjacent journals is in opposite directions, the sum must not exceed 0.076 mm (0.003 in.) total indicator reading. When the high spots of run-out on the adjacent journals are in the same direction, the difference must not exceed 0.076 mm (0.003 in.) total indicator reading.

1.7.2.4 Journal Diameter Measurements

Measure all of the main and connecting rod bearing journal diameters. See Figure 1-118.

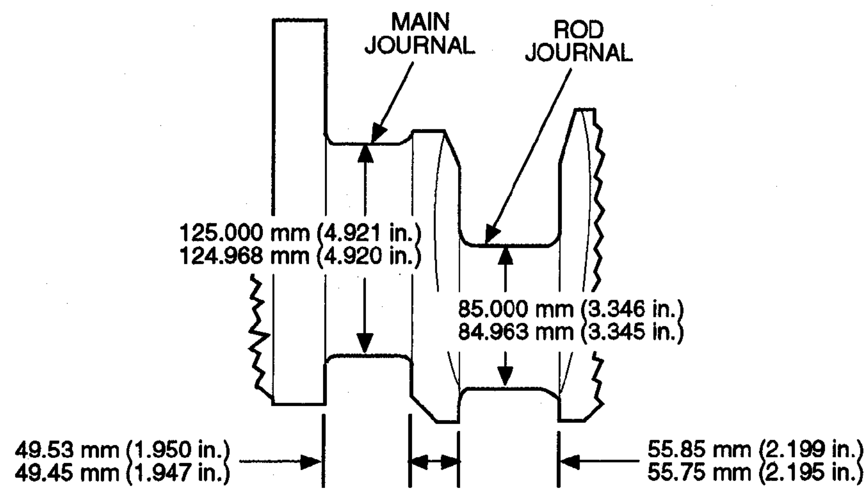

Figure 1-118 Dimensions of Crankshaft Journals

Measure the journals at several places on the circumference so that taper, out-of-round and bearing clearances can be determined. If the crankshaft is worn so that the maximum connecting rod or main bearing journal-to-bearing shell clearance (with new shells) exceeds 0.1270 mm (0.005 in.) (connecting rod journals) or 0.1422 mm (0.0056 in.) (main bearing journals), the crankshaft must be reground. Measurements of the crankshaft should be accurate to the nearest 0.0025 mm (0.0001 in.). Also, if the main bearing journal taper of a used crankshaft exceeds 0.0381 mm (0.0015 in.) or the out-of-round is greater than 0.0254 mm (0.001 in.) the crankshaft must be reground. Specifications for the crankshaft are listed in Table 1-21.

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Also, measure the distance between crankshaft thrust washer surfaces. See Figure 1-119.

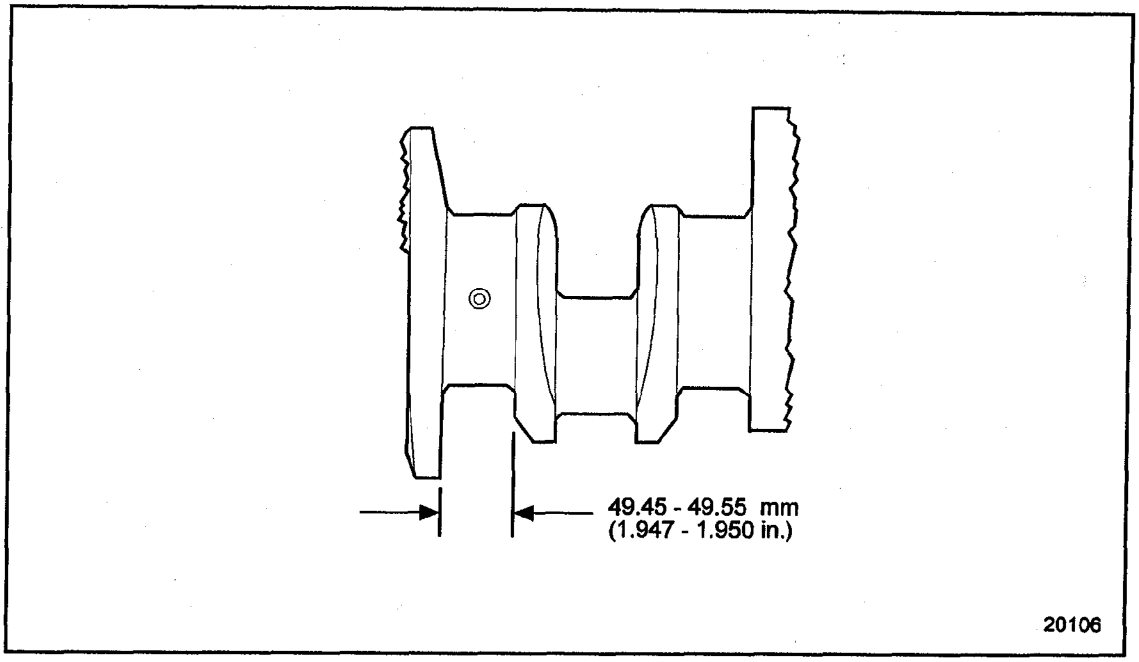

Figure 1-119 Dimensions for No. 6 Main Bearing Journal Thrust Width

1.7.2.5 Inspection for Cracks

Carefully check the crankshaft for cracks which start at an oil hole and follow the journal surface at an angle of 45 degrees to the axis. Any crankshaft with such cracks must be replaced. Several methods of determining the presence of minute cracks not visible to the eye are available: refer to section 1.7.2.6, for magnetic particle method, refer to section 1.7.2.7, for fluorescent magnetic particle method, or refer to section 1.7.2.8, for fluorescent penetrant method.

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1.7.2.6 Magnetic Particle Method

Magnetize the crankshaft and then cover it with a fine magnetic powder or solution. The crankshaft must be demagnetized after the test to avoid engine damage.

NOTICE:
Very fine cracks may be missed using the magnetic particle method, especially on discolored or dark surfaces. They will be disclosed under the black light. If the crankshaft is discolored or has dark surfaces, the magnetic particle method should not be used. Refer to section 1.7.2.7 for suitable alternate method.

Flaws, such as cracks, form a small local magnet which causes the magnetic particles in the powder or solution to gather there, effectively marking the crack.

1.7.2.7 Fluorescent Magnetic Particle Method

This method is similar to the magnetic particle method, but is more sensitive since it employs magnetic particles which are fluorescent and glow under black light. Refer to section 1.7.2.6.

1.7.2.8 Fluorescent Penetrant Method

This is a method which may be used on both non-magnetic and magnetic materials. A highly fluorescent liquid penetrant is applied to the part. Then the excess penetrant is removed from the surface and the part is dried. A developing powder is then applied which helps to draw the penetrant out of the flaws by capillary action. Inspection is carried out under a black light.

A majority of indications revealed by the above inspection methods are normal and harmless and only in a small percentage of cases is reliability of the part impaired when indications are found. Since inspection reveals the harmless indications with the same intensity as the harmful ones, detection of the indications is but a first step in the procedure. Interpretation of the indications is the most important step.

All crankshafts are magnetic particle inspected after manufacture to ensure against any shafts with harmful indications getting into the original equipment or factory parts stock.

Crankshaft failures are rare and when one cracks or breaks completely, it is very important to make a thorough inspection for contributory factors. Unless abnormal conditions are discovered and corrected, there will be a repetition of the failure.

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There are two types of loads imposed on a crankshaft in service: a bending force and a twisting force. The design of the shaft is such that these forces produce practically no stress over most of the surface. Certain small areas, designated as critical areas, sustain most of the load. See Figure 1-120.

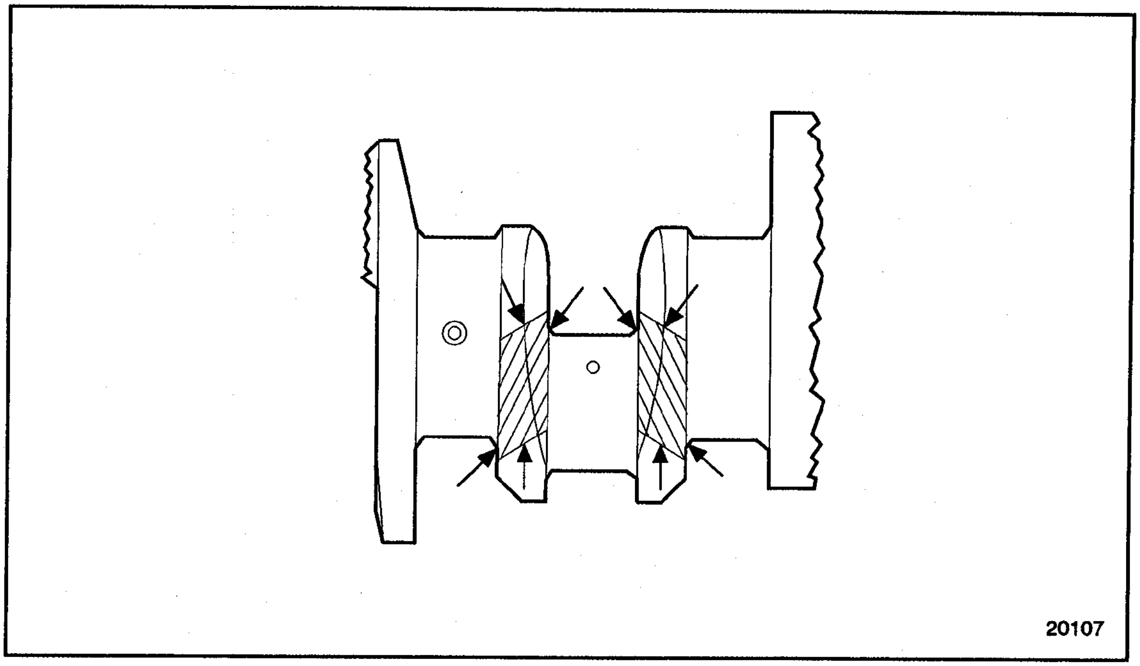

Figure 1-120 Critical Crankshaft Loading Zones

1.7.2.9 Bending Fatigue

Failures can result from bending of the crankshaft.

The crankshaft is supported between each of the cylinders by a main bearing and the load imposed by the gas pressure on top of the piston is divided between the adjacent bearings. An abnormal bending stress in the crankshaft, particularly in the crank fillet, may be a result of misalignment of the main bearing bores, improperly fitted bearings, bearing failures, a loose or broken bearing cap, or unbalanced pulleys. Also, drive belts which are too tight will impose a bending load upon the crankshaft.

Failures resulting from bending start at the pin fillet and progress throughout the crank cheek, sometimes extending into the main journal fillet. If main bearings are replaced due to one or more badly damaged bearings, a careful inspection must be made to determine if any cracks have started in the crankshaft. These cracks are most likely to occur on either side of the damaged bearing.

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1.7.2.10 Torsional Fatigue

Failures result from torsional vibration which takes place at high frequency. A combination of abnormal speed and load conditions may cause the twisting forces to set up a vibration, referred to as torsional vibration, which imposes high stresses at the locations. See Figure 1-121.

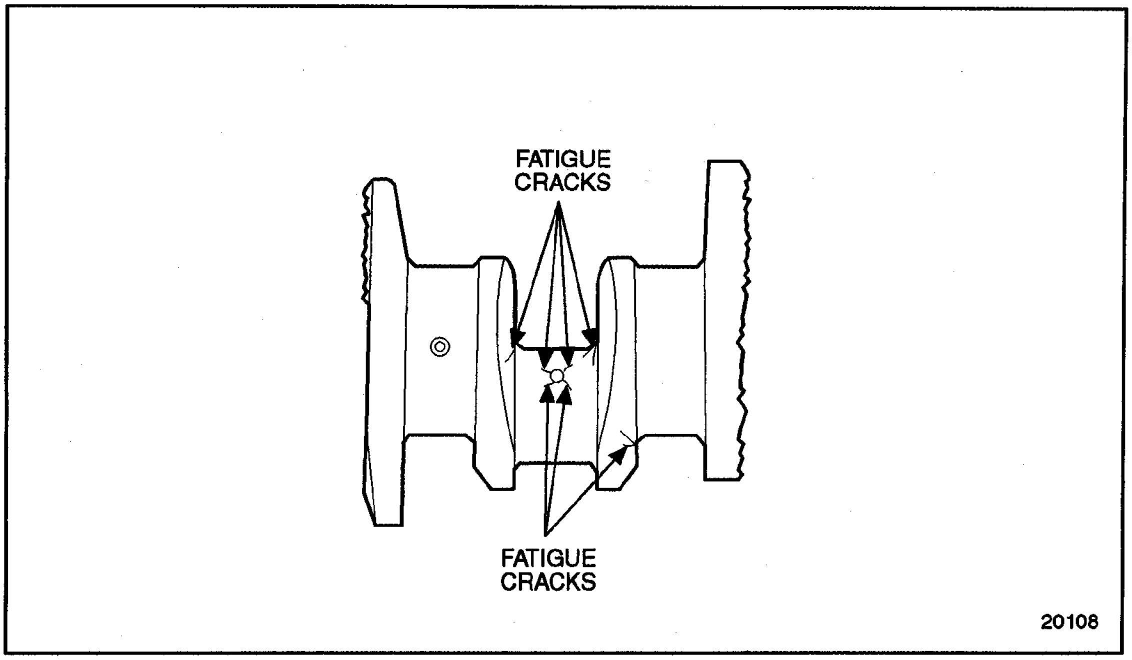

Figure 1-121 Crankshaft Fatigue Cracks

Torsional stresses may produce a fracture in either the connecting rod journal or the crank cheek in the rear. Torsional failures may also occur at the front end of the crankshaft at the crankshaft timing gear drive key slot. Connecting rod journal failures are usually at the fillet or oil hole at 45 degrees to the axis of the shaft.

A loose, damaged or defective vibration damper, a loose flywheel or the introduction of improper or additional pulleys or couplings are usual causes of this type of failure. Also, overspeeding of the engine or overriding the engine electronic control system to allow engine overspeeding may be contributory factors.

1.7.2.11 Crankshaft Cracks

As previously mentioned, most of the indications found during inspection of the crankshaft are harmless. The two types of indications to look for are circumferential fillet cracks at the critical areas and 45° cracks (45° to the axis of the shaft) starting from either the critical fillet locations or the connecting rod journal holes. See Figure 1-121. Replace the crankshaft when cracks of this nature are found. Refer to section 1.7.3.

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1.7.2.12 Crankshaft Grinding

The use of properly remanufactured crankshafts is very important to maximize crankshaft main and connecting rod bearing life.

Remanufactured crankshafts must conform to specifications. See Figure 1-121. The dimensional requirements for journal axial profile, radial chatter and oil hole washout require confirmation with a Gould 1200 Surface Analyzer (or equivalent). Information on Gould 1200 is available in the "Glossary". Refer to section ADDITIONAL INFORMATION 1.A.

NOTE:
Visual inspection cannot be relied upon to confirm the compliance to journal quality specifications.

The procedure of crankshaft journal polishing can easily create axial profile and oil hole washout conditions beyond specifications. Any polishing operation should be followed by Gould 1200 (or equivalent) measurements to assure conformance to remanufactured specifications. Refer to section ADDITIONAL INFORMATION1.A, "Crankshaft Remanufactoring Procedures".

All used crankshafts that have not been reground must meet the dimensional specifications standard or be reground to specifications. Refer to section ADDITIONAL INFORMATION 1.A, "Crankshaft Remanufactoring Procedures".

In addition to standard size crankshaft thrust washers, 0.127 mm (0.005 in.) and 0.254 mm (0.010 in.) oversize thrust washers are available. Thrust surface specifications are listed in Table 1-21.

Remanufactured crankshafts should be stamped on the edge of the No. 1 crank throw (counterweight) with the appropriate undersize dimensions for identification purposes.

NOTE:
Crankshaft main bearing journals and/or connecting rod journals which exhibit discoloration due to excessive overheating from bearing failure are NOT acceptable for rework.

If one or more main or connecting rod journals require grinding, grind all of the main journals or all of the connecting rod journals to the same required size.

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1.7.3 Installation of Crankshaft

Install the crankshaft using the following procedure:

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

1. Steam clean it to remove the rust preventive and blow out the oil passages with compressed air.
2. Install the upper main bearing shells in the block. If the old bearing shells are to be used again, install them in the same locations from which they were removed. Refer to section 1.9.3.

NOTE:
When a new or reground crankshaft is installed, ALL new main and connecting rod (upper and lower) bearing shells and new thrust washers must also be installed.

NOTE:
If the crankshaft surfaces were reground, it may be necessary to install oversize thrust washers on one or both sides of the No. 6 main journal. See Figure 1-113.

3. Install the thrust washer upper halves in the counterbores on either side of the No. 6 bearing saddle. Coat the backs of the thrust washers (without oil grooves) with petroleum jelly and stick them in place with the oil-grooved sides facing away from the saddle.
4. Apply clean engine oil 360 degrees around all crankshaft bearing journals and install the crankshaft in place so that the timing marks on the crankshaft timing gear and the bull gear are aligned. Refer to section 1.21.2.1.

NOTE:
It may be easier to remove the bull gear assembly and re-time the engine.

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5. Install the main bearing shells in the main bearing caps as follows:

NOTE:
Whether the engines were built with or without thrust washers in the No. 6 main bearing cap, they are no longer required; they do not need to be reinstalled.

[a] Align the tang on the lower main bearing shell with the groove in the main bearing cap. Install the bearing shell to the main bearing cap.

NOTE:
The main bearing caps are bored in position and stamped with position number. They must be installed in their original positions, with the marked (numbered) side of each cap toward the cooler (right) side of the cylinder block.

[b] If the old bearing shells are to be used again, install them in the same bearing caps from which they were removed.

6. Install the main bearing caps together with lower bearing shells in place. Install the main bearing cap bolt. See Figure 1-122.

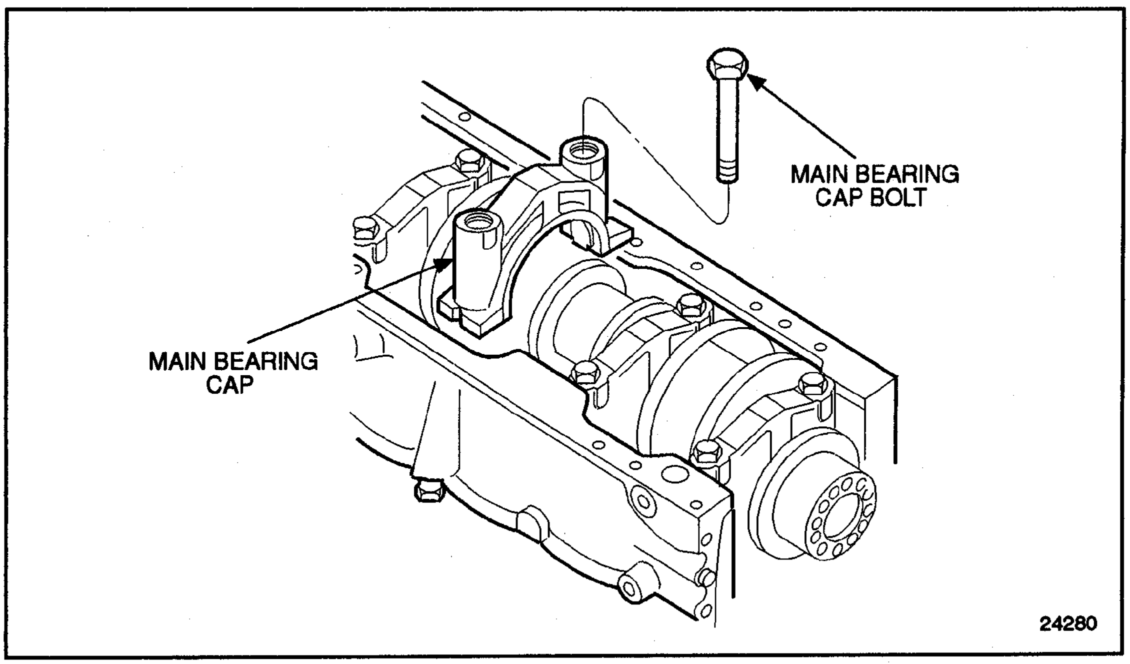

Figure 1-122 Main Bearing Cap Installation

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7. Apply a small quantity of International Compound #2® (or equivalent) to the bolt threads and underside of the bolt heads. Install the main bearing cap bolts and draw them up snug. Rap the main bearing caps sharply with a fiber mallet or plastic hammer to insure the caps are fully seated.
8. Torque all of the main bearing cap bolts to 470-530 N·m (347-391 lb·ft). Begin at the center caps and work progressively toward each end. Tighten the bolts to half the specified torque and then repeat the tightening sequence to the torque limit.

NOTE:
If the bearings have been installed properly, the crankshaft will turn freely with all of the main bearing cap bolts drawn to the specified torque.

9. Check the crankshaft end by moving the crankshaft toward the gage with a small 304.8 mm (less than 12 in.) pry bar. See Figure 1-123. Keep a constant pressure on the pry bar and zero the pointer on the dial indicator. Then, remove and insert the pry bar on the other side of the bearing cap. Force the crankshaft in the opposite direction and note the amount of end play on the dial. The end play should be 0.099-0.419 mm (0.0039 -0.0165 in.). Insufficient end play can be the result of a misaligned No. 6 main bearing, a misaligned upper thrust washer or a burr or dirt on the inner face of one or more of the thrust washers.

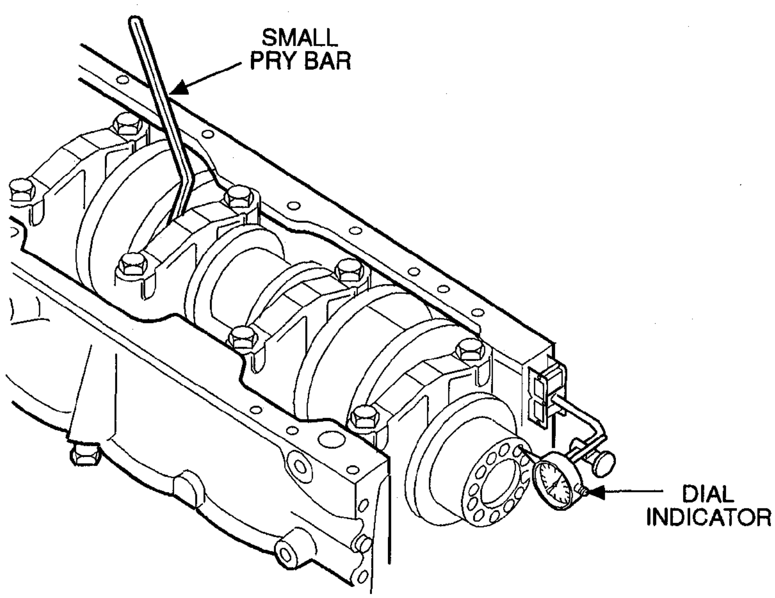

Figure 1-123 Measuring Crankshaft End Play

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10. Assemble the timing wheel and crankshaft gear on the crankshaft. Refer to section 1.27.3.
11. Install the piston and connecting rod assemblies. Refer to section 1.18.5. Torque the connecting rod cap nuts to 160-185 N·m (118-137 lb·ft).
12. Install the cylinder head. Refer to section 1.2.5.
13. Install the flywheel housing. Refer to section 1.16.3.
14. Replace the rear crankshaft seal with new seal and sleeve assembly. Refer to section 1.8.7.
15. Install the flywheel. Refer to section 1.14.3.
16. Install the lubricating oil pump, inlet and outlet pipes. Refer to section 3.2.6.
17. Install the gear case cover and engine front support. Refer to section 1.10.3.
18. Replace the front crankshaft seal with new seal and sleeve assembly. Refer to section 1.8.7.
19. Install the viscous vibration damper. Refer to section 1.12.3.
20. Install the crankshaft pulley. Refer to section 1.13.3.
21. Install the oil pan. Refer to section 3.11.4.
22. Use a chain hoist and spreader bar with hooks attached to the lifting brackets at each end of the engine and remove the engine from the overhaul stand. See Figure 1-5.
23. Remove the overhaul stand adaptor plate from the engine block. See Figure 1-7.
24. Install any accessories that were removed.
25. Install the engine to the equipment from which it was removed.
26. Fill the cooling system. Refer to section 13.13.4.
27. Fill the engine crankcase to correct operating level. Refer to section 13.13.1.
28. After replacing the main or connecting rod bearings or installing a new or reground crankshaft, operate the engine as outlined in the "Run-In Schedule." Refer to section 11.8.3.2.

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1.8 CRANKSHAFT OIL SEALS

An oil seal is used at each end of the crankshaft to retain the lubricating oil in the crankcase. The sealing lips of the crankshaft oil seals are held firmly, but not tight, against the crankshaft sealing surfaces by a spring, thus preventing oil from escaping from the engine crankcase.

A unidirectional laydown-lip crankshaft oil seal, with a dust lip, is used at the front of the crankshaft. The rear oil seal is pressed into the flywheel housing. With dry flywheel housings, a single Teflon-lip seal is used. With wet flywheel housings, a two-lip, laydown type seal is used. See Figure 1-124 and see Figure 1-125.

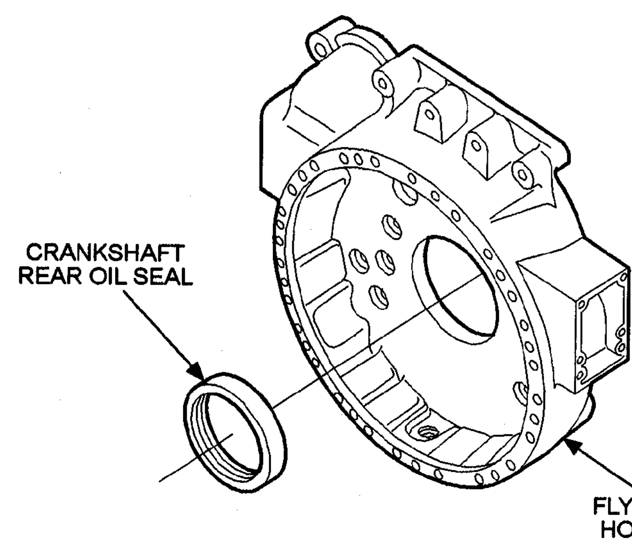

Figure 1-124 Crankshaft Rear Oil Seal

NOTICE:
Failure to use the required seal in a dry or wet flywheel housing environment may result in seal damage and oil leakage.

A unidirectional, single Teflon lip seal with an integral dust lip is used at the rear of engines with dry flywheel housings.

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The Chicago Rawhide® unitized front oil seal is pressed into the gear case cover after the cover is installed. See Figure 1-125.

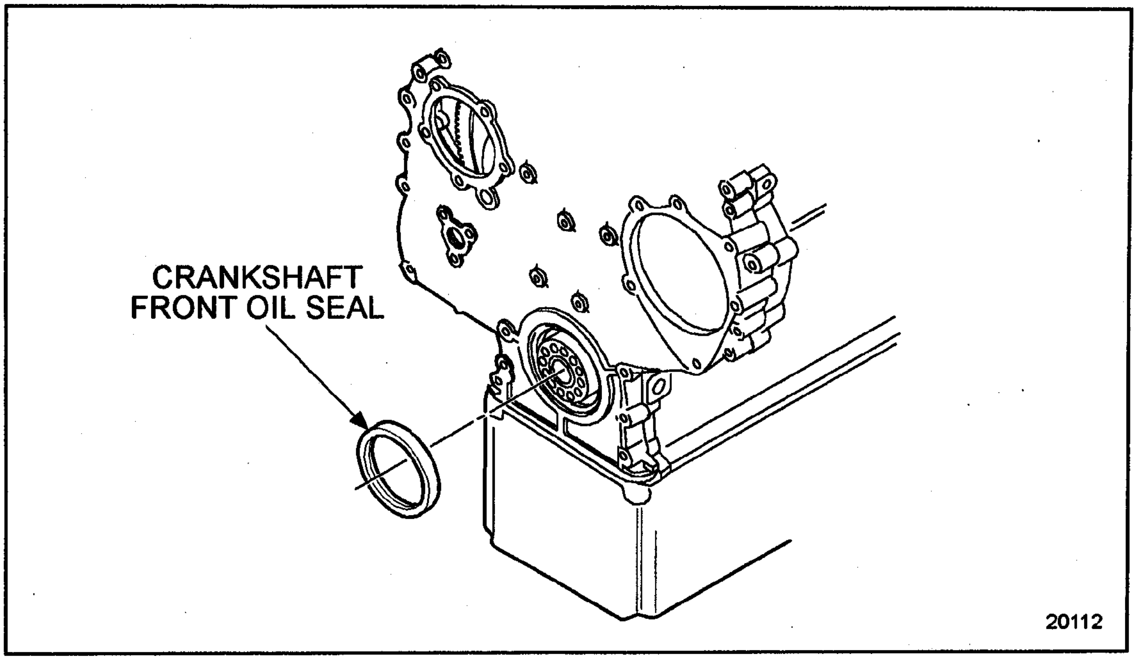

Figure 1-125 Crankshaft Front Oil Seal

The seal element runs against a wear sleeve which is an integral part of the seal assembly for the Chicago Rawhide seal.

Teflon® is a registered trademark of E.I. DuPont de Nemours and Company, Inc.
Chicago Rawhide® is a registered trademark of CR Industries.

The lip of the seals bears against the crankshaft hub surface.

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1.8.1 Repair or Replacement of Oil Seal

To determine if repair is possible or replacement is necessary, perform the following procedure. See Figure 1-126.

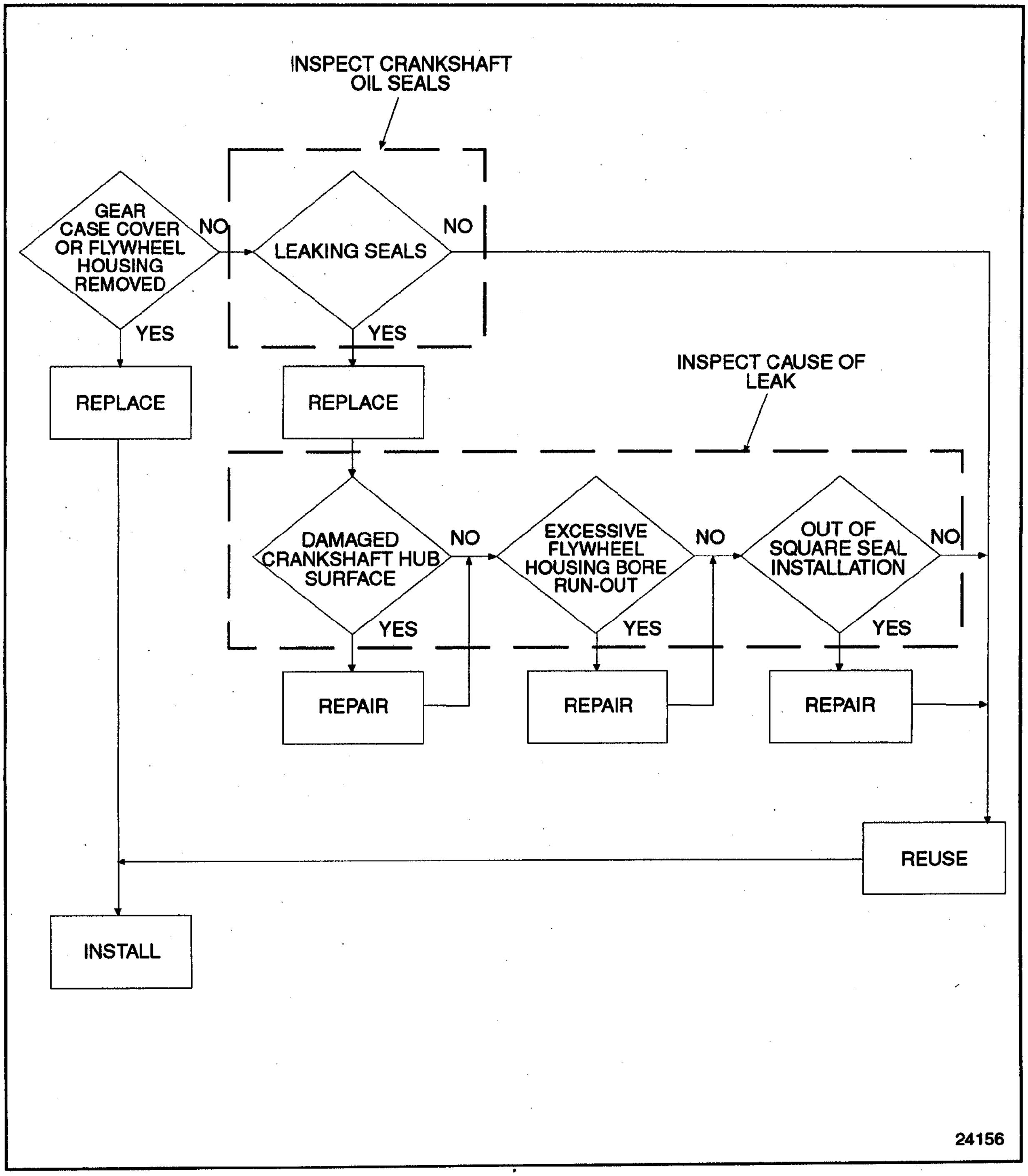

Figure 1-126 Flowchart for Repair or Replacement of Crankshaft Oil Seal

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1.8.2 Removal of Front and Rear Crankshaft Oil Seal

The rear crankshaft oil seals can be removed with either the flywheel housing installed or removed. The front crankshaft seal can be removed with the front gear case housing removed or installed.

NOTICE:
Due to the possibility of damage to the crankshaft oil seals, any time the gear case cover or flywheel housing is removed from the engine, the crankshaft oil seals must be replaced.

1. Remove the crankshaft oil seal as follows:
   [a] If the gear case housing is removed, refer to section 1.8.3.
   [b] If the gear case housing is installed, refer to section 1.8.4.
2. For the flywheel housing seal, refer to section 1.8.5.

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1.8.3 Removal of Front Crankshaft Oil Seal (Gear Case Housing Removed)

The Federal Mogul® front crankshaft oil seal may be removed with the gear case housing removed from the engine.

Perform the following steps if the gear case housing is removed from the engine.

NOTE:
The crankshaft oil seals must be removed if the gear case housing has been removed from the engine.

1. Support the outer face of the gear case housing on wood blocks.
2. Drive the oil seal out with a brass drift and hammer. Clean the seal bore in the housing. See Figure 1-127.

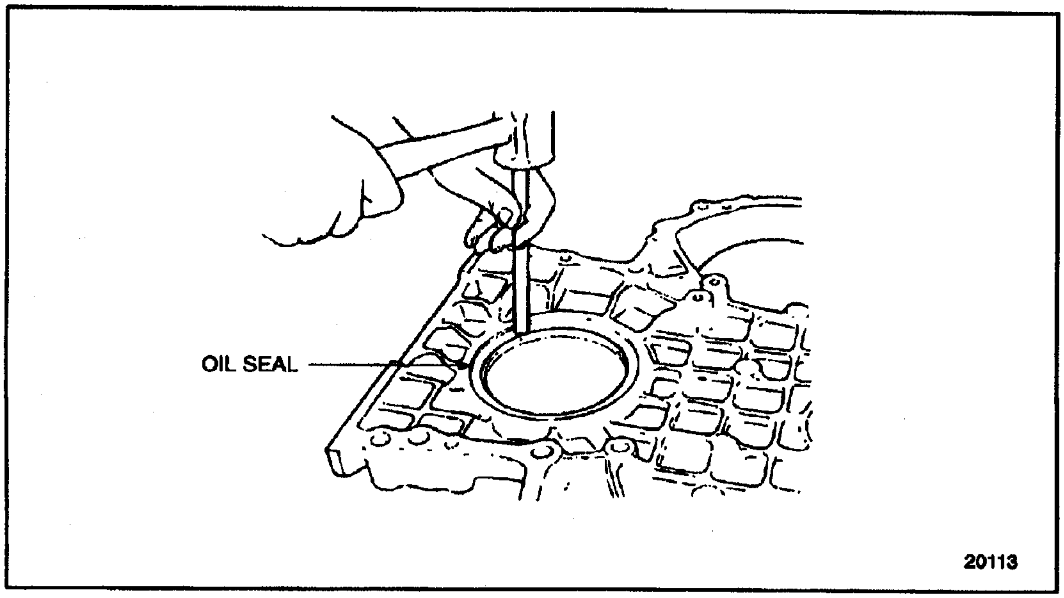

Figure 1-127 Front Crankshaft Oil Seal Removal

1.8.4 Removal of Front Crankshaft Oil Seal (Gear Case Housing Still Installed)

The front crankshaft oil seal may be taken out without removing the gear case housing. This may be done by using oil seal removal tool J 41329 part of J 35993.

NOTE:
Before proceeding, determine if seal to be removed is Federal Mogul or Chicago Rawhide brand. Remove and clean all rust and dirt from the crankshaft surface.

Remove Federal Mogul seal as follows:

1. Install puller, J 41329 part of J 35993, over crankshaft and hold against seal. See Figure 1-128.
2. Using variable speed drill motor and 5/32" bit, drill through outer and inner case of seal using smallest hole "A" as a guide.

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3. Without moving J 41329 part of J 35993, drill two additional "A" holes equally spaced.

NOTE:
All six holes may be drilled if using three holes proves unsuccessful in pulling seal.

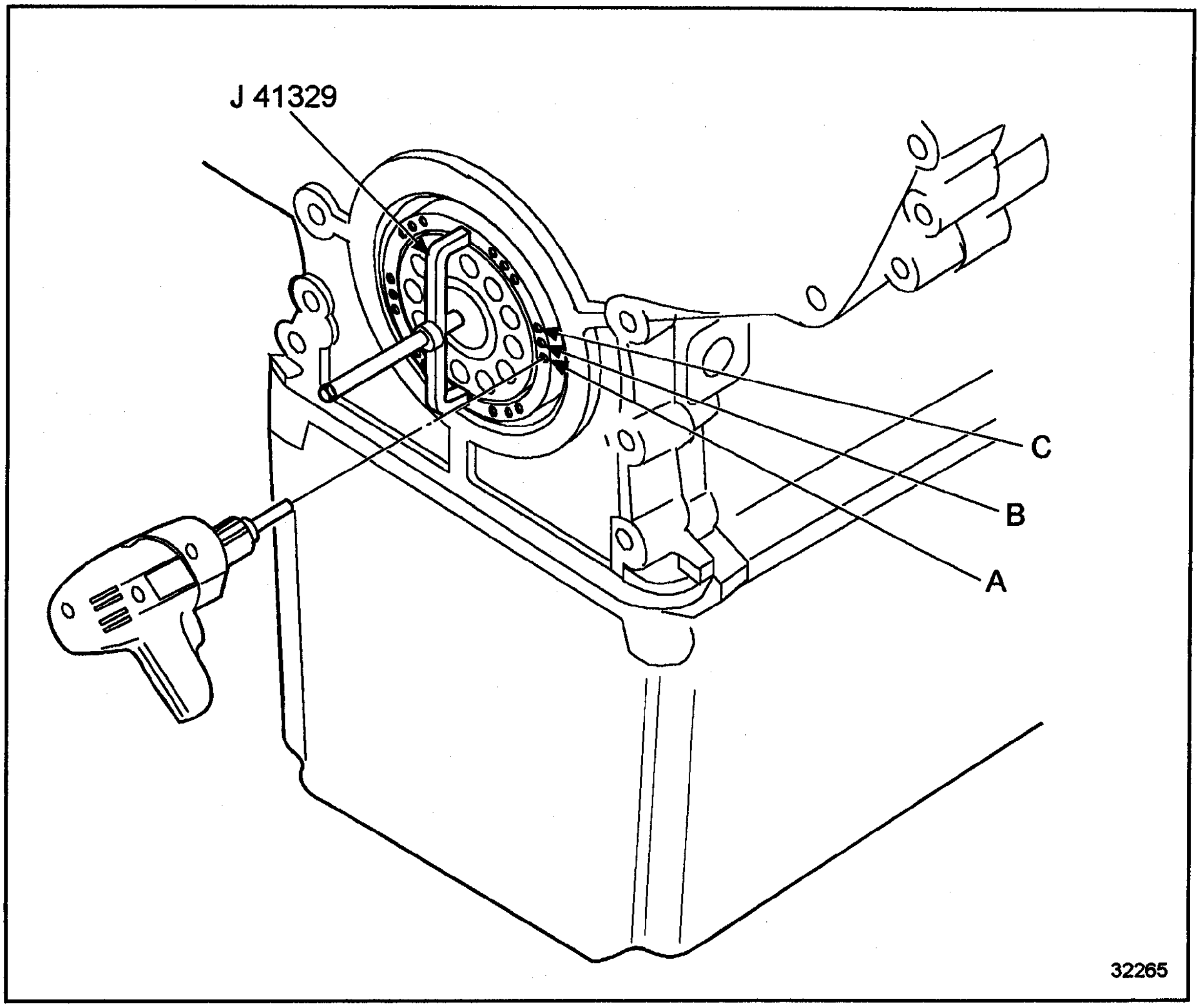

Figure 1-128 Removing Front Crankshaft Oil Seal from Gear Case Cover

4. Rotate J 41329 part of J 35993 clockwise until the "B" holes align with drilled holes and install sheet metal screws.
5. Apply thread lubricant, J 23444-A part of J 35686, to forcing screw and remove seal.
6. Remove the sheet metal screws from the tool. Discard the oil seal.

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7. Remove oil sleeve using crank oil sleeve remover, J 37075-A. See Figure 1-129.

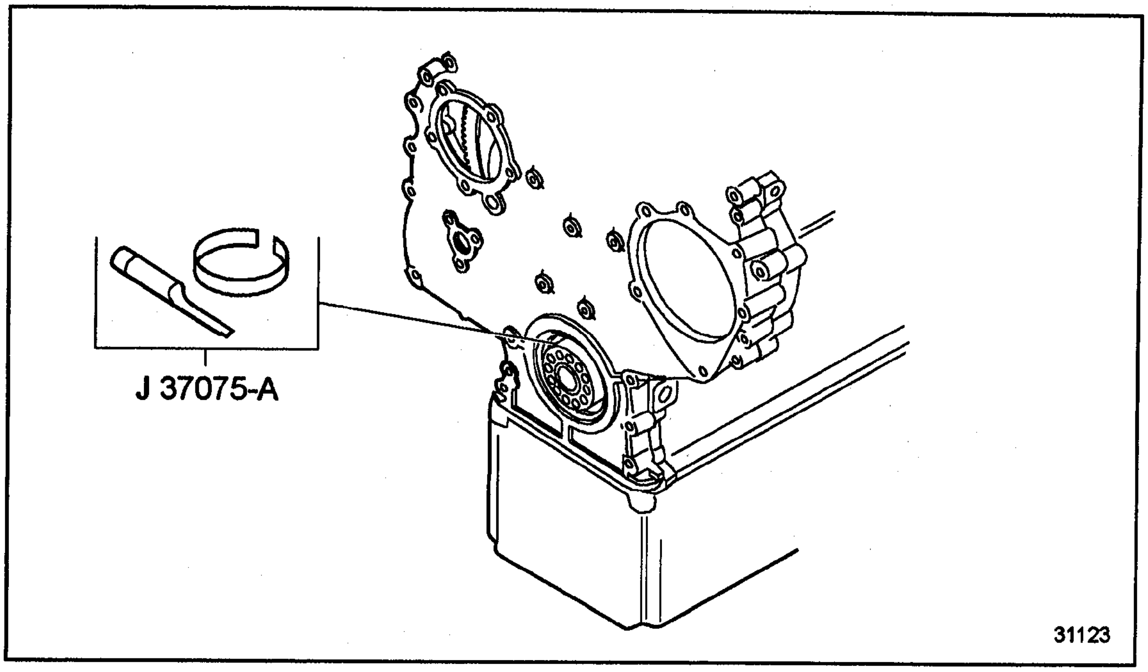

Figure 1-129 Oil Seal Sleeve Removal Tool for the Federal Mogul Seal

NOTE:
Crocus cloth may be used to clean up the high spots from the surface of the crankshaft. Clean the crankshaft contact surface thoroughly.

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Remove the Chicago Rawhide seal as follows:

Chicago Rawhide® is a registered trademark of CR Industries.

1. Install puller, J 41329 part of J 35993, over crankshaft and hold against seal. See Figure 1-130.

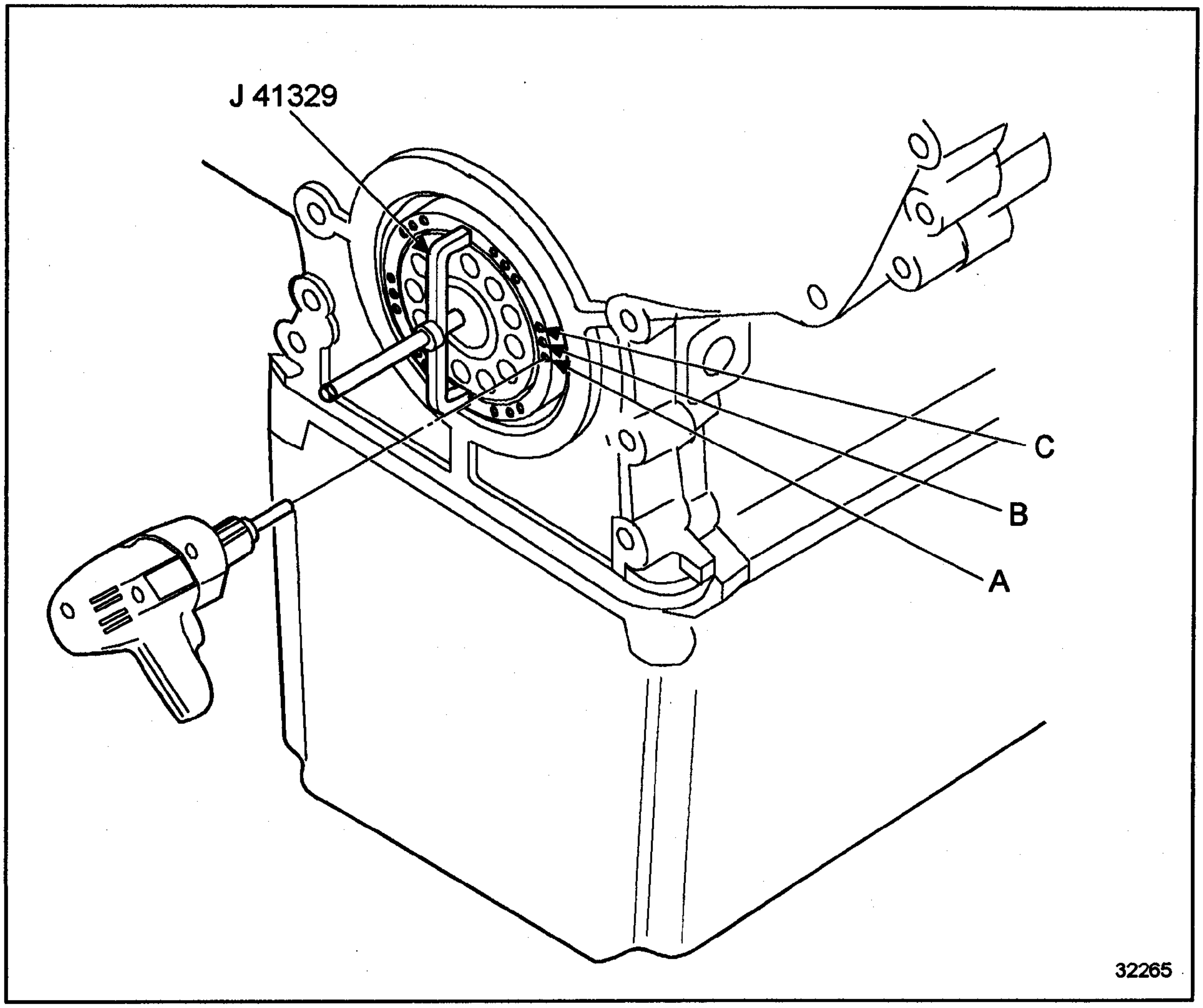

Figure 1-130 Removing Front Crankshaft Oil Seal from Gear Case Cover

2. Using variable speed drill motor and 5/32 in. bit, drill through outer and inner case of seal using smallest hole "A" as a guide.
3. Without moving J 41329 part of J 35993, drill two additional "A" holes equally spaced.

NOTE:
All six holes may be drilled if using three holes proves unsuccessful in pulling seal.

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4. Rotate J 41329 part of J 35993 clockwise until the "B" holes align with drilled holes and install sheet metal screws.
5. Apply thread lubricant, J 23444-A part of J 35686, to forcing screw and remove seal.

NOTE:
If seal is difficult to remove, there is probably debris on the crankshaft preventing the wear sleeve from passing over the crankshaft. Push the seal in 1/8", clean crankshaft surface thoroughly and repeat the removal procedure.

6. Remove the sheet metal screws from the tool. Discard the oil seal.

1.8.5 Removal of Rear Crankshaft Oil Seal (Flywheel Housing Installed)

The rear crankshaft oil seal may be taken out without removing the flywheel housing. This may be done by using oil seal removal tool, J 41329 part of J 35993.

1. To replace the rear oil seal, with transmission removed, remove the flywheel. Refer to section 1.14.2.

NOTE:
Before proceeding, determine if seal to be removed is Federal Mogul® or CR brand. Remove and clean all rust and dirt from the crankshaft surface.

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Remove the Federal Mogul seal as follows:

1. Install puller, J 41329 part of J 35993, over crankshaft and hold against seal.
2. Using variable speed drill motor and 5/32" bit, drill through outer and inner case of seal using smallest hole "A" as a guide. See Figure 1-131.

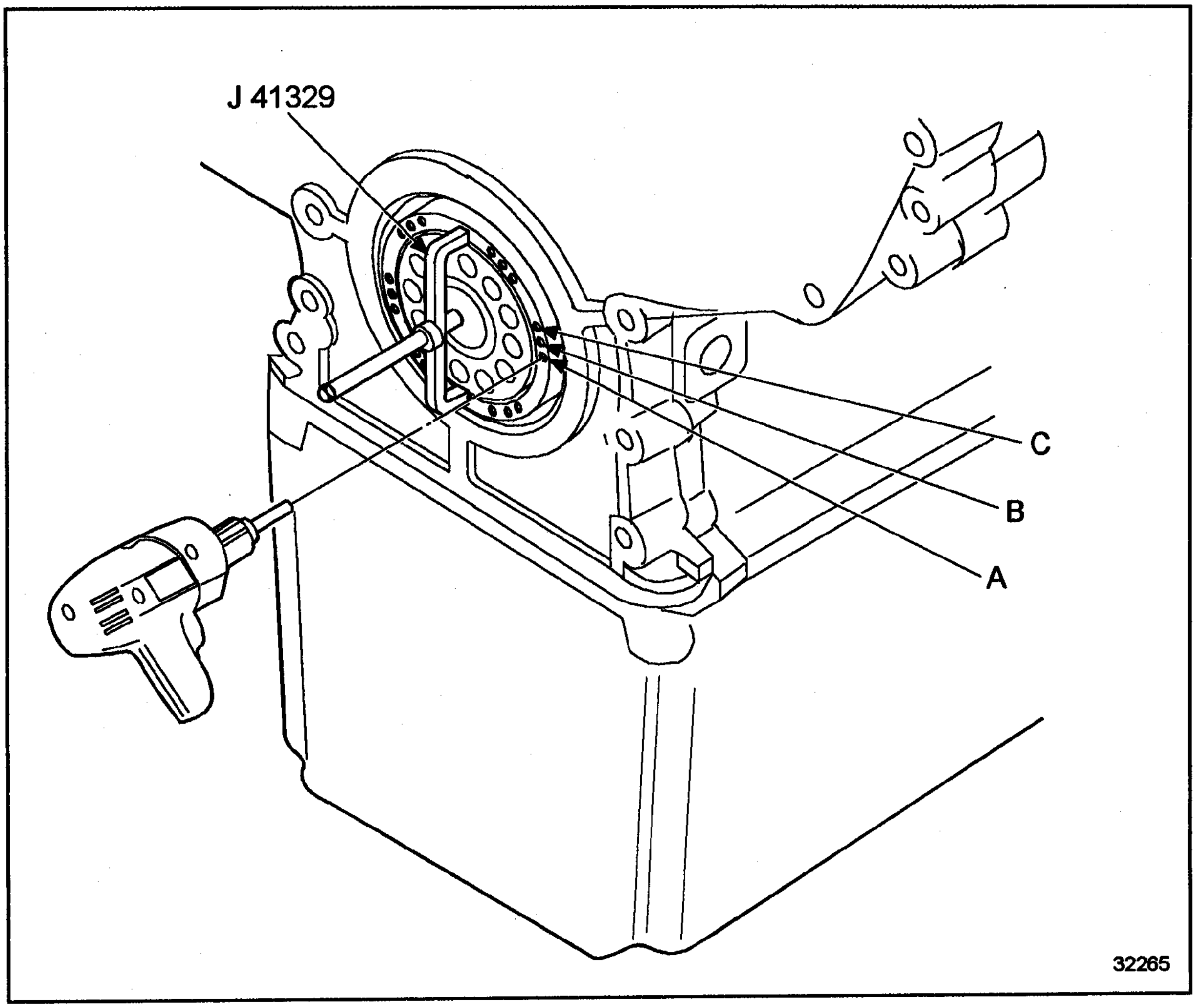

Figure 1-131 Rear Oil Seal Removal

3. Without moving J 41329 part of J 35993, drill two additional "A" holes equally spaced.

NOTE:
All six holes may be drilled if using three holes proves unsuccessful in pulling seal.

4. Rotate J 41329 part of J 35993 clockwise until the "B" holes align with drilled holes and install sheet metal screws.
5. Apply thread lubricant, J 23444-A part of J 35686, to forcing screw and remove seal.
6. Remove the sheet metal screws from the tool. Discard the oil seal.

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Remove the CR seal as follows:

1. Install puller, J 41329 part of J 35993, over crankshaft and hold against seal.
2. Using variable speed drill motor and 5/32" bit, drill through outer and inner case of seal using smallest hole "A" as a guide. See Figure 1-132.

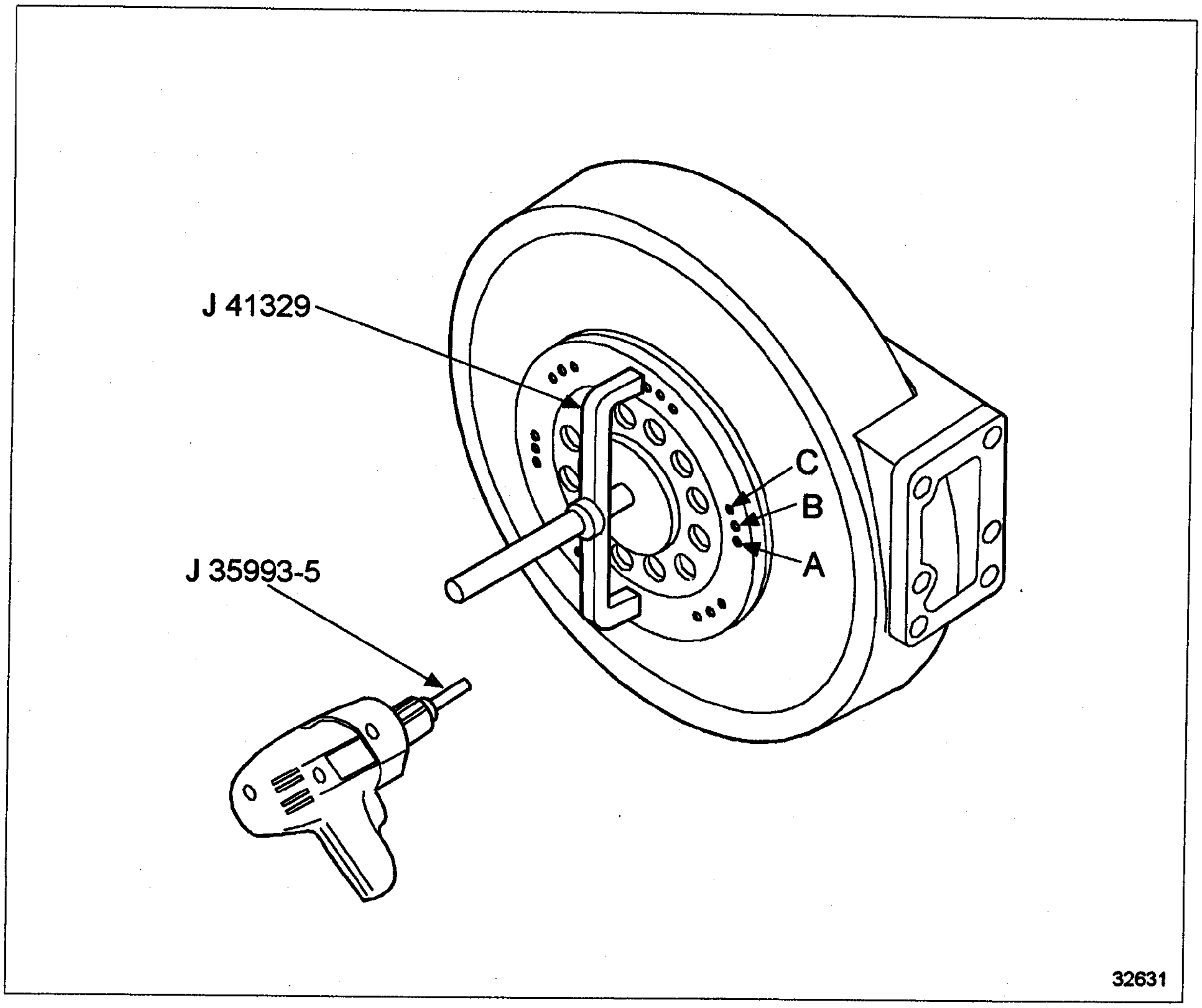

Figure 1-132 Rear Oil Seal Removal

NOTE:
All six holes may be used if using three holes proves unsuccessful in pulling seal.

3. Apply thread lubricant J 23444-A part of J 35686 to forcing screw and remove seal.

NOTE:
If seal is difficult to remove, push seal in 1/8 in., clean crankshaft surface thoroughly and repeat the removal procedure.

4. Remove the sheet metal screws from the tool. Discard the oil seal.

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1.8.6 Removal of Rear Oversized Crankshaft Seal with Wear Sleeve

If seal removed is an oversized seal with wear sleeve, the old wear sleeve must also be removed as follows:

1. To remove a worn wear sleeve, use crank shaft wear sleeve remover, J 37075-A. See Figure 1-133.
   [a] Install hardened steel sleeve removal tool into flywheel housing bore. Using socket and breaker bar, rotate tool in three different locations, 2, 4, and 8 o'clock positions, to score the sleeve, until sleeve stretches sufficiently so it can be slipped off the end of the crankshaft.
   [b] Crocus cloth may be used to clean up the high spots from the surface of the crankshaft. Clean the crankshaft. Clean the crankshaft contact surface thoroughly.

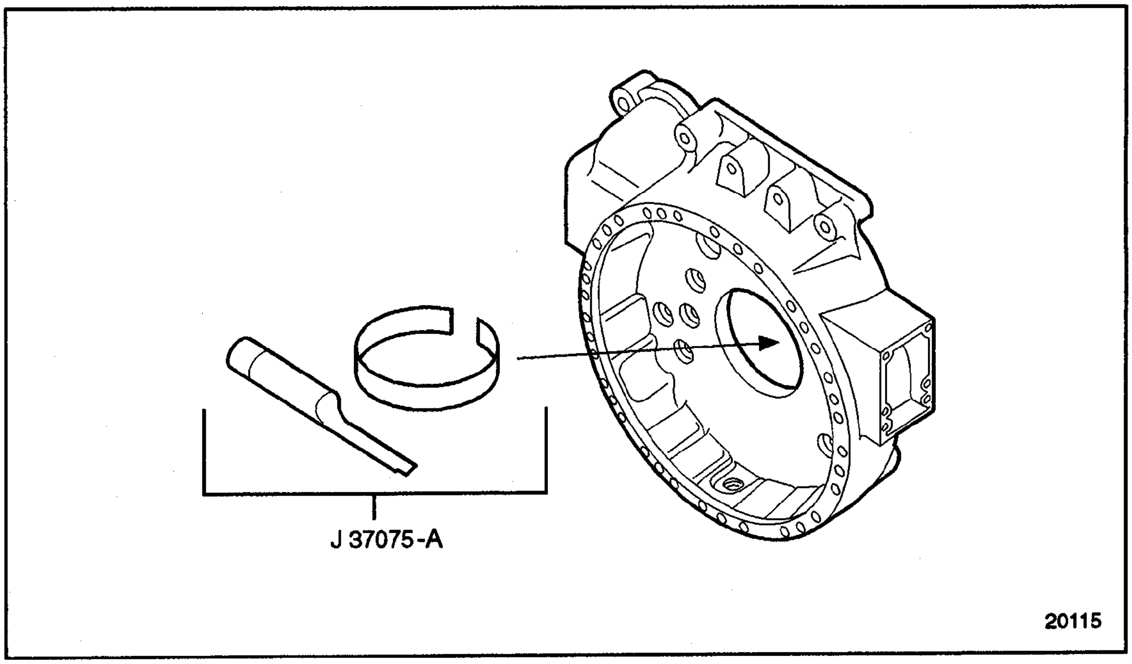
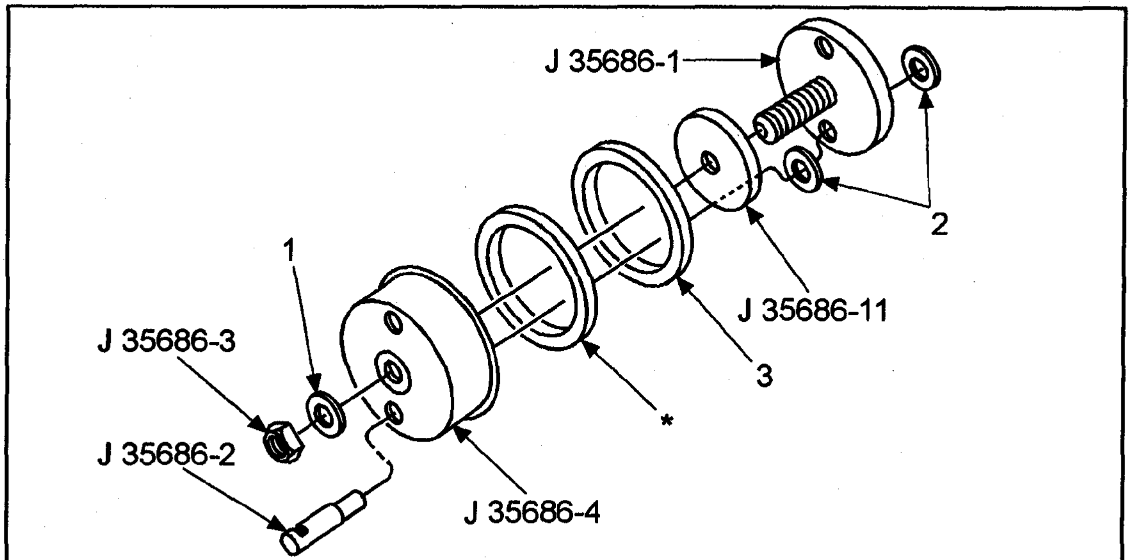


Figure 1-133 Rear Oil Seal Wear Sleeve Removal

1.8.7 Installation of Front and Rear Crankshaft Oil Seal and Wear Sleeve

Install the front oil seal as follows:

An oil seal sleeve, integral to the seal assembly, is pressed onto the end of the crankshaft and provides a replacement wear surface at the point of contact with the oil seal. The sleeve and seal are supplied assembled. The assembly is installed using the crankshaft oil seal and sleeve installation tool. The Federal Mogul® oil seal is installed using tool,J 35686-A, with collar J 35686-10. The Chicago Rawhide® (CR) oil seal is installed using J 35686-B, but uses collar J 35686-20. See Figure 1-134 and see Figure 1-135.



1. Washer
2. Washer
3. Crankshaft Seal

Figure 1-134 Front Crankshaft Oil Seal and Sleeve Installation Tool Set

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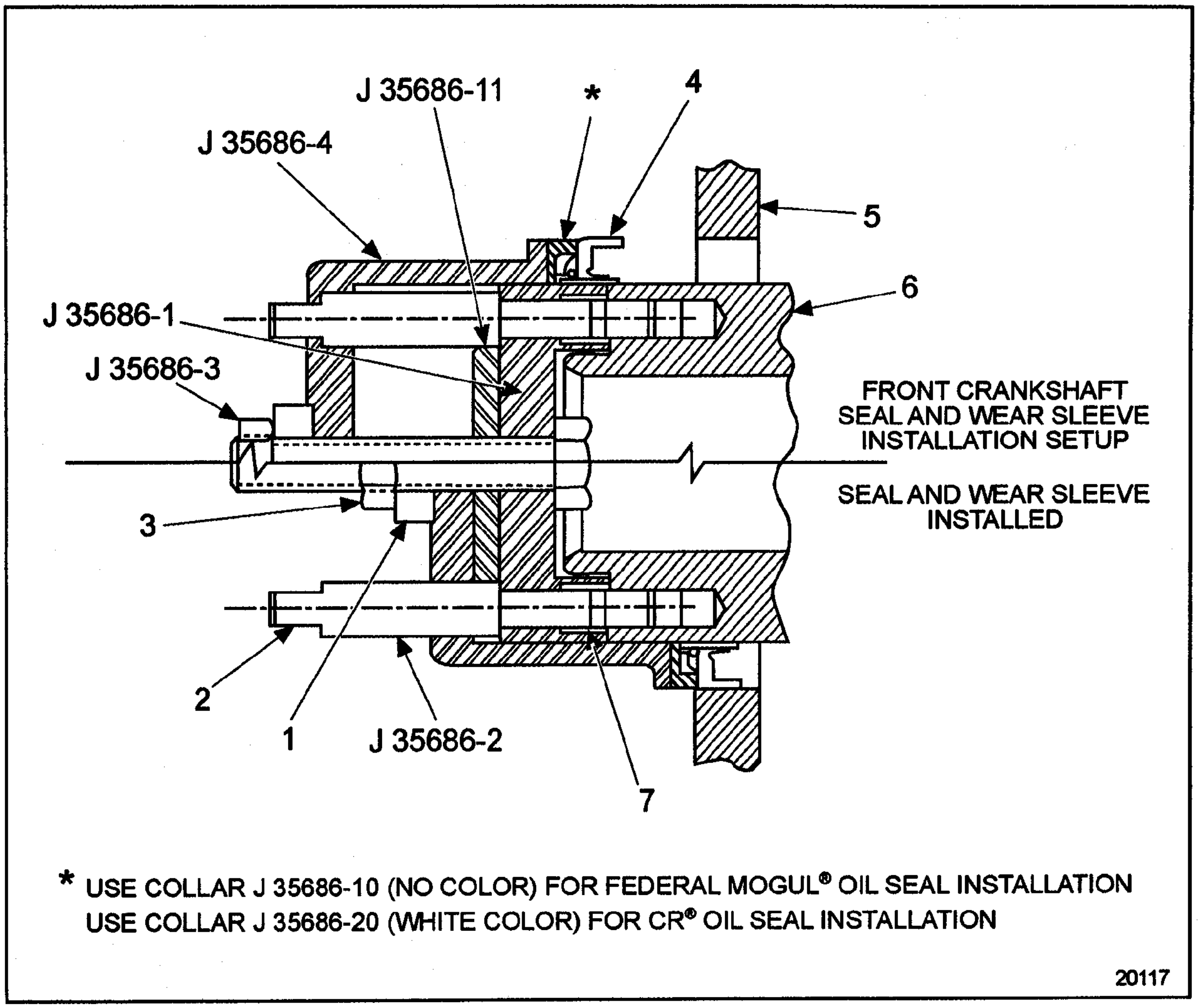

1. Thrust Plate
2. Wrench Flat 1/2 in., Guide Stud
3. 3/4 - 10 Hex Nut
4. Seal and Wear Sleeve Assembly
5. Gear Case/Flywheel Housing
6. Crankshaft
7. Guide Stud Retainer (O-ring)

Figure 1-135 Front Crankshaft Oil Seal

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Install an oversize oil seal and sleeve, as follows:

1. Install the new, oversize oil seal and wear sleeve assembly to the housing.

NOTE:
The assembly used in dry flywheel housings has a unidirectional, lip type Teflon inner sealing lip and a forward facing Teflon dust lip. The assembly used in wet flywheel housings has a double-lip seal with unidirectional inner and outer laydown type Teflon sealing lips.

2. Add new adapter ring and spacers. Do not separate the two.

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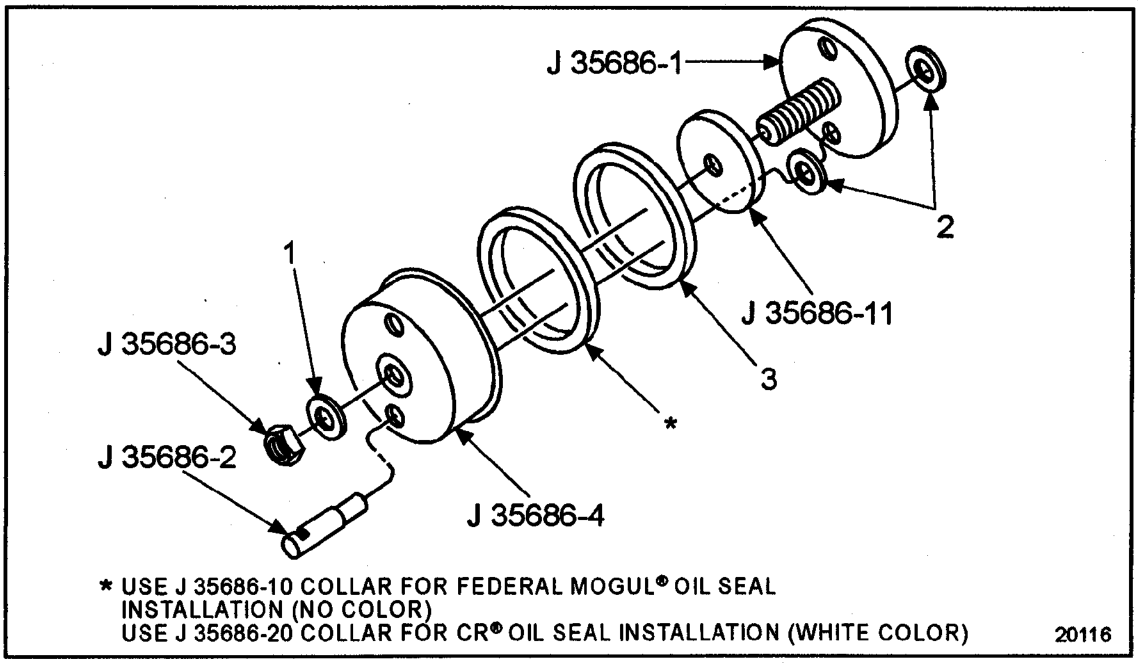
Perform the following steps to install the rear oil sleeve:

NOTE:
Rear oil seals have a color code of green for engines built after 6R491683.

NOTE:
The assembly used in dry flywheel housing has unidirectional, lip type Teflon inner sealing lip and a forward facing Teflon dust lip. The assembly used in wet flywheel housings has a double-lip seal with unidirectional inner and outer laydown type Teflon sealing lips.

1. Install the two guide studs, J 35686-2, through the holes provided in the base, J 35686-1, and into two of the tapped holes in the crankshaft, 180 degrees apart. See Figure 1-136. Tighten the guide studs using the appropriate wrench on the flats of the studs. The base must be tight against the end of the crankshaft.



1. Washer
2. Washer
3. Crankshaft Seal

Figure 1-136 Rear Oil Seal Installation

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2. For rear crankshaft oil seal installations only, install spacer and J 35686-11, to the center screw of the base. See Figure 1-137 and see Figure 1-135.

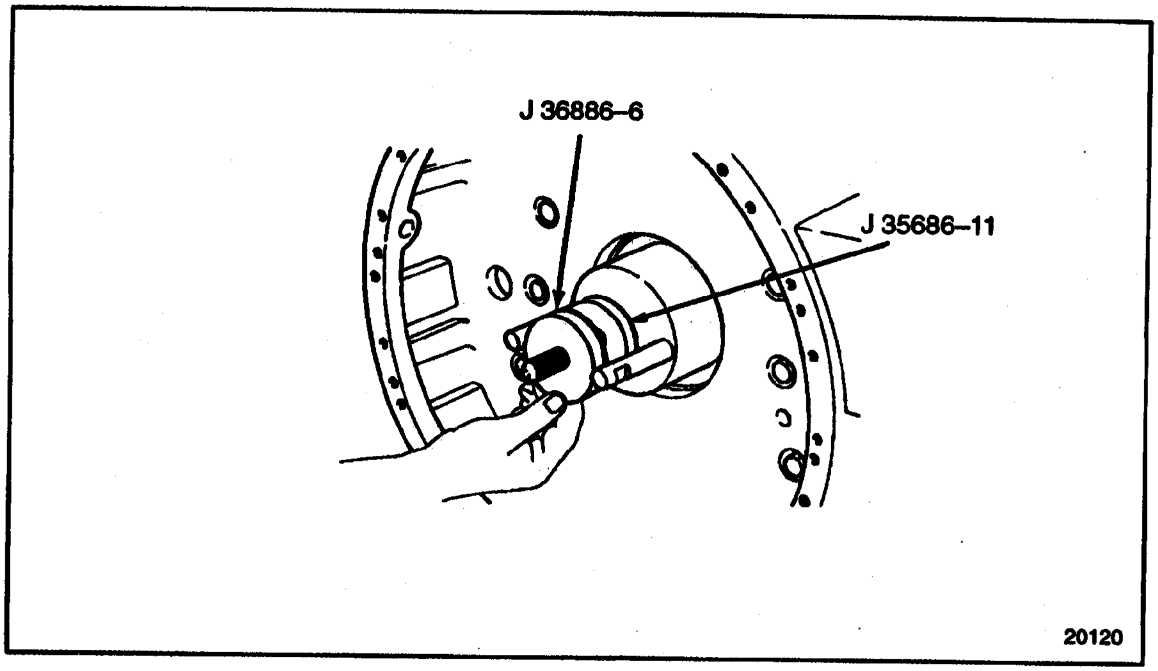

Figure 1-137 Rear Oil Seal Installation

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3. Install the rear housing and adapter ring with seal and sleeve assembly in place on the guide studs. See Figure 1-138.

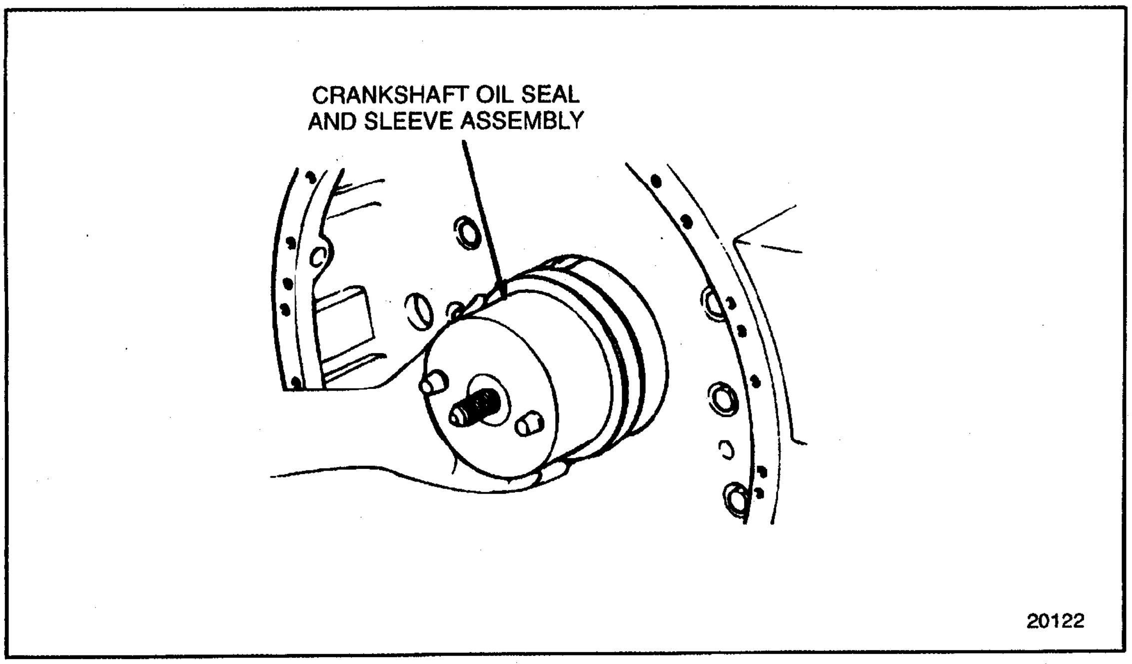

Figure 1-138 Rear Oil Seal and Sleeve Installation

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4. Install the thrust bearing tool with the case side toward the installer housing. Install the hex nut to the center screw of the base. See Figure 1-139.

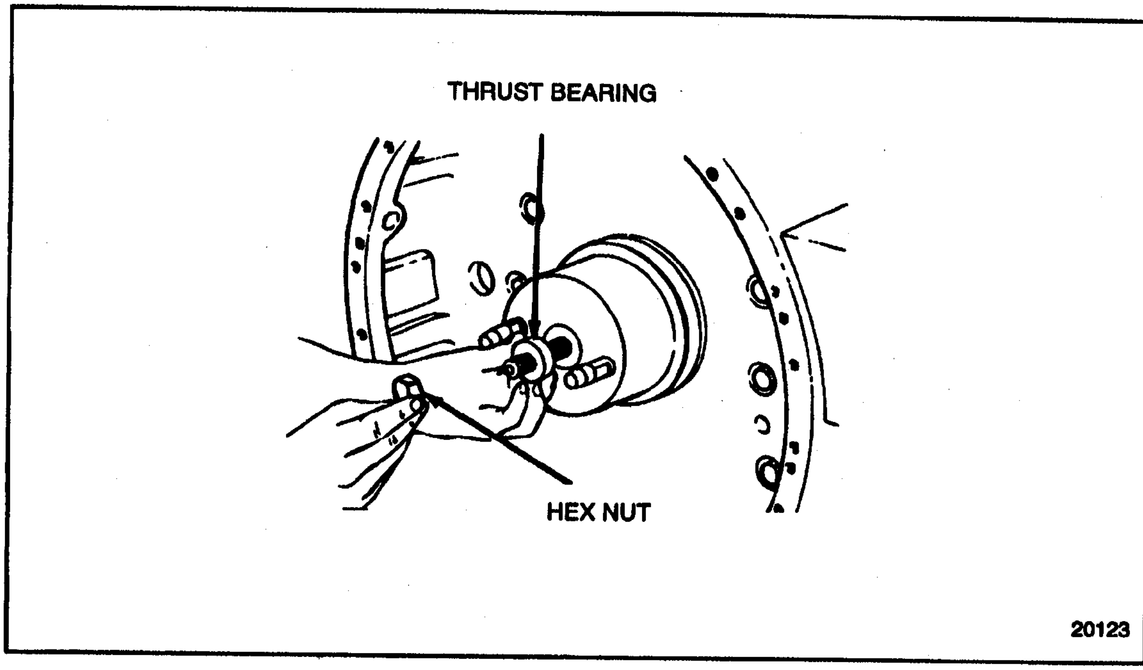

Figure 1-139 Thrust Bearing Installation

5. Tighten the hex nut by hand until all the slack is taken up. Use a ratchet and socket to tighten the hex nut, and install the wear sleeve to the crankshaft and the oil seal to the flywheel housing and/or gear case cover. See Figure 1-140.

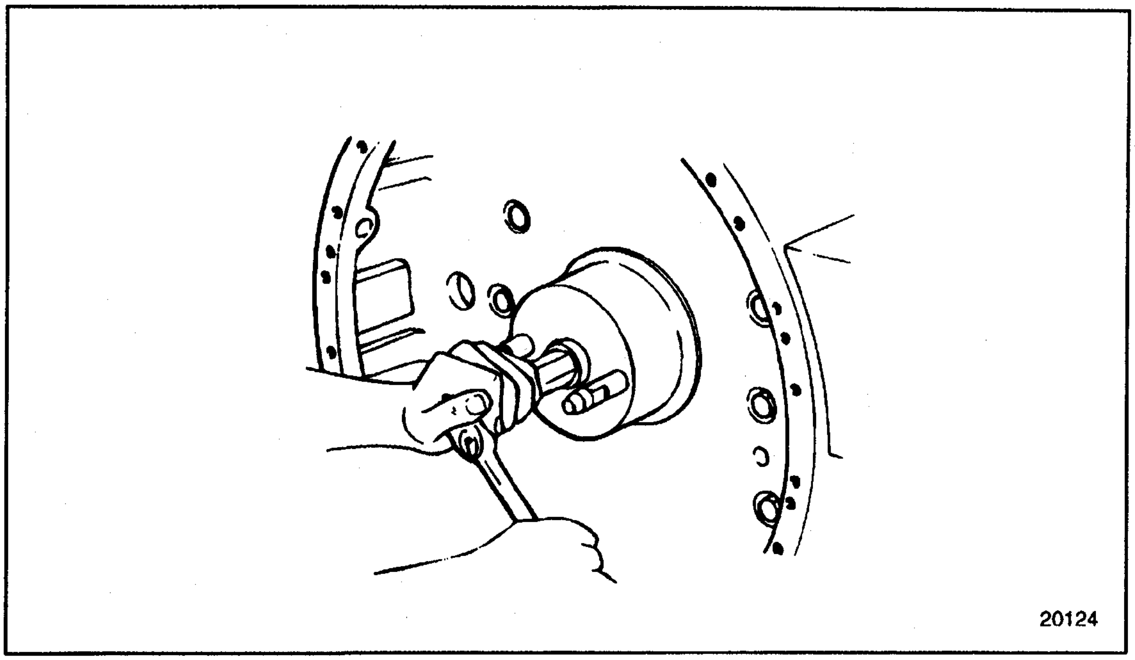

Figure 1-140 Oil Seal and Sleeve Installation

6. When the inside surface of the housing is seated against the base (spacers on rear oil seal installation), the seal and sleeve are properly positioned and installed.

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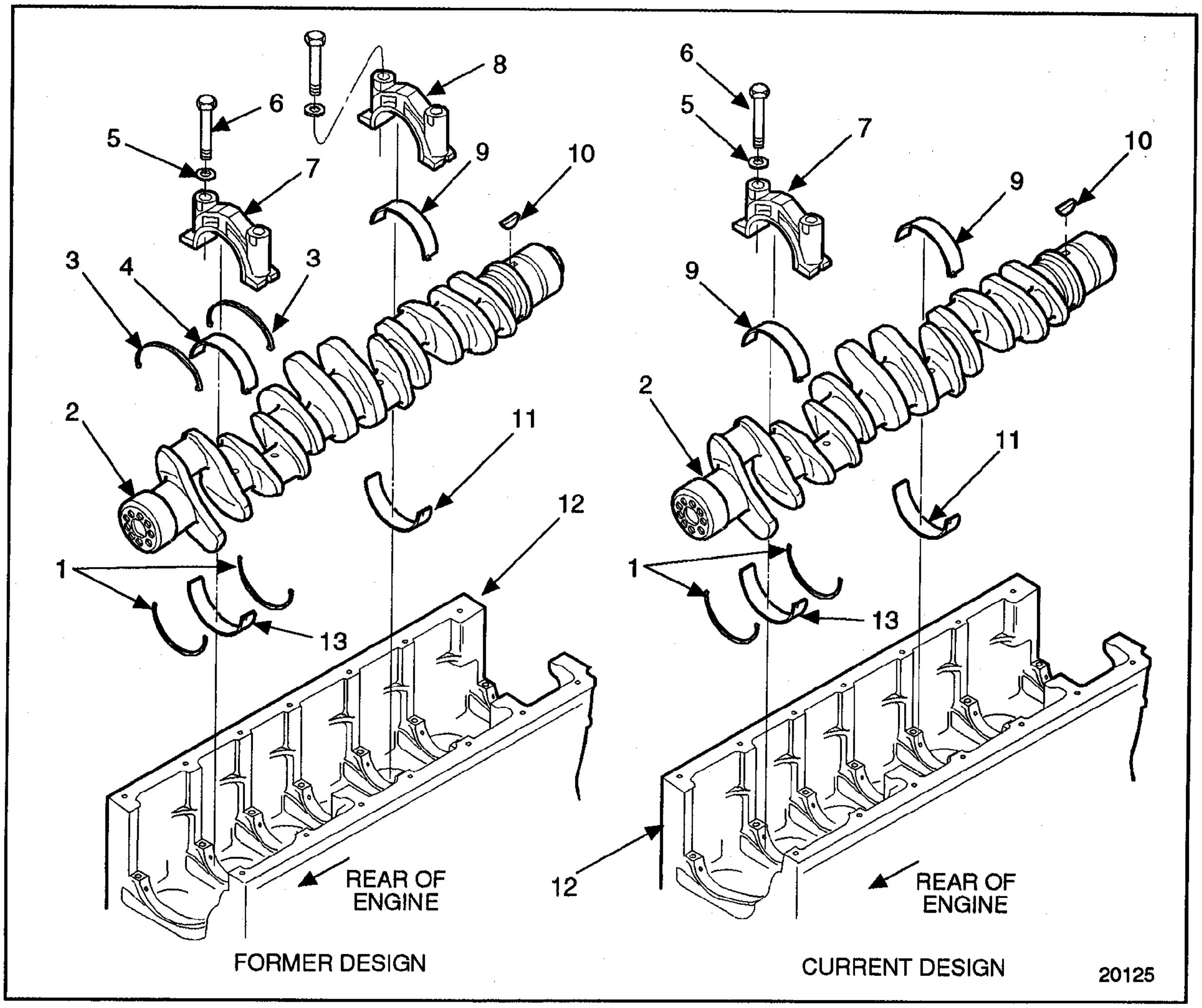
1.9 CRANKSHAFT MAIN BEARINGS

The crankshaft main bearing shells are precision made and are replaceable without machining. They consist of an upper bearing shell seated in each cylinder block main bearing support and a lower bearing shell seated in each main bearing cap. See Figure 1-141.



1. Upper No. 6 Thrust Washers
2. Crankshaft
3. Lower No. 6 Thrust Washers
4. Lower No. 6 Thrust Bearing Shell
5. Washer
6. Bolt
7. No. 6 Main Cap
8. Main Cap No. 1, 2, 3, 4, 5 & 7
9. Lower Thrust Bearing Shell
10. Woodruff Key
11. Upper Thrust Bearing Shell No. 1, 2, 3, 4, 5 & 7
12. Cylinder Block
13. Upper No. 6 Thrust Bearing Shell

Figure 1-141 Main Bearing Caps, Bearing Shells and Crankshaft Thrust Washers

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The upper and lower bearing shells are located in the respective block and bearing cap by a tang. The tang is located at the parting line at one end of each bearing shell. The tangs are offset from center to aid correct insertion. Bearing shell sets are supplied as a matched assembly and should not be mixed.

A hole in each upper bearing shell registers with a vertical oil passage in the cylinder block. Lubricating oil, under pressure, passes from the cylinder block oil gallery by way of the bearing shells to the drilled passage in the crankshaft, then to the connecting rods and connecting rod bearings. The upper bearing shell is also grooved.

The lower main bearing shells have no oil holes or grooves. Therefore, the upper and lower main bearing shells must not be interchanged.

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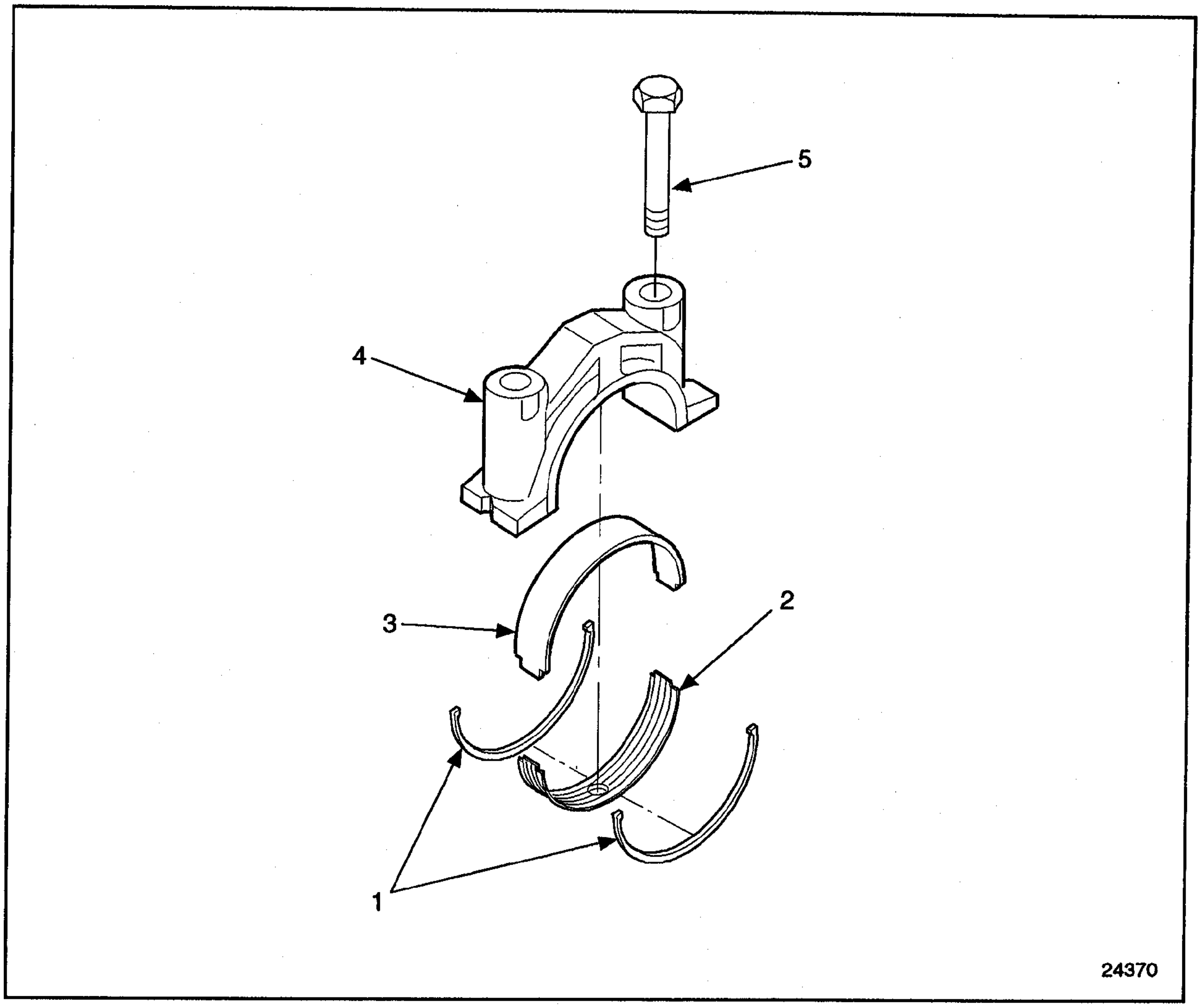
Thrust washers on each side of the No. 6 main bearing absorb the crankshaft thrust. The two-piece washers utilize locking tangs that register with locating notches in the bearing shell. See Figure 1-142.



1. Upper Thrust Washer (2)
2. Upper No. 6 Bearing Shell
3. Lower No. 6 Bearing Shell
4. No. 6 Main Bearing Cap
5. Bolt

Figure 1-142 No. 6 Thrust Bearing Detail

The condition of the lower bearing shells may be observed by removing the main bearing caps.

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1.9.1 Repair or Replacement of Crankshaft Main Bearings

To determine if repair is possible or replacement is necessary, perform the following procedure. See Figure 1-143.

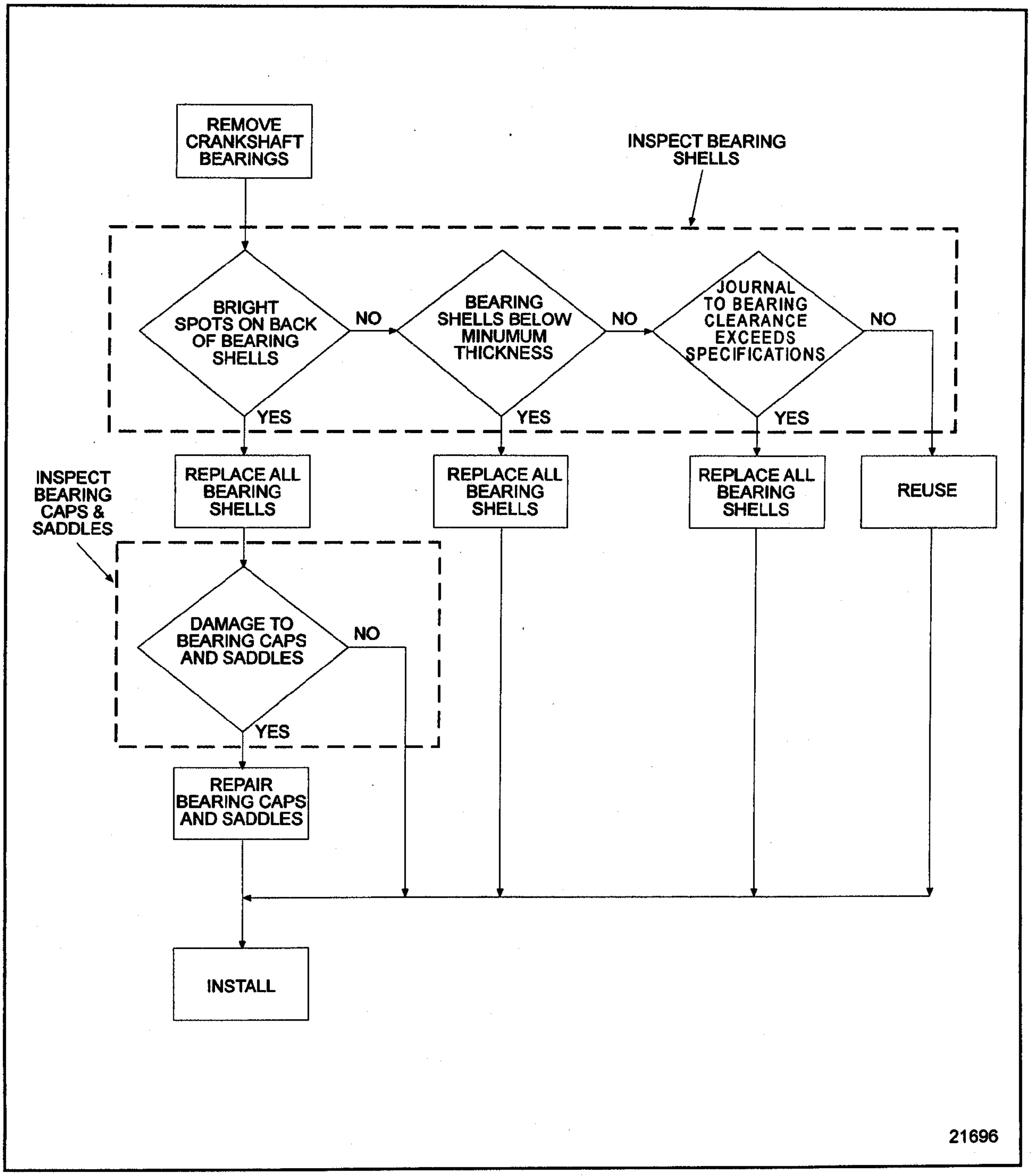

Figure 1-143 Flowchart for Repair or Replacement of Crankshaft Main Bearings

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1.9.2 Removal of Main Bearing Shells

The main bearing caps are numbered consecutively, indicating their respective positions. When removed, the bearing caps (and the bearing shells, if they are to be reinstalled) must always be reinstalled in their original position.

1. Drain the oil pan, refer to section 13.13.1 and remove the oil pan to expose the main bearing caps refer to section 3.11.2.
2. Remove the oil pump pickup and outlet pipes, and the oil pump. Refer to section 3.2.2.
3. Remove one bearing cap at a time and inspect the lower bearing shell. Refer to section 1.9.2.2.

NOTE:
If shims are used between the oil pump and the cylinder block, save the shims so that they can be reinstalled in exactly the same location as removed. The shims are used to adjust the crankshaft timing gear-to-oil pump drive gear lash.

4. To remove the upper main bearing shells without crankshaft removal, it will be necessary to use the main bearing shell remover and installer tool set, J 36187 . See Figure 1-144.

NOTE:
Remove and reinstall both upper and lower bearing shells for each main journal being inspected before moving on to the next main journal. Never remove more than one main bearing cap at a time except for No. 6 and No. 7.

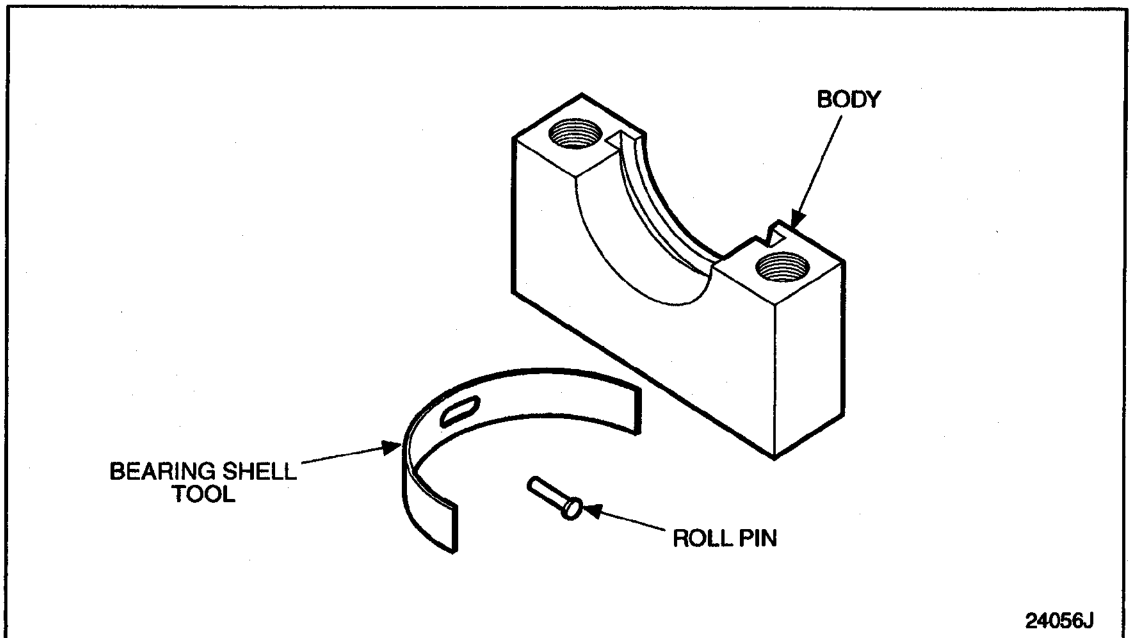

Figure 1-144 Main Bearing Shell Remover and Installer Tool Set

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5. To bar the engine over, use the square hole in the middle of the crankshaft pulley, to position the crankshaft throw. Position the crankcase throw for the main bearing being worked on so that the oil delivery hole is pointing upward. See Figure 1-145.

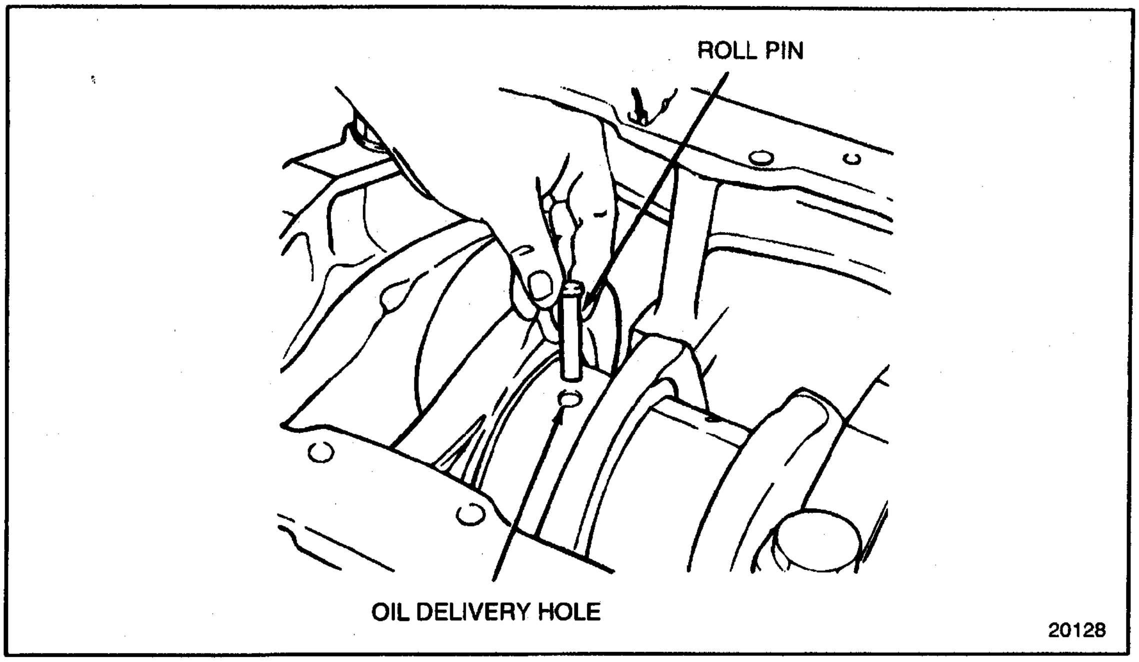

Figure 1-145 Roll Pin Hole Installation

6. Install the roll pin to the oil delivery hole in the crankshaft journal. See Figure 1-145. If this operation is being performed in-frame, use petroleum jelly to retain the roll pin in the hole.
7. For the No. 6 main bearing journal, it will be necessary to install the lower main bearing thrust washers (previously removed) to the machined faces of the body from the tool kit. Stick the thrust washers to the main cap using petroleum jelly. Index the locating tangs on the thrust washers with the cutouts on the bearing shell. See Figure 1-146.

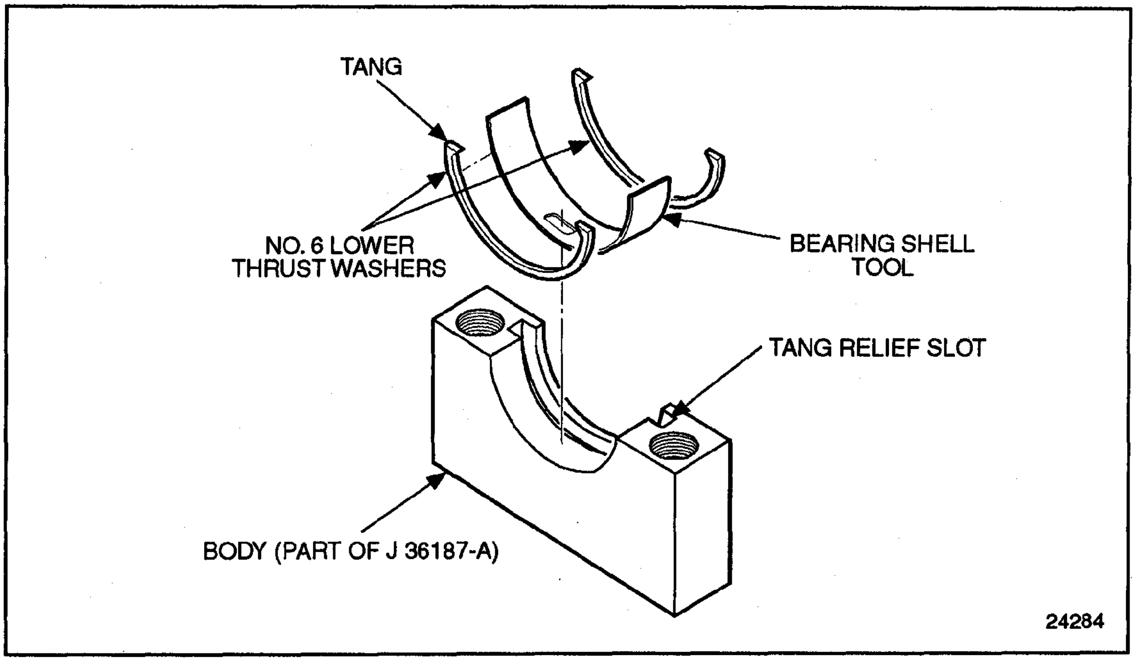

Figure 1-146 Upper Main Bearing Shell Removal-Tool Set-Up

8. Using the main bearing cap bolts and washer removed from the engine, install the assembled main bearing cap remover and installer tool to the main bearing saddle being worked on. The word "Front" stamped on the tool must face the front of the engine. Be sure that the roll pin in the oil delivery hole registers with the cutout section of the bearing shell tool before tightening the main bearing cap bolts. See Figure 1-147.

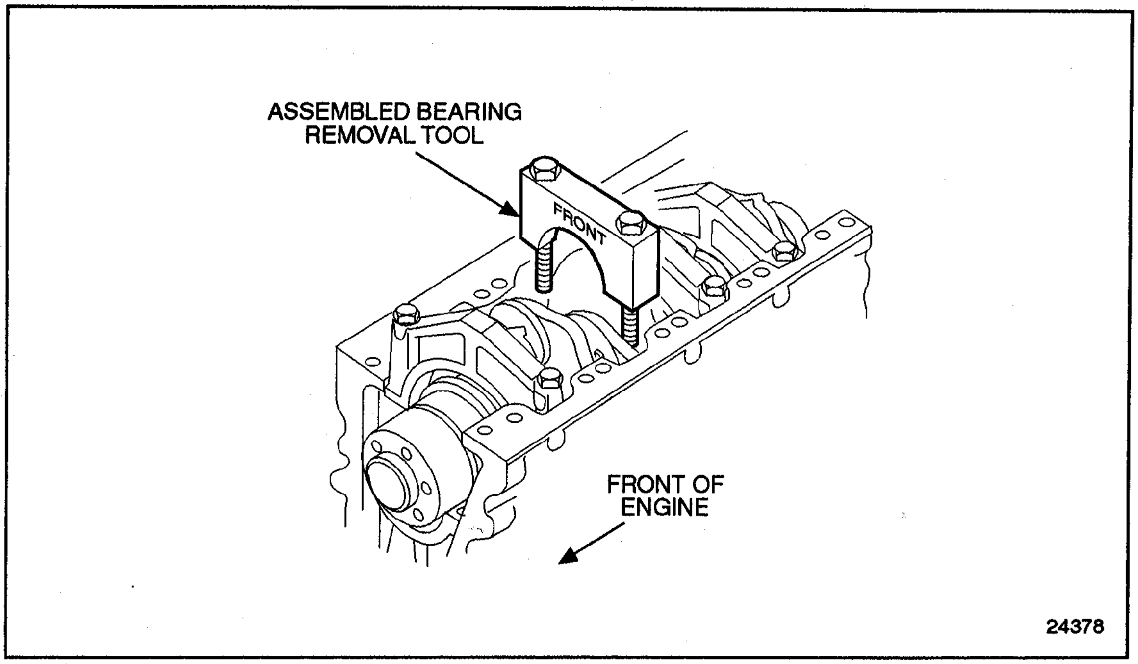

Figure 1-147 Upper Main Bearing Shell Remover Tool Installation

NOTE:
Only the No. 6 main bearing shell requires use of the thrust washers on the sides of the remover tool. For main bearings No. 1, 2, 3, 4, 5, and 7, it will not be necessary to install the thrust washers to the tool.

9. Torque the main bearing cap bolts until they are snug 13-27 N·m (10-20 lb·ft).
10. Using the square hole in the middle of the crankshaft pulley, bar the engine over in a clockwise direction when viewed from the front, approximately 180 degrees until the tang of the upper main bearing contacts the block. This will roll the bearing shell tool (and the thrust washers for No. 6 main bearing) into the upper main bearing saddle.

NOTE:
Keep all bearing shells and thrust washers segregated by number, so that they may be reinstalled exactly as removed if the bearing shells are reused. Shells and washers may be marked with a permanent marker or equivalent. Do not punch mark or otherwise disturb the surface of the shells and washers to mark them.

11. Remove the main bearing cap tool from the saddle.

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12. Remove the upper shell (and two thrust washers when working on No. 6 main) from the tool.
13. Inspect the bearing shells (and thrust washers for No. 6 main). Refer to section 1.9.2.2.
14. Install the upper main bearing to be used, in the main bearing installer and remover with the word "Front" facing the front of the engine. If the No. 6 main bearing is being done, install the thrust washers to the bearing. Refer to step 7 in this procedure.
15. Position the remover and installer with the bearings in the saddle being worked on and install the main bearing cap bolts and washers. Torque the bolts until they are snug 13-27 N·m (10-20 lb·ft).
16. Using the square hole in the crankshaft pulley, bar the engine over slowly, in a counterclockwise direction, approximately 180 degrees until the bearing split line is even with the cap and block joint face. Care must be taken not to bar the engine over too far and damage the bearing tang.
17. Remove the bearing remover and installer assembly, J 36187.
18. Install the lower main bearing shell to be used, into the engine main bearing cap.

NOTE:
Thrust washers in the No. 6 main bearing cap are no longer required if the engine was built with them. They do not need to be reinstalled.

19. Coat the threads and underside of the heads of the main bearing cap bolts with International Compound #2®. Position the main bearing cap, with bearing(s) in place into the saddle and install the bolts and washers. Rap the main bearing caps sharply with a fiber mallet or plastic hammer to ensure the caps are fully seated. Torque the bolts to 470-530 N·m (347-391 lb·ft).
20. It will be necessary to reinstall the upper and lower main bearing shells (and the upper thrust washers for the No. 6 main) and the main bearing cap, for the bearings being inspected or replaced before proceeding to the next main bearing saddle. Refer to section 1.9.3.
21. Repeat this procedure for each main bearing saddle until all seven sets of main bearings have been removed and inspected or replaced.

NOTE:
No. 7 main bearing journal does not have an oil hole, so the bearing remover cannot be used at that position. The No. 7 upper main bearing should be removed with both No. 6 and No. 7 main bearing caps off. Using a suitable tool, push on the No. 7 upper bearing on the side opposite the tang and dislodge the bearing tang from the tang slot in the cylinder block. Carefully push and pull the bearing the rest of the way out, taking care not to damage the bearing shell. Rotate the crankshaft, and apply some pressure to the side of the bearing while rotating.

22. After removal, clean the bearings.

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1.9.2.1 Cleaning of Main Bearings

Perform the following to clean the main bearing:

1. Immerse the bearing in cleaning agent.

CAUTION:
To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

2. Blow dry the main bearings with compressed air and inspect for damage and wear. Refer to section 1.9.2.2.

1.9.2.2 Inspection of Crankshaft Main Bearings

Bearing failures may result from deterioration (acid formation) or contamination of the oil or loss of oil. An analysis of the lubricating oil may be required to determine if corrosive acid and sulphur are present, which cause acid etching, flaking and pitting. Bearing seizure may be due to low oil or no oil.

Inspect the bearings for scoring, pitting, flaking, etching; or signs of overheating. The bearing overlay may develop minute cracks or small isolated cavities (checking) on the bearing surface during normal engine operation. These are characteristics of and are not detrimental to this type of bearing. They should not be replaced for these minor surface imperfections, since function of the bearings is in no way impaired and they will give many additional hours of trouble-free operation.

Inspect the backs of the bearing shells for bright spots, which indicate they have been moving in the bearing caps. If such spots are present, discard the bearing shells, and inspect the bearing caps and upper bearing saddles.

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Measure the thickness of the bearing shells at a point, 90 degrees from the parting line. See Figure 1-148.

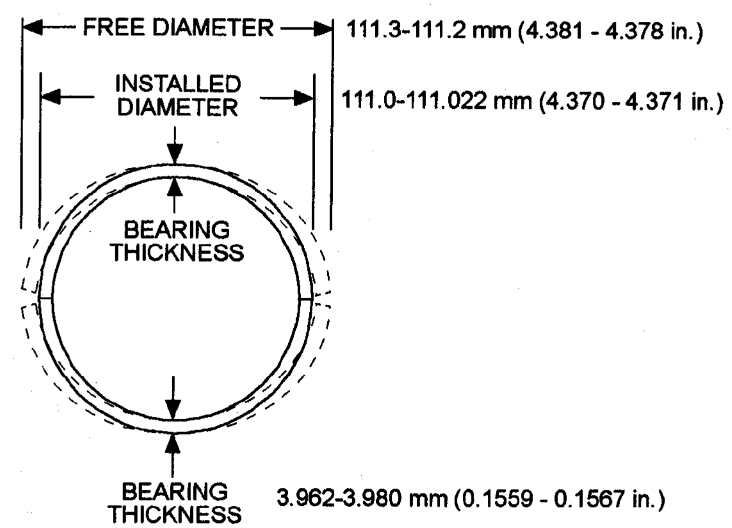

Figure 1-148 Main Bearing Measurements

Tool J 4757, placed between the bearing shell and a micrometer, will give an accurate measurement. The bearing shell thickness will be the total thickness of the steel ball in the tool and the bearing shell, less the diameter of the ball. This is the only practical method for measuring the bearing thickness, unless a special micrometer is available for this purpose. The minimum thickness of a worn standard main bearing shell is 3.937 mm (0.155 in.). If any of the bearing shells are thinner than this dimension, replace all of the bearing shells. A new standard bearing shell has a thickness of 3.962-3.980 mm (0.1560 -0.1567 in.). If any bearing shell shows wear through the overlay across the width of the shell, all bearing shells must be replaced.

In addition to the thickness measurement, check the clearance between the main bearings and the crankshaft journals. This clearance may be determined with the crankshaft in place by means of a soft plastic measuring strip that is squeezed between the journal and the bearing as described in "Checking Bearing Clearance". Refer to section ADDITIONAL INFORMATION 1.A. With the crankshaft removed, measure the outside diameter of the crankshaft main bearing journals and the inside diameter of the main bearing shells when installed in place with the proper torque 470-530 N·m (347-391 lb·ft) torque on the bearing cap bolts. When installed, the bearing shells are 0.0254 mm (0.001 in.) larger in diameter at the parting line than 90 degrees from the parting line.

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The bearing shells do not form a true circle out of the engine. When installed, the bearing shells have a squeeze fit in the main bearing bore and must be tight when the bearing cap is drawn down. This crush assures a tight, uniform contact between the bearing shell and bearing seat. Bearing shells that do not have sufficient crush will not have uniform contact, as shown by shiny spots on the back, and must be replaced. If the clearance between any crankshaft journal and its bearing shells exceeds 0.1524 mm (0.006 in.), all of the bearing shells must be discarded and replaced. This clearance is 0.040-0.127 mm (0.0016 -0.005 in.) with new parts.

If installing new replacement bearings, it is very important to thoroughly inspect the crankshaft journals. Also, damaged bearings may cause bending fatigue and resultant cracks in the crankshaft. Refer to section 1.7.2.11, and refer to section 1.7.2.9.

Do not replace one main bearing shell alone. If one bearing shell requires replacement, install all new upper and lower shells.

NOTE:
Anytime a new or reground crankshaft is used, all new bearing shells must be used.

Bearing shells are available in 0.254, 0.508 and 0.762 mm (approximately 0.010,.020 and 0.030 in.) undersize for service with reground crankshafts as listed in Table 1-10to determine what size bearings are required. Ensure the correct bearing to journal clearance is maintained when using these parts.

NOTE:
Bearing shells are NOT reworkable from one undersize to another undersize under any circumstances.

Inspect the crankshaft thrust washers. If the washers are discolored or worn excessively, or if the crankshaft end play is excessive, replace the thrust washers. Inspect the crankshaft thrust surfaces. Refer to section 1.7.2.1. If, after dressing or regrinding the thrust surfaces, new standard size thrust washers do not hold the crankshaft end play within the specified limits, it may be necessary to install oversize thrust washers on one or both sides of the No. 6 main bearing. A new standard size thrust washer is 3.56-3.48 mm (0.140 -0.137 in.) thick. Thrust washers are available in 0.127 and 0.254 mm (0.005 and 0.010 in.) oversize.

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1.9.3 Installation of Main Bearings Shells (Crankshaft Removed)

Install the main bearing shells as follows:

1. Check that all of the parts are clean and dry.
2. Apply clean engine oil 360° around each crankshaft main journal and install the upper main bearing shells to their respective saddles in the cylinder block. Note the locating tangs and be sure the oil holes register with the galleries in the cylinder block.
3. Be sure to install the drilled bearing shells in the cylinder block and the plain bearing shells in the bearing caps. The upper and lower main bearing shells are not alike; the upper shell is drilled for lubrication, the lower bearing shell is not. If they are not installed correctly, the oil flow to the bearings and to the upper end of the connecting rods will be blocked off. Used bearing shells must be reinstalled on the same journal from which they were removed.
4. Perform all of the steps under "Installation of Crankshaft." Refer to section 1.7.3.
   - [a] Measure the main bearing clearances. Refer to section ADDITIONAL INFORMATION 1.A, "Checking Bearing Clearances" in "Shop Notes".
5. Measure the crankshaft end play. The minimum and maximum specifications are listed in Table 1-21.
6. Toruqe all of the main bearing cap bolts to 470-530 N·m (347-391 lb·ft).
7. Measure the main bearing bores with dial bore gage, J 5347-B. The minimum specifications are listed in Table 1-15.

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1.10 GEAR CASE COVER

The gear case cover and gear case housing bolt together at the front of the engine to form a sealed compartment for the engine gear train. See Figure 1-149.

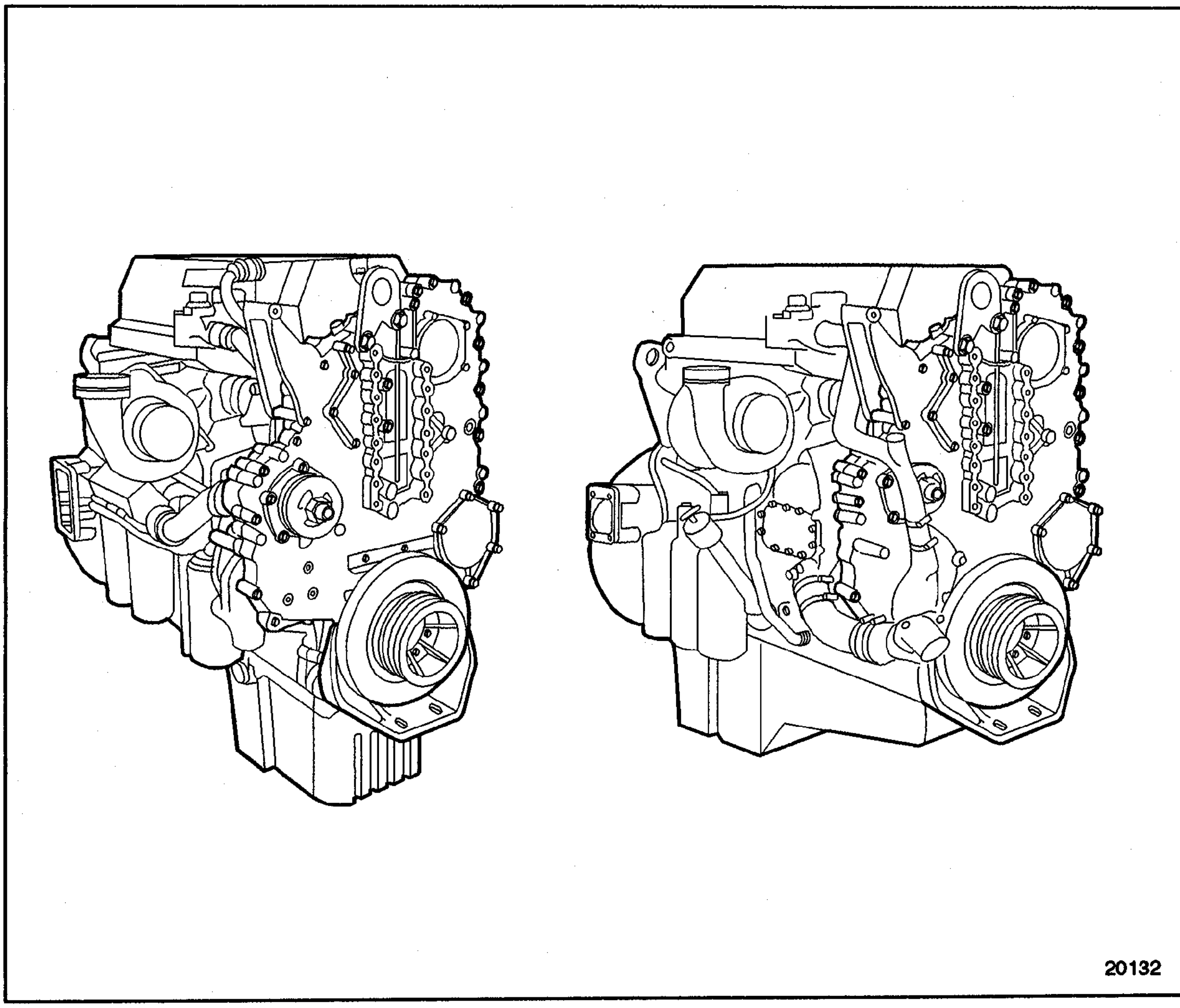

Figure 1-149 Engine Gear Case and Cover

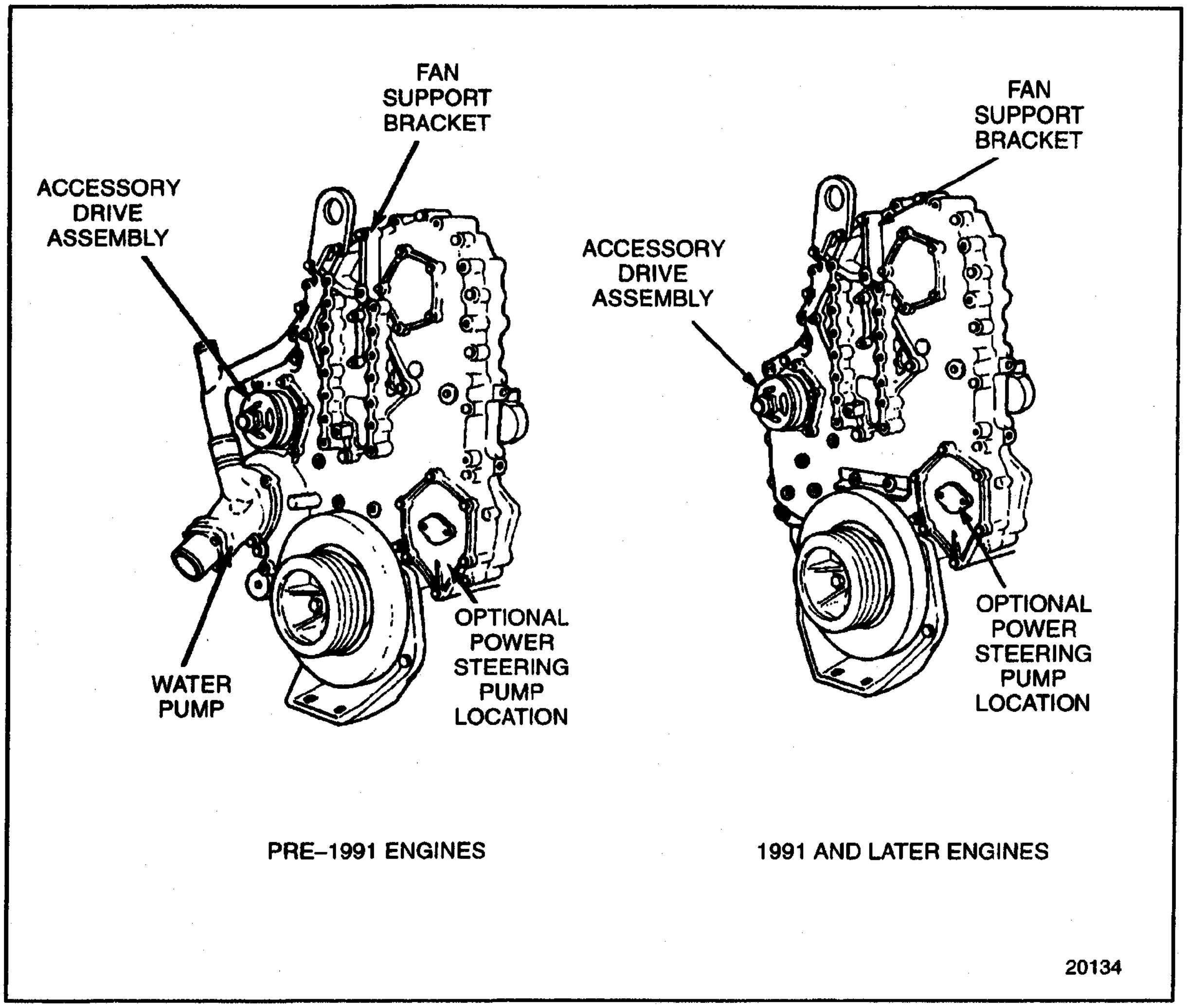

Figure 1-150 Gear Case Cover-mounted Components

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The gear case cover also serves as a retainer for the crankshaft front oil seal. See Figure 1-151.

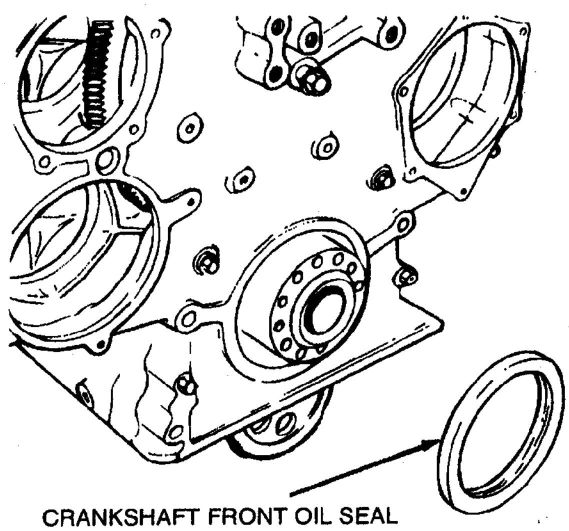

Figure 1-151 Crankshaft Front Oil Seal

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Several components that are mounted to the gear case cover include the water pump (pre-1991 engines only), accessory drive assembly, and fan support bracket See Figure 1-152.

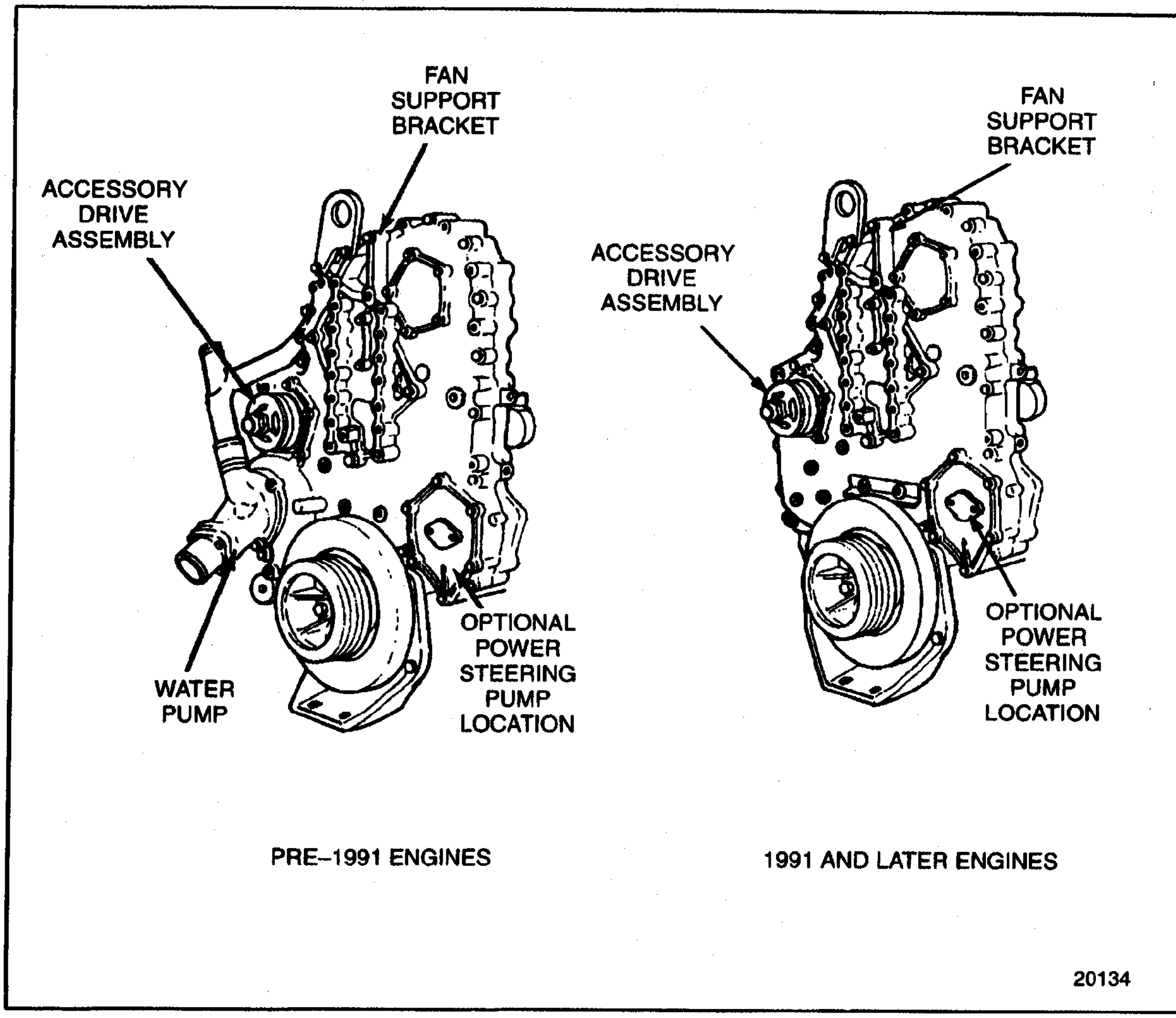

Figure 1-152 Gear Case Cover-mounted Components

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The front engine support is bolted to the front of the gear case cover, directly behind the crankshaft pulley and vibration damper. See Figure 1-153 and see Figure 1-154.

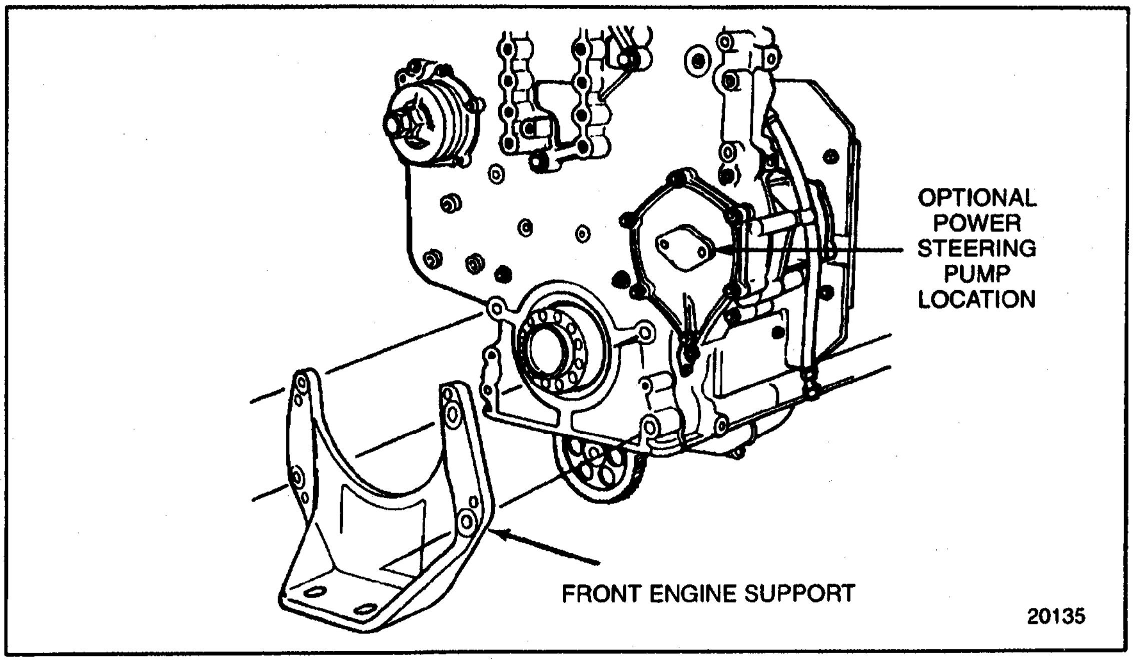

Figure 1-153 Typical Front Engine Support

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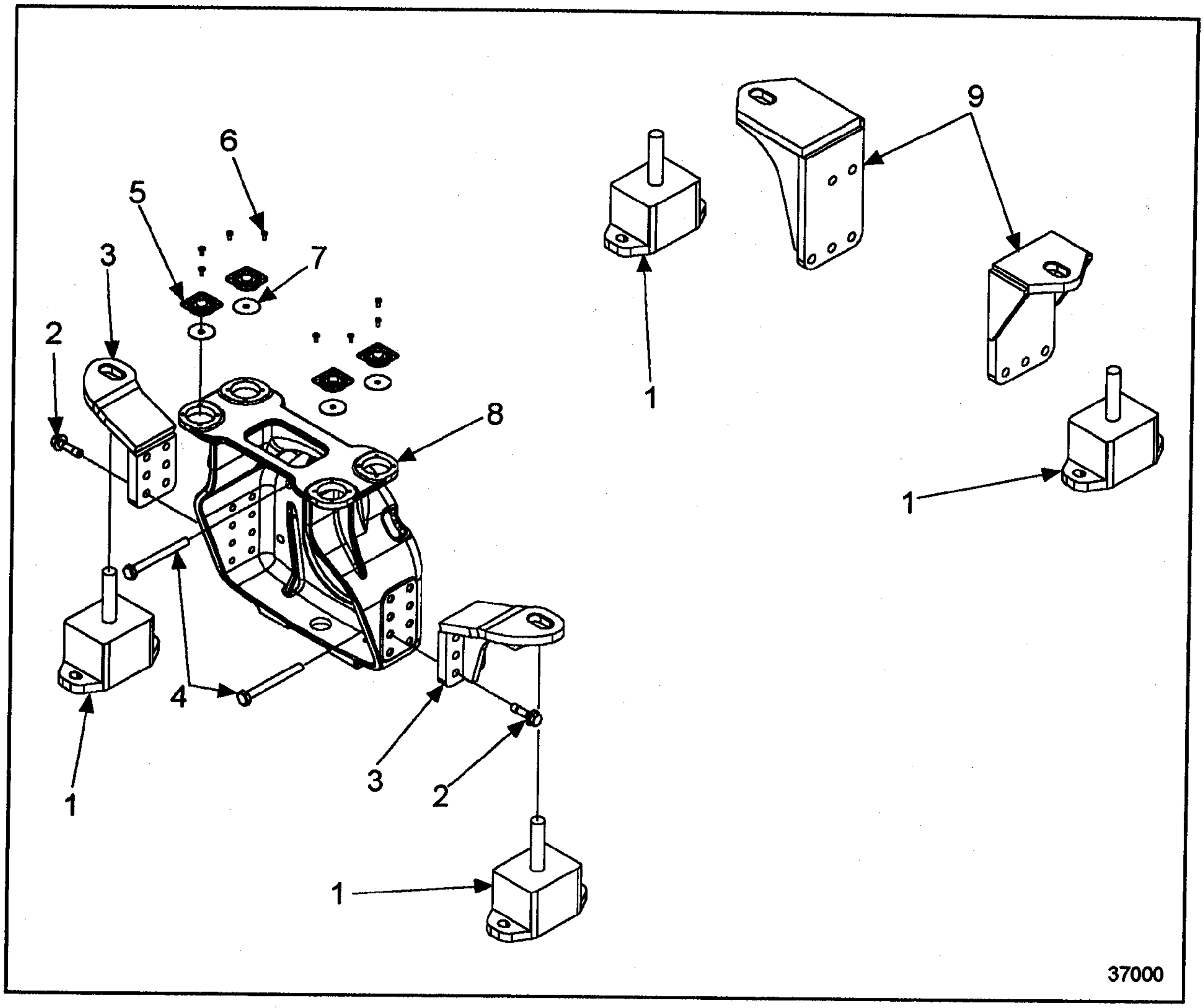

1. Bracket, Engine Mounting
2. Short Mounting Bracket
3. Front Heat Exchanger Support Mounting Bracket
4. Long Mounting Bolt
5. Isolator, Heat Exchanger
6. Screw, Isolator Mounting
7. Washer
8. Heat Exchanger Support
9. Bracket, Rear Engine Mounting

Figure 1-154 Typical Front Engine Support Heat Exchanger-Cooled Pleasure Craft Marine

Several access covers are provided on the gear case cover for service of the engine without removing the gear case cover. Removal of the camshaft drive gear access cover will allow the removal of the camshaft drive gear-to-camshaft bolt for camshaft and cylinder head removal without removing the gear case cover. See Figure 1-155.

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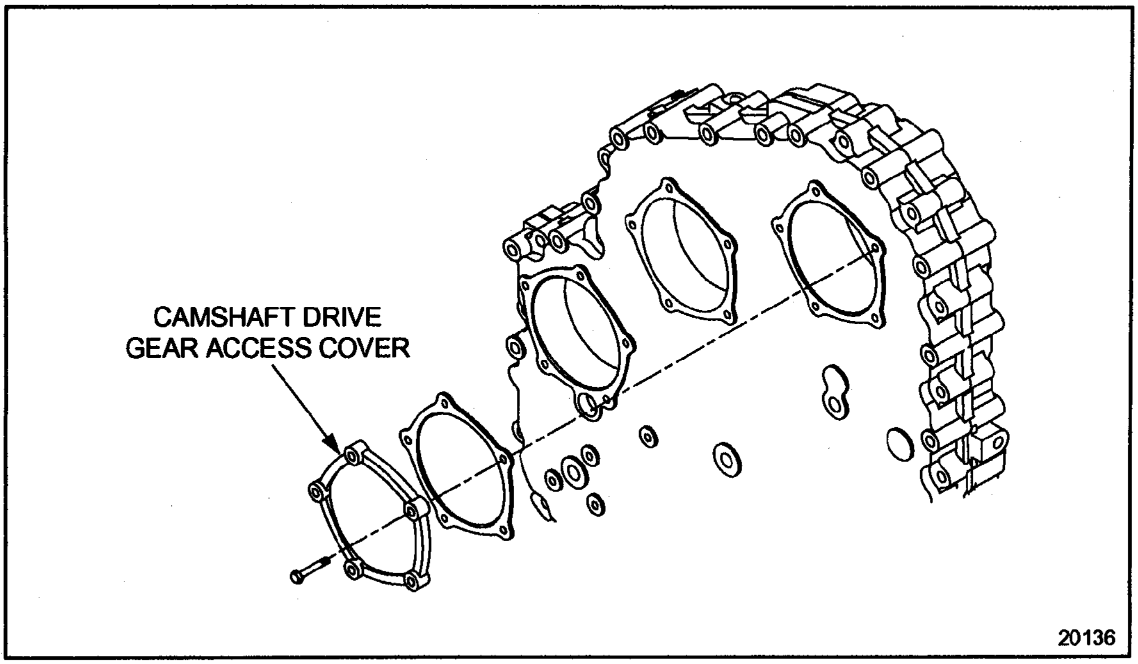

Figure 1-155 Camshaft Drive Gear Access Cover

The fan support bracket includes the access cover for the adjustable idler gear. See Figure 1-156.

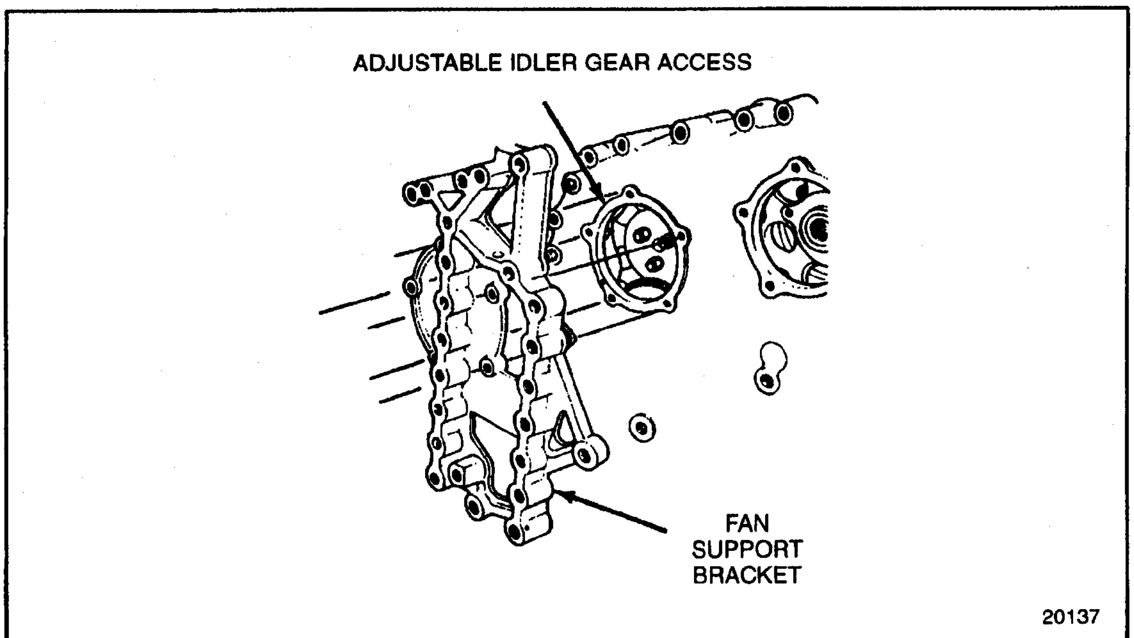

Figure 1-156 Fan Support Bracket

With the fan support bracket and the camshaft drive gear access cover removed, the gear lash between the adjustable idler gear and the camshaft drive gear can be measured and adjusted Refer to section 1.21.2.1.

On vehicles without power steering, an access cover is provided for inspection of the air compressor drive gear. See Figure 1-157.

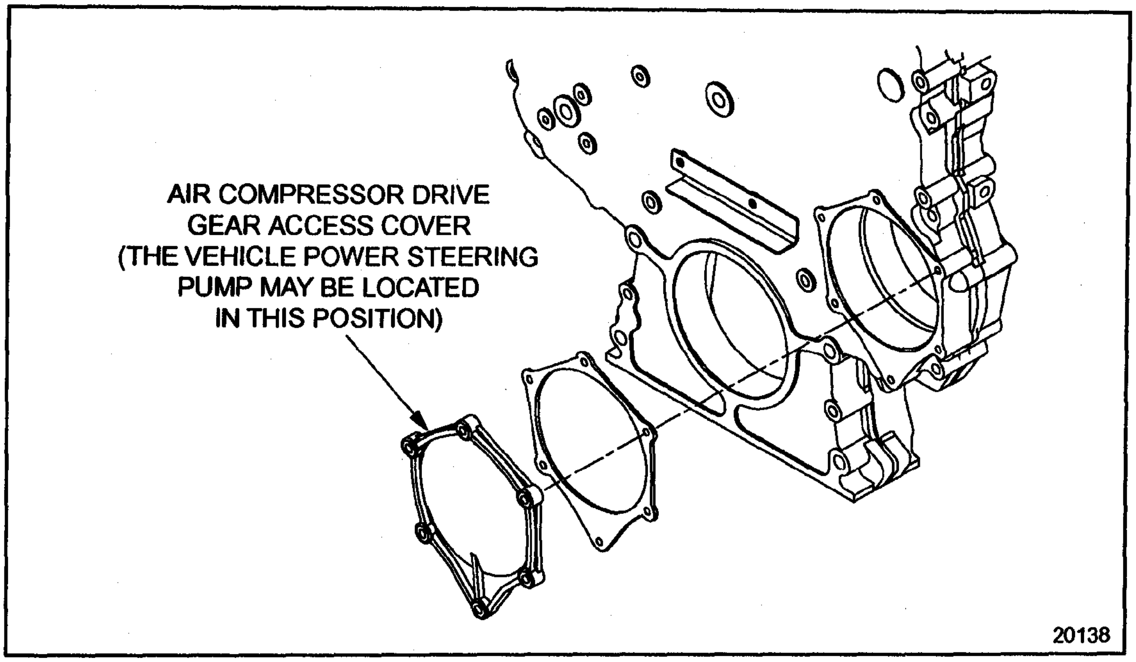

Figure 1-157 Air Compressor Drive Gear Access Cover

On some vehicles equipped with power steering, the power steering hydraulic pump is mounted to the gear case cover in the place of the access cover, and is driven by a short coupling that fits in the splined hole in the center of the air compressor drive gear. The pump is installed with a gasket.

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1.10.1 Repair or Replacement of Gear Case Cover

To determine if repair is possible or replacement is necessary, perform the following procedure. See Figure 1-158.

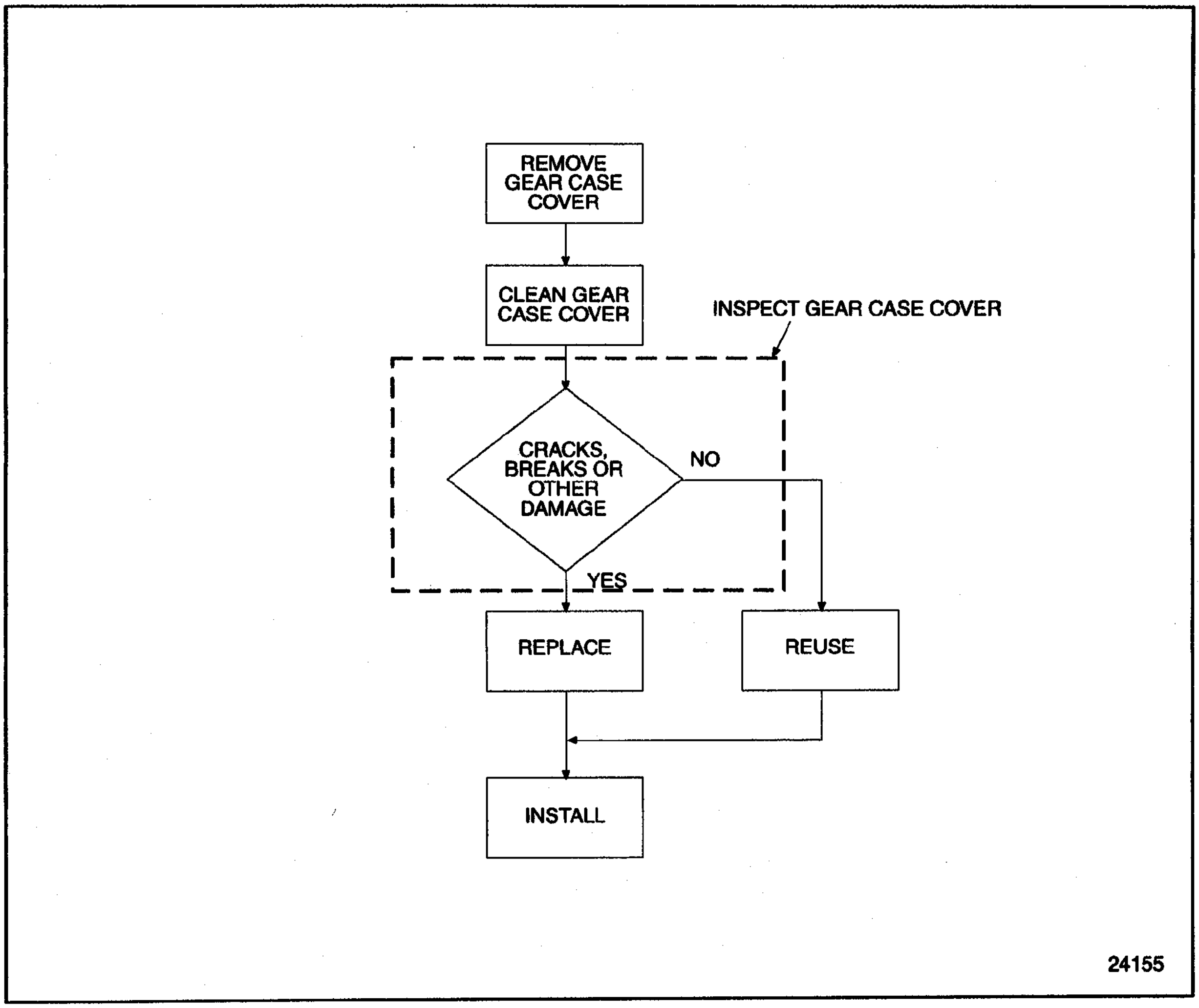

Figure 1-158 Flowchart for Repair or Replacement of Gear Case Cover

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1.10.2 Removal of Engine Gear Case Cover

With the engine mounted on an overhaul stand. Remove the gear case cover as follows:

NOTICE:
Do not hit the face of the damper to loosen it. Damage to the internal components may result. The oil pan cannot be used to support the front of the engine in a vehicle, as its thermoplastic construction will not support the weight.

1. Drain the engine oil and remove the engine oil pan. Refer to section 13.13.1, for oil draining and refer to section 3.11.2.
2. Loosen the fan hub mounting bolts. Loosen the fan adjusting bolt. Back the adjuster off far enough to remove the drive belts. Remove the fan and fan hub assembly. Refer to section 4.7.2.
3. Loosen the alternator mounting bolts. Remove the alternator drive belts, alternator, and mounting brackets (if so equipped). Refer to section 8.2.2. See Figure 1-159.

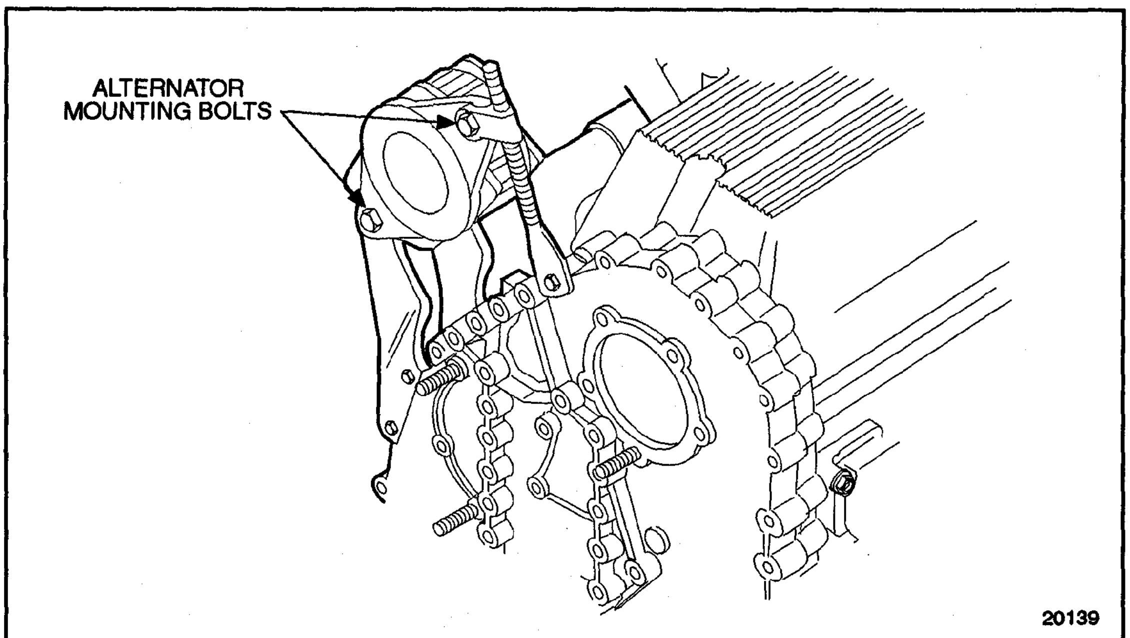

Figure 1-159 Alternator and Related Parts

4. Loosen the air conditioner compressor and mounting brackets (if so equipped). Refer to OEM guidelines.

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5. Remove the five fan support bolts. See Figure 1-160.

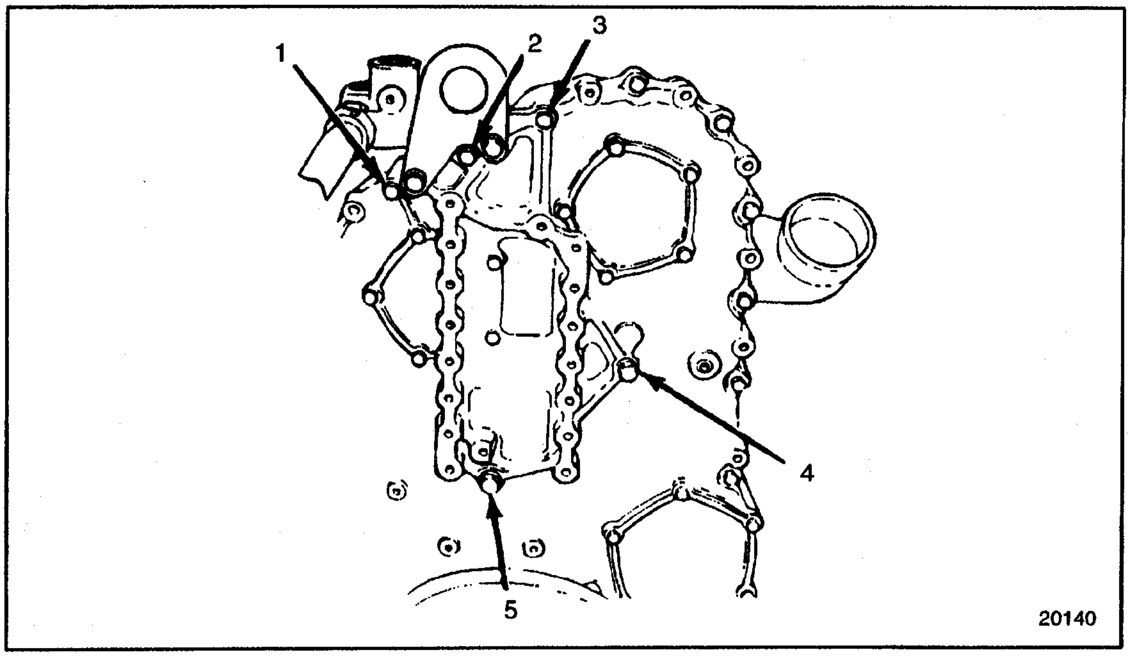

Figure 1-160 Fan Support Bolt Location

6. Remove the water pump assembly. Refer to section 4.3.2 for front mounted water pump. Refer to section 4.2.2 for gear case mounted.
7. Remove the power steering pump (if so equipped). Refer to OEM guidelines.
8. Remove the crankshaft pulley. Refer to section 1.13.2.
9. Remove the vibration damper. Refer to section 1.12.2.
10. Remove the front engine mount by removing the four bolts securing the front engine mount to the gear case cover.

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11. Loosen and remove the five bolts that secure the accessory drive assembly to the gear case cover. See Figure 1-161.

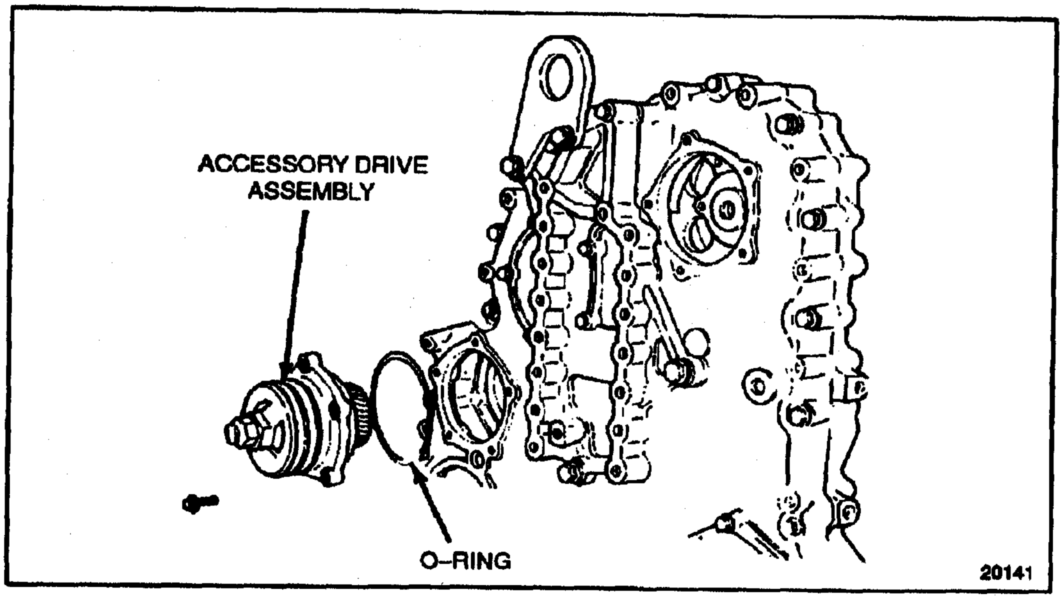

Figure 1-161 Accessory Drive Assembly

12. Remove the accessory drive assembly by pulling it straight out of the gear case cover to avoid damaging the rubber O-ring. See Figure 1-161.

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13. There are a total of 34 bolts that secure the gear case cover to the gear case. Bolts 17, 18, 19 and 20 were removed with the front engine mount. Bolts F1 through F5 were removed in a previous step; refer to step 12. Loosen and remove bolts 1 through 16, 21, 22 (see note).

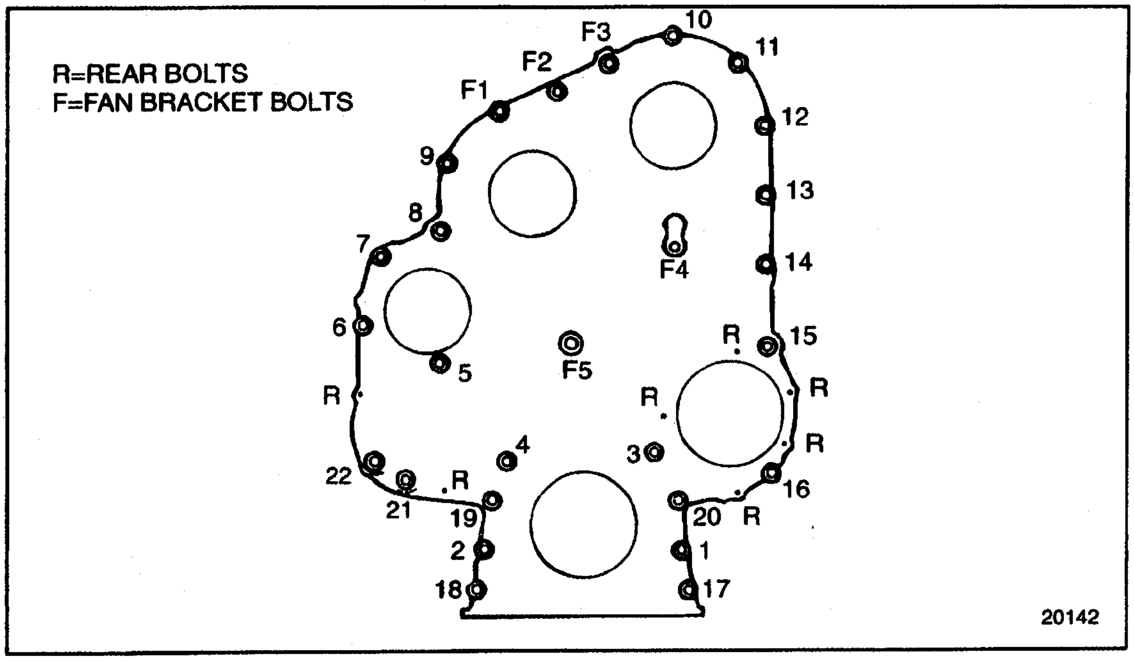

Figure 1-162 Gear Case Cover Bolt Arrangement (Front)

NOTE:
Bolts 21 and 22 are rear bolts on pre-1991 engines.

[a] Remove the SRS. Refer to section 2.29.2.

[b] Remove the air compressor drive assembly by removing the six bolts on the back of the gear case on the intake side of the engine located around the air compressor drive assembly. See Figure 1-163.

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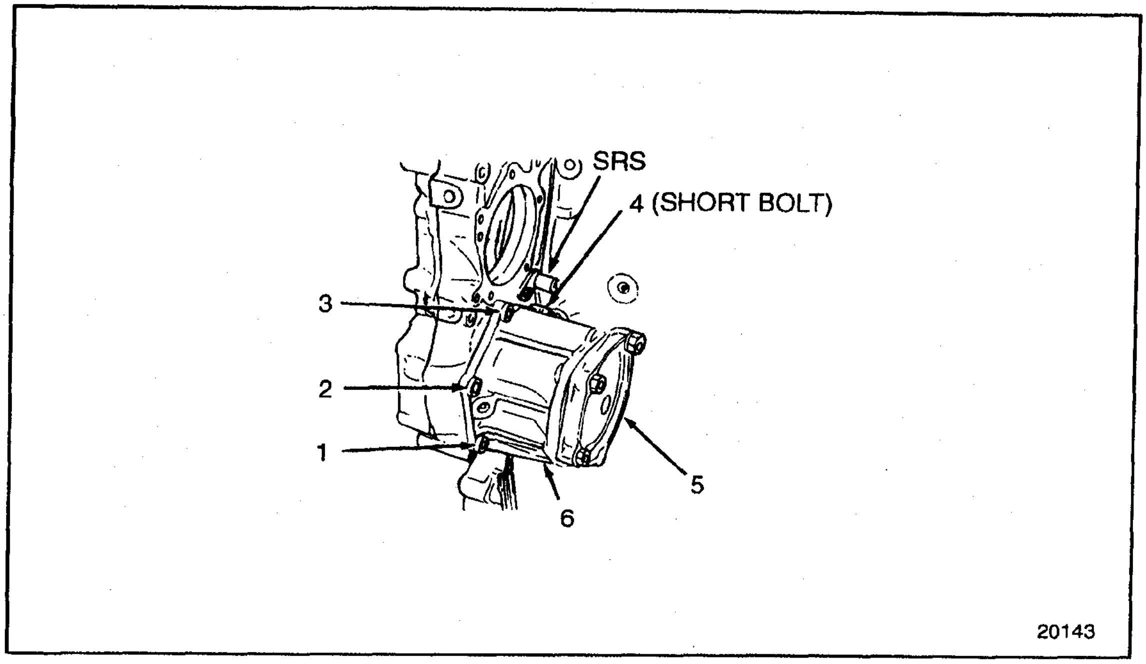


Figure 1-163 Gear Case Cover Bolt Arrangement (Left Rear)

[c] Remove the bolts on the back of the gear case on the water pump (right) side of the engine. See Figure 1-164.

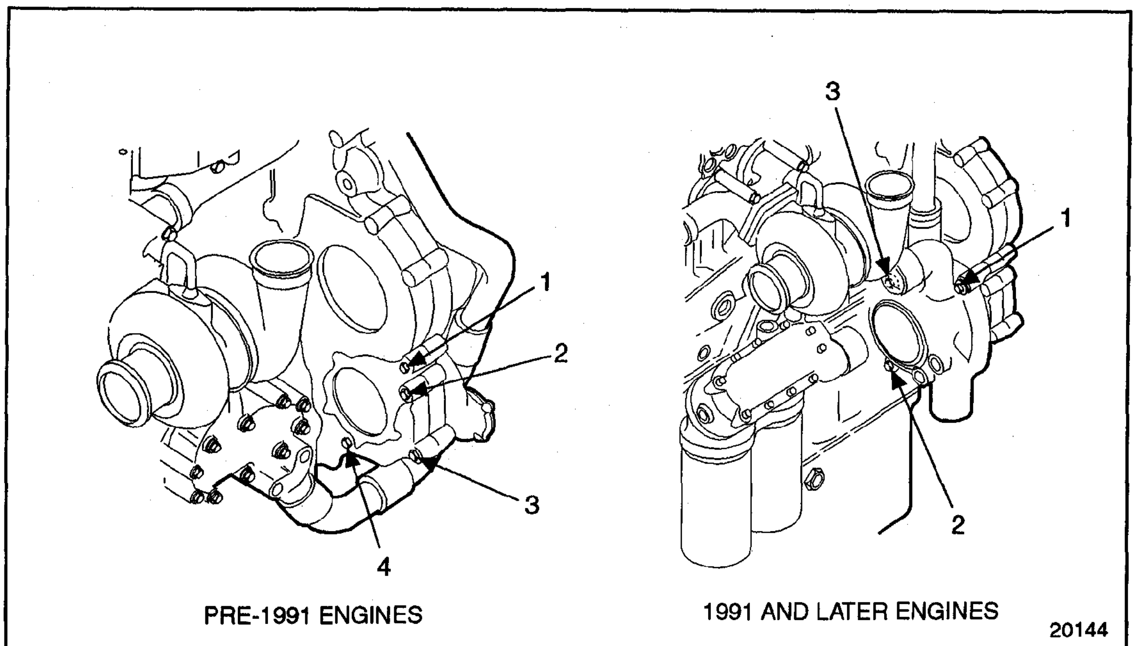
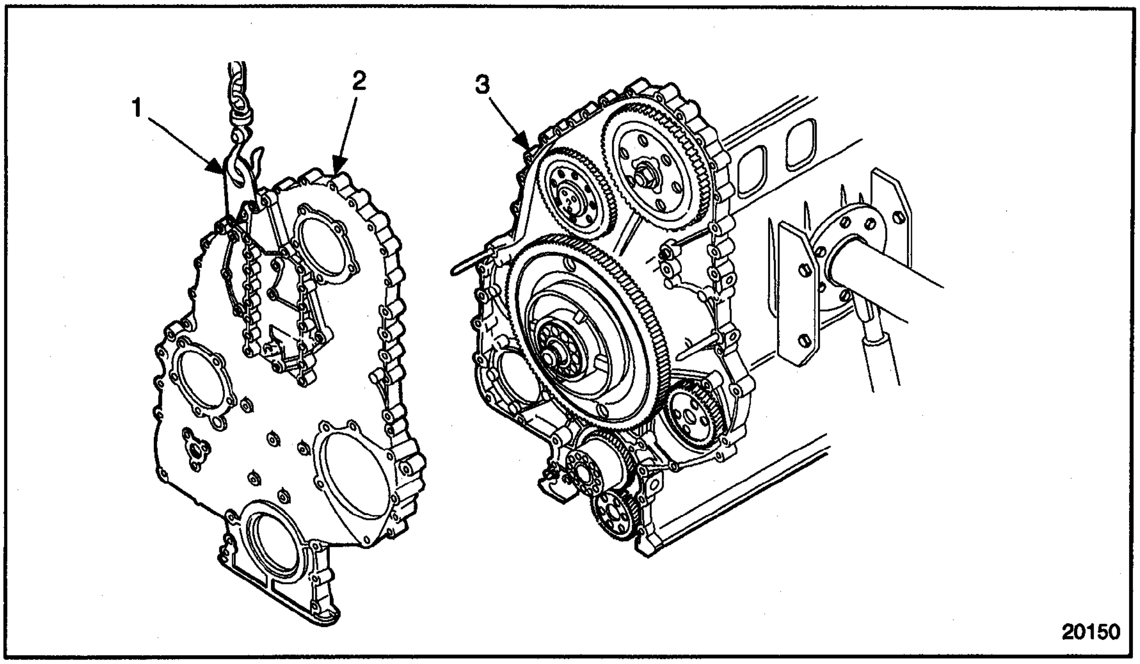


Figure 1-164 Gear Case Cover Bolt Arrangement (Right Rear)

14. Support the gear case cover with a suitable lifting device, using the front engine lift bracket. See Figure 1-165.



1. Engine Lifter Bracket
2. Gear Case Cover
3. Gear Case Housing

Figure 1-165 Engine Gear Case Cover Support

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NOTE:
There is a rubber O-ring installed between the center of the bull gear hub and the gear case cover. The O-ring may adhere to the cover when it is removed. Be sure the O-ring is not lost. See Figure 1-166.

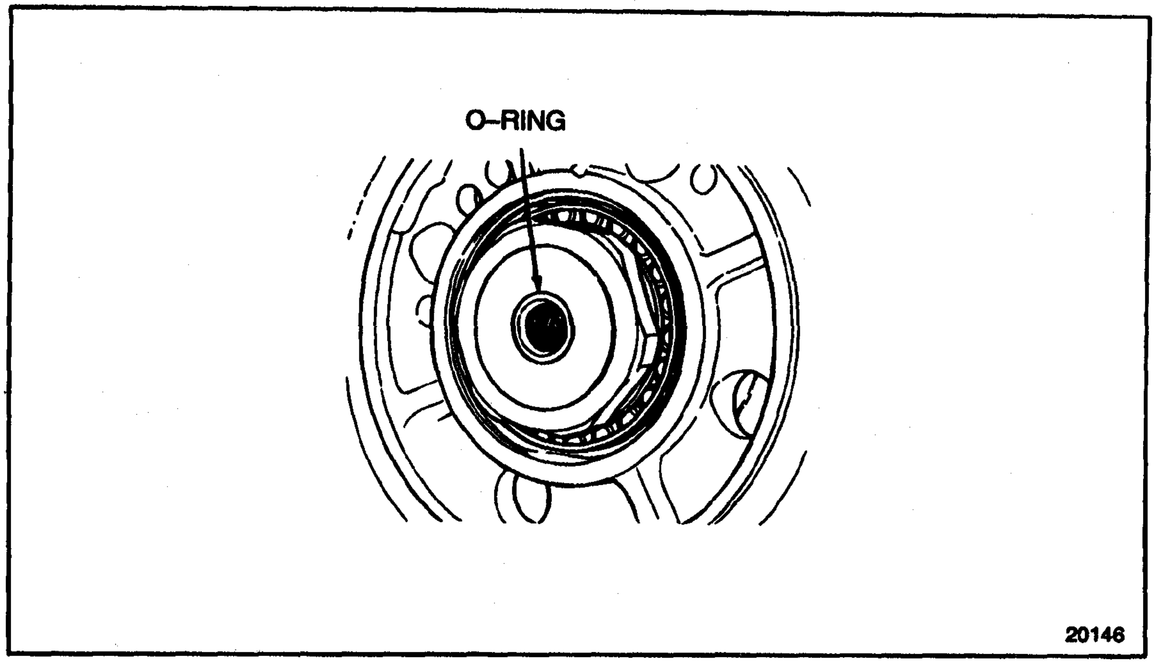

Figure 1-166 Bull Gear O-ring

15. Tap the gear case cover with a fiber mallet or plastic hammer to loosen it from the gear case. Remove the engine gear case cover.

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1.10.2.1 Inspection of Gear Case Cover

Inspect the gear case cover as follows:

1. Clean all of the old gasket sealer from the mating surfaces of the gear case and gear case cover. Refer to General Information, "Cleaning".
2. Clean the gasket material from the mating surfaces of any components or access covers that were removed from the gear case cover, and the gear case cover itself.

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

3. Clean all of the removed parts except the electrical components with clean fuel oil and dry with compressed air.

NOTE:
Any time the gear case cover is removed, the crankcase oil seal must be replaced. Install the new front oil seal after the gear case cover has been installed to the engine.

4. If necessary, remove the crankshaft front oil seal at this time. Refer to section 1.8.2. Inspect the gear case cover for stress cracks or breaks in the casting. Refer to section 1.10.2.1. Repair or replace as necessary. Refer to section 1.11.3.
5. Inspect all O-rings for signs of dryness or splitting. Replace as necessary.

1.10.3 Installation of Gear Case Cover

Perform the following steps for gear case installation:

1. Apply a continuous 1/16 in. bead of Gasket Eliminator PT-7276 (Loctite® 518) or equivalent to the mating surface of the gear case.

NOTE:
Gasket eliminator cures with the absence of air. The length of time between gear case cover installation and torquing the bolts that secure the gear case cover to the gear case should be kept to a minimum.

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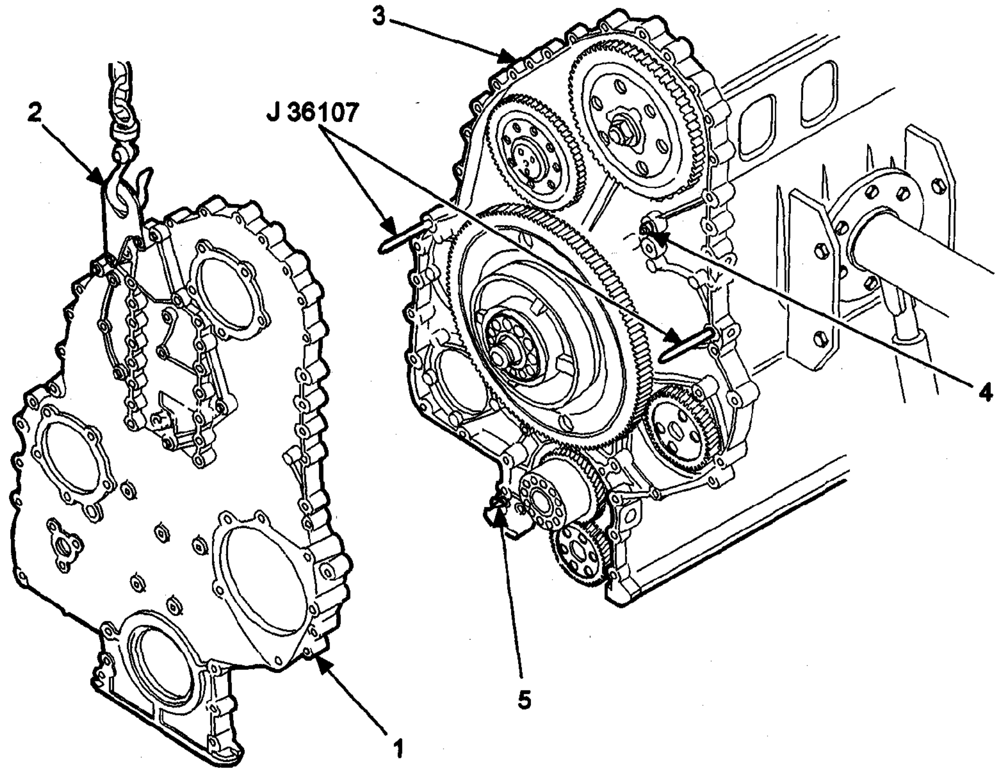
2. Install two guide studs, J 36107, to the gear case. See Figure 1-167.



1. Front Gear Case Cover
2. Front Engine Lift Bracket
3. Front Gear Case Housing
4. Locating Dowel (Round)
5. Locating Dowel (Diamond)

Figure 1-167 Gear Case Cover Guide Stud Location

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3. Support the gear case cover with a suitable lifting device, using the front engine lift bracket. See Figure 1-165.
4. Position the gear case cover on the guide studs and slide it forward. Index the two dowels in the gear case. See Figure 1-167.
5. There are 34 bolts that secure the gear case cover to the gear case (including five for the fan support bracket). Install them as follows:

NOTICE:
With gasketless parts such as the gear case cover; the torque values and tightening sequences are critical to prevent parts warpage.

[a] Install the shorter bolts, No. 1 through 16, 21, 22 (see note), in various locations at the front of the gear case cover. Finger-tighten them. Remove the guide studs when installing bolts 7 and 14. See Figure 1-168.

NOTE:
Bolts 21 and 22 are rear bolts on pre-1991 engines.

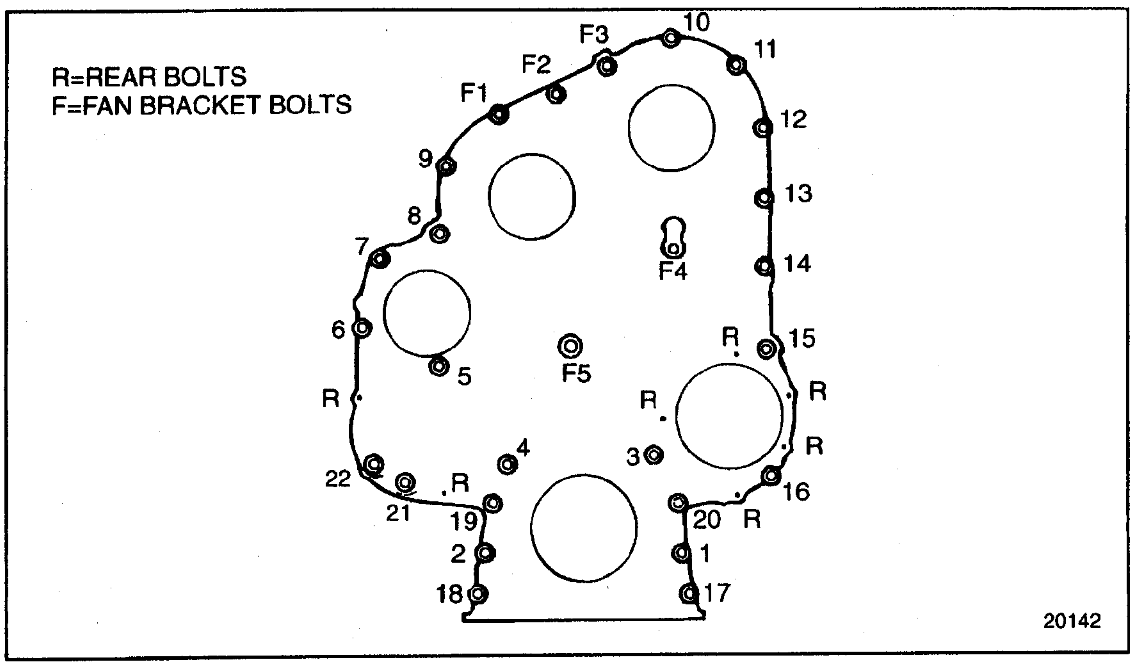

Figure 1-168 Gear Case Cover Bolt Torque Sequence (Front)

[b] Torque bolts 1 through 16, 21, 22 (see note), to 58-73 N·m (43-54 lb·ft).

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[c] Install the front engine mount to the gear case cover. Install the four, longer, front engine mount-to-gear case cover bolts, finger-tight.

[d] Torque bolts 17, 18, 19 and 20 to 160-200 N·m (118-148 lb·ft). See Figure 1-168.

[e] Bolts F1 through F5 are fan support bracket bolts. Install the fan support bracket and torque bolts F1, F2 and F3 to 58-73 N·m (43-54 lb·ft). Torque bolts F4 and F5 to 160-200 N·m (118-148 lb·ft).

[f] Install the six bolts on the intake (left) side of the engine around the air compressor drive. Torque the bolts to 58-73 N·m (43-54 lb·ft), using the sequence. See Figure 1-169.

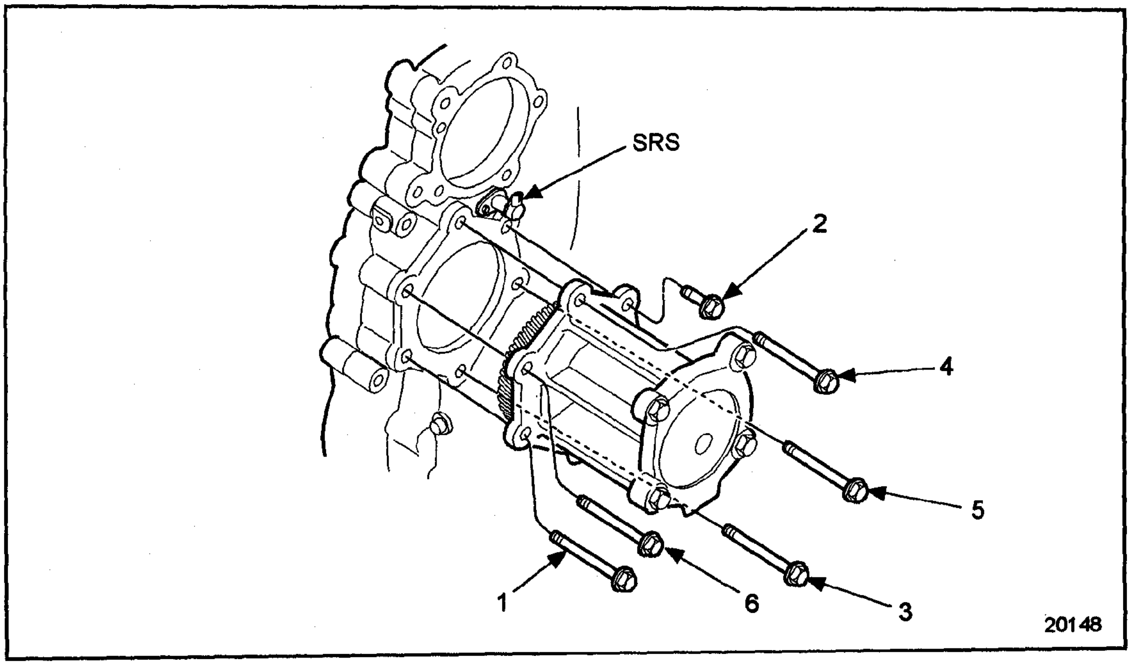

Figure 1-169 Air Compressor Drive Torque Sequence

[g] Install the SRS to the gear case; refer to section 2.29.3.

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[h] Install the two rear mounted bolts (pre - 1991 engines only) bolts on the exhaust (right) side of the engine. Torque the number 2 and 3 bolts to 58-73 N·m (43-54 lb·ft) torque. See Figure 1-170.

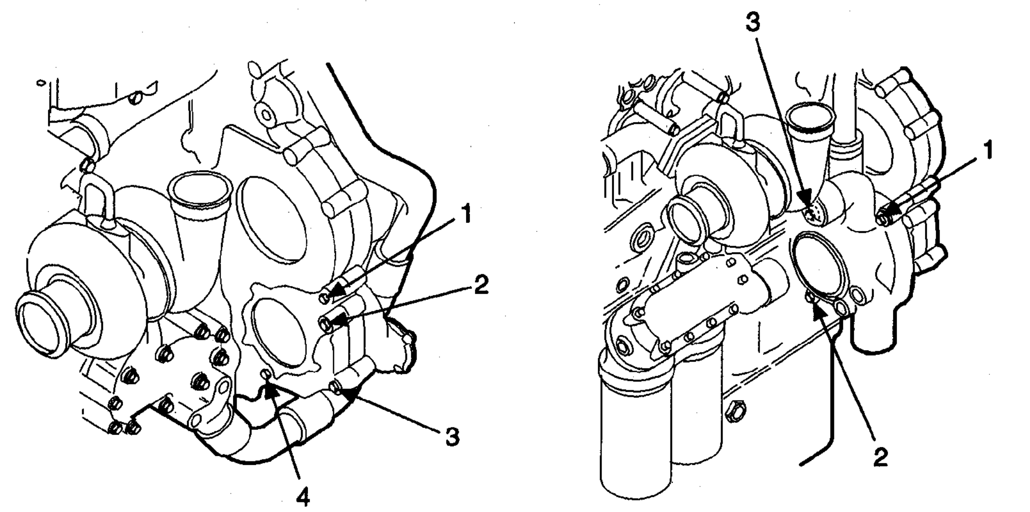

Figure 1-170 Gear Case Cover Bolt Torque Sequence (Right Rear)

6. Install a new crankshaft front oil seal. Refer to section 1.8.7.
7. Install the accessory drive assembly to the gear case. Refer to section 1.28.5.
8. Install the vibration damper to the crankshaft. Refer to section 1.12.3.
9. Install the crankshaft pulley to the end of the crankshaft. Refer to section 1.13.3.
10. Install the water pump assembly. Refer to section 4.2.8 for gear case mounted. Refer to section 4.3.7 for front mounted.
11. Install a new gasket between the power steering pump cover and the gear case (if so equipped).
12. Install the power steering pump cover to the gear case cover with the six bolts. Tighten the bolts progressively in a star-shaped pattern to draw the power steering pump in evenly. Torque the bolts to 30-38 N·m (22-28 lb·ft), using a star-shaped pattern.
13. Insert a new gasket between the camshaft drive gear access cover and the gear case cover.

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14. Install the camshaft drive gear access cover to the gear case cover. Torque the bolts to 30-38 N·m (22-28 lb·ft), using the tightening sequence. See Figure 1-171.

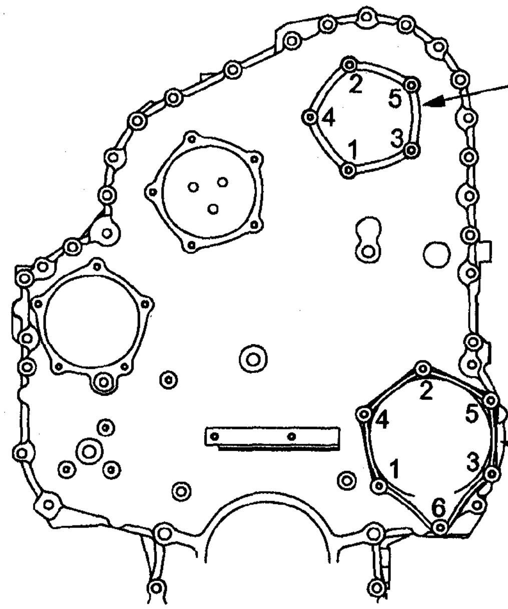

Figure 1-171 Access Cover Bolt Torque Sequences

15. Install the air conditioner compressor and brackets. Install the air conditioner compressor drive belt. Refer to OEM guidelines.
16. Install the alternator and brackets. Refer to section 8.2.3. Install the alternator drive belts. Refer to section 13.13.10.
17. Adjust the alternator and air conditioner compressor drive belts to the specifications. Refer to section 13.13.10.
18. Install the engine oil pan. Refer to section 3.11.4. Fill the crankcase with recommended lubricating oil. Refer to section 13.13.1.

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1.10.4 Installation of Acoustical Gear Case Covers

Install acoustical covers as outlined below. See Figure 1-172, and see Figure 1-173, for Group A installations with accessory drive. See Figure 1-174 and see Figure 1-175for installation on Group B without accessory drive. See Figure 1-176 and see Figure 1-177for typical Group C installations. See Figure 1-178 and see Figure 1-179for Group D installations.

1. Using required fasteners, install front gear case acoustical cover and accessory drive acoustical cover. Tighten bolts and nut(s) to the torque values: listed in Table 1-4.
2. Using required fasteners and clips, install right rear and left rear covers. Tighten bolts and nut(s) to the torque values listed in Table 1-4.

Bolt or Nut Size	Required Torque
M6 x 1.0	13-16 N·m (10-12 lb·ft)
M8 x 1.25	30-38 N·m (22-28 lb·ft)
M10 x 1.5	58-73 N·m (43-54 lb·ft)

Table 1-4 Acoustical Cover Fastener Torque Values

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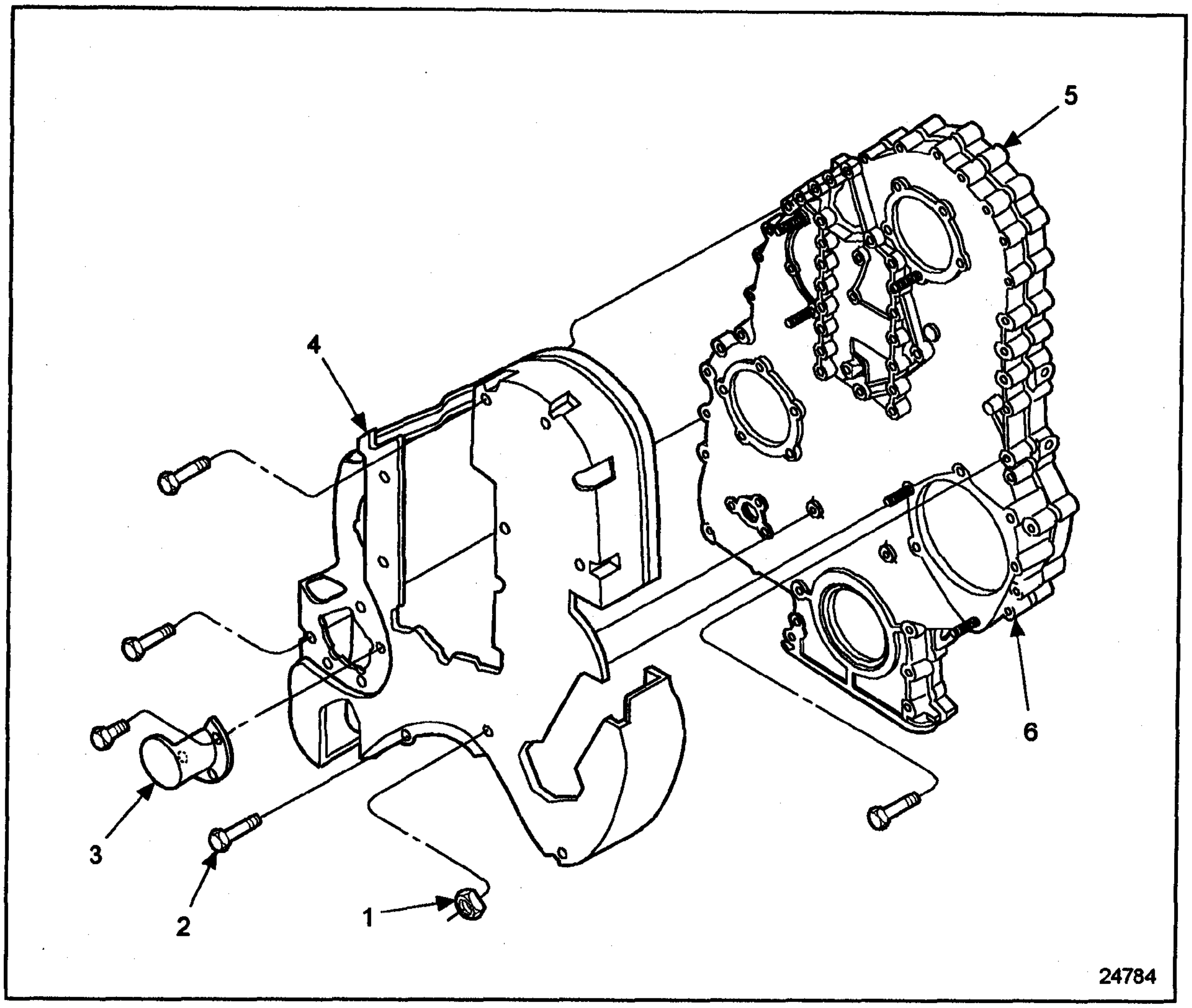

1. Nut
2. Bolt
3. Acoustical Cover Clip
4. Acoustical Cover
5. Gear Case
6. Gear Case Cover

Figure 1-172 Typical Group A Front Acoustical Cover Installation (With Accessory Drive)

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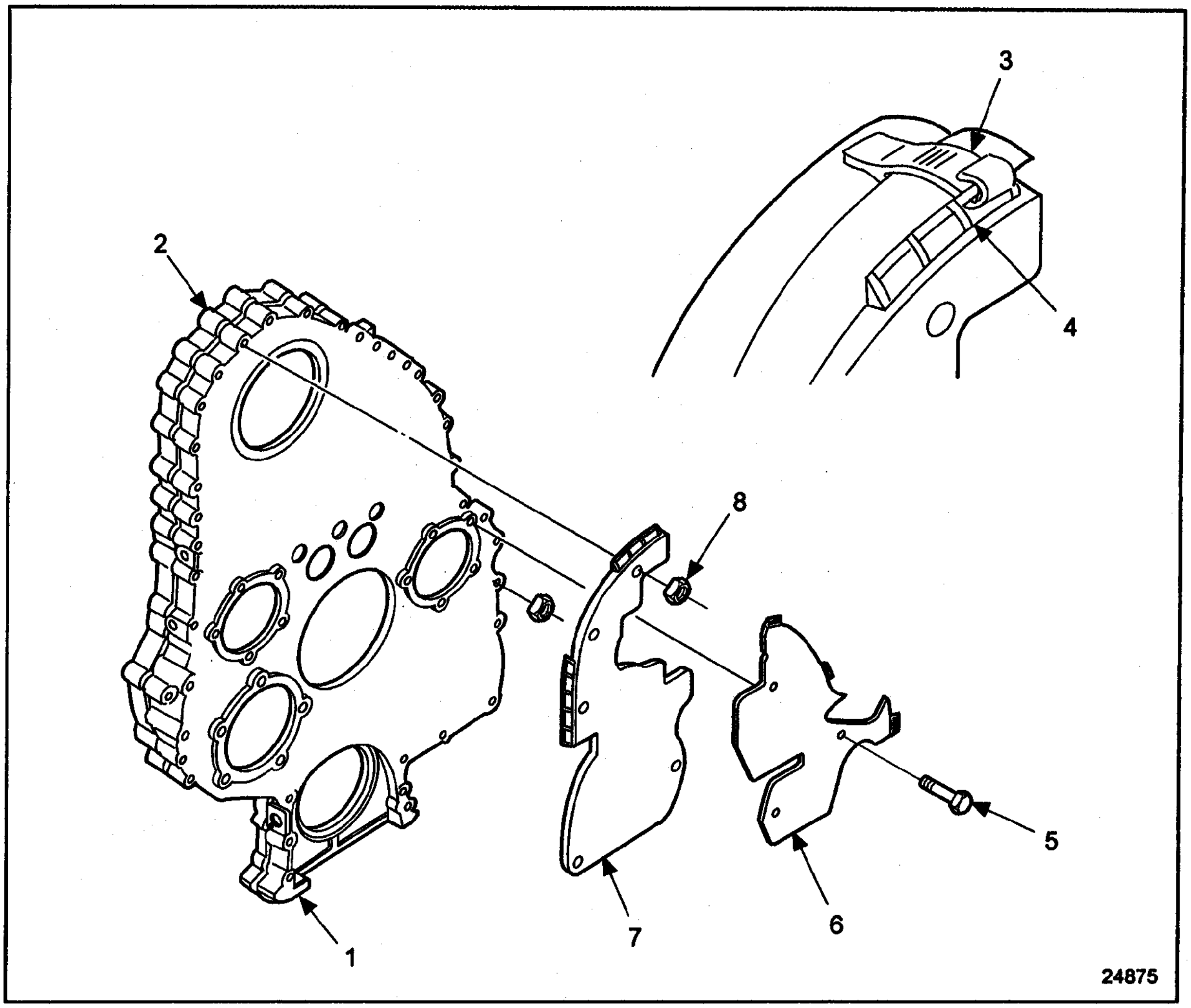

1. Gear Case Cover
2. Gear Case
3. Acoustical Cover Snap
4. Acoustical Cover Clip
5. Bolt
6. Acoustical Cover
7. Acoustical Cover
8. Nut

Figure 1-173 Typical Group A Rear Acoustical Cover Installation (With Accessory Drive)

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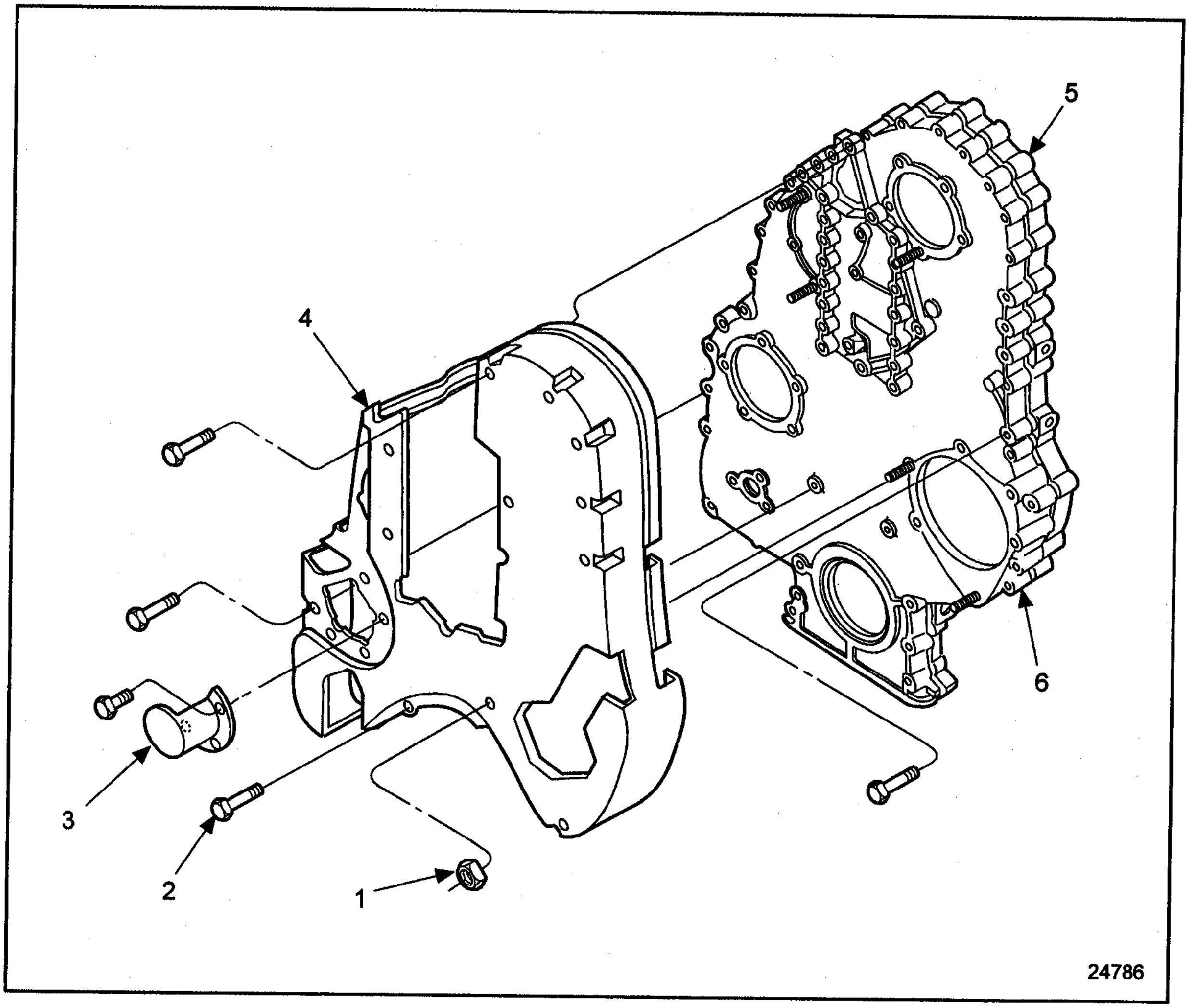

1. Nut
2. Bolt
3. Acoustical Cover Clip
4. Acoustical Cover
5. Gear Case
6. Gear Case Cover

Figure 1-174 Typical Group B Front Acoustical Cover Installation (No Accessory Drive)

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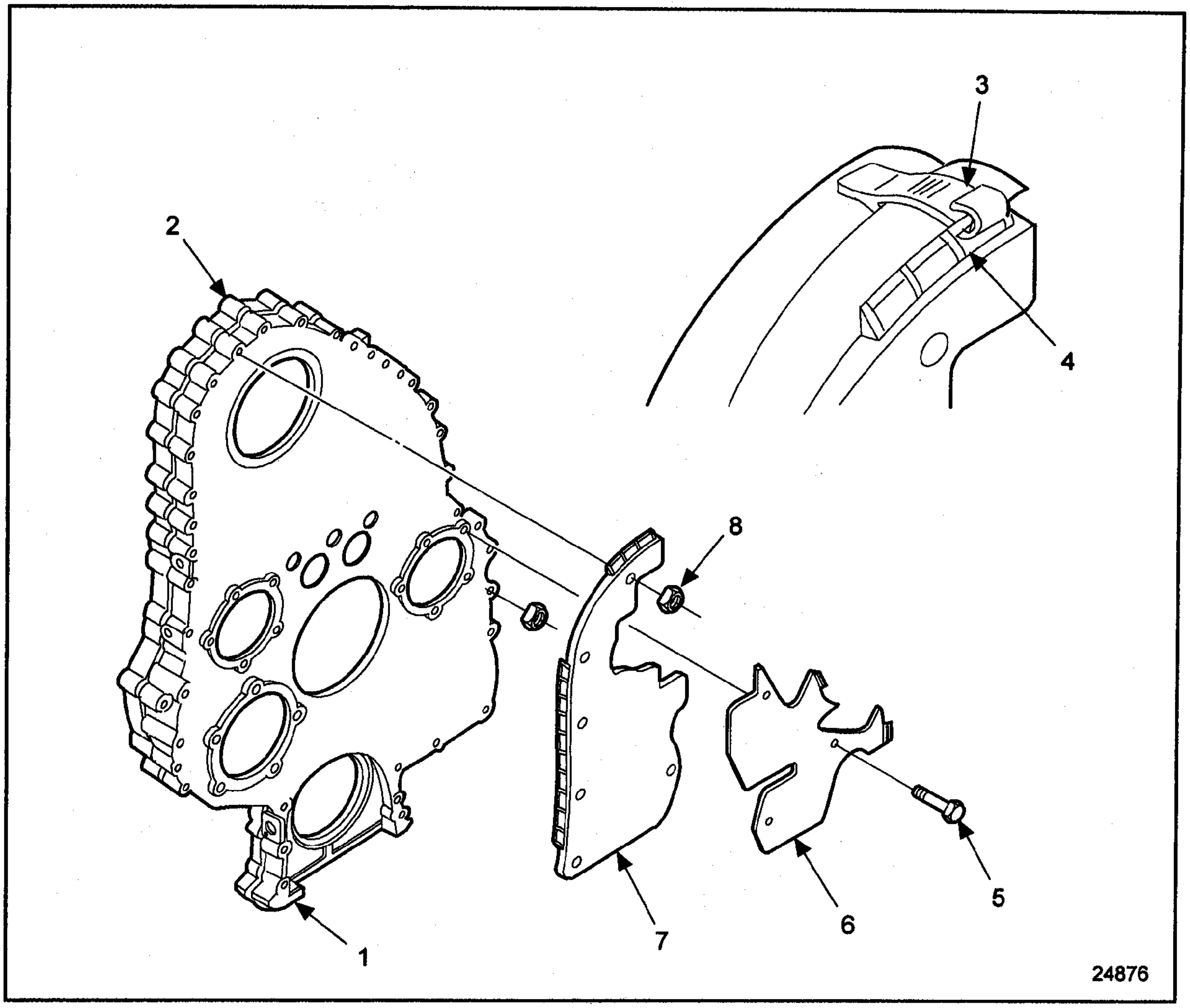

1. Gear Case Cover
2. Gear Case
3. Acoustical Cover Snap
4. Acoustical Cover Clip
5. Bolt
6. Acoustical Cover
7. Acoustical Cover
8. Nut

Figure 1-175 Typical Group B Rear Acoustical Cover Installation (No Accessory Drive)

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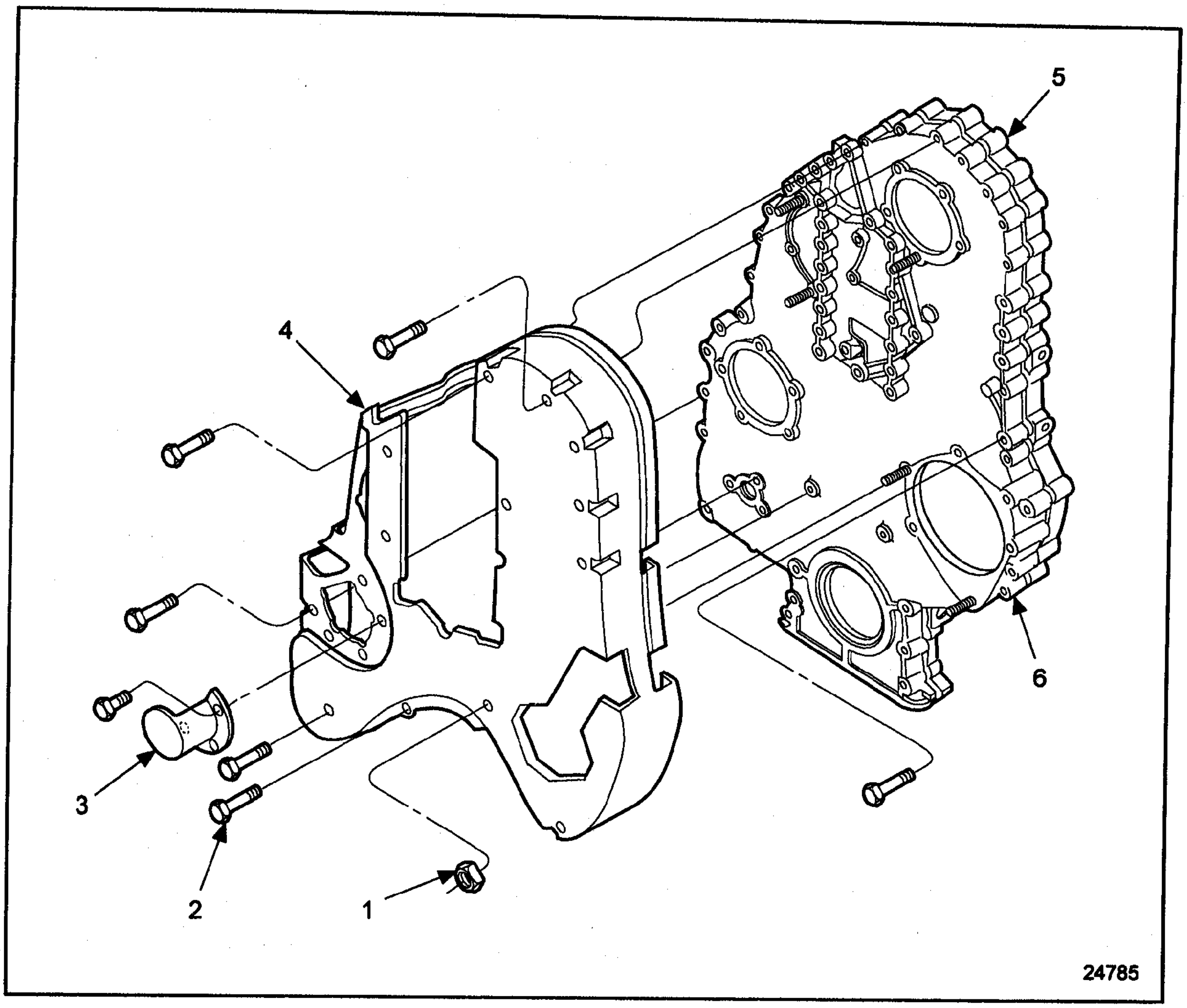

1. Nut
2. Bolt
3. Acoustical Cover Clip
4. Acoustical Cover
5. Gear Case
6. Gear Case Cover

Figure 1-176 Typical Group C Front Acoustical Cover Installation

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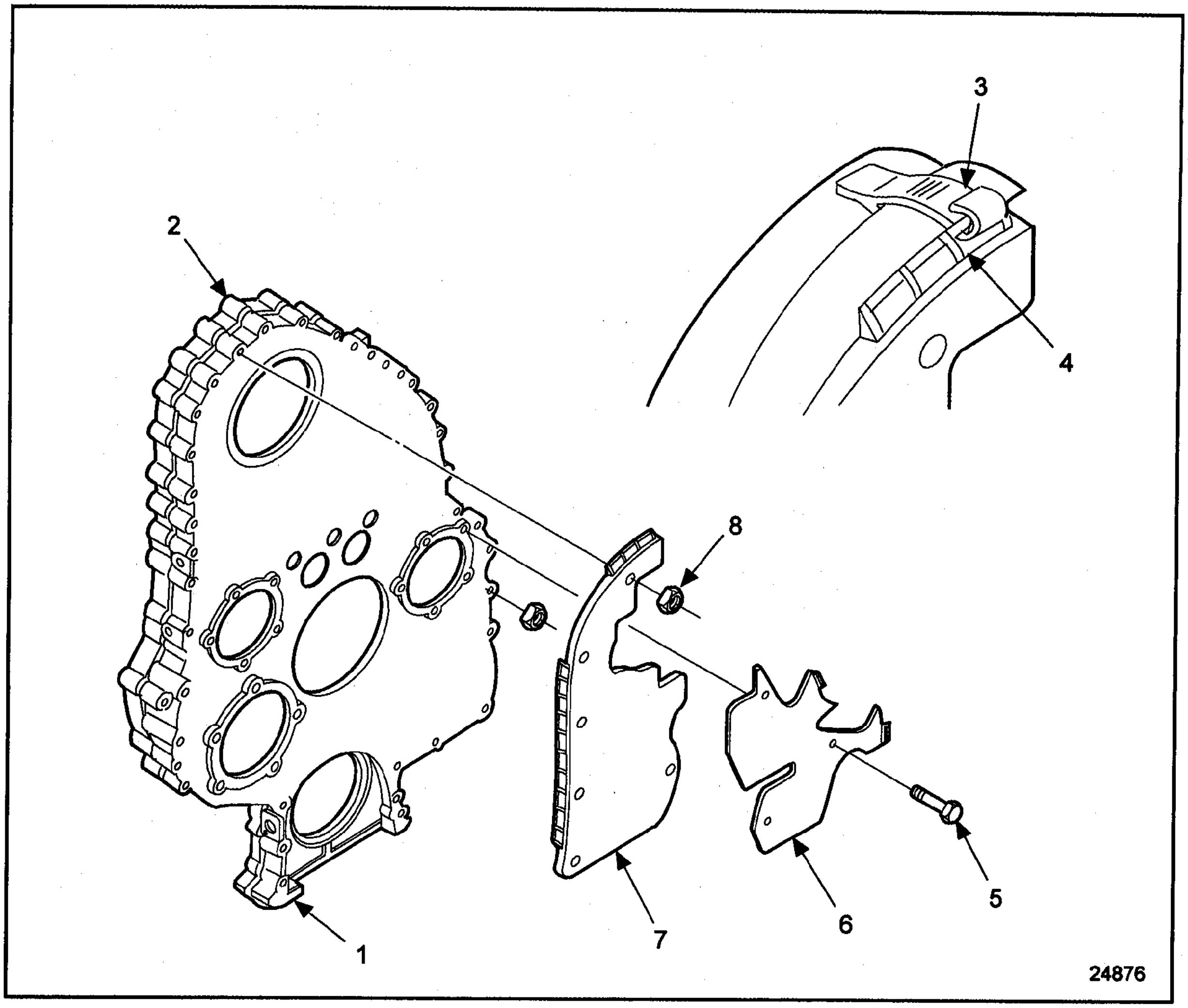

1. Gear Case Cover
2. Gear Case
3. Acoustical Cover Snap
4. Acoustical Cover Clip
5. Bolt
6. Acoustical Cover
7. Acoustical Cover
8. Nut

Figure 1-177 Typical Group C Rear Acoustical Cover Installation

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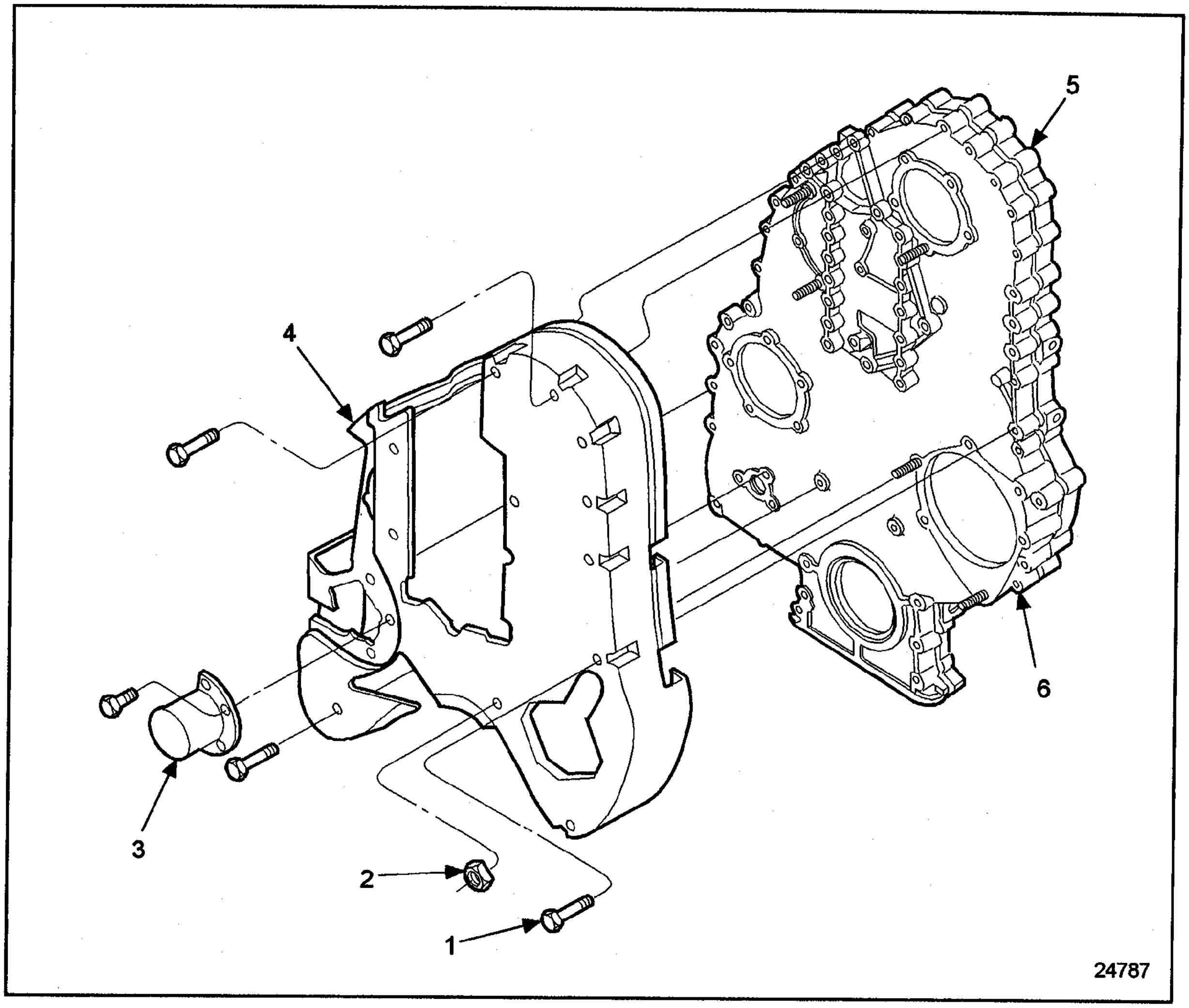

1. Bolt
2. Nut
3. Acoustical Cover Clip
4. Acoustical Cover
5. Gear Case
6. Gear Case Cover

Figure 1-178 Typical Group D Front Acoustical Cover Installation

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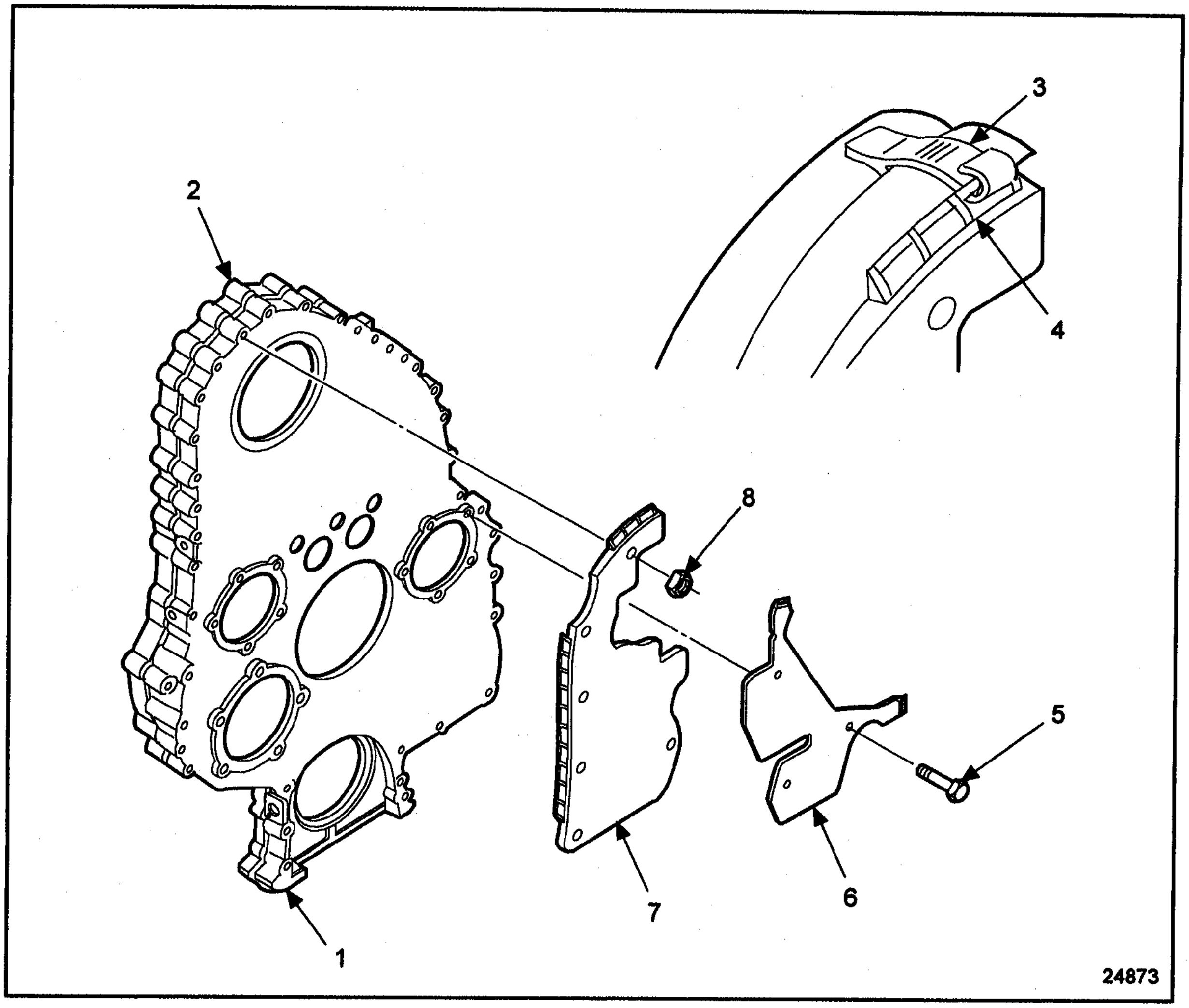

1. Gear Case Cover
2. Gear Case
3. Acoustical Cover Snap
4. Acoustical Cover Clip
5. Bolt
6. Acoustical Cover
7. Acoustical Cover
8. Nut

Figure 1-179 Typical Group D Rear Acoustical Cover Installation

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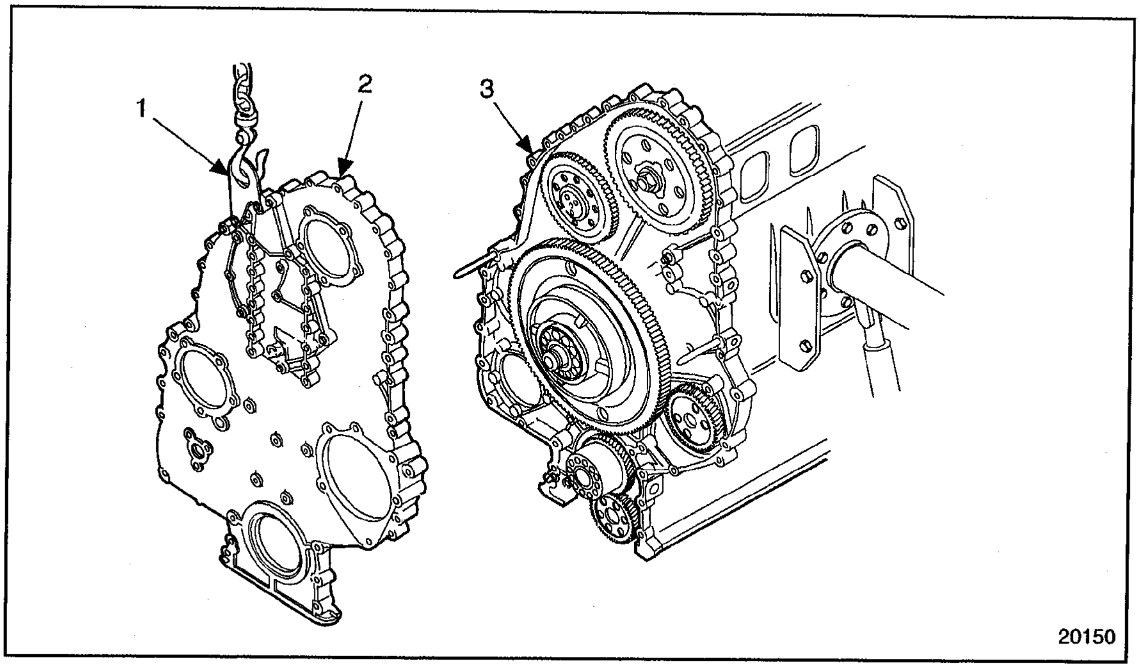
1.11 GEAR CASE

The gear case housing is constructed of cast iron, with machined mating surfaces, and is bolted to the front of the engine cylinder block. The gear case and gear case cover are bolted together to provide a sealed compartment for the engine gear train. See Figure 1-180.



1. Lifting Bracket
2. Gear Case Cover
3. Gear Case Housing

Figure 1-180 Gear Case and Gear Case Cover

Several components are mounted to the gear case, including the adjustable idler gear assembly, see Figure 1-181, the fuel pump drive assembly, see Figure 1-182, the air compressor drive assembly or raw water pump drive assembly, see Figure 1-183; the water pump assembly (1991 and later engines) see Figure 1-184; and the camshaft thrust plate and drive gear assembly see Figure 1-199.

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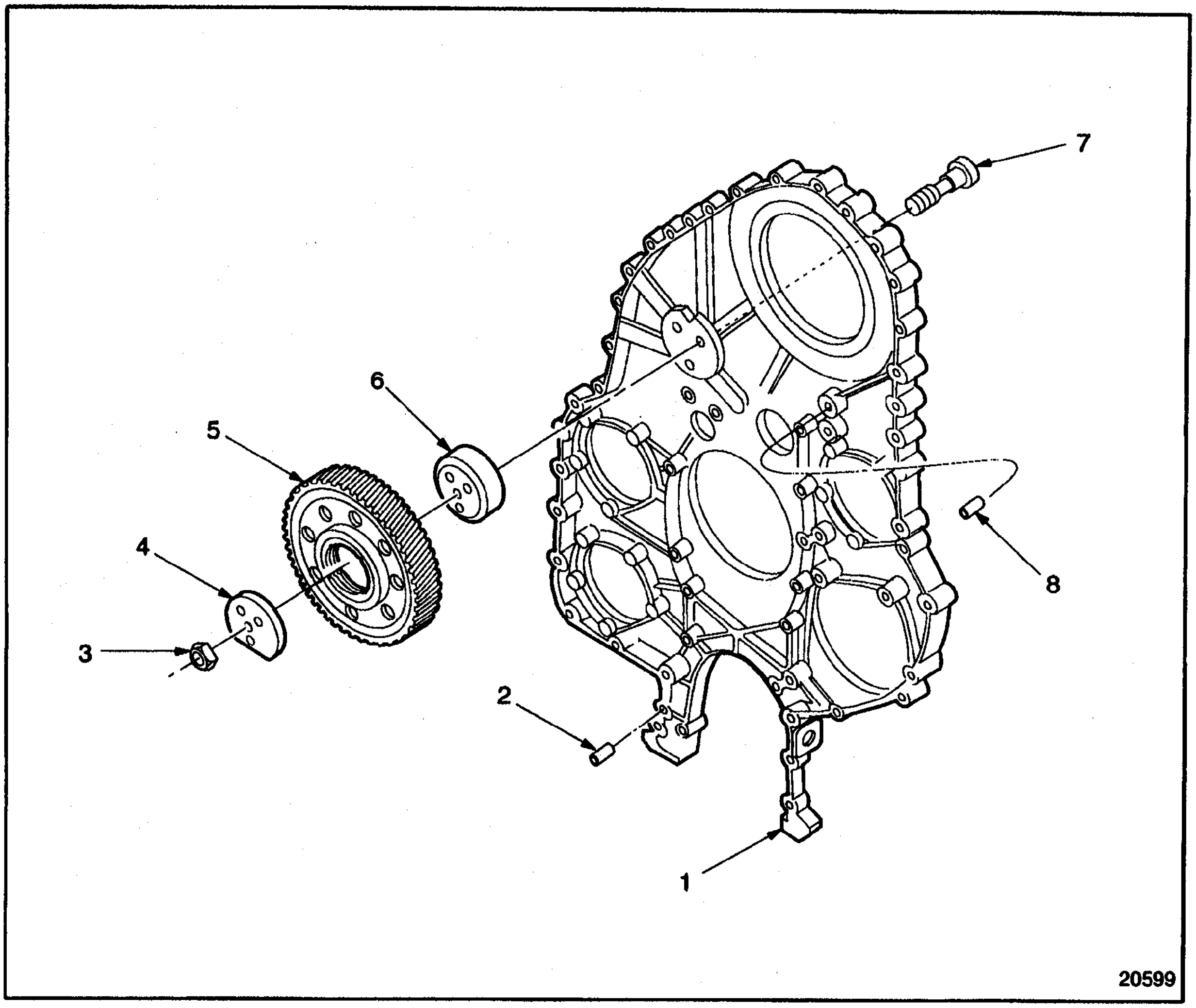

1. Gear Case
2. Diamond Dowel
3. Adjustable Idler Gear Locknut (3)
4. Adjustable Idler Gear Hub, Retainer
5. Adjustable Idler Gear
6. Adjustable Idler Hub
7. Adjustable Idler Gear Stud (3)
8. Round Dowel

Figure 1-181 Adjustable Idler Gear Assembly

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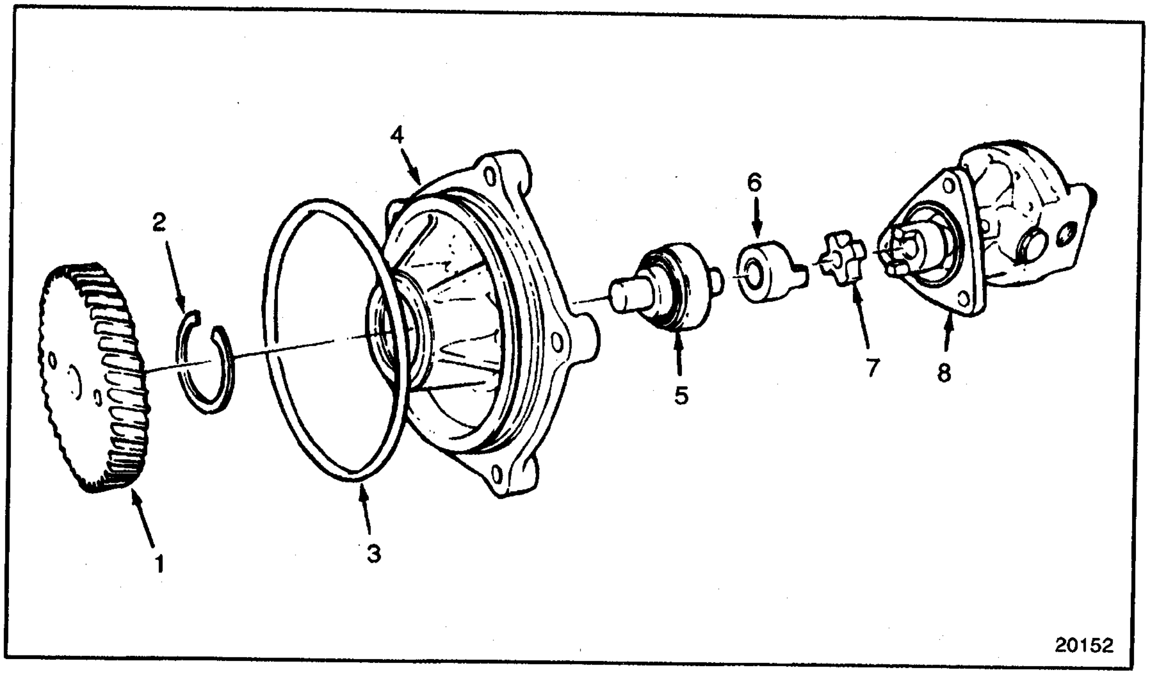

1. Fuel Pump Drive Gear
2. Snap Ring
3. O-ring
4. Fuel Pump Drive Housing
5. Shaft and Bearing Assembly
6. Fuel Pump Drive Hub
7. Fuel Pump Drive Coupling
8. Fuel Pump Assembly

Figure 1-182 Fuel Pump Drive Assembly

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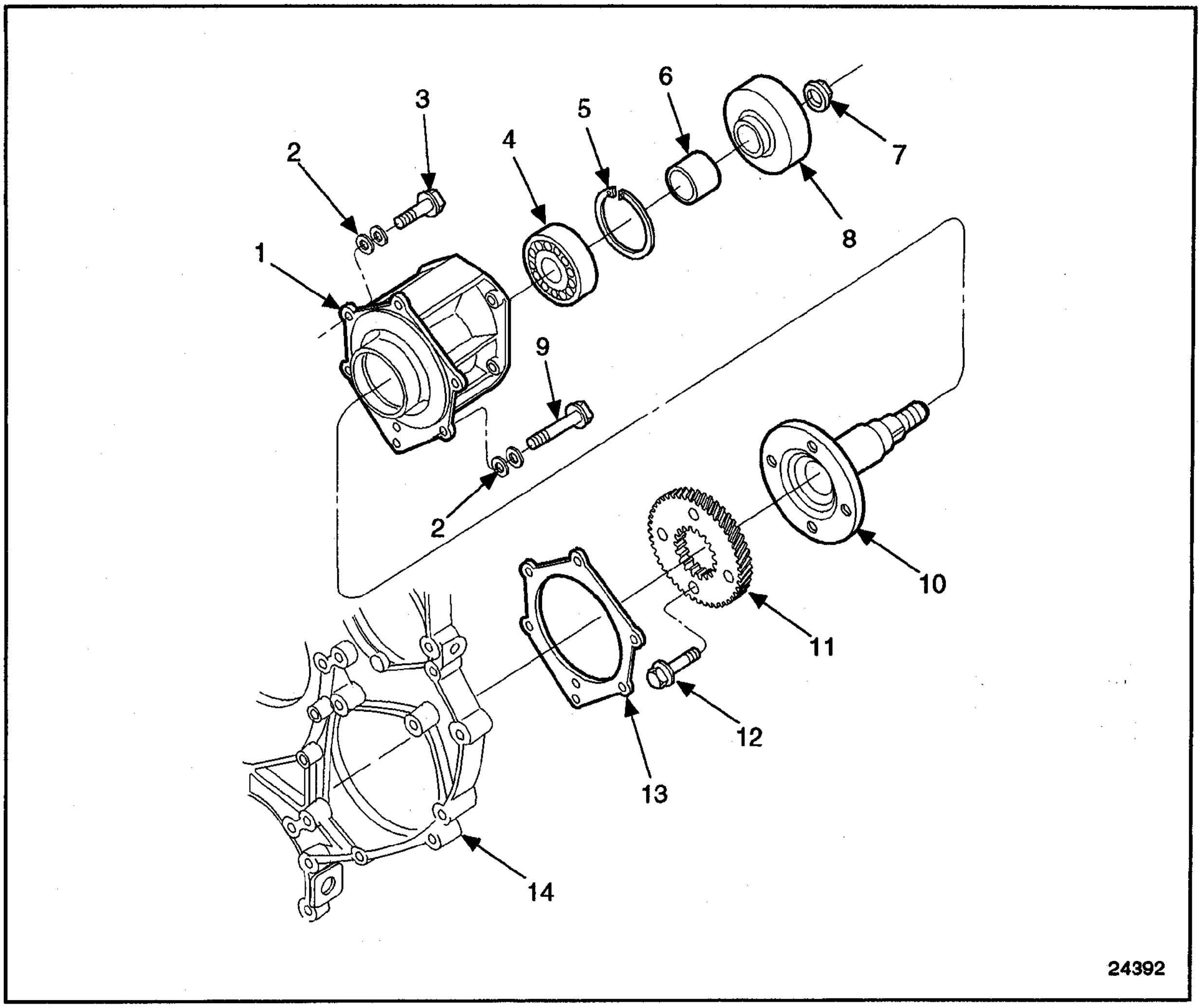

1. Drive Housing
2. Washers
3. Drive Housing Short Bolt
4. Drive Ball Bearing
5. Snap Ring
6. Spacer
7. Drive Hub
8. Drive Hub Flange Nut
9. Drive Housing Long Bolt
10. Drive Shaft
11. Drive Gear
12. Drive Gear Bolt
13. Drive Housing Gasket
14. Gear Case Housing

Figure 1-183 Air Compressor or Raw Water Pump Drive Assembly

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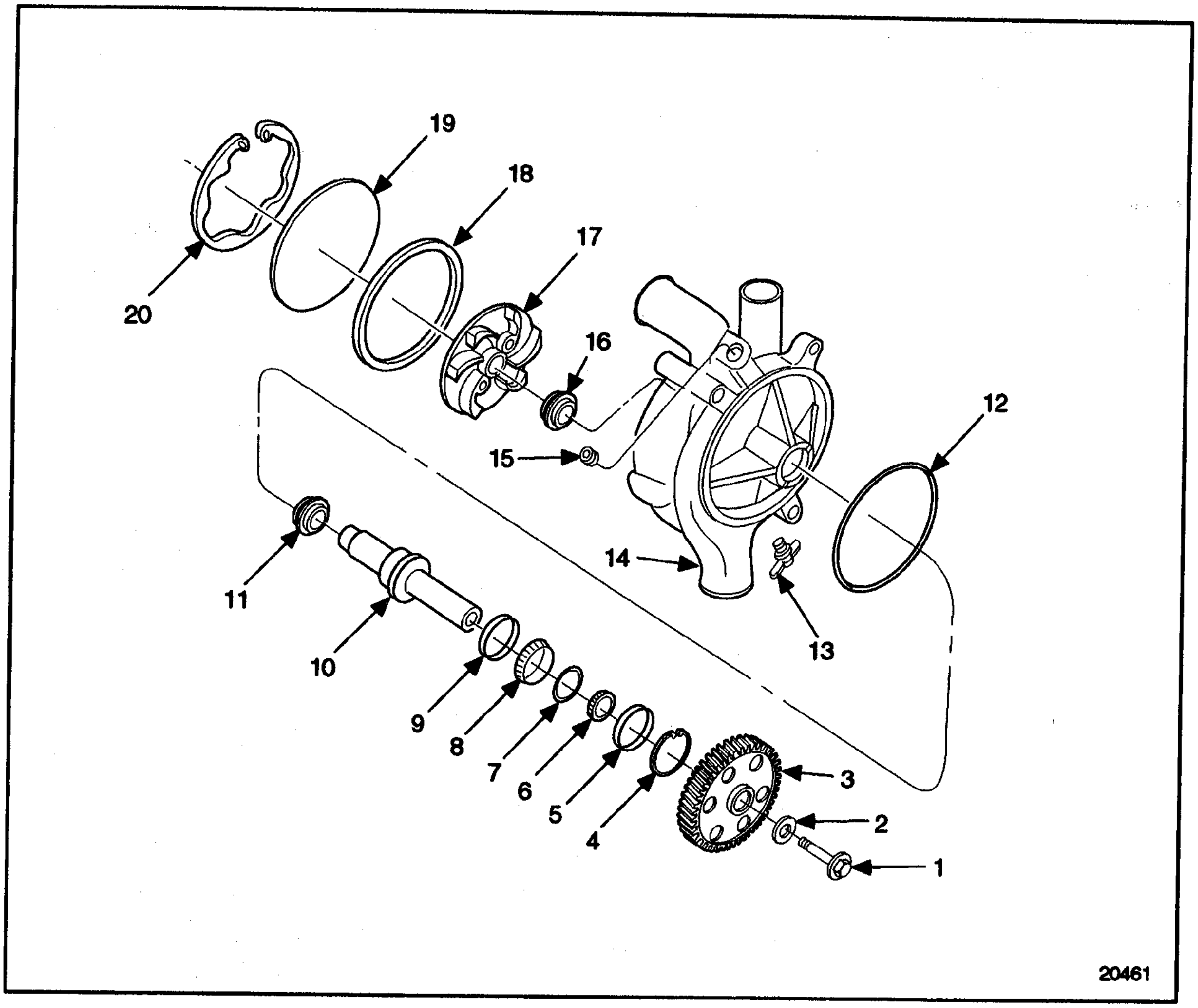

1. Retaining Bolt
2. Washer
3. Water Pump Drive Gear
4. Snap-ring
5. Bearing Race
6. Bearing
7. Spacer Rings (2)
8. Bearing
9. Bearing Race
10. Drive Shaft
11. Oil Seal
12. Water Pump Housing O-ring
13. Drain Cock
14. Water Pump Housing
15. Water Pump Housing Pipe Plug
16. Water Seal
17. Impeller
18. Water Pump Cover O-ring
19. Water Pump Cover
20. Water Pump Cover Snap Ring

Figure 1-184 Water Pump Assembly

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To eliminate the possibility of oil leakage at the adjustable idler gear stud location, Detroit Diesel recommends the following:

When rebuilding a Series 60 engine, or if the gear case is removed for any reason, the three original adjustable idler gear studs should be removed and replaced with new studs.

Before pressing studs into the gear case, coat the shanks and underside of the stud heads with Loctite® No. 242 Sealant. This will prevent any oil leakage around the studs during engine operation.

The Timing Reference Sensor (TRS) is an electronic component that is bolted to the side of the gear case on the intake (left) side of the engine just above the oil pan. See Figure 1-185.

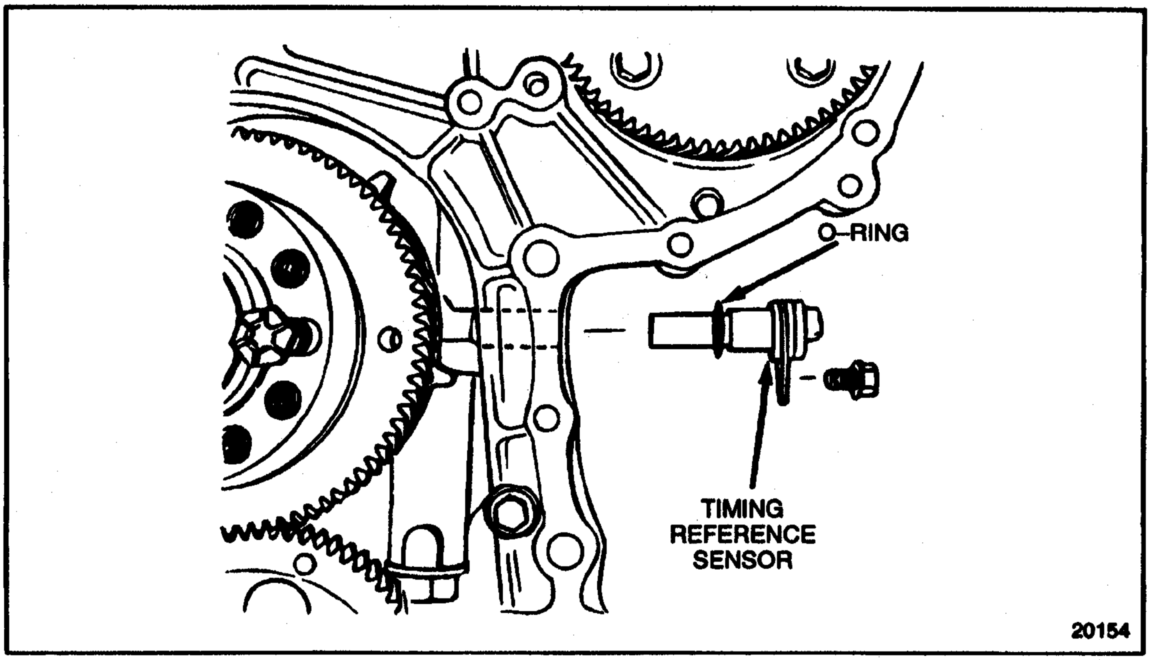

Figure 1-185 Timing Reference Sensor (TRS)

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The Synchronous Reference Sensor (SRS) is an electronic component that is bolted to the gear case at the lower, intake (left) side of the engine. See Figure 1-186.

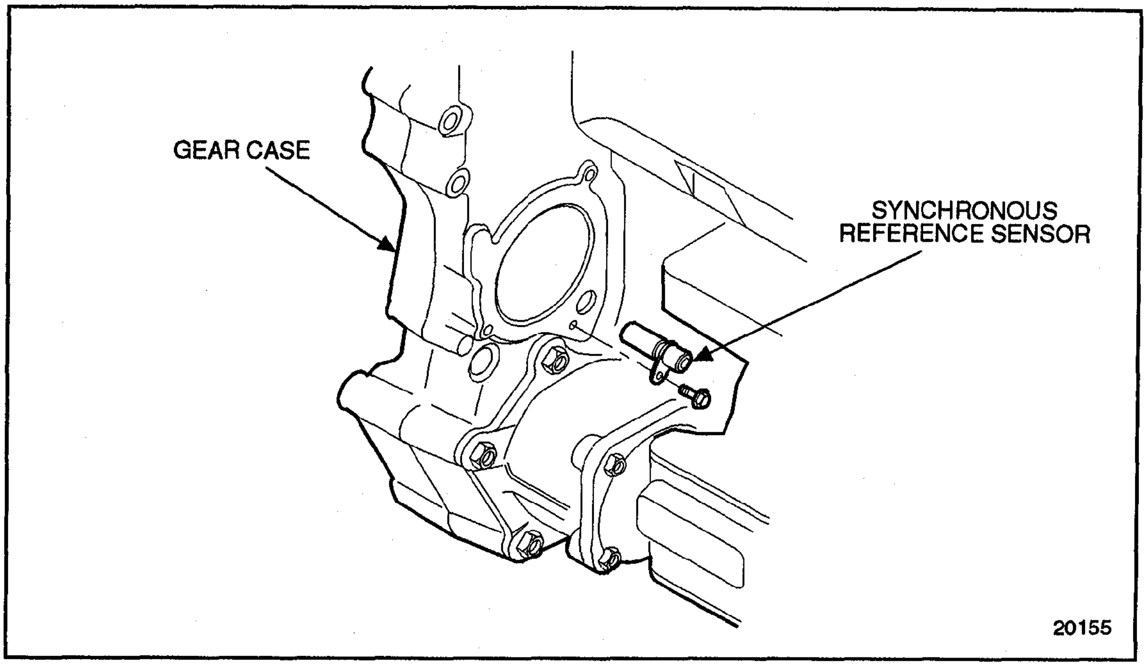

Figure 1-186 Synchronous Reference Sensor

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An opening is provided in the center of the gear case, for the bull gear and camshaft idler gear assembly, which bolts directly to the engine block. See Figure 1-187.

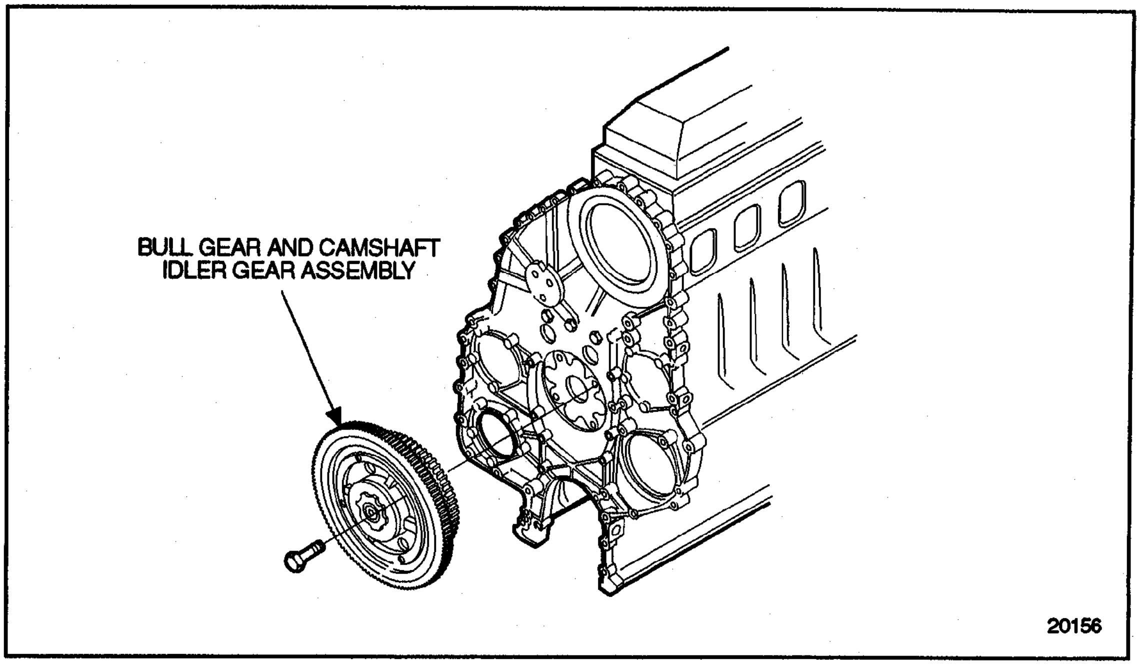

Figure 1-187 Bull Gear and Camshaft Idler Gear Assembly

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An access cover is provided at the rear of the gear case on the cooler (right) side of the engine. This access cover provides an opening for inspection of the accessory drive assembly drive gear. See Figure 1-188.

NOTE:
This access cover opening may be cast closed on the rear of the gear case.

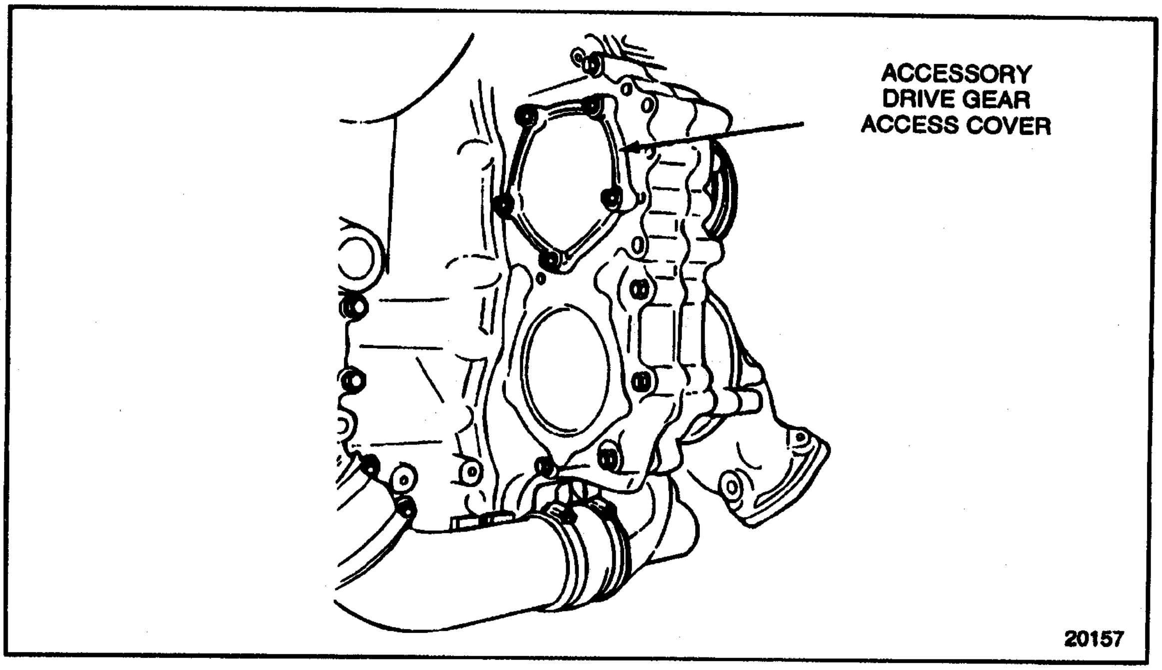

Figure 1-188 Accessory Drive Gear Access Cover (Pre-1991 Engines)

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For gear lash measurement and adjustment procedures for the gears in the engine gear train, Refer to section 1.21.2.1.

An oil gallery is drilled in the gear case casting, for lubrication of the adjustable idler gear assembly. A hole in the front of the cylinder block, indexes with the gear case gallery. At the edge of the gear case the gallery is threaded for insertion of a plug. An exit hole feeds the adjustable idler gear assembly. See Figure 1-189.

NOTE:
Do not use the oil plug location for an oil supply or for checking oil pressure.

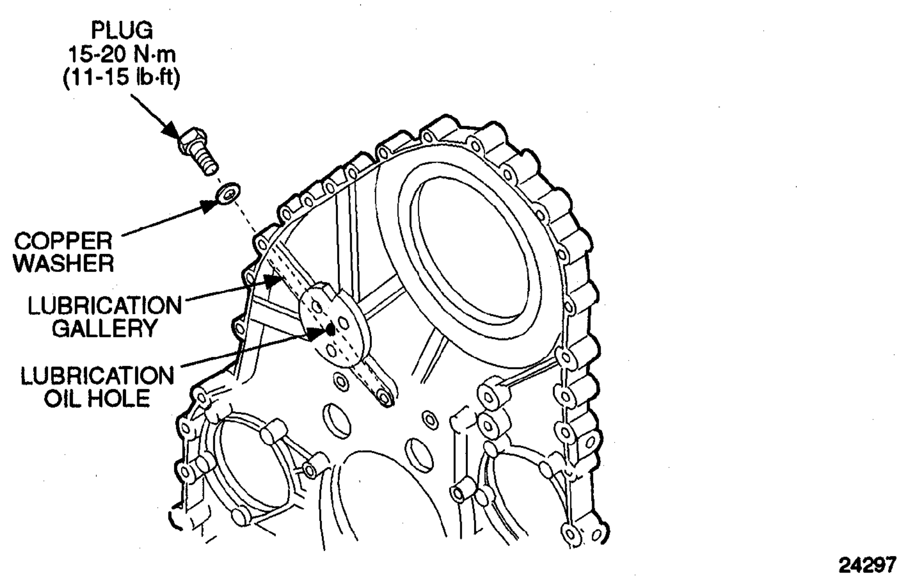

Figure 1-189 Adjustable Idler Gear Lubrication Gallery

1.11.1 Repair or Replacement of Gear Case

To determine if repair is possible or replacement is necessary, perform the following procedure. See Figure 1-190.

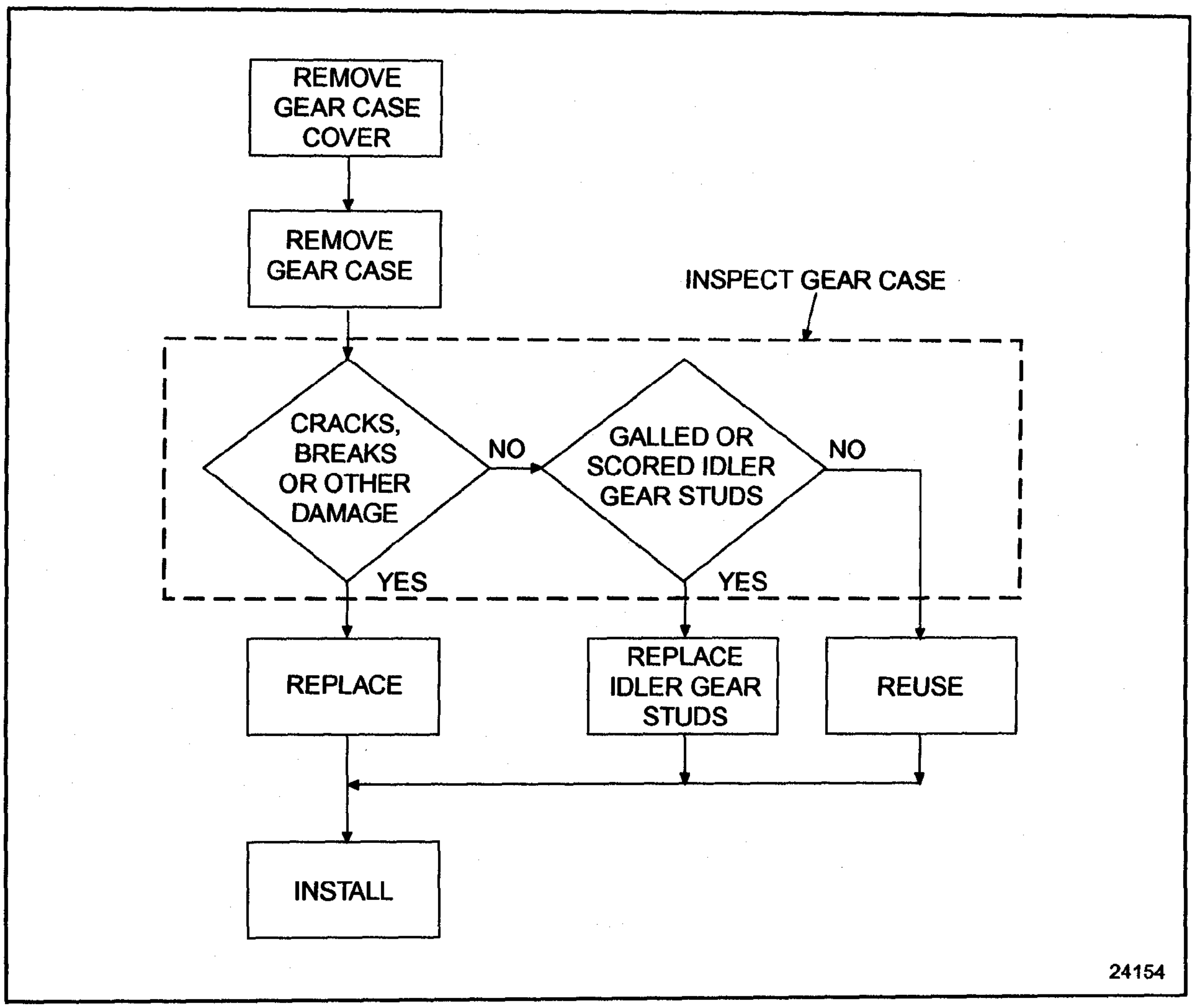

Figure 1-190 Flowchart for Repair or Replacement of Gear Case

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1.11.2 Removal of Gear Case

Perform the following steps to remove the gear case:

1. Remove the SRS. Refer to section 2.29.2.
2. Remove the TRS. Refer to section 2.30.2.
3. Remove the rocker arm assemblies. Refer to section 1.3.2.
4. On heat exchanger-cooled marine engines, remove the water-cooled charge air cooler. Refer to section 4.4.2. Or remove the heat exchanger tank. Refer to section 2.13.1.
5. Perform all of the steps for camshaft removal. Refer to section 1.23.2.
6. Remove the 3 bolts that secure the camshaft gear pilot tool, J 35906, to the gear case and remove the tool.
7. Remove gear case cover. Refer to section 1.10.2, for step 1through step 13 Supporting the gear case cover with a suitable lifting device, but don't remove it.
8. Remove the fuel pump from the fuel pump drive assembly (or air compressor). Refer to section 2.6.2.
9. Remove the air compressor. Refer to section 10.1.5.
10. Remove the air compressor drive assembly. Refer to section 10.3.2.
11. Install the crankshaft protector, J 35994, to the oil seal contact area of the crankshaft. This will help to protect the crankshaft seal surface when removing the bull gear and camshaft idler gear assembly. See Figure 1-191.

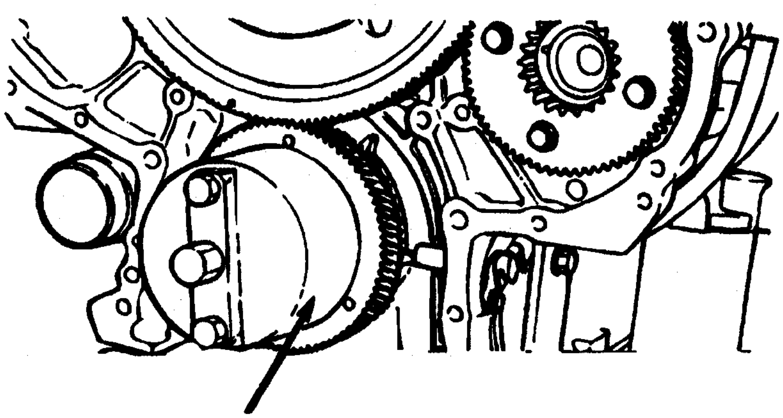

Figure 1-191 Crankshaft Protector Installation

12. Remove the bull gear and camshaft idler gear assembly from the engine. Refer to section 1.26.2.
13. Remove the adjustable idler gear assembly from the gear case. Refer to section 1.25.2.
14. Using a plastic hammer or fiber mallet, tap the rear face of the camshaft thrust plate to remove the thrust plate, camshaft drive gear hub and camshaft drive gear from the gear case.
15. Remove the 12 bolts that secure the gear case to the engine block. See Figure 1-192. Also remove the bolt that secures the gear case stabilizer bracket to the gear case.

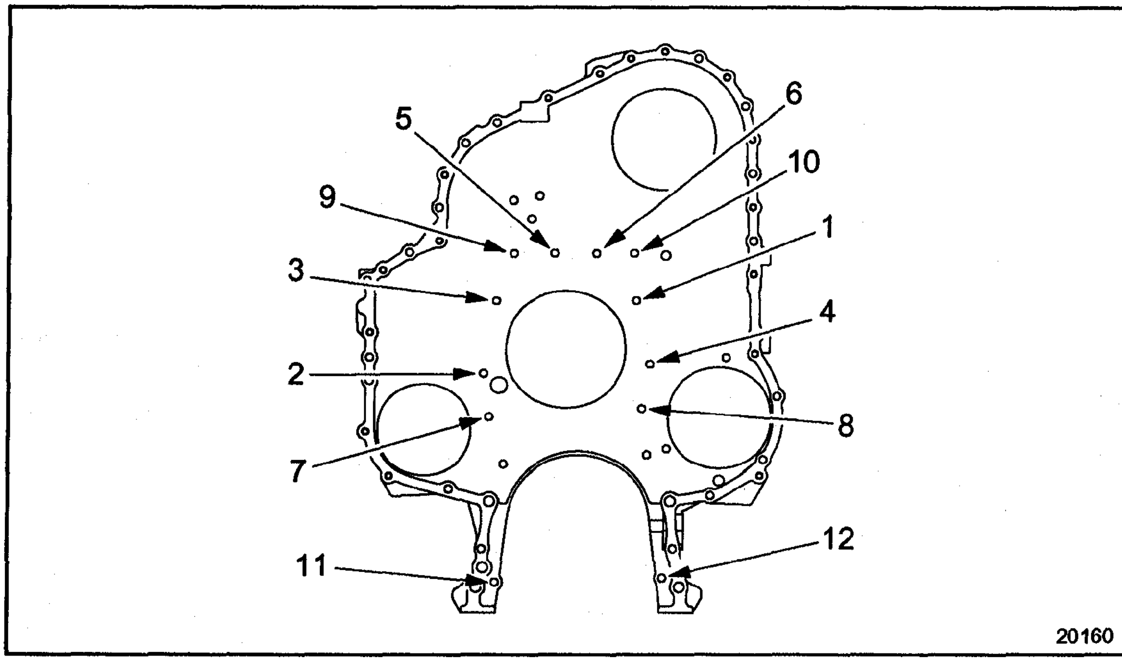

Figure 1-192 Gear Case Mounting Bolt Locations

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16. Using a leather or cloth-wrapped strap, support the gear case. See Figure 1-193.

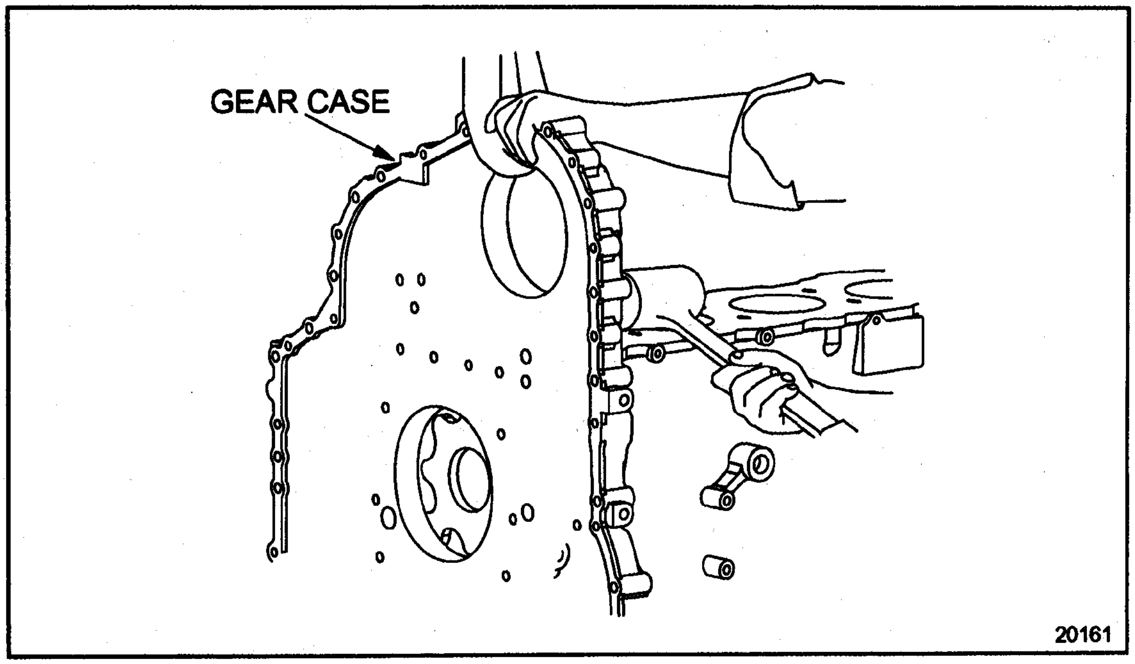

Figure 1-193 Gear Case Removal

17. Use a rubber hammer or plastic mallet to loosen the gear case from the cylinder block dowels.

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1.11.2.1 Inspection of Gear Case

Clean all of the old gasket sealer from the mating surfaces of the gear case, gear case cover, and engine block. Refer to "Gasket Eliminator Removal," in the "General Information" section at the beginning of this manual. Clean the gasket material from the mating surfaces of any components or access covers that were removed from the gear case cover or gear case. Clean all of the parts with clean fuel oil and dry with compressed air. Remove the oil gallery plug at the edge of the gear case. See Figure 1-189.

CAUTION:
To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

Use compressed air to ensure the oil gallery is completely free of blockage. If necessary, use a wire brush to clean the gear case oil gallery.

Inspect the gear case for stress cracks, breaks, or other damage. Repair or replace as necessary. Inspect the adjustable idler gear studs for signs of galling or scoring. Replace as necessary. Inspect all the individual components as outlined under the appropriate section.

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1.11.3 Installation of Gear Case

Use the following instructions for gear case installation:

1. Apply a thin film of gasket eliminator PT-7276 (Loctite® 518) or equivalent to the cylinder block. See Figure 1-194. Carefully smooth the bead around the block-to-gear case oil passage to avoid contamination.

NOTE:
The installation of Gasket Eliminator to the gear case-to-block mating surfaces at the top of the block is critical. Excess gasket eliminator material can extrude into the oil passage between the block and gear case, causing early failure of components. In addition, the bull gear recess area MUST be cleaned of any and all foreign material after installation of the gear case to the engine block.

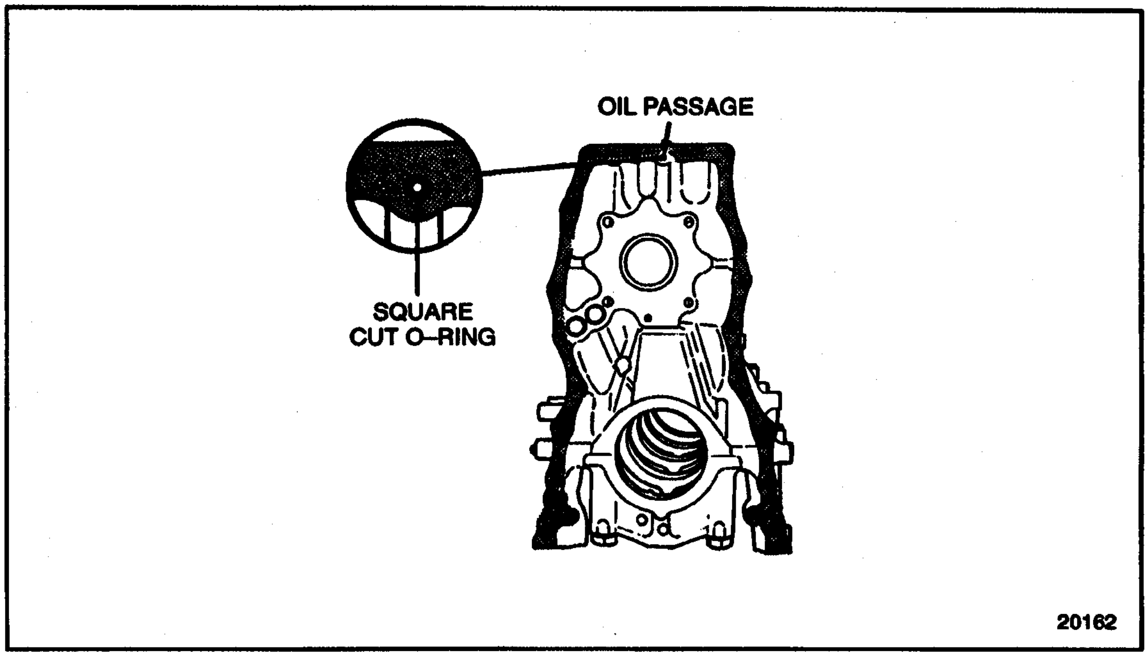

Figure 1-194 Gasket Eliminator Application

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2. Insert gear case alignment plug, J 35651, into the bull gear and camshaft idler gear hub recess in the cylinder block. See Figure 1-195.

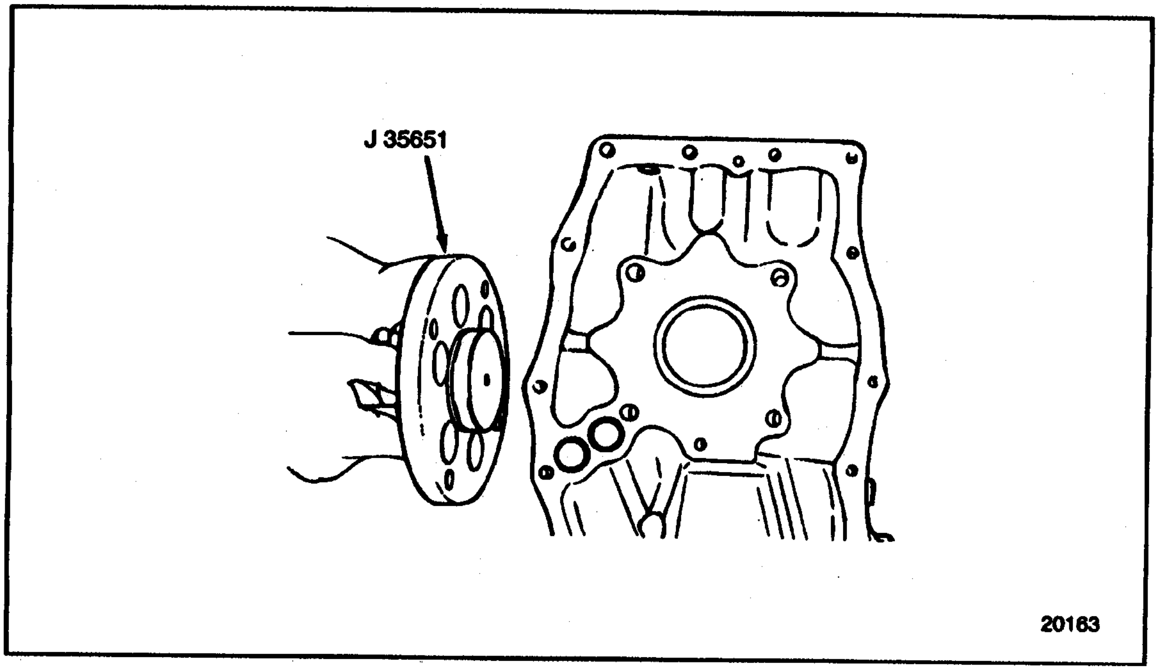

Figure 1-195 Gear Case Alignment Plug

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3. Using a suitable lifting sling made of cloth or leather, position the bull gear and camshaft idler gear opening of the gear case over the gear case alignment plug. Index the hole in the gear case mating surface with the diamond dowel at the lower left corner of the cylinder block. See Figure 1-196.

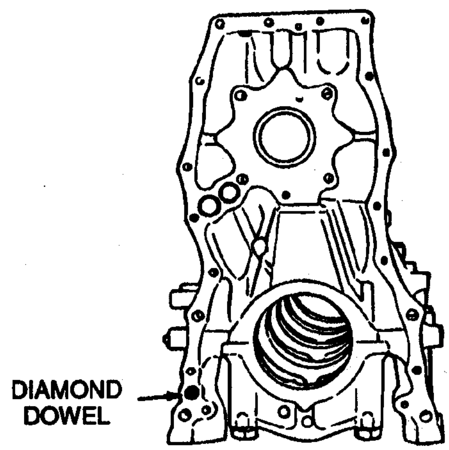

Figure 1-196 Cylinder Block Locating Diamond Dowel

4. With the gear case alignment plug fully seated, the gear case centered on the alignment plug and the diamond dowel in the cylinder block indexed with its mating hole in the gear case, the gear case is positioned properly for bolt installation. See Figure 1-197.

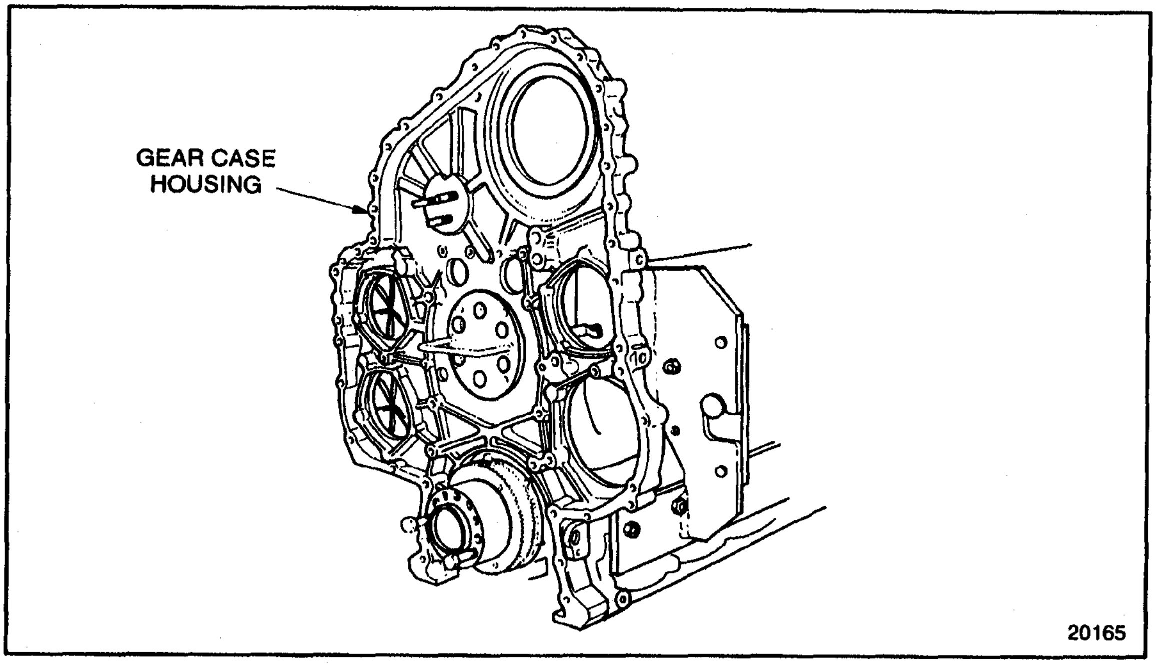

Figure 1-197 Gear Case Positioning

NOTE:
Gasket Eliminator cures with the absence of air. The time between the installation of the gear case, and torquing of the bolts that secure the gear case to the cylinder block should be kept to a minimum.

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5. Install the 12 gear case-to-cylinder block retaining bolts, finger-tight.
6. Torque the gear case-to-cylinder block bolts to 58-73 N·m (43-54 lb·ft). See Figure 1-198.

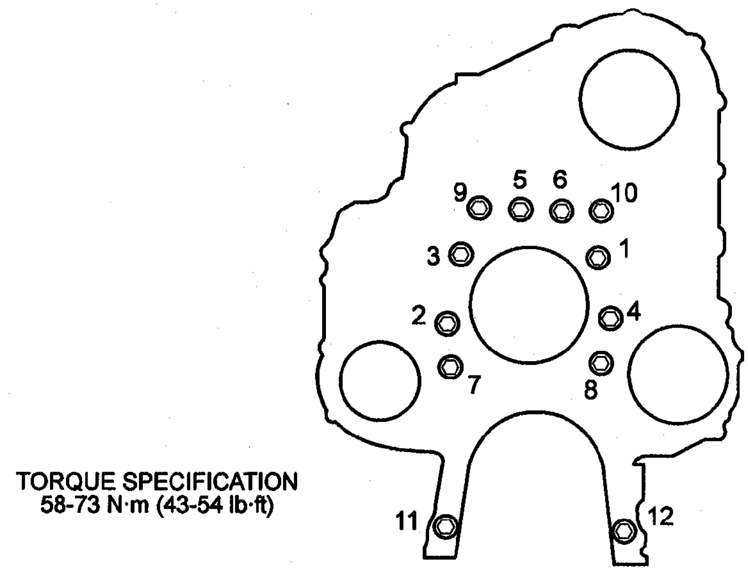

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Figure 1-198 Gear Case Housing Bolt Torque Sequence

7. Remove the gear case alignment plug from the gear case.
8. Install the air compressor. Refer to section 10.1.8.
9. Install the air compressor drive assembly. Refer to section 10.3.6.
10. Install the fuel pump drive assembly to the gear case, if so equipped. Refer to section 2.6.5 or refer to section 2.6.6.
11. Install the fuel pump to the fuel pump drive assembly (or air compressor). Refer to section 2.7.3.

NOTE:

For 1991 and later model year engines, refer to section 4.2.8or refer to section 4.3.7and install the water pump assembly.

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12. Lubricate the rubber O-ring on the camshaft thrust plate with clean engine oil. Install the camshaft thrust plate assembly, with the camshaft drive gear and hub in place to the gear case, using a plastic hammer or fiber mallet to tap the thrust plate rearward in the gear case just enough to start it in the gear case. See Figure 1-199.

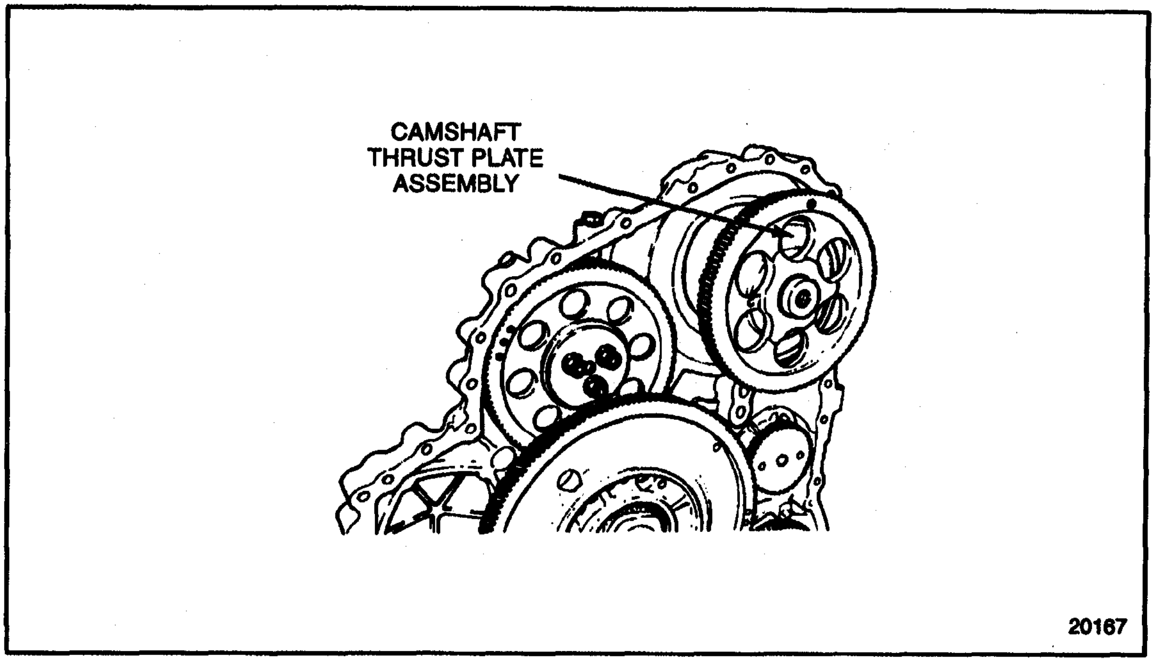

Figure 1-199 Camshaft Thrust Plate Installation

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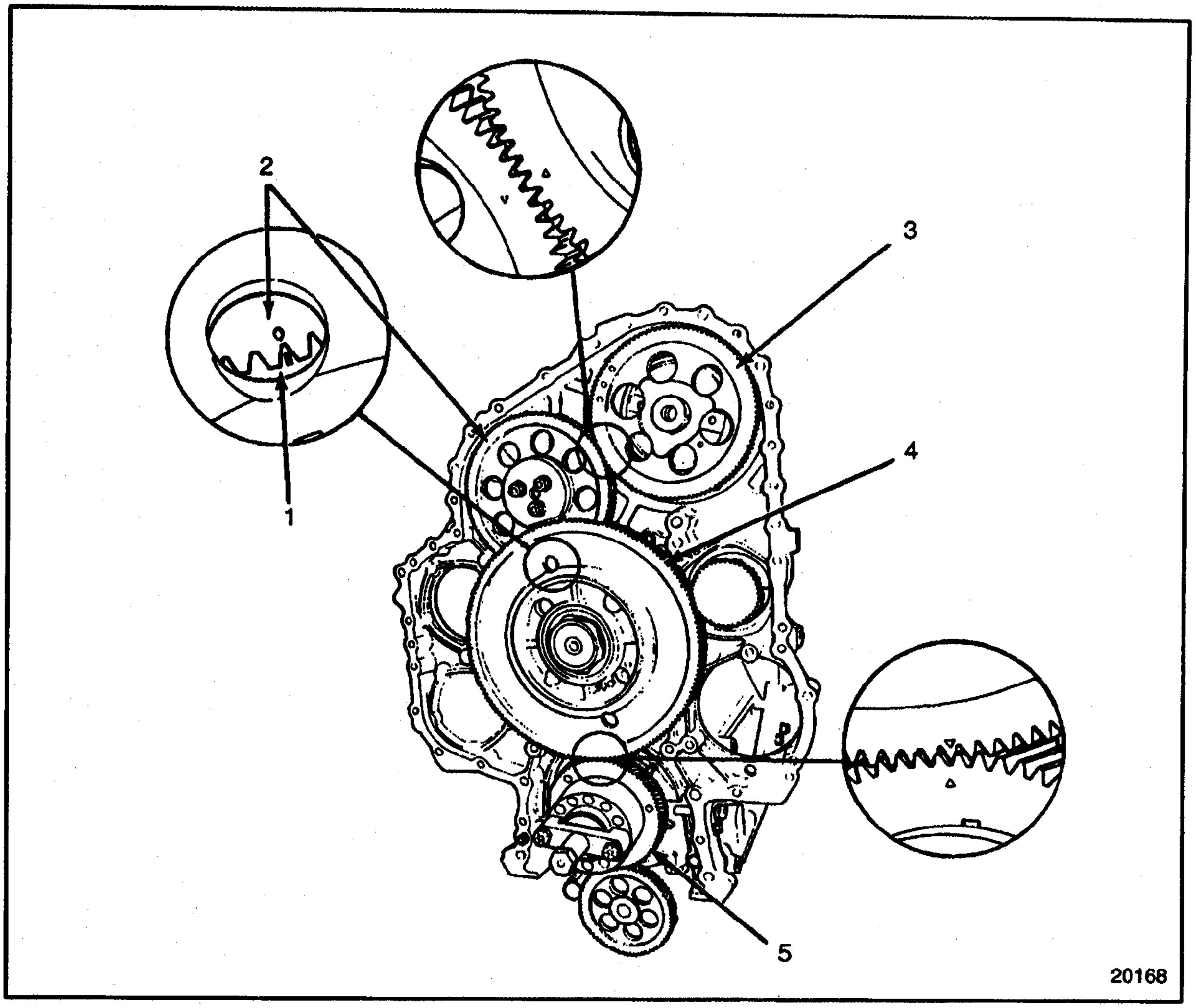
13. Install the adjustable idler gear assembly to the gear case. Refer to section 1.25.3. Align the timing marks of the adjustable idler gear and camshaft drive gear. See Figure 1-200.



1. Camshaft Idler Gear
2. Adjustable Idler Gear
3. Camshaft Drive Gear
4. Bull Gear
5. Crankshaft Timing Gear

Figure 1-200 Engine Gear Train Timing Marks

14. Inspect the bull gear and camshaft idler gear access opening in the gear case and remove any foreign material.

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15. Install two bull gear guide studs, J 35785 to the cylinder block. See Figure 1-201.

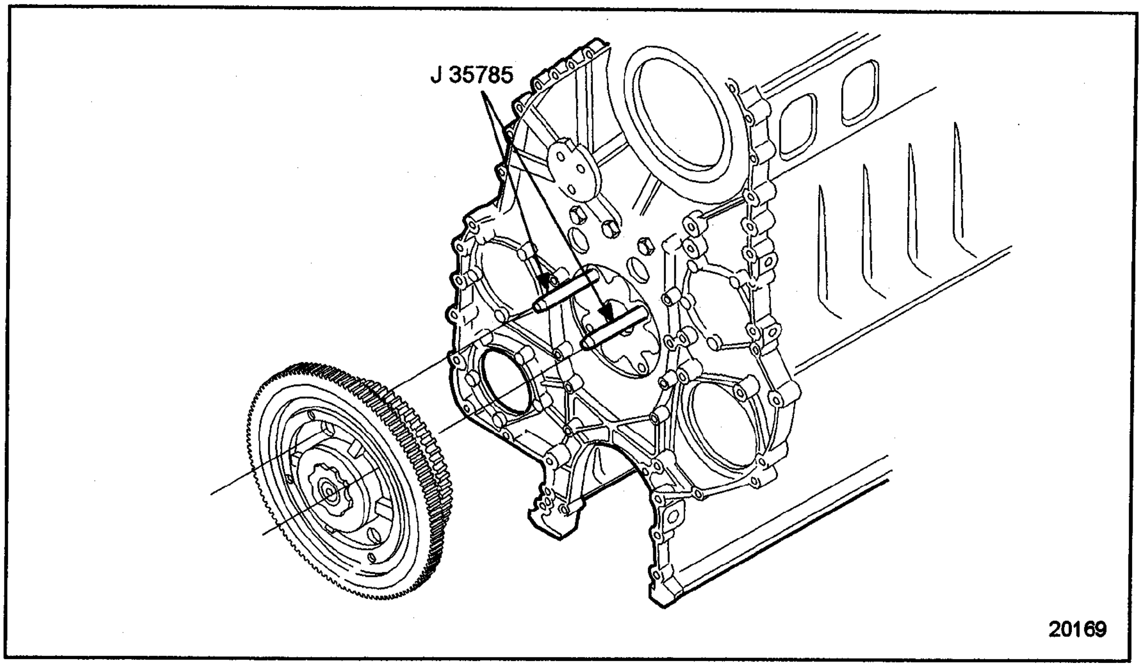

Figure 1-201 Bull Gear Guide Stud Installation

NOTICE:
Always install crankshaft protector when installing the bull gear and camshaft idler gear assembly to prevent damaging the crankshaft oil seal contact surface.

16. Install the crankshaft protector, J 35994 to the oil seal contact area of the crankshaft. This will help to protect the crankshaft seal surface when installing the bull gear and camshaft idler gear assembly.
17. Install the bull gear and camshaft idler gear assembly to the guide studs. Align the timing marks on the bull gear and the crankshaft timing gear and the camshaft idler gear and adjustable idler gear; see Figure 1-200, and slide the bull gear and camshaft idler gear assembly forward to seat it in the recess in the gear case and cylinder block.
18. Working through the lightening holes in the bull gear, install two of the bull gear assembly mounting bolts through the hub and into the cylinder block. Finger-tighten the bolts.
19. Remove the two bull gear guide studs. Install the remaining two bull gear assembly mounting bolts. Torque the bolts to 101-126 N·m (75-93 lb·ft). Tighten in a clockwise sequence.
20. Check the timing marks on the gears to ensure the gear train is properly timed. See Figure 1-200.

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21. Perform the following:
    - [a] For crankshaft timing gear-to-oil pump gear lash measurement. Perform step 2, refer to section 1.21.2.1.
    - [b] For crankshaft timing gear-to bull gear lash measurement. Perform step 3, refer to section 1.21.2.1.
    - [c] To install the gear case cover. Refer to section 1.10.3.
22. Refer to section 1.23.5, "Installation of Camshaft Bearing" and perform the necessary steps.
23. For bull gear-to-accessory drive gear lash measurement, perform step 10Refer to section 1.21.2.1.
24. If the stabilizer bracket has not been removed, loosen the two bolts securing the bracket to the cylinder head. Install the gear case stabilizer bracket-to-gear case bolt and torque to 58-73 N·m (43-54 lb·ft). Then, retorque the stabilizer bracket-to-cylinder head bolts to 58-73 N·m (43-54 lb·ft).
25. Continue engine assembly.

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1.12 CRANKSHAFT VIBRATION DAMPER

A viscous type vibration damper is mounted on the front end of the crankshaft to reduce torsional vibrations to a safe value. See Figure 1-202.

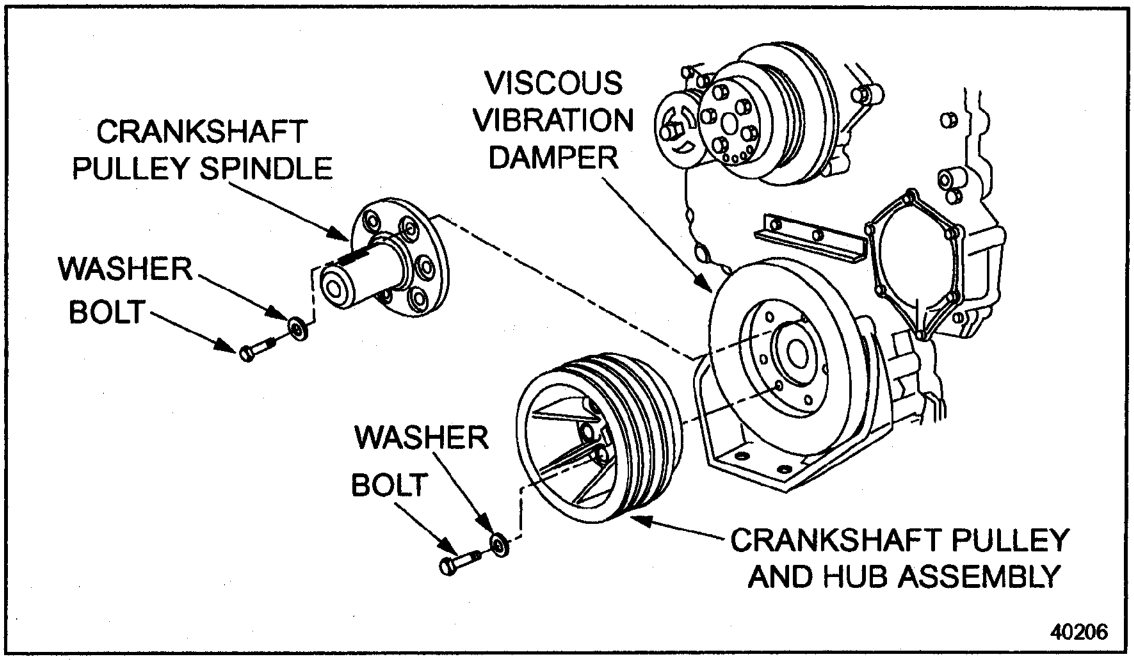

Figure 1-202 Viscous Vibration Damper Mounting with Crankshaft Pulley or Crankshaft Pulley and Hub Assembly with Spindle

Prior to April 1993, 11.1 liter engines with less than 320 hp (238 kW) were equipped with a 313.4 mm (12.34 in.) damper and 11.1 liter engines with 320 hp (238 kW) or more were equipped with a 342.9 mm (13.5 in.) damper, and all 12.7 liter engines, were equipped with a 342.9 mm (13.5 in.) damper.

Beginning in April 1993, all Series 60 engines are built with a 342.9 mm (13.5 in.) damper.

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A vibration damper safety shield is recommended in industrial and marine applications in which the engine operates without a hood or other protective covering in an open or unprotected area.

A properly designed and installed safety shield protects the damper from damage, prevents direct physical contact with the damper during engine operation, and significantly reduces the potential for damper-related personal injury.

Detroit Diesel Corporation does not manufacture, sell or install vibration damper safety shields due to the wide variety of installations in which Detroit Diesel engines are applied. Space restrictions in these numerous applications make it necessary to design an appropriate type of shield for each installation.

The responsibility for designing and installing properly shaped and constructed safety shields, therefore, rests with the OEM (Original Equipment Manufacturer), distributor, or other fabricator designing or manufacturing products in which they apply Detroit Diesel engines.

During operation, the outer shell, which is firmly attached to the crankshaft, turns at the same speed as the crankshaft, its motion being transferred to the flywheel through the fluid within the shell. Since "fluid-drive" is more or less inefficient with frequent speed changes, considerable flywheel slippage will take place as the power impulses are transmitted through the crankshaft. In this type of operation, the slippage is desirable since the acceleration and deceleration of the flywheel in the damper lessens the vibration amplitude, reducing its effects to a level harmless to the engine.

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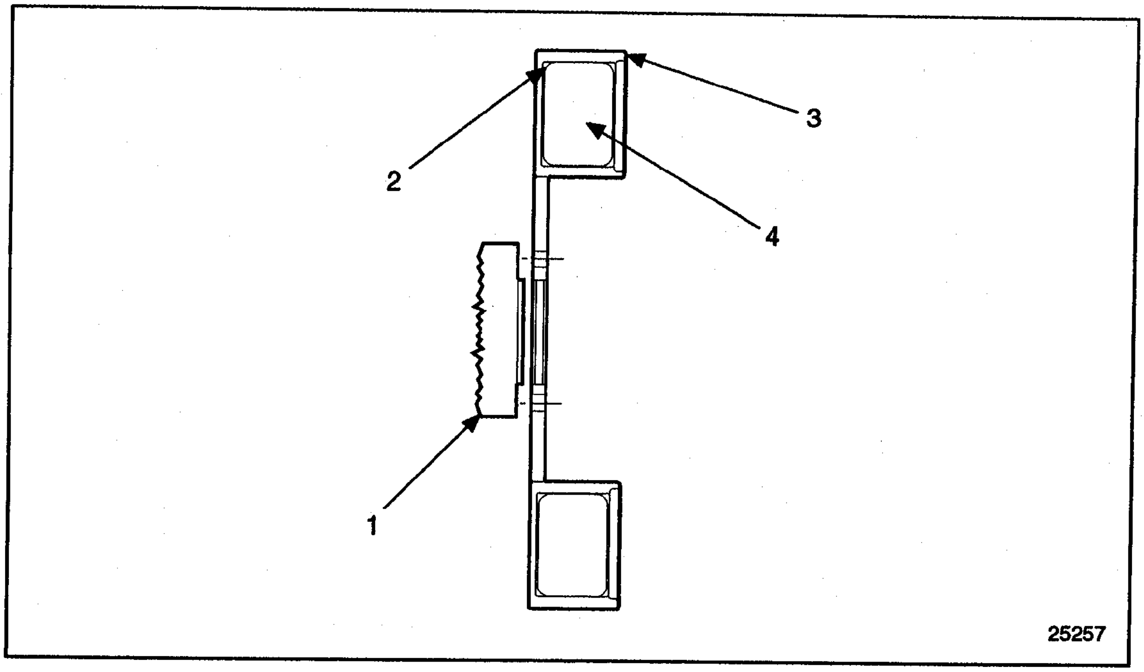
The viscous damper assembly consists of a sealed outer shell, an internal flywheel and a quantity of highly viscous fluid. See Figure 1-203.



1. Crankshaft
2. Viscous Fluid
3. Damper Shell
4. Internal Flywheel

Figure 1-203 Viscous Vibration Damper Detail

1.12.1 Repair or Replacement of Crankshaft Vibration Damper

To determine if repair is possible or replacement is necessary, perform the following procedure. See Figure 1-204.

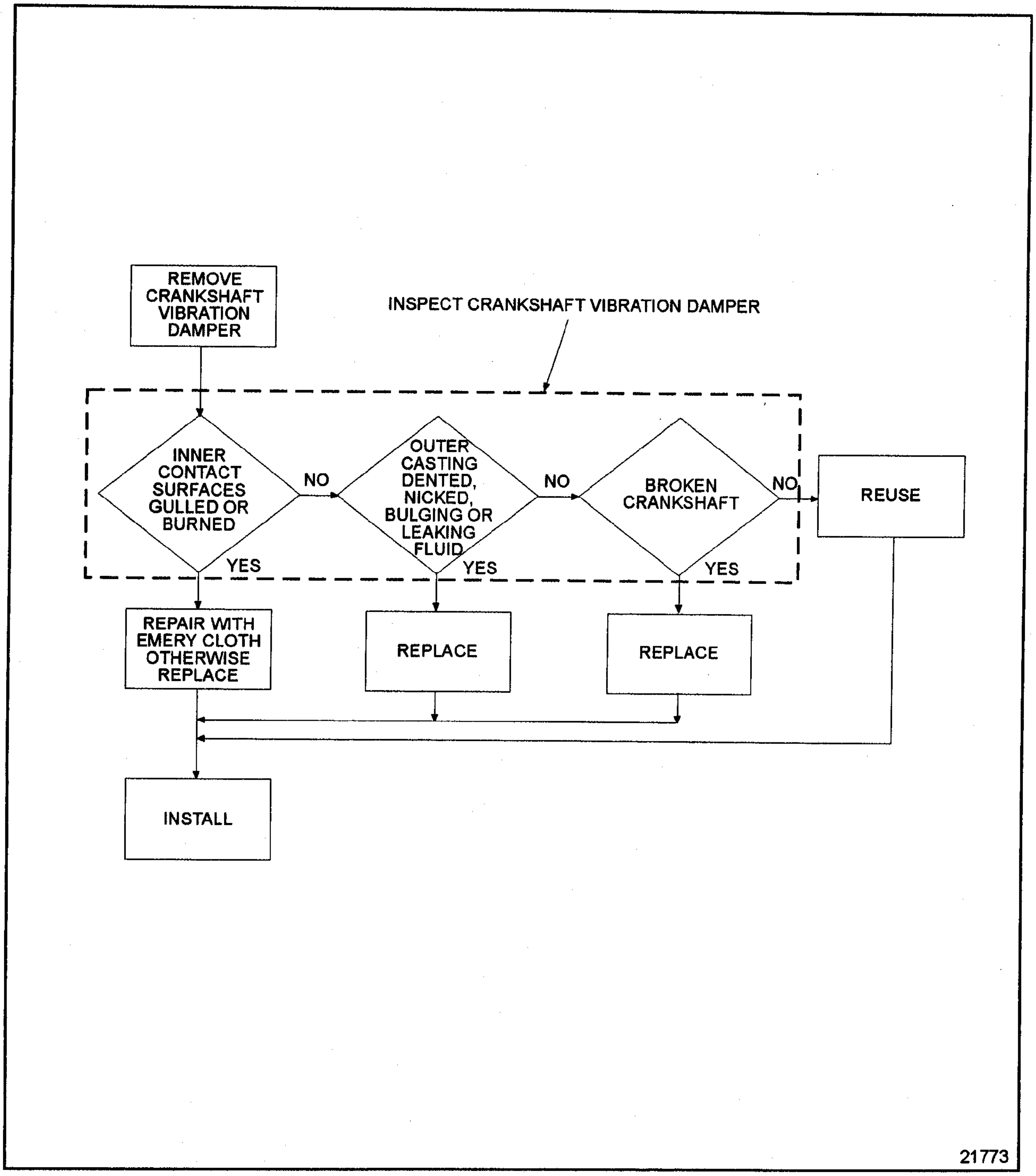


Figure 1-204 Flowchart for Repair or Replacement of Crankshaft Damper

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1.12.2 Cleaning and Removal of Crankshaft Vibration Damper

Precleaning is not necessary.

CAUTION:
To avoid injury from the projection of tools or other objects that may fall on or behind the vibration damper of an engine, always check and remove these items before starting the engine.

Remove crankshaft vibration damper as follows:

1. Remove the drive belts from the crankshaft pulley. Refer to section 13.13.10.
2. Remove the inspection plug in the bottom of the flywheel housing and install the flywheel lock, J 36375–A. See Figure 1-205.

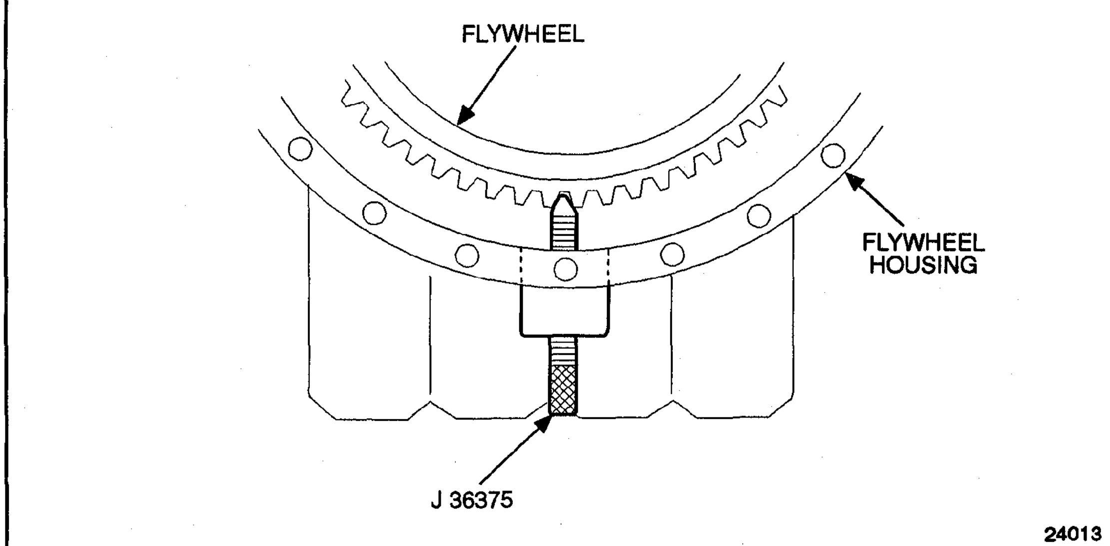

Figure 1-205 Flywheel Lock

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3. Thread the center screw of the tool in until the tip of the tool rests between two teeth of the flywheel ring gear.

NOTE:
It may be necessary to bar the engine over (using the square hole in the middle of the crankshaft pulley or the center bolt when the pulley and hub assembly with spindle is used) so that the tool center screw is exactly between two teeth.

4. Tighten the knurled knob finger-tight.
5. On keel-cooled marine engines, remove the charge air cooler tank. Refer to section 4.4.2.
6. Remove the isolated pulley from the spindle by removing the large center bolt (if equipped with this pulley style).
7. Remove two of the six crankshaft pulley or crankshaft pulley spindle to crankshaft special attaching bolts and hardened washers that are 180 degrees apart. Discard the bolts. These bolts are not reusable.
8. Install two guide studs, J 36235 into the holes where the bolts were removed.

NOTICE:
Use care when removing the crankshaft pulley as the vibration damper may come off. If the damper is allowed to fall, internal damage to the damper will result.

9. Remove the remaining four special crankshaft pulley bolts and hardened washers. Discard the bolts. These bolts are not reusable.

NOTICE:
Do not pound with a hammer or pry with other tools to remove the viscous damper from the crankshaft, since the outer shell may be dented and cause the flywheel to turn at the same speed as the outer shell. This renders the damper ineffective. The damper CANNOT be repaired.

10. Remove the vibration damper by sliding it off the guide studs.
11. Remove the flywheel lock and guide studs.

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1.12.2.1 Inspection of the Vibration Damper

Inspect the vibration damper as follows:

NOTICE:
Dents may render the damper in effective.

1. Inspect the outer casing of the damper for damage.
   [a] Check outer casing for dents, cracks, nicks, fluid leaks or bulges.
   [b] If any dents or cracks are detected, replace with new damper.
   [c] Bulges or splits indicate that the damper fluid has deteriorated. If any are detected, replace with new damper.
2. Inspect the damper inner contact surfaces and the crankshaft end for damage. See Figure 1-206.
   [a] Check for galling or burrs.
   [b] Slight scratches or burrs may be removed with an emery cloth.
   [c] If deep scratches are detected, replace with new damper.

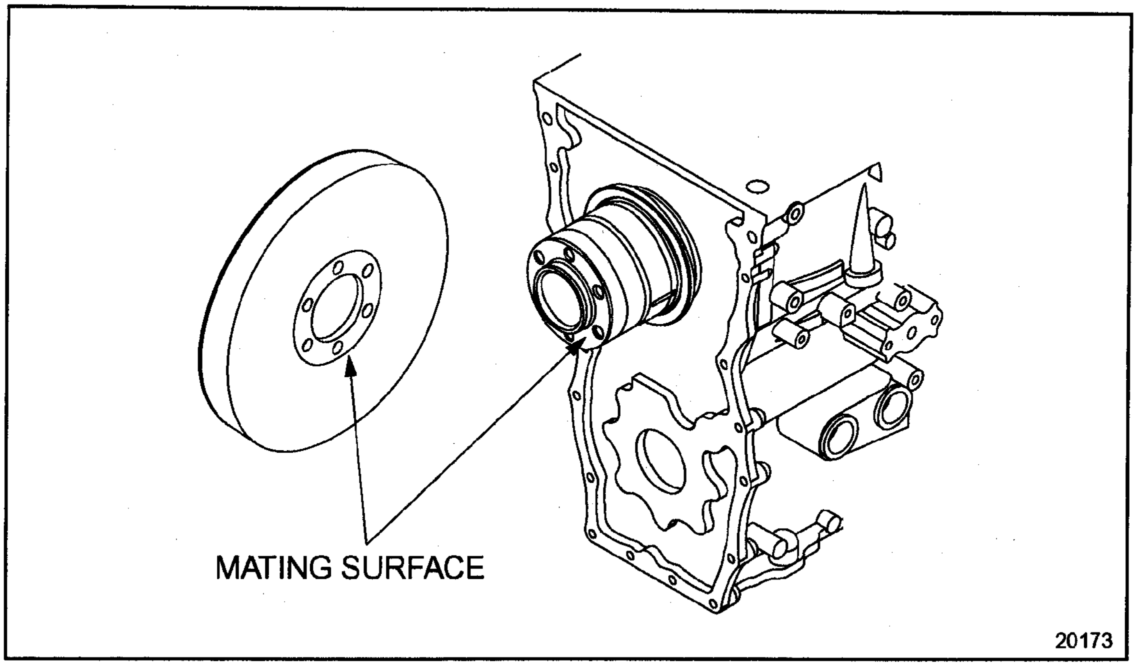

Figure 1-206 Damper and Crankshaft Contact Surfaces

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3. Regardless of its condition, a viscous type damper must be replaced at normal engine overhaul or whenever the engine has experienced crankshaft breakage.
4. If the vibration damper has been damaged, inspect the crankshaft. Refer to section 1.7.2.1. Crankshaft damage may have resulted.

NOTICE:
A loose engine mount could lead to damage of the vibration damper by allowing the engine to move slightly during operation.

NOTE:
It is good practice to periodically inspect the engine mounts to be sure they are not loose, cracked or deteriorated.

1.12.3 Installation of Crankshaft Vibration Damper

Install the crankshaft vibration damper as follows:

1. Install the flywheel lock, J 36375–A, to the inspection plug hole in the bottom of the flywheel housing. See Figure 1-205.

NOTE:
It may necessary to bar the engine over (using barring tool J 36237) so that the tool center screw is exactly between two teeth.

2. Thread the center screw of the tool in until the tip of the tool rests between two teeth of the flywheel ring gear. Tighten the knurled knob finger-tight.
3. Install two guide studs, J 36235, to two of the holes in the crankshaft pulley 180 degrees apart. A light coating of an antiseize compound should be applied to the pilot diameter (not the face of the crankshaft) to reduce future removal difficulty.
4. Install the vibration damper to the end of the crankshaft. The six holes in the damper are equally spaced, and the damper may be installed in any position. The part number on the face of the damper should face out, away from the engine.
5. Install the crankshaft pulley or crankshaft pulley spindle to the crankshaft. The crankshaft pulley or crankshaft pulley spindle may be installed in any position. Refer to section 1.13.3.

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NOTICE:

Crankshaft pulley and spindle mounting bolts are considered single-use items and *must not be reused.* Always use new bolts when mounting the crankshaft pulley or spindle. Reusing bolts may result in excessive bolt stretch during installation, leading to loss of bolt torque and loosening during engine operation, which may cause severe engine damage.

6. Install four new special bolts, with hardened washers installed, through the pulley or crankshaft pulley spindle and damper and into the crankshaft. Finger-tighten the bolts.
7. Remove the two guide studs.
8. Install the remaining two new special bolts with hardened washers installed.
9. Torque the six crankshaft pulley bolts to 182-210 N·m (134-155 lb·ft). Proceed in a clockwise direction until all bolts are torqued.
10. Install crankshaft pulley and hub assembly (if equipped with this pulley style). Refer to section 1.13.3
11. Remove the flywheel lock tool.
12. Install the pipe plug to the inspection hole in the flywheel housing.
13. Install the drive belts to the crankshaft pulley. Adjust the belt tensions to the specifications. Refer to section 13.13.10.
14. Install any other components that were removed for this operation.
15. Refer to section 11.8 for verification of proper crankshaft vibration damper installation.

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1.13 CRANKSHAFT PULLEY

Two crankshaft pulley arrangements exist. Some early engines were built with a pulley, a crankshaft pulley hub and woodruff keys. Later engines are built with the crankshaft pulley bolted directly to the crankshaft.

For the crankshaft pulley bolted directly to the crankshaft, see Figure 1-207. In this case the pulley is attached to the crankshaft with six special bolts and washers. The vibration damper is clamped between the crankshaft pulley and the crankshaft.

NOTE:
Do not substitute any other bolts or washers. The crankshaft pulley bolts and washers are special parts. These bolts are not reusable.

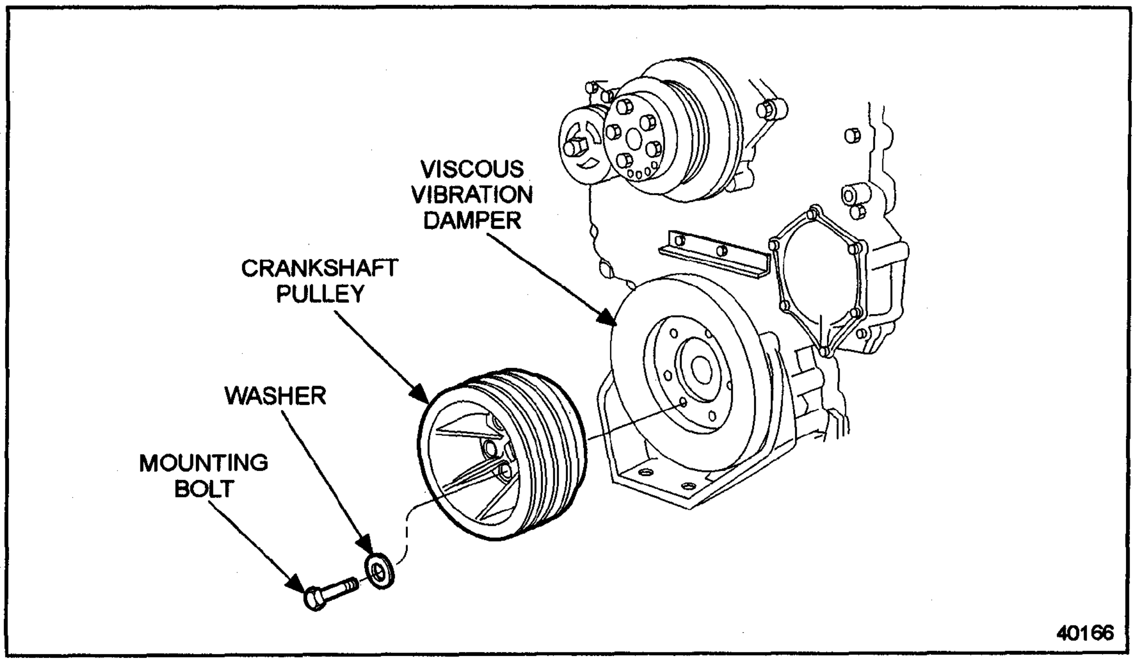

Figure 1-207 Crankshaft Pulley Mounted Directly to the Crankshaft

The crankshaft pulley is of the rigid design. Six bolt holes through the pulley are equally spaced. A relief area is machined around each bolt hole and acts as a seating surface for the hardened washers. See Figure 1-208.

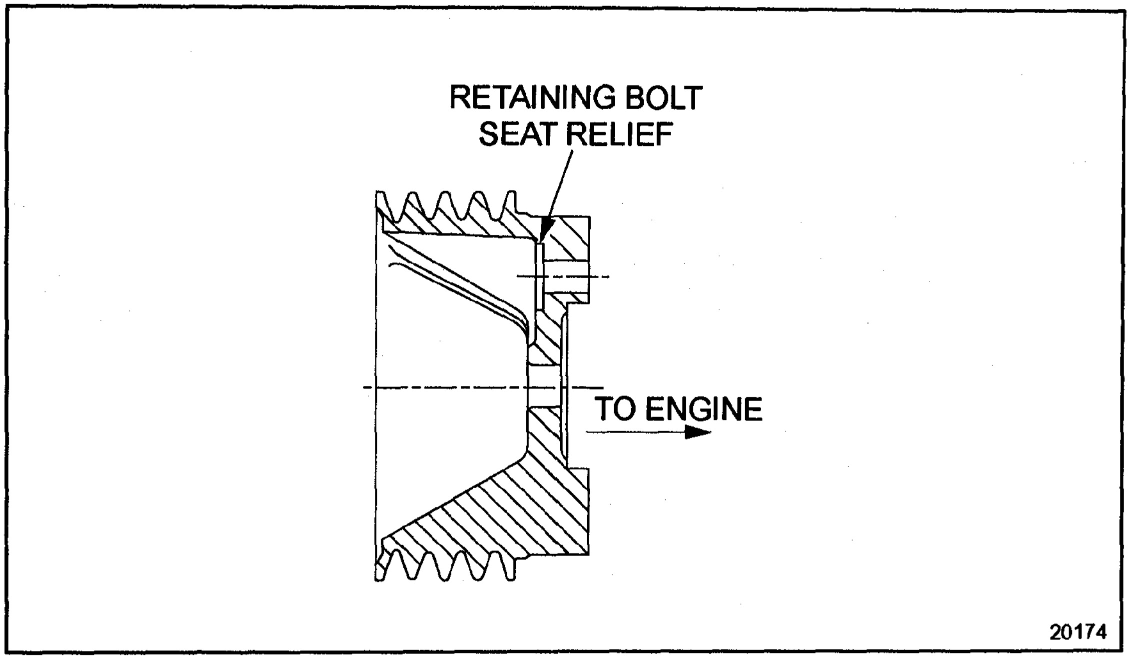

Figure 1-208 Crankshaft Pulley Cross-Section

Four 12.7 mm (.50 in.) vee-type grooves in the crankshaft pulley provide drive belt seating surfaces.

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A 3/4 in. square drive hole in the center of the crankshaft pulley allows the use of a 3/4 in. drive breaker bar or ratchet for barring the engine over. See Figure 1-209.

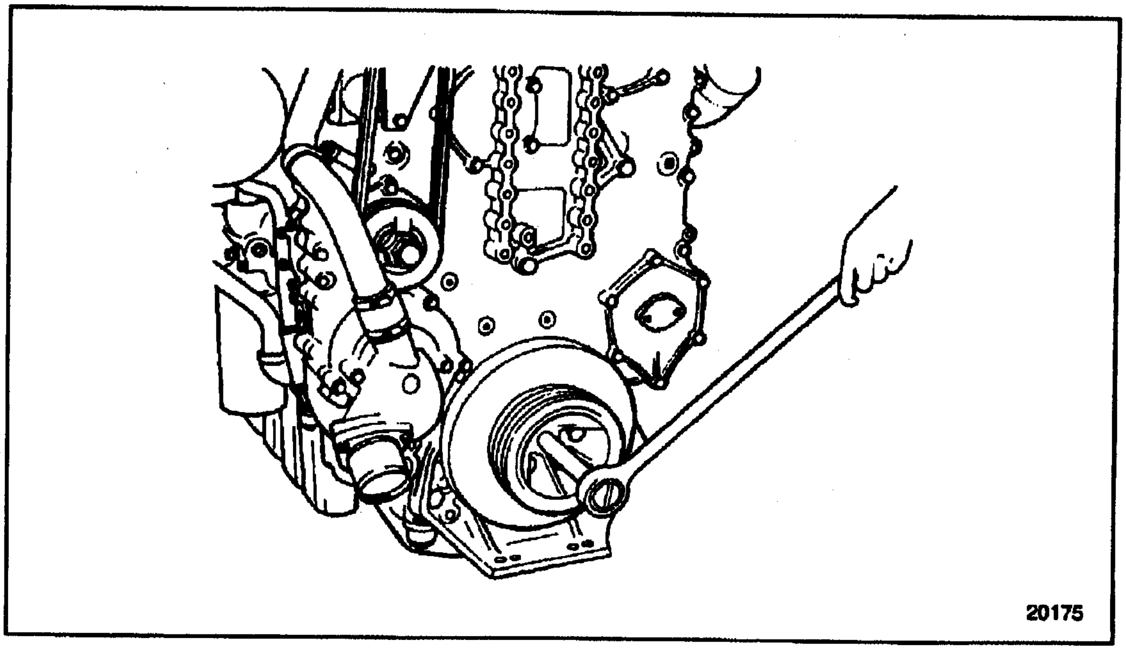

Figure 1-209 Barring Engine Over

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For the crankshaft pulley and hub assembly with spindle, see Figure 1-210. The spindle is attached to the crankshaft with six special bolts and washers, which also secure the vibration damper to the crankshaft. Two woodruff keys and the crankshaft pulley bolt secure the crankshaft pulley and hub assembly to the spindle.

NOTE:
Do not substitute any other bolts or washers. The spindle bolts and washers are special parts. These bolts are not reusable.

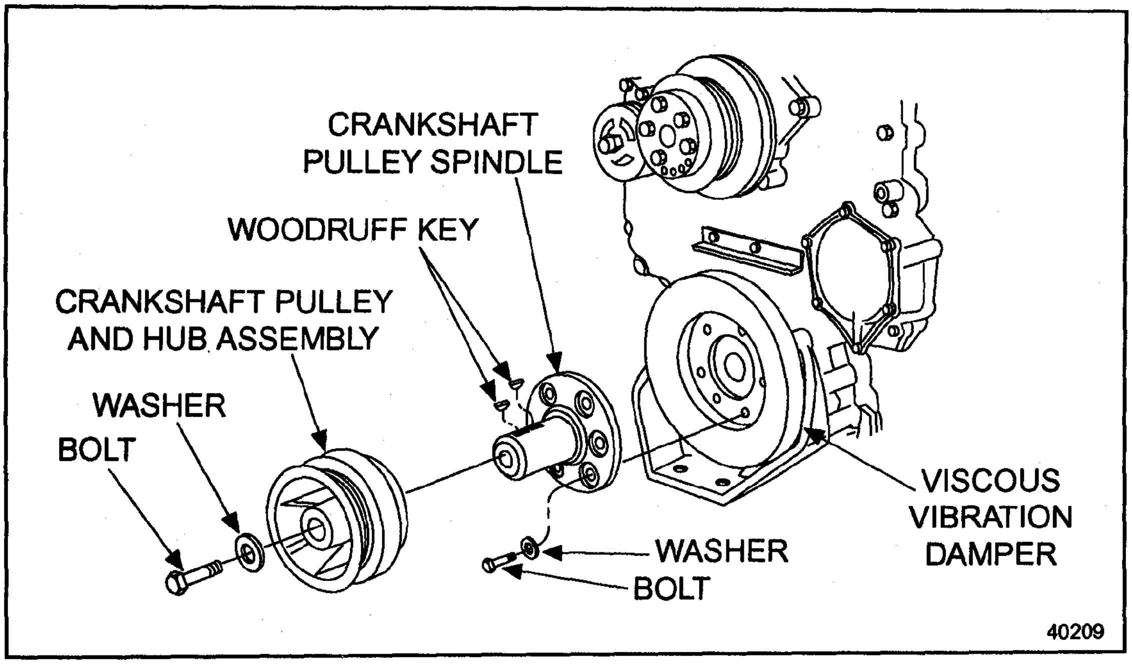

Figure 1-210 Crankshaft Pulley and Hub Assembly Installation with Spindle

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The spindle has six equally spaced mounting holes. A relief area is machined around each bolt hole and acts as a seating surface for the hardened washers. See Figure 1-211.

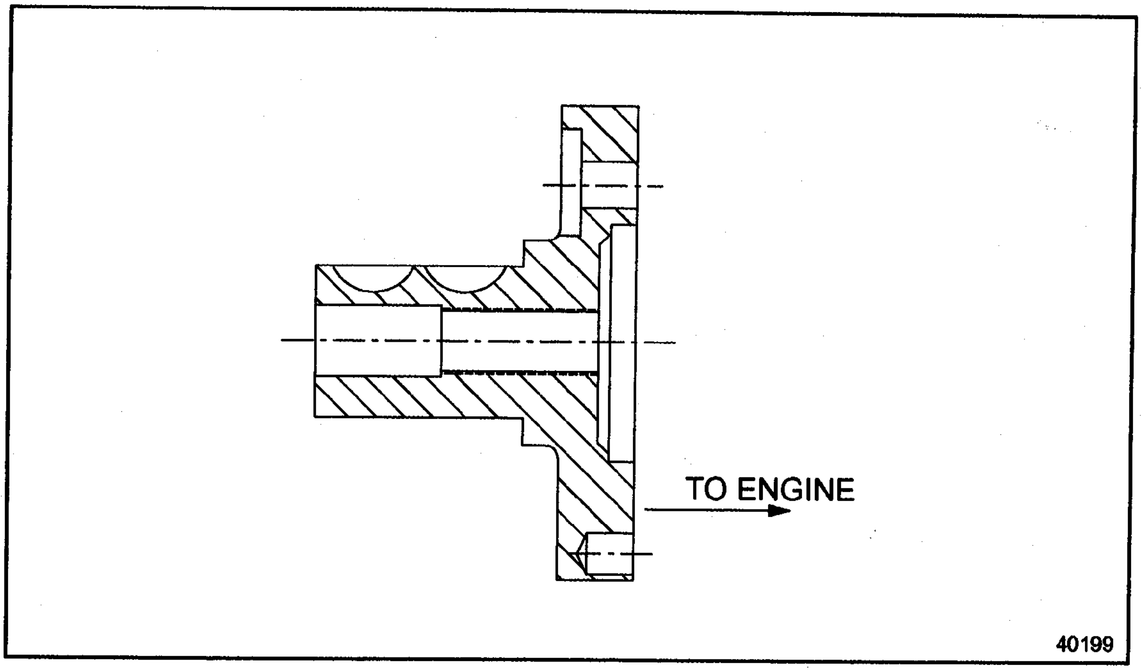

Figure 1-211 Crankshaft Pulley Spindle

The crankshaft pulley assembly is secured to the spindle with two woodruff keys, a crankshaft pulley bolt and hardened washer. The crankshaft pulley bolt is also used to bar the engine over. See Figure 1-210.

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1.13.1 Repair or Replacement of Crankshaft Pulley

To determine if repair is possible or replacement is necessary, perform the following procedure. See Figure 1-212.

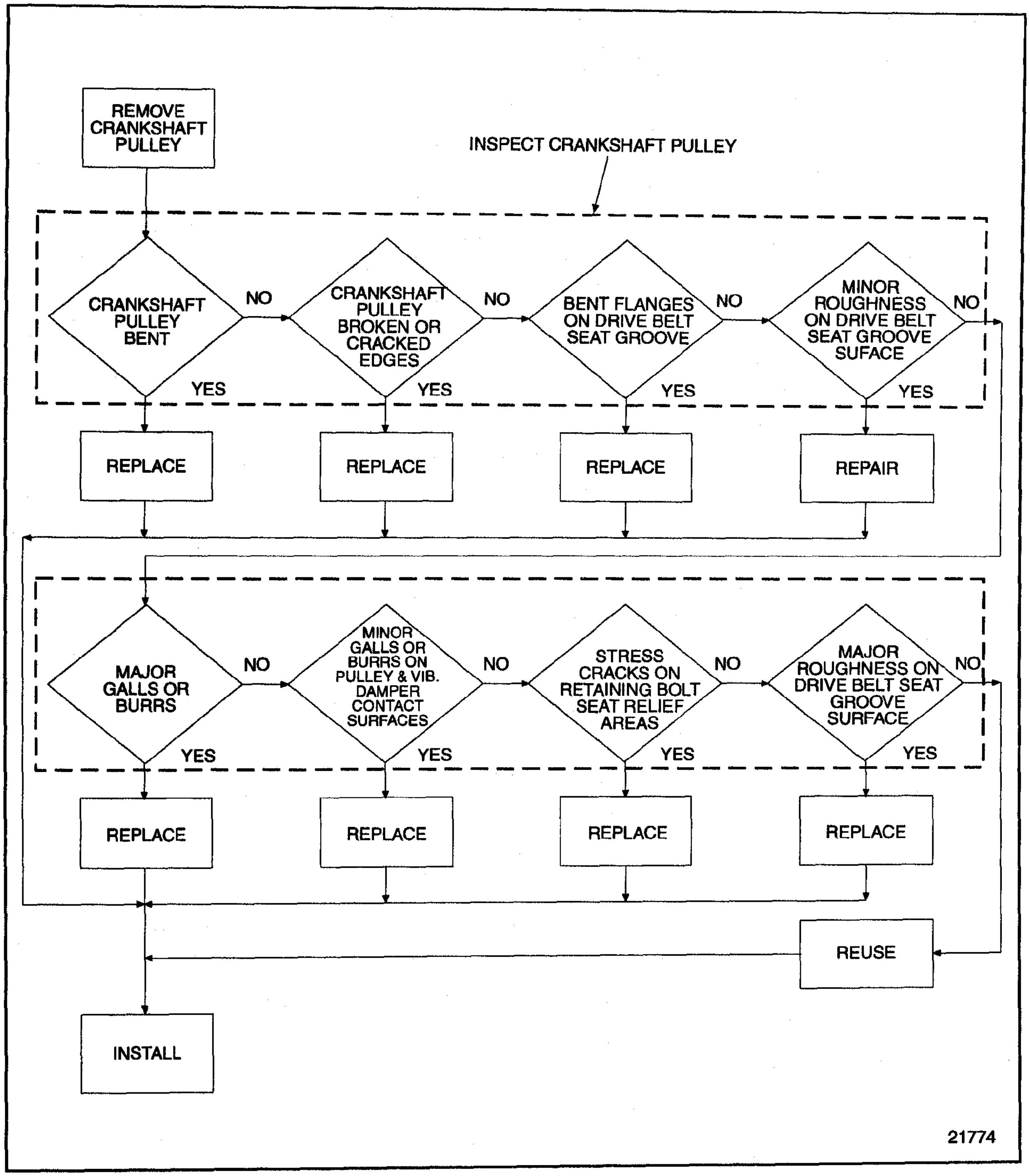

Figure 1-212 Flowchart for Repair or Replacement of Crankshaft Pulley

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1.13.2 Removal and Cleaning Crankshaft Pulley

Precleaning is not necessary.

Remove the crankshaft pulley as follows:

1. Remove the drive belts from the crankshaft pulley.
2. Remove the inspection plug in the bottom of the flywheel housing.
3. Install the flywheel lock, J 36375–A. See Figure 1-205.
4. Thread the center screw of the tool in until the top of the tool rests between two teeth of the flywheel ring gear.

NOTE:
It may be necessary to bar the engine over (using the square hole in the middle of the crankshaft pulley) so that the tool center screw is exactly between two teeth.

5. Finger-tighten the knurled knob.
6. Remove two of the six crankshaft pulley-to-crankshaft attaching bolts and hardened washers that are 180 degrees apart. Discard the bolts. These bolts are not reusable. See Figure 1-213.

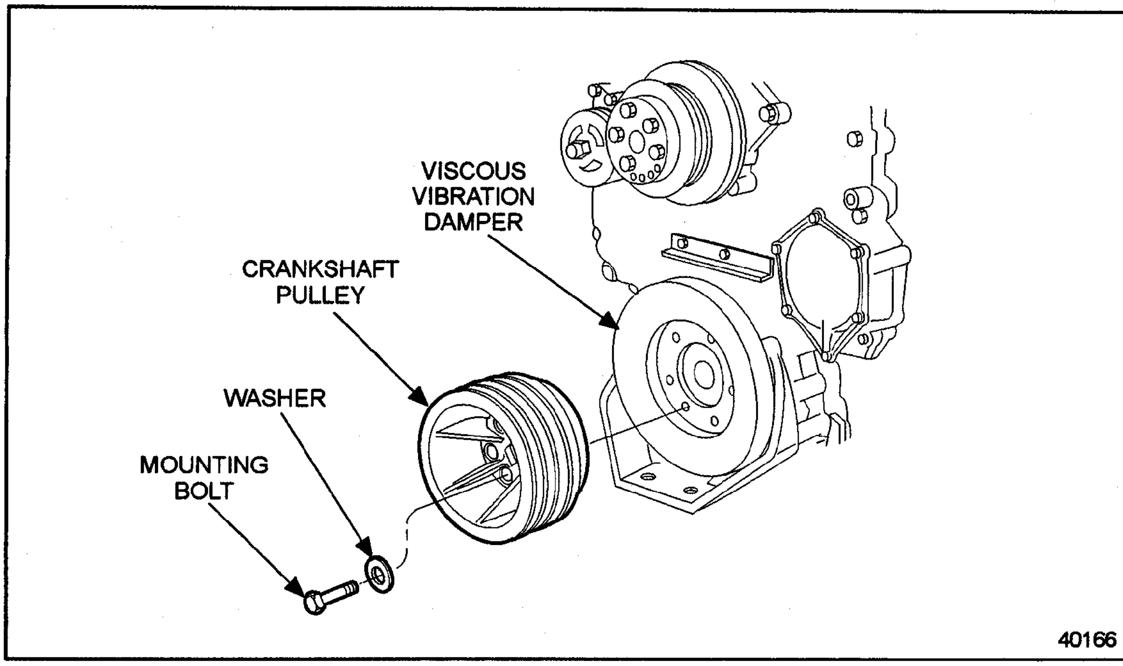

Figure 1-213 Crankshaft Pulley Mounted Directly to the Crankshaft

7. Install two guide studs, J 36235 , to the holes where the bolts were removed.

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NOTICE:
Use care when removing the crankshaft pulley as the vibration damper, which is slip fitted over a pilot diameter of the crank, may come off. If the damper is allowed to fall, internal damage to the damper will result.

8. Remove the remaining four crankshaft pulley bolts and hardened washers. Discard the bolts. These bolts are not reusable.
9. Remove the crankshaft pulley by sliding it off the guide studs.

NOTE:
Leave the guide studs in place to prevent the vibration damper from falling off.

Remove the spindle-mounted pulley and hub assembly as follows:

1. Remove the drive belts from the crankshaft pulley.
2. Remove the inspection plug in the bottom of the flywheel housing.
3. Install the flywheel lock, J 36375-A. See Figure 1-214.

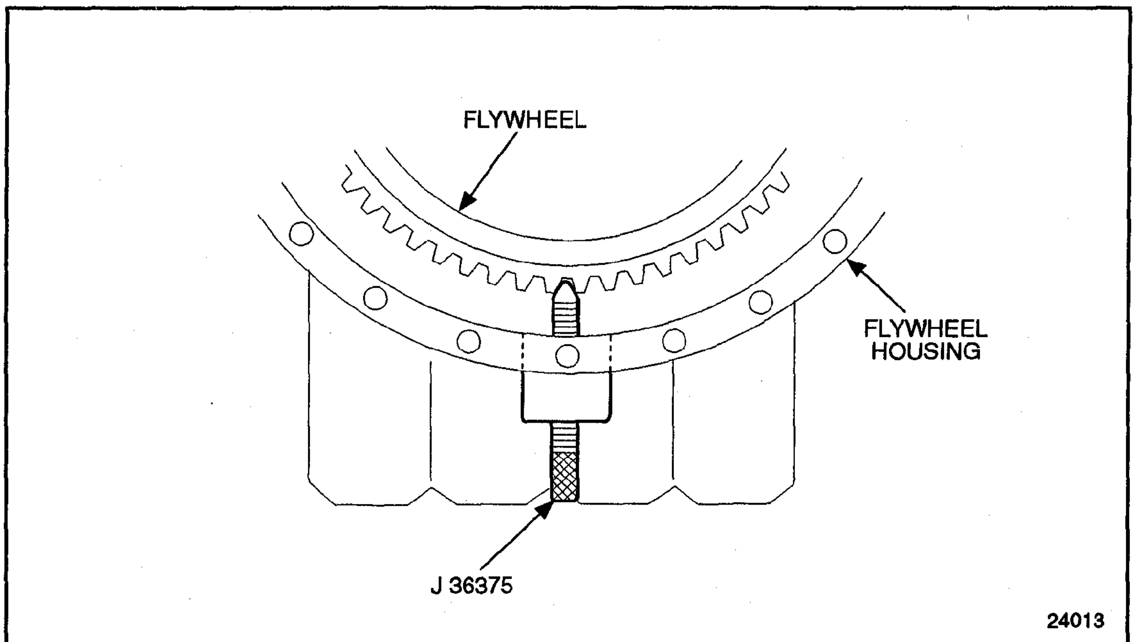

Figure 1-214 Flywheel Lock

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4. Thread the center screw of the tool in until the top of the tool rests between two teeth of the flywheel ring gear.

NOTE:
It may be necessary to bar the engine over using the crankshaft pulley bolt so that the tool center screw is exactly between two teeth.

5. Finger-tighten the knurled knob.
6. Loosen the center bolt holding the pulley and hub assembly to the spindle. See Figure 1-215.

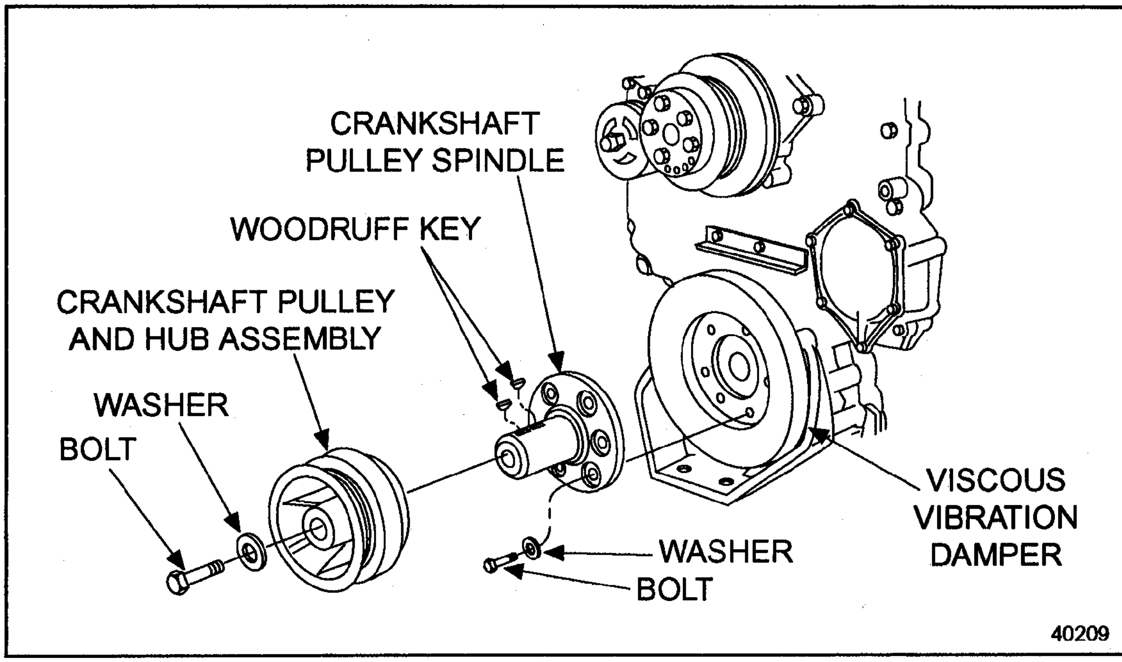

Figure 1-215 Crankshaft Pulley and Hub Assembly Installation with Spindle

7. With the pulley properly supported, remove the bolt and washer and pull the pulley and hub assembly off of the spindle.
8. Remove two of the six spindle-to-crankshaft attaching bolts and hardened washers that are 180 degrees apart. Discard the bolts. These bolts are not reusable.
9. Install two guide studs, J 36325, to the holes from which the bolts were removed.

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NOTICE:
Use care when removing the spindle as the vibration damper, which is slip fitted over a pilot diameter of the crank, may come off. If the damper is allowed to fall, internal damage to the damper will result.

10. Remove the remaining four spindle attaching bolts and hardened washers. Discard all six bolts. These bolts are not reusable.
11. Remove the spindle by sliding it off the guide studs.

NOTE:
Leave the guide studs in place to prevent the vibration damper from falling off.

1.13.2.1 Inspection of Crankshaft Pulley or Spindle and Crankshaft Pulley and Hub Assembly

Inspect the crankshaft pulley, spindle or hub assembly components as follows:

1. Inspect the crankshaft pulley or spindle and crankshaft pulley and hub assembly.

NOTICE:
A loose or bent crankshaft pulley or spindle, after extended operation, may result in a cracked crankshaft.

   [a] Determine if the crankshaft pulley or spindle is bent, broken or has cracked edges.
   [b] If damage is detected, replace with a new part.
   [c] If damage to the crankshaft pulley, pulley and hub assembly or spindle is extensive, refer to section 1.12.2.1, and inspect the vibration damper. Inspect the crankshaft, refer to section 1.7.
2. Inspect the drive belt seat grooves.
   [a] Check drive belt seat grooves for bent flanges or a rough belt seating surface.
   [b] Smooth rough seating surfaces with an emery cloth or a stone.
   [c] If flanges are bent, replace the pulley.
3. Inspect the retaining bolt seat relief areas.
   [a] Check relief area for stress cracks.
   [b] If stress cracks are discovered, replace the pulley or spindle.

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NOTICE:
A loose or bent crankshaft pulley, after extended operation, may result in a cracked crankshaft.

4. Inspect the direct-mounted pulley (or spindle) and vibration damper inner contact surfaces. See Figure 1-216.
   [a] Check for galling or burrs. See Figure 1-216.
   [b] Minor galls or burrs may be smoothed with an emery cloth.
   [c] If galls or burrs are major, the pulley or spindle will need to be replaced.

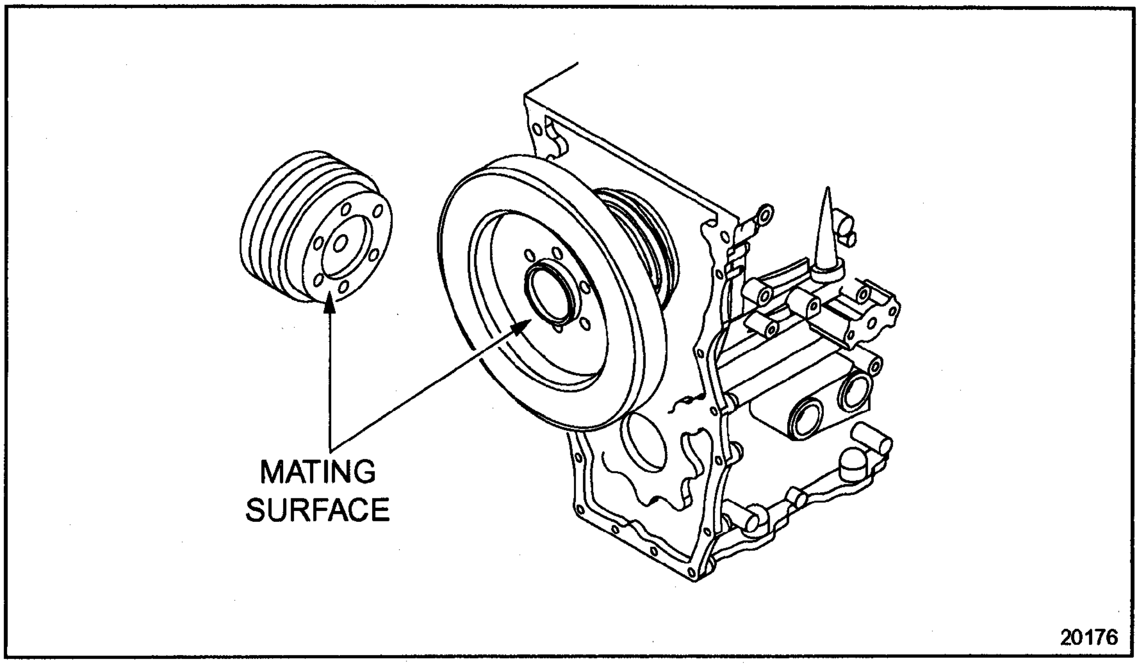

Figure 1-216 Crankshaft Pulley and Vibration Damper Inspection

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1.13.3 Installation of Crankshaft Pulley

Install the crankshaft-mounted pulley as follows:

1. If removed, install the flywheel lock J 36375–A to the inspection plug hole in the bottom of the flywheel housing. See Figure 1-214.
2. Thread the center screw of the tool until the tip of the tool rests between two teeth of the flywheel ring gear.

NOTE:
It may be necessary to bar the engine slightly using engine barring tool, J 36237, so that the tool center screw is exactly between two teeth.

3. Finger-tighten the knurled knob.

NOTICE:
Use care when installing the crankshaft pulley as the vibration damper, which is slip fitted over a pilot diameter of the crank, may come off. If the damper is allowed to fall, internal damage to the damper will result.

4. Install two guide studs to two of the holes in the crankshaft that are 180 degrees apart.
5. Install the vibration damper over the guide studs and onto the crankshaft. Refer to section 1.12.3.
6. Install the crankshaft pulley over the guide studs and onto the crankshaft. The crankshaft pulley may be installed in any position.

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NOTICE:

Crankshaft pulley and spindle mounting blots are considered single-use items and *must not be reused.* Always use new bolts when mounting the crankshaft pulley or spindle. Reusing bolts may result in excessive bolt stretch during installation, leading to breakage or loss of bolt torque and loosening during engine operation, which may cause severe damage.

7. Install four new special crankshaft pulley-to-crankshaft attaching bolts with hardened washers installed, through the pulley and damper and into the crankshaft. Finger tighten the bolts. See Figure 1-217.

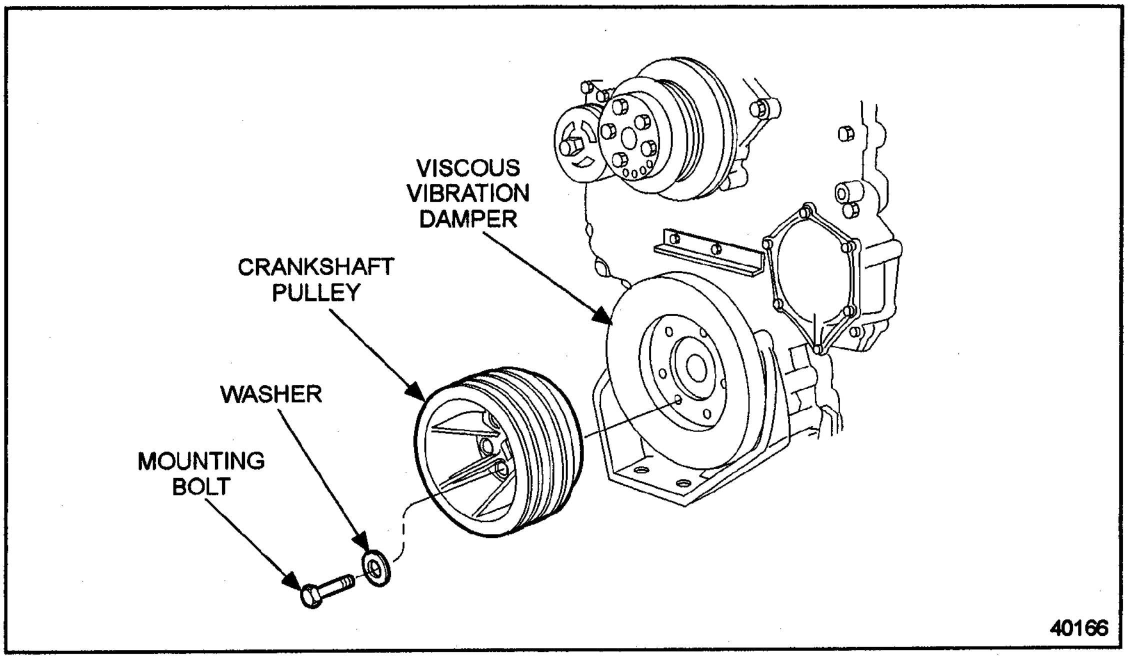

Figure 1-217 Crankshaft Pulley Mounted Directly to the Crankshaft

8. Remove the two guide studs.
9. Install the remaining two new special crankshaft pulley-to-crankshaft attaching bolts with hardened washers installed.
10. Torque the six new special bolts to 182-210 N·m (134-155 lb·ft). Proceed in a clockwise direction until all bolts are torqued.
11. Remove the flywheel lock tool.
12. Install the pipe plug to the inspection hole in the flywheel housing.
13. Install the drive belts to the crankshaft pulley. Adjust the belt tensions to the specifications. Refer to section 13.13.10.
14. Install any other components that were removed for this operation.

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Install the spindle mounted pulley and hub assembly as follows:

1. Install the flywheel lock, J 36375-A. See Figure 1-218.

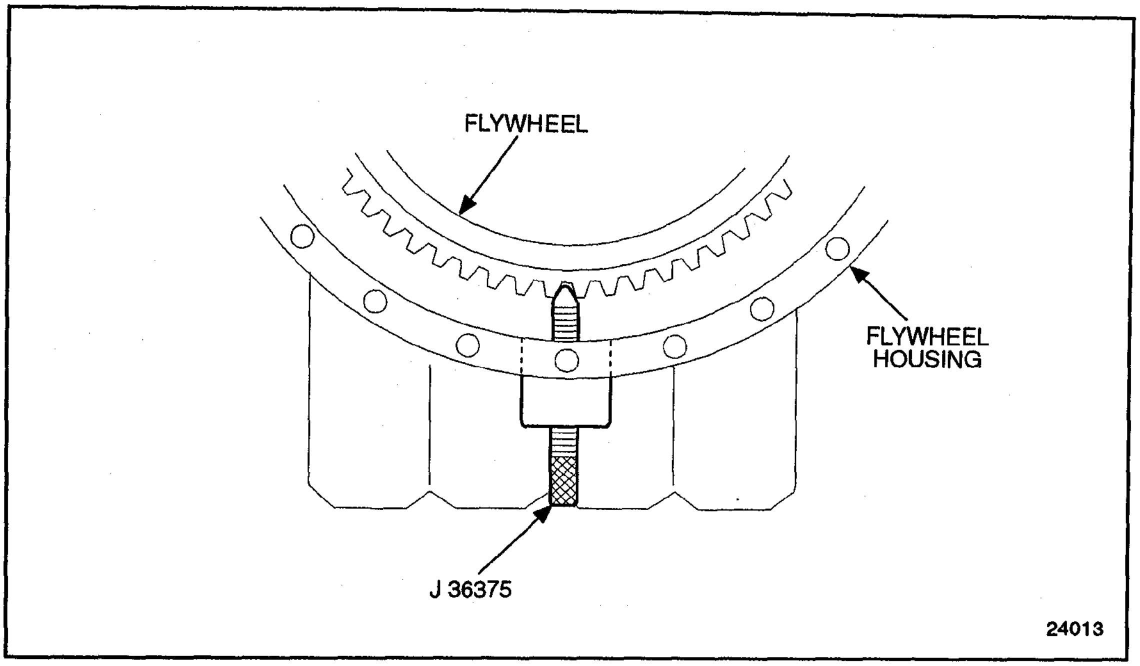

Figure 1-218 Flywheel Lock

2. Thread the center screw of the tool in until the top of the tool rests between two teeth of the flywheel ring gear.
3. Finger tighten the knurled knob.

NOTE:
It may be necessary to bar the engine over using the crankshaft pulley bolt so that the tool center screw is exactly between two teeth.

4. Install two guide studs to two of the holes in the crankshaft that are 180 degrees apart.
5. Install the vibration damper over the guide studs and onto the crankshaft. Refer to section 1.12.3.

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NOTICE:
Use care when installing the crankshaft pulley spindle as the vibration damper, which is slip fitted over a pilot diameter of the crank, may come off. If the damper is allowed to fall, internal damage to the damper will result.

6. Install the crankshaft pulley spindle over the guide studs, onto the crankshaft and against the vibration damper. The crankshaft pulley spindle may be installed in any position. See Figure 1-219.

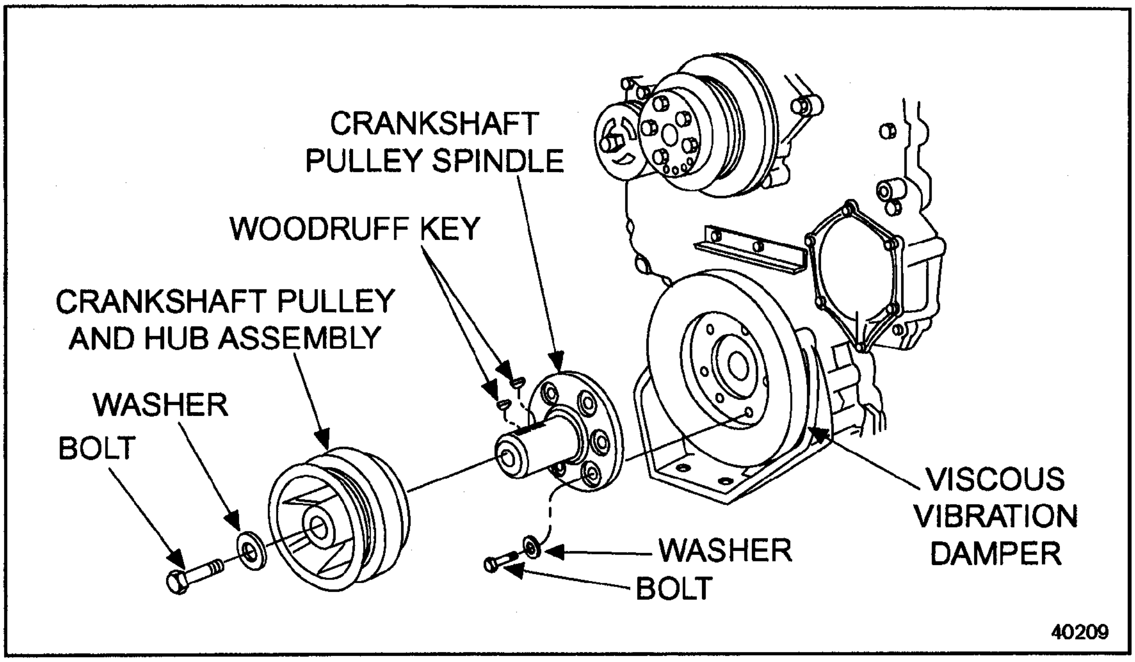

Figure 1-219 Crankshaft Pulley and Hub Assembly Installation with Spindle

7. Install four new special crankshaft pulley spindle-to-crankshaft attaching bolts with hardened washers installed.
8. Remove the two guide studs.
9. Install the remaining two new special crankshaft pulley spindle-to-crankshaft attaching bolts with hardened washers installed.
10. Torque the six new special bolts to 182-210 N·m (134-155 lb·ft). Proceed in a clockwise direction until all bolts are torqued.
11. With the pulley properly supported, install the bolt and washer and pull the pulley to the spindle.
12. Torque the center bolt holding the pulley to the spindle to 610 N·m (450 lb·ft).
13. Remove the flywheel lock tool.

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14. Install the pipe plug to the inspection hole in the flywheel housing.
15. Install the drive belts to the crankshaft pulley. Adjust the belt tensions to the specifications. Refer to section 13.13.10 .
16. Install any other components that were removed for this operation.
17. Refer to section 11.3 for verification of proper crankshaft pulley installation.

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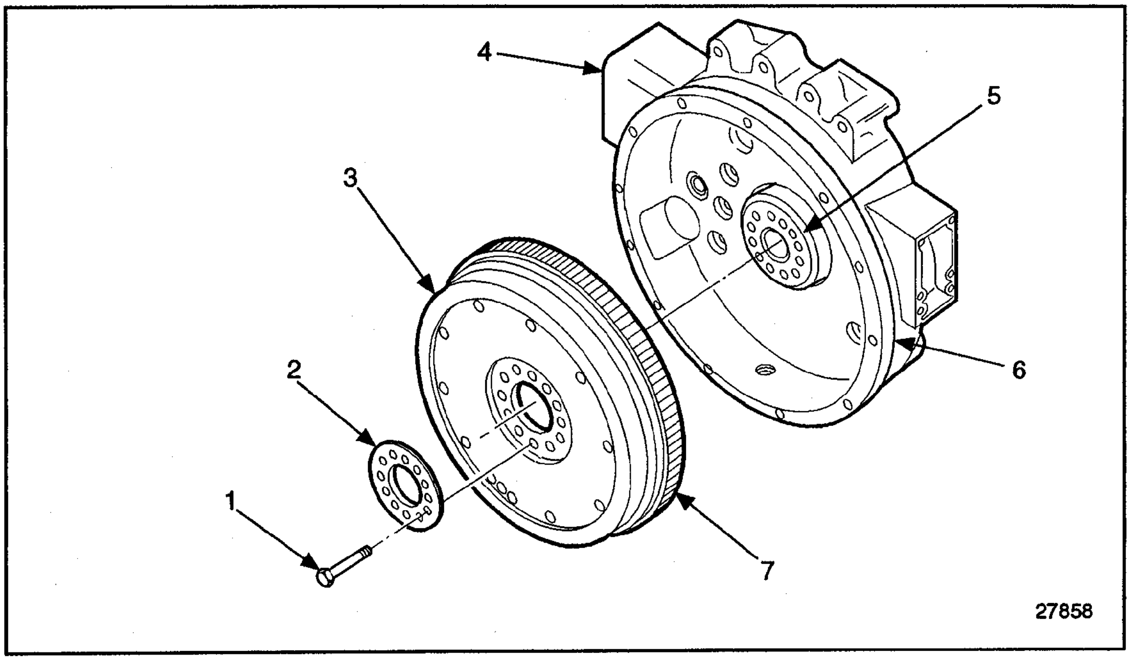
1.14 FLYWHEEL

The flywheel is attached to the rear end of the crankshaft with twelve bolts. The bolt holes in the crankshaft and flywheel are equally spaced. The flywheel is not indexed to the crankshaft, and may be installed in any position. A scuff plate is used between the flywheel and the bolt heads to prevent the bolt heads from scoring the flywheel surface. See Figure 1-220 for a typical Series 60G flywheel assembly or see Figure 1-221 for a typical diesel flywheel assembly.



1. Bolt
2. Scuff Plate
3. Flywheel
4. Flywheel Housing
5. Crankshaft
6. Flywheel Housing Spacer
7. Ring Gear

Figure 1-220 Typical Flywheel Assembly (Series 60G Engine)

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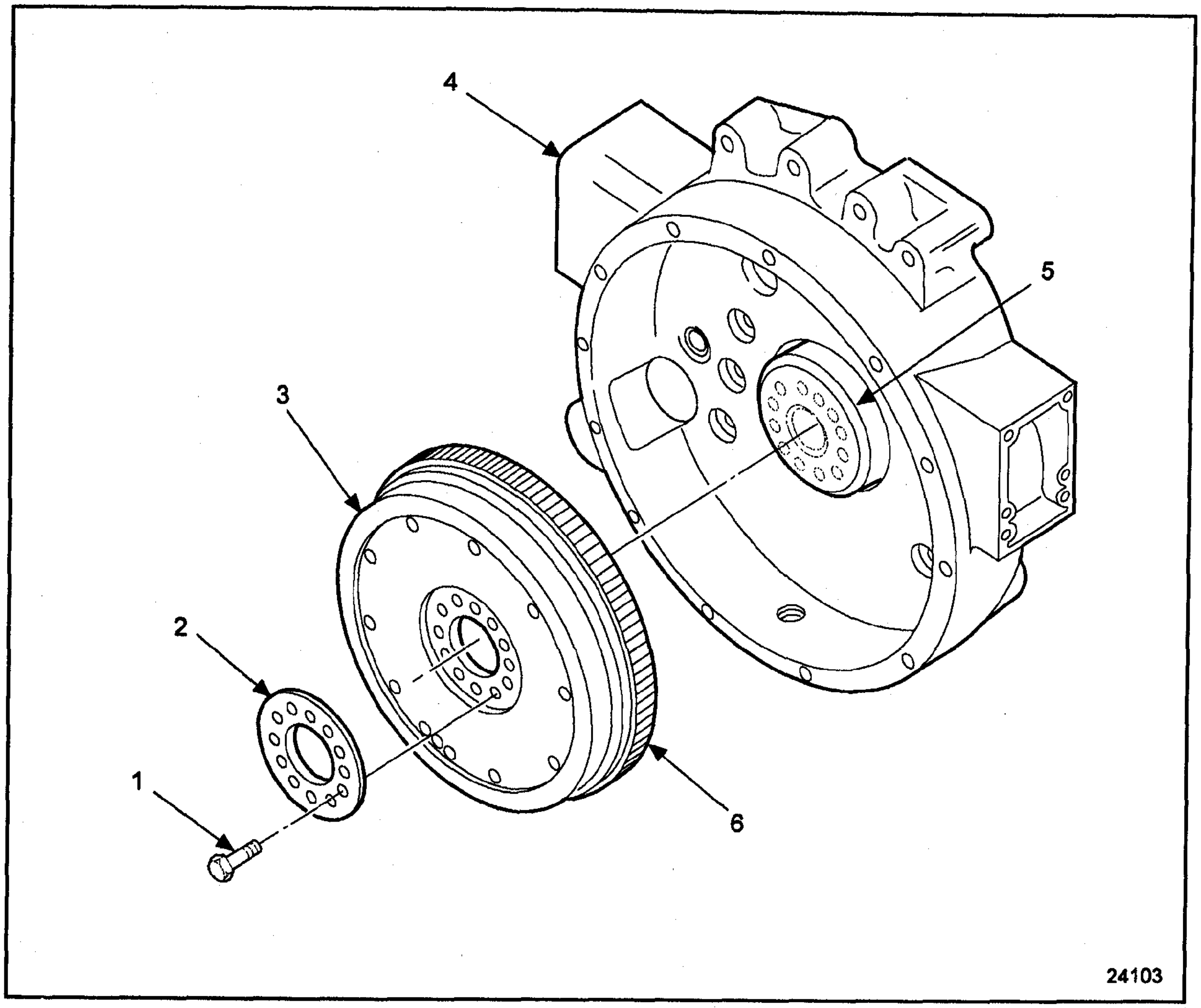

1. Bolt (12)
2. Scuff Plate
3. Flywheel
4. Flywheel Housing
5. Crankshaft
6. Ring Gear

Figure 1-221 Typical Flywheel Assembly (Diesel)

A steel ring gear, which meshes with the starting motor pinion, is shrunk onto the rim of the flywheel.

The flywheel is machined to provide true alignment with the clutch. The clutch plate, if used, is bolted to the flywheel with 3/8 in.-16 bolts.

The flywheel must be removed for service operations such as replacing the starter ring gear, crankshaft oil seal, crankshaft or the flywheel housing.

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1.14.1 Repair or Replacement of Flywheel

To determine if repair is possible or replacement is necessary, perform the following procedure. See Figure 1-222.

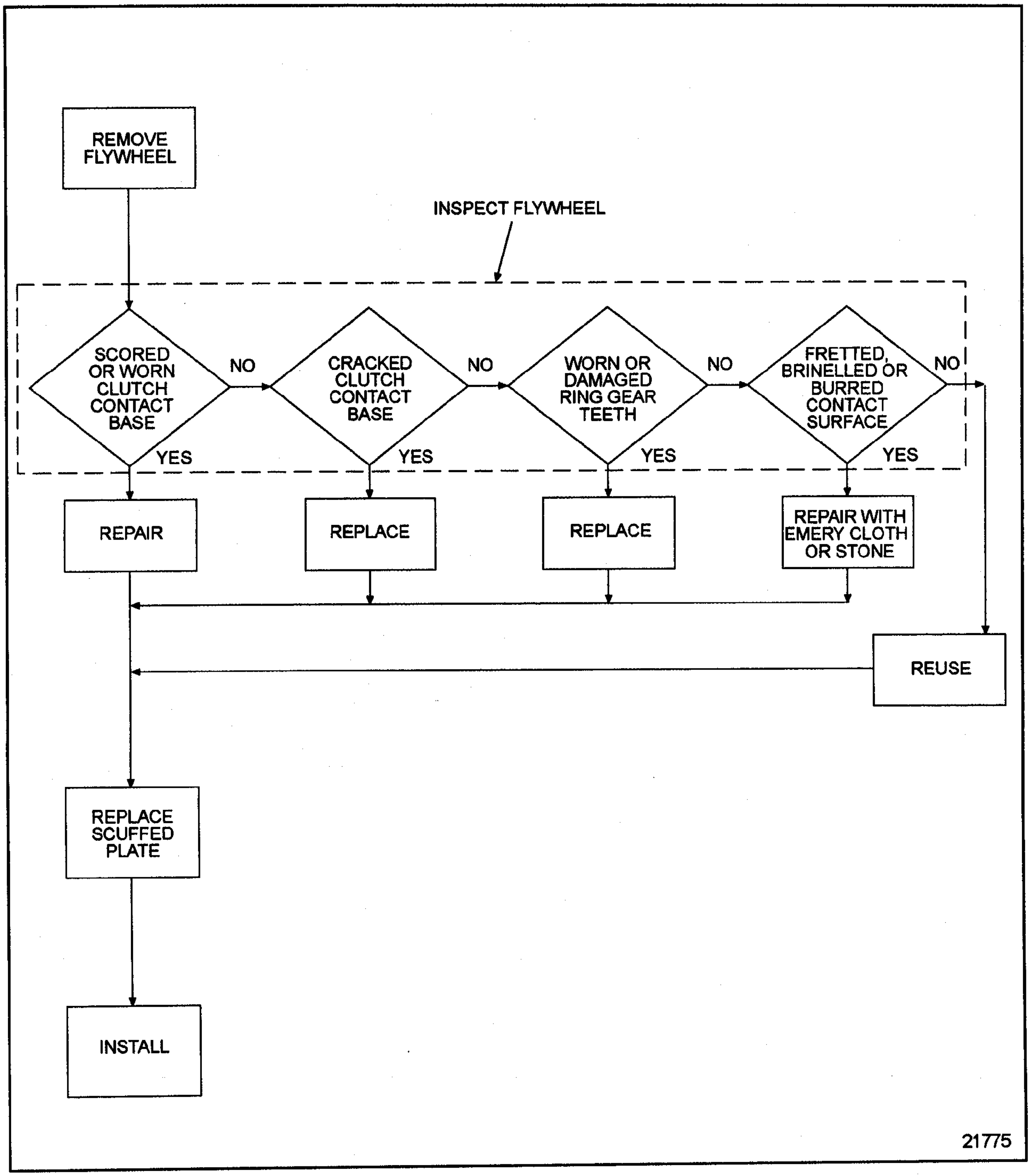

Figure 1-222 Flowchart for Repair or Replacement of Flywheel

1.14.2 Removal and Cleaning of Flywheel

Precleaning is not necessary.

Remove the flywheel as follows:

1. Remove the inspection plug in the bottom of the flywheel housing.
2. Install the flywheel lock, J 36375–A. See Figure 1-205.
3. Thread the center screw of the tool in until the tip of the tool rests between two teeth of the flywheel ring gear.

NOTE:
It may be necessary to bar the engine over (using the square hole in the middle of the crankshaft pulley) so that the tool center screw is exactly between two teeth.

4. Finger-tighten the knurled knob.
5. Remove eleven of the twelve flywheel attaching bolts, leaving one bolt at the 12 o'clock position.
6. Install two flywheel guide studs, J 36235, through the flywheel and into the crankshaft at the 3 and 9 o'clock positions. See Figure 1-223.

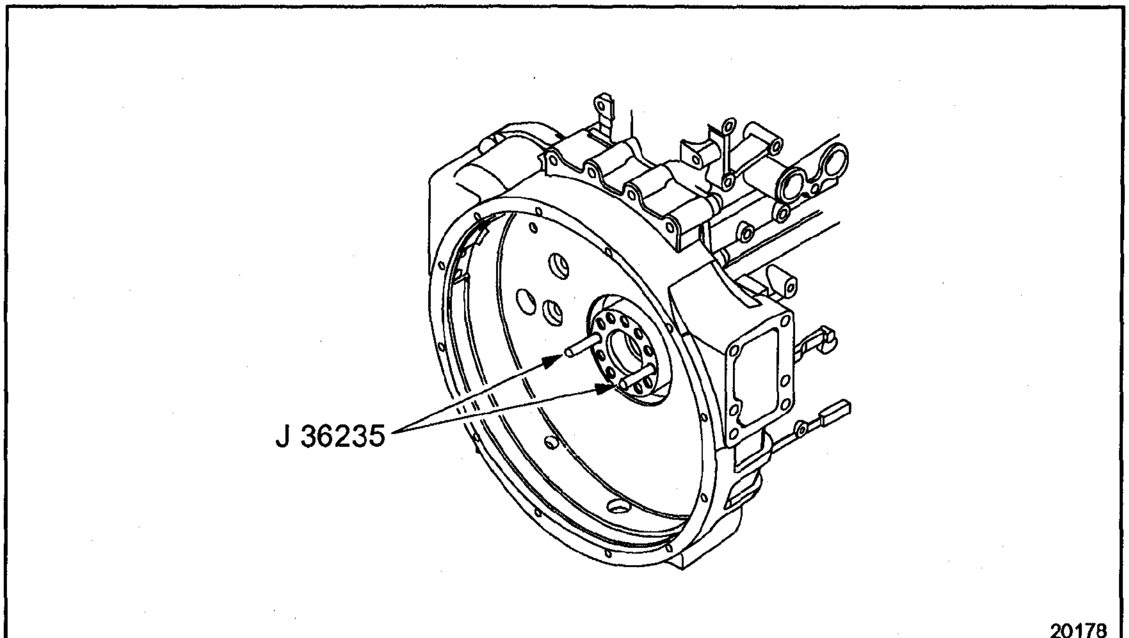

Figure 1-223 Flywheel Guide Studs

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7. Attach the flywheel lifting tool, J 25026, or some other suitable lifting device, to the flywheel. See Figure 1-224.

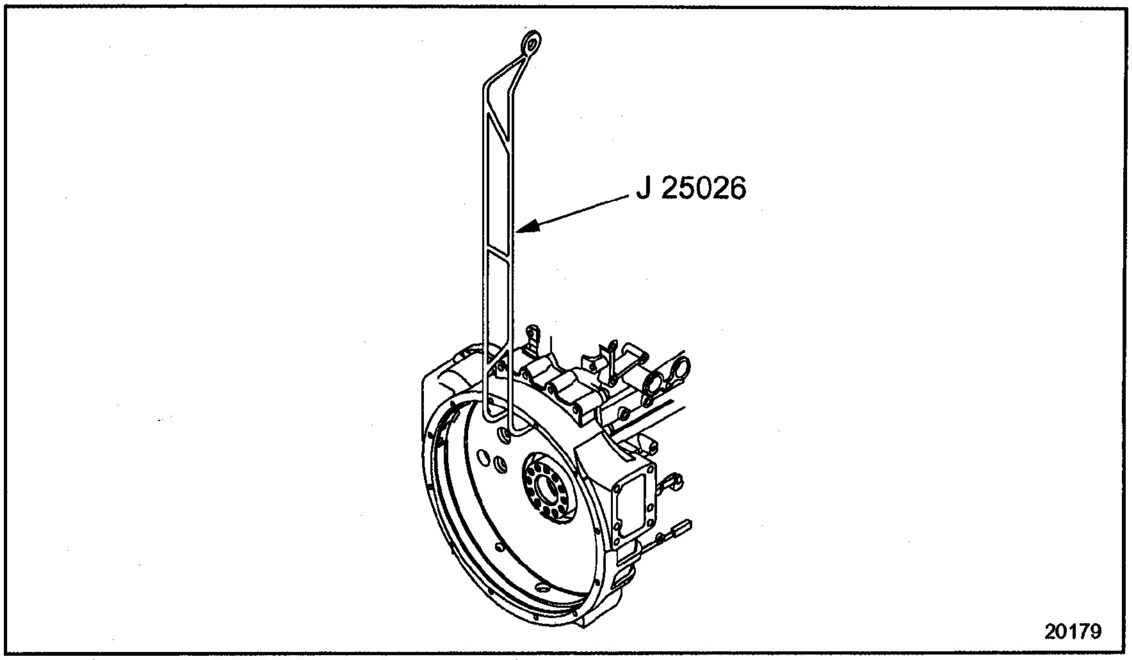

Figure 1-224 Flywheel Removal

8. Attach a chain hoist to the lifting tool.
9. Loosen, but do not remove the last flywheel attaching bolt.
10. Remove the flywheel lock.

CAUTION:

To avoid injury from a falling flywheel when removing the last bolt, hold the flywheel against the crankshaft by hand to prevent it from slipping off the crankshaft. The flywheel is not doweled to the crankshaft.

11. Remove the last flywheel attaching bolt and scuff plate. (Discard scuff plate.)
12. Remove flywheel.

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1.14.2.1 Inspection of Flywheel

Inspect the flywheel as follows:

1. Inspect the clutch contact base of the flywheel.
   [a] Check clutch contact base for scoring, wear, or cracks.
   [b] The flywheel may be refaced, if the clutch contact face is scored or worn.

NOTE:
Do not remove more than 0.508 mm (0.020 in.) material from the flywheel. Maintain all of the radii when resurfacing.

   [c] The flywheel must be replaced, if the clutch contact face shows cracks.
2. Inspect the ring gear.
   [a] Check ring gear for excessively worn or damaged gear teeth.
   [b] If damaged gear teeth are detected, replace the ring gear. Refer to section 1.15.2.
3. Inspect crankshaft and flywheel contact surface.
   [a] Check the butt end of the crankshaft and flywheel contact surface for fretting, brinelling, or burrs. See Figure 1-225.
   [b] Lightly stone the contact surface to remove any fretting, brinelling, or burrs.

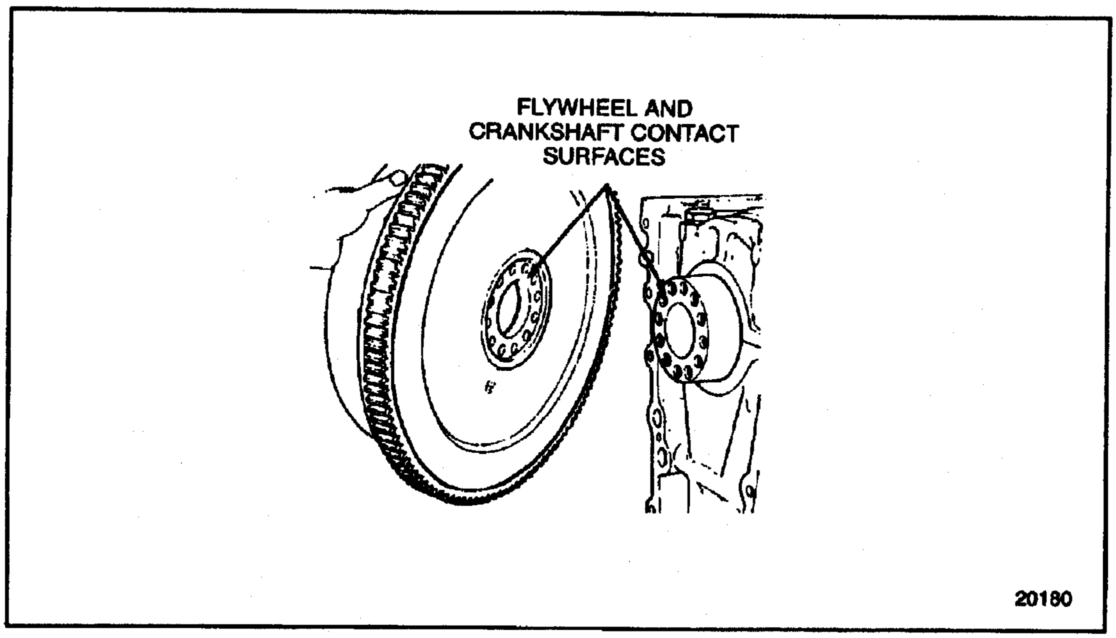

Figure 1-225 Crankshaft and Flywheel Mating Surfaces

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1.14.3 Installation of Flywheel

Install the flywheel as follows:

1. Install two flywheel guide studs, J 36235, into two of the tapped holes in the crankshaft at the 3 and 9 o'clock position.
2. Attach the flywheel lifting tool and, using a chain hoist, position the flywheel in the flywheel housing. Align the flywheel bolt holes with the crankshaft bolt holes.

NOTICE:
A new scuff plate must be used whenever the flywheel is removed. Failure to replace the scuff plate may cause the flywheel bolts to loosen, even when torqued correctly.

3. Using a new scuff, install two bolts with International Compound #2® (or equivalent) through the plate 180 degrees from each other.
4. Install the flywheel lock, J 36375–A. See Figure 1-205.
5. Remove the flywheel lifting tool and guide studs.

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6. Apply International Compound #2® (or equivalent) to the threads and to the bolt head contact area (underside) of the remaining bolts. The bolt threads must be completely filled with International Compound #2® (or equivalent). Any excess must be wiped off. See Figure 1-226.

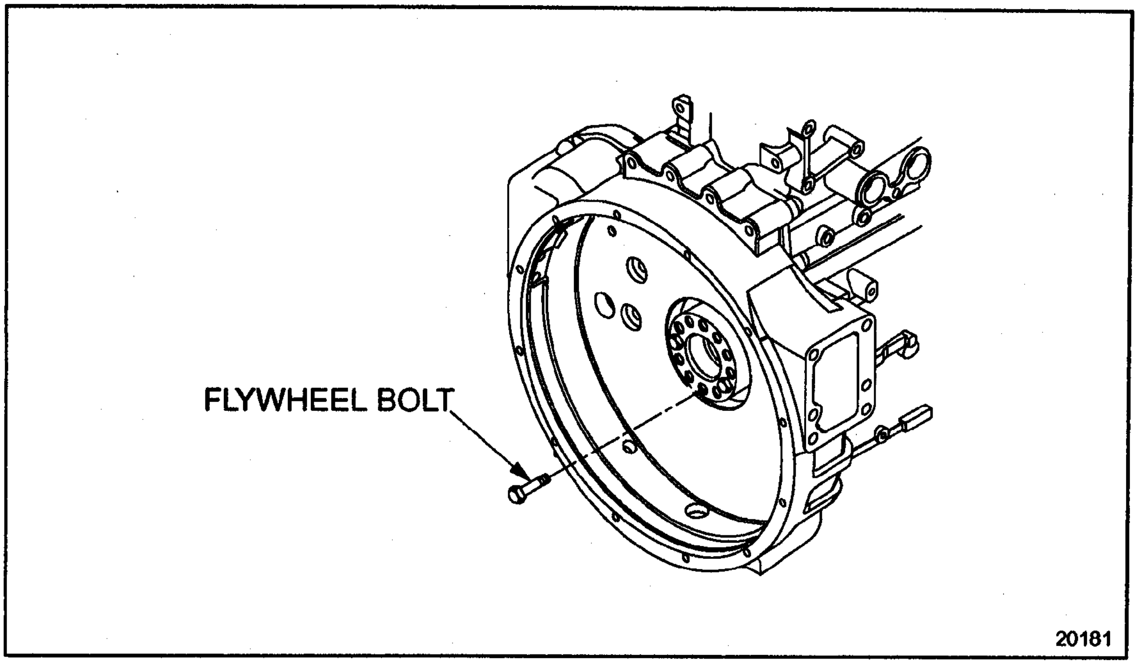

Figure 1-226 Flywheel Bolt Preparation

NOTE:
International Compound #2® or equivalent must never be used between two surfaces where maximum friction is desired, as between the crankshaft and the flywheel.

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7. Install the bolts and torque them to 75 N·m (55 lb·ft).
8. Turn the bolts an additional 120 degrees, or 2 flats on a six-point bolt. See Figure 1-227.

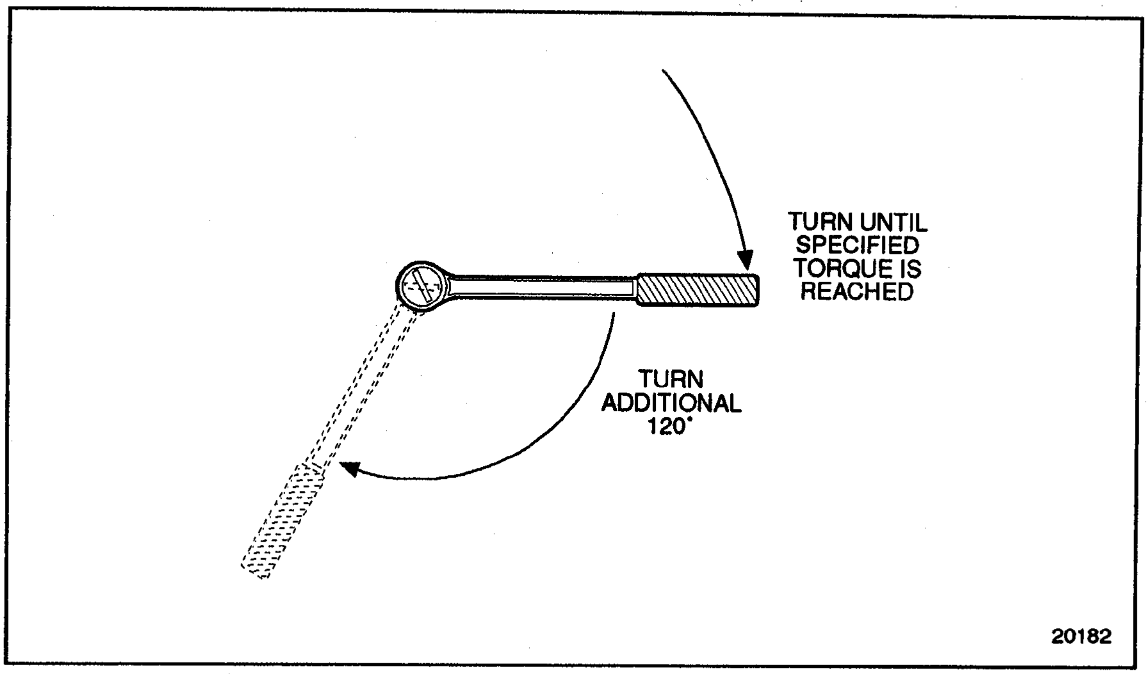

Figure 1-227 Torque Turn Limits

9. Remove the flywheel lock tool, J 36375–A.
10. Install the pipe plug and torque to 45-56 N·m (33-41 lb·ft).
11. Mount a dial indicator with a magnetic base on the flywheel housing. See Figure 1-228.

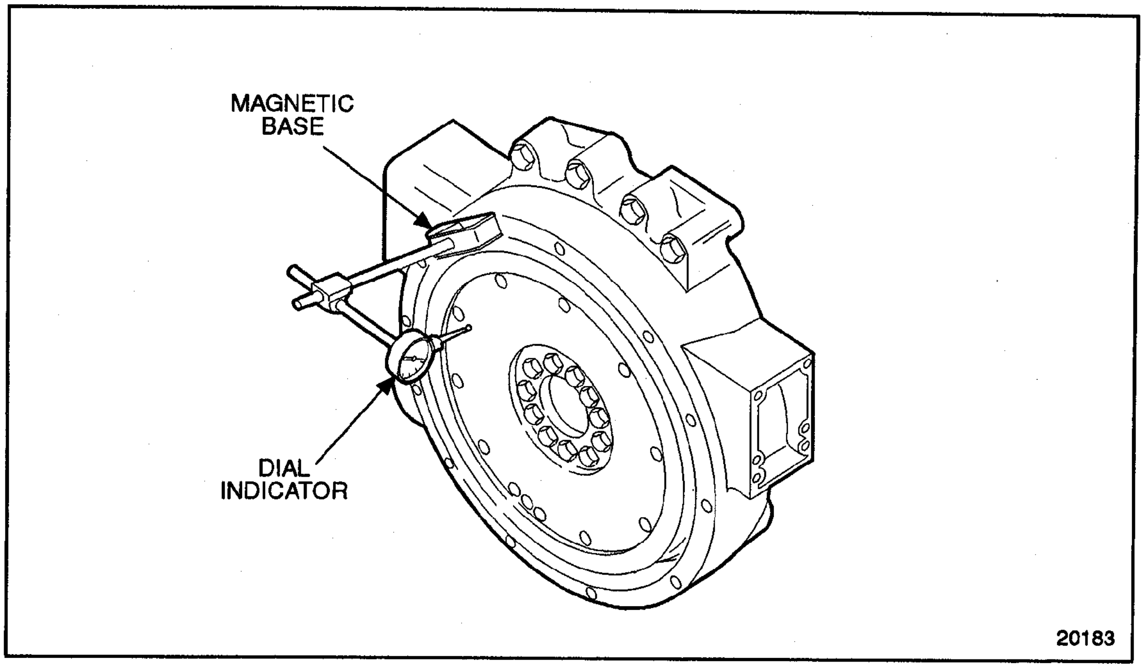

Figure 1-228 Measuring Flywheel Run-out

12. Check the run-out of the flywheel at the clutch contact face.
13. The maximum allowable run-out is 0.001 mm per millimeter of radius (0.001 in. per inch of radius) total indicator reading per inch of radius (or 0.001 mm per millimeter of radius). The radius is measured from the center of the flywheel to the outer edge of the clutch contact face of the flywheel. Example: A 14 in. clutch would allow 0.177 mm (0.007 in.) total indicator reading.
14. If maximum total indicator reading exceeds, 0.001 mm per millimeter of radius (0.001 in. per inch of radius), it may be necessary to repeat the assembly procedure until the cause can be detected and eliminated.

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1.15 RING GEAR

The steel ring gear, which meshes with the starting motor pinion, is shrunk onto the rim of the flywheel.

1.15.1 Repair or Replacement of Ring Gear

Inspection of the flywheel indicated that ring gear replacement is necessary. See Figure 1-229.

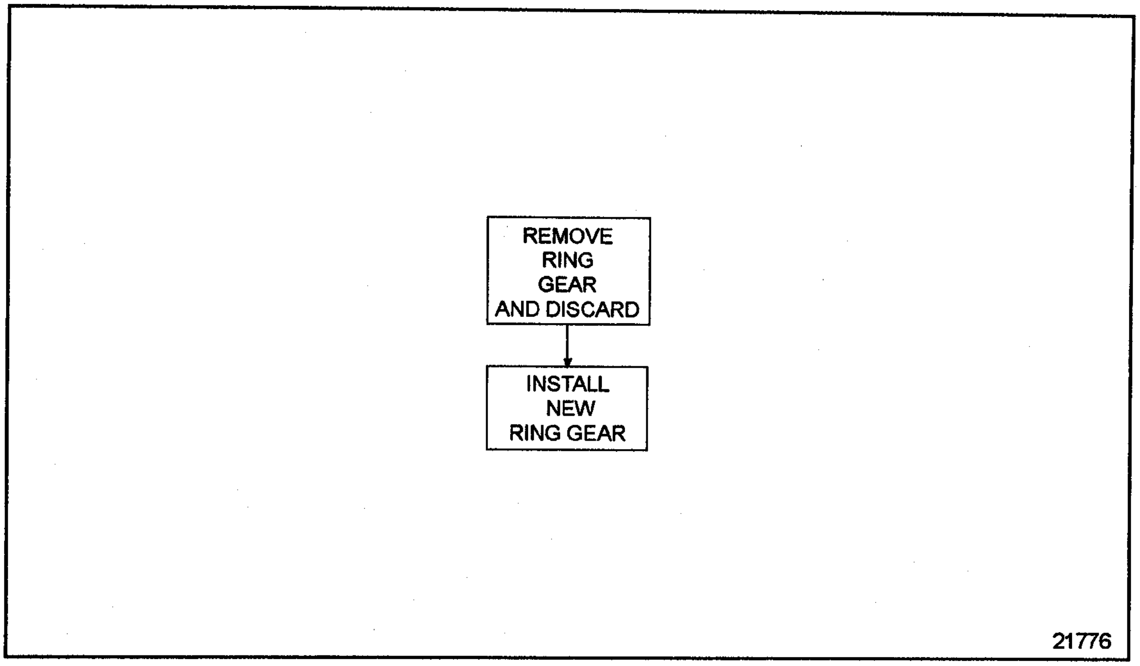

Figure 1-229 Flowchart for Repair or Replacement of Ring Gear

1.15.2 Removal and Cleaning of Ring Gear

Precleaning is not necessary.

Remove the ring gear as follows:

1. Using an acetylene torch, cut the ring gear 1/2 to 3/4 of the way through, without allowing the flame to touch the flywheel.
2. The uncut portion will now yield. Tap the ring gear to remove it from the flywheel.

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1.15.3 Installation of Ring Gear

Install the ring gear as follows:

1. Support the flywheel, ring gear side up, on a solid flat surface.

CAUTION:
To avoid injury from burning, use lifting tools and heat-resistant gloves when handling heated components.

NOTICE:
Do not under any circumstances, heat the gear over 204°C (399°F). Excessive heat may destroy the original heat treatment. Heat indicating "crayons" which are placed on the ring gear and melt at a predetermined temperature, may be obtained from most tool vendors. Use of these "crayons" will ensure against overheating the gear.

2. Rest the ring gear on a flat METAL SURFACE, and heat the gear uniformly with an acetylene torch, keeping the torch moving around the gear to avoid hot spots.
3. Use a pair of tongs to place the gear on the flywheel with the chamfer, if any, facing the same direction as on the gear just removed.
4. Tap the gear in place against the shoulder on the flywheel. If the gear cannot be tapped into place readily so that it is seated all the way around, remove it, and apply additional heat.

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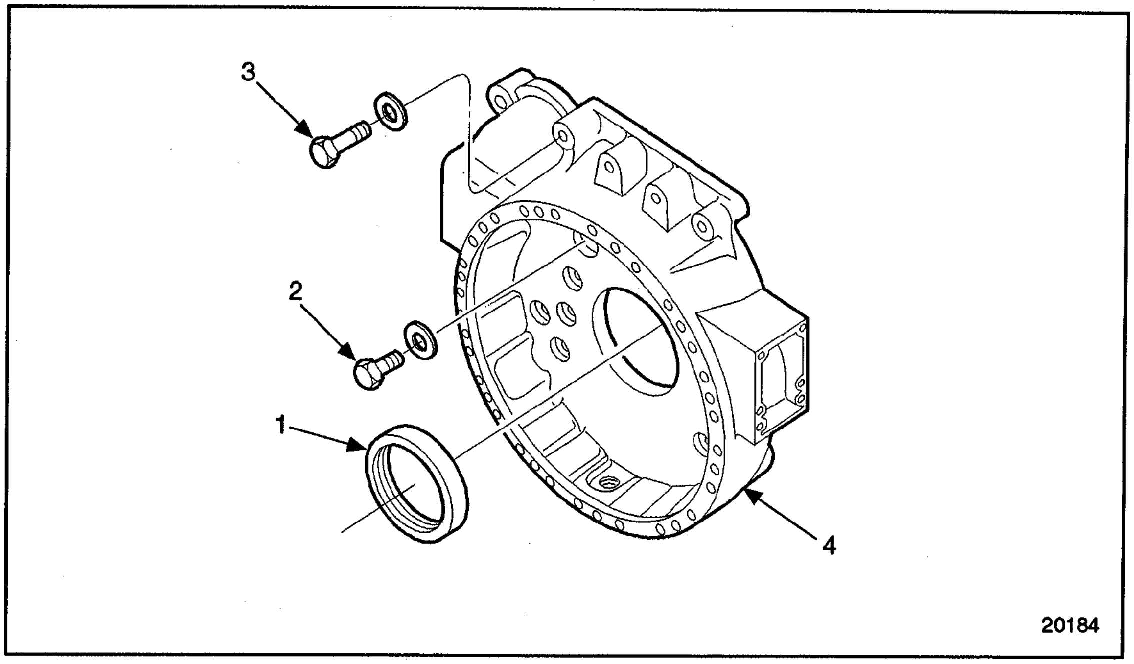
1.16 FLYWHEEL HOUSING

The flywheel housing is a one-piece casting mounted against the rear of the cylinder block. It provides a cover for the flywheel and serves as a support for the cranking motor and the transmission. See Figure 1-230.



1. Crankshaft Rear Oil Seal
2. Inner Bolt (8 short)
3. Outer Bolt (4 long)
4. Flywheel Housing

Figure 1-230 Flywheel Housing and Related Parts

The crankshaft rear oil seal, which is pressed into the housing, may be removed or installed without removing the housing. Refer to section 1.8.2.

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1.16.1 Repair or Replacement of Flywheel Housing

To determine if repair is possible or replacement is necessary, perform the following procedure. See Figure 1-231.

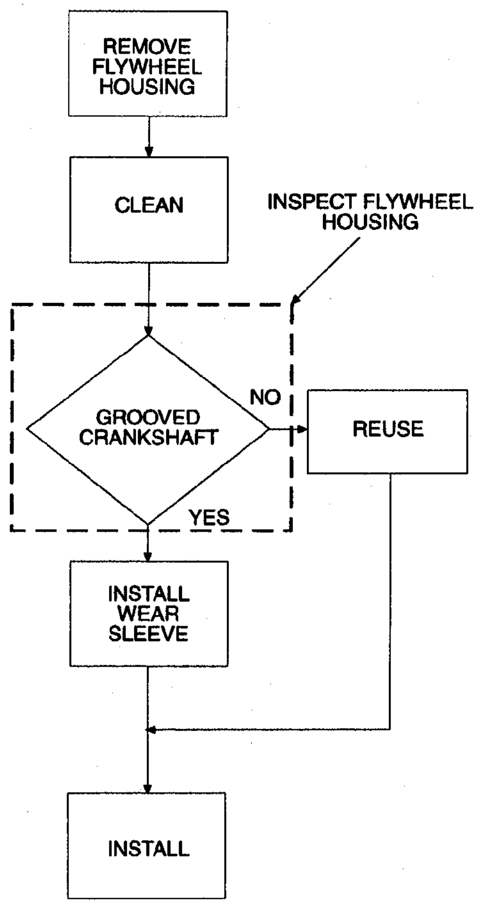

Figure 1-231 Flowchart for Repair or Replacement of Flywheel Housing

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1.16.2 Removal and Cleaning of Flywheel Housing

Precleaning is not necessary.

Remove the flywheel housing as follows:

1. If the engine is removed from the vehicle, mount the engine on an overhaul stand. Refer to section 1.1.2.
2. Drain the engine oil; refer to section 13.13.1, and remove the oil pan; refer to section 3.11.2.
3. Remove the flywheel and scuff plate. Refer to section 1.14.2.
4. Remove the four long outer bolts and the eight short inner bolts that secure the flywheel housing to the engine. See Figure 1-230.
5. To guide the flywheel housing until it clears the end of the crankshaft, thread two guide studs, J 35785 for 12 mm bolts, or J 43431 for 14 mm bolts, into the cylinder block. See Figure 1-232.

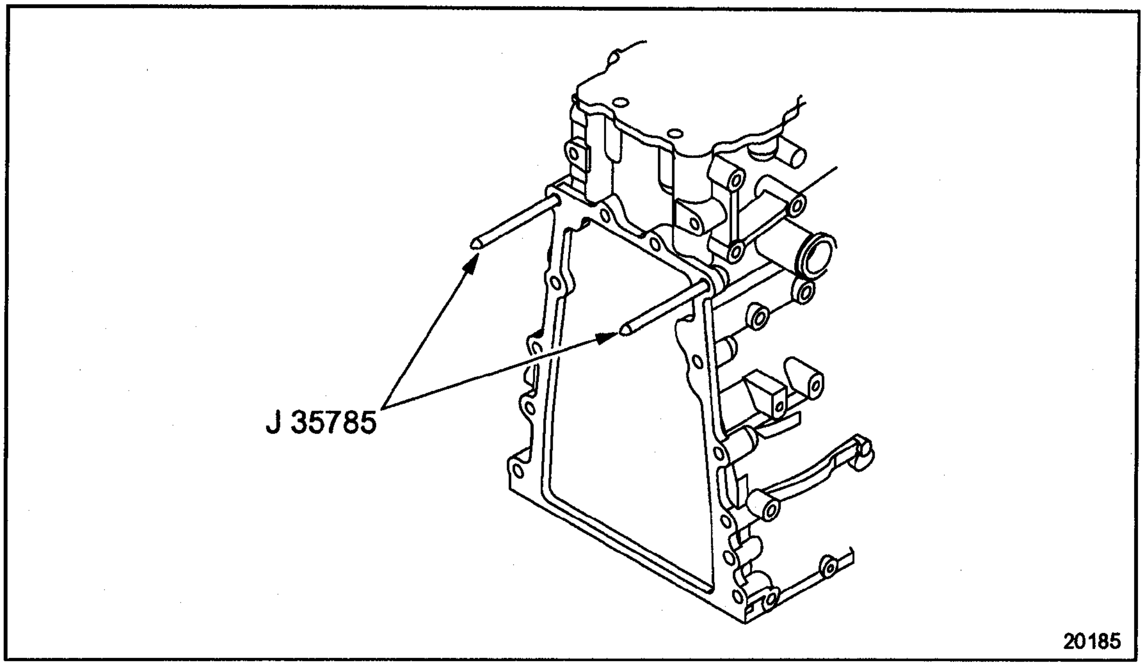

Figure 1-232 Pilot Stud Installation

NOTE:
The illustration is shown with the flywheel housing already removed for clarity.

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6. Thread eye bolts into the tapped holes in the side pads of the flywheel housing.
7. Attach a suitable sling to the eye bolts and strike the front face of the housing alternately on each side with a soft hammer to loosen and work it off the dowel pins.
8. Remove and discard the crankshaft rear oil seal.
9. Remove all sealing material from the flywheel housing. Refer to section, "Cleaning" in the "General Information" section at the beginning of this manual.

1.16.2.1 Inspection of Flywheel Housing and Rear Oil Seal Area of Crankshaft

Inspect the flywheel housing as follows:

1. Inspect flywheel housing for cracks and any other damage.
   - [a] If sealing surface is damaged, repair with emery cloth.
   - [b] If cracked, repair is not possible.
2. Inspect the crankshaft where the rear oil seal makes contact.
   - [a] Check for groove in crankshaft.
   - [b] If crankshaft is grooved, install a wear sleeve over the crankshaft end. An oversized I.D. rear oil seal must be used with the rear sleeve. Refer to section 1.8.7.

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1.16.3 Installation of Flywheel Housing

Install the flywheel housing as follows:

1. Apply a continuous 1.6 mm (1/16 in.) bead of Loctite® 518 gasket eliminator, or equivalent, to the cylinder block where it mates with the flywheel housing. See Figure 1-233.

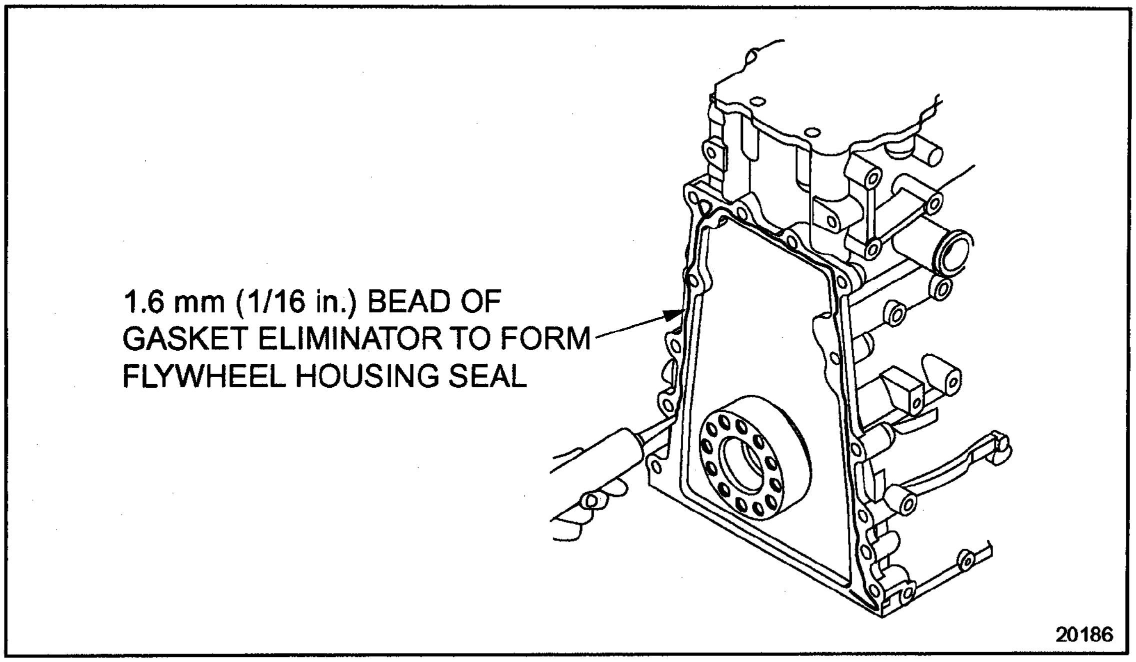

Figure 1-233 Gasket Eliminator Installation

2. Thread two aligning studs, J 35785 for 12 mm bolts or J 43431 for 14 mm bolts, into the cylinder block to guide the housing in place. See Figure 1-232.
3. Support the housing and position it over the crankshaft and against the cylinder block.

NOTE:
Whenever crankshaft rear seal is put over the crankshaft, use crankshaft oil seal expander. Refer to section 1.8.7.

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4. Install all of the housing bolts in their proper location, finger-tighten them.
5. Remove the pilot studs.
6. Torque the eight short and four long flywheel housing bolts using the proper tightening sequence. See Figure 1-234.
   [a] If the bolts are 12 mm, torque to 112-126 N·m (83-93 lb·ft).
   [b] If the bolts are 14 mm, torque to 160-200 N·m (118–148 lb·ft).

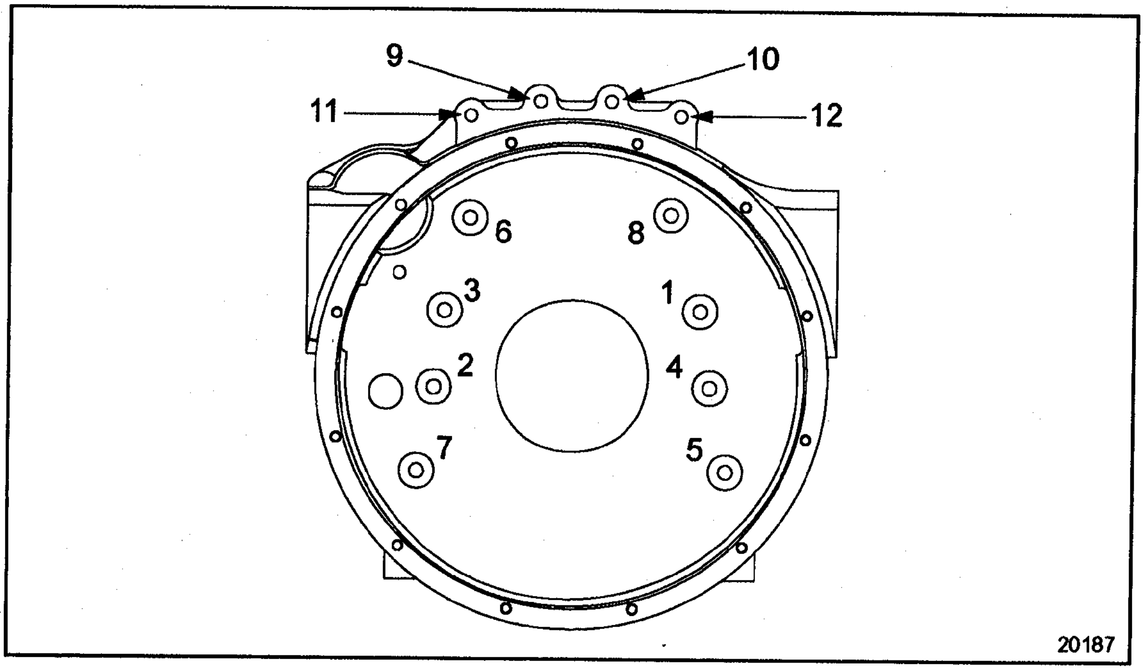

Figure 1-234 Flywheel Housing Bolt Torque Sequence

7. Install the crankshaft rear main oil seal. Refer to section 1.8.7.
8. Install the flywheel. Refer to section 1.14.3.
9. Install oil pan; refer to section 3.11.4, and refill the engine with new oil; refer to section 13.13.1.

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1.16.3.1 Test for Flywheel Housing Bore Concentricity

Check the flywheel housing bore concentricity, and bolting flange run-out with tool set, J 9737-C, as follows:

1. Thread the base post, J 9737-3 part of J 9737–D, into one of the tapped holes on the outer edge of the flywheel.
2. Assemble the dial indicators on the base post with the attaching parts provided in the tool set.
3. Position the dial indicators straight and square with the flywheel housing bell face and inside bore of the bell. Make sure each indicator has adequate travel in each direction. See Figure 1-235.

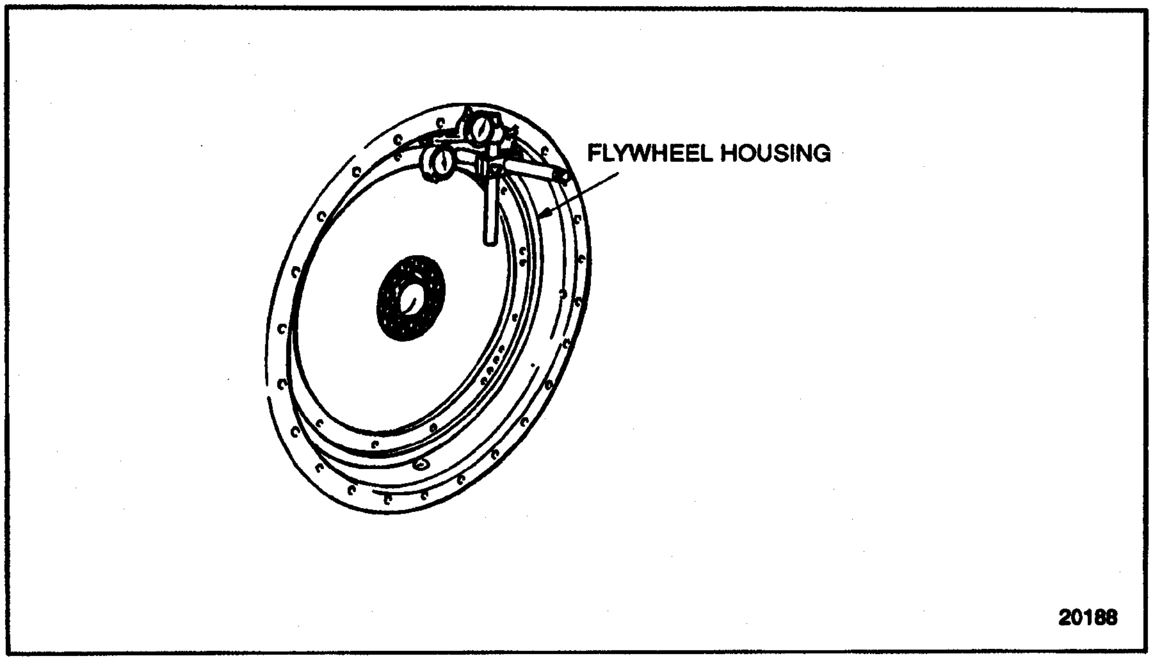

Figure 1-235 Measuring Flywheel Housing Bore Concentricity and Bolting Flange Run-out

4. Tap the end of the crankshaft (not the crankshaft pulley) with a soft hammer to force it toward one end of the block to ensure end play is in one direction only.
5. Adjust each dial indicator to read zero at the twelve o'clock position.

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6. Bar the engine and rotate the crankshaft one complete revolution, taking readings at 90 degree intervals (four readings each for the bore and bolting flange face). See Figure 1-236.

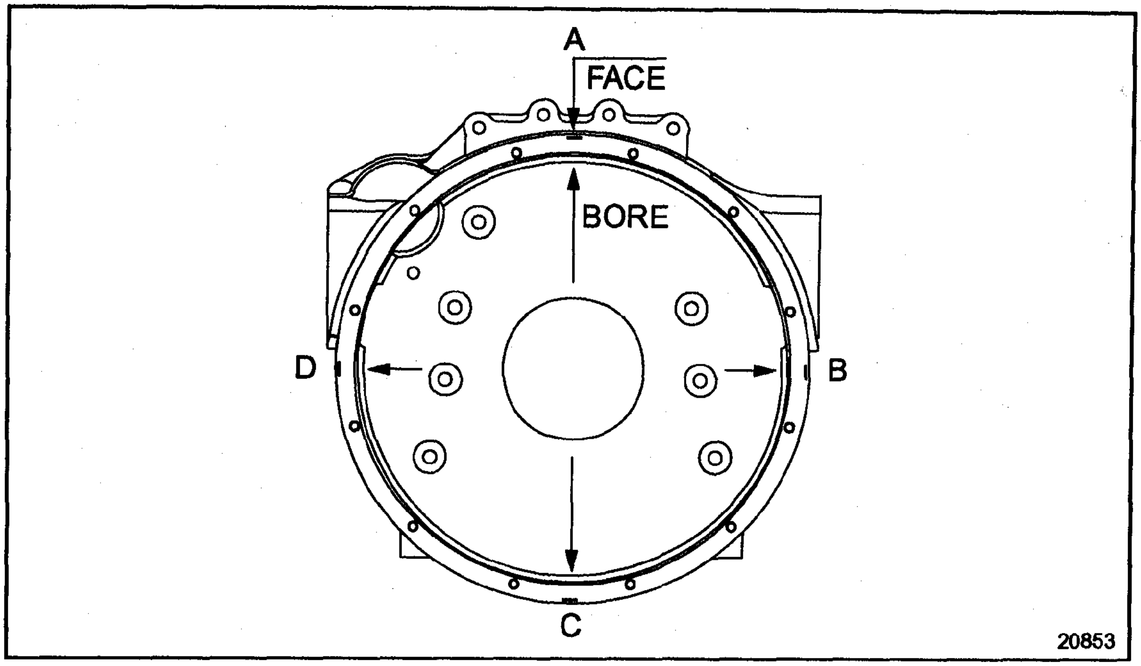

Figure 1-236 Flywheel Housing

7. Remove the wrench or cranking bar before recording each reading to ensure accuracy.
   [a] The maximum total indicator reading must not exceed 0.33 mm (0.013 in.) for either the bore or the face.
   [b] If the run-out exceeds the maximum limits, remove the flywheel and flywheel housing and check for dirt or foreign material between the flywheel housing and the cylinder block or oil pan.
8. Clean the mating surfaces once again. Refer to section "General Information, Cleaning" in the beginning of this manual.
9. Install flywheel housing. Torque the eight short and four long bolts to the cylinder block using the proper tightening sequence. See Figure 1-234.
   [a] If the bolts are 12 mm, torque to 112-126 N·m (83-93 lb·ft).
   [b] If the bolts are 14 mm, torque to 160-200 N·m (118-148 lb·ft).
10. Install the flywheel. Refer to section 1.14.3.
11. Check the run-out again. If desired run-out cannot be accomplished, replace the flywheel housing.

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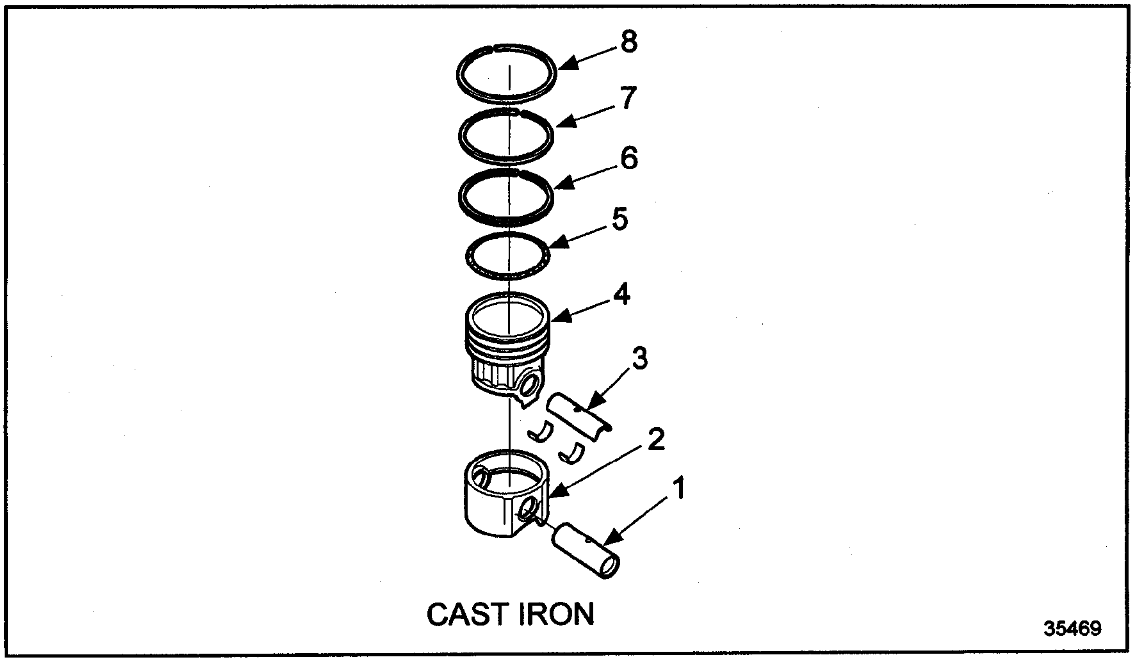
1.17 PISTON AND PISTON RING

Series 60 engines currently use two types of pistons. Non-premium engines use pistons with cast iron domes and skirts and open-end connecting rods. Premium engines (identified by the letters "PK" or "BK" in the fifth and sixth positions of the model number) built on or after March 16, 1998 use pistons with forged steel domes, aluminum skirts, and closed-end connecting rods. High torque engines (identified with "FK" or "HK" in the model number) also uses a steel piston, but of a larger diameter (14L).

NOTE:
Steel and cast iron cylinder components must not be mixed in an engine.

The cast iron cross-head piston is a two-piece piston consisting of a dome and a skirt. The dome and skirt are held together by the piston pin. Ring grooves are machined in the piston dome. See Figure 1-237.



1. Piston Pin
2. Piston Skirt
3. Three-piece Bushing
4. Piston Dome
5. Oil Ring Expander
6. Oil Control Ring
7. Compression Ring
8. Fire Ring

Figure 1-237 Cast Iron Piston and Related Parts

NOTE:
Series 60G engine incorporates a 3.5 mm fire ring, a rectangular cut compression ring and a three-piece oil ring. See Figure 1-238. The compression ring is identified with a purple stripe.

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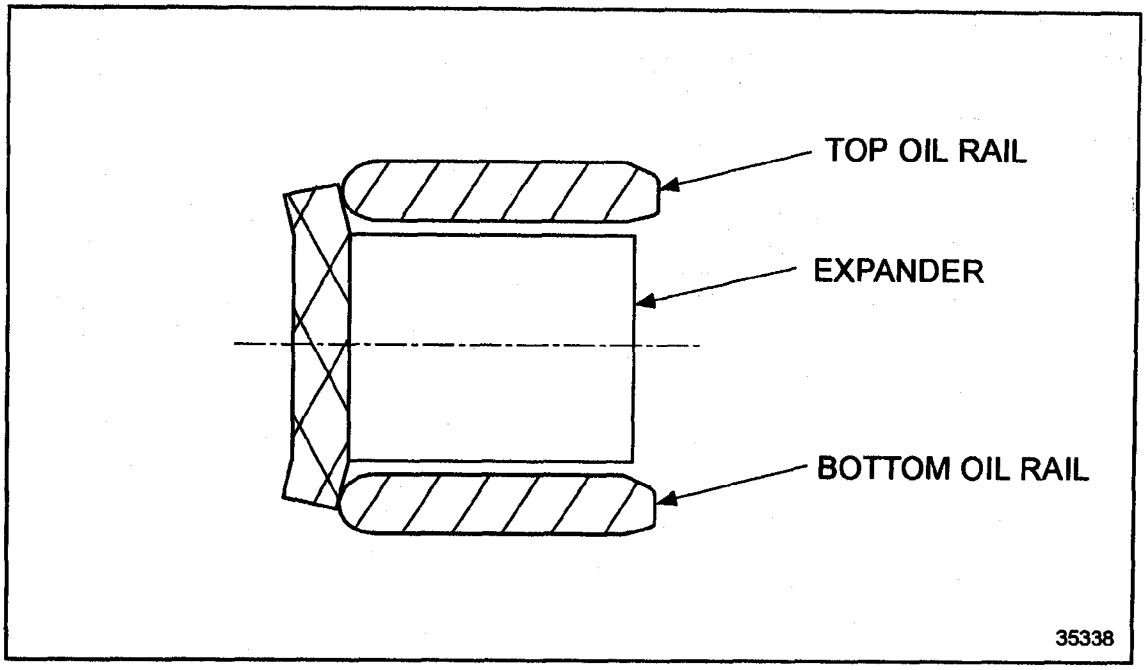

Figure 1-238 Three–piece Gas Oil Ring

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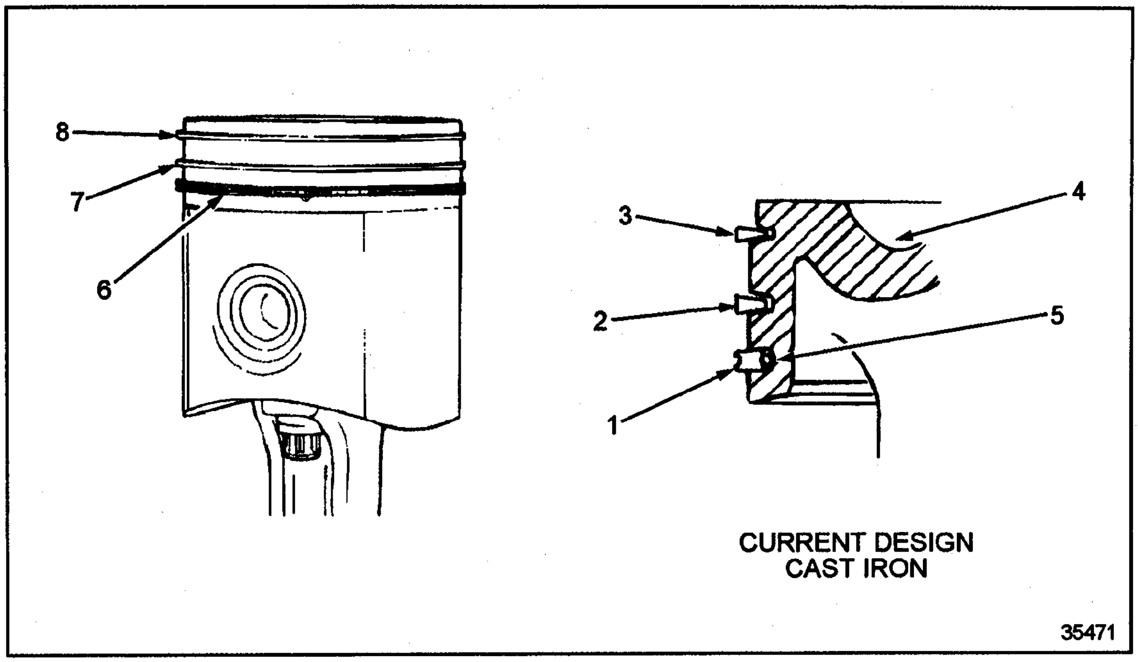
Each piston is fitted with a fire ring, compression ring and one-piece oil control ring with expander. See Figure 1-239, and see Figure 1-240.



1. Oil Control Ring
2. Compression Ring*
3. Fire Ring
4. Piston Dome
5. Oil Ring Expander
6. Oil Control Ring
7. Compression Ring*
8. Fire Ring*

* Identification Mark to Face Top of Dome

Figure 1-239 Piston Ring Location

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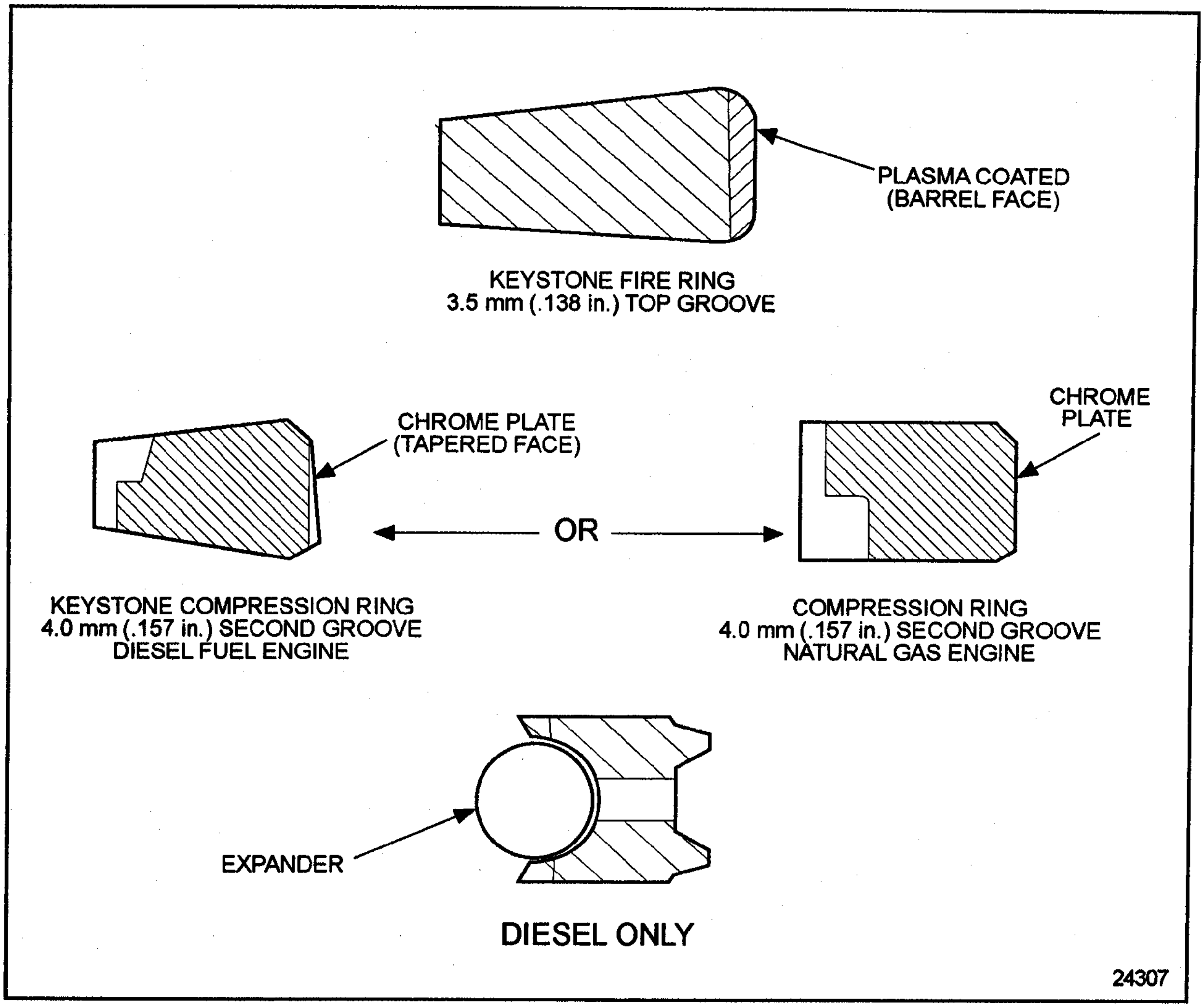
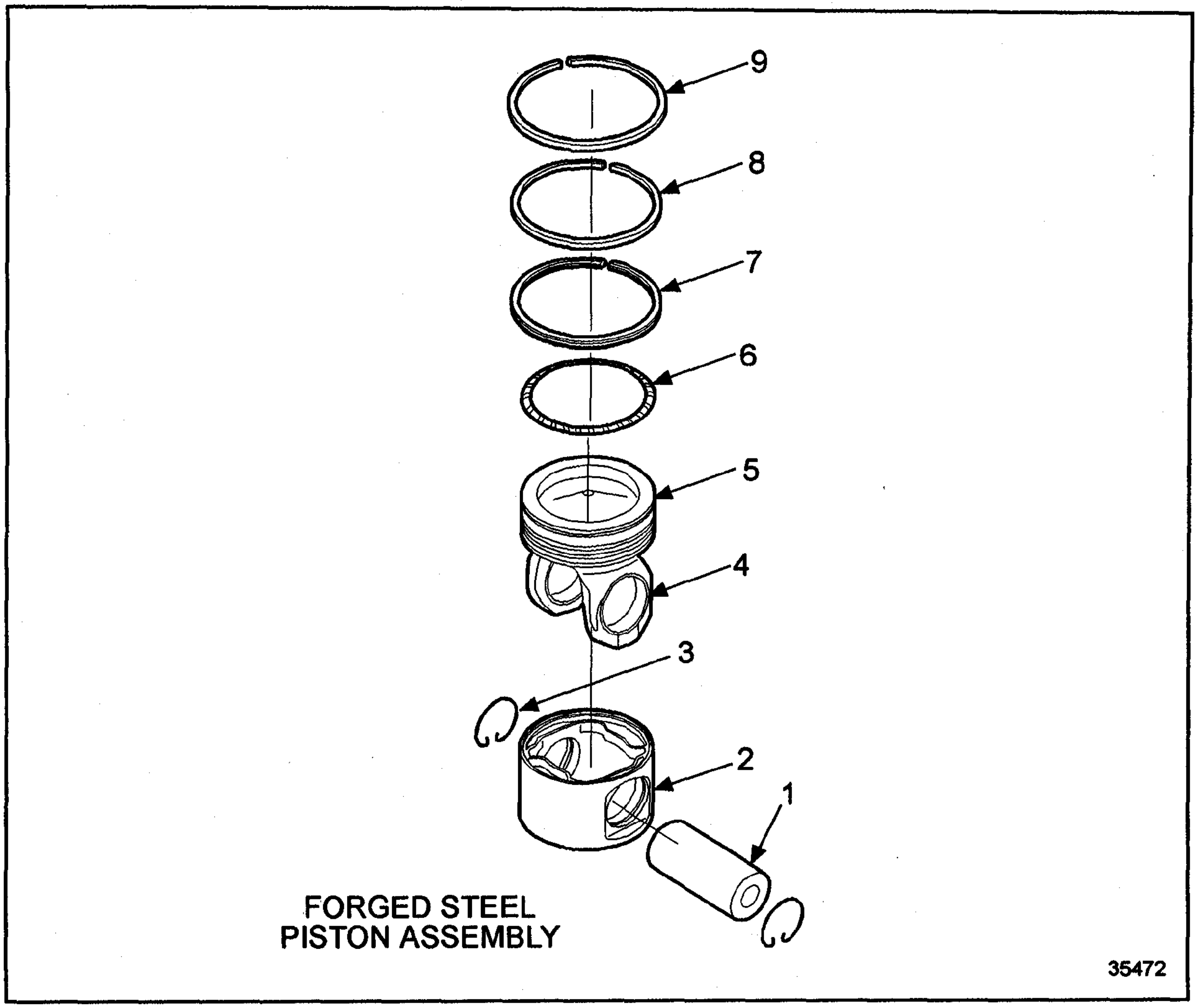


Figure 1-240 Comparison of Piston Ring Packs

The forged steel cross-head piston is two-piece piston consisting of a dome and a skirt. The dome and skirt are held together by the piston pin. Ring grooves are machined in the piston dome. See Figure 1-241.



1. Piston Pin
2. Piston Skirt
3. Snap Ring
4. Piston Pin Bushing
5. Piston Dome
6. Oil Ring Expander
7. Oil Control Ring
8. Compression Ring
9. Fire Ring

Figure 1-241 Forged Steel Piston and Related Parts

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Each piston is fitted with a fire ring, compression ring, and one-piece oil control ring with expander.

The fire and compression rings are installed with the "football" mark facing up, see Figure 1-242.

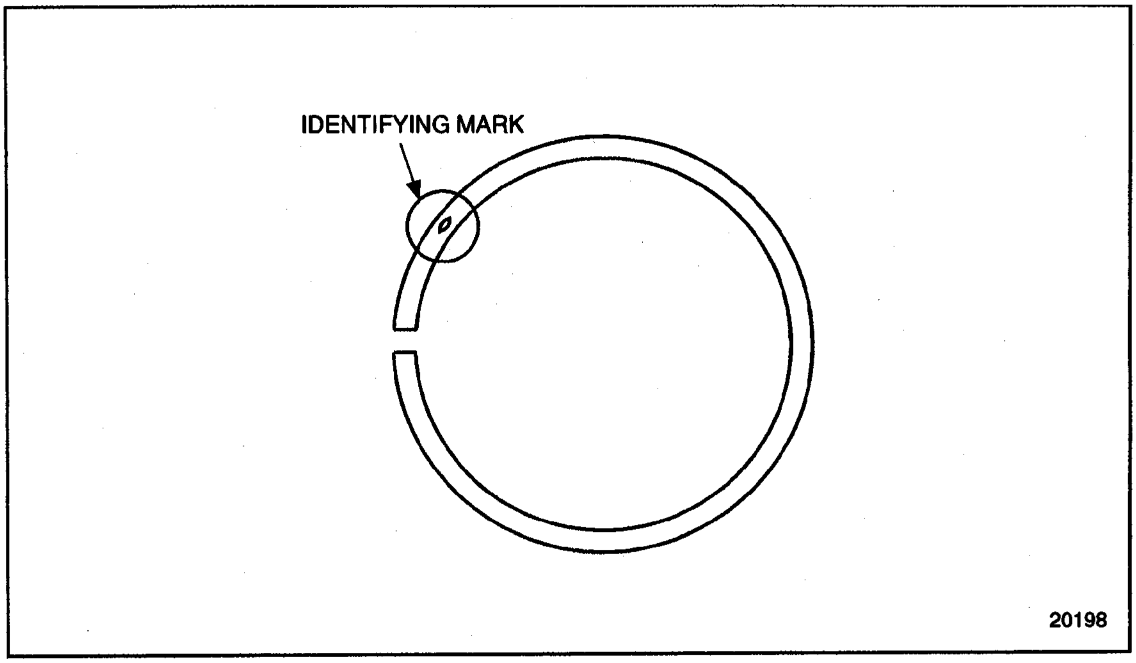

Figure 1-242 Fire and Compression Ring Identification

A one-piece oil control ring is used in the third groove. The expander is of Spira-Lox construction.

The forged steel piston uses a floating piston pin which rides on the one-piece bushing pressed into the end of the connecting rod.

The connecting rod and solid-core piston pin do not have drilled center orifices for lubrication. Oil for lubrication and cooling is supplied by oil spray from piston-cooling nozzles installed at the bottom of each piston bore.

During engine operation, gas loads pushing down on the piston dome are taken directly by the piston pin and connecting rod bushing. The piston skirt, being separate, is free from vertical load distortion. Thermal distortion is also reduced as the piston dome expands. As the connecting rod swings to one side on the downward travel of the piston, the major portion of the side thrust is taken by the piston skirt.

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Two oil relief channels are drilled into the oil ring groove area, on each side of the dome, just above the piston pin bore. These channels are not drilled through the piston. The channels help the excess oil, scraped from the cylinder walls, return to the crankcase. See Figure 1-243.

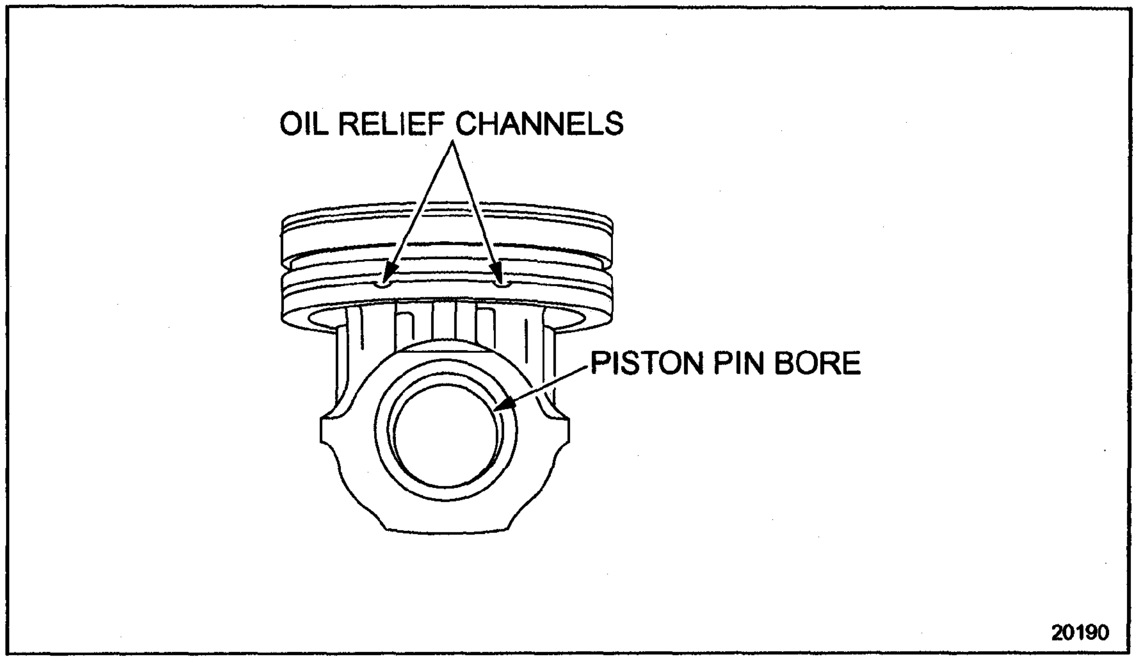

Figure 1-243 Piston Oil Relief Channels

Two cast iron dome designs have been used in Series 60 engines. The earlier design had a non-serviceable bearing. The piston dome and piston pin bearing of the most recent design are separate parts and may be serviced separately.

Two special bolts and spacers are used to attach the connecting rod to the piston pin.

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The solid-core piston pin has a drilled hole through the center to provide lubricating oil to the piston dome for cooling. A threaded hole on each side of the oil hole receives the connecting rod attaching bolts. See Figure 1-244.

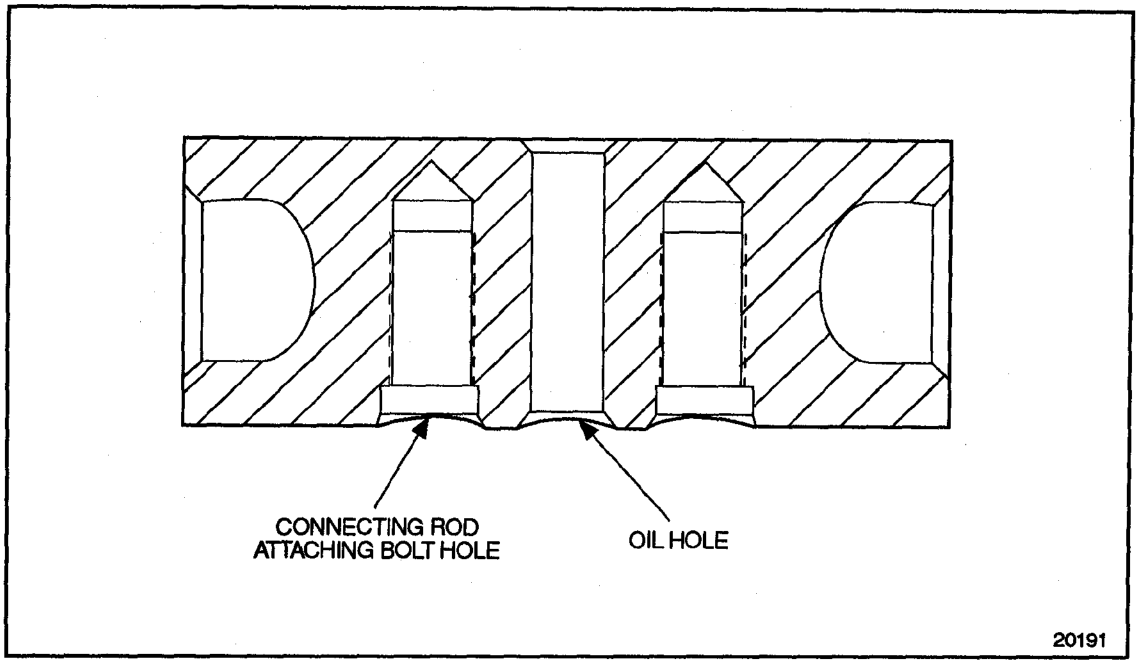

Figure 1-244 Piston Pin Cross Section

Internal parts of the piston are lubricated and cooled by the engine lubricating oil. Oil is pressure-fed up the drilled passage in the connecting rod, through the piston pin, then through the center hole in the bearing to the underside of the piston dome. A portion of the oil lubricates the piston pin and bearing.

During engine operation, gas loads pushing down on the piston dome are taken directly by the piston pin and bearing. The piston skirt, being separate, is free from vertical load distortion. Thermal distortion is also reduced as the piston dome expands. As the connecting rod swings to one side on the downward travel of the piston, the major portion of the side thrust is taken by the piston skirt.

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1.17.1 Repair or Replacement of Piston and Piston Ring

To determine if repair is possible or replacement is necessary, perform the following procedure. See Figure 1-245.

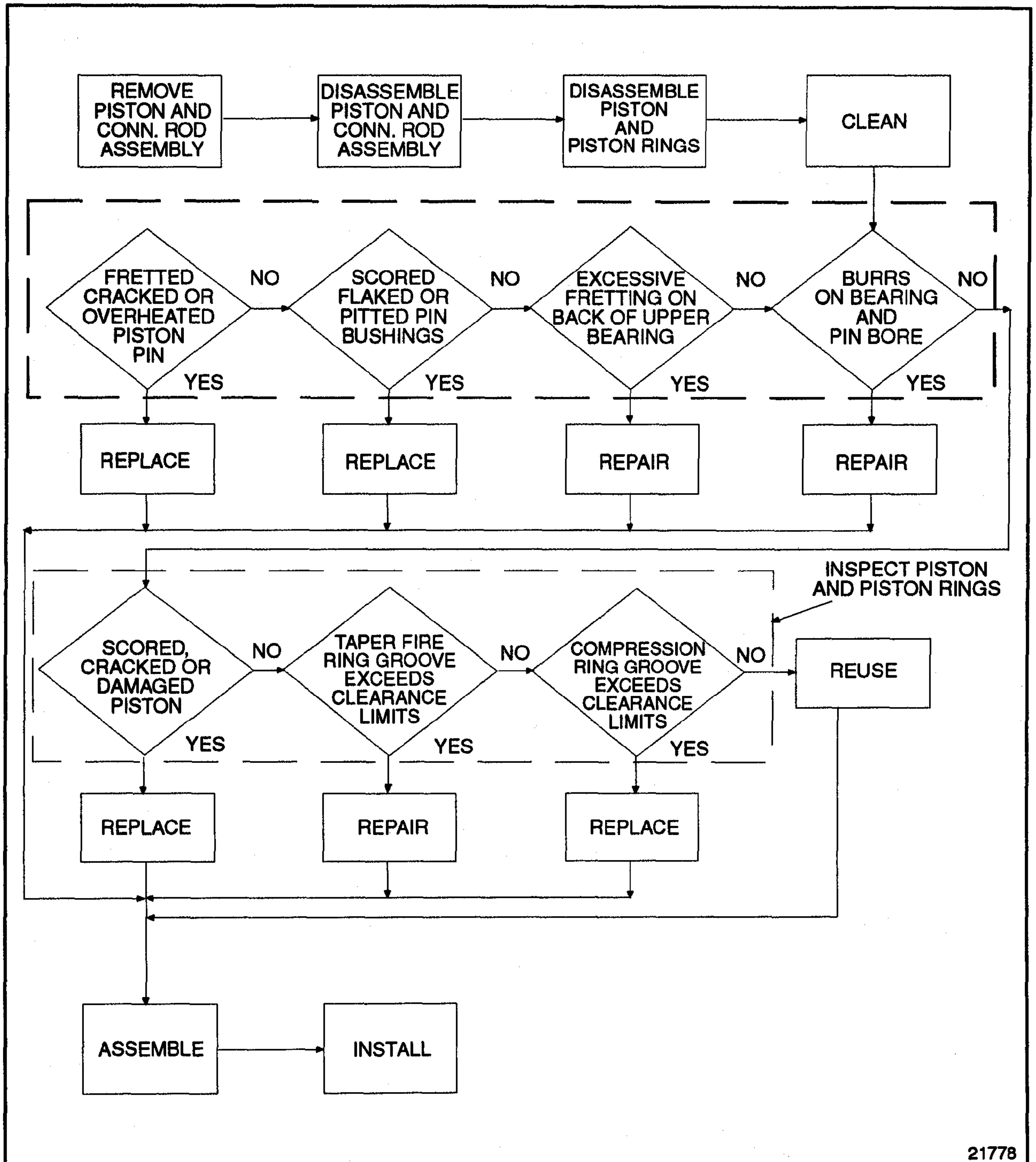

Figure 1-245 Flowchart for Repair or Replacement of Piston and Piston Rings

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1.17.2 Removal and Cleaning of Piston and Piston Ring

Refer to section 1.18.2 for piston and connecting rod assembly removal procedure.

1.17.3 Disassembly of Piston and Piston Ring

Disassemble the piston and piston rings as follows:

1. Remove the piston rings with tool J 22405-02. See Figure 1-246.

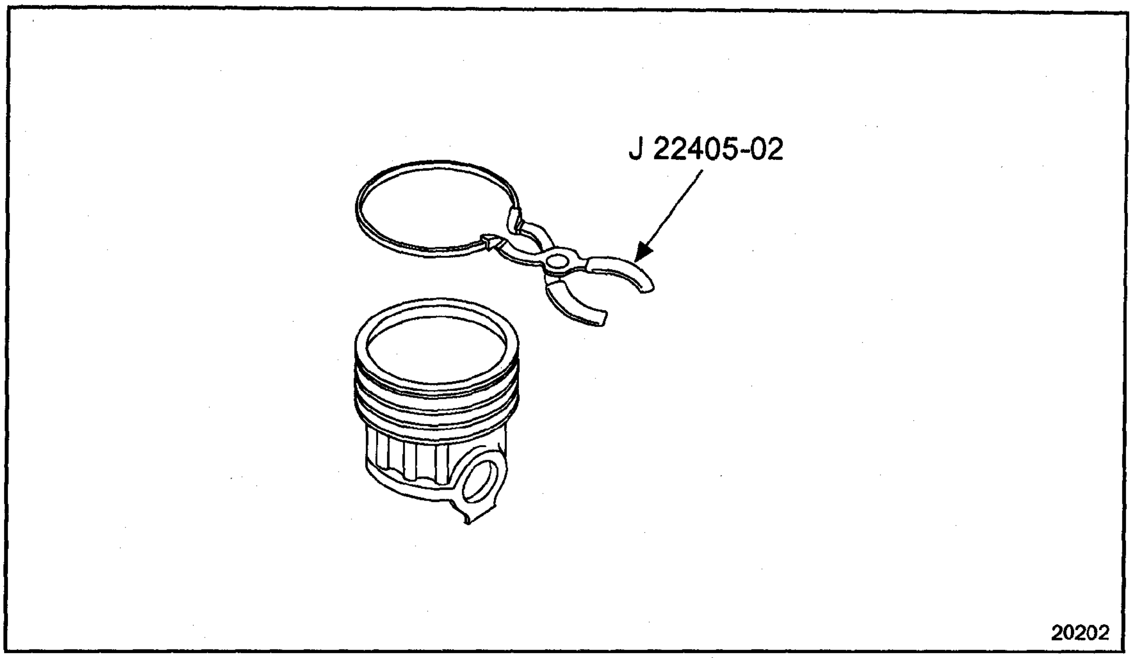

Figure 1-246 Removal of Piston Rings

NOTICE:
The pin, bushing, skirt and dome must be match-marked to assure proper position and orientation.

2. Withdraw the piston pin and mark the front of the piston with a paint pencil, so it can be returned to the correct cylinder location.

NOTE:
Steel pistons will require the removal of the circlip before withdrawing the piston pin.

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3. Perform the following steps on current cast iron domes:
   [a] Separate the piston skirt from the piston dome and mark the front of the dome ear and skirt with a paint pencil, so they can be returned to the correct location.
   [b] Remove the piston pin bearings, marking the front of them with a paint pencil, so they can be returned to the correct location.

NOTE:
Bearings are not serviced separately on steel pistons.

NOTE:
The lower pin bore bearings are removed from the pin bore first, by pushing the bearing legs outward by hand at the split lines from inside the dome saddle ear. The upper bearing may be held in the bore by oil on the back of the bearing, making removal from the pin bore by hand difficult.

CAUTION:
To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

NOTICE:
Prying between the bearing back and dome bore may damage the dome saddle bore or raise burrs which will make installation of new bearings difficult.

DDC recommends that compressed air be directed between the dome pin bore and back of the bearing at one end until the bearing pops up out of the bearing retaining hole.

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1.17.3.1 Inspection of Piston and Piston Rings

Clean the piston and piston rings prior to inspection as follows:

NOTICE:
Do not attempt to clean the piston skirt by glass beading. It will remove the tinplating. Do not refinish or polish the piston pin.

1. Clean the piston components with fuel oil.

CAUTION:
To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

2. Dry the piston components with compressed air.
3. If fuel oil does not remove the carbon deposits, use a chemical solvent that will not harm the tinplate on the piston skirt.

NOTICE:
After cleaning, do not leave glass beads in the piston dome. **Do not allow the glass beading to contact any area of the piston pin bushing or pin bore.** Glass beading will remove the tinplating.

4. The piston dome, including the compression ring grooves, is not tin-plated and may be wire-brushed to remove any hard carbon. Glass beading can be used to clean a piston dome. Micro Bead Glass Shot MS-M 0.0736-0.1473 mm (0.0029 -0.0058 in.) is recommended. The machine used for this process must be able to withstand air pressures of 552-689 kPa (80-100 lb/in.^{2}).

NOTE:
Do not wire-brush the piston skirt.

5. Clean the ring grooves with a suitable tool or a piece of an old compression ring that has been ground to a bevel edge.
6. Clean the inside surfaces of the piston dome and skirt and the oil relief channels in the oil ring grooves.

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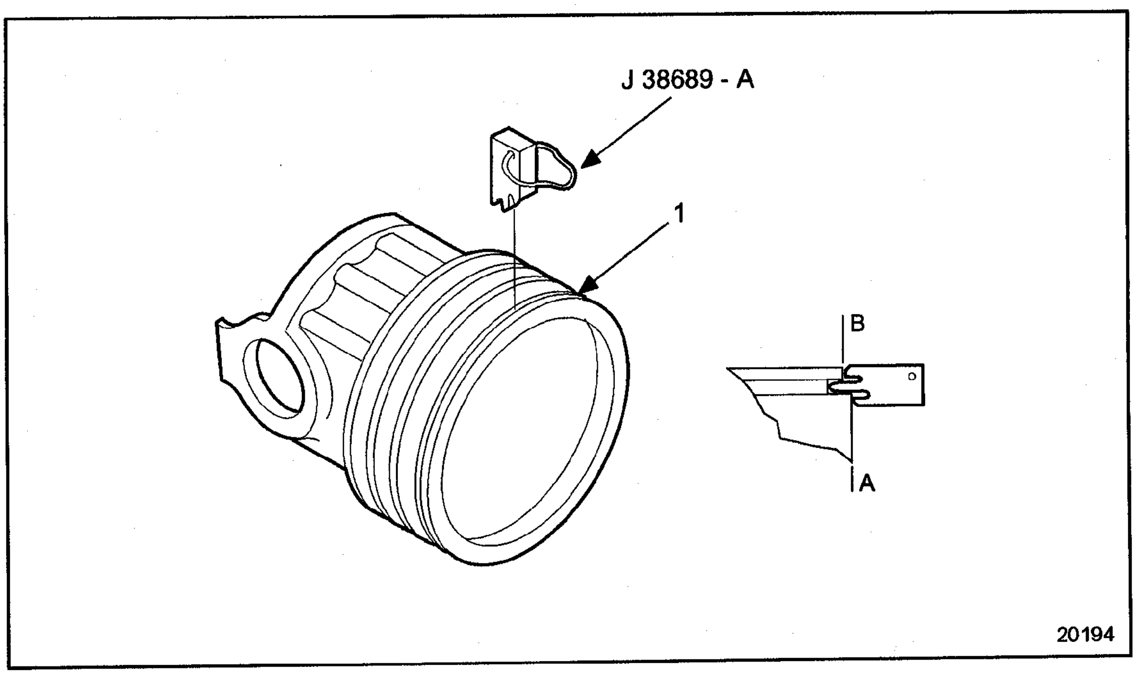
Inspect the piston and piston rings as follows:

1. Inspect the piston skirt and dome.
   [a] Check the skirt and dome for score marks, cracks, damaged ring grooves or overheating indications.
   [b] If any of these indications are present, replace the piston.

NOTE:
Burn spots may indicate an obstruction in the connecting rod or piston pin oil passage.

2. Inspect the tapered fire ring groove (top) in the piston dome.
   [a] Using the piston ring land step gage, J 35884-A (2.5 mm ring groove) or J 38609 (3.5 mm ring groove), check tapered fire ring groove. See Figure 1-247.
   [b] Insert the center tang of the tool gage into the top piston ring groove ash. See Figure 1-247.
   [c] Hold the tool at a 90 degree angle to the ring groove to prevent false readings.
   [d] With the center tang into the ring groove as far as it will go, there should be no contact of the piston with the shoulders of the gage. If the gage makes contact at point A or point B, the fire ring groove is worn beyond usable limits. Check the groove clearance at four spots, at 90 degree intervals. Measure the ring land parallel to and at 90 degrees to the wrist pin.
   [e] If fire ring groove is worn beyond usable limits, replace piston dome.



1. Fire Ring Groove

Figure 1-247 Checking Fire Ring Groove

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3. Inspect tapered compression ring groove (second) in the piston dome.
   [a] Using piston ring land step gage, check the groove as in the compression ring groove.
   [b] If the compression ring groove is worn beyond usable limits, replace piston dome.
4. Inspect the piston pin.
   [a] Check the piston pin for fretting, cracking or signs of overheating.
   [b] If these are detected, replace piston pin.
   [c] Measure piston pin outside diameter. Specifications are listed in Table 1-20.
   [d] If piston pin is out of specifications, replace with new part.

NOTE:
If piston pin used with a cast iron piston is replaced for any reason, the piston pin bushing for that cylinder must also be replaced.

NOTE:
If the piston pin used on steel dome engines is replaced for any reason, the dome must also be replaced for that cylinder.

5. Inspect the piston pin bushings as follows:
   [a] Check the piston pin bushings for scoring, pitting, flaking, cracking, excessive wear, or signs of overheating.
   [b] If these conditions are present, the bearings must be replaced.

NOTE:
On steel dome engines, if bearing replacement is necessary then the dome assembly must be replaced as well.

NOTE:
Early second keystroke ring (SKR) design piston domes have an integral piston pin bushing. The piston pin bushing cannot be replaced in these piston domes. If there is distress to the piston pin bushing, the entire piston dome assembly must be replaced, with current cast iron design.

NOTICE:
If a piston pin bushing is replaced for any reason, the piston pin for that cylinder must also be replaced.

6. Inspect the back of the upper bushing.
   [a] Check the bushing for excessive fretting.
   [b] If excessive fretting is evident, replace all three bushings.
   [c] The corresponding fretting in the piston dome can be removed using crocus cloth, wet with fuel oil.

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7. On steel piston engines, inspect the connecting rod bushing.
   [a] Check the bushing for excessive fretting.
   [b] If excessive fretting is evident, replace the connecting rod assembly.
8. Inspect the edges of the bearings and piston dome pin bore.
   [a] Check the edges of the bearing and piston dome pin bore for dents and dings.
   [b] If any are found, it is acceptable to remove burrs at the bearings or pin bore edges by careful filing.

NOTE:
Remove any dirt or debris on the backs of the bearing or dome pin bore that may take up clearance required for bearing or piston pin installation.

9. If the piston pin used with a forged steel piston is replaced for any reason, the connecting rod bushing *must* be inspected for wear before the rod is installed. If the bushing is worn beyond limits, the connecting rod *must* be replaced. Refer to section 1.17.3.1 for connecting rod bushing inspection procedure.
10. Check the cylinder liner and block bore for excessive out-of-round, taper and high spots which could cause failure of the piston. Specifications are listed in Table 1-16.
11. Check the block bore for excessive out-of-round, taper, and high spots that could cause failure of the piston. Specifications are listed in Table 1-15.

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1.17.4 Assembly of Piston and Piston Rings

Prior to installing the piston rings, the ring gap of each piston ring must be measured.

1. Insert the piston rings inside of the cylinder liner one at a time, using a piston dome (inserted upside down into the liner) to push the ring down. The piston dome should be inserted into the liner, to the same depth as the ring being positioned.
2. For the oil control ring, insert the piston dome down into the liner, until the oil control ring land is just into the liner. This will ensure that the rings are parallel with the top of the liner, and that they are positioned in the liner within the normal area of ring travel.
3. After the three rings have been positioned in the liner, measure the ring gap of the top ring with a feeler gage. See Figure 1-248. Remove the ring from the liner after the measurement is complete.

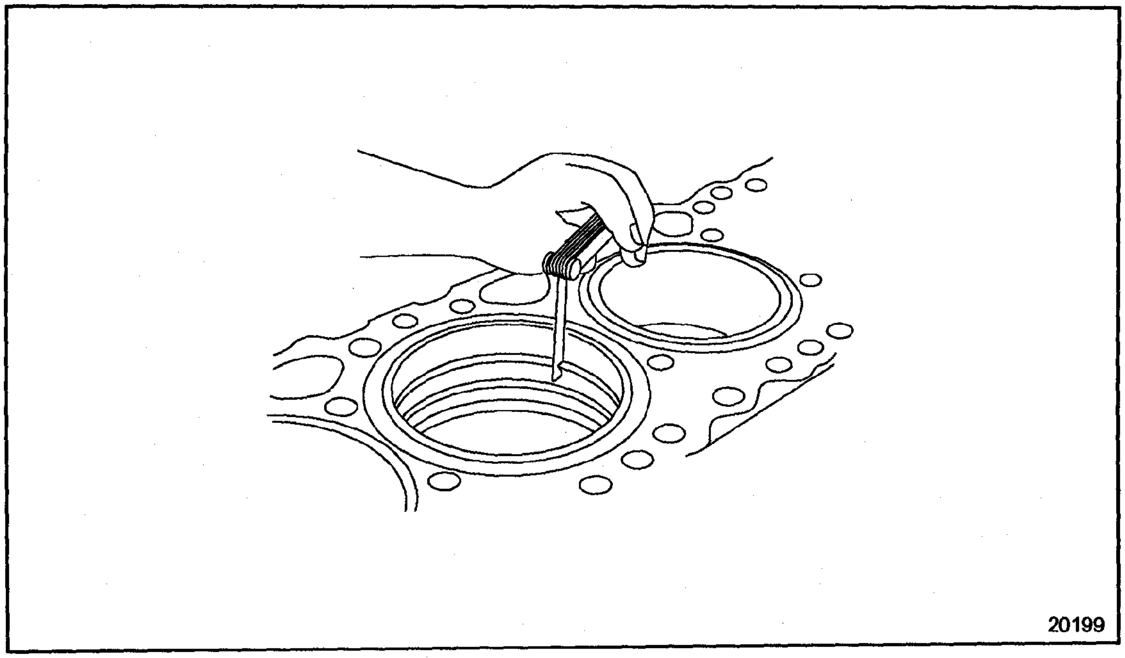

Figure 1-248 Piston Ring Gap Measurement

4. Repeat this procedure for each ring, and record your measurements. Allowable ring end gaps are listed in Table 1-5 and listed in Table 1-6.

Ring	Ring End Gap
Fire Ring (2.5 mm [0.098 in.] chrome)	0.40 - 0.87 mm (0.016 - 0.034 in.)
14L Fire Ring: 3.0 mm (0.118 in.)	0.60 - 0.85 mm (0.024 - 0.033 in.)
Fire Ring (3.5 mm [0.138 in.] plasma)	0.51 - 0.87 mm (0.020 - 0.034 in.)
Compression Ring	0.81 - 1.31 mm (0.032 - 0.051 in.)
14L Compression Ring	0.63 - 0.98 mm (0.025 - 0.039 in.)
Oil Control Ring	0.40 - 0.81 mm (0.016 - 0.032 in.)
14L Oil Control Ring	0.21 - 0.51 mm (0.008 - 0.020 in.)

Table 1-5 Allowable Ring End Gap — All Diesel (Except Pleasure Craft Marine) Engines

Ring	Ring End Gap
12.7L Fire Ring: 3.0 mm (0.118 in.)	0.60 - 0.80 mm (0.024 - 0.031 in.)
Compression Ring	0.81 - 1.31 mm (0.032 - 0.051 in.)
Oil Control Ring	0.40 - 0.81 mm (0.016 - 0.032 in.)

Table 1-6 Allowable Ring End Gap — Pleasure Craft Marine Engine

5. Refer to section 1.17.5for assembly of rings for diesel engines or refer to section 1.17.6 for Series 60G engines.

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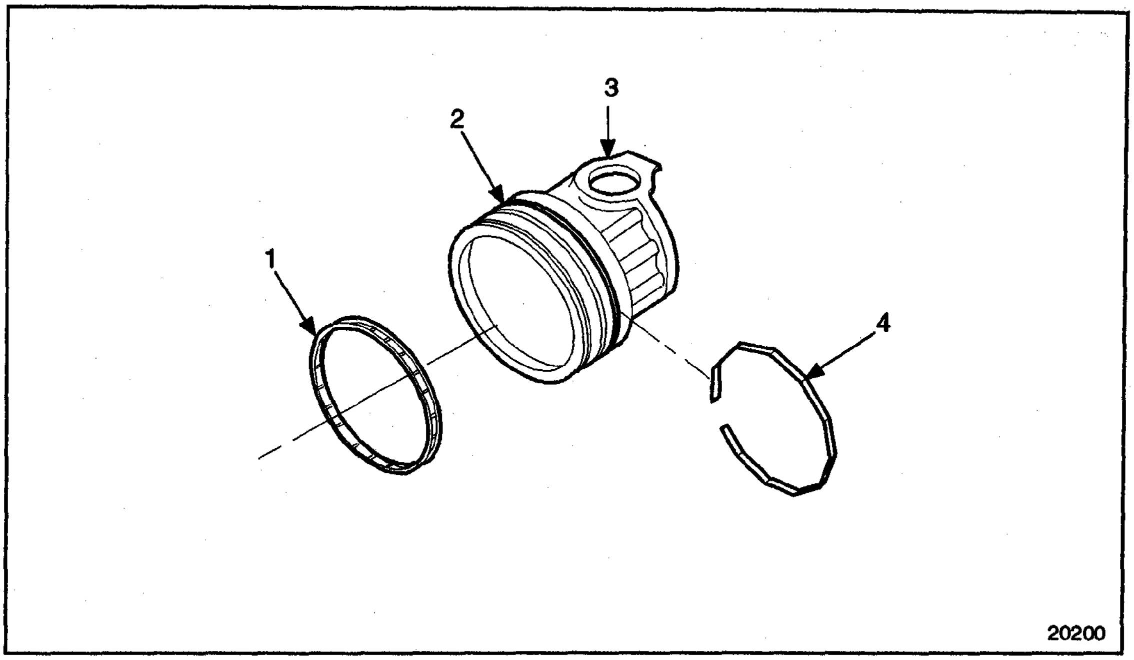
1.17.5 Assembly of S60 Diesel Piston Rings

Assemble the piston and piston pin rings as follows:

1. Install the ring expander in the oil control ring groove in the piston. See Figure 1-249.



1. Oil Control Ring
2. Oil Control Ring Groove
3. Piston
4. Oil Control Ring Expander

Figure 1-249 Piston Ring Installation (Diesel)

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2. Install the oil control ring by hand. See Figure 1-250.

NOTE:
The oil control ring may be installed in either direction.

NOTE:
Install expander into inside diameter groove of ring with expander spring gap located 180° from the oil control ring gap.

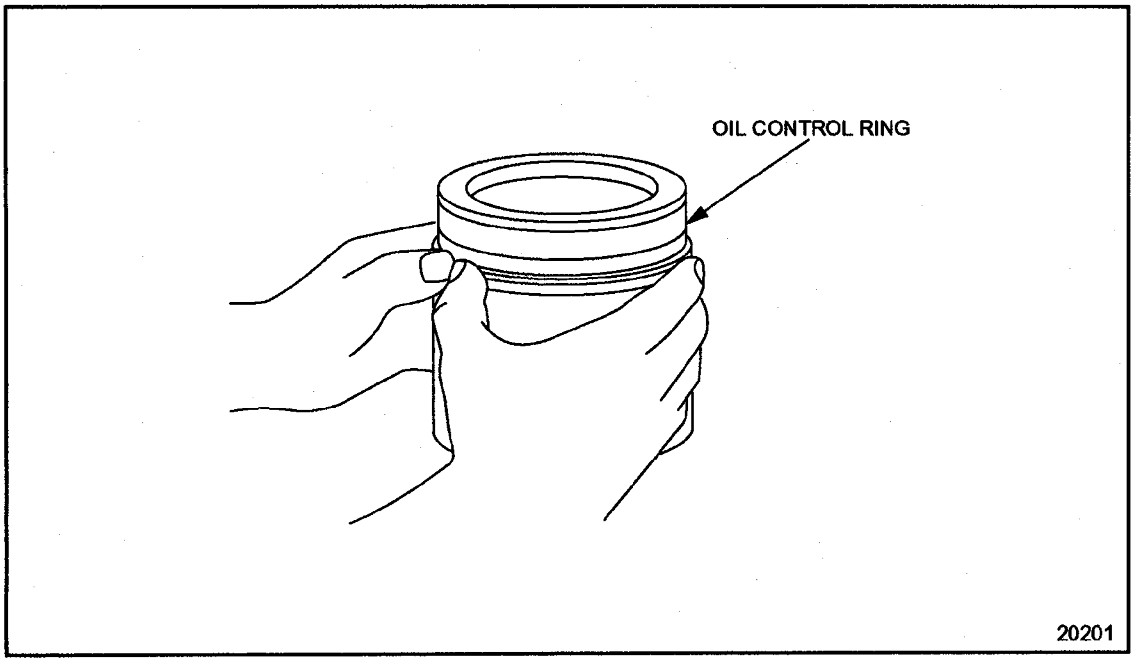

Figure 1-250 Oil Control Ring Installation (Diesel)

NOTE:
The oil control ring expander has a white paint stripe. Make sure the paint mark can be seen after the oil control ring is installed at ring gap.

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Install the fire and compression rings as follows:

NOTICE:
To avoid breaking or overstressing the rings, do not spread them any more than necessary to slip them over the piston dome.

1. Starting with the compression ring (second groove), install the compression ring and fire ring with tool J 22405-02. See Figure 1-251. Make sure the identifying dimple on the rings is installed up, toward the dome of the piston. See Figure 1-242for ring identification and locations.
2. Stagger the ring gaps around the piston. See Figure 1-251.

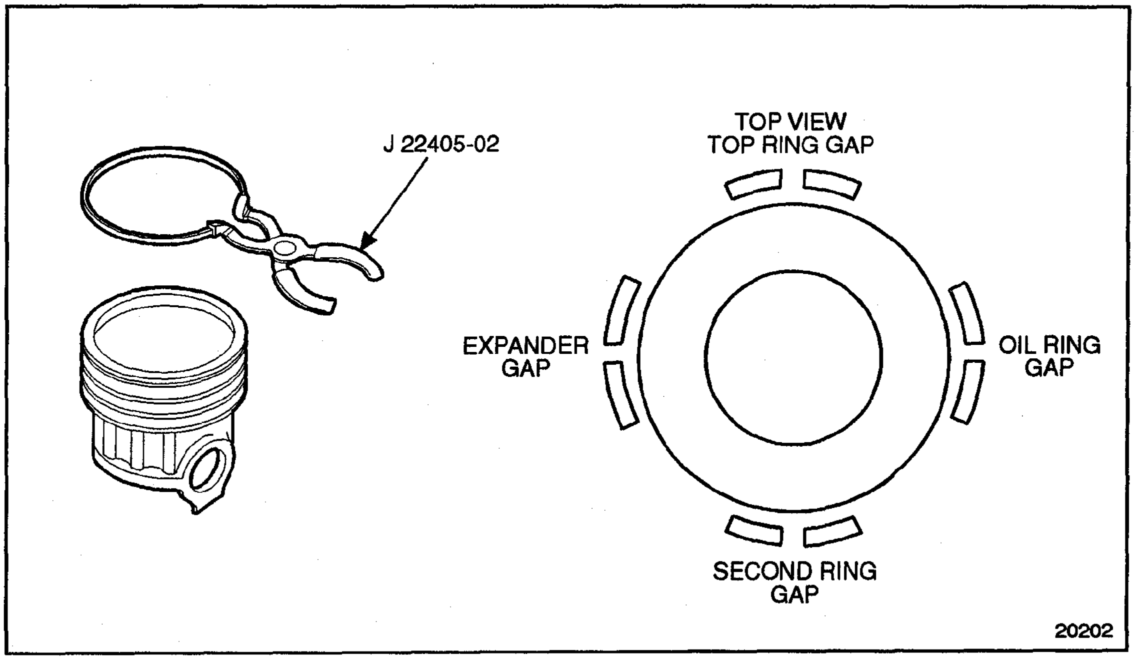

Figure 1-251 Piston Ring Positioning (Diesel)

3. Refer to section 1.18.4 for piston and connecting rod assembly procedure.

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1.17.6 Assembly of Series 60G Piston Rings

Install the oil control ring for the Series 60G engine as follows:

1. Install the expander in the bottom groove of the piston.
2. Install the upper and lower rails ensuring one is on the upper side of the expander and the other is on the lower side of the expander.

NOTE:
The expander and both rails may be installed with either side up. There is no "football" mark on any of the three oil ring components for natural gas engines.

3. Orient the ring gaps of the rails 180 degrees apart so that they align with the paint marks on the expander. The expander should be 90 degrees from the oil ring gaps.

Install the compression and fire ring for the Series 60G engine as follows:

1. Install the compression ring (rectangular cut shape) in the second groove of the piston, using tool J 22405-02. See Figure 1-252.

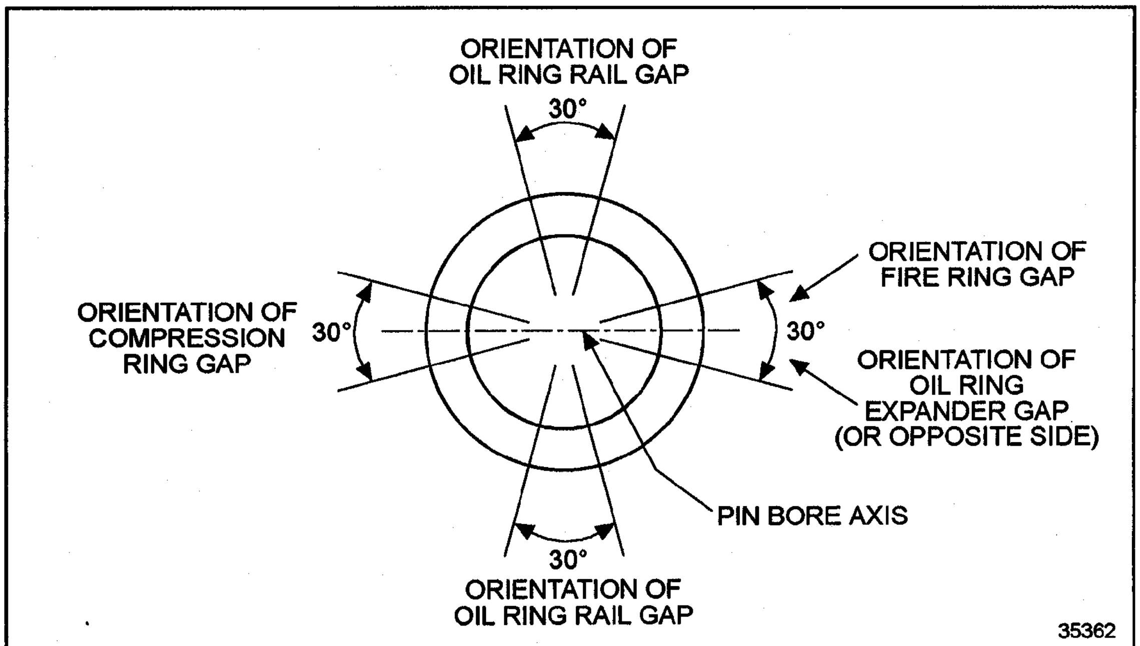

Figure 1-252 Installation of Compression Ring with J 22405–02

2. Install the fire ring in the top groove of the piston, using tool J 22405-02.

3. Stagger the ring gaps around the piston. See Figure 1-253.

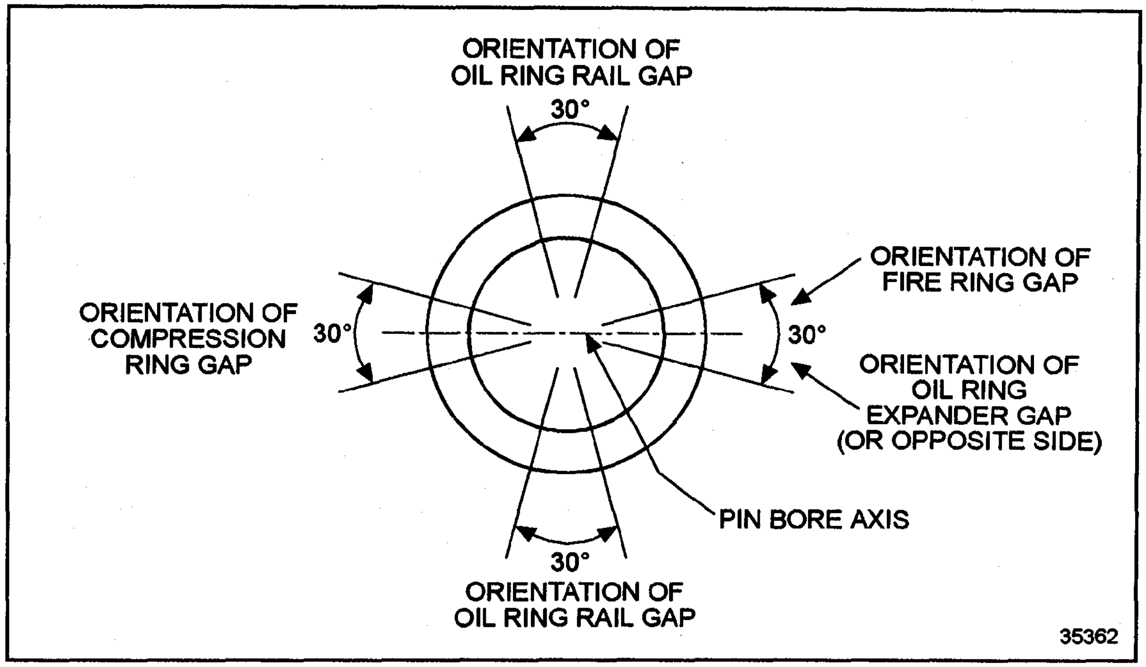

Figure 1-253 Top View of Piston Dome

4. Refer to section 1.18.4 for piston and connecting rod assembly procedure.

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1.18 PISTON AND CONNECTING ROD ASSEMBLY

Since the piston and connecting rod assembly is one unit made of two separate components, the components will be addressed in separate sections.

For general piston information, refer to section 1.17.

For general connecting rod assembly information, refer to section 1.19. The 14L engine requires that the piston, connecting rod, and cylinder liner be removed as an assembly.

NOTE:
Some 14L and steel cylinder kit procedures differ from the cast iron procedures. Information regarding 14L and steel cylinder kits will follow cast iron procedures when different.

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1.18.1 Repair or Replacement of Piston and Connecting Rod

To determine if repair is possible or replacement is necessary, perform the following procedure. See Figure 1-254.

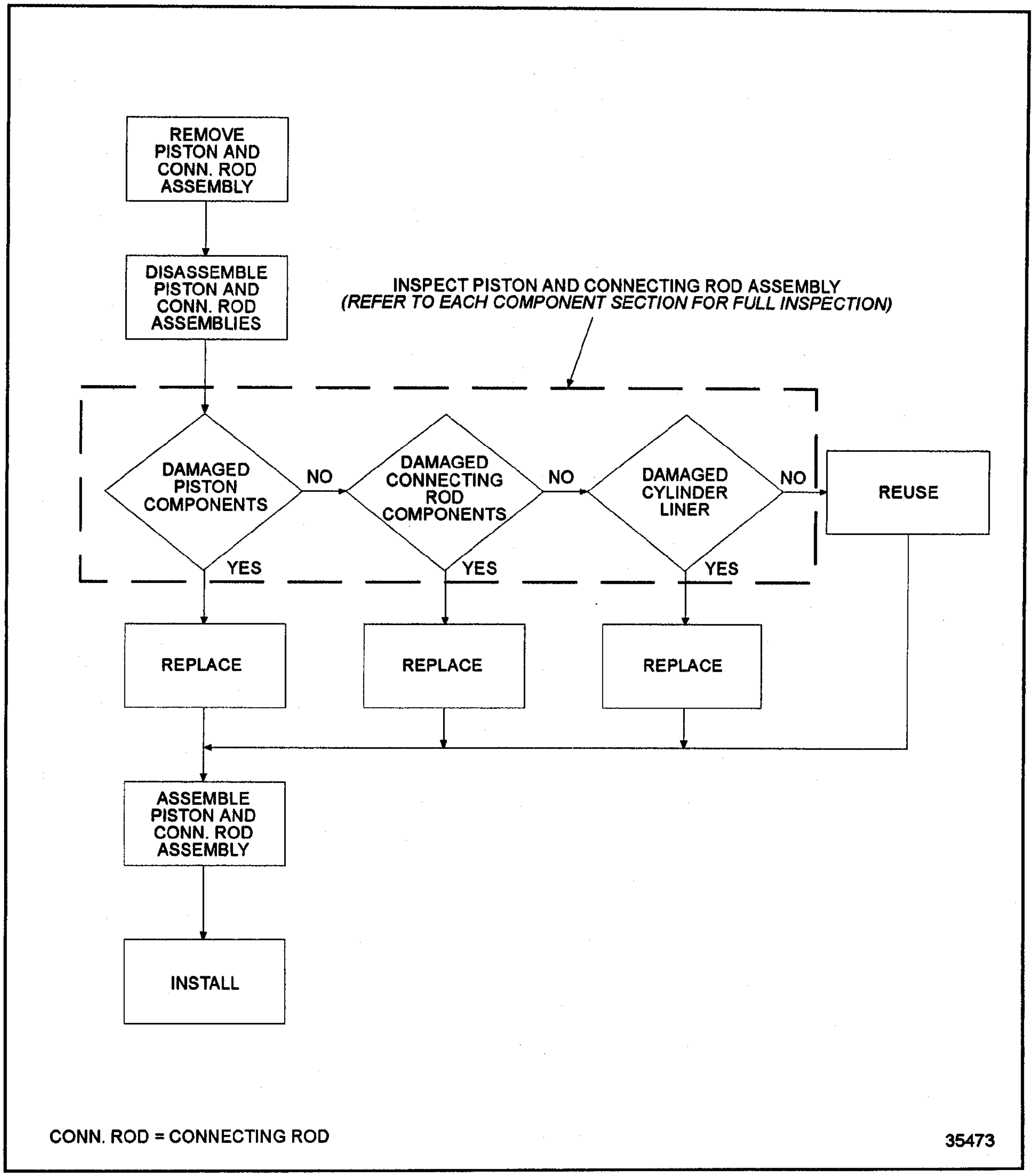

Figure 1-254 Flowchart for Repair or Replacement of Piston and Connecting Rod

1.18.2 Removal and Cleaning of Piston and Connecting Rod

Precleaning is not necessary.

Remove the piston and connecting rod assembly as follows (except 14L):

1. Drain the engine cooling system. Refer to section 13.13.4.
2. Drain the engine oil. Refer to section 13.13.1.
3. Remove the oil pan. Refer to section 3.11.2.
4. For pre-1991 engines, disconnect and remove the lubricating oil pump inlet pipe and screen assembly, oil pump outlet pipe and lubricating oil pump. Refer to section 3.2.2. See Figure 1-255.

NOTE:
It is not necessary to remove the oil pump on 1991 and later model year engines.

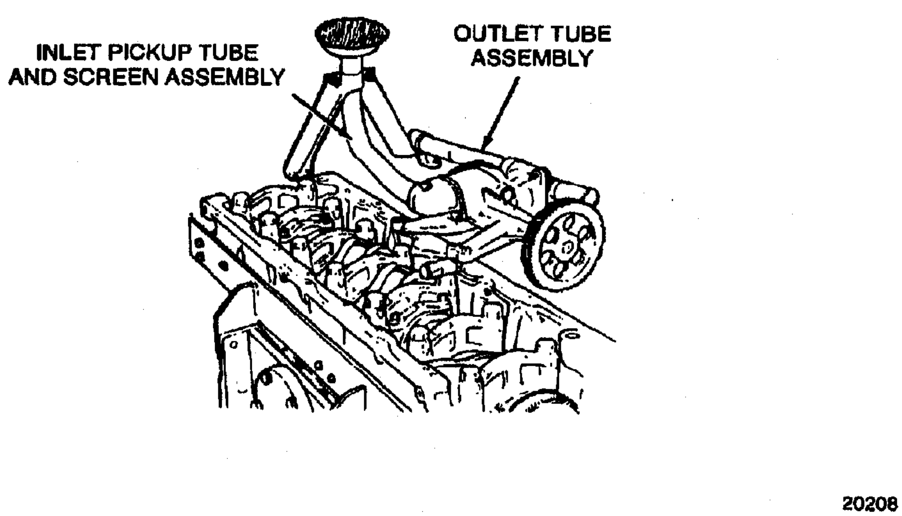

Figure 1-255 Oil Pump Removal (Pre-1991 Engines)

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5. Remove the cylinder head. Refer to section 1.2.2.
6. Use an emery cloth to remove any carbon deposits from the upper surface of the cylinder liner.

NOTICE:
If installed, remove the piston cooling nozzles from the base of the cylinder bores to prevent nozzle damage, during piston removal.

7. Remove the bearing cap and lower bearing shell from the connecting rod.
8. Install connecting rod guides, J 35945 (or equivalent) for removing cast iron pistons or J 43661 (or equivalent) for removing forged steel pistons, to protect the crankshaft journals, to protect the crankshaft journals.
9. Push the piston and rod assembly out through the top of the cylinder block.

NOTE:
The piston cannot be removed from the bottom of the cylinder block.

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10. Assemble the bearing cap and lower bearing shell to the connecting rod after removal. If not already marked, match-mark the rod and cap (on the tang side) with the cylinder number from where they were removed. See Figure 1-256.

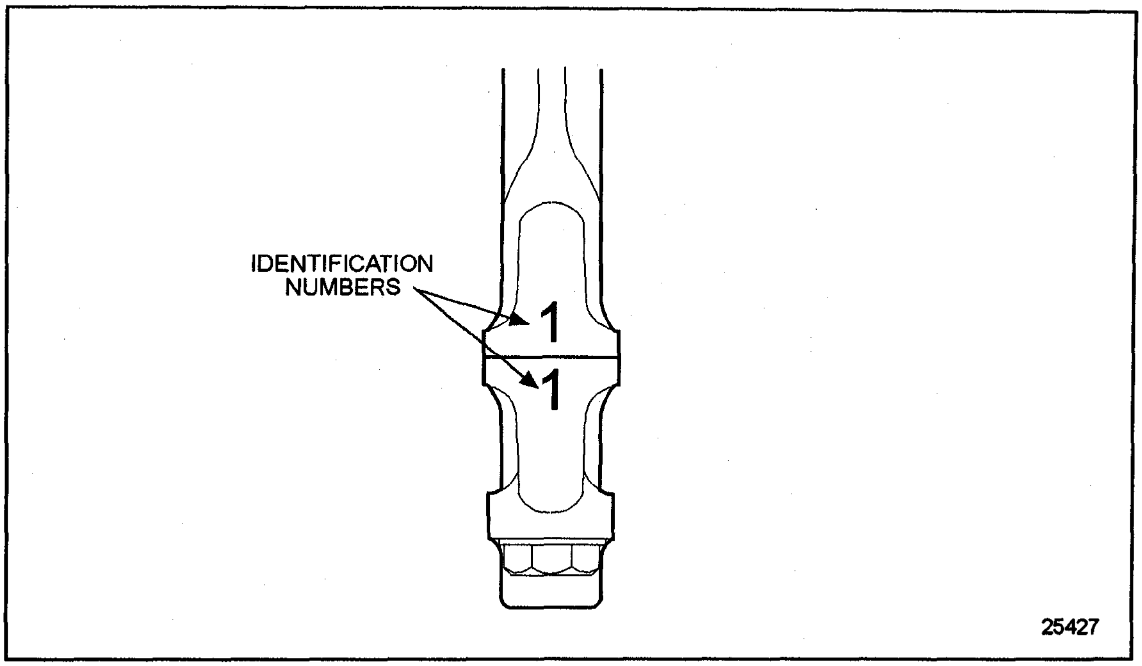

Figure 1-256 Connecting Rod and Cap Identification

NOTE:
When removed, the bearing cap and the bearing shell must be reinstalled on the original connecting rod before another connecting rod bearing cap is removed.

NOTE:
If removing the piston and connecting rod assembly to work on the cylinder liner, stop here. Refer to section 1.20.2 for cylinder liner removal procedure.

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Remove the 14L cylinder liner, piston and connecting rod assembly as follows:

1. Drain the engine cooling system. Refer to section 13.13.4.
2. Drain the engine oil. Refer to section 13.13.1.
3. Remove the oil pan. Refer to section 3.11.2.
4. Remove the cylinder head. Refer to section 1.2.2.
5. Position the crankshaft journal for the cylinder kit assembly to be removed at bottom dead center.
6. Remove the bearing cap.
7. Insert cylinder kit removal tool J 43396 in the bore of the cylinder to be removed. Tighten the bolt snug. (Do not overtighten.)See Figure 1-257.

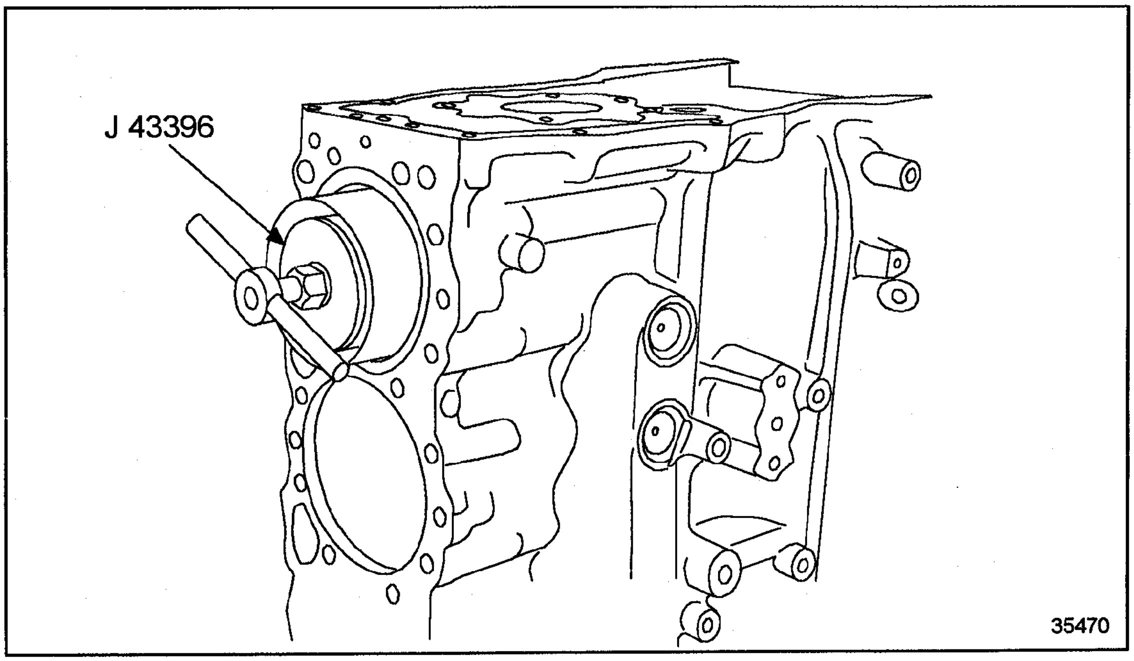

Figure 1-257 Cylinder Kit Removal Tool J 43396

8. Install the rod bolt protectors, J 34317. Close the air valve in the removal tool.
9. Rotate the engine by hand until the entire cylinder kit assembly is pushed up where the liner can be removed by grabbing the tool to pull the kit completely out of the engine block.

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10. Assemble the bearing cap and lower bearing shell to the connecting rod after removal. If not already marked, match-mark the rod and cap (on the tang side) with the cylinder number from where they were removed. See Figure 1-258.

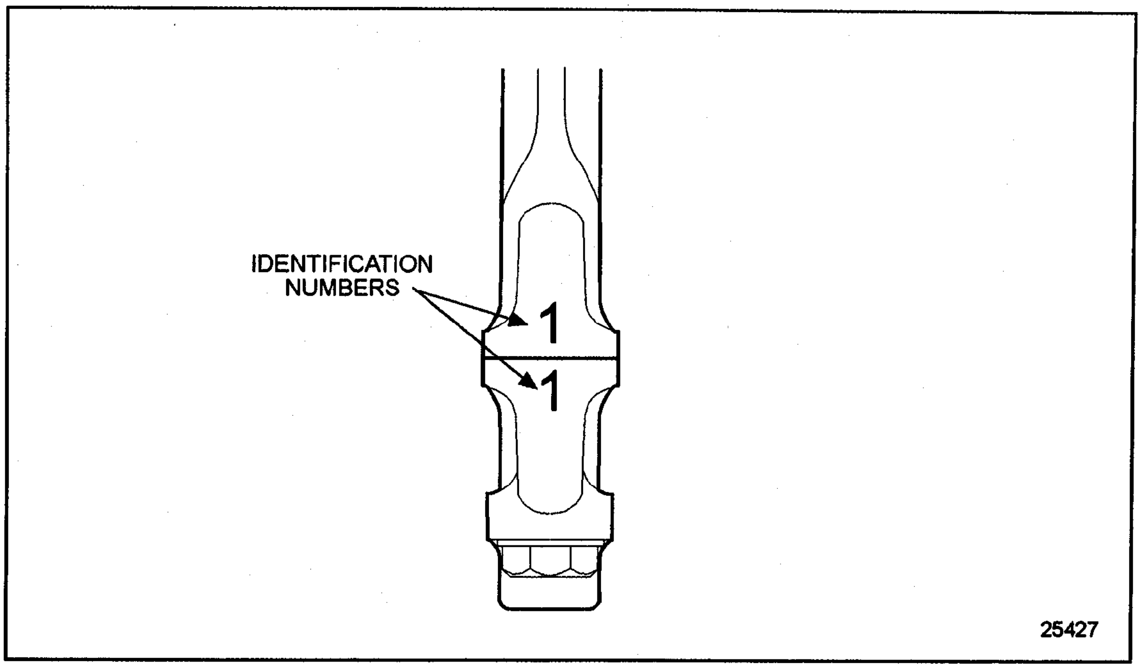

Figure 1-258 Connecting Rod and Cap Identification

NOTE:
When removed, the bearing cap and the bearing shell must be reinstalled on the original connecting rod before another connecting rod bearing cap is removed.

11. Withdraw the piston and rod assembly through the bottom of the cylinder liner.

NOTE:
The rod will not fit through the inside diameter of the cylinder liner.

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1.18.3 Disassembly of Piston and Connecting Rod Assembly

Piston assembly components should be segregated by cylinder and match-marked during disassembly to ensure they are assembled in the same position and orientation.

NOTICE:
Stamping cylinder numbers on the piston assembly will damage the components.

It is best to use a paint pencil. For cast iron pistons, mark the pin, skirt, bushing, and dome ear at the front. For forged steel pistons, mark the pin, skirt, and dome.

If the second ring on the cast iron piston is a rectangular section, the engine should be fitted with the current cast iron piston assemblies that contain a Second Keystone Ring (SKR) configuration. Former piston rings must **NOT** be used in the SKR configuration.

Disassemble the cast iron piston and connecting rod assembly as follows:

1. Place the piston, dome down, on the round plate of the piston and connecting rod holding fixture, J 36211. See Figure 1-259.

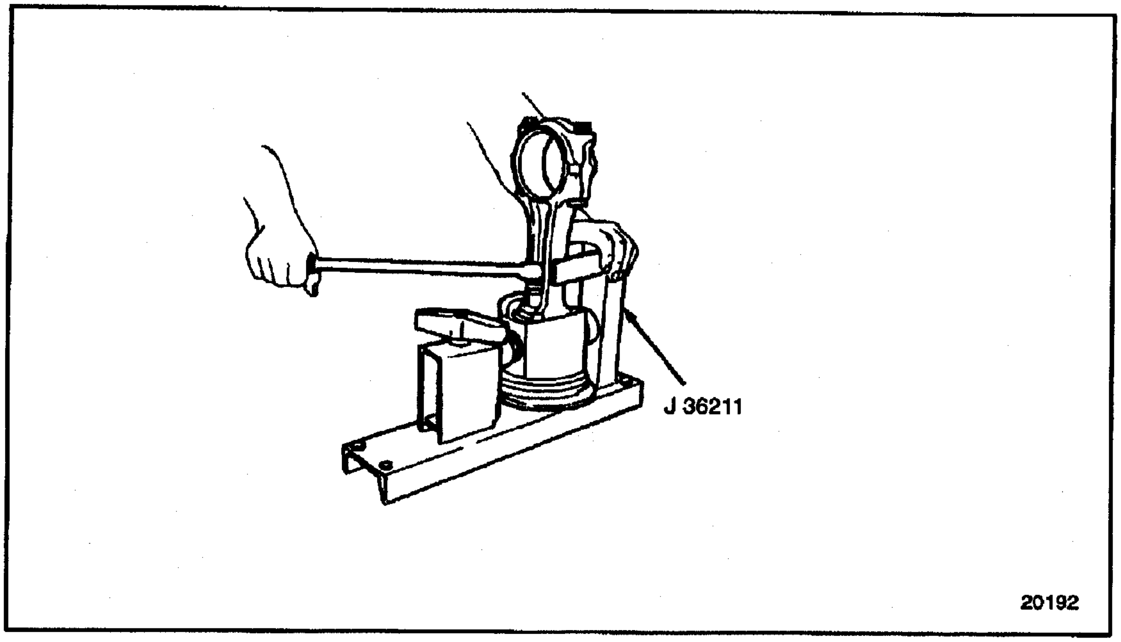

Figure 1-259 Piston Connecting Rod Holding Fixture

2. Slide the movable portion of the fixture until it contacts the piston pin and tighten the handle.

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3. Loosen the two bolts that secure the connecting rod to the piston pin and remove the two bolts and spacers.
4. Remove the connecting rod.
5. Remove the piston, pin and skirt from the holding fixture.

Disassemble the 14L liner, piston and connecting rod assembly as follows:

1. Using the required snap ring pliers, remove the circlip-type snap rings from the piston skirt.
2. Slide out the piston pin and remove the rod from the piston.
3. Disassemble the piston dome from the skirt. It is best to use a paint pencil to mark the pin, skirt, and dome.

Disassemble the forged steel piston and connecting rod assembly as follows:

1. Place the piston, dome down, on the table. See Figure 1-260.

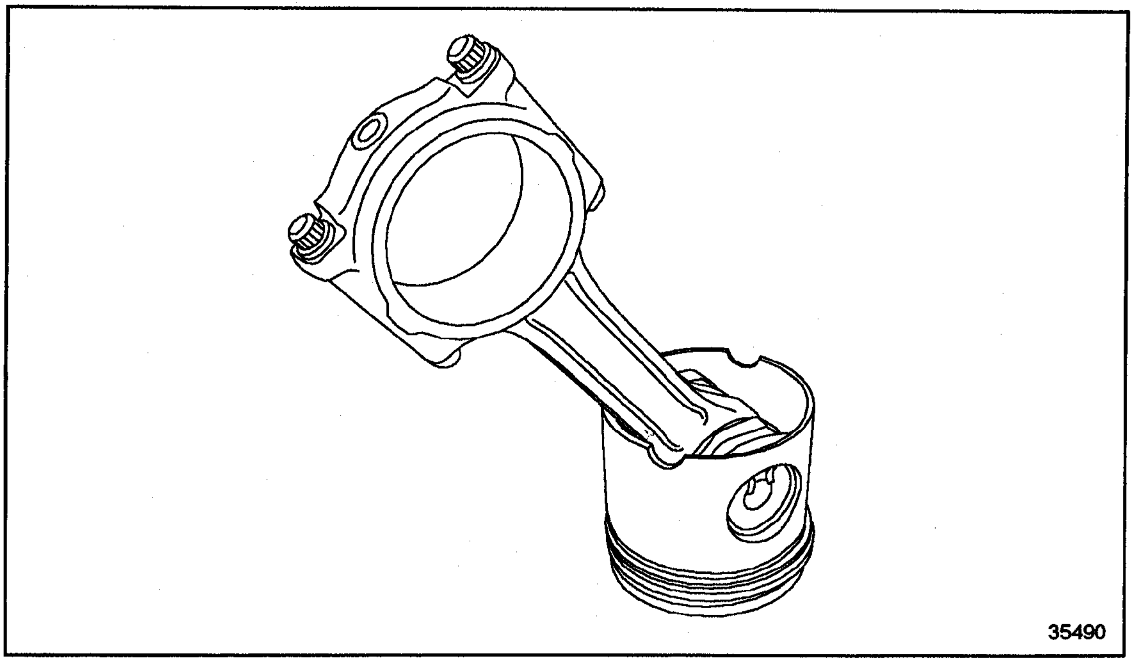

Figure 1-260 Positioning of the Piston and Connecting Rod Assembly

2. Using the required snap ring pliers, remove the circlip-type snap rings from the piston skirt.
3. Slide out the piston pin and remove the rod from the piston.
4. Disassemble the piston dome from the skirt.

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1.18.3.1 Inspection of Piston and Connecting Rod Assembly

Refer to section 1.17.3 for disassembly of the piston and piston ring.

Refer to section 1.17.3.1 for inspection of the piston and piston ring.

Refer to section 1.19.3 for disassembly of the connecting rod.

Refer to section 1.19.3.1 for inspection of the connecting rod.

NOTE:
Steel dome piston pin bearings are not serviced. If they are found damaged then the replacement of the dome is required. The same is true for the rod bearings. If they are found damaged then the replacement of the rod is required as well.

1.18.4 Assembly of Piston and Connecting Rod Assembly

Assemble the cast iron piston and connecting rod assembly as follows:

NOTICE:
The connecting rod-to-piston pin attaching bolts and spacers are specially designed components. No other bolts or spacers may be used. Piston pin bolts are considered one-use items and **must** be replaced with new bolts when removed for any reason. Failure to observe this precaution may result in bolt loosening or breaking during engine operation, which may cause serious engine damage.

1. Discard used piston pin bolts and replace with new bolts.
2. Because of the low clearance fit between the piston pin and three-piece pin bearing, care in handling and cleanliness of piston dome bore, bearings, and piston pin are important. Otherwise, assembly may be impossible. The specifications on reusing piston assembly components are listed in Table 1-17 and listed in Table 1-20.
3. The pin bore and bearing backs should be wiped clean prior to installation of the bushings in the piston dome.
4. Installing piston pin bearings (with the piston dome standing on the rim) requires the upper bearing piece to be inserted through the end of the pin bore and dropped over the retaining pin.
5. The lower bearing pieces are inserted flat side in by tilting the bearing at approximately a 30 degree angle from the vertical away from the dome ear.
6. Set the edge of the bearing parting line on the edge of the upper piece notch and rotate the lower bushing up and into place. The lower bearing can then be pushed full into the bore with the thumb.
7. Lubricate the piston pin bearings with clean engine oil. (Straight 30 weight oil is recommended.)
8. Set the piston skirt on the piston dome.

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9. Align the piston pin holes in the dome and skirt.
10. Check the piston pin for foreign matter in the bolt holes.
11. Lubricate the pin with clean engine oil and install in the bores with the bolt holes facing the connecting rod, away from the dome.

NOTE:
The piston pin may feel considerably tighter than with conventional designs and possibly may not be turned easily by hand. Proper pin and bearing installation should result in a piston assembly in which the pin can be turned with the connecting rod while the piston dome is standing on the rim and the piston skirt is held with the other hand.

12. Apply a small amount of International Compound #2®, or equivalent, to the bolt threads and bolt head contact surfaces and both ends of the spacers.

NOTICE:
The connecting rod-to-piston pin attaching bolts and spacers are specially designed components. No other bolts or spacers may be used. Piston pin bolts are considered one-time use items and must be replaced with new bolts when removed for any reason. Failure to observe this precaution may result in bolt loosening or breakage during engine operation, which may cause serious engine damage.

13. Install the spacers on the two special connecting rod-to-piston attaching bolts.
14. After clamping the connecting rod in holding fixture, J 36211, torque each piston pin bolt to 95-122 N·m (70-90 lb·ft). See Figure 1-259.
15. Complete the process by tightening the bolts to 150.2–163.8 N·m (110–120 lb·ft) final torque.

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Assemble the steel piston and connecting rod assembly as follows:

1. Position the piston dome on it's rim. See Figure 1-261.

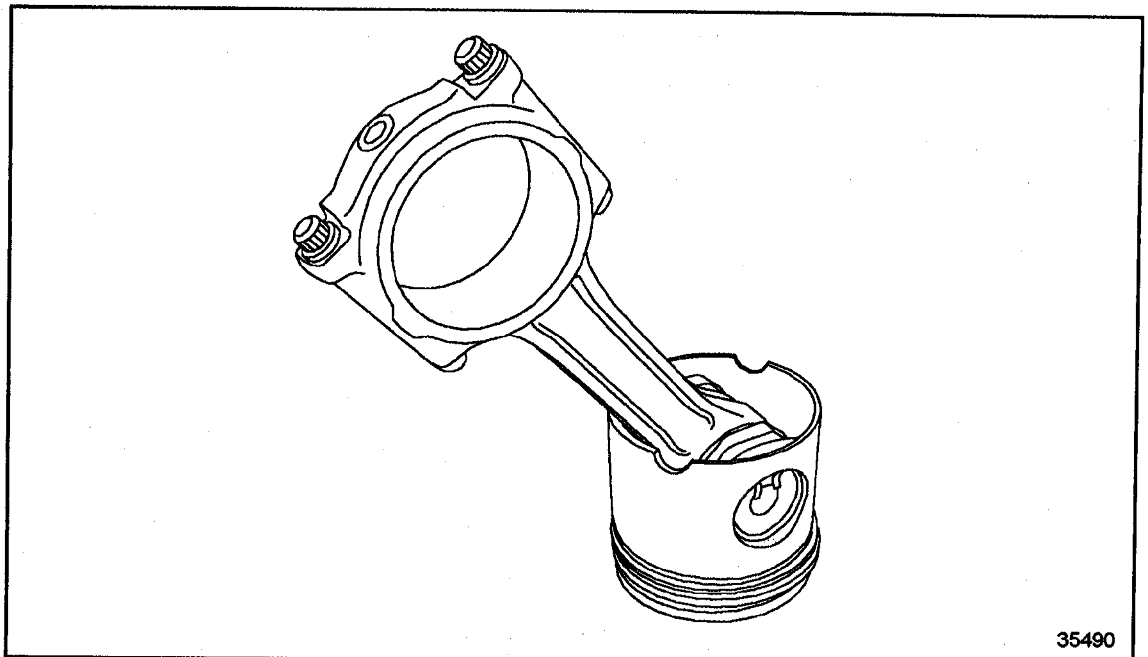

Figure 1-261 Positioning of Piston Dome

2. Set the piston skirt on the piston dome.
3. Place the piston skirt on the piston dome with the notches facing away from the dome.
4. Align the piston pin bores of the dome and skirt.
5. Lubricate the piston pin bearings in the dome and connecting rod with clean engine oil.
6. Using the required snap ring pliers, install one of the circlip-type snap rings into the recess in the piston skirt. Orient the snap ring gap to either the 12 o'clock or 6 o'clock position.
7. Lubricate the pin with clean engine oil.
8. Position the end of the connecting rod inside the piston dome.
9. Install piston pin into the pin bores through rod until it rests against the previously installed snap ring.
10. Using the required snap ring pliers, install the other circlip-type snap ring into the recess in the piston skirt to lock the pin in place. Orient the snap ring gap to either the 12 o'clock or 6 o'clock position.

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1.18.5 Installation of Piston and Connecting Rod Assembly

To install the piston and connecting rod assembly to the engine (except 14L), perform the following:

1. If the rings have been removed, install them onto the dome, refer to section 1.17.4. If the piston rings are installed, proceed to step 2.
2. Add clean engine oil to a clean pan at least 305 mm (12 in.) in diameter, until the level reaches approximately 76 mm (3 in.).
3. Place the piston and connecting rod assembly into pan, with the dome of the piston on the bottom of the pan. See Figure 1-262.
4. Coat the piston liberally with the engine oil, saturating the piston rings and lands.

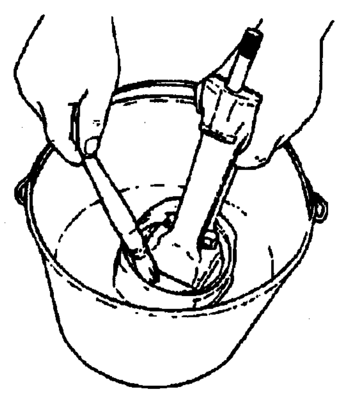

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Figure 1-262 Piston and Connecting Rod Assembly Lubrication

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5. Remove assembly from pan and position (stagger) the piston ring gaps properly on the piston at 90 degree intervals. See Figure 1-263 for diesel engines and see Figure 1-264 for natural gas engines.

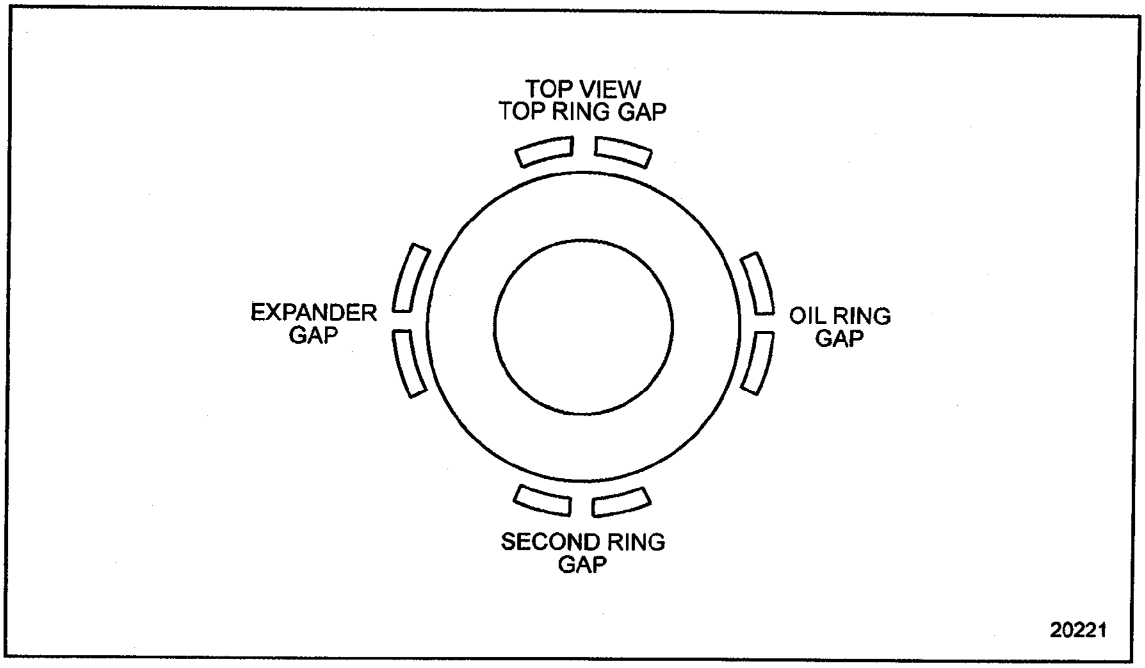

Figure 1-263 Piston Ring Positioning (Diesel)

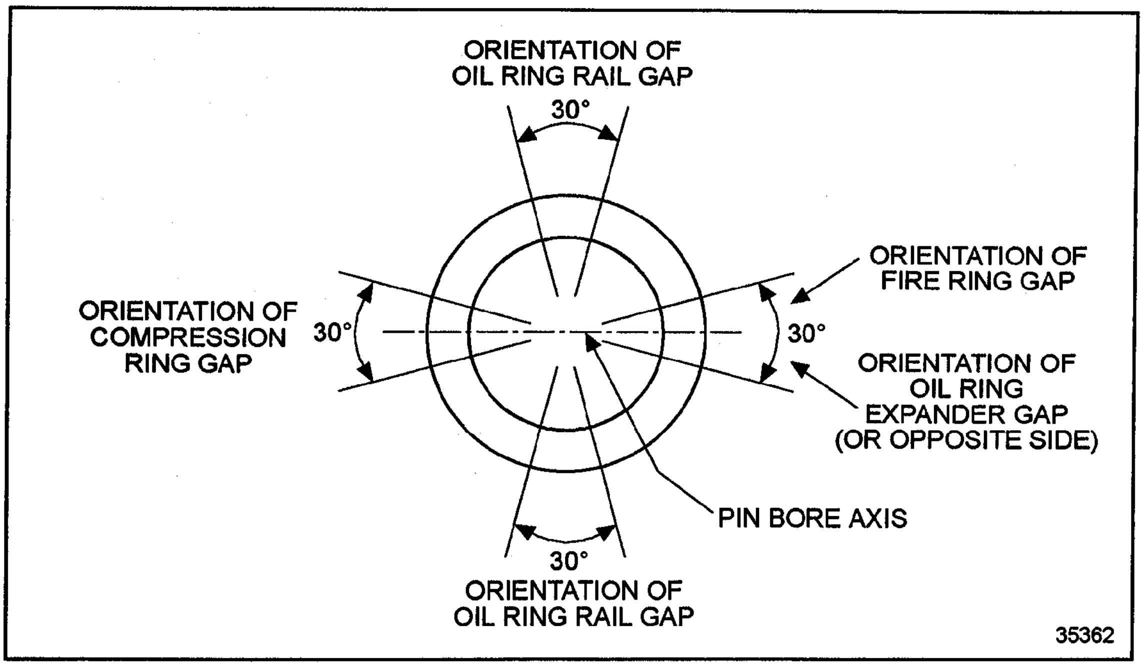

Figure 1-264 Piston Ring Positioning (Natural Gas)

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6. Place the piston, dome down, in the bottom of the pan. Center the dome of the piston within the pan.
7. Coat the inside diameter of the ring compression tool, J 35598–A, liberally with clean engine oil from the pan.

NOTICE:
Inspect the piston ring compressor for nicks or burrs, especially at the non-tapered inside diameter end. Nicks or burrs on the inside diameter of the ring compressor may result in damage to the piston rings.

8. Install the tapered end of the piston ring compression tool over the end of the connecting rod, and down onto the piston. As the compression tool slides down the piston to the piston ring area, apply slow, even pressure on both sides of the compression tool to compress the rings. See Figure 1-265.

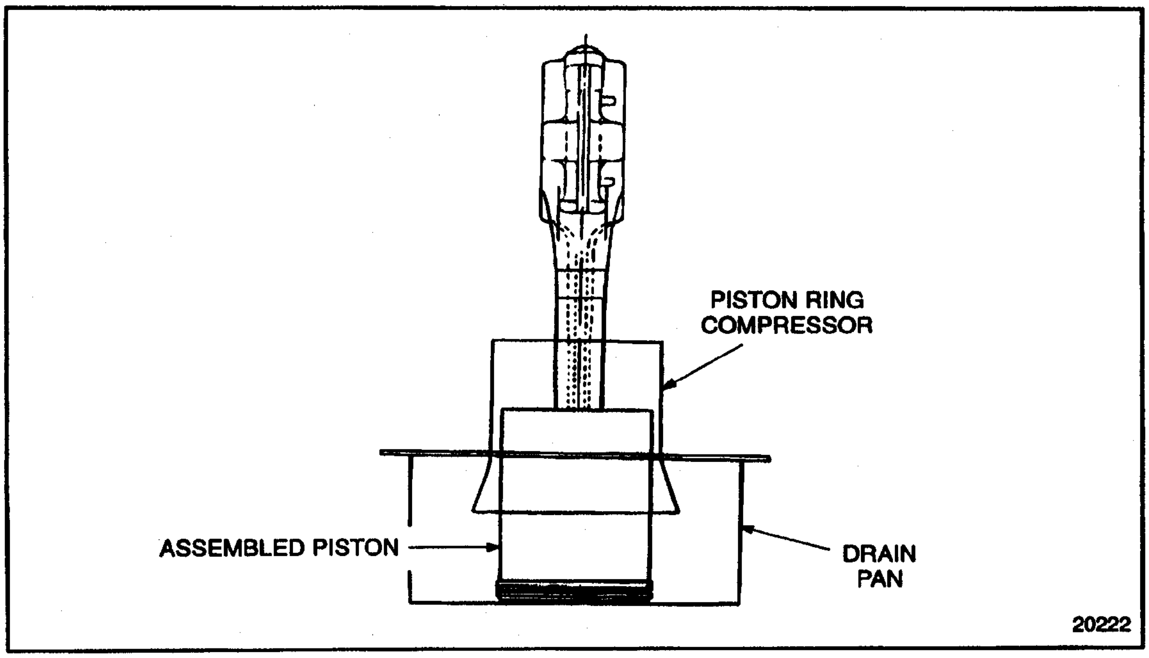

Figure 1-265 Installing Piston and Connecting Rod Assembly into Ring Compressor

9. Slide the compression tool down until it contacts the bottom of the drain pan.
10. Position the crankshaft so that the connecting rod journal for the cylinder being worked on is at bottom-dead-center.
11. Remove the cap from the connecting rod.

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NOTICE:

Do not allow the connecting rod to contact the cylinder liner on installation, or damage to the liner may occur. The numbers on the side of the connecting rod and cap identify the rod with the cap and indicate the particular cylinder in which they are used. If a new service connecting rod is to be installed, the same identification numbers must be stamped in the same location (on the tang side of the rod and cap) as on the connecting rod that was replaced.

12. Install connecting rod guide, (J 35945 for cast iron piston or J 43661 for forged steel piston) over the ends of the connecting rod bolts to prevent damaging the crankshaft journals or the joint face of the rod. The guides also prevent the connecting rod from contacting the liner and damaging the surface. See Figure 1-266.

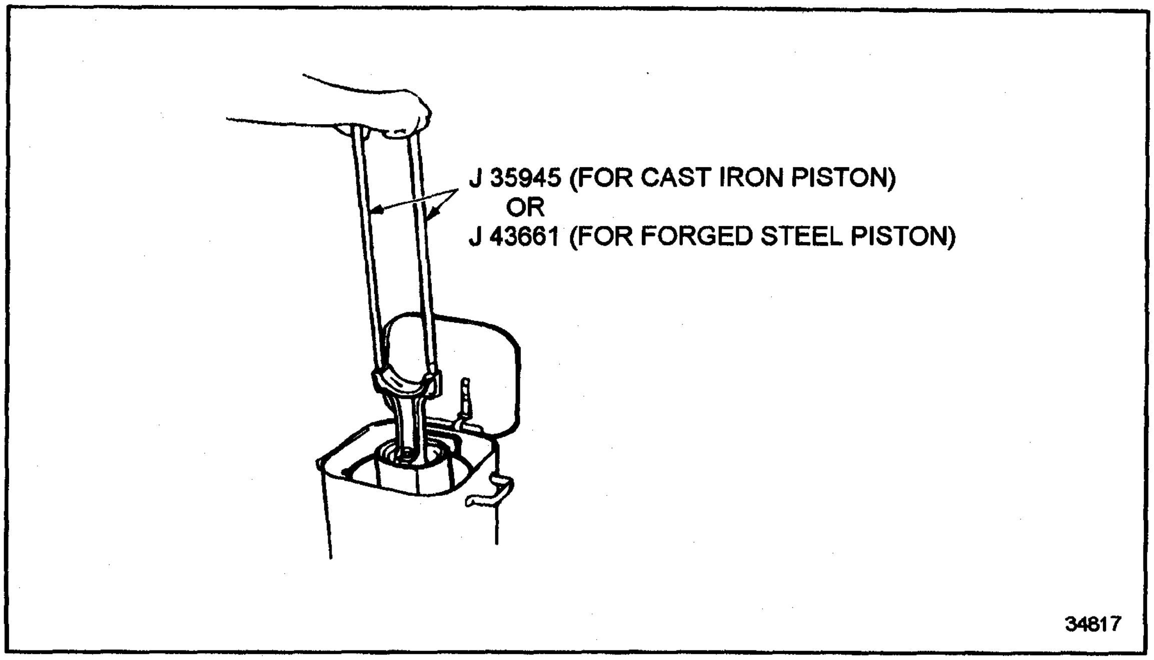

Figure 1-266 Connecting Rod Guides Installation

NOTE:

The connecting rod guides are threaded at the upper end and attach to the rod bolts.

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NOTICE:
Do not lift the assembly using the connecting rod guides. The assembly could dislodge from the connecting rod guides and could cause engine damage.

13. Grasp the connecting rod assembly with one hand, and the piston ring compressor with the other. Lift the assembly out of the pan, and allow excess oil to drain back into the pan.

NOTE:
Do not allow the piston to slide out of the bottom of the ring compressor.

14. With the crankshaft throw in the bottom position, ensure the number on the connecting rod is towards the cooler side of the engine, place the ring compressor and the piston and connecting rod assembly over the cylinder where it is to be installed. See Figure 1-267.

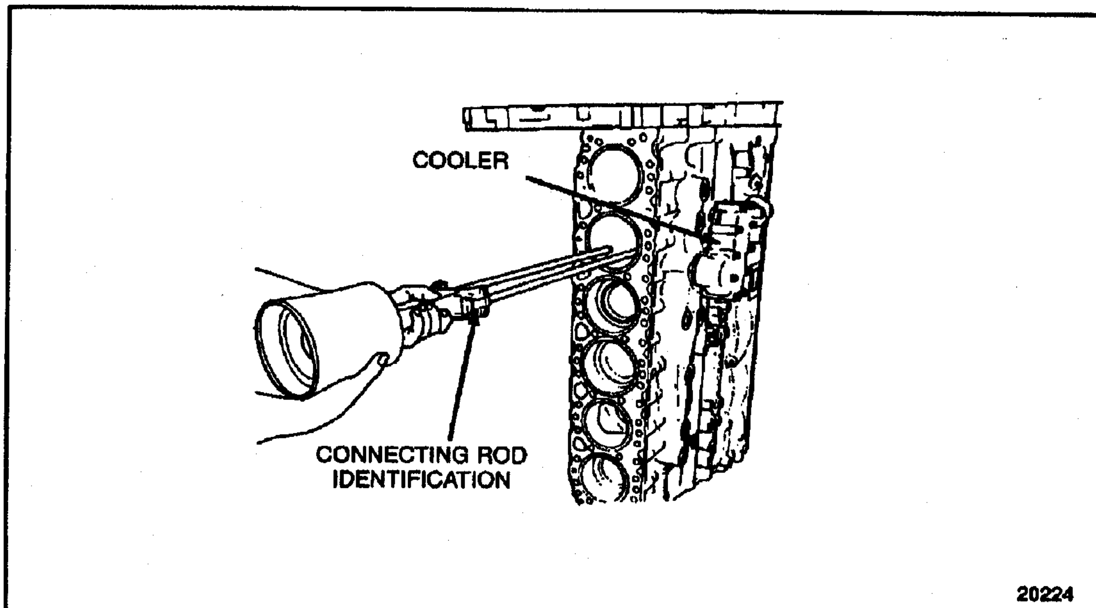

Figure 1-267 Connecting Rod Indexing

NOTE:
There are orientation lugs cast into one side of the upper and lower sections of the connecting rod. These orientation lugs face the front of the engine. See Figure 1-268.

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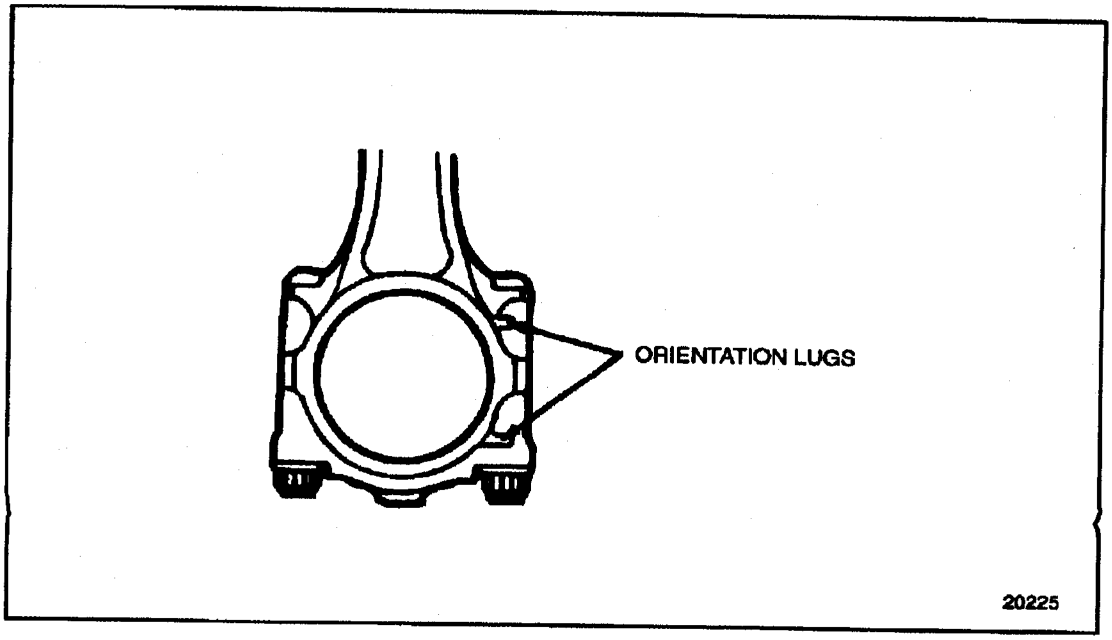

Figure 1-268 Orientation Lugs

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NOTICE:
When installing a forged steel piston into the engine, care must be taken to avoid damaging the piston cooling nozzle installed at the base of the cylinder bore. Before loading the piston into the liner, turn the connecting rod so that the bearing end is offset approximately 10–15 degrees and not perpendicular to the crankshaft, as is the case with cast iron pistons. This will ensure that the rod end does not strike the nozzle when the piston is pushed in. Once the rod end is past the nozzle, turn the rod so that the bearing end is perpendicular to the crankshaft journal.

NOTICE:
Failure to orient the piston connecting rod properly during forged steel piston installation may result in the bearing end of the rod striking the nozzle, causing damage to the nozzle or loosening it from the block. A damaged, bent, or loosened nozzle may cause a loss of main gallery oil pressure. A loosened nozzle may cause a loss of main gallery oil pressure. In these cases, piston overheating or lack of adequate lubrication may result in severe engine damage.

15. Position the ring compressor, with piston and connecting rod inside, into the proper cylinder until the ring compressor is resting squarely on the cylinder liner. See Figure 1-269.

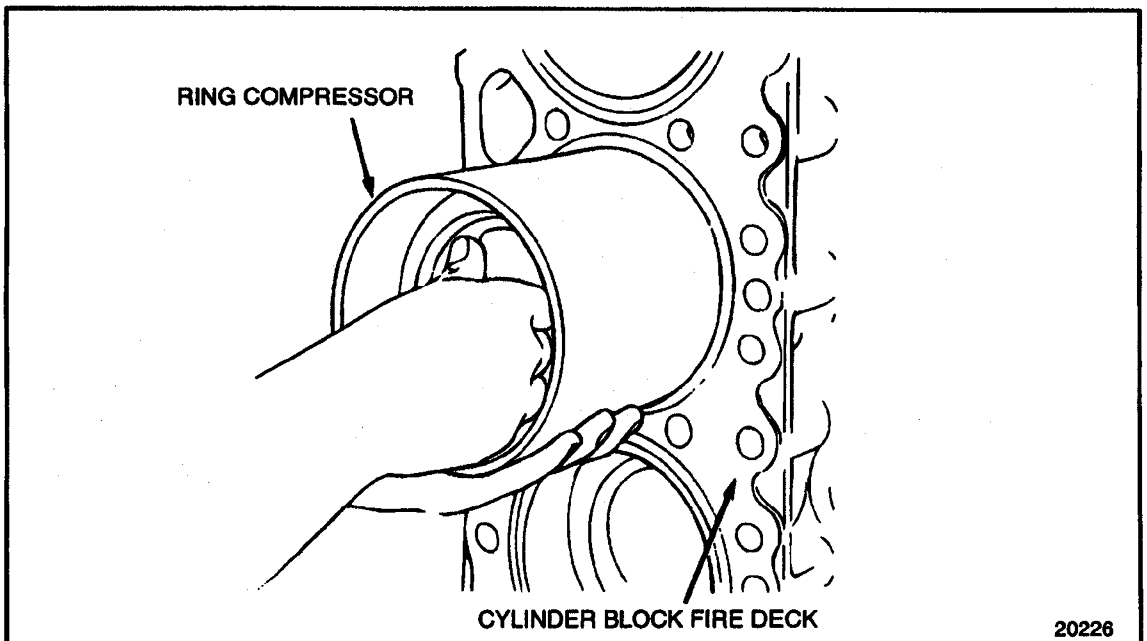

Figure 1-269 Use of Ring Compressor

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NOTICE:
Do NOT force the piston into the liner. The oil ring expander applies considerable force on the oil ring. Therefore, care must be taken during the loading operation to prevent ring breakage.

16. Push the piston and connecting rod assembly down into the liner until the piston is free of the ring compressor.
17. Remove the piston ring compressor.
18. Push or tap the piston and connecting rod assembly into the liner, turning the rod, if necessary, until the upper bearing shell is firmly seated on the appropriate crankshaft journal.
19. Remove the connecting rod guide from the ends of the connecting rod bolts.

NOTE:
Be sure the connecting rod bolts have not been unseated or turned and the bearing locating tang is in its proper location.

20. Place the lower bearing shell in the connecting rod cap, indexing the tang on the bearing with the notch in the cap.
21. Lubricate the bearing shell with clean engine oil.
22. Install the bearing cap. The number on the cap and rod should be on the same (oil cooler) side. See Figure 1-270.

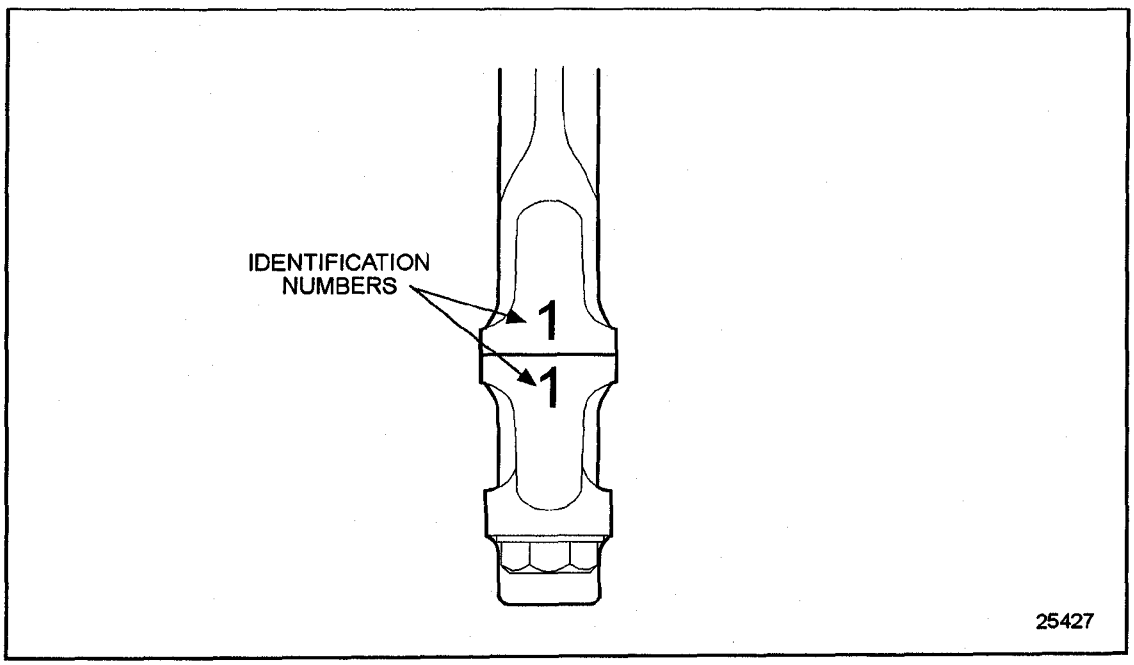

Figure 1-270 Connecting Rod and Cap Identification

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23. Torque the connecting rod bolts alternately to 160-185 N·m (118-137 lb·ft).
24. Check connecting rod side clearance by moving the rod from crank cheek to crank cheek. If there is no clearance, check for proper bearing cap installation.
25. Install the remaining piston and rod assemblies in the same manner.
26. Install a new head gasket. Refer to section 1.2.5.
27. Install the cylinder head. Refer to section 1.2.5.
28. If previously removed, install the piston cooling nozzles at the base of the cylinder bores.
29. Install the lubricating oil pump inlet pipe and screen assembly, and the lubricating oil pump. Refer to section 3.2.6.
30. Install the oil pan. Refer to section 3.11.4.
31. Complete any other engine assembly as necessary.
32. After the engine has been completely assembled, refill the crankcase to the proper level on the dipstick. Refer to section 13.13.1.
33. Close the drain cocks and fill the engine with the recommended coolant. Refer to section 13.13.4, for refilling procedure and refer to section 5.4.

NOTE:
Coolant system maintenance is very important. Bleed off all the air from the system and top off.

34. Perform the following steps for verifying repairs made to the piston and connecting rod assembly:
    [a] If new parts such as pistons, rings, cylinder liners or bearings were installed, operate the engine on the run-in schedule. Refer to section 11.8.3.2.
    [b] If used parts such as pistons, rings, cylinder liners or bearings were installed, refer to section 11.3 for verification of proper piston and connecting rod assembly installation.

Install the 14L liner, piston and connecting rod assembly to the engine as follows:

1. If the rings have been removed, install them onto the dome, refer to section 1.17.4. If the piston rings are installed, proceed to step 2.
2. Add clean engine oil to a clean pan at least 305 mm (12 in.) in diameter, until the level reaches approximately 76 mm (3 in.).
3. Place the piston and connecting rod assembly into pan, with the dome of the piston on the bottom of the pan. See Figure 1-271.

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4. Coat the piston liberally with the engine oil, saturating the piston rings and lands.

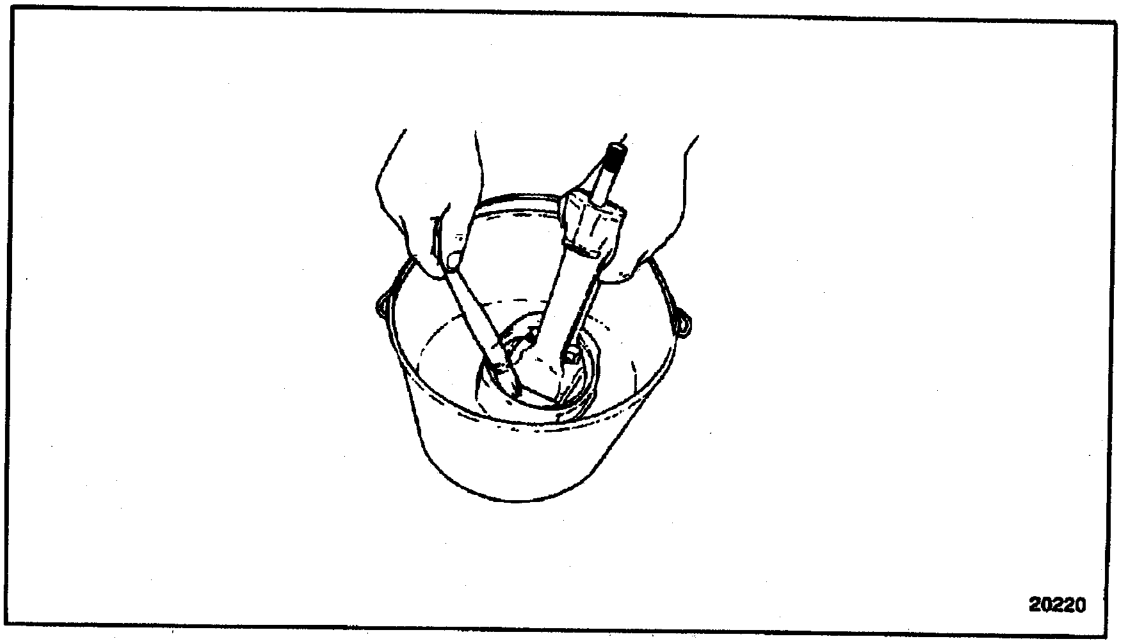

Figure 1-271 Piston and Connecting Rod Assembly Lubrication

5. Remove assembly from pan and position (stagger) the piston ring gaps properly on the piston at 90 degree intervals. See Figure 1-272 for diesel engines.

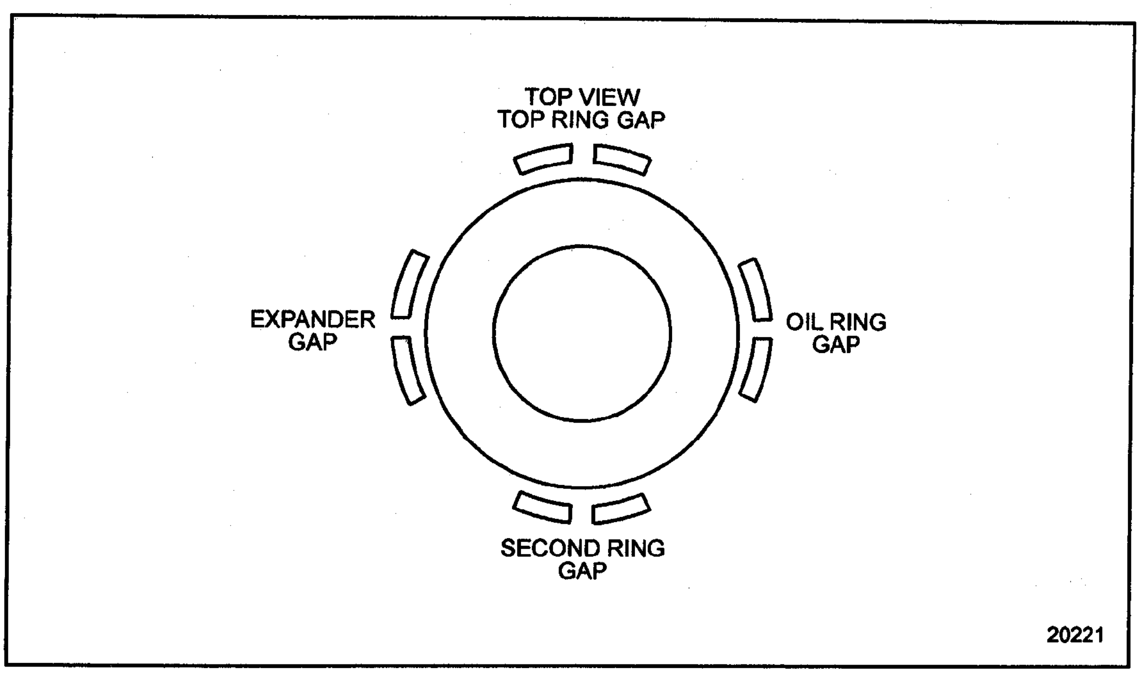

Figure 1-272 Piston Ring Positioning (Diesel)

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6. Place the piston, dome down, in the bottom of the pan. Center the dome of the piston within the pan.
7. Coat the inside diameter of the ring compression tool, J 43397 liberally with clean engine oil from the pan.
8. Clamp the ring compressor, with groove of the compressor facing the connecting rod, around the dome and rings.
9. Once the compressor is "clamped," ensure the piston can rotate freely. If rotation is hindered, remove the compressor and reposition the dome and rings, or inspect for ring damage.
10. Lubricate and install cylinder liner seals.
11. Lubricate the inside of the cylinder liner.
12. Position the liner so it rests on its flange.
13. Position the ring compressor clamped around the dome and rod assembly so the groove rests on the bottom of the cylinder liner. See Figure 1-273.

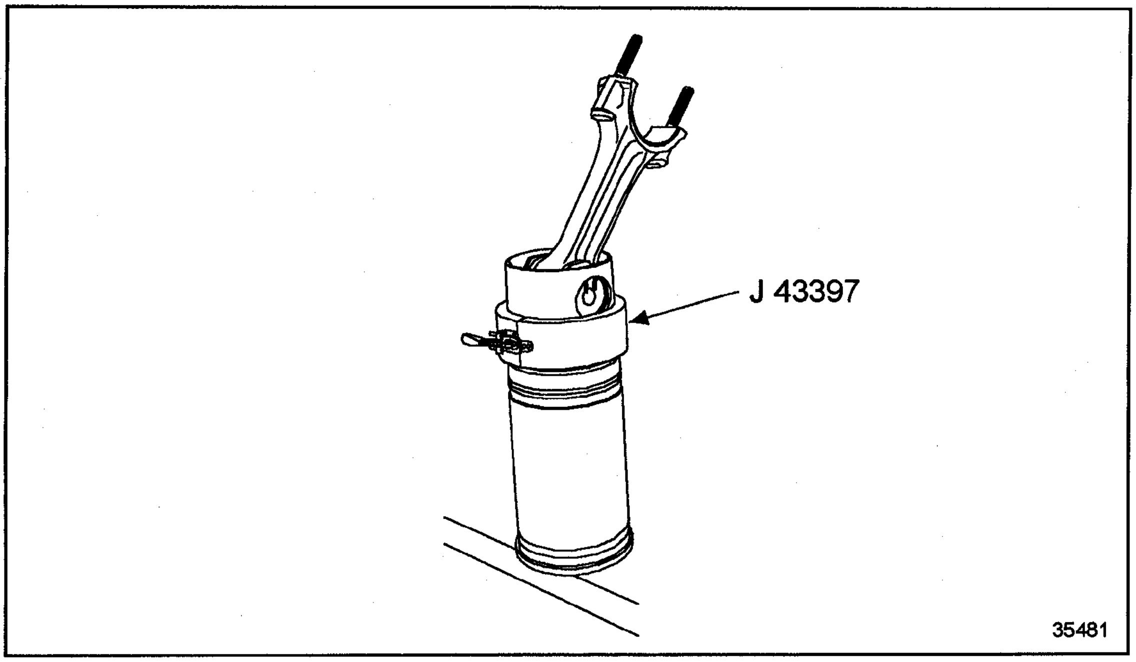
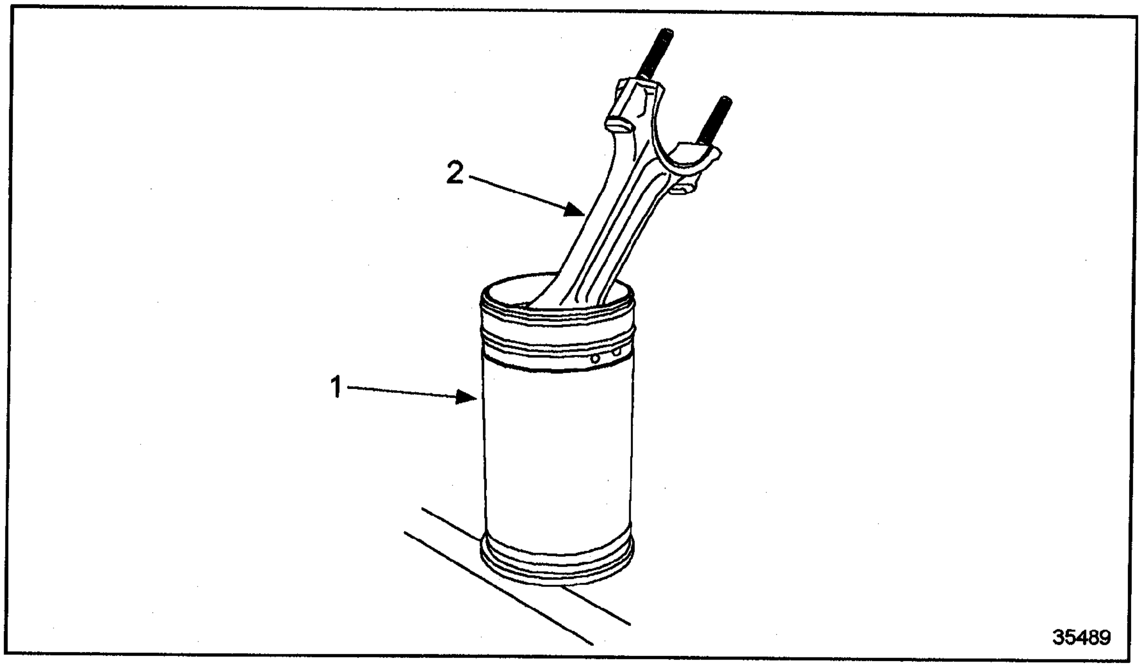


Figure 1-273 Installation of Ring Compressor

NOTICE:

Do NOT force the dome into the liner. Considerable force on the dome could scratch or otherwise damage the inside of the cylinder liner. Therefore, care must be taken during the installation of the dome to prevent damage.

14. With care and moderate pressure, press the dome into the liner until the dome is approximately half way into the liner. See Figure 1-274.



1. Cylinder
2. Piston Rod

Figure 1-274 Installation of Piston and Rod Assembly

15. Remove the ring compressor.
16. Remove the cap from the connecting rod.
17. Install rod bolt protectors, J 43661.
18. Position the throw of the crankshaft journal to bottom dead center for the cylinder being installed with the liner, piston and connecting rod assembly.

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19. Slide the cylinder kit assembly into the cylinder block noting the position of the connecting rod to ensure the rod is assembled to the same position as it was when removed. Push by hand until resistance is felt. See Figure 1-275.

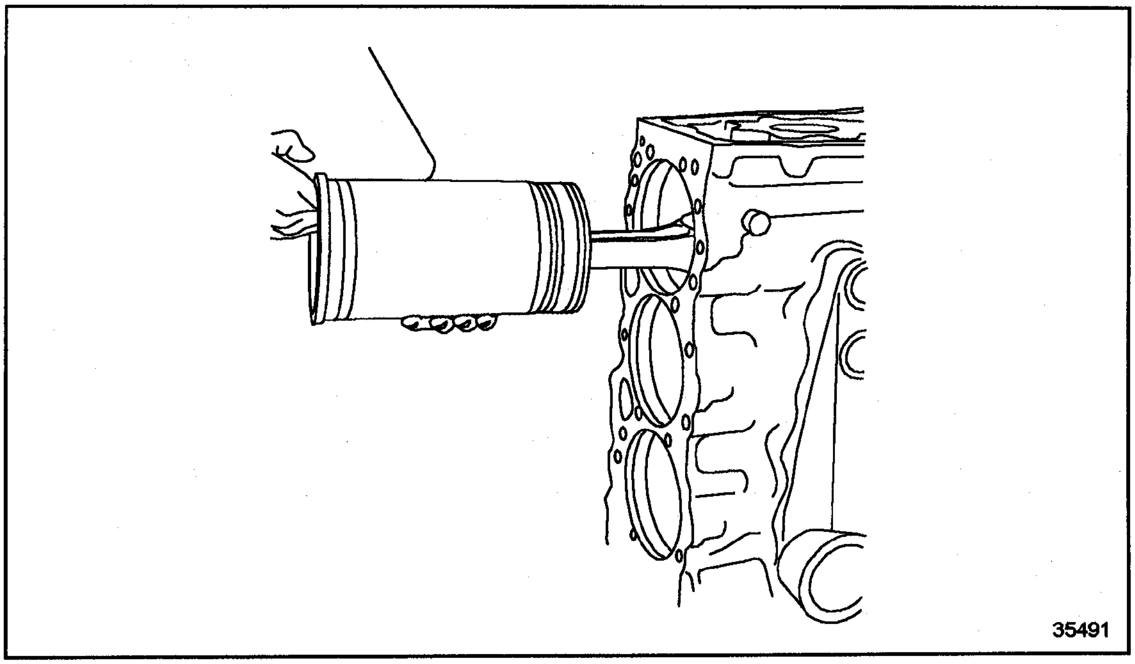

Figure 1-275 Installation of Liner, Piston and Rod Assembly into Engine Block

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20. Install J 35597, over the kit to be installed. See Figure 1-276.

NOTE:
It is necessary to leave the cylinder kit installation tool in place until after the liner protrusion is measured.

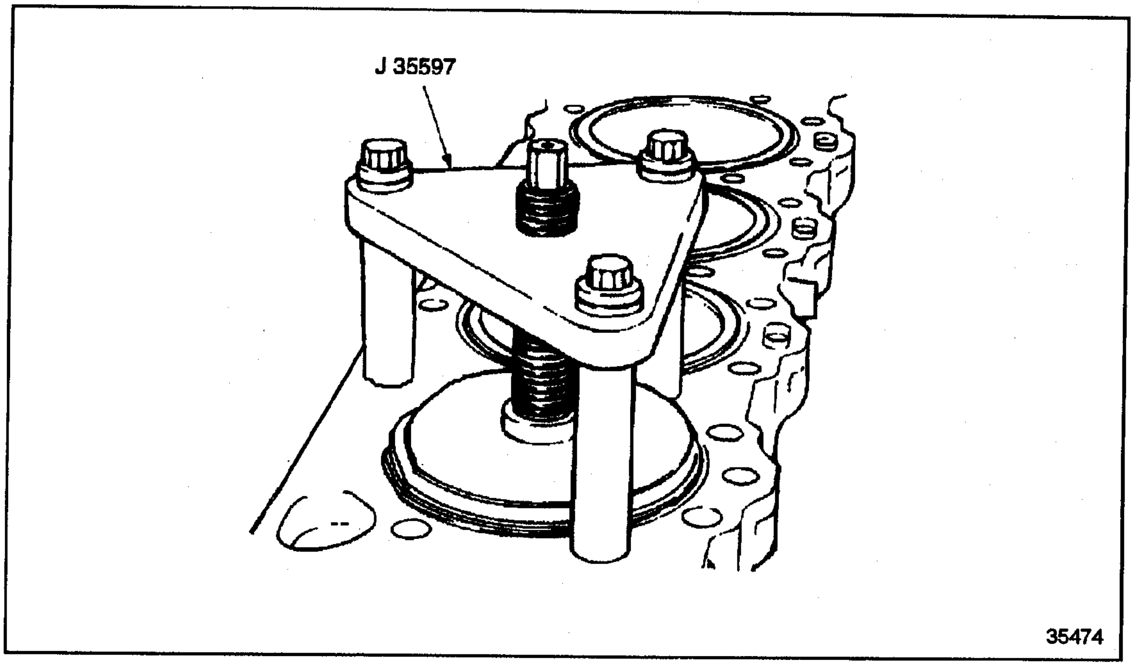

Figure 1-276 Cylinder Liner Installation Tools

21. Thread three cylinder head bolts through the tool and into a head bolt hole, so that the round shoe of the tool is centered over the liner.
22. Tighten the three bolts.

NOTE:
It is not necessary to torque the bolts.

23. Turn the threaded center bolt in a clockwise direction. As the round shoe of the tool reaches the liner, ensure that the shoe is properly positioned into the cylinder liner.

NOTE:
Use care for proper rod positioning during installation.

24. Continue turning the bolt until the liner bottoms in the cylinder counterbore. Apply a tightening torque of 60 N·m (44 lb·ft) to the installation tool center bolt.
25. Install a dial indicator sled gage. See Figure 1-276.

26. Measure the distance from the top of the liner flange to the top of the block. See Figure 1-277.
    [a] Allowable liner protrusion is 0.000-0.076 mm (0.000 -0.003 in.) with no more than 0.0508 mm (0.002 in.) variation between any two adjacent cylinders. Specifications are listed in Table 1-16.
    [b] If the liner protrusion exceeds the maximum allowable, remove the kit and check for debris under the liner flange.

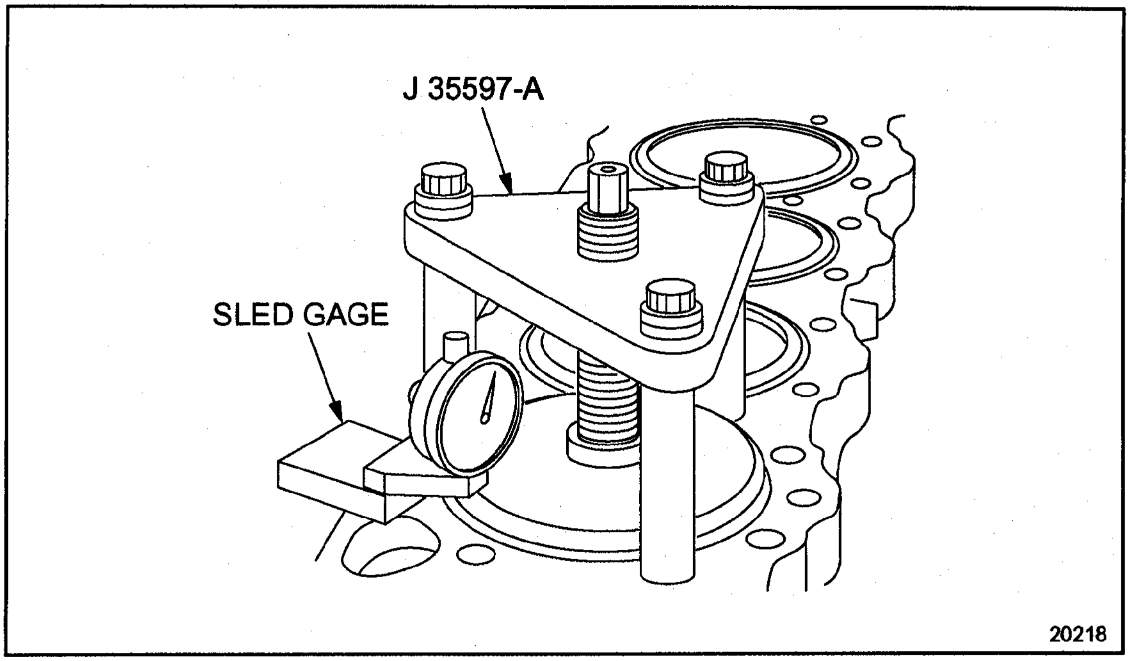

Figure 1-277 Cylinder Liner Protrusion

27. Remove the cylinder liner tool.
28. Push or tap the piston and connecting rod within the liner until the upper rod bearing is firmly seated on the appropriate crankshaft journal.
29. Remove the rod bolt protectors.
30. Lubricate the lower bearing shell with clean engine oil.
31. Install the bearing cap. The number on the cap and rod should be on the same (oil cooler) side.
32. Torque the connecting rod bolts alternately to 160-185 N·m (118-137 lb·ft).
33. Check connecting rod side clearance by moving the rod from crank cheek to crank cheek. If there is no clearance, check for proper bearing cap installation.
34. Install the remaining piston and rod assemblies in the same manner.
35. Install a new head gasket. Refer to section 1.2.5.
36. Install the cylinder head. Refer to section 1.2.5.

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37. If previously removed, install the piston cooling nozzles at the base of the cylinder bores.
38. Install the lubricating oil pump inlet pipe and screen assembly, and the lubricating oil pump. Refer to section 3.2.6.
39. Install the oil pan. Refer to section 3.11.4.
40. Complete any other engine assembly as necessary.
41. After the engine has been completely assembled, refill the crankcase to the proper level on the dipstick. Refer to section 13.13.1.
42. Close the drain cocks and fill the engine with the recommended coolant. Refer to section 13.13.4, for refilling procedure and refer to section 5.4.

NOTE:
Coolant system maintenance is very important. Bleed off all the air from the system and top off.

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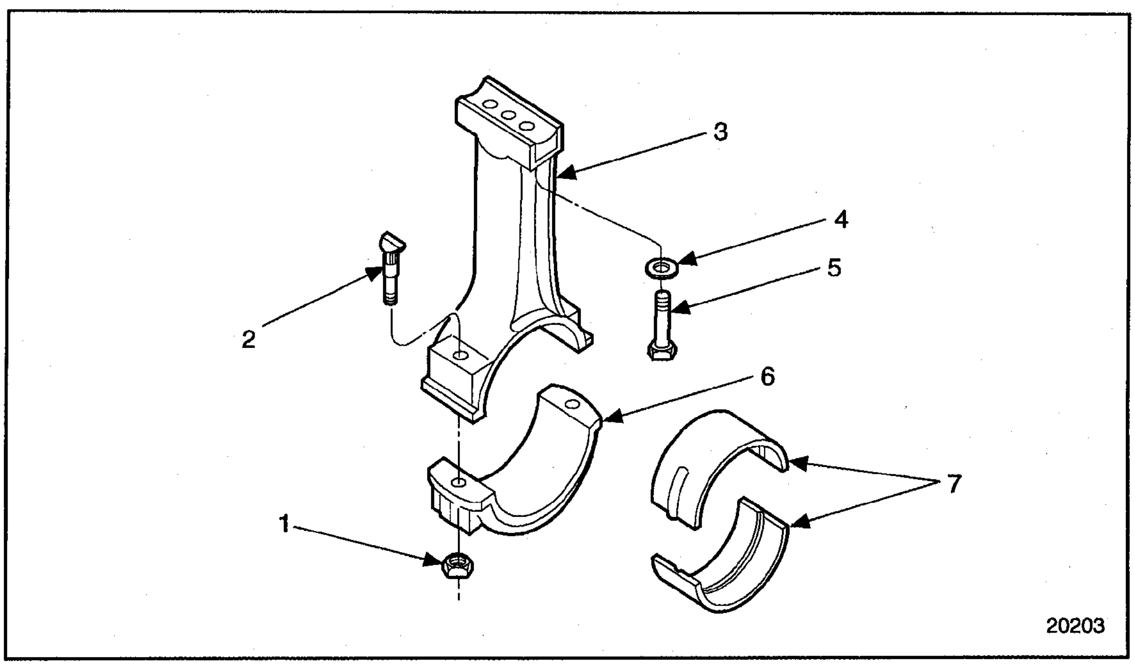
1.19 CONNECTING ROD

Two types of connecting rod are used in Series 60 engines. The open end or saddle type connecting rod is used with cast iron pistons which have bolt-on, style piston pins. The closed end or trunk type connecting rod is used with forged steel pistons which have floating, trunk style piston pins.

NOTICE:
Do not mix forged steel pistons used with closed end connecting rods and cast iron pistons used with open-end connecting rods in the same engine. This will cause severe engine damage.

OPEN-END CONNECTING ROD: The open-end connecting rod is forged to an "I" section with an open or saddle type contour at the upper end and a bearing cap at the lower end. The surface of the connecting rod is shot-peened for added strength. Therefore, no grinding is permitted since it will remove the benefits of shot-peening.

The upper end of the connecting rod is machined to match the contour of the piston pin. The piston pin is secured to the connecting rod with two special bolts and spacers. The lower bearing cap is secured to the connecting rod by two specially machined bolts and nuts. See Figure 1-278.



1. Connecting Rod Nut (2)
2. Notched Bolt (2)
3. Connecting Rod
4. Spacer Washer (2)
5. Piston Pin Bolt (2)
6. Connecting Rod Bearing Cap
7. Bearing Shells

Figure 1-278 Connecting Rod and Bearing Shells (Open-End Rod)

The two special bolts locate the cap relative to the upper end. The assembly is machined as a unit and must not be used in the engine with any other cap or upper end. Orientation of the cap to the upper end is identified by stamped numbers.

NOTE:
The Series 60G engine connecting rod is shorter in length and identified by "Natural Gas" on the side.

The current connecting rods with smaller rod chamfers replaced the former connecting rods, effective with the following engine serial numbers: (listed in Table 1-7.)

Engine Model	Engine Serial Number
6067WK60 (11.1L)	6R184522
6067GK60 (12.7L)	6R188251

Table 1-7 New Connecting Rod Replacements

This change was made to allow installation of new, wider connecting rod bearings that provide improved oil film thickness and reduced bearing pressures.

The rod chamfers on the current connecting rods are smaller than those on the former rods. This has been done to provide proper support for the wider bearings. To conform with this change, new crankshafts with smaller fillet radii have been released. Refer to section 1.7 for information on the new crankshafts.

NOTE:
The current connecting rods, bearings, and crankshafts *must* be used together to ensure interchangeability. Former parts cannot be mixed with new parts in the same engine. The former connecting rods will continue to be available for engines built prior to the unit serial numbers as listed in Table 1-7.

The connecting rod bearing shells are precision made and are of the replaceable type. The upper bearing shell is seated in the connecting rod and a lower bearing shell is seated in the connecting rod cap. These bearings are not identical. The upper and lower bearing shells are located in the connecting rod by a tang at the parting line at one end of each bearing shell. See Figure 1-278.

The tri-metal bearing wear surfaces use a steel backing. First, an optimum composition (copper, tin and lead) lining is bonded to the steel back. A nickel barrier above the lining and the overlay serves to prevent tin migration. A soft lead overlay, 0.025 mm (0.001 in.) thick, provides run-in protection, and an initial wear surface. A flash tin plate, front and back, is for added corrosion protection and resistance during shipping and handling. These bearings are identified by the satin silver sheen of the tin when new, and a dull gray of the overlay after being in service.

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The oil hole through the upper bearing shell supplies oil to the oil passage in the connecting rod, thereby providing a supply of lubricating oil from the crankshaft to the connecting rod bearings, piston-pin bushing, and underside of the piston dome. The upper shell is grooved from one edge to the oil hole. The lower shell has a full-length (180 degree) groove. See Figure 1-279.

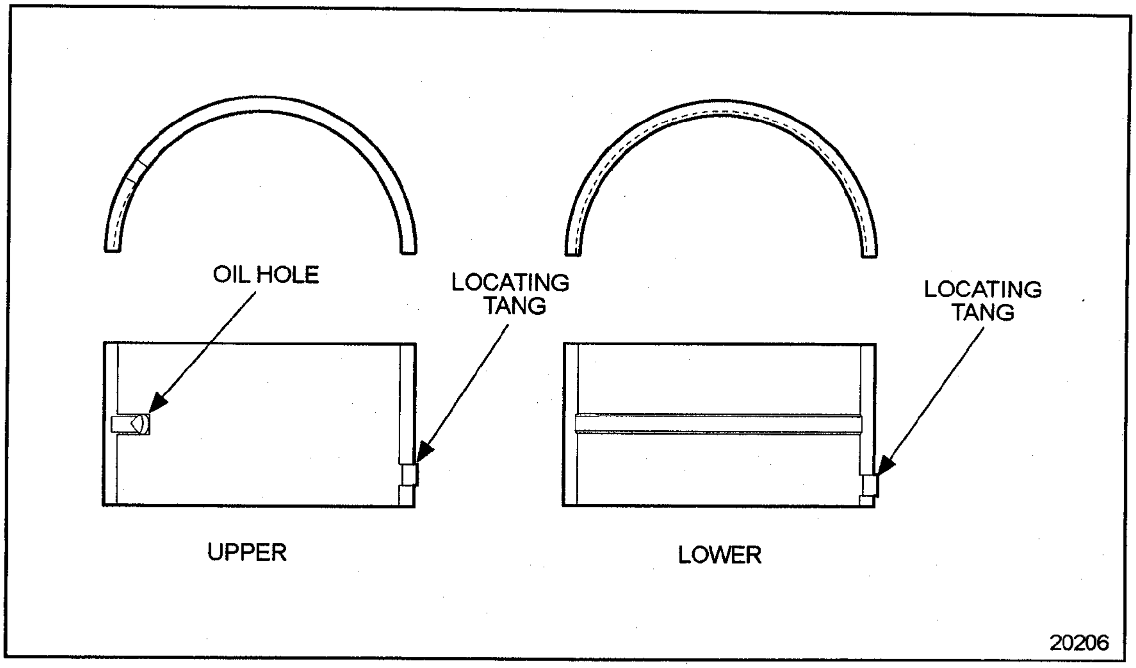

Figure 1-279 Connecting Rod Bearing Detail (Open-End Rod)

The connecting rods bearing caps are numbered according to the cylinder position with matching numbers stamped on the connecting rod tang side.

The current, wider connecting rod bearings replaced the former connecting rod bearings as listed in Table 1-24.

This change was made to improve oil film thickness and reduce bearing pressures. The current bearings are 47.44-47.14 mm (1.868-1.856 in.) wide. The former bearings were 43.44-43.13 mm (1.710-1.698 in.) wide. To provide full support for the wider bearings, new connecting rods with smaller rod chamfers and current crankshafts with smaller fillet radii were also released. Refer to section 1.7 for information on the current crankshafts.

NOTE:
The current connecting rod bearings, connecting rods, and crankshafts *must* be used together to ensure interchangeability. Former parts cannot be mixed with new parts in the same engine. The former bearing shells will be available for engines built prior to the unit serial numbers as listed in Table 1-7.

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CLOSED-END CONNECTING ROD: Each connecting rod is forged to an "I" section with a closed hub at the upper end and a bearing cap at the lower end. See Figure 1-281. Unlike the open-end connecting rod, the closed end rod is not drilled prior to model year 2000. Lubrication for the piston and piston pin is supplied by a spray nozzle bolted to the block at the base of each cylinder bore. (Current blocks are drilled and tapped for installation of the cooling nozzles into the main oil gallery.) These nozzles spray crankcase oil upwards onto the piston and piston pin during engine operation, providing the required lubrication and cooling.

NOTE:
The current connecting rod for 14 L engines and model year 2000 12.7 L engines use a drilled passage way through the rod to lubricate the piston pin bushing. These connecting rods cannot be mixed within an engine with the former non-drilled connecting rod. See Figure 1-280.

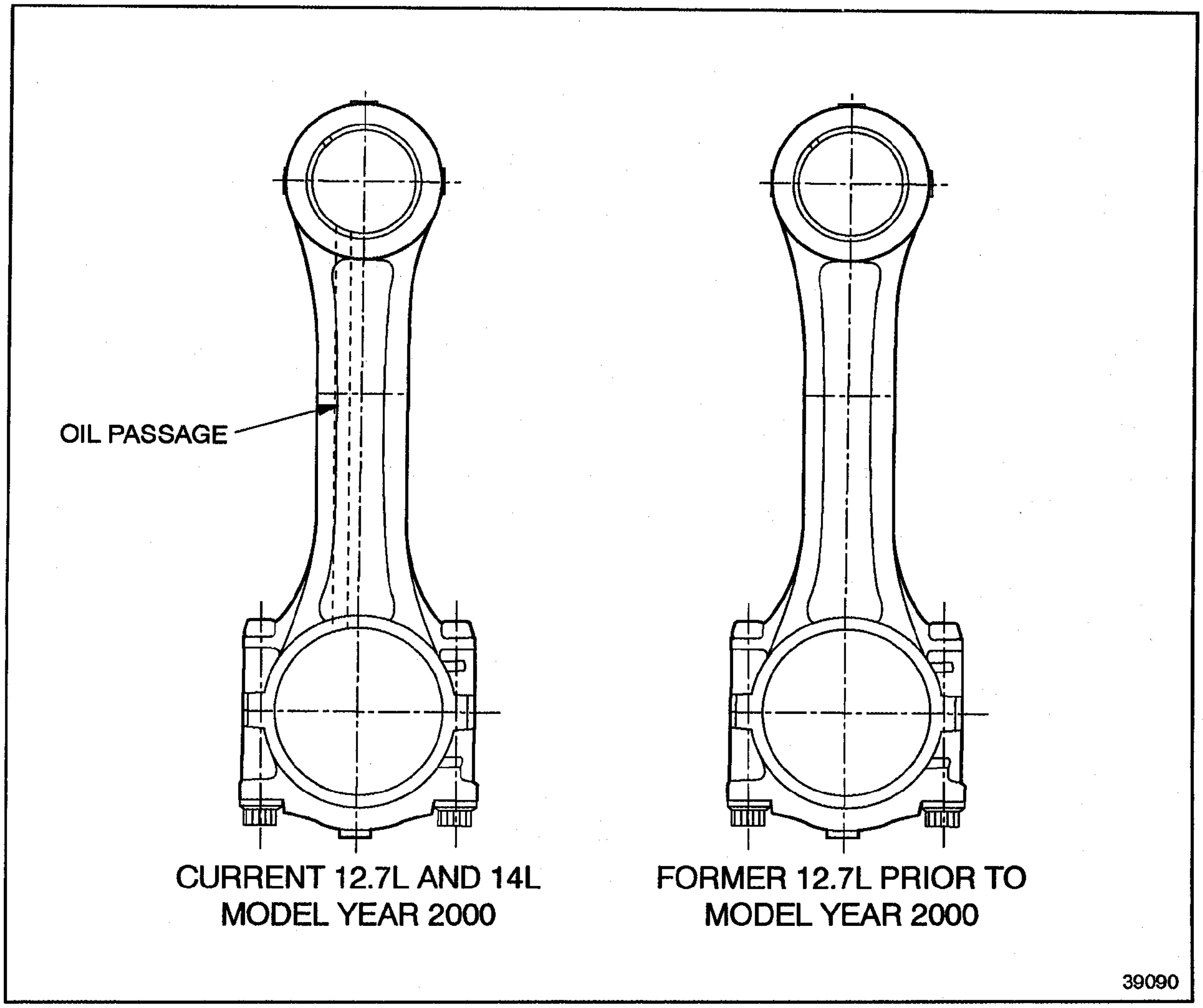

Figure 1-280 Current and Former Closed-End Connecting Rods

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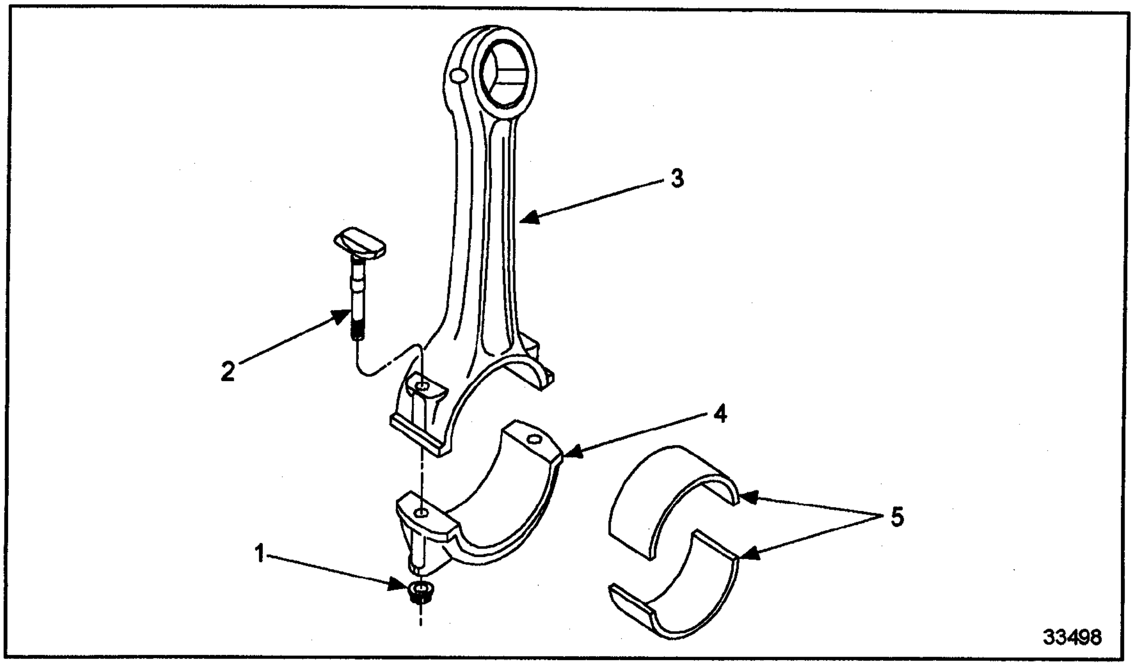

1. Connecting Rod Nut (2)
2. Notched Bolt (2)
3. Connecting Rod
4. Connecting Rod Bearing Cap
5. Bearing Shells

Figure 1-281 Connecting Rod and Bearing Shells (Closed-end Rod)

The upper end of the rod has a pressed-in, machined bushing with two scallops, 180 degrees apart. Spray oil entering these scallops lubricates the piston pin and bushing during engine operation. The piston pin floats in the bushings of both the piston and the connecting rod.

The lower bearing cap is secured to the connecting rod by two specially machined bolts and nuts. See Figure 1-281.

The two special bolts locate the cap relative to the upper end. The assembly is machined as a unit and must not be used in the engine with any other cap or upper end. Orientation of the cap to the upper end is identified by stamped numbers.

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Closed-end connecting rods prior to model year 2000 have no center-drilled lubricating oil passage. Therefore, upper and lower connecting rod bearings used with these rods are grooveless. See Figure 1-282, see Figure 1-283and see Figure 1-284.

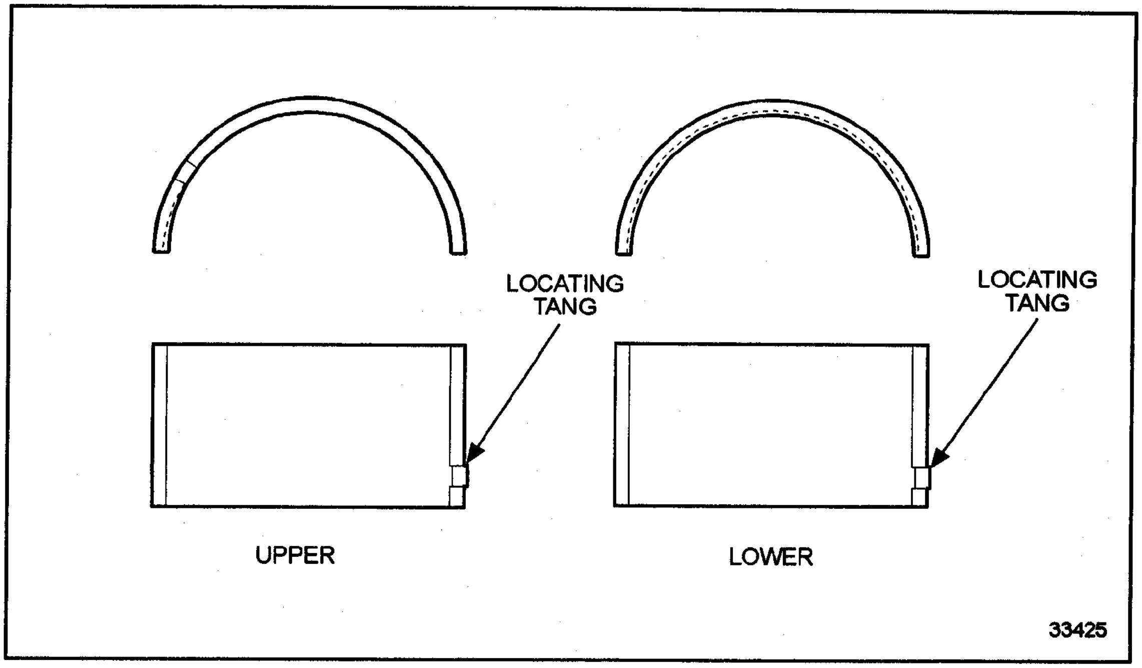

Figure 1-282 Connecting Rod Bearing Detail (Closed End Rod)

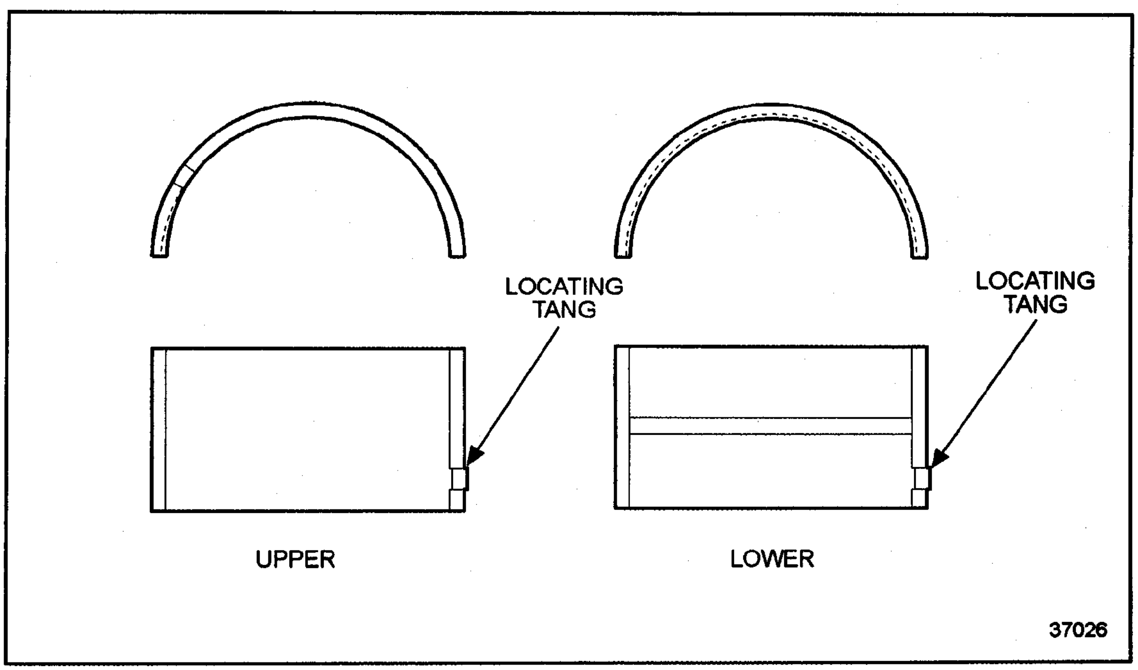

Figure 1-283 Connecting Rod Bearing Detail for Pleasure Craft Marine (Closed End Rod)

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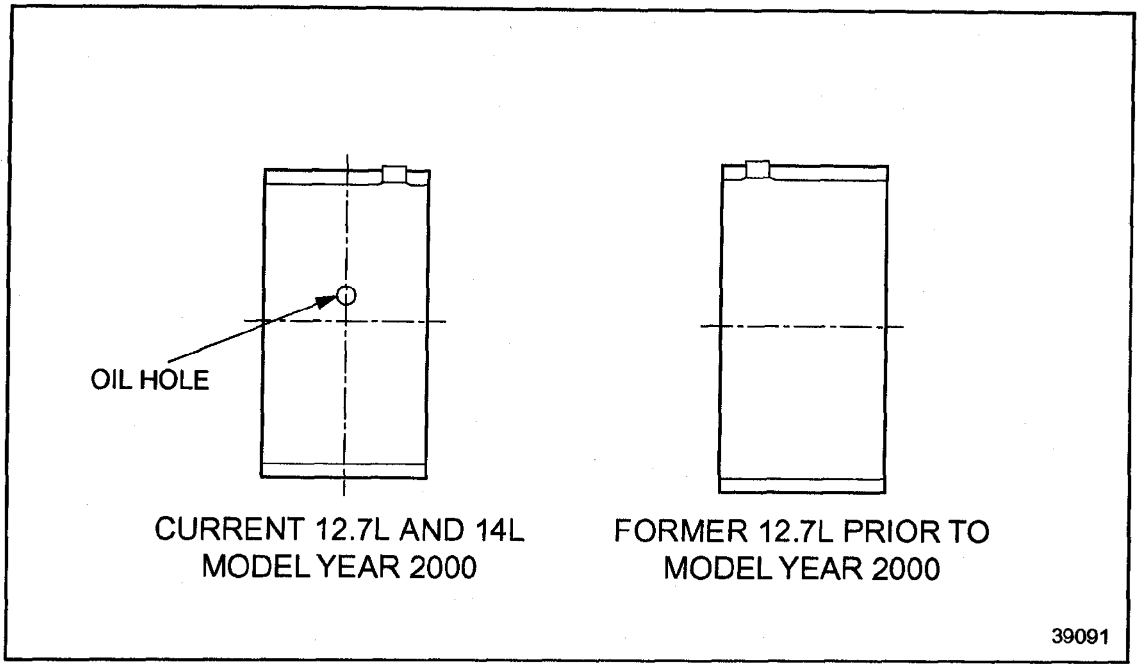

Figure 1-284 Connecting Rod Bearings for 14 L and 12.7 L Engines

The connecting rod bearing caps are numbered according to the cylinder position with matching numbers stamped on the connecting rod tang side.

The connecting rod bearing shells are precision made and are of the replaceable type. The upper bearing shell is seated in the connecting rod and a lower bearing shell is seated in the connecting rod cap. These bearings are identical. The upper and lower bearing shells are located in the connecting rod by a tang at the parting line at one end of each bearing shell.

The tri-metal bearing wear surfaces use a steel backing. First, an optimum composition (copper, tin and lead) lining is boded to the steel back. A nickel barrier above the lining and the overlay serves to prevent tin migration. A soft lead overlay, 0.025 mm (0.001 in) thick, provides run-in protection, and an initial wear surface. A flash tin plate, front and back, is for added corrosion protection and resistance during shipping and handling. These bearings are identified by the satin silver sheen of the tin when new and a dull gray of the overlay after being in service.

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1.19.1 Repair or Replacement of Connecting Rod

To determine if repair is possible or replacement is necessary, perform the following procedure. See Figure 1-285.

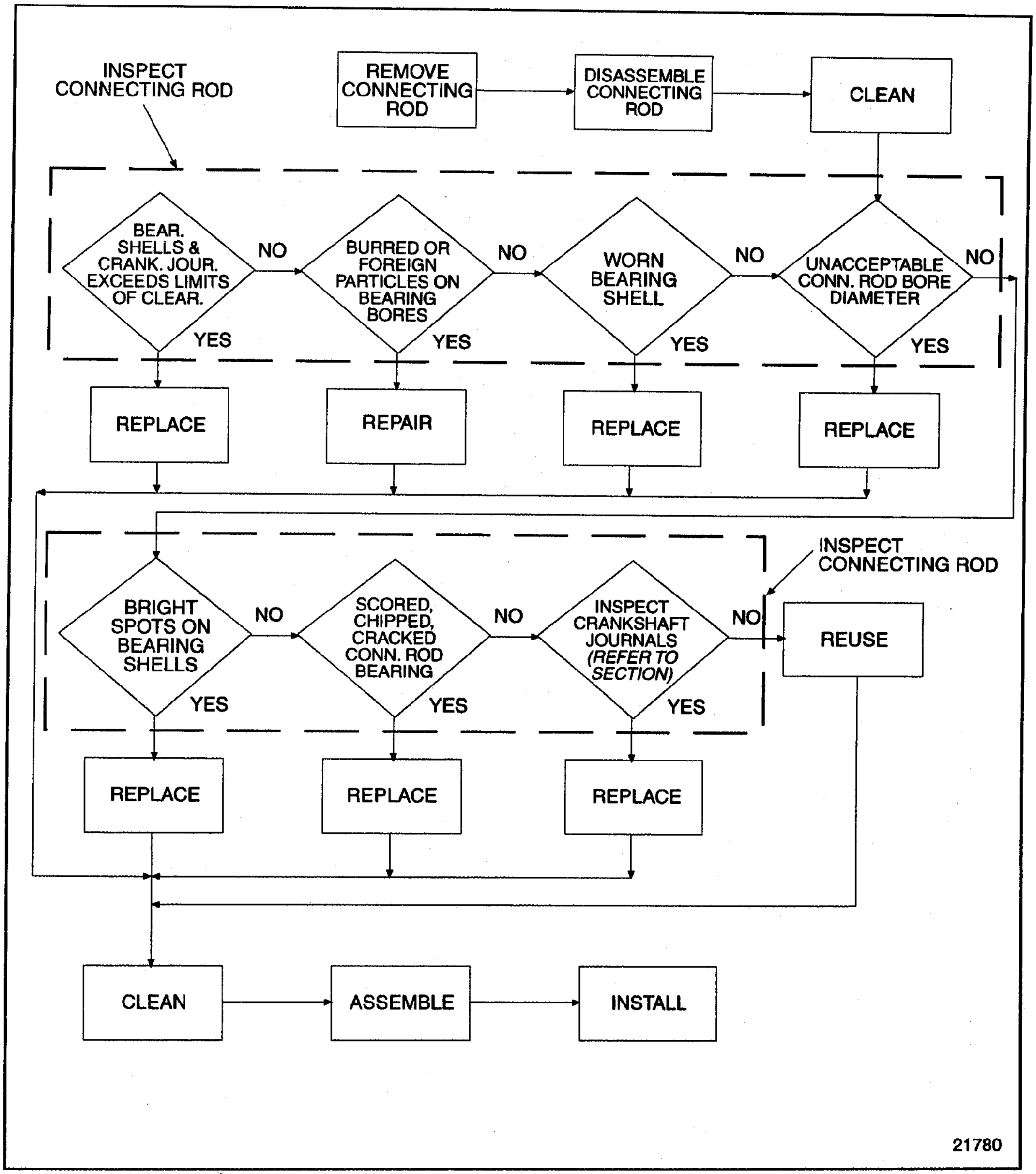

Figure 1-285 Flowchart for Repair or Replacement of Connecting Rod

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1.19.2 Removal and Cleaning of the Connecting Rod

Before removal, make sure the connecting rods and caps are stamped with their correct cylinder location. If not marked, stamp location (1-6) on the tang side (cooler side) of the rod and cap.

Refer to section 1.18.2 for piston and connecting rod assembly removal procedure.

1.19.3 Disassembly of Connecting Rod

Disassemble the connecting rod as follows:

NOTE:
It is best to disassemble, inspect and assemble each connecting rod separately. It is very important to keep the connecting rod cap, and the upper and lower bearing shells to the original connecting rod.

1. Loosen and remove the two notched bolts. See Figure 1-278.
2. Remove connecting rod cap and bearings shells. See Figure 1-278.

1.19.3.1 Inspection of Connecting Rod

Clean the bearings prior to inspection as follows:

1. Clean the bearings with fuel oil.

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

2. Dry the bearings with compressed air.

Inspect the open-end connecting rod as follows:

1. Inspect the connecting rod saddle at the piston pin contact surface for traces of fretting and corrosion.
2. To repair, wet with fuel oil and smooth with crocus cloth.

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Inspect the closed-end connecting rod as follows:

NOTICE:
Reusing a connecting rod with a damaged or loose bushing may result in severe cylinder kit damage.

1. Inspect the piston pin bushing for indications of scoring. If scoring is found, replace the rod.
2. Inspect the piston pin bushing for indications of overheating. A bushing that has overheated may become loose. If a loose bushing is found, the rod *must be removed.*

1.19.4 Assembly of Connecting Rod

Assemble connecting rod as follows:

1. Install the connecting rod cap with the numbers on the same (oil cooler) side on the connecting rod.
2. Lubricate the bolt threads with clean engine oil.

NOTICE:
Do not over torque the connecting rod bolt nuts. Over torque may permanently distort the connecting rod cap.

NOTICE:
Be sure the connecting rod bolt has not turned in the connecting rod before torque is applied to the nut.

3. Torque the bolt nuts to 160-185 N·m (118-137 lb·ft).

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1.19.4.1 Inspection of Assembled Connecting Rod

Measure the connecting rod bearing diameter at five locations. See Figure 1-286.

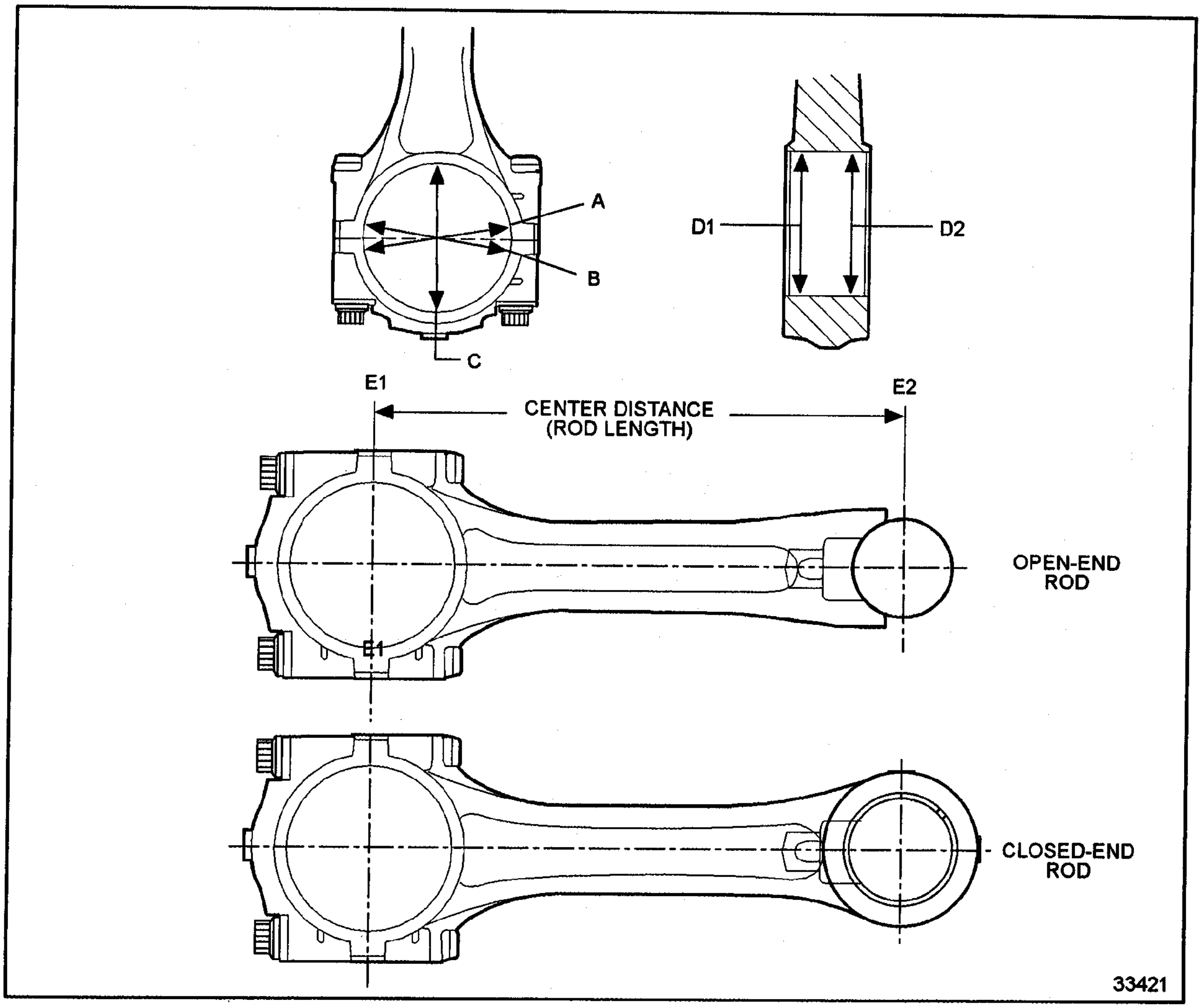

Figure 1-286 Dimensional Inspection of Connecting Rods

1. Calculate size of diameter at split line, W. [W= (A+B) ÷ 2]
2. Calculate the average bore out-of-round, X. [X=W-C] X must be between -0.012 and 0.012 mm (-0.0005 and 0.0005 in.).
3. Calculate the average connecting rod bearing bore size, Y. [Y= (W+X) ÷ 2] Y must be between:
   [a] For 12.7 and 11.1 L; 91.288 and 91.313 mm (3.594 and 3.595 in.).
   [b] For 14L; 101.288 and 101.3133 mm (3.988 and 3.989 in.).
4. Determine taper, Z. [Z=D2-D1] Z must be between -0.012 and 0.012 mm (-0.0005 and 0.0005 in.).

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5. Determine the rod length by finding the distance between E1 and E2. See Figure 1-286.
   [a] The acceptable rod length specification for 11.1 Liter connecting is: 281.95-282.05 mm (11.1004-11.1043 in.).
   [b] The acceptable rod length specification for both 12.7 Liter and 14 Liter connecting rods is: 269.25-269.35 mm (10.6004-10.6043 in.).
   [c] The acceptable rod length specification for Series 60G Engines is: 262.90-263.00 mm (10.3504-10.3543 in.).
   [d] If the connecting rod bore is not to specifications, the rod must be scrapped and cannot be machined.
6. If a new connecting rod is required, stamp the cylinder number on the connecting rod and cap. Refer to section 1.18.3.

1.19.4.2 Inspection of Connecting Rod Bearings and Bearing Bores

Inspect the connecting rod bearing as follows:

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

1. Clean the rust preventive from a service replacement connecting rod.
   [a] On an open-end rod, blow compressed air through the drilled oil passage to be sure it is clean of obstructions. Also make sure the split line (cap to rod) is thoroughly cleaned.
   [b] On a closed-end rod, inspect the piston pin bearing for wear, scoring, or out-of-round condition. Refer to section Specifications.
2. Check connecting rod bearing wear surfaces for scoring, pitting, flaking, chipping, cracking, loss of overlay, or signs of overheating.
   [a] Overlay plated bearings may develop very small cracks or small isolated cavities ("checking") on the bearing surface during engine operation. These are characteristics of and are NOT detrimental to this type of bearing. The bearings should not be replaced for these minor surface imperfections. The upper bearing shells, which carry most of the load, will normally show signs of distress before the lower bearing shells do. If the overlay is worn through to the copper across the bearing shell, all the bearing shells must be replaced.
   [b] If any of these conditions are detected, replace the bearings.

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3. Inspect the backs of the connecting rod bearing shells.
   [a] Check for bright spots that indicate shells have been shifting in their bores.
   [b] If bright spots are evident, replace the bearings shells.
4. Inspect the connecting rod bearing bores.
   [a] Check for burrs or foreign particles.
   [b] Use an emery cloth to smooth bore surface, otherwise replace part.
5. Inspect the bearings shells.
   [a] Measure the thickness of the bearing shells, using a micrometer and ball attachment, J 4757. Refer to section 1.9.2.2. The minimum thickness of a worn standard connecting rod bearing shell should not be less than 3.086 mm (0.1215 in.).
   [b] If either bearing shell is thinner than this dimension, replace both bearing shells.
6. Inspect the bearing shells and the crankshaft journals.
   [a] Check the clearance between the connecting rod bearing shells and the crankshaft journals using a soft plastic measuring strip which is squeezed between the journal and the bearing. Refer to section ADDITIONAL INFORMATION 1.A, "Checking Bearing Clearances" in "Shop Notes" section.
   [b] If the connecting rod bearing-to-journal clearance exceeds 0.152 mm (0.006 in.) with used parts, replace with a new bearing.

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NOTICE:
Do not mix former non-drilled and current drilled closed-end connecting rods in the same engine, since this may affect engine balance.

NOTE:
The current bearing shells for 14 L engines and 12.7 L engines for model year 2000 have an oil hole in them to allow oil to flow into the connecting rod. See Figure 1-287.

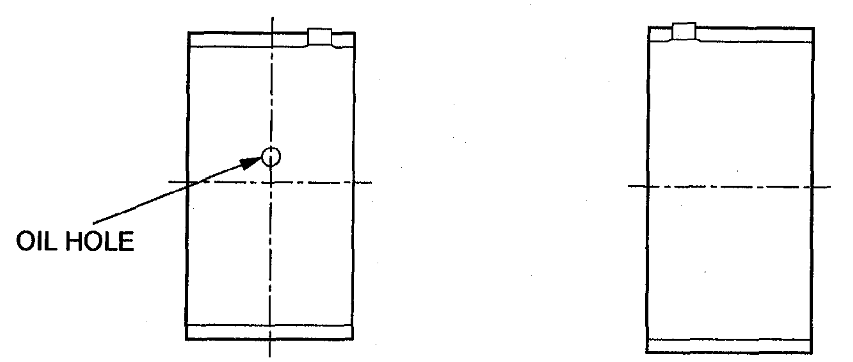

Figure 1-287 Connecting Rod Bearings for 14 L and 12.7 L Engines

NOTE:
Before installing the bearings, inspect the crankshaft journals. Refer to section 1.7.2.4. Do NOT replace one connecting rod bearing shell alone. If one bearing shell requires replacement, install both new upper and lower bearing shells. Also, if a new or reground crankshaft is to be used, install all new bearing shells.

NOTE:
Bearing shells are NOT reworkable from one undersize to another under any circumstances.

Bearing shells are available in 0.254, 0.508 and 0.762 mm (approximately 0.010, 0.020, and 0.030 in.) undersize for service with reground crankshafts. The bearing size specifications are listed in Table 1-24.

1.19.5 Installation of Connecting Rod

Refer to section 1.18.5 to install the piston and connecting rod assembly.

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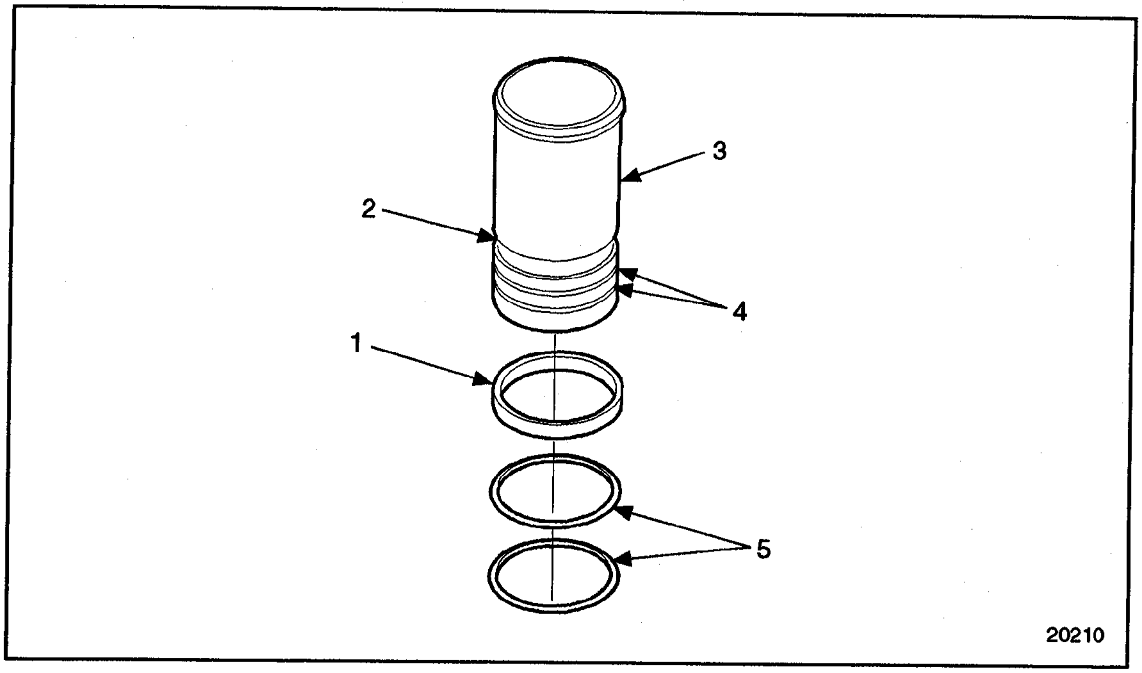
1.20 CYLINDER LINER

The cylinder liner is of the replaceable wet type, made of alloy cast iron, and is slip fit in the cylinder block. See Figure 1-288.



1. Crevice Seal
2. Crevice Seal Groove
3. Cylinder Liner
4. O-ring Grooves
5. D-ring Seals

Figure 1-288 Cylinder Liner and Related Parts

Coolant in the cylinder block water jacket surrounds the liner and cools it directly. A cooling channel is also cut into the liner immediately below the flange. Coolant flow through this channel and around the rest of the liner controls critical ring and liner temperatures for long cylinder component life.

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The liner is inserted in the cylinder bore from the top of the cylinder block. The flange at the top of the liner fits into a counter bore in the cylinder block. See Figure 1-289.

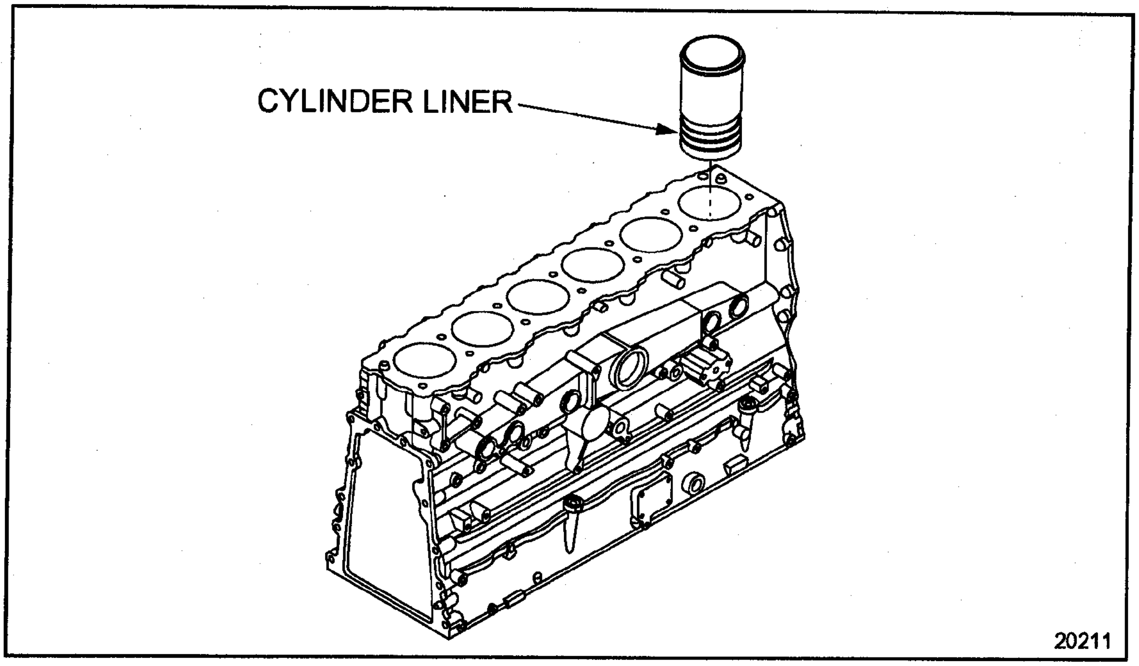

Figure 1-289 Cylinder Liner to Block Positioning

NOTE:
The cylinder liner, piston and connecting rod must be installed as a assembly in 14L engines. Refer to section 1.18.

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NOTICE:
The crevice seal prevents coolant from being pumped in and out of the area adjacent to the liner lower block location which could result in cavitation and corrosion damage to the liner and the block.

A crevice seal, fitting in the wide uppermost groove in the liner helps to stabilize the liner in the cylinder block bore. This system also keeps any debris that is in the cooling system from causing abrasion damage to the upper "D" liner seal ring. See Figure 1-290.

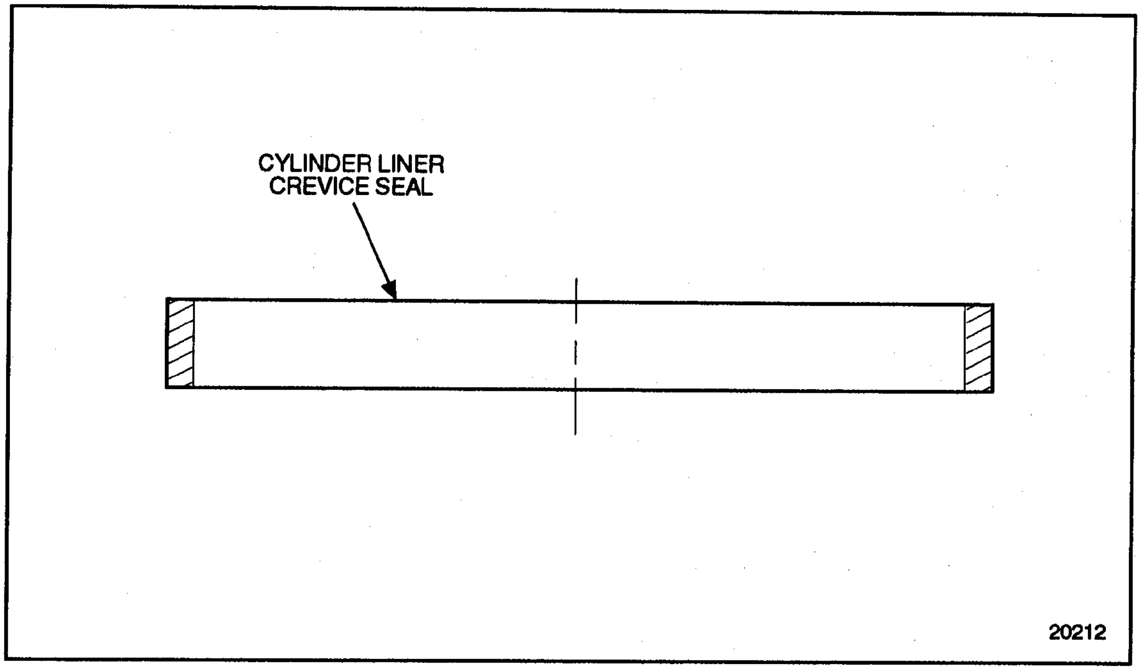

Figure 1-290 Cylinder Liner Crevice Seal Cross-Section

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Two teflon-coated, D-shaped seal rings, recessed in the lower two grooves in the cylinder liner, are used between the liner and the block to prevent coolant and oil leakage. See Figure 1-291.

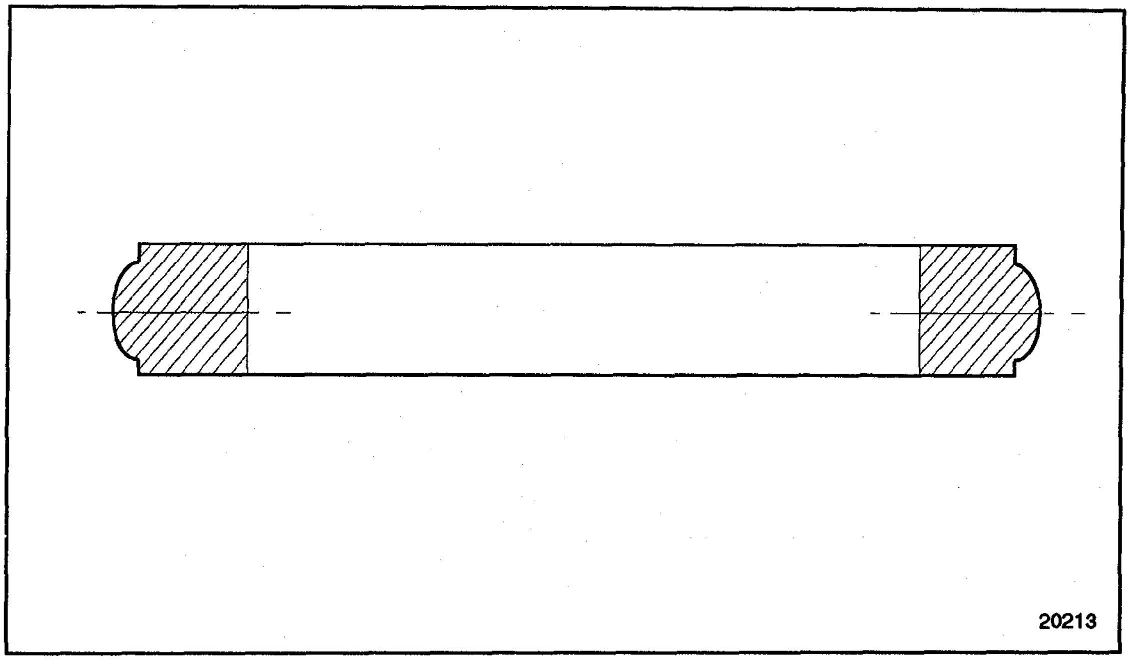

Figure 1-291 Cylinder Liner Seal Ring Cross-section

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A weep hole for each cylinder is drilled through the cylinder block exterior, into the cylinder bore area. This weep hole is located between the two D-shaped seal rings. It is used to determine if engine coolant is leaking past the upper liner seal, or if oil is leaking past the lower liner seal. See Figure 1-292. A special rubber plug prevents dirt from getting into the "D" seal ring areas and causing abrasive damage. At the same time it allows leaking oil or coolant a path out of the engine for detection.

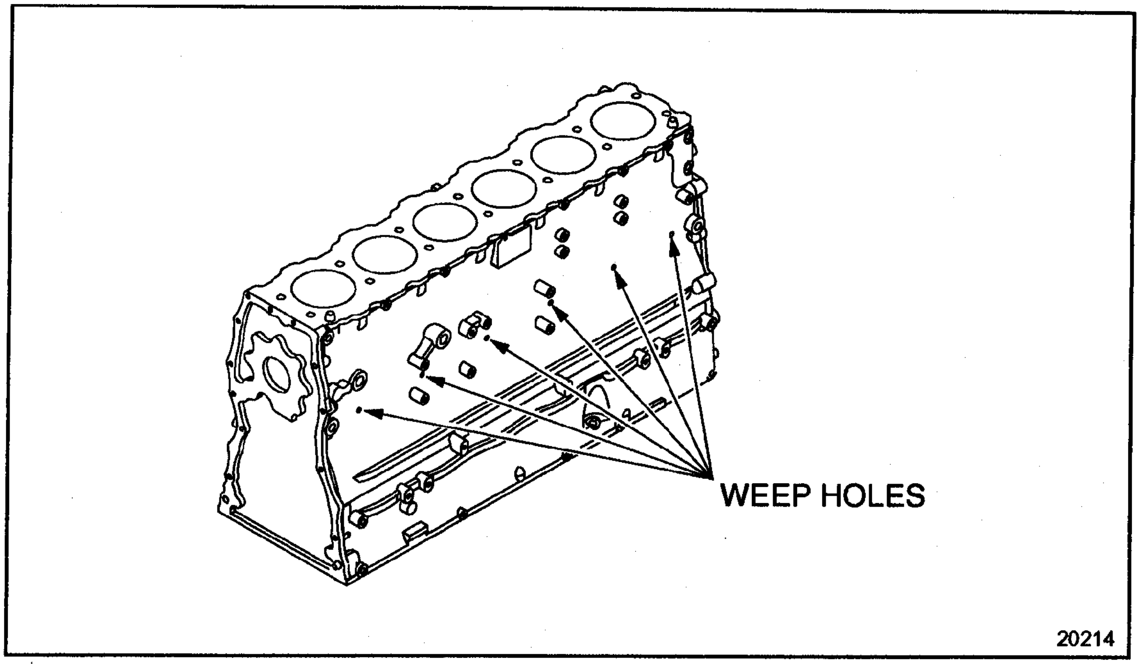

Figure 1-292 Weep Hole Plug Locations

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1.20.1 Repair or Replacement of Cylinder Liner

To determine if repair is possible or replacement is necessary, perform the following procedure. See Figure 1-293.

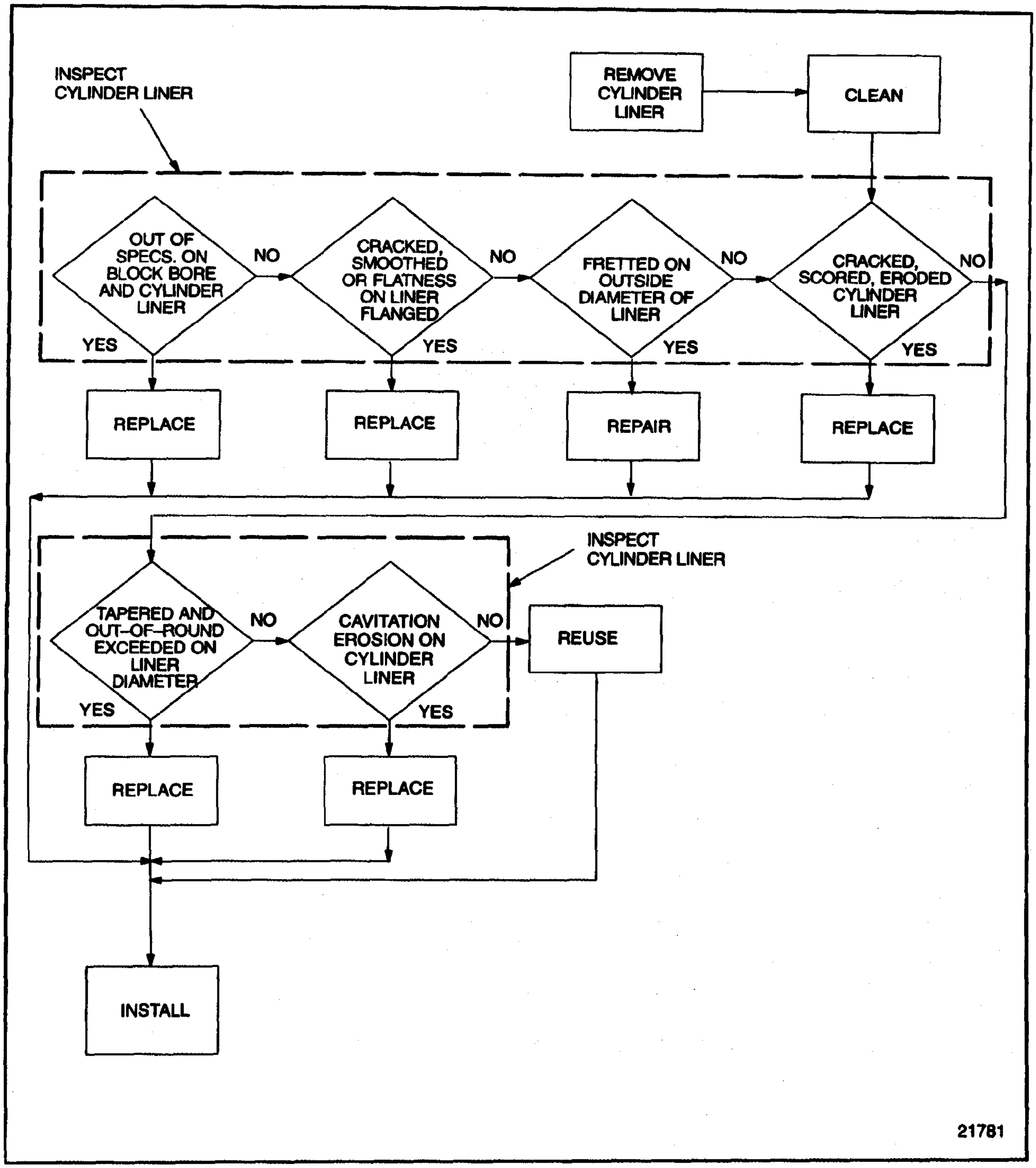

Figure 1-293 Flowchart for Repair or Replacement of Cylinder Liner

1.20.2 Removal and Cleaning of Cylinder Liner

Precleaning is not necessary.

NOTICE:
The proper method must be followed when removing a cylinder liner. Damage to the liner and the cylinder block may occur if the proper tools and procedures are not used.

1. Remove the piston and connecting rod as an assembly. Refer to section 1.18.2.
2. Remove the cylinder liner with cylinder liner remover, J 35791. See Figure 1-294.

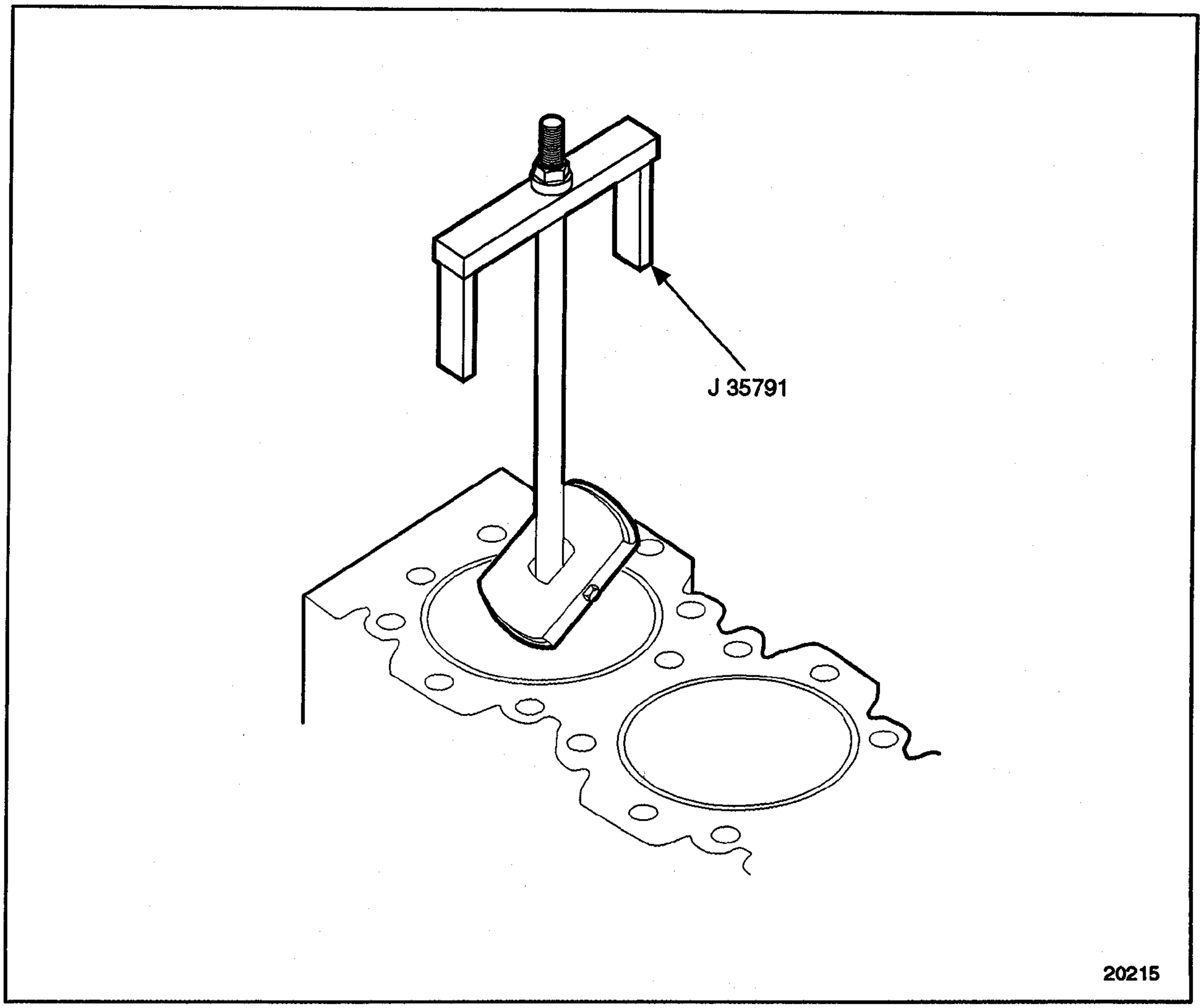

Figure 1-294 Cylinder Liner Remover

[a] Ease the shoe of the liner removal tool down into the liner.

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[b] Place the shoe into the bottom edge of the liner.

[c] Turn the nut on the tool in a clockwise direction to remove liner from the block.

NOTE:
After removing liners from an engine and prior to installing liners, always store them in an upright position until ready for use. Liners left on their side for any length of time can become egg-shaped and distorted, making installation in cylinder bores difficult or impossible. If the cylinder liners are to be reused, they should be marked so they may be installed to the same cylinder from which they were removed.

[d] Remove the tool from the liner.

[e] Remove the seals (all three) from the liner and discard them.

1.20.2.1 Cleaning of the Cylinder Liner

Clean the cylinder liner prior to inspection as follows:

1. If cleaning a new or used liner, wash the liner with a strong detergent and warm water solution, scrubbing with a non-metallic bristle brush.
2. Rinse with hot water or steam.

CAUTION:
To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

3. Dry the liner with compressed air.

NOTICE:
If the liners are not to be installed at this time, oil them lightly with clean engine lubricating oil and store them upright in a clean, dry area. Do not allow the liners to rest on their sides and do not store anything on top of the liners.

4. Coat the bore of the liner with clean engine lubricating oil.
5. Allow the liner to sit for 10 minutes (to allow the oil to work into the surface finish).
6. Wipe the inside of the liner with clean, white paper towels.
7. If a dark residue appears on the towels, repeat the oiling and wiping procedure until residue no longer appears.

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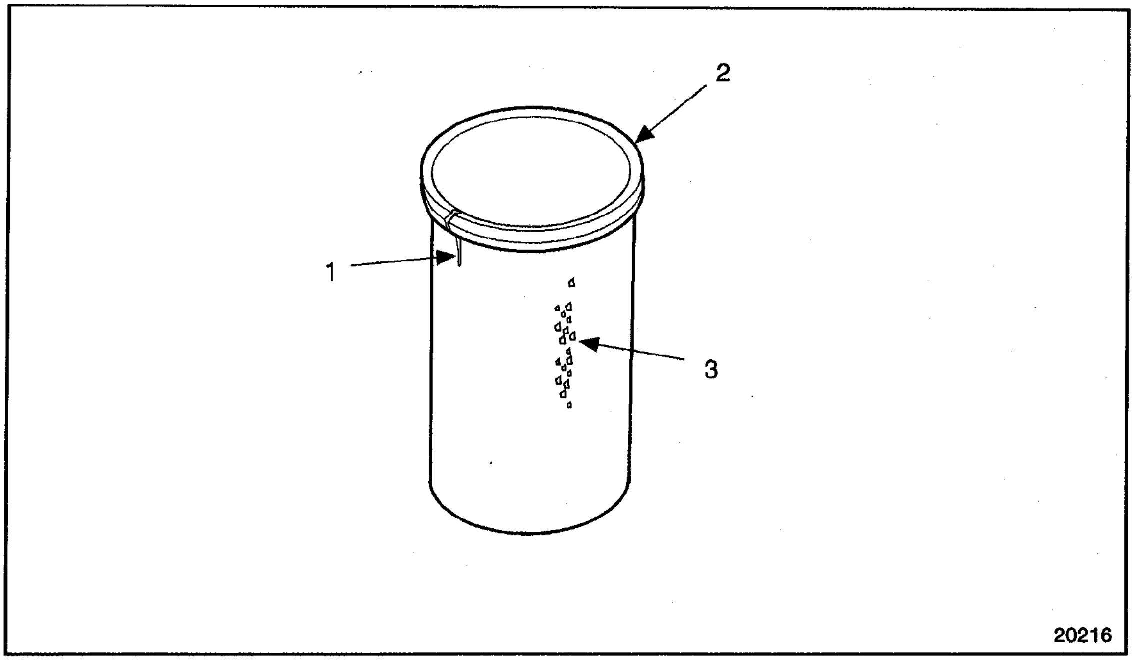
1.20.2.2 Inspection of Cylinder Liner

Inspect the cylinder liner as follows:

1. Inspect the cylinder liner.
   [a] Check the cylinder liner for cracks or scoring.
   [b] If any of these are detected, replace with a new part.

NOTICE:
Erosion is due to poor cooling system maintenance. If uncorrected, it will eventually make holes through the liner. This can result in combustion gases blowing water out of the radiator, oil in the coolant, or when the engine is stopped will allow water to flow into the cylinder and result in major engine damage due to water in the oil or hydraulic lockup.

   [c] Check the cylinder liner for cavitation erosion. See Figure 1-295.



1. Cracks
2. Cylinder Liner
3. Erosion

Figure 1-295 Cylinder Liner Cavitation Erosion

   [d] If cavitation erosion occurs, replace with a new part. Refer to section 1.20.3.

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NOTICE:
Series 60 cylinder liners are honed at the factory with a process that cannot be duplicated in the field. For this reason, honing of used liners should not be attempted.

2. Inspect the outside diameter of the liner.
   [a] Check liner for fretting.
   [b] If any fretting is found, remove it from the surface of the liner with a coarse, flat stone.
3. Inspect the liner flange.
   [a] Check the liner flange for cracks, smoothness and flatness on both the top and bottom surfaces.
   [b] If these are detected, replace with a new part.
4. Inspect the block bore and cylinder liner.
   [a] Measure the block bore and the outside diameter of the liner. The liner specifications are listed in Table 1-16. The block specifications are listed in Table 1-15. Refer to section 1.1.3.3 for procedures.
   [b] If the liner does not meet specification, replace with a new part.

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5. Inspect inside diameter of cylinder liners.

   [a] Set the cylinder bore gage on zero in master setting fixture. Use cylinder bore gage, J 5347-B, to measure the inside diameter of the liner of various points. The maximum diameter of a used liner is 130.100 mm (5.122 in.) for 12.7 and 11.1 L and 133.100 mm (5.244 in.) for 14L at any measurement location. See Figure 1-296. Also check the liner for taper and out-of-round.

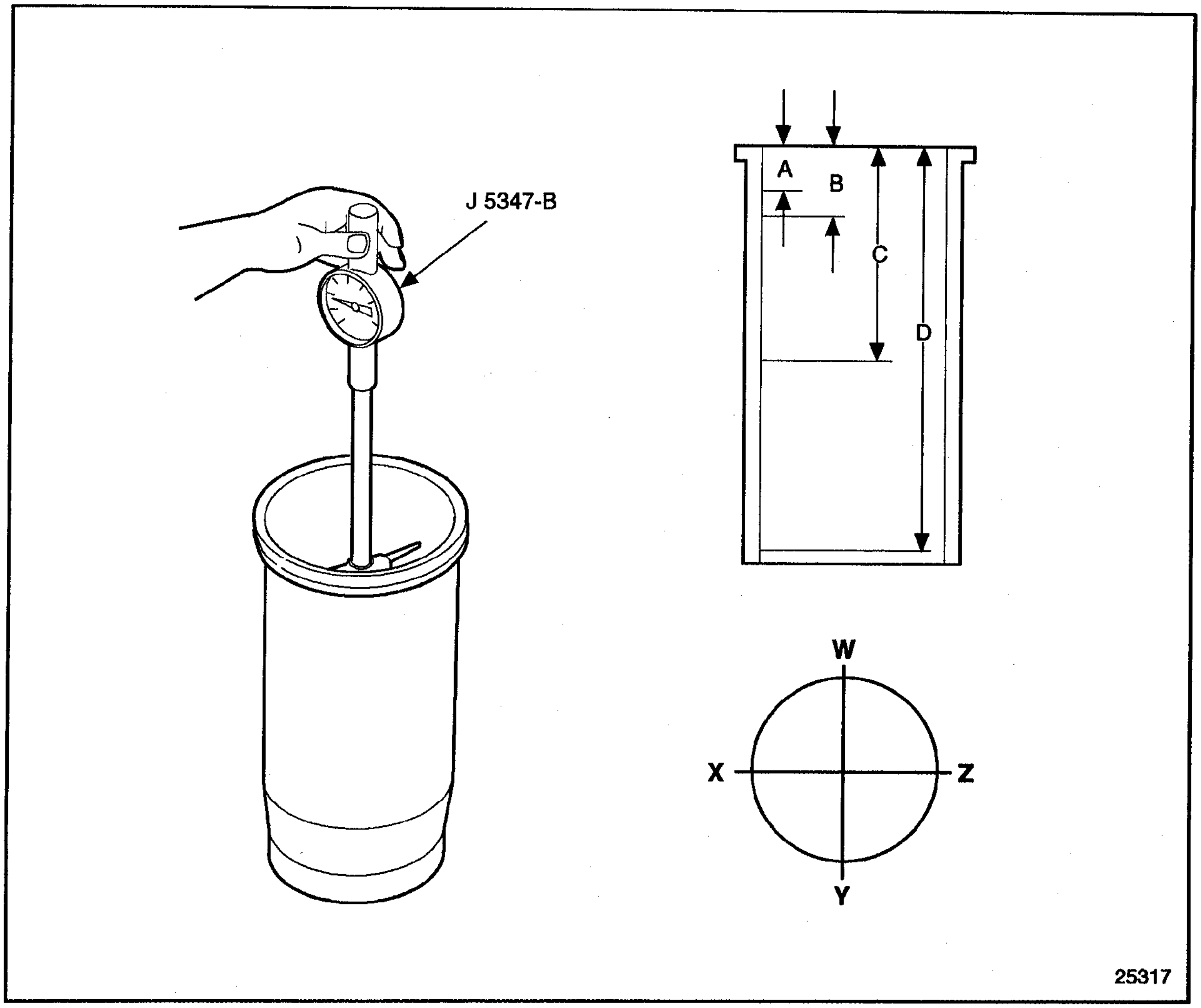

Figure 1-296 Cylinder Liner Measurement Diagram

   [b] If the taper and out-of-round exceed 0.025 mm (0.001 in.), replace with a new part.

6. Inspect the cylinder liner.

   [a] Check the seal ring and crevice seal grooves for burrs or sharp edges.

   [b] If any are detected, smooth with an emery cloth.

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1.20.3 Installation of Cylinder Liner

Install the cylinder liner as follows:

NOTE:
Refer to section 1.18 for 14L liner, piston and connecting rod procedure.

1. Wipe the inside and outside of the liner clean. Be sure the block bore and counter bore are clean, so the liner flange will seat properly. The block counter bore depth must be 8.9255-8.9662 mm (0.3514 -0.3533 in.) and must not vary more than 0.04 mm (0.0015 in.) in depth around the circumference. No two adjacent block counter bores may range in depth more than 0.025 mm (0.001 in.) when gaged along the longitudinal cylinder block centerline. Specifications are listed in Table 1-15, and listed in Table 1-16.

NOTE:
Thoroughly clean the cylinder block liner counter bores to remove any foreign material. Foreign material in the cylinder liner counter bores can cause the liner to seat improperly.

NOTE:
If the fire deck surface of the cylinder block has been machined, the counter bores must be machined the same amount to keep the cylinder liner counter bore depth within limits.

2. Lubricate the seal rings and crevice seal with clean petroleum jelly.
3. Install two new seal rings and a new crevice seal into their respective grooves in the liner.
4. Insert the cylinder liner into the cylinder bore.

NOTE:
Do not exert excessive force on the liner, while pushing it down.

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5. Install J 35597, over the liner to be installed. See Figure 1-297.

NOTE:
It is necessary to leave the cylinder liner installation tool in place until after the liner protrusion is measured.

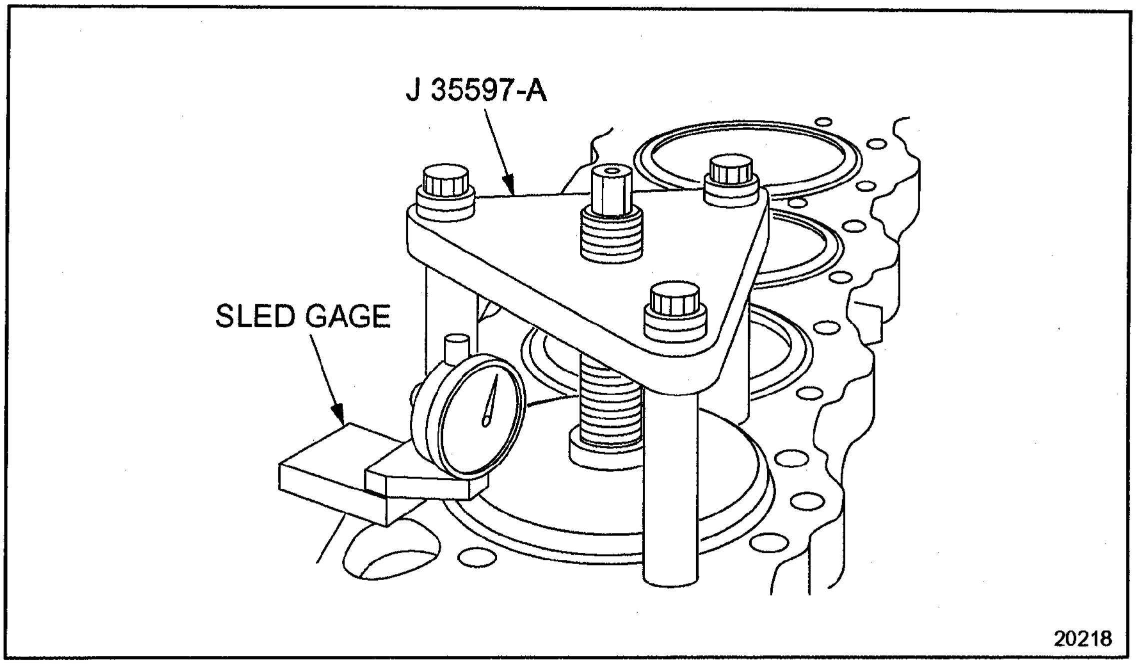

Figure 1-297 Cylinder Liner Installation Tools

6. Thread three cylinder head bolts through the tool and into a head bolt hole, so that the round shoe of the tool is centered over the liner.
7. Tighten the bolts.

NOTE:
It is not necessary to torque the bolts.

8. Turn the threaded center bolt in a clockwise direction. As the round shoe of the tool reaches the liner, ensure that the shoe is properly positioned into the cylinder liner.
9. Continue turning the bolt until the liner bottoms in the cylinder counterbore. Apply a tightening torque of 60 N·m (44 lb·ft) to the installation tool center bolt.
10. Install a dial indicator sled gage. See Figure 1-276.

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11. Measure the distance from the top of the liner flange to the top of the block. See Figure 1-298.
    - [a] Allowable liner protrusion is 0.000-0.076 mm (0.000 -0.003 in.) with no more than 0.0508 mm (0.002 in.) variation between any two adjacent cylinders. Specifications are listed in Table 1-16.
    - [b] If the liner protrusion exceeds the maximum allowable, remove the liner and check for debris under the liner flange.

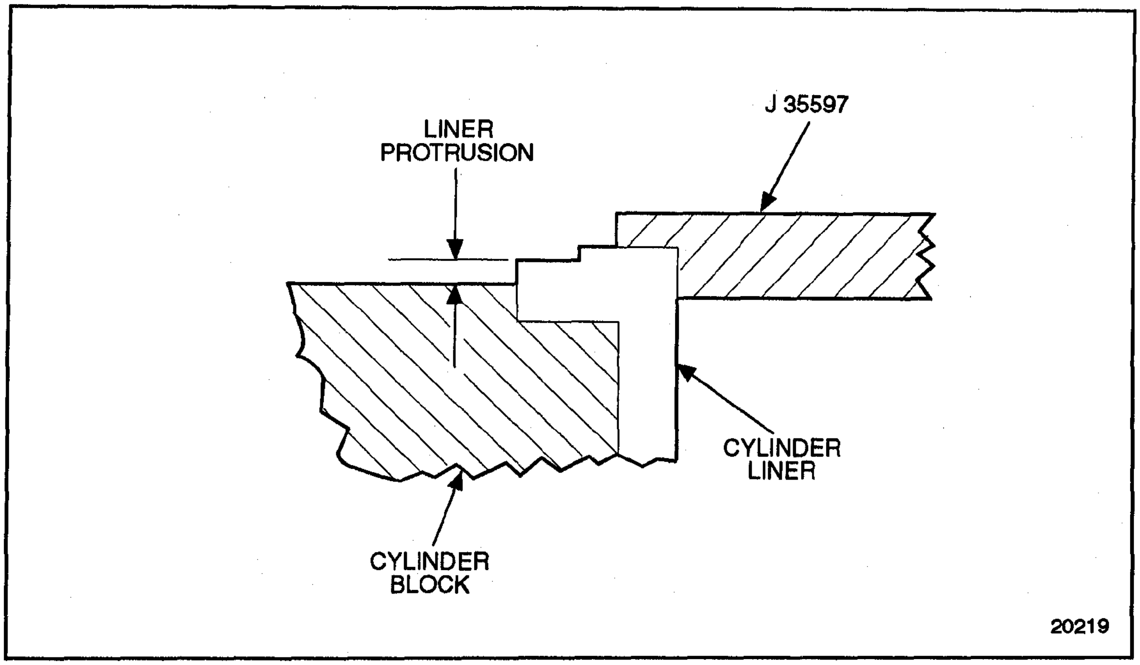

Figure 1-298 Cylinder Liner Protrusion

12. Remove the cylinder liner tool.
13. With all of the cylinder liners installed and the liner protrusion measurements within specifications, install the piston and connecting rod assemblies. Refer to section 1.18.5.

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1.21 GEAR TRAIN AND ENGINE TIMING

The gear train is completely enclosed between the gear case and gear case cover and is located at the front of the engine. The gear train consists of a camshaft drive gear, camshaft idler gear, fuel pump drive gear, air compressor and power steering pump drive gear, bull gear, oil pump drive gear, crankshaft timing gear, water pump drive gear, accessory pulley drive gear, and adjustable idler gear. The gear ratio of each gear in relationship to the crankshaft timing gear is shown directly below the gear title. See Figure 1-299.

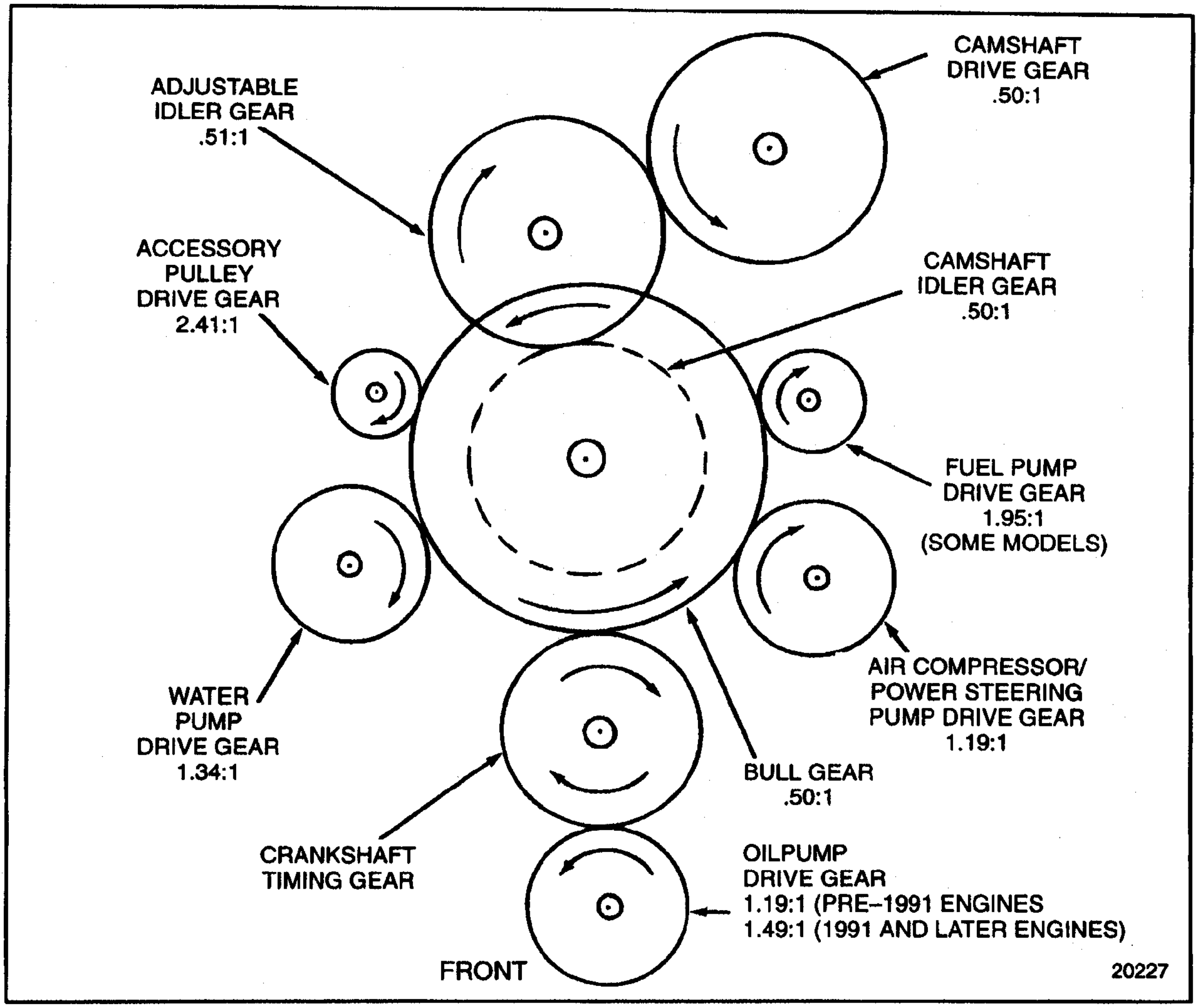

Figure 1-299 Engine Gear Train

The crankshaft timing gear, pressed onto the front end of the crankshaft, directly drives the bull gear and oil pump drive gear, and indirectly (through the bull gear), drives the fuel pump drive gear, air compressor and power steering pump drive gear, accessory pulley drive gear and water pump drive gear.

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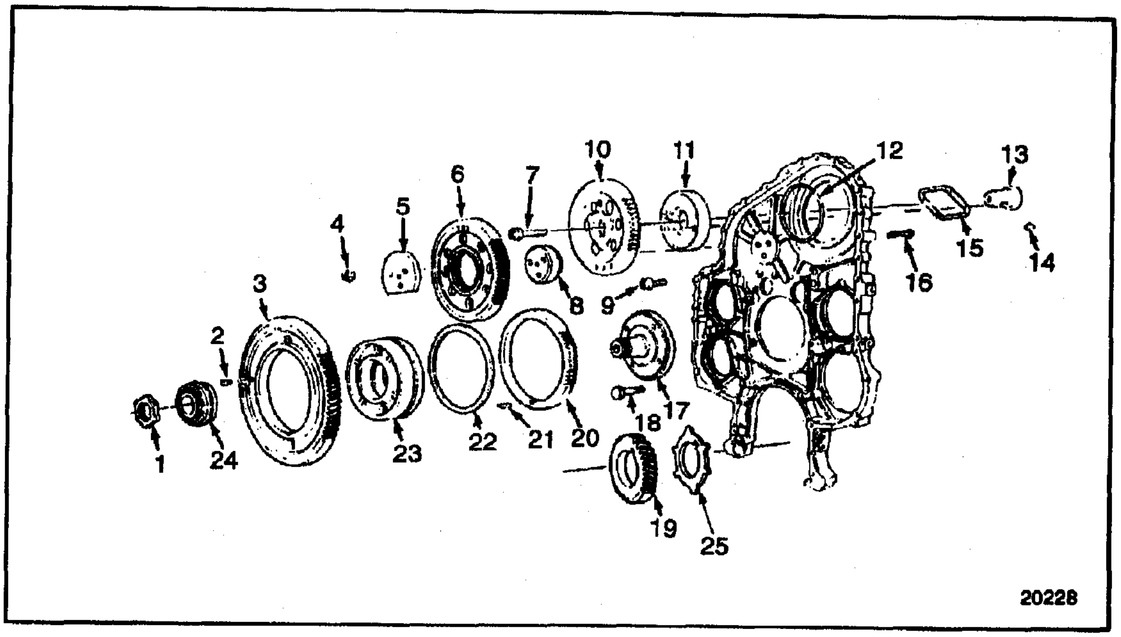
The camshaft idler gear is mounted to the rear of the bull gear on the same carrier, and rotates along with the bull gear at the same speed. This camshaft idler gear drives the adjustable idler gear, which in turn, drives the camshaft drive gear. See Figure 1-300.



1. Bull Gear Retaining Nut
2. Timing Pin
3. Bull Gear
4. Adjustable Idler Gear Retaining (3) Locknut
5. Adjustable Idler Gear Plate
6. Adjustable Idler Gear
7. Camshaft Retaining Bolt
8. Adjustable Idler Gear Hub
9. Thrust Plate Retaining (2) Bolt
10. Camshaft Drive Gear
11. Camshaft Thrust Plate
12. Camshaft Thrust Plate Seal O-ring
13. Camshaft Drive Gear Hub
14. Camshaft Drive Gear Hub Key
15. Camshaft Thrust Plate Seal
16. Adjustable Idler Gear Hub Retaining Stud
17. Bull Gear and Idler Gear Hub
18. Bull Gear Hub Retaining (4) Bolt
19. Crankshaft Timing Gear
20. Camshaft Idler Gear
21. Bull Gear and Idler Gear Key
22. Spacer
23. Bull Gear and Idler Gear Carrier
24. Bull Gear and Idler Gear Bearings
25. Crankshaft Timing Rings

Figure 1-300 Gear Train and Related Parts

The bull gear and camshaft idler gear are a press-fit to the bull gear and camshaft idler gear carrier. Both gears are keyed to the carrier by the same key. The carrier is supported by two tapered roller bearings, which ride on a hub bolted to the engine block by four bolts. The bull gear and camshaft idler gear assembly is retained to the hub by a **left-hand threaded nut.**

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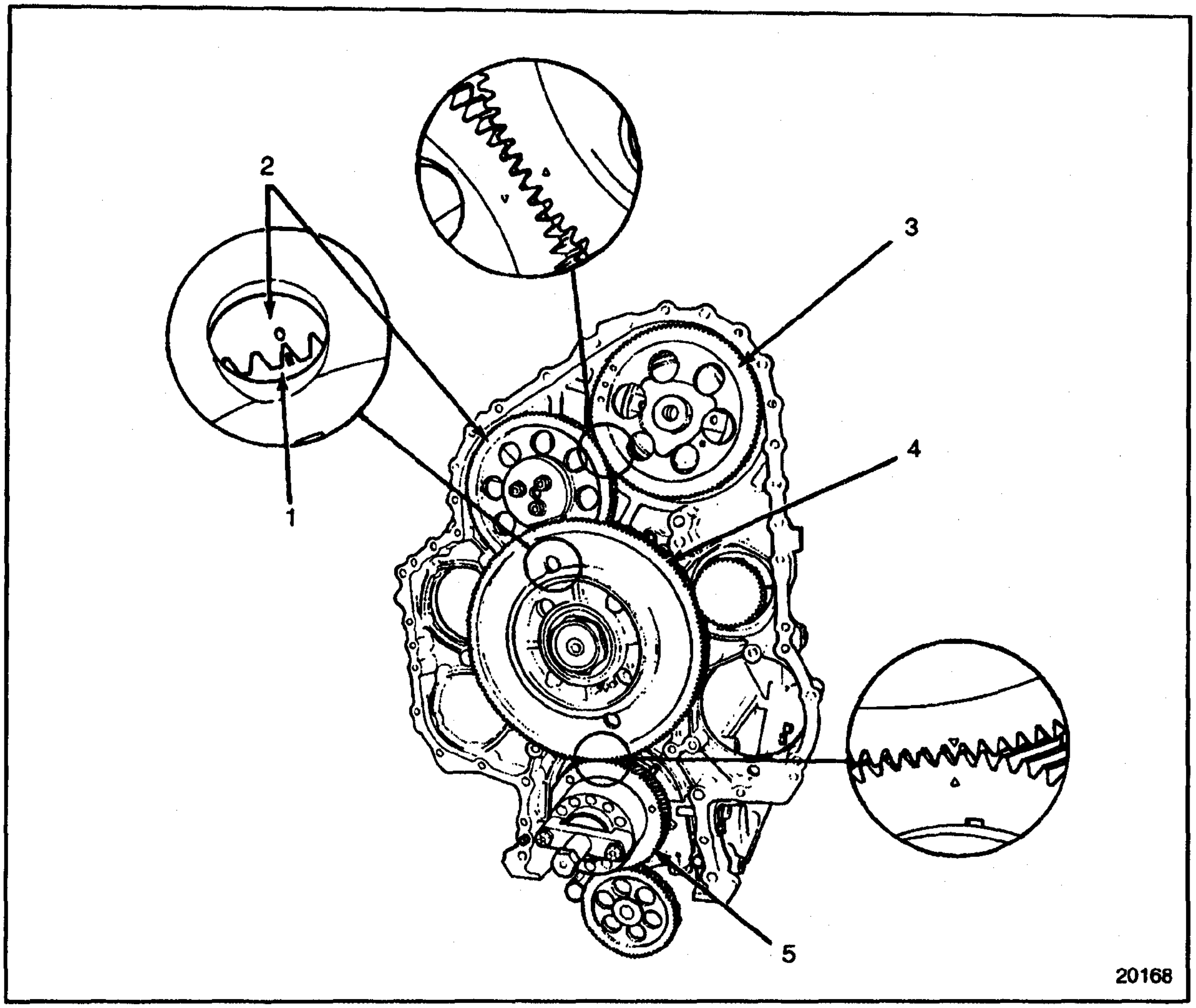
The camshaft idler gear drives the camshaft drive gear through an adjustable idler gear. The adjustable idler gear is supported by a bushing and is mounted on an adjustable hub secured by three studs pressed into the gear case from the rear.

The camshaft must be in time with the crankshaft timing gear. Since there are three gears between them, timing marks have been stamped or etched on the face of the gears to facilitate correct gear train timing. See Figure 1-301.



1. Camshaft Idler Gear
2. Adjustable Idler Gear
3. Camshaft Drive Gear
4. Bull Gear
5. Crankshaft Timing Gear

Figure 1-301 Engine Gear Train and Timing Marks

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The symbol system of marking the gears makes gear train timing a comparatively easy operation. When assembling the engine, work from the crankshaft timing gear to the camshaft drive gear and line up the appropriate symbols on the gears as each gear assembly is installed on the engine.

There are no timing marks on the drive gears for the fuel pump, air compressor and power steering pump, water pump or accessory drive pulley. Therefore, it is not necessary to align these gears in any particular position during their installation.

The backlash between the various mating gears in the gear train should be 0.051 - 0.229 mm (0.002 - 0.009 in.) and should not exceed 0.305 mm (0.012 in.) backlash between worn gears.

Gear train noise is usually an indication of excessive gear lash, chipped, pitted or burred gear teeth or excessive bearing wear. Therefore, when noise develops in a gear train, the gear case cover should be removed and the gear train and its bearings inspected. A rattling noise usually indicates excessive gear lash whereas a whining noise indicates too little gear lash.

The gear train is lubricated by oil splash. The bull gear and camshaft idler gear are pressure-fed lubricating oil through two holes in the bull gear recess area of the engine block. See Figure 1-302.

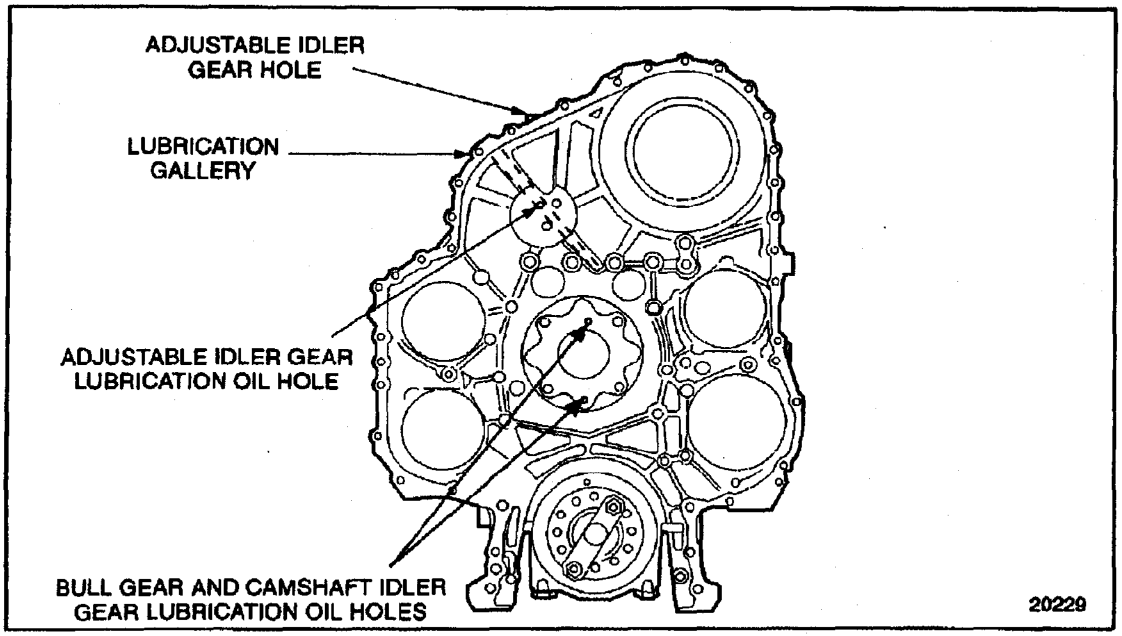

Figure 1-302 Gear Train Lubricating Oil Hole Locations

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These two holes are connected to the main oil gallery. The adjustable idler gear assembly is pressure-fed by an oil gallery in the gear case that indexes with a hole in the engine block. The hole in the engine block is connected to the main oil gallery.

The correct relationship between the crankshaft and the camshaft must be maintained to properly control the opening and closing of the intake and exhaust valves, and the operation of the fuel injectors and to help maintain engine balance.

The crankshaft and camshaft gears can only be mounted in one position as they are both keyed to their mating parts. Therefore, when the engine is properly timed, the timing marks on the various gears will match. See Figure 1-301.

An "out of time" engine may result in valve-to-piston dome contact, a no-start condition or loss of power.

1.21.1 Repair or Replacement of Gear Train and Engine Timing

To determine if repair is possible or replacement is necessary, perform the following procedure. See Figure 1-303.

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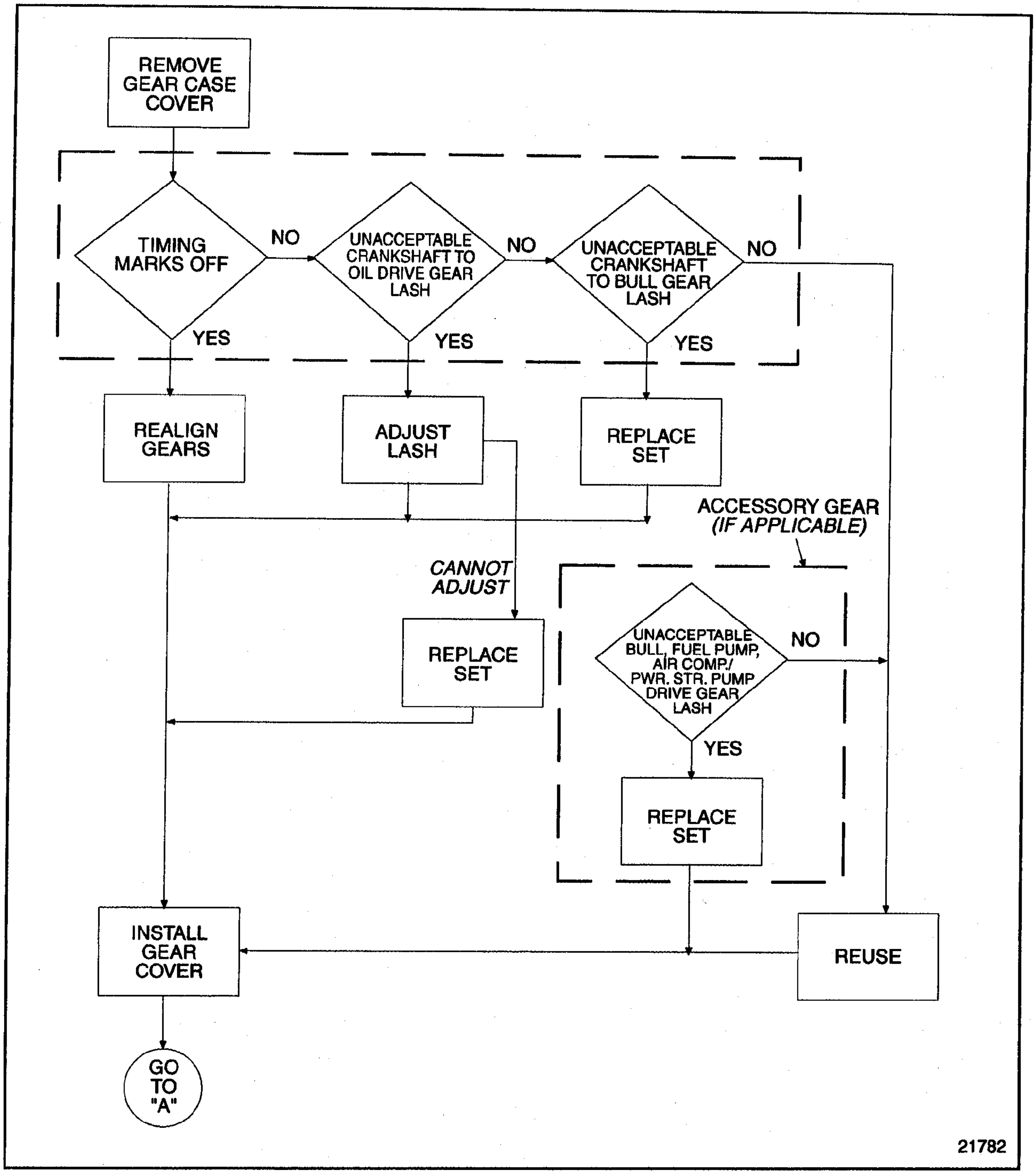

Go to "A", see Figure 1-304.

Figure 1-303 Flowchart for Repair or Replacement of Gear Train and Engine Timing - Part 1 of 3

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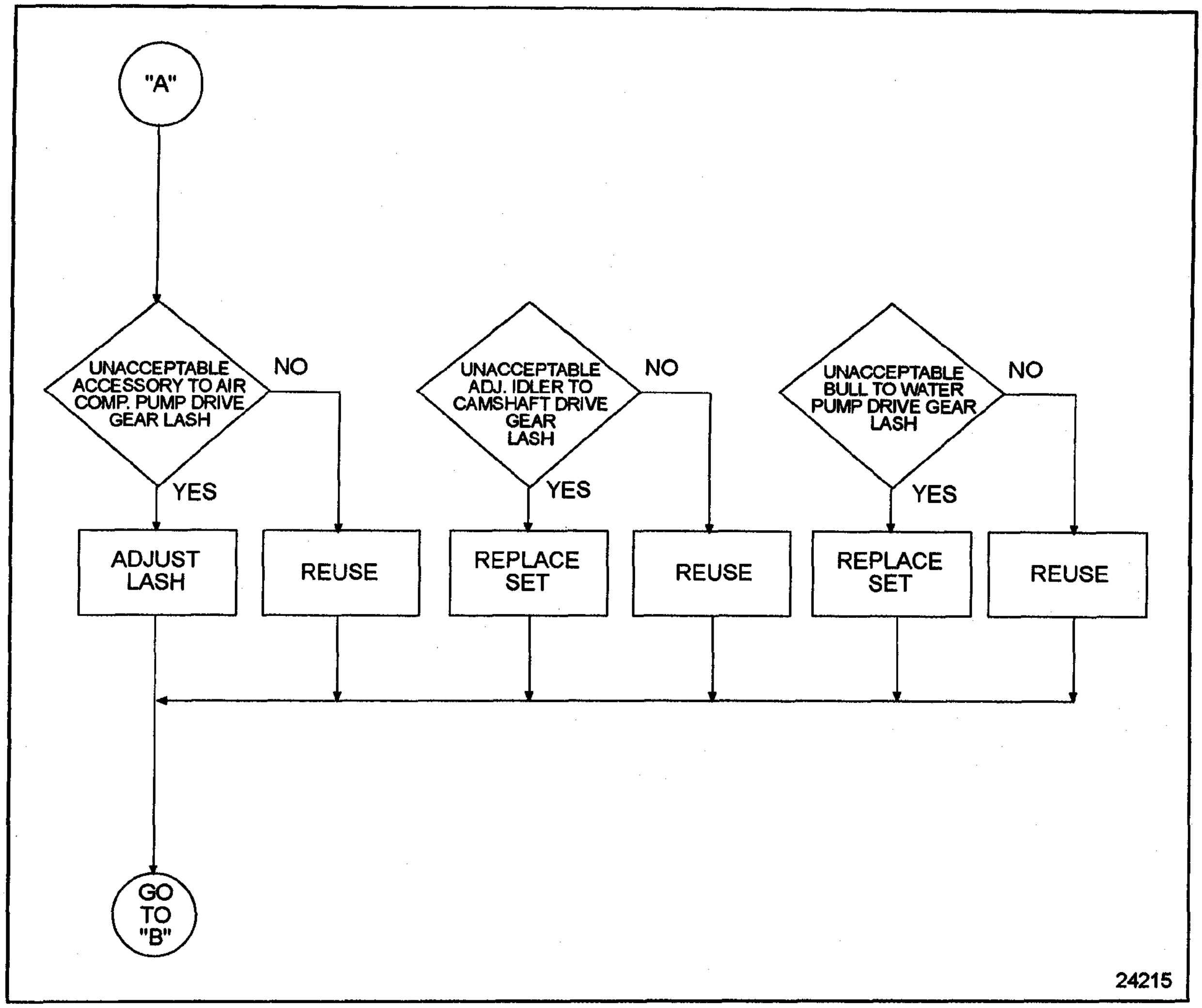

Go to "B", see Figure 1-305.

Figure 1-304 Flowchart for Repair or Replacement of Gear Train and Engine Timing - Part 2 of 3

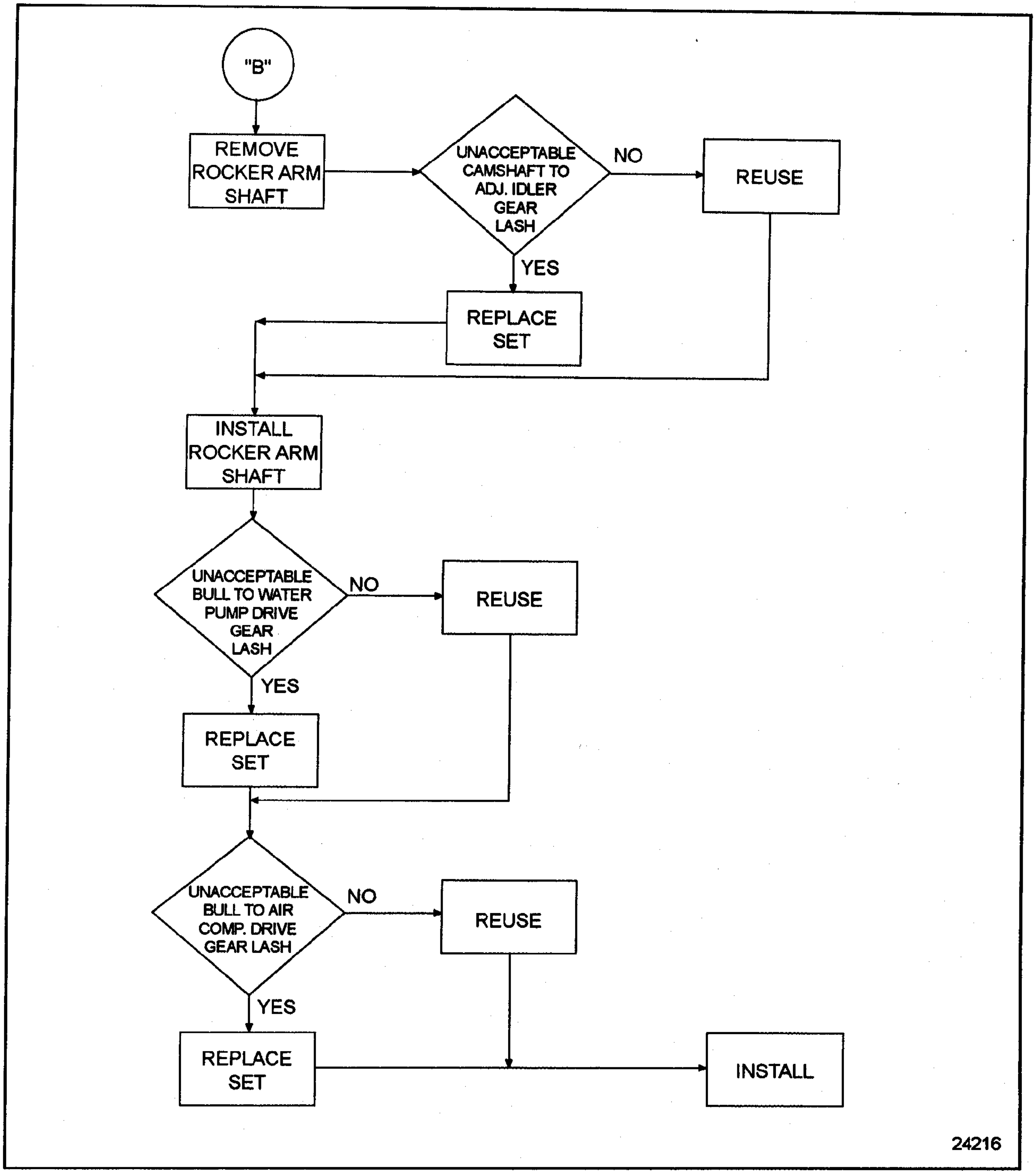

Figure 1-305 Flowchart for Repair or Replacement of Gear Train and Engine Timing - Part 3 of 3

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1.21.2 Cleaning of Gear Train and Engine Timing

When an engine is out of time, the camshaft timing can be checked by following the camshaft timing check procedure. Refer to section 1.23.6.1. If the engine is out of time, a visual inspection of the gear train is required. Refer to section 1.10.2 and perform all of the steps under "Removal of Gear Case Cover" .

1.21.2.1 Check Engine Timing

Gear train noise is usually an indication of excessive gear lash, chipped, pitted or burred gear teeth, or excessive bearing wear. Therefore, when noise develops in a gear train, the gear case cover should be removed and the gear train and its bearings inspected. A rattling noise usually indicates excessive gear lash. A whining noise indicates too little gear lash.

1. Check engine timing as follows:

   [a] Examine all timing marks to ensure they are aligned. See Figure 1-301.

   [b] It may be necessary to remove the gears to align the timing marks. Refer to section 1.26.2.

NOTE:
The gear ratio between the adjustable idler gear and the camshaft drive gear causes a "hunting-tooth" situation. Therefore, the bull gear and rocker arm assemblies should be removed to align the timing marks. See Figure 1-301.

   [c] If any gears are removed or installed, or if lash between any two gears is out of specification, check the lash between the mating gears.

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2. Check the crankshaft timing gear-to-oil pump idler gear lash measurement as follows:

   [a] Fasten a dial indicator and magnetic base to the cylinder block so that the stem of the dial indicator rests on a tooth of the oil pump drive gear. See Figure 1-306.

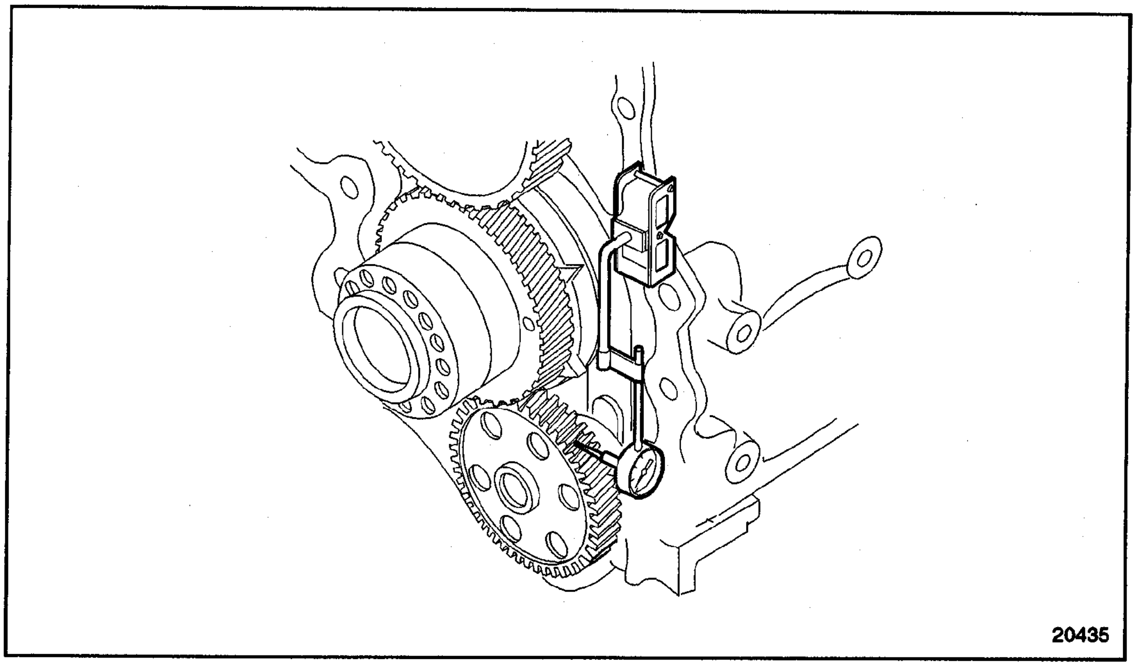

Figure 1-306 Crankshaft Timing Gear-to-Oil Pump Idler Gear Lash Measurement

NOTE:
The oil pump design changed effective with 1991 model year engines. However, the oil pump gear lash measurement procedure is the same for both style pumps.

   [b] Hold the crankshaft timing gear stationary, and rotate the oil pump drive gear in one direction, as far as it will go, without moving the crankshaft timing gear.

   [c] Zero the dial indicator.

   [d] Move the oil pump drive gear in the opposite direction, as far as it will go, without moving the crankshaft timing gear.

   [e] Read and record the total gear lash.

NOTE:
The gear lash must be checked in four positions 90 degrees apart.

NOTE:
The lash between the crankshaft timing gear and oil pump drive gear must be measured with the engine in a running position. See Figure 1-306.

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Proper lash between the crankshaft timing gear and oil pump drive gear is 0.051-0.229 mm (0.002 -0.009 in.).

The gear lash between the crankshaft timing gear and the oil pump drive gear can be adjusted utilizing shims inserted between the oil pump body and the cylinder block. See Figure 1-307.

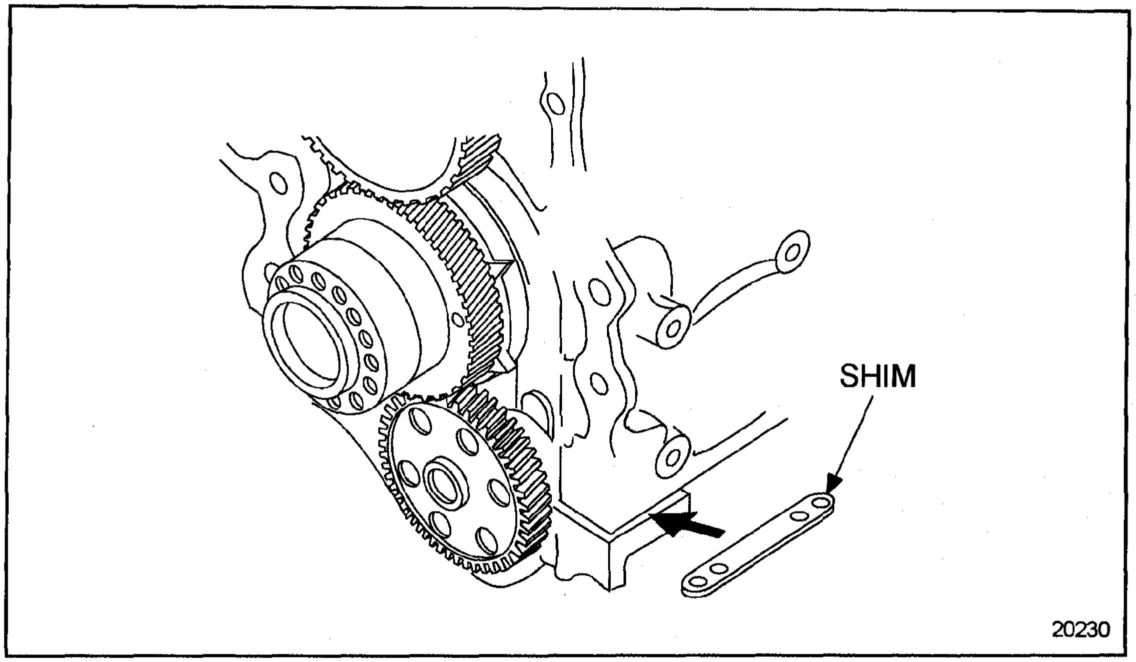

Figure 1-307 Lubricating Oil Pump Shim Installation

[f] Remove or install shims as necessary to obtain the proper gear lash clearance.

NOTE:

When adjusting for gear tooth lash by installing or removing shims, the same number of shims must be changed under each foot so that the pump will always be level on the engine block. The insertion or removal of one 0.127 mm (0.005 in.) shim will change the gear tooth lash by approximately 0.102 mm (0.004 in.).

NOTE:

If it is necessary to remove the oil pump, refer to section 3.2.2.

[g] If the use of shims cannot bring gear lash within acceptable limits, the gear or gears for that gear set must be replaced.

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3. Check the crankshaft timing gear-to-bull gear lash measurement as follows:
   [a] Install a dial indicator and magnetic base. See Figure 1-308.

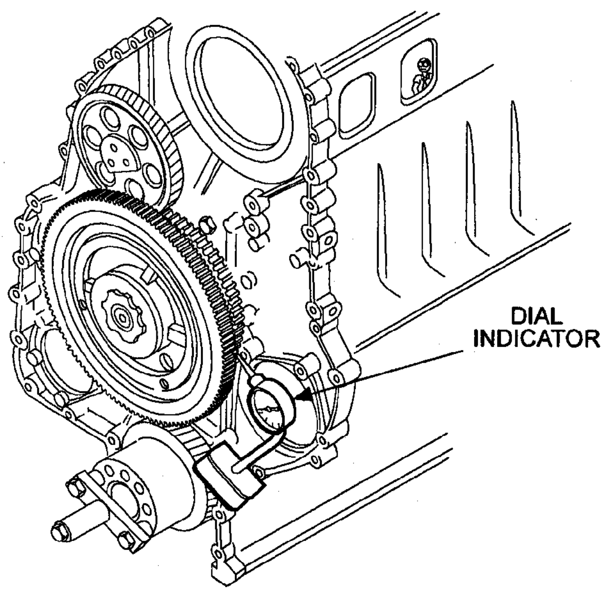

Figure 1-308 Crankshaft Timing Gear-to-Bull Gear Lash Measurement

   [b] Adjust the stem of the dial indicator to rest on the center of a tooth on the bull gear.
   [c] Preload the bull gear.
   [d] Zero the dial indicator pointer.
   [e] Hold the crankshaft timing gear stationary with one hand. Rotate the bull gear and check the total gear lash in four positions of crank gear, approximately 90 degrees apart.
   [f] Although gear lash for the remaining gear sets is not adjustable, the lash must still be measured. Lash specifications is 0.051-0.229 mm (0.002 -0.009 in.) for new parts and a maximum of 0.305 mm (0.012 in.) for used parts.
   [g] If lash measurement is exceeded, replace gear with a new part.

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4. The procedure for measuring the lash between the bull gear and the fuel pump drive gear (if applicable) and the air compressor and power steering pump drive gear is similar to the steps just mentioned. Refer to step 3and perform step 3[a], as the first step and refer to step 3[g], as the final step.Gear case cover must be installed to continue on checking the engine timing. Refer to section 1.10.3and perform all of the steps under gear case cover installation.

NOTE:
Due to the possibility of damaging the crankshaft front oil seal, whenever the gear case cover is removed, the front crankshaft oil seal must be replaced. Replace the crankshaft front oil seal after the gear case cover is installed. Refer to section 1.8.1.

5. The procedure for measuring the lash between the accessory drive gear and air compressor pump drive gear (on vehicle without power steering) is similar to the steps just mentioned. Refer to step 3 and perform step 3[a], as the first step and refer to step 3[g], as the final step.

NOTE:
Lash can be measured with the gear case cover installed. Access covers are provided for checking the lash between these gears and the bull gear. For engines with no access cover for accessory drive, gear lash is to be measured off the accessory drive pulley.

6. The procedure for measuring the lash between the adjustable idler gear and camshaft drive gear is similar to the steps just mentioned. Refer to step 3 and perform step 3[a], as the first step and refer to step 3[g], as the final step.

NOTE:
These gears are measured and adjusted with the gear case cover installed.

7. The procedure for measuring the lash between the bull gear and the water pump drive gear is similar to the steps just mentioned. Refer to step 3and perform step 3[a], as the first step and refer to step 3[g], as the final step.

NOTE:
These gears can be measured with the pump installed.

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8. When measuring or adjusting the gear lash between the adjustable idler gear and the camshaft drive gear, the valve and injector spring pressures must be removed from the camshaft lobes. Use the following procedure for this adjustment:

NOTE:
The front and rear rocker shafts look identical, but must not be interchanged due to different oil passage patterns. The outboard ends of the rocker arm shafts are marked for identification with the DDC logo. See Figure 1-309. Use care to ensure that the rocker arm shaft assemblies are replaced exactly as removed.

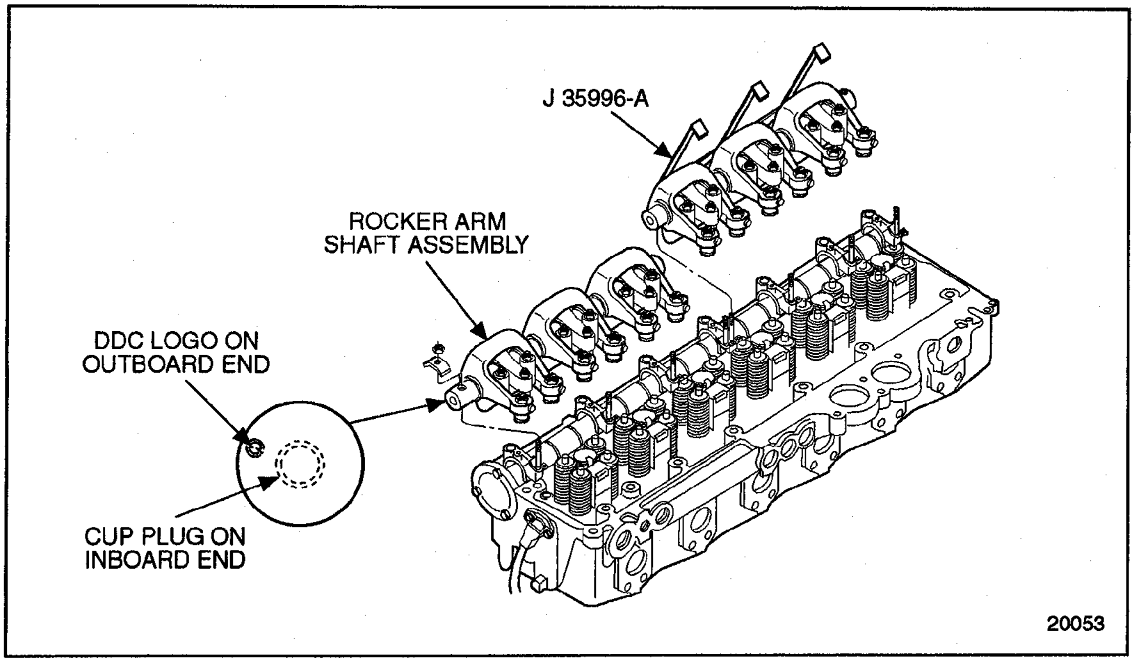
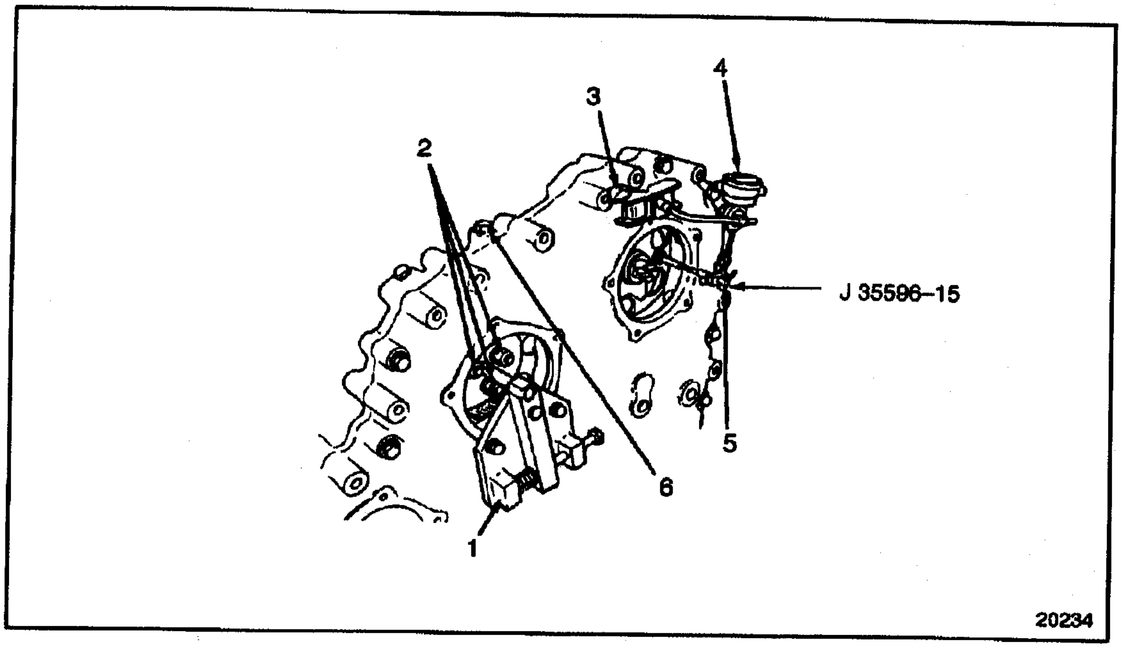


Figure 1-309 Rocker Arm Shaft Identification Mark

[a] Install the gear lash pedestal, J 35596-15, into the threaded hole of the camshaft drive gear. See Figure 1-310. Bar the engine over until the tool is at the three o'clock position.



1. Gear Lash Adjustment Tool
2. Adjustable Idler Gear Retaining Nut
3. Magnetic Base
4. Dial Indicator
5. Pedestal Idler Gear Hole
6. Adjustable Idler Gear Retaining Nut

Figure 1-310 Camshaft Drive Gear-to-Adjustable Idler Gear Lash Measurement

NOTE:
Since the teeth of the camshaft drive gear are not accessible with the gear case cover installed, the lash is measured on the pedestal installed in the threaded hole, which is located exactly half-way between the center and edge of the camshaft drive gear. For this reason, the reading obtained will be exactly 1/2 of the actual gear lash.

[b] Mount a dial indicator adaptor and dial indicator. See Figure 1-310.

[c] Adjust the stem of the dial indicator to rest on the flat of the pedestal.

[d] If the adjustable idler gear has been removed, torque the three flanged nuts that retain the adjustable idler gear hub to the gear case to 57-67 N·m (42-49 lb·ft) to seat the assembly before proceeding.

[e] Loosen the three locknuts that retain the adjustable idler gear hub to the gear case until they are hand tight.

[f] Insert the dowel portion of the gear lash adjusting tool, J 35596, through the hole in the adjustable idler gear retaining plate and into the adjustable idler gear hub, using the bottom two adjustable idler gear cover bolt holes. See Figure 1-310.

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[g] Turn the adjusting screw of the tool in a clockwise direction to force the adjustable idler gear against the camshaft drive gear, until there is zero lash between the two gears. See Figure 1-311.

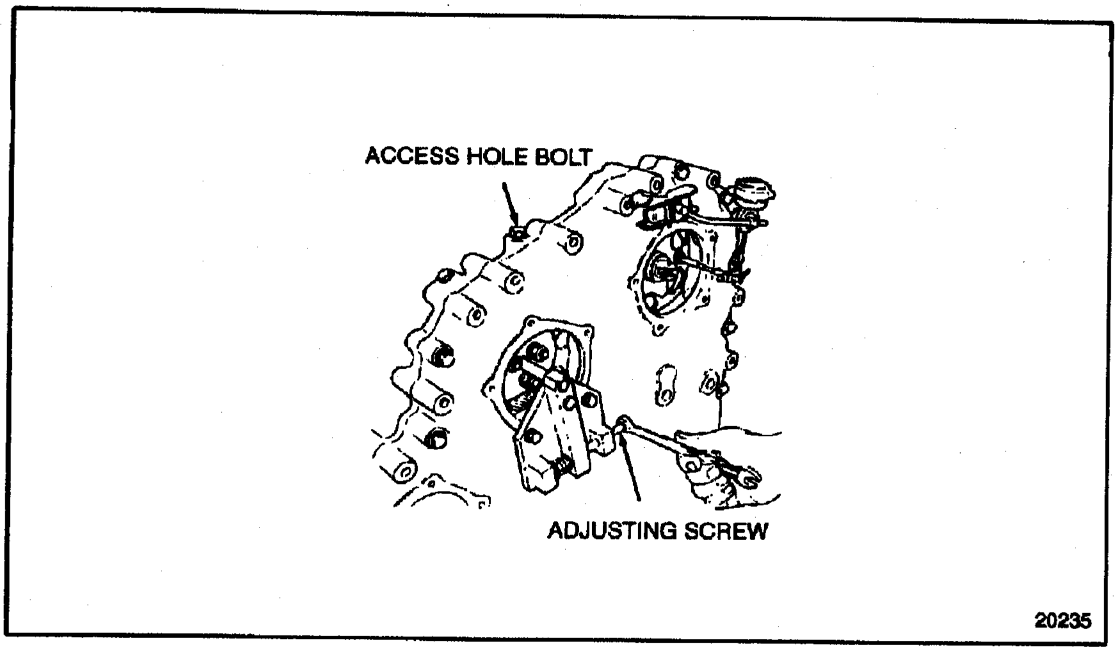

Figure 1-311 Adjustable Idler Gear-to-Camshaft Drive Gear Lash Adjustment

[h] Zero the dial indicator.

[i] Hold the adjustable idler gear by inserting a screwdriver through the hole provided in the gear case. Engage one of the adjustable idler gear teeth and apply pressure on the screwdriver to move the gear in a counterclockwise direction. This will prevent the gear from moving.

[j] Attempt to turn the camshaft drive gear, and watch the dial indicator pointer.

NOTE:
If there is zero lash between the two gears, the dial indicator pointer will not move from zero.

[k] Turn the adjusting screw of the tool approximately 1-1/2 turns or until the proper gear lash is obtained.

[l] When checking gear lash, hold the adjustable idler gear stationary. Refer to step 8[i] as the first step and refer to step 8[j]as the final step, and rotate the camshaft drive gear with your right hand. See Figure 1-312.

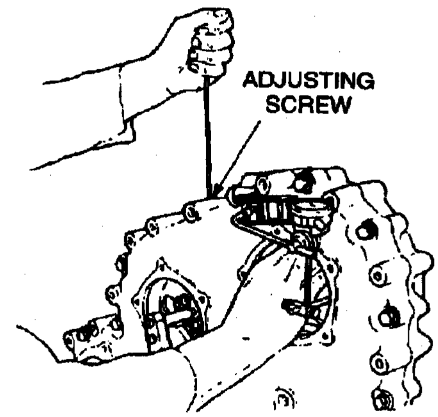

Figure 1-312 Checking Adjustable Idler Gear-to-Camshaft Drive Gear Lash

NOTE:
Remember to multiply the reading obtained by two to get the actual lash measurement. The specification of gear lash is 0.051-0.229 mm (0.002 -0.009 in.) with a maximum of 0.305 mm (0.012 in.) for used parts.

[m] Check the gear lash with the pedestal at the 3, 6, 9 and 12 o'clock positions, exactly as previously performed.

[n] When the proper readings of 0.025-0.114 mm (0.001 -0.0045 in.) are obtained at all four (4) positions, hold the idler gear. Refer to step 8[i] as the first step and refer to step 8[j] as the final step, and torque the top two adjustable idler gear flanged nuts to 57-67 N·m (42-49 lb·ft).

[o] Check the gear lash again as outlined above, with the flanged nuts torqued, to ensure that gear lash is still within limits.

[p] If proper lash measurement cannot be obtained, replace gear(s) with new part(s). Refer to section 1.24.2, refer to section 1.25.2, refer to section 1.27.2and refer to section 1.26.2.

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[q] Remove the gear lash adjusting tool from the gear case.

[r] Torque the bottom adjustable idler gear flanged nut to 57-67 N·m (42-49 lb·ft) torque.

[s] Remove the dial indicator and pedestal from the gear case.

[t] Before installing the rocker arm shaft assemblies, check the torque on the end studs to ensure they were not loosened at time of removal. The torque specification is 101-116 N·m (75-86 lb·ft).

[u] Install the rocker arm shaft assemblies to the cylinder head. Refer to section 1.3.3.

[v] Adjust the intake and exhaust valve clearances, and fuel injector heights. Refer to section 12.2.

[w] Install the valve rocker cover. Refer to section 1.6.8for a one-piece valve rocker cover and refer to section 1.6.9 for two-piece and three-piece rocker covers.

[x] Install the camshaft drive gear access cover and the gear case cover. Refer to section 1.10.3.

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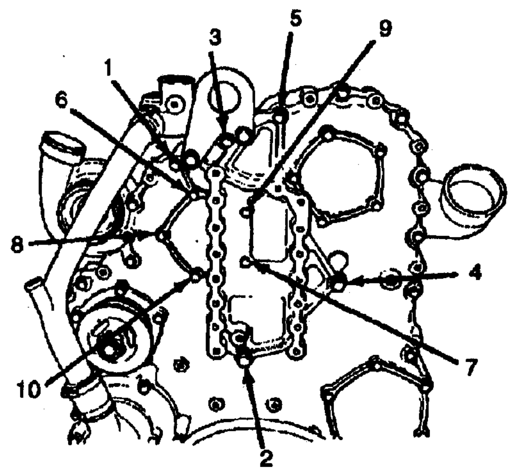
9. Install the fan support bracket "if required" as follows:

   [a] Clean the mating surfaces of the fan support bracket and gear case of all old gasket eliminator. Refer to the section on "Gasket Eliminator" in the "General Information" section at the beginning of this manual.

   [b] Apply a 1/16 in. bead of Gasket Eliminator PT-7276 (Loctite® 518), or equivalent, to the machined surface of the gear case cover surrounding the adjustable idler gear access.

   [c] Install the fan support bracket to the gear case cover using the torque values and tightening sequence. See Figure 1-313.



Bolt	Torque
1-3-5	58-73 N·m (43-45 lb·ft)
2-4	160-200 N·m (118-148 lb·ft)
6 to 10	30-38 N·m (22-28 lb·ft)

Figure 1-313 Fan Support Bracket Bolt Torque Sequence

10. Check the bull gear-to-accessory drive gear lash measurement as follows:

[a] Install the gear lash tool, J 38662 and mount a magnetic dial indicator base and dial indicator to the gear case cover. See Figure 1-314.

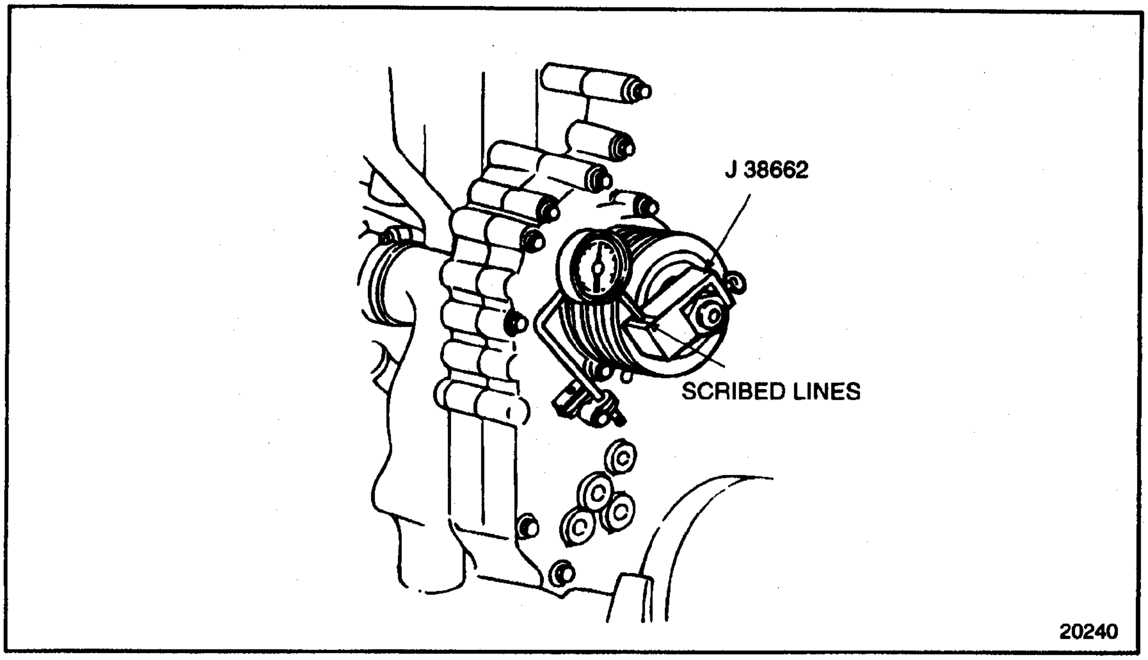


Figure 1-314 Accessory Drive Gear-to-Bull Gear Lash Measurement

[b] Position the dial indicator to read between the scribed lines on the tool. See Figure 1-314.

[c] Rotate the accessory drive pulley, read and record the total gear lash.

[d] Gear lash measurements are 0.051-0.229 mm (0.002 -0.009 in.) for new parts, and 0.305 mm (0.012 in.) for used parts.

[e] If proper lash measurement cannot be obtained, replace gear with a new part. Refer to section 1.26.2.

[f] Remove the dial indicator and gear lash tool.

11. Check the bull gear-to-water pump drive gear lash measurement for 1991 and later engines (with water pump impeller slip tester, J 35687-1) as follows:

NOTE:
The bull gear-to-water pump drive gear lash can be measured using the water pump impeller slip tester, J 35687-1, refer to step 11[a] through step 11[g]. Or by using the water pump gear lash tool, J 38977, refer to step 12Early built 1991 engines will need the water pump gear lash checked with the slip tester. These engines do not have a threaded hole in the water pump drive gear retaining bolt to accept the gear lash tool.

CAUTION:

To avoid injury from flying parts when working with components under spring tension, wear adequate eye protection (face shield or safety goggles).

[a] Remove the water pump cover snap ring with snap ring pliers. Remove water pump cover and seal ring.

[b] Install the water pump impeller slip tester, J 35687-1, to the water pump impeller with two 5/16-18 bolts, using the instructions supplied with the tool. See Figure 1-315.

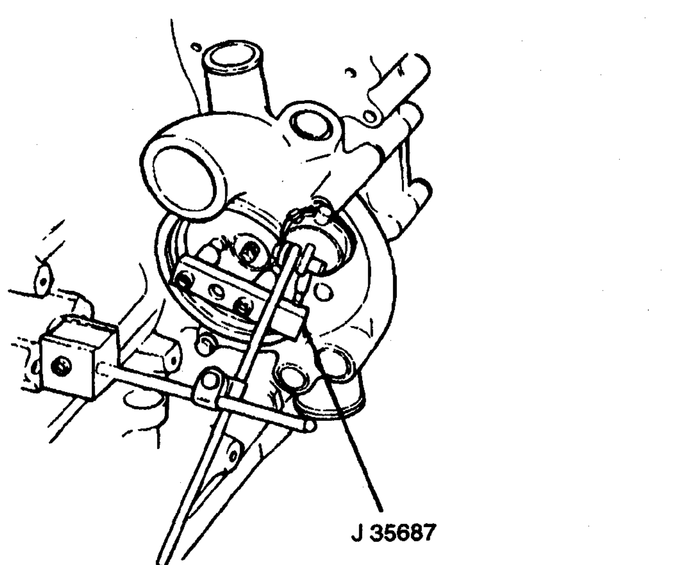


Figure 1-315 Water Pump Impeller Slip Tester Method

[c] One leg (the long one) of the tool has an inscribed line. Measuring with a dial indicator at this line of the tool, the gear lash measurement will be an exact 1:1 reading. Gear lash specifications are 0.051-0.229 mm (0.002 -0.009 in.).

[d] If proper lash cannot be obtained, replace gear with a new part. Refer to section 1.26.2.

[e] Remove the dial indicator.

[f] Remove the tool from the water pump.

[g] Inspect the water pump cover seal for cracks or splitting. Refer to section 4.2.3.1 gear mounted or refer to section 4.3.3.1for front mounted water pump. Replace seal if damage is found.

12. Check the bull gear-to-water pump drive gear lash measurement for 1991 and later engines (with water pump gear lash tool, J 38977) as follows:

[a] Remove the pipe plug in the gear case cover.

[b] Install the water pump gear lash tool, J 38977-A, through the hole in the gear case and thread it into the special water pump drive gear retaining bolt. See Figure 1-316.

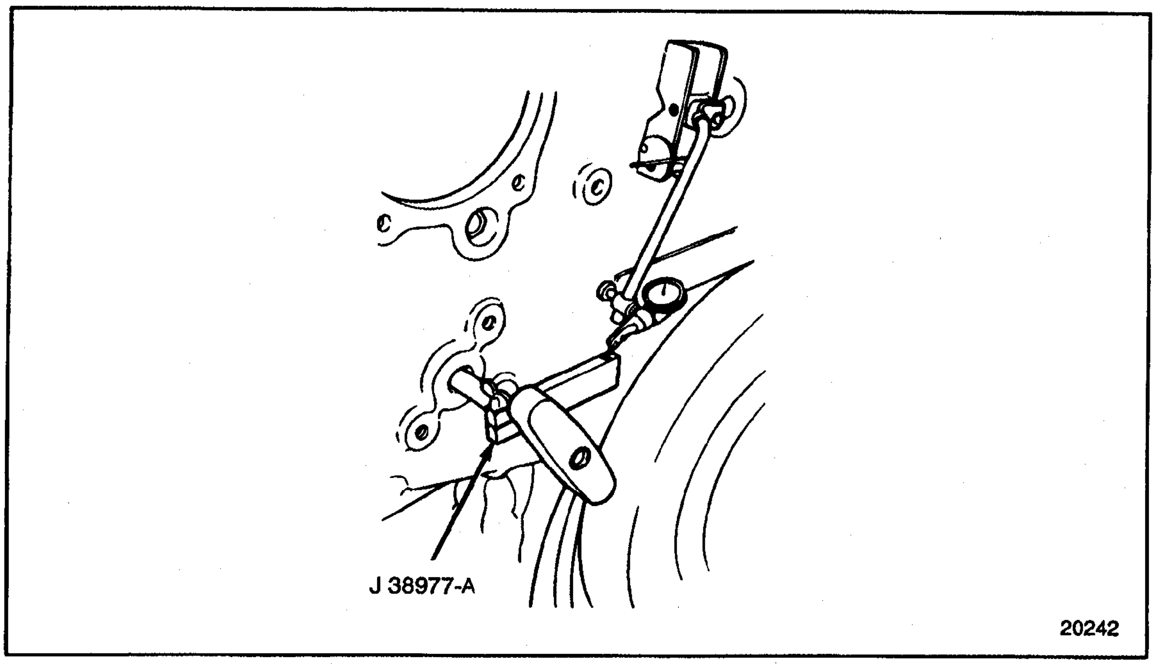


Figure 1-316 Water Pump Gear Lash Tool Method

[c] The arm of this tool has an inscribed line. Measuring with a dial indicator at this line of the tool, the gear lash measurement will be an exact 1:1 reading. Gear lash specifications are 0.051-0.229 mm (0.002 -0.009 in.).

[d] If proper lash cannot be obtained, replace the gear with a new part.

[e] Remove the dial indicator and the gear lash tool.

[f] Install the pipe plug in the gear case cover. Torque to 24-31 N·m (18-23 lb·ft).

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13. Check the bull gear-to-water pump drive gear lash measurement of pre-1991 engines (with the water pump impeller slip tester method) as follows.

NOTE:
Skip step 13 and the following step 14, if the engine was built after 1990.

NOTE:
The bull gear-to-water pump drive gear lash can be measured using the water pump impeller slip tester, J 35687-1, or by inserting a bolt into one of the tapped holes in the water pump impeller. The lash can then be measured using a dial indicator.

[a] Install the water pump impeller slip tester, J 35687-1, to the water pump impeller with two 5/16-18 bolts, using the instructions supplied with the tool. See Figure 1-317.

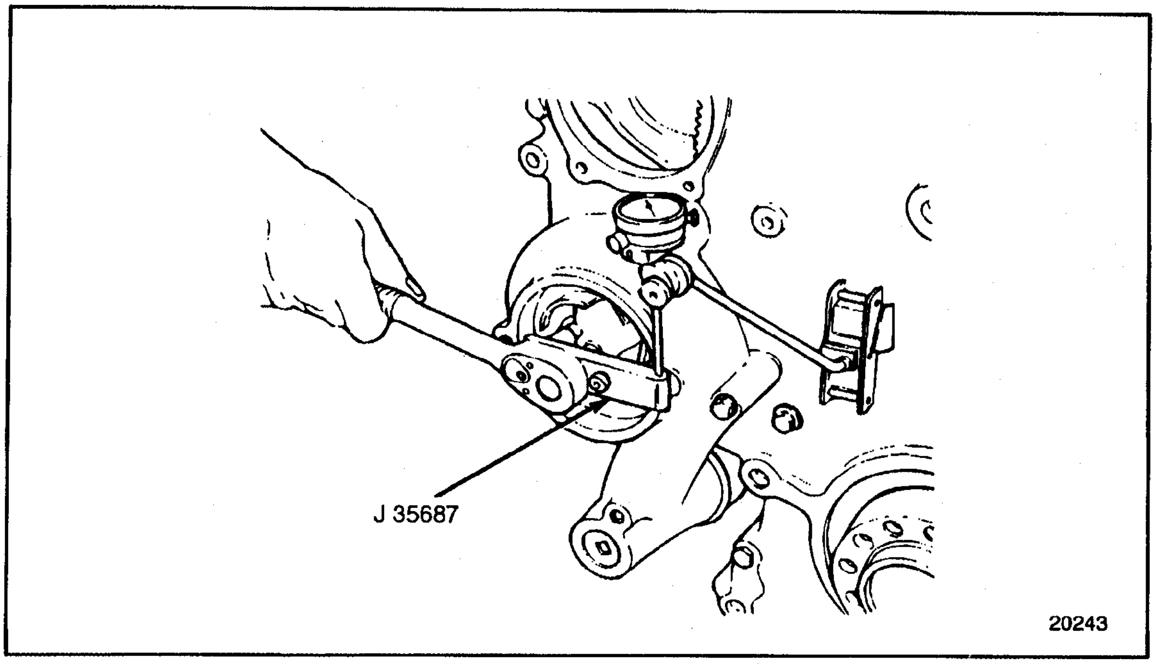

Figure 1-317 Water Pump Drive Gear Lash Measurement

[b] One leg (the long one) of the tool has an inscribed line. Measuring with a dial indicator at this line of the tool, the gear lash measurement will be an exact 1:1 reading. Gear lash specifications are 0.051-0.229 mm (0.002 -0.009 in.).

[c] If proper lash measurement cannot be obtained, replace the gear with a new part. Refer to section 1.26.2.

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14. Check the bull gear-to-water pump drive gear lash measurement for pre-1991 engines (with the bolt method) as follows:

    [a] Install a 5/16-18 bolt and nut into one of the tapped holes in the water pump impeller. See Figure 1-318.

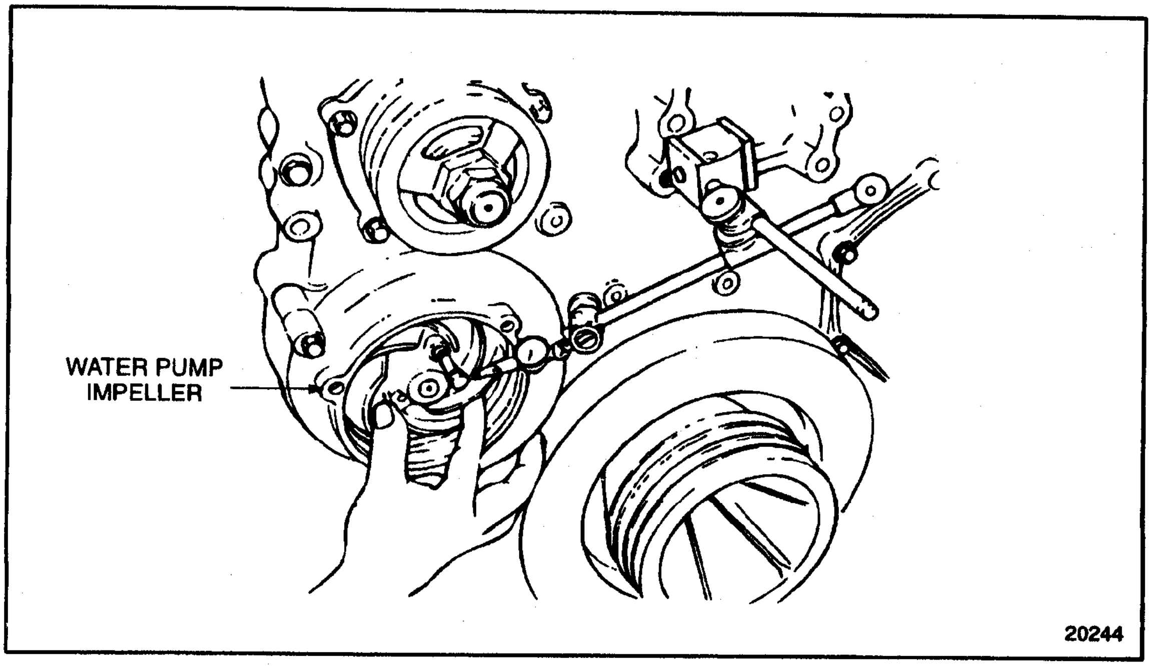

Figure 1-318 Water Pump Drive Gear-to-Bull Gear Lash Measurement

[b] Install a magnetic dial indicator base and dial indicator. See Figure 1-318.

[c] Position the stem of the dial indicator on a flat of the bolt.

[d] Preload the water pump impeller.

[e] Zero the dial indicator.

[f] Rotate the water pump impeller, read and record the total gear lash. Multiply this reading by 2.45 to obtain actual lash. Gear lash measurements are 0.051 to 0.229 mm (0.002 -0.009 in.).

[g] If proper lash cannot be obtained, replace the gear with a new part. Refer to section 1.26.2.

[h] Remove the dial indicator base and dial indicator.

[i] Remove the bolt and nut from the water pump impeller (if used).

[j] Inspect the rubber seal ring on the water pump cover for splitting or cracks. Install a new seal, if necessary, between the water pump cover and the water pump housing. Refer to step 11, and perform step 11[g].

[k] Install the two bolts that secure the water pump cover to the water pump housing. Torque the bolts to 30-38 N·m (22-28 lb·ft).

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15. Check the bull gear-to-air compressor drive gear lash measurement as follows:

    [a] Mount a magnetic dial indicator base and dial indicator to the gear case cover so that the stem of the dial indicator may be positioned on a tooth of the air compressor drive gear.

    [b] Preload the drive gear in one direction.

    [c] Zero the dial indicator.

    [d] Rotate the air compressor drive gear, read and record the total gear lash. Gear lash measurements are 0.051-0.229 mm (0.002 -0.009 in.) for new parts, with a maximum of 0.305 mm (0.012 in.) for used gears.

    [e] If proper lash cannot be obtained, replace the gear with a new part. Refer to section 1.26.2.

    [f] Remove the dial indicator and magnetic base.

    [g] Install the power steering drive coupling to the air compressor drive gear (if equipped with power steering) and insert a new O-ring on the power steering pump (if so equipped).

    [h] Install the power steering pump to the gear case cover, meshing the drive coupling properly.

    [i] Install and torque the power steering pump mounting bolts to 30-38 N·m (22-28 lb·ft). Tighten the five bolts alternately and evenly, in a star-shaped pattern, to progressively draw the power steering pump into the gear case cover.

NOTE:
Do not force the bolts. If resistance is encountered, remove the power steering pump and re-engage the drive hub with the coupling.

    [j] If the engine is not equipped with power steering, install the air compressor drive gear access cover using a new gasket.

    [k] Install and torque the retaining bolts to 30-38 N·m (22-28 lb·ft), using a star-shaped pattern.

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1.21.3 Installation of Gear Train and Engine Timing

After all of the gear lash measurements have been taken, assemble the engine components as follows:

1. Install the air conditioner compressor and brackets (if so equipped). Install the air conditioner drive belt.
2. Install the alternator and brackets. Refer to section 8.2.3.
3. Install the alternator drive belts. Refer to section 13.13.10.
4. Install the fan and fan hub assembly. Refer to section 4.7.6.
5. Adjust the alternator, fan and air conditioner compressor drive belts to the specifications. Refer to section 13.13.10. Torque the accessory mounting bolts to specifications.
6. Install any other equipment such as hoses, brackets, lines or electrical looms that were removed to gain access to the engine gear case cover.
7. Install the engine oil pan. Refer to section 3.11.4.
8. Fill the engine crankcase. Refer to section 13.13.1.
9. Refer to section 11.8 for verification of proper gear train and engine timing.

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1.22 THRUST PLATE PERIMETER SEAL

The camshaft thrust plate perimeter seal forms a seal between the camshaft thrust plate and the gear case cover. If the seal should require replacement due to leakage, the seal can be replaced without removing the cylinder head. The following procedure should be used if the perimeter seal requires replacement.

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1.22.1 Repair or Replacement of Thrust Plate Perimeter Seal

To determine if repair or replacement of the thrust plate perimeter seal is necessary, perform the following procedure. See Figure 1-319.

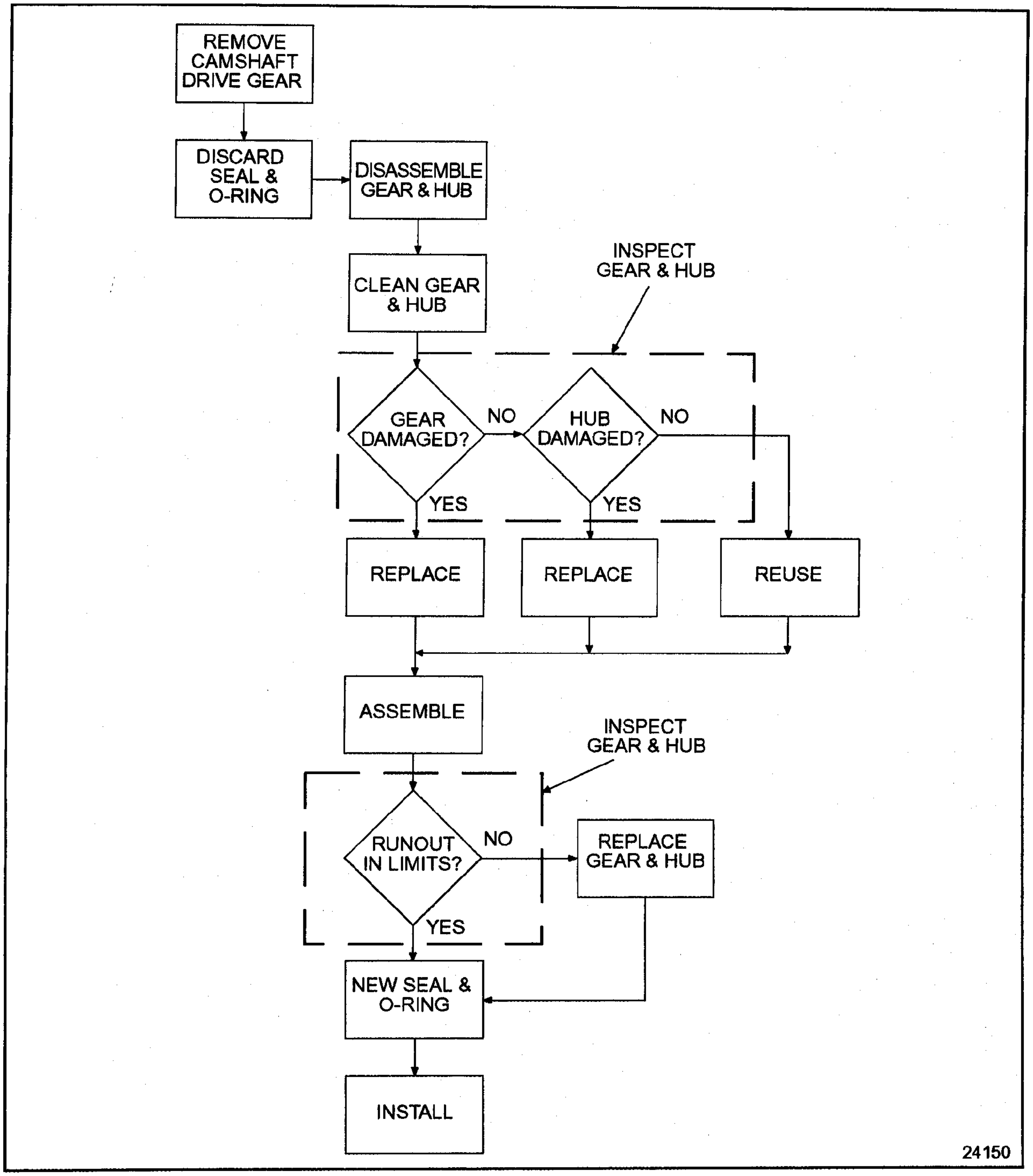

Figure 1-319 Flowchart for Repair or Replacement of Camshaft Thrust Plate Perimeter Seal

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1.22.2 Removal of Thrust Plate Perimeter Seal

Remove the thrust plate perimeter seal as follows:

1. Remove the air cleaner and charge air cooler ducting from the turbocharger and air intake manifold. Refer to section 6.2.2.
2. If the upper radiator hose prevents removal of the valve rocker cover, drain coolant into a suitable container until it is below the level of the thermostat housing outlet. Then disconnect the hose from the thermostat housing. Refer to section 4.5.2.
3. Remove the valve rocker cover. Refer to section 1.6.1.
4. Remove the five bolts that secure the camshaft drive gear access cover to the gear case cover. See Figure 1-320.

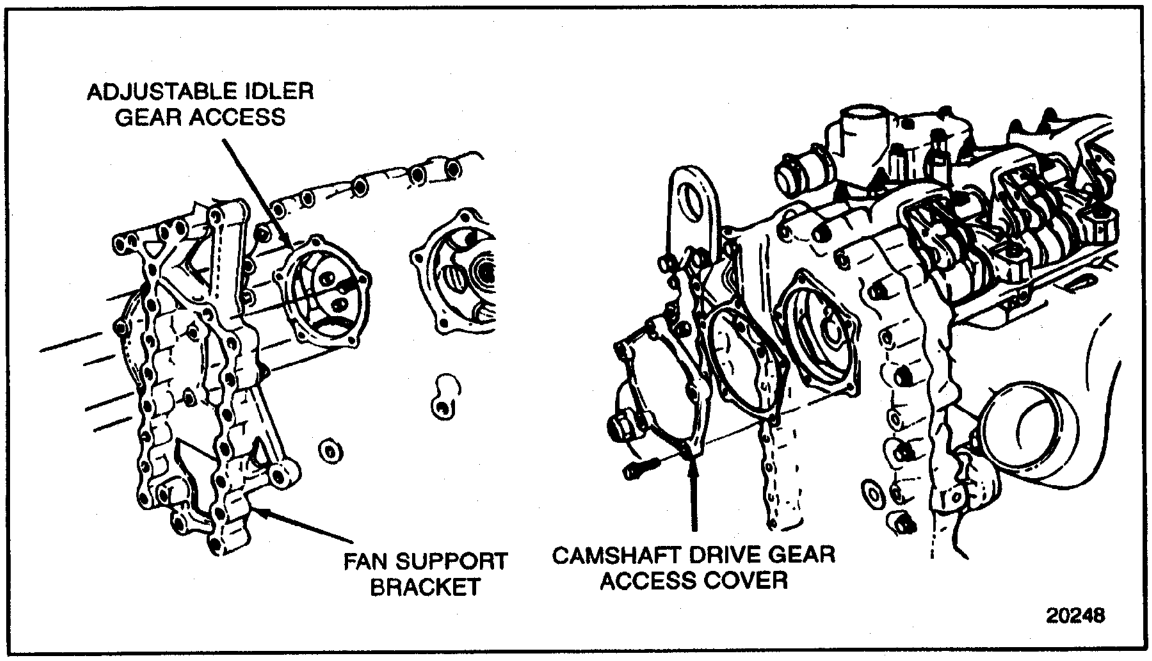

Figure 1-320 Camshaft Drive Gear Access Cover and Adjustable Idler Gear Access

5. Remove Jake Brakes®, if equipped. Refer to section 1.29.2.
6. Remove the rocker and rocker shaft assemblies. Refer to section 1.3.2.
7. Using LPS® Contact Cleaner or equivalent residue-free solvent, clean the gear case back/thrust plate area to improve visual access to the seal area. Wipe the area dry with paper towels.
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8. Using an appropriate marker, scribe a vertical locator line across the gear case and the back face of the camshaft thrust plate. This will insure proper positioning of the thrust plate during reassembly. See Figure 1-321.

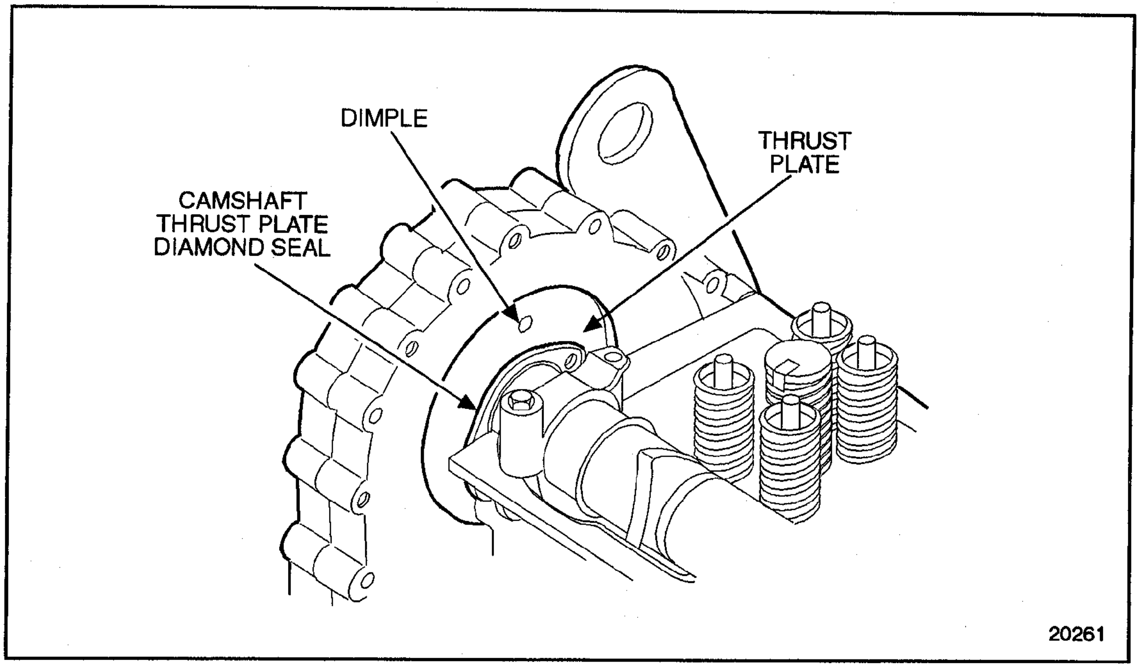

Figure 1-321 Camshaft Thrust Plate Clearance

9. Using the square hole in the middle of the crankshaft pulley, rotate the crankshaft to align the lightening holes in the camshaft drive gear with the camshaft thrust plate mounting bolts, providing access to the bolts.

10. Using an appropriate marker such as a grease pencil, mark the gear teeth. This will insure proper cam timing during reassembly.

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11. Insert the shoe of the camshaft drive gear torque holding tool, J 35652, through a lightening hole of the camshaft drive gear. See Figure 1-322.

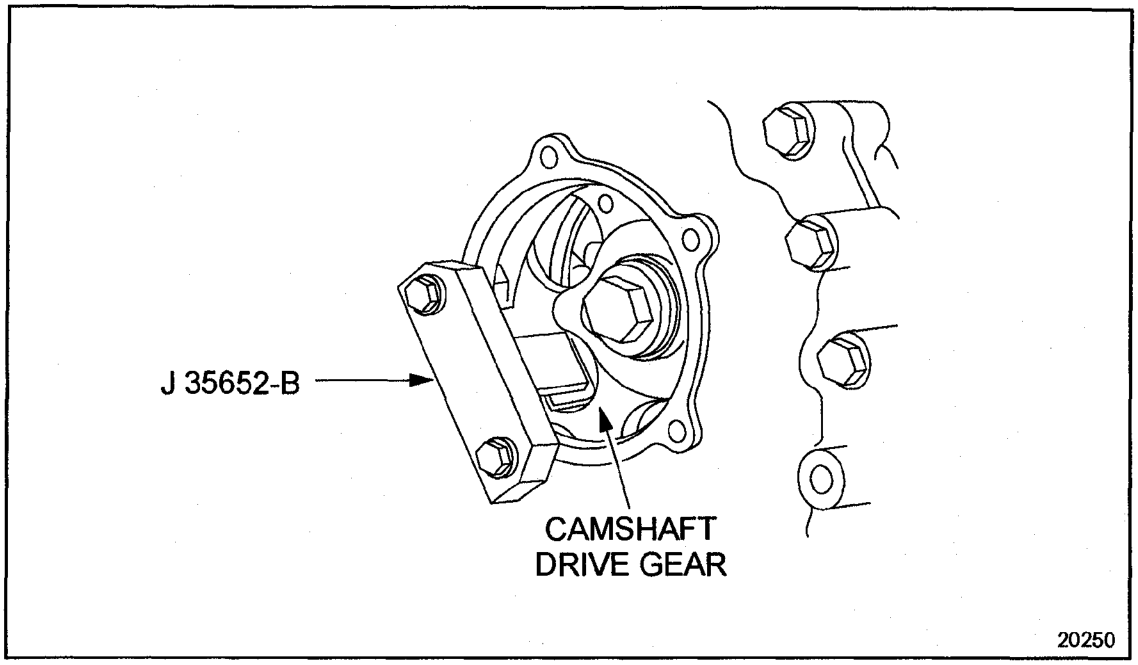

Figure 1-322 Installation of Camshaft Drive Gear Torque Holding Tool

12. Using the 3/4 in. square hole in the center of the crankshaft pulley, bar the engine over slightly so that the bolt holes in the holding tool align with the access cover bolt holes in the gear case cover.
13. Install the camshaft drive gear torque holding tool, J 35652, to the gear case, engaging one of the lightening holes in the camshaft drive gear. Use two of the access cover bolts to secure the tool to the gear case cover.
14. Using a long 3/4 in. drive breaker bar and a 27 mm impact socket, remove the camshaft drive gear mounting bolt. Discard the bolt.
15. Remove camshaft drive gear torque holding tool J 35652 from the gear case cover.
16. Insert a clean shop towel into the gear case opening to prevent removed bolts from falling into the gear case.

NOTICE:
Do not allow bolts or the shop towel to fall into the gear case. Failure to remove loose bolts or the shop towel from the gear case may result in severe gear train damage at engine startup.

17. Remove the two camshaft thrust plate mounting bolts carefully to avoid dropping them into the gear case. Refer to section 1.23.2.

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18. Reverse camshaft gear pilot tool J 35906 by turning it 180 degrees and install it to the camshaft drive gear access opening using three of the access cover bolt holes. The J tool number should face away from the engine and the hub end of the tool should be inside the access hole. Tighten the three tool retaining bolts.
19. Engage the puller bolt in the threads of the camshaft drive gear hub until the bolt is tight. Turn the bolt clockwise, pulling the thrust plate towards the front of the engine approximately 6-7 mm (1/4 in.) until the camshaft hub contacts the J tool and the perimeter seal is clearly accessible. The gap between the end of the camshaft and the thrust plate should be wide enough to permit the perimeter seal to pass through.
20. Remove the number 1 camshaft bearing cap using socket tool J 36003 part of J 36003–A . See Figure 1-323.

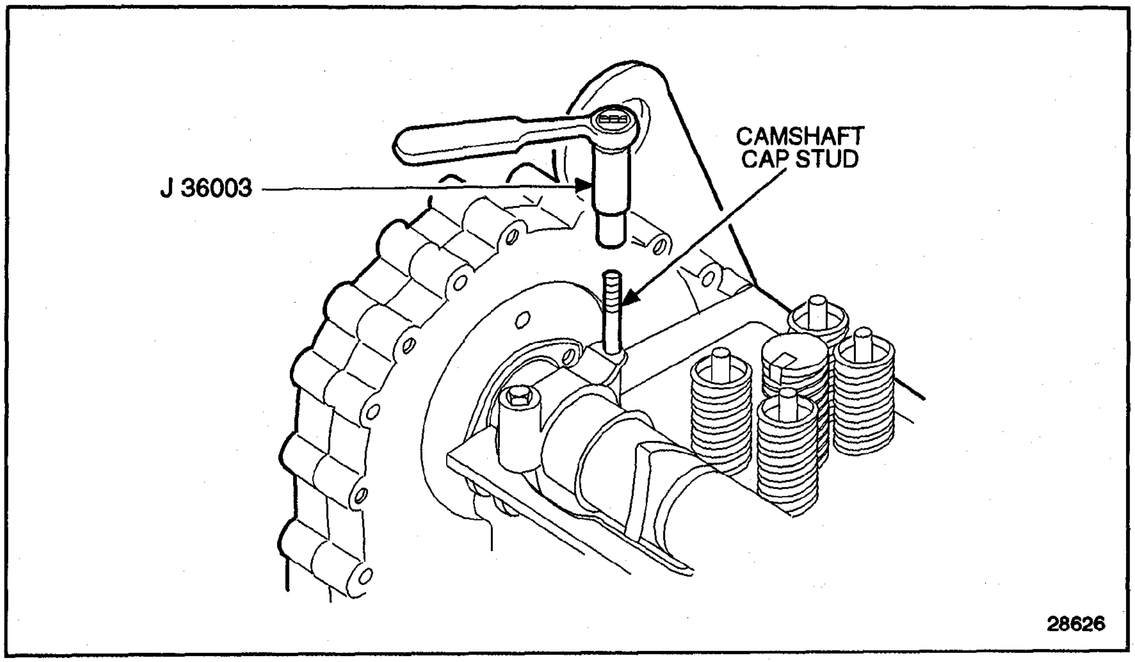

Figure 1-323 Removal of Camshaft Cap Stud

21. Using a flat-bladed screwdriver on the side of one of the camshaft lobes, lever the camshaft back and away from the thrust plate.
22. Using a hook-end pick, J 39227, reach into the thrust plate bore in the gear case, hook the perimeter seal, and pull it off of the thrust plate. Pass the seal between the thrust plate and camshaft and discard. Pull the diamond seal from the thrust plate groove and discard.

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1.22.2.1 Inspection of Thrust Plate Perimeter Seal Groove

Inspect the thrust plate perimeter seal groove as follows:

1. Rotate the thrust plate by hand and visually inspect to make sure all seal material is completely out of the seal groove. If necessary, use a work light or flashlight to thoroughly inspect the groove.
2. Wipe the groove clean after inspection.

1.22.3 Installation of Thrust Plate Perimeter Seal

Install the thrust plate perimeter seal as follows:

NOTICE:
Failure to install seals properly, failure to install new, dry (no lubrication) bolts where required, or failure to tighten bolts to the required torque using an accurately calibrated hand torque wrench may result in bolt loosening and loss of clamping load, which may cause severe engine damage.

NOTICE:
Do not use RTV or any other type of sealant on the thrust plate perimeter seal. Application of sealant will prevent proper seal crush (flow), which may result in seal leakage.

1. Lubricate a new perimeter seal with clean engine oil and, after passing it between the thrust plate and cylinder head, carefully install it in the thrust plate groove. If necessary, blunt the end of a hook type pick and use the curve of the pick to push the seal into the groove . The former two-bolt thrust plate oil seal design was redesigned to provide superior oil sealing characteristics. See Figure 1-324 for design configuration. The current thrust plate oil seal uses a three-bolt design, as of serial number 6R352129.

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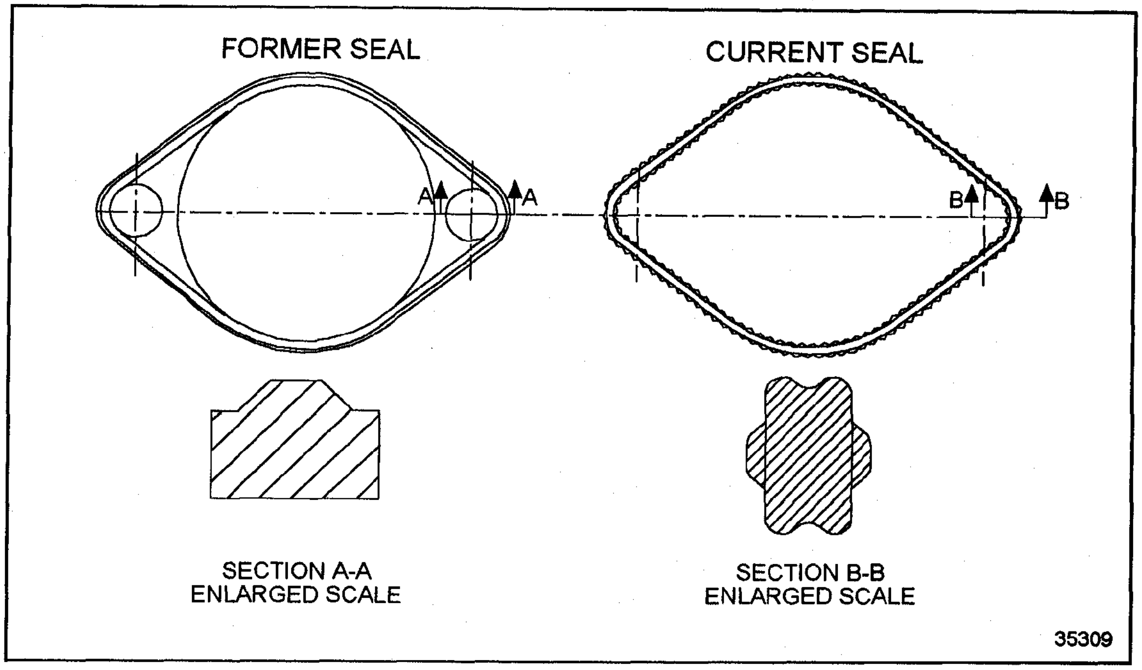

Figure 1-324 Camshaft Thrust Plate Oil Seal

NOTE:

The point of the hook must be blunted to avoid damaging the seal.

2. Rotate the thrust plate by hand and visually inspect to insure the seal is fully seated in the thrust plate groove. If necessary, use a work light or flashlight to make sure the seal is seated.

NOTICE:
Failure to properly seat the perimeter seal in the thrust plate groove will result in seal leakage during engine operation.

3. Inspect the thrust plate diamond seal groove to make sure all seal material is removed. Clean the diamond seal groove with LPS® Contact Cleaner or equivalent residue-free cleaner. *Do not use mineral spirits, since this will leave a residue.* Wipe and dry the area thoroughly with clean paper towels.

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CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

NOTICE:

Always bow out the cam cap bolt holes in the cylinder head before applying sealant and installing the cam cap. Failure to observe this step may cause lubricating oil trapped in the holes to push the sealant away from the cap when bolts are installed, resulting in a leak path.

4. For proper adhesion of the sealant at the cam cap/cylinder head joints, this area *must* be completely cleaned and all residue removed before new sealant is applied. Clean the cylinder head and bearing cap contact surfaces thoroughly with LPS® Contact Cleaner or equivalent residue-free cleaner. Wipe dry with clean paper towels.

NOTICE:

Failure to clean surfaces completely and remove all residue may result in improper gasket eliminator application, which may cause oil seepage during engine operation.

NOTICE:

Do not use RTV or any other type of sealant or spray adhesive on the camshaft diamond seal. Application of sealant or adhesive will prevent proper seal crush (flow), which may result in seal leakage.

NOTE:

Camshaft thrust plate diamond seals are not reusable. When replacement of a perimeter seal or removal of the camshaft is required, a new camshaft diamond seal *must* be installed.

5. Install a new diamond seal in the thrust plate, making sure it is securely seated in the thrust plate seal groove.

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6. For engines built after May 1999, use sealant 23525918 (50 mL) or 23525919 (330 mL) in the two diagonal groove cuts of the front bearing cap only. For engines built prior to May 1999, apply DDC gasket eliminator 23523064, or equivalent, to the joint surfaces of the number 1 camshaft bearing cap. See Figure 1-325. To help insure proper adhesion of the gasket eliminator to the bearing cap, do not apply oil to the number 1 cam bearing or journal before installation of the bearing cap.

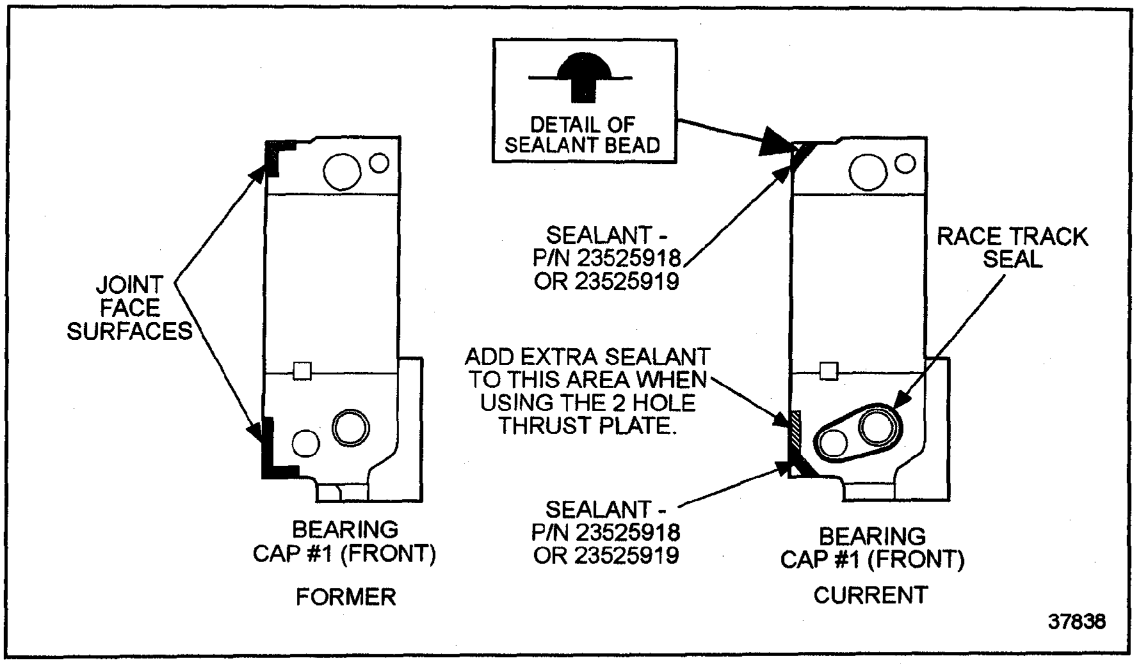
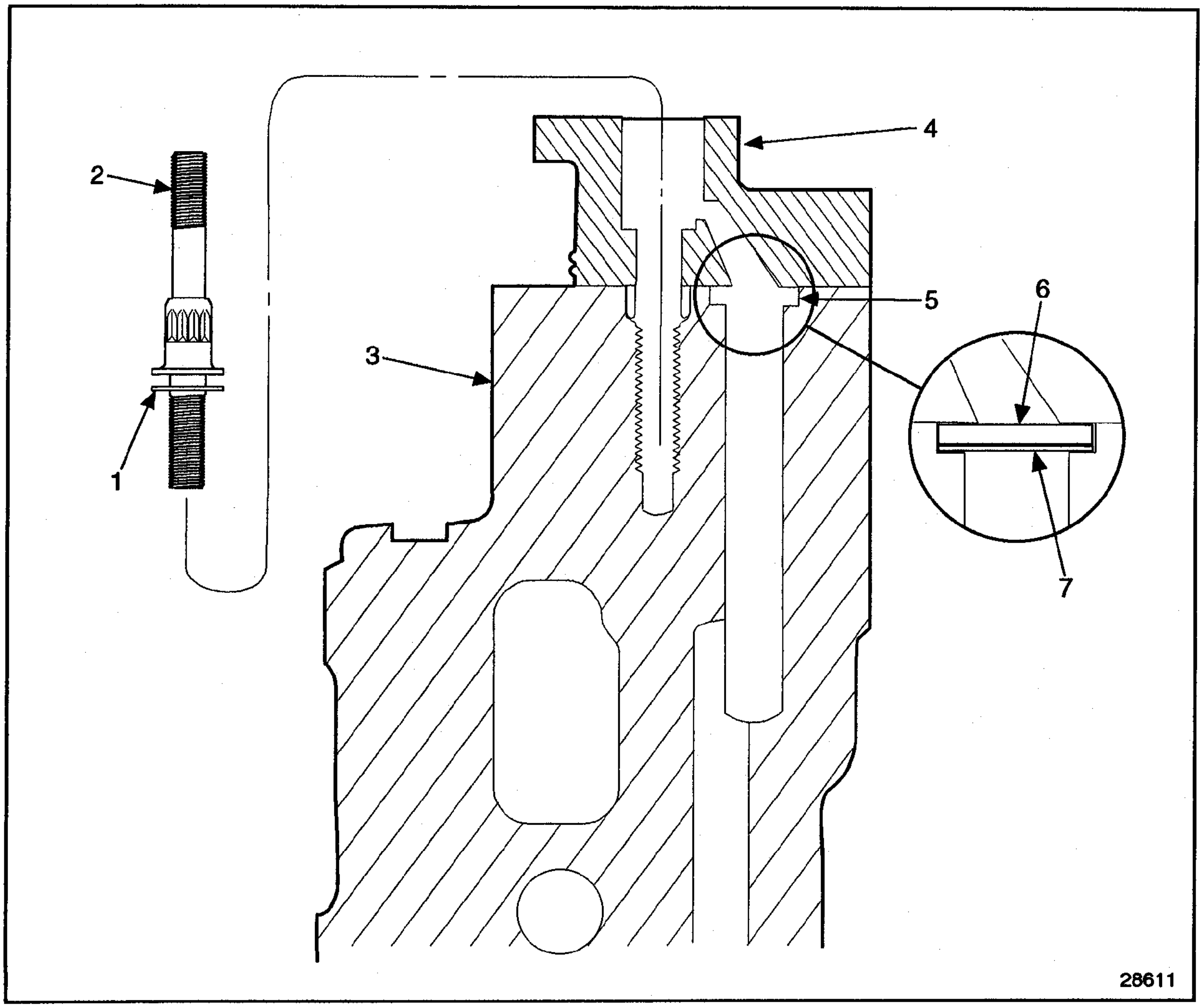


Figure 1-325 Gasket Eliminator Application

7. When replacing the number 1 cam cap on engines with serial numbers between 06R0295500 and 06R0301875, the depth of the cam cap oil passage seal recess in the cylinder head *must* be measured before camshaft cap installation. See Figure 1-326.



1. Bearing Cap Stud Seal
2. Bearing Cap Stud
3. Cylinder Head
4. Camshaft Bearing Cap
5. Bearing Cap Oil Passage
6. Oil Passage Seal Ring
7. Shim (If Required)

Figure 1-326 Cross-sectional View of Cylinder Head and Camshaft Bearing Cap

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NOTICE:

Failure to install the shim under the seal when cam bearing cap seal bore depth is more than 3.04 mm may result in oil leakage around the seal during engine operation.

8. If bore depth is not within 2.64 mm - 3.04 mm, seal shim part number 23521153 *must* be installed *under* the square cut ring seal to provide proper sealing.
9. With a new square cut seal (and shim, if required) installed in the cylinder head oil passage seal recess, replace the number 1 cam cap. Install a new cap stud seal (part number 23521111) onto the flange of the camshaft cap stud, then thread the stud and the camshaft cam bolt into the cylinder head. See Figure 1-322. Alternating back and forth, torque cap stud and bolt progressively to 128–148 N·m (94–109 lb·ft).
10. Loosen the large center bolt of tool J 35906 until it almost disengages from the camshaft hub.
11. Align the dowel on the camshaft with the cam hub. Push rearward on the tool J 35906 bolt while centering the thrust plate in the gear case bore and observing the alignment marks made previously on the thrust plate and gear case.
12. Install a metric bolt and washer in a gear case cover bolt hole next to the access hole.

NOTE:

To insure proper camshaft-to thrust plate alignment, the scribe marks on the gear case and thrust plate *must* be aligned before the thrust plate is reinstalled in the gear case.

13. Carefully align the scribe marks on the thrust plate and gear case. Then, using a flat-bladed screwdriver or pry bar placed on the bolt washer and working from side to side, lever the thrust plate back toward the camshaft. With the thrust plate securely installed in the gear case, remove the metric bolt and washer carefully to avoid dropping them into the gear case.

NOTICE:

Improper installation of the camshaft thrust plate bolts may result in thrust plate bolt stretching or breakage. Bolt stretching may result in an inaccurate torque. Bolt breakage may cause severe gear train damage.

14. Remove tool J 35906. Carefully install new, dry (no lubrication) thrust plate mounting bolts through the thrust plate and into the cylinder head and No. 1 camshaft bearing cap. Using a 13 mm socket and an accurately calibrated hand torque wrench, torque the bolts alternately and progressively to 30 - 38 N·m (22 - 28 lb·ft). To avoid excessive tightening and possible bolt stretching, do not use an air wrench, since this may not provide an accurate torque.

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NOTICE:
Always use a new bolt when replacing the camshaft hub. The camshaft retaining bolt is considered a single-use item and *cannot be reused,* regardless of apparent condition. Reusing this bolt may result in excessive bolt stretch, which could lead to loss of bolt torque, hub loosening, and severe engine damage.

15. Coat the threads and underside of the head of the camshaft drive gear-to-camshaft bolt with International Compound #2®. Check the marks previously made on the gear teeth to insure proper cam gear timing. Install the bolt to the camshaft, finger tighten.

NOTICE:
Only tool J 35652 should be used to hold the camshaft drive gear stationary while loosening or tightening the camshaft drive gear-to-camshaft bolt to prevent component damage.

NOTE:
The camshaft should be held in place while starting the camshaft drive gear-to-camshaft bolt, to prevent disengaging the camshaft dowel from the thrust plate hub, requiring disassembly and timing of the camshaft.

16. Insert tool J 35652 through a lightening hole of the camshaft drive gear.
17. Using the 3/4 in. square hole in the center of the crankshaft pulley, bar the engine over slightly to position the camshaft drive gear holding tool so that the bolt holes in the holding tool align with the access cover bolt holes in the gear case cover.
18. Install two of the access cover bolts to secure the tool to the gear case cover.

NOTE:
Ensure any residual oil is removed from the dowel face of the camshaft and mating hub before installing the drive gear.

19. Apply a light coating of International Compound #2® to the camshaft drive gear mounting bolt threads and the underside of the bolt head. Using a 27 mm impact socket and suitable torque wrench, torque the camshaft drive gear-to-camshaft bolt to 75 N·m (55 lb·ft). Then turn the bolts clockwise 120 degrees (two flats of the bolt head) to achieve the required torque.
20. Remove camshaft drive gear torque holding tool J 35652.
21. Install the access cover plate to the gear case cover. Refer to section 1.10.3.
22. Install the rocker and rocker shaft assemblies. Refer to section 1.3.3.
23. Install the Jake Brakes®, if equipped. Refer to section 1.29.5.
24. Install the valve rocker cover. Refer to section 1.6.7 or refer to section 1.6.8.
25. Install or reconnect any other components that were removed or disconnected for this procedure.

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1.23 CAMSHAFT AND CAMSHAFT BEARING

The Series 60 camshaft is located on top of the cylinder head, just below the valve cover. The camshaft actuates the intake and exhaust valves and injector operating mechanism. See Figure 1-327.

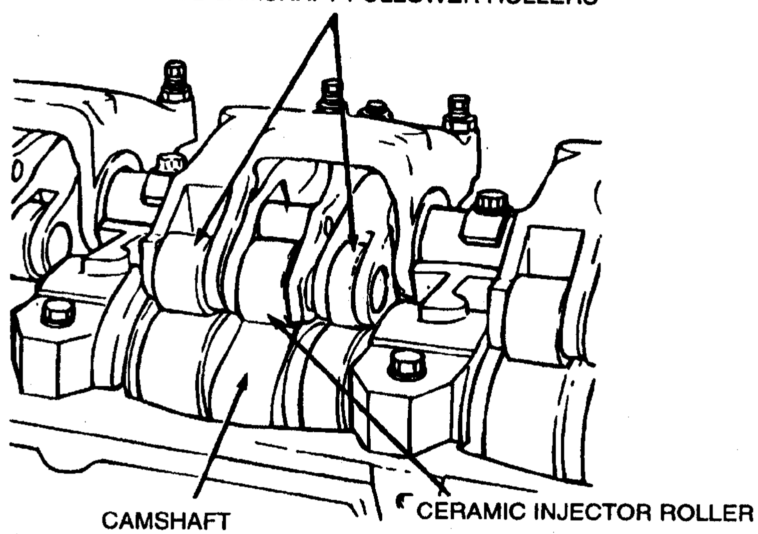

Figure 1-327 Camshaft and Related Parts

NOTE:
The Series 60G camshaft has no injector lobe on the cam.

The camshaft is supported by seven bearing assemblies, consisting of precision-type, replaceable bearing shell inserts that are split at their center lines. Current non-tin-plated production bearing shells are identified by their shiny aluminum color. Current tin-plated service bearing shells have a dull gray sheen. The lower bearing shell is positioned in a saddle that is integral with the cylinder head. The upper bearing shell is held in place by a machined camshaft cap. Upper and lower bearing shells are identical and have locating tangs and oil holes. Only the upper bearing shell oil holes index with oil supply holes in the camshaft caps. See Figure 1-328. These camshaft caps are precision line-bored after assembly to the cylinder head. Caps are NOT interchangeable once the head is finished. Caps are numbered and must NOT be interchanged with other caps of the same part number from stock or from a different cylinder head.

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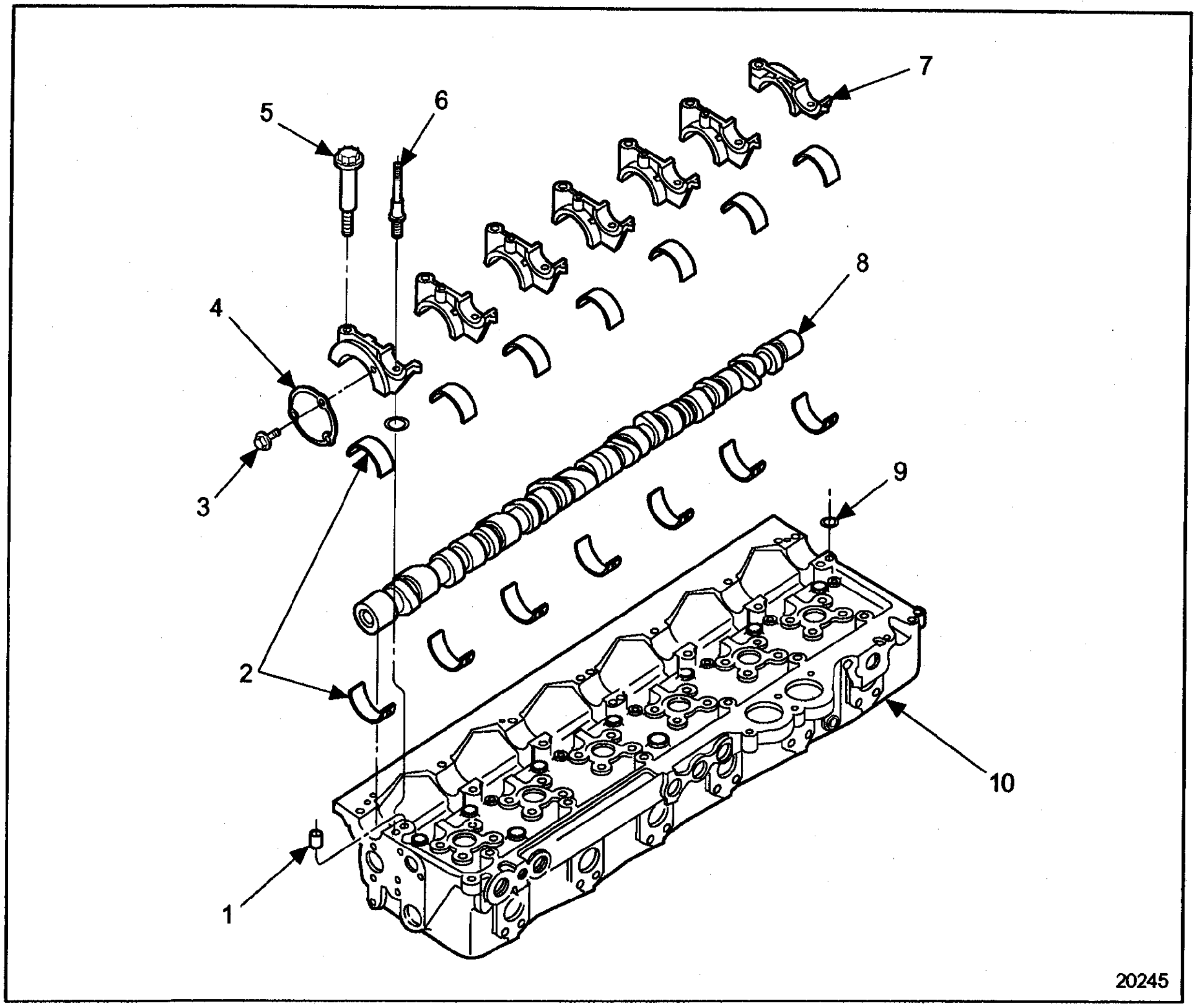

1. Dowel	6. Stud, Camshaft Cap (2)
2. Bearing Shells	7. Camshaft Cap
3. Bolt, Camshaft Cover	8. Camshaft
4. Rear, Camshaft Access Cover	9. O-ring
5. Bolt, Camshaft Cap (13)	10. Cylinder Head

Figure 1-328 Camshaft and Related Parts

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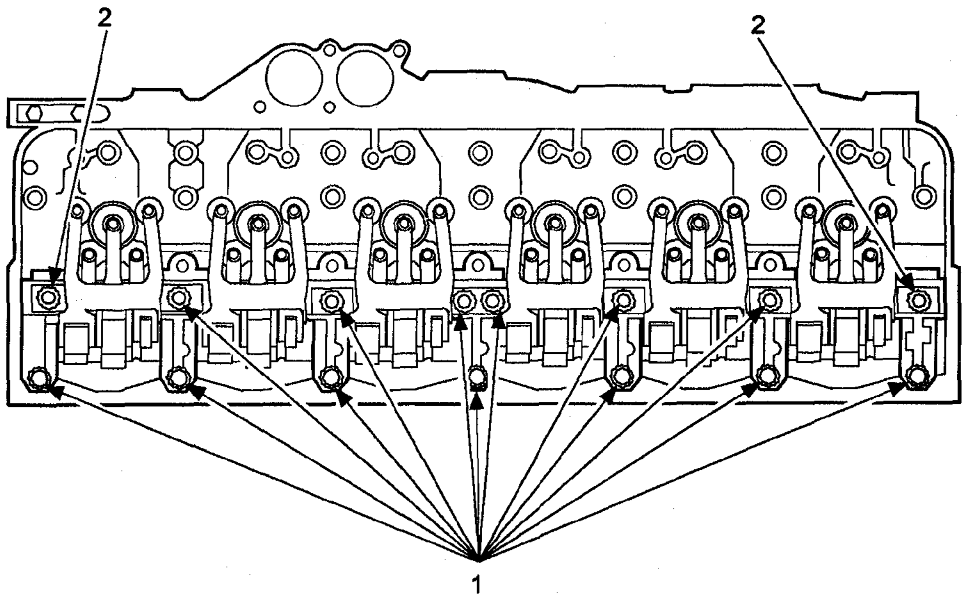
The No. 4 camshaft cap is secured to the cylinder head with three bolts; cap numbers 2, 3, 5, and 6 use two bolts each. Caps one and seven have a stud and one bolt each. The stud and nut arrangement on the end caps (1 and 7) allows rocker arm shaft removal without disturbing the gasket eliminator seal from the end camshaft caps to the cylinder head. There are four different camshaft cap configurations. Only the intermediate caps No. 2, 3, 5, and 6 are identical but must not be interchanged during re-assembly. See Figure 1-329.



1. Camshaft Cap Bolt (13)
2. Camshaft Cap Stud and Nut (2)

Figure 1-329 Camshaft Bolt and Cap Location

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The camshaft is driven by a camshaft drive gear, located in the gear case at the front of the engine and is driven, through a series of intermediate gears, by the crankshaft timing gear. Refer to section 1.21.2.1, for gear train information and camshaft drive gear lash measurement and adjustment procedures. See Figure 1-330.

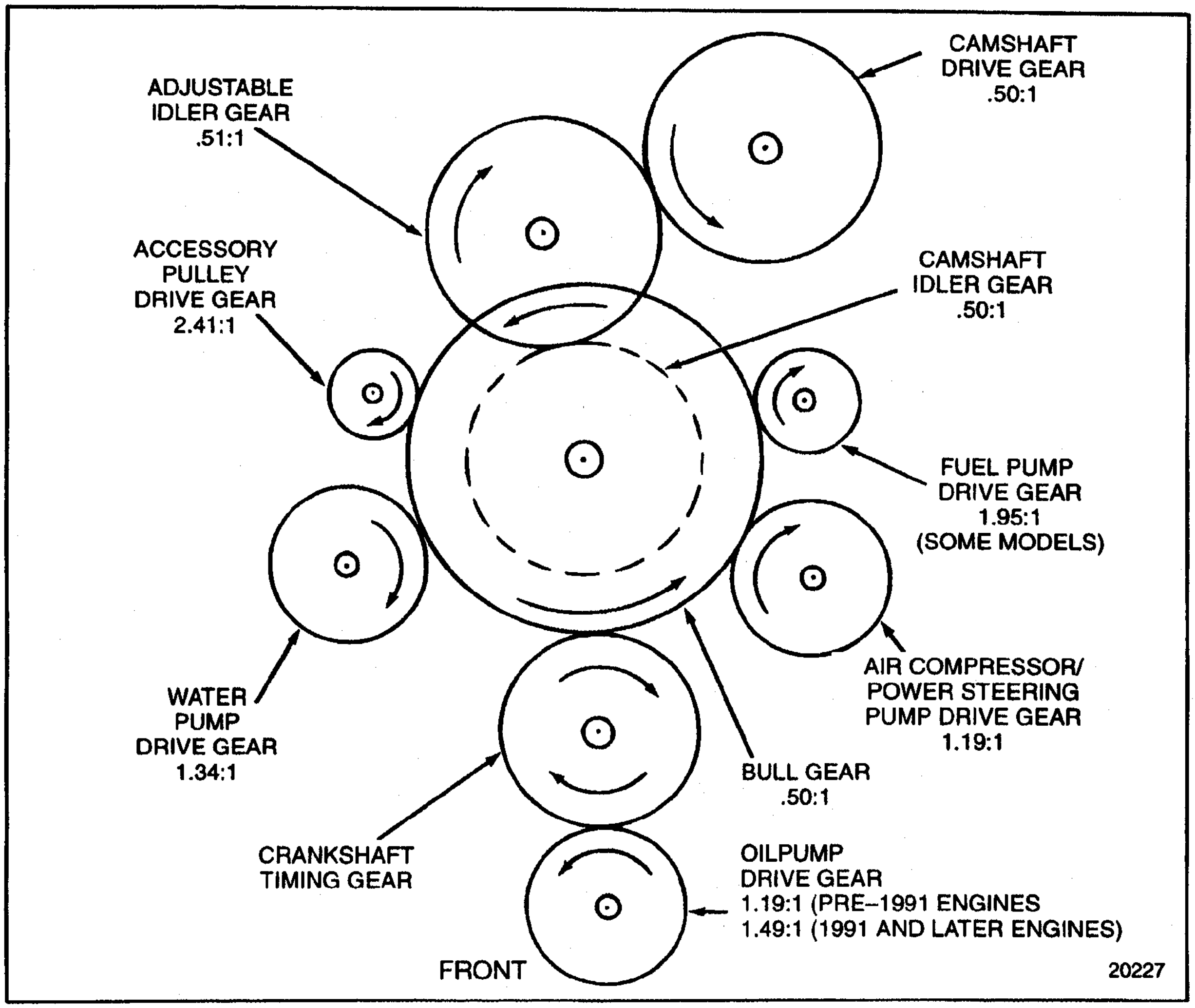

Figure 1-330 Engine Gear Train

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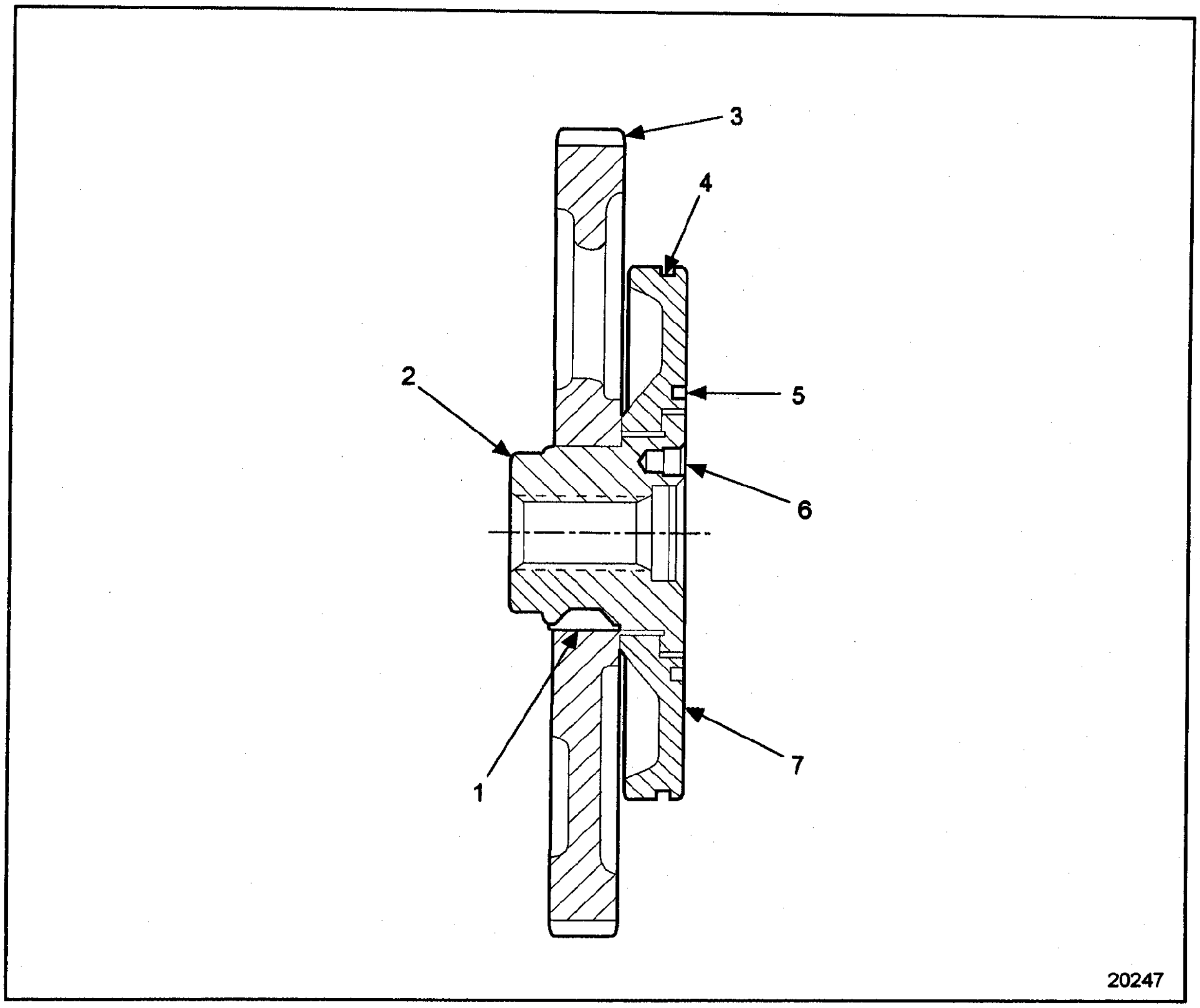
The camshaft drive gear is indexed to the camshaft drive gear hub by a Woodruff key and retained by a bolt which goes through the camshaft drive gear and hub and threads into the end of the camshaft. The camshaft has a dowel which indexes and fits into the mating hole in the camshaft hub. See Figure 1-331.



1. Woodruff Key
2. Camshaft Drive Gear Hub
3. Camshaft Drive Gear
4. O-ring Groove
5. Seal Groove
6. Camshaft Dowel Hole
7. Camshaft Thrust Plate

Figure 1-331 Cross-Section of Camshaft Drive Gear and Related Parts

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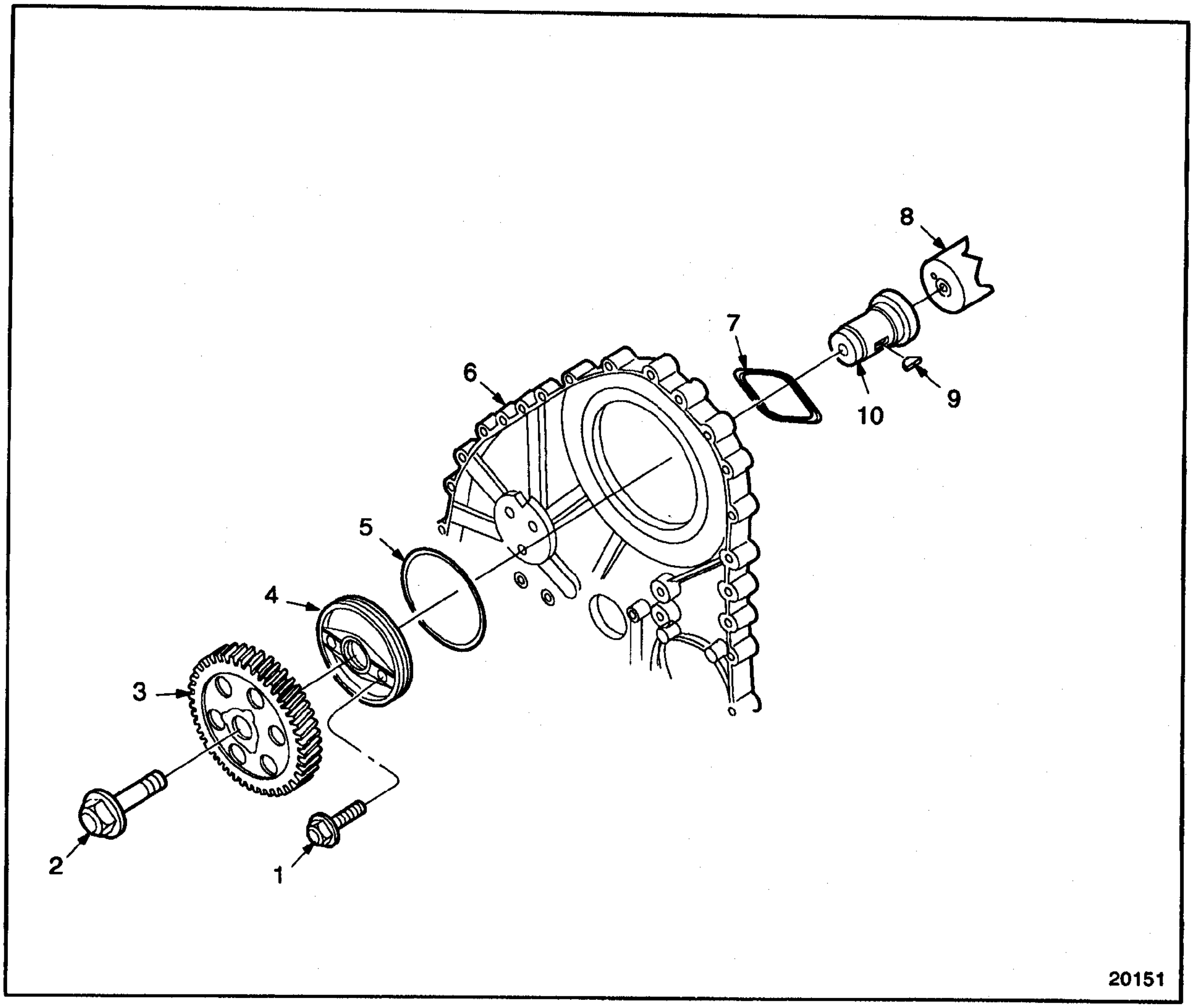
The camshaft hub is located in the camshaft thrust plate, which is positioned in an opening in the gear case housing. See Figure 1-332.



1. Bolt, Thrust Plate Retaining (2)
2. Bolt, Camshaft Hub Retaining
3. Drive Gear, Camshaft
4. Thrust Plate, Camshaft
5. O-ring
6. Gear Case
7. Seal, Thrust Plate
8. Camshaft
9. Key
10. Hub

Figure 1-332 Camshaft Thrust Plate and Related Parts

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Access openings are provided in the gear case cover for camshaft drive gear lash adjustment and camshaft retaining bolt removal. See Figure 1-333.

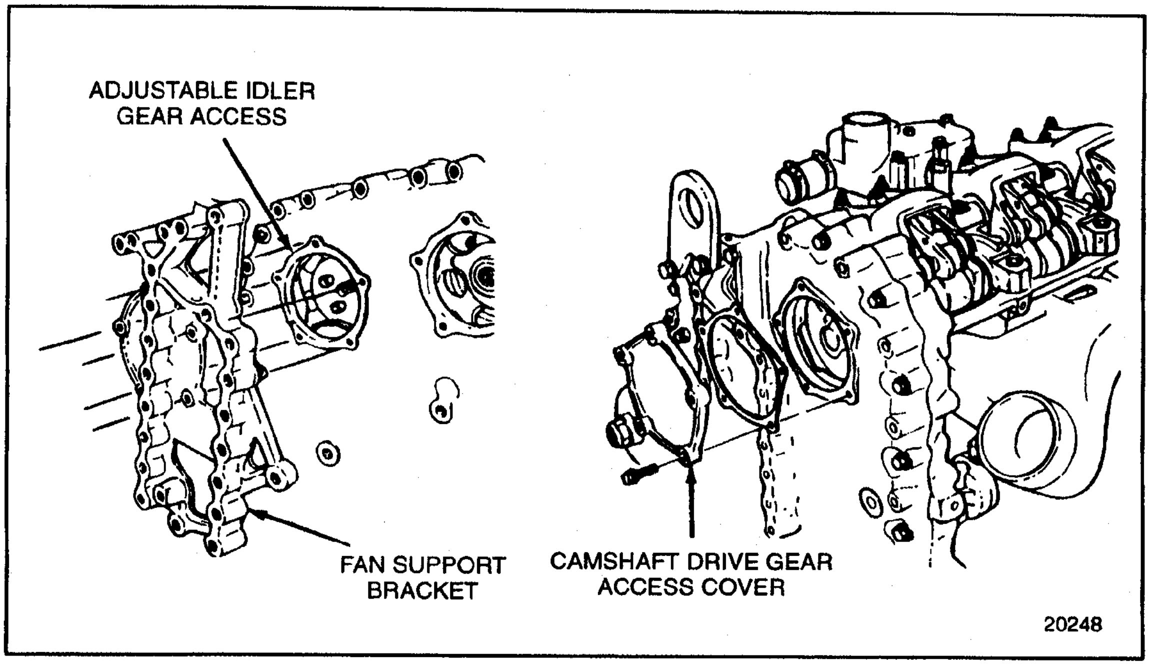

Figure 1-333 Camshaft Drive Gear Access Cover and Adjustable Idler Gear Access

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A cover is provided at the rear end of the camshaft and is secured to the No. 7 camshaft bearing cap and the cylinder head by three bolts. See Figure 1-334.

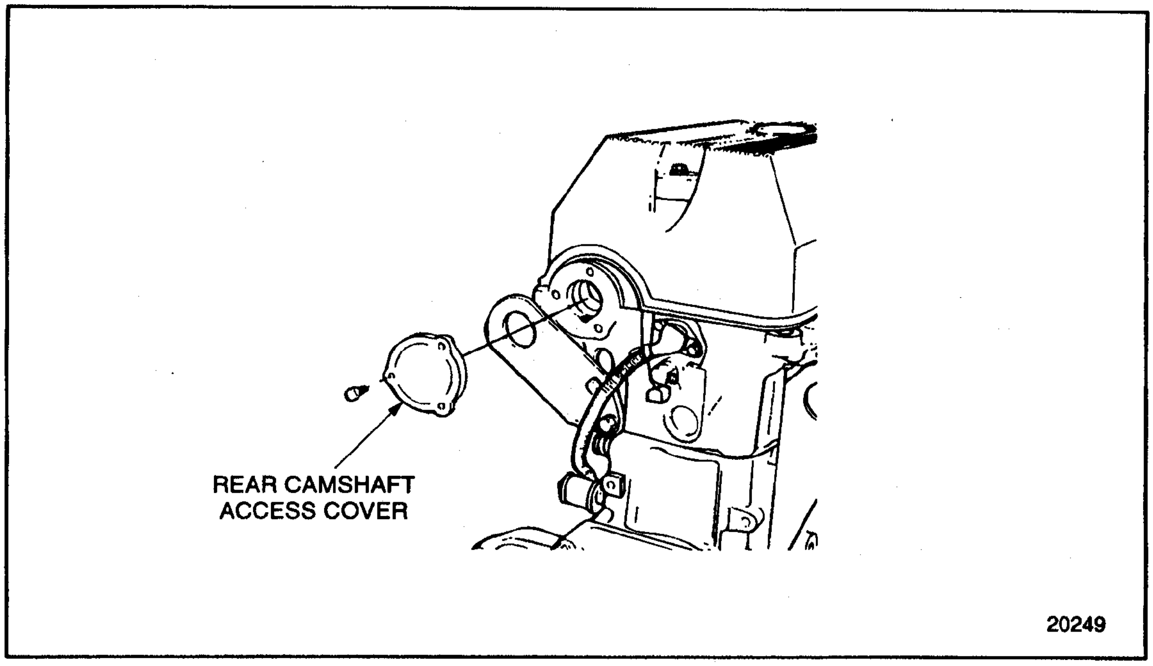

Figure 1-334 Rear Camshaft Access Cover

Vertical oil passages at the front and rear of the cylinder head deliver oil from the cylinder block front and rear oil galleries to the No. 1 and 7 lower camshaft bearing saddles. >From there, the oil is directed upward (through the enlarged stud hole) to the No. 1 and 7 upper bearing caps. A drilled passage in each of these caps exits at the rocker arm shaft seat area, where it indexes with a hole in each rocker arm shaft. The rocker arm shafts have internal oil passages that deliver oil to the rocker arm bushings and intermediate upper camshaft bearings. Some of the oil supplied to the rocker arm bushing passes through the oil hole in the bushing to the rocker arm. The rocker is drilled to supply oil to the camshaft follower, roller pin, and bushing. The rocker is also drilled to supply oil to the valve adjusting screw, valve button, retainer clip, intake, and exhaust valve stems and the fuel injector follower. The No. 4 camshaft cap is "Y" drilled, forming an oil path connection between the front and rear rocker arm shafts, to ensure complete lubrication. See Figure 1-335.

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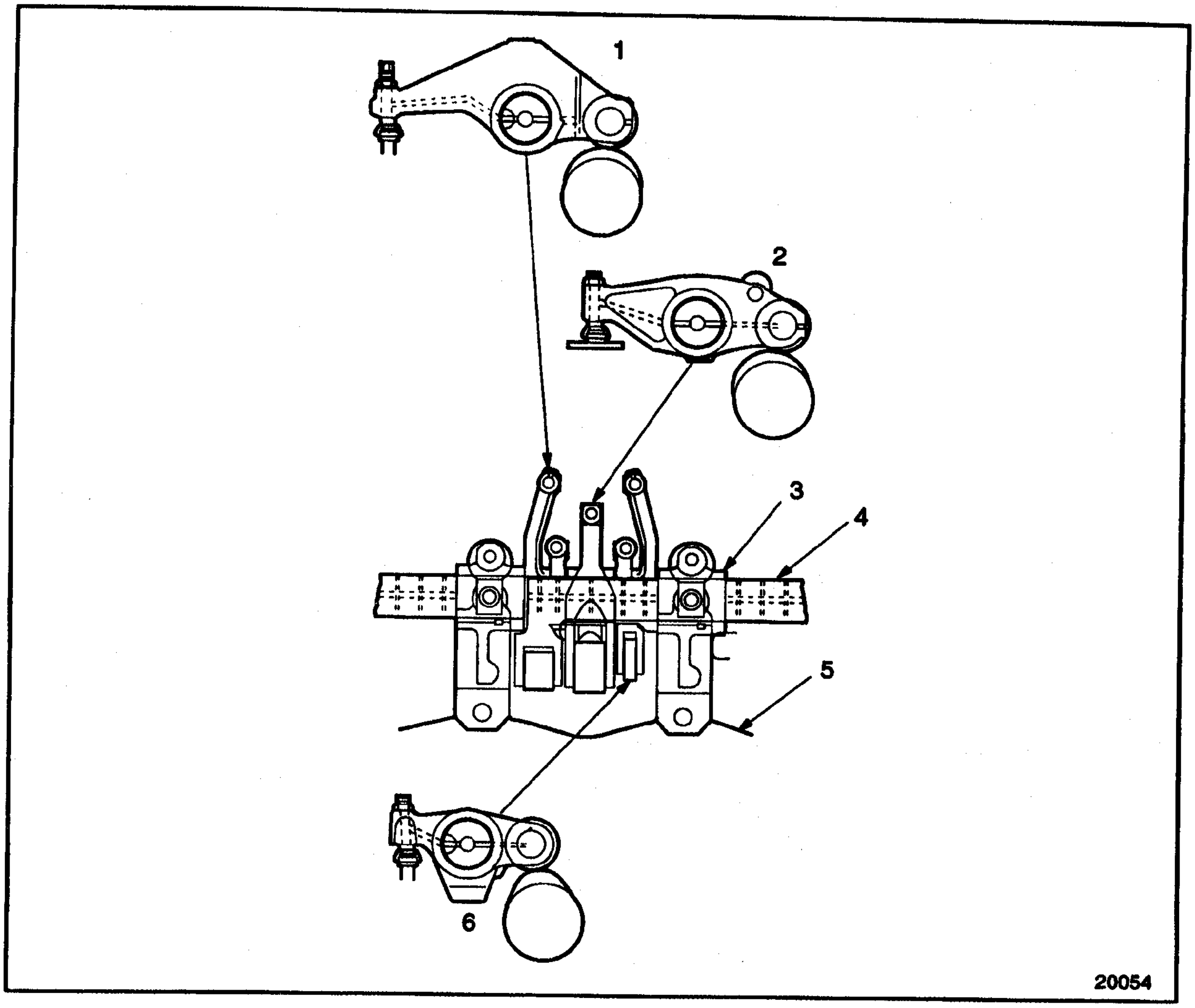

1. Rocker Arm, Exhaust Valve
2. Rocker Arm, Fuel Injector
3. Camshaft Cap
4. Rocker Arm Shaft
5. Cylinder Head
6. Rocker Arm, Intake Valve

Figure 1-335 Cylinder Head Lubrication Schematic

1.23.1 Repair or Replacement of Camshaft and Camshaft Bearing

To determine if repair or replacement of the camshaft and camshaft bearings is necessary, perform the following procedure. See Figure 1-336.

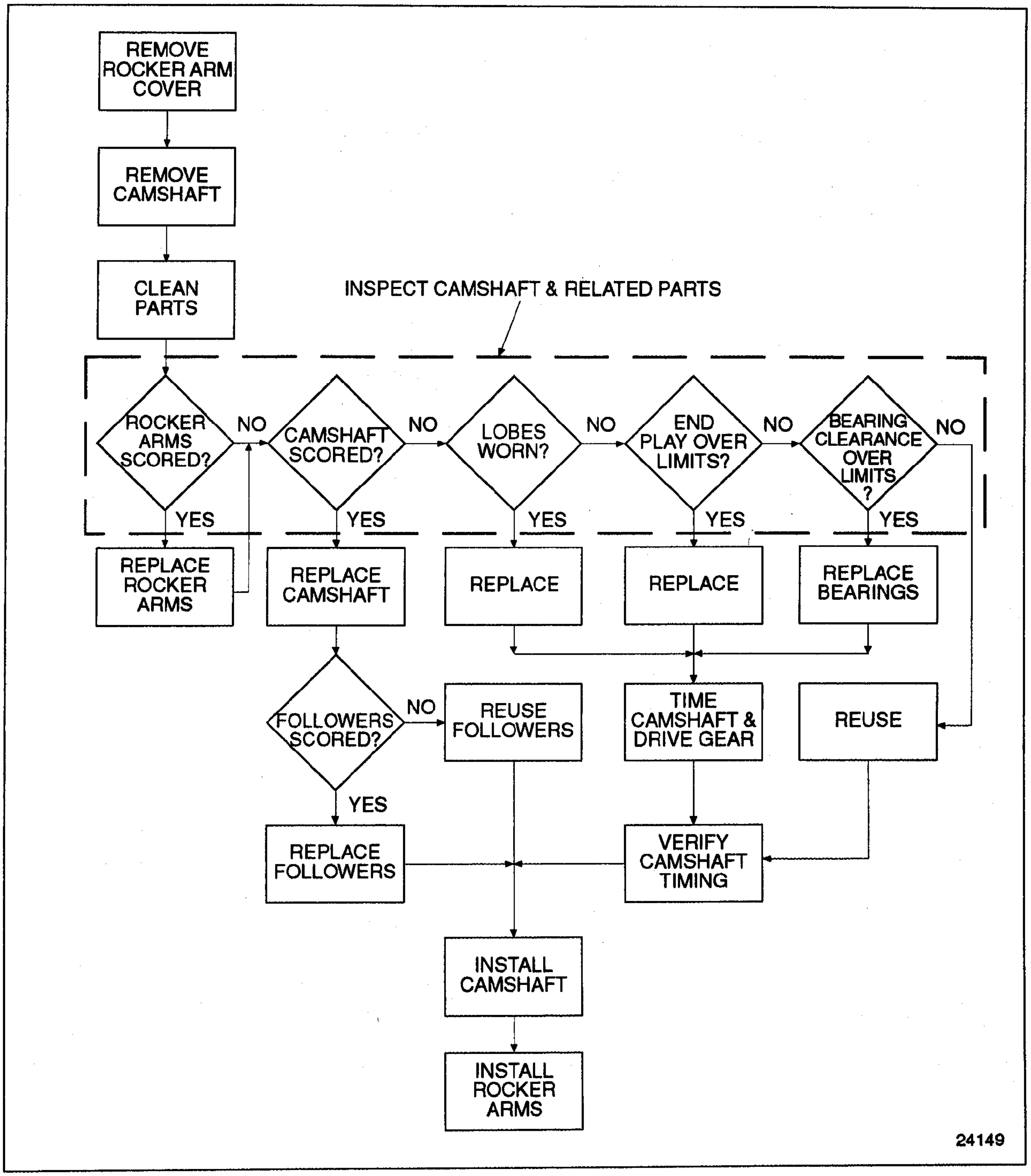

Figure 1-336 Flowchart for Repair or Replacement of Camshaft and Related Parts

1.23.2 Removal of Camshaft and Camshaft Bearing

Removal of camshaft and camshaft bearings as follows:

1. Remove the valve rocker cover. Refer to section 1.6.2 (one-piece), refer to section 1.6.3(two-piece), refer to section 1.6.5 (three-piece).
2. Remove the five bolts that secure the camshaft drive gear access cover to the gear case. See Figure 1-333.
3. Remove both rocker arm shaft assemblies. Refer to section 1.3.2.

NOTICE:
Only special tool, J 35652, should be used to hold the camshaft drive gear stationary while loosening or tightening the camshaft drive gear-to-camshaft bolt. Other tools or devices can cause engine damage.

4. Insert the shoe of the camshaft drive gear torque holding tool, J 35652, through a lightening hole of the camshaft drive gear.
5. Bar the engine over slightly to position the camshaft drive gear holding tool so that the bolt holes in the holding tool align with the access cover bolt holes in the gear case cover, using the 3/4 in. square hole in the center of the crankshaft pulley.
6. Install J 35652 to the gear case, engaging one of the lightening holes in the camshaft drive gear. Use two of the access cover bolts to secure the tool to the gear case. See Figure 1-337.

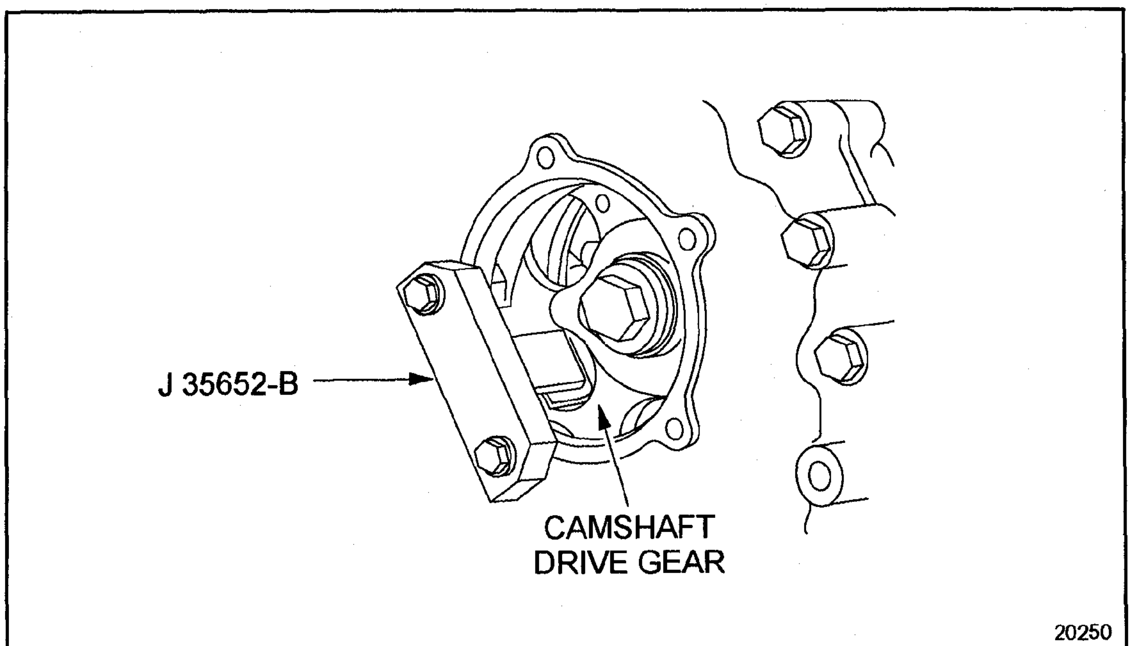

Figure 1-337 Camshaft Drive Gear Torque Holding Tool Installation

7. Use a long 3/4 in. drive breaker bar and a 27 mm impact socket to remove the camshaft drive gear-to-camshaft bolt.
8. Remove the camshaft drive gear torque holding tool from the gear case.
9. Rotate the crankshaft, using the square hole in the middle of the crankshaft pulley, to align the lightening holes in the camshaft drive gear to the camshaft thrust plate mounting bolts.
10. Remove the two camshaft thrust plate mounting bolts carefully, to avoid dropping them into the gear case. See Figure 1-338.

NOTE:
A clean shop towel may be inserted into the gear case opening to trap the bolts in case they are dropped. Do not allow the shop towel to drop into the gear case.

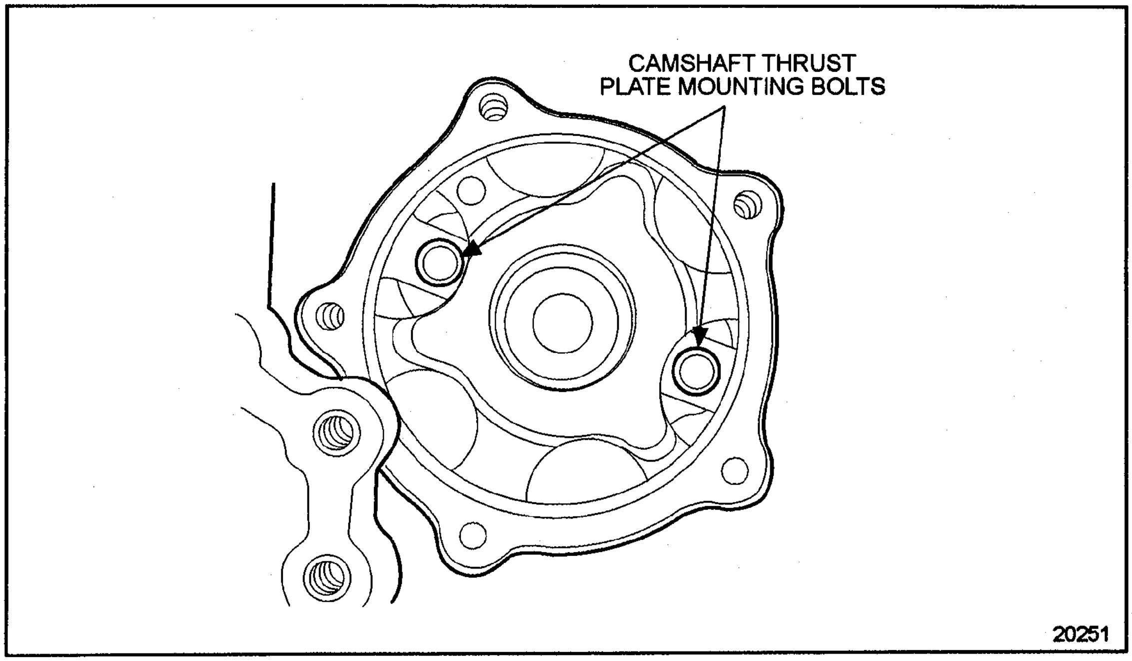

Figure 1-338 Camshaft Thrust Plate Mounting Bolts

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11. Install J 35906, to the camshaft drive gear access opening, using three of the access cover bolt holes. Engage the puller screw in the threads of the camshaft drive gear hub, until the screw is tight. See Figure 1-339.

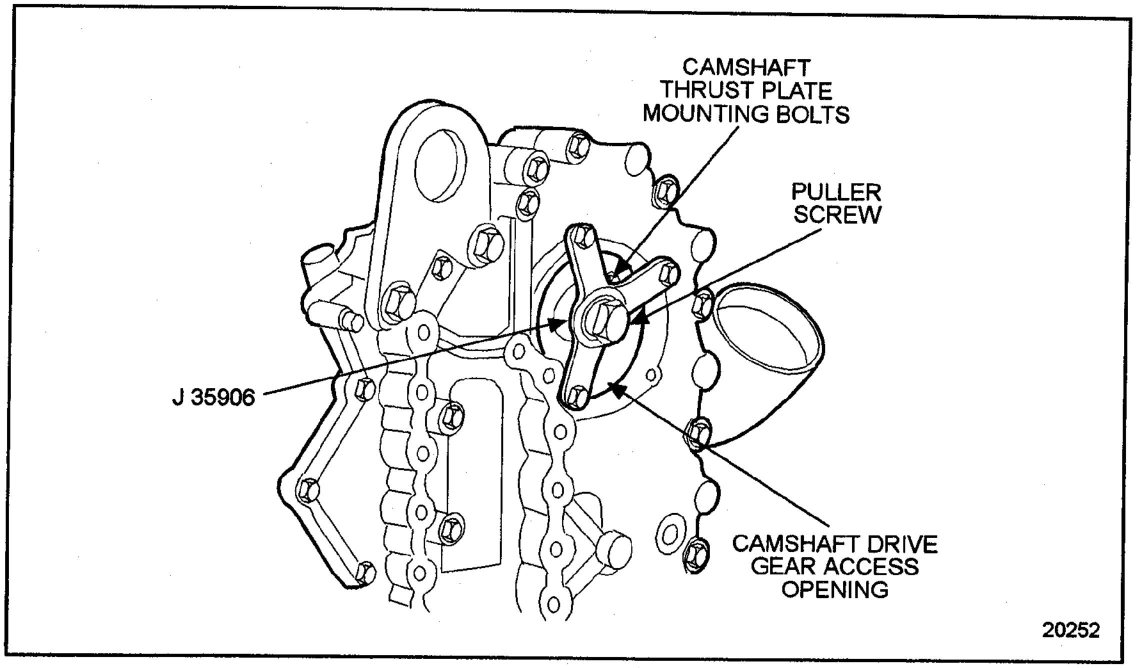

Figure 1-339 Camshaft Thrust Plate Remover

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12. Continue turning the puller screw to pull the camshaft drive gear hub and thrust plate forward approximately 6-7 mm (1/4 in.) until the thrust plate seal is clear of the camshaft front bearing cap and cylinder head. See Figure 1-340.

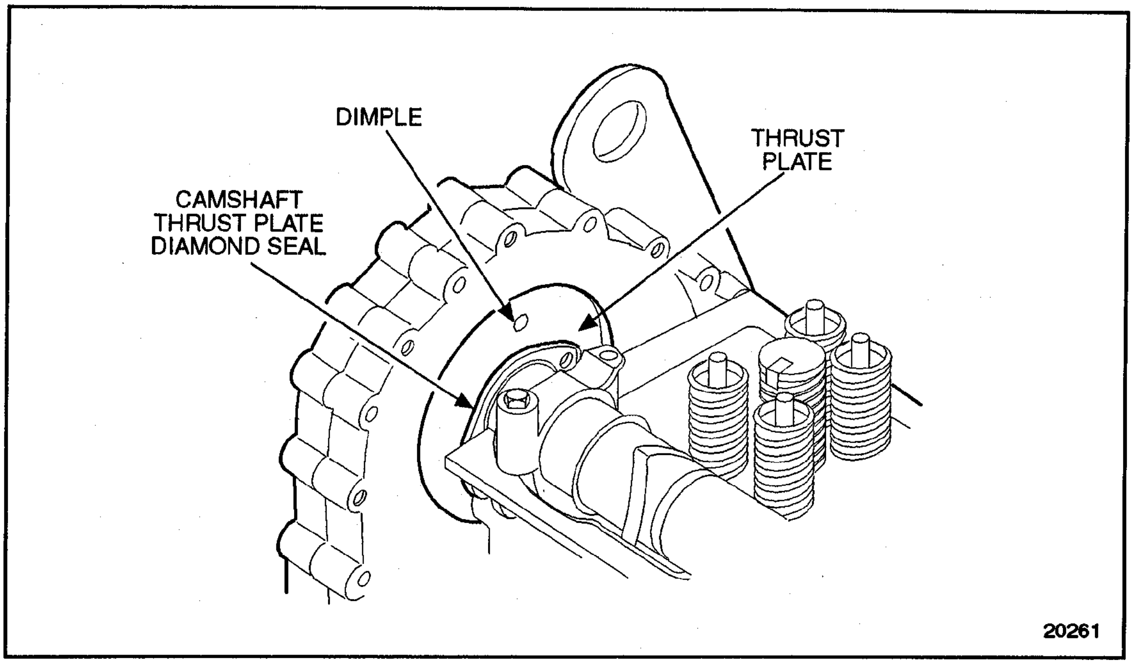

Figure 1-340 Camshaft Thrust Plate Clearance

13. Remove the three bolts that secure the rear camshaft cover to the engine and remove the cover.

14. Remove the remaining seven camshaft cap bolts. Remove the No. 1 and 7 studs using socket tool, J 36003 part of J 36003–A. See Figure 1-341.

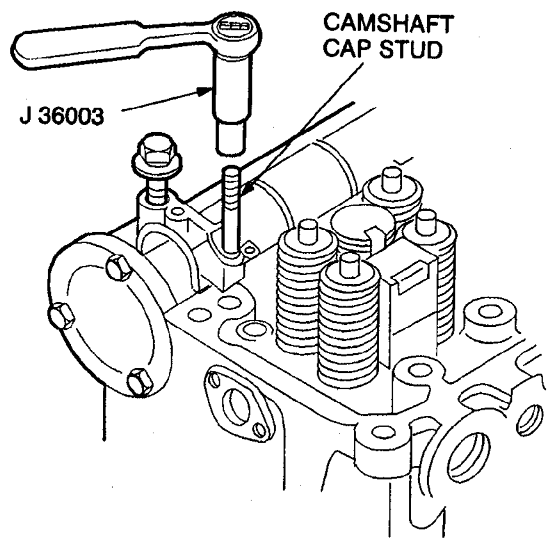

Figure 1-341 Camshaft Cap Stud Removal

15. Remove the seven camshaft bearing caps and the upper bearing shells. Keep the caps and shells together for possible later installation. Tag the bearing cap location, as they must always be installed in the same location.
16. The camshaft gear pilot tool will remain in place, holding the camshaft drive gear in contact with the adjustable idler gear, to prevent accidental disengagement. This arrangement makes it unnecessary to re-time the gear train.

NOTE:
The camshaft gear can go out of time if the pilot tool is removed.

17. Slide the camshaft rearward to completely disengage the dowel from the hub. Lift out the camshaft.
18. Remove the lower camshaft bearing shells, and group them with the upper shells and caps for possible reuse.

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1.23.3 Disassembly of Camshaft and Camshaft Bearing

Refer to section 1.24.2 for disassembly of camshaft drive gear, camshaft hub and thrust plate assembly.

NOTE:
Disassembly of camshaft and drive gear assembly is not required for inspection. Disassembly will require timing of the camshaft gear again.

1.23.3.1 Inspection of Camshaft and Camshaft Bearing

Inspect camshaft and camshaft bearings as follows:

1. Clean all of the removed parts in clean fuel oil.
2. Ensure all oil passages are clear.

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

3. Dry with compressed air.
4. Inspect the rocker arm components for scoring. Refer to section 1.3.2.2.
5. Replace damaged rocker arm components.
6. Inspect the camshaft lobes and journals for scoring, pitting, or flat spots.

NOTE:
Camshafts may exhibit surface pits on the exhaust lobes. See Figure 1-342. Extensive durability and field testing has shown that surface pits on the exhaust lobes can occur early in the operation of the engine. These blemishes do not adversely affect engine performance or the durability of the camshaft and followers. Camshafts with this condition may be reused.

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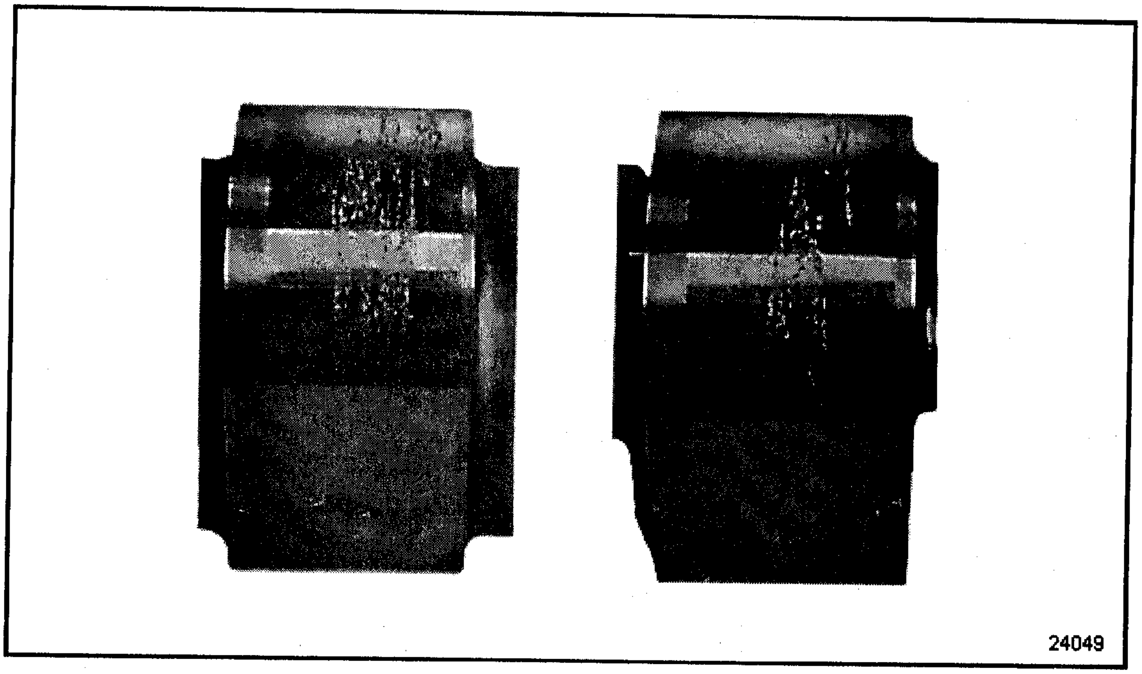

Figure 1-342 Camshafts Acceptable for Reuse

NOTE:
Camshafts exhibiting extensive wear and pitting must be replaced. See Figure 1-343.

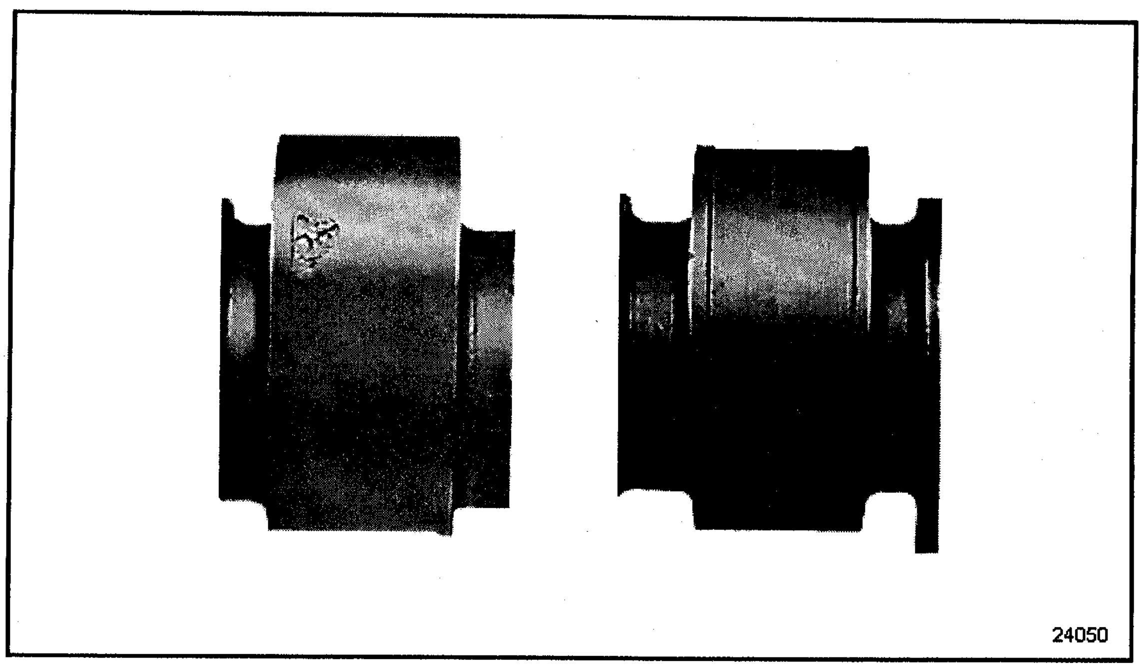

Figure 1-343 Camshafts Not Acceptable for Reuse

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7. If the camshaft is scored, inspect the camshaft follower rollers.
8. Replace damaged camshaft followers.
9. If there is a doubt as to the acceptability of the camshaft for further service, determine the extent of camshaft lobe wear as follows:

NOTE:
The camshaft can be in or out of the engine during this procedure.

[a] Using a feeler gage, 0.038-0.254 mm (0.0015 -0.010 in.) and a piece of square, hard material 3 x 10 x 25 mm (1/8 in. x 3/8 in. x 1 in.), measure the flat on the injector rise side of the camshaft lobes and nose of valve lobes. See Figure 1-344.

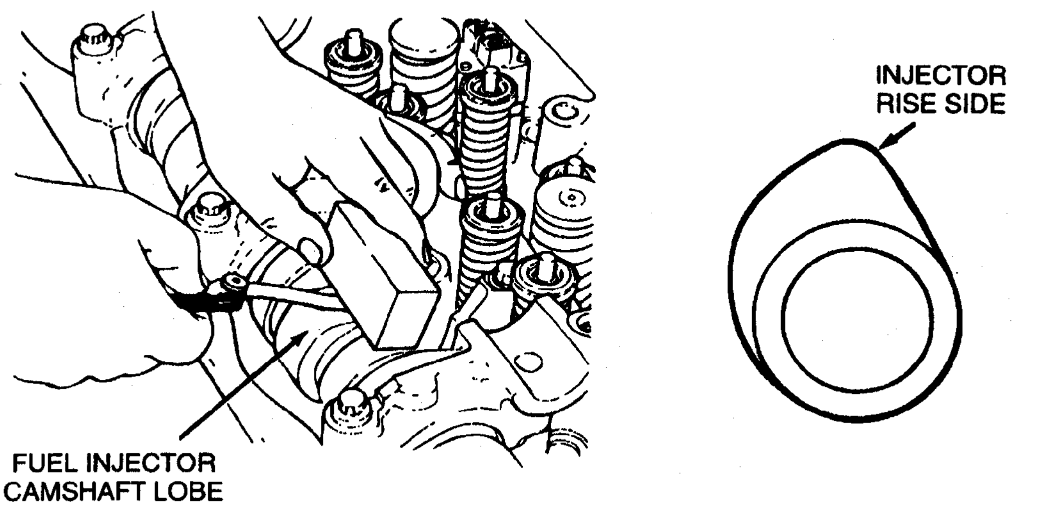

Figure 1-344 Checking Camshaft Lobe Wear

[b] If the flats measure greater than 0.076 mm (0.003 in.) in depth and there are no other camshaft defects, replace the camshaft.

[c] Inspect the camshaft bearings for signs of excessive wear, scoring or pitting.

[d] Replace camshaft bearings as necessary.

NOTE:
If one camshaft bearing needs to be replaced, replace both of the camshaft bearing shells.

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[e] Check the camshaft bearing clearance using plastic gaging material under each upper shell.

NOTE:
Check camshaft bearing clearance with bearing shells, camshaft, bearing caps and rocker arm shafts (without rocker assemblies in place) installed, and cap bolts, studs and nuts tightened to specification.

[f] Allowable clearance is 0.09 - 0.166 mm (0.0035 -0.0065 in.) or a maximum of 0.191 mm (0.0075 in.) with used parts.

[g] Replace excessively worn or scored parts.

[h] After completing the camshaft bearing clearance measurements, remove the rocker arm shafts, bearing caps, camshaft, and camshaft bearings. Keep the caps and shells together for possible reuse.

[i] Clean all of the plastic gaging material from the bearing shells and camshaft journals if used parts are to be reused.

[j] Remove all of the Gasket Eliminator from both the cylinder head and camshaft caps. Refer to section "Cleaning" in the "General Information" section at the beginning of this manual.

[k] Coat the No. 1 and 7 bearing shell inserts with clean engine oil and install them to their respective locations in the cylinder head and camshaft caps.

[l] Install the camshaft to its normal position in the bearing saddles. Install the No. 1 and 7 camshaft caps to the cylinder head.

[m] Install the No. 1 and 7 camshaft cap outboard bolts and inboard studs and torque, using tool J 36003 part of J 36003–A to the studs to 128–148 N·m (94–109 lb·ft).

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[n] Using a dial indicator with magnetic base, check the run-out of the camshaft at the No. 4 bearing journal. See Figure 1-345.

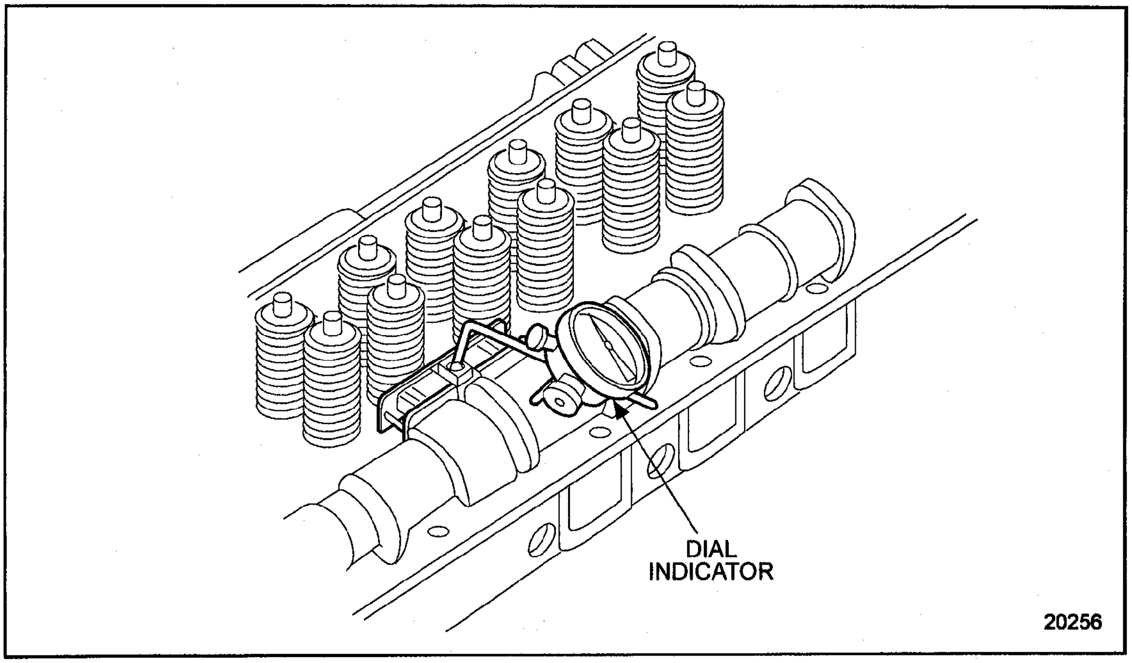

Figure 1-345 Camshaft Run-out Measurement

[o] If camshaft run-out exceeds 0.050 mm (0.002 in.), replace the camshaft.

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1.23.4 Assembly of Camshaft and Camshaft Bearing

Refer to section 1.24.3 for assembly of camshaft drive gear, camshaft hub and thrust plate assembly.

1.23.5 Installation of Camshaft and Camshaft Bearing

Install the camshaft and camshaft bearings as follows:

1. Coat the lower camshaft bearing shells with clean engine lubricating oil, and install them to their original positions. Note the position of oil holes and locating tangs.

NOTE:
If new bearings are to be installed, the upper and lower shells MUST be replaced as a set.

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

2. When installing a new camshaft, steam clean it to remove the rust preventive and blow dry with compressed air.

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3. Before installing the camshaft dowel into the camshaft hub, ensure that the dimple in the thrust plate is located at the 12 o'clock position to properly position bolt holes to cam cap and cylinder head. See Figure 1-346.

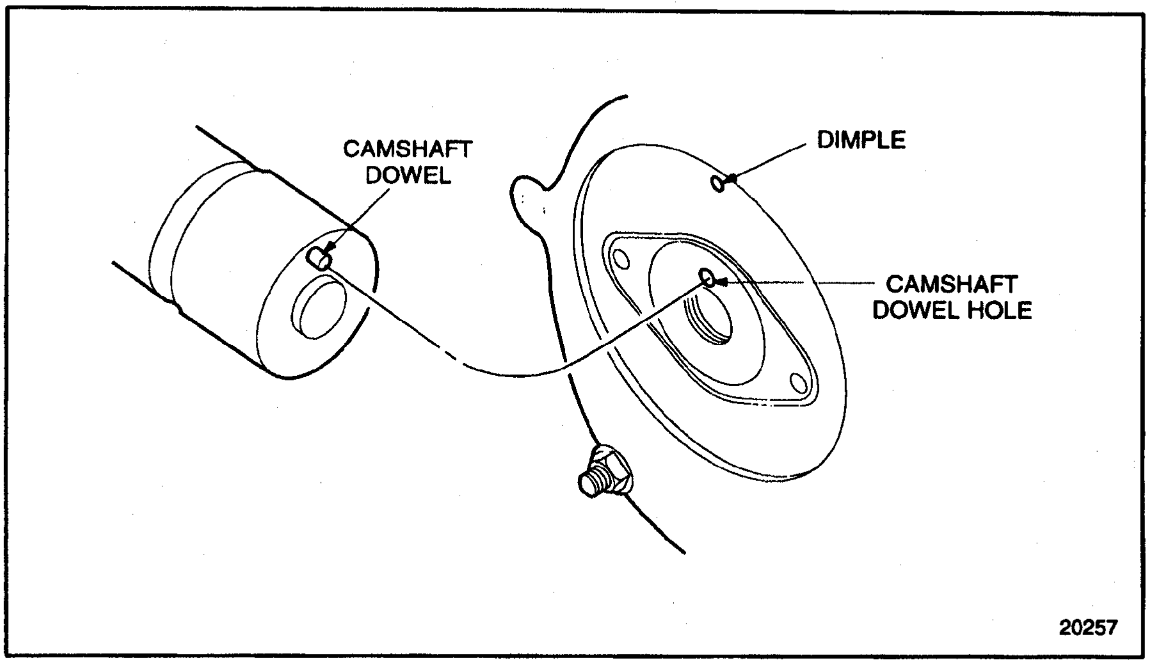

Figure 1-346 Indexing Camshaft Dowel

4. Coat the lobes and journals of the camshaft with clean engine lubricating oil. Index the dowel pin in the camshaft with the dowel hole in the camshaft hub.
5. Lower the camshaft into position and slide the camshaft forward, making certain that the camshaft dowel indexes with its mating hole in the camshaft thrust plate hub.
6. Install the upper bearing shells to the No. 1, 4 and 7 camshaft caps, noting the position of the oil holes and locating tangs.

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NOTICE:
Do not apply oil to the number 1 or number 7 camshaft bearing shells. These shells *must* be clean and dry for proper sealant application. Applying oil to the number 1 or number 7 shells may result in oil leakage from the camshaft bearing caps. **NOTE:** The camshaft will still have adequate clearance from the number 1 and number 7 shells due to the oil film thickness on bearings 2 through 6.

7. Coat the number 2 through number 6 bearing shells with clean engine lubricating oil.
8. For engines built after May 1999, a race track seal is used on the Number 1 bearing cap. For bearing cap Number 7, use one rubber O-ring in the counterbore in the cylinder head. Before assembling the camshaft cap to the cylinder head, ensure the O-ring is in place on the cylinder head.
9. For engines built prior to May 1999, install the two rubber O-rings to the counterbores in the cylinder head at the Number 1 and 7 camshaft cap locations. Before assembling the camshaft caps to the cylinder head, ensure the two O-rings are in place on the cylinder head.

NOTICE:
For proper adhesion, assemble parts while RTV is wet. So not allow RTV to form a skin. Gasket Eliminator must be kept from the bearing shell sets and bearing surfaces. Gasket Eliminator cures with the absence of air. The length of time between installation of the Number 1 and 7 camshaft caps, and torquing the camshaft cap bolts and nuts should be kept to a minimum or improper lubrication will result causing engine damage.

10. Clean and dry the camshaft bearing cap joint face surfaces as well as the portions of the cylinder head face that mate with. These areas must be clean and dry for proper sealant adhesion. Use LPS®, Permatex®, or an equivalent non-filming degreaser.

11. Apply a continuous 1.6 mm (1/16 in.) bead of DDC gasket eliminator part number 23523064, or equivalent, to the joint face surfaces of the No. 1 and 7 camshaft caps. The bead must extend to the front edge of both caps. See Figure 1-347.

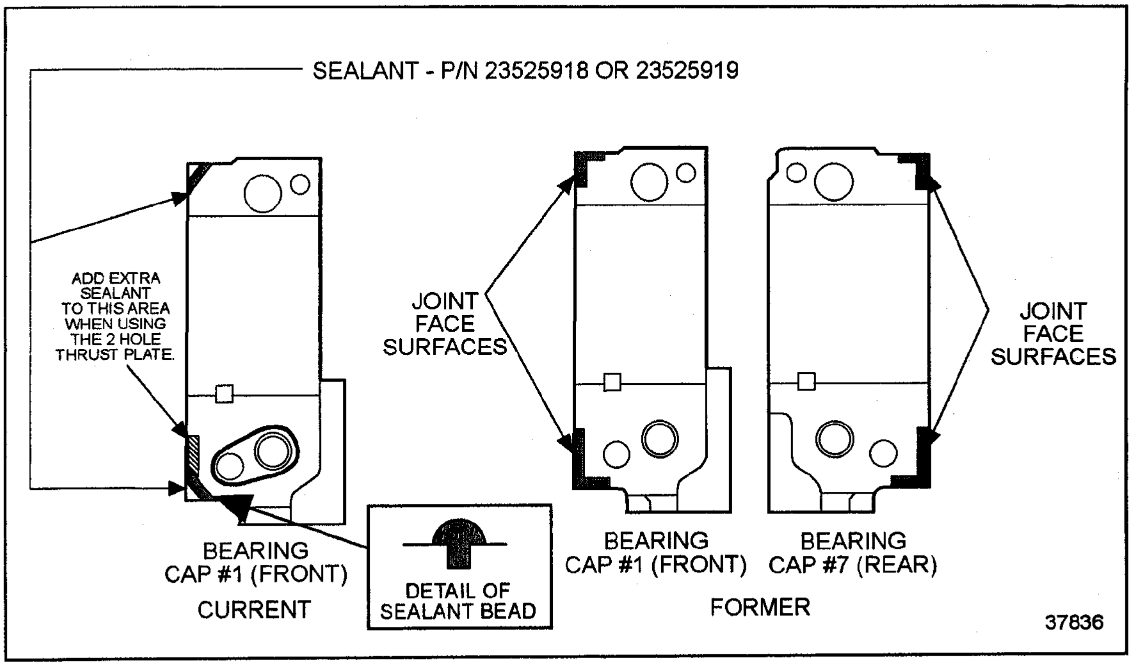

Figure 1-347 Gasket Eliminator Application

12. Install the No. 1, 4 and 7 camshaft caps, with bearing shells in place, to their respective locations.
13. Install and tighten the two inboard studs and outboard bolts on bearing caps No. 1 and 7 using tool J 36003 part of J 36003–A, torque to 128–148 N·m (94–109 lb·ft).
14. Install the No. 4 bearing cap outboard bolt and torque it to 126-146 N·m (93-108 lb·ft).
15. Remove the three bolts holding the camshaft gear pilot, J 35906 to the gear case. Remove the camshaft gear pilot.
16. Working through the camshaft drive gear access hole in the front of the gear case, tap the center of the camshaft drive gear with a fiber mallet or plastic hammer to move the camshaft thrust plate, hub and camshaft drive gear rearward in the gear case until the camshaft thrust plate bolts can be started in the cylinder head and No. 1 camshaft cap.

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NOTICE:

Use care to ensure that the camshaft dowel is not disengaged during this step or damage to engine may result.

NOTICE:

Use care to prevent dropping thrust plate mounting bolts into the gear case. If not removed, fasteners dropped into the gear case may cause severe engine damage during start-up.

17. Install the thrust plate mounting bolts through the thrust plate and into the cylinder head and No. 1 camshaft cap. Using a 13 mm socket and ratchet, tighten the bolts alternately and progressively to draw the thrust plate straight into the gear case. Torque the bolts to 30-38 N·m (22-28 lb·ft).
18. Coat the threads and underside of the head of the camshaft drive gear-to-camshaft bolt with International Compound #2® (or equivalent). Install the bolt to the camshaft, finger-tighten.

NOTE:

The camshaft should be held in place while starting the camshaft drive gear-to-camshaft bolt, to prevent disengaging the camshaft dowel from the thrust plate hub and requiring disassembly and timing of camshaft.

NOTICE:

Only J 35652 should be used to hold the camshaft drive gear stationary while loosening or tightening the camshaft drive gear-to-camshaft bolt to prevent component damage.

19. Insert J 35652 through a lightening hole of the camshaft drive gear.
20. Bar the engine over slightly to position the camshaft drive gear holding tool so that the bolt holes in the holding tool align with the access cover bolt holes in the gear case cover using the 3/4 in. square hole in the center of the crankshaft pulley to bar the engine over.
21. Install the two of the access cover bolts to secure the tool to the gear case.
22. Torque bolt to 75 N·m (55 lb·ft).

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23. Turn bolt an additional 120 degrees. See Figure 1-348.

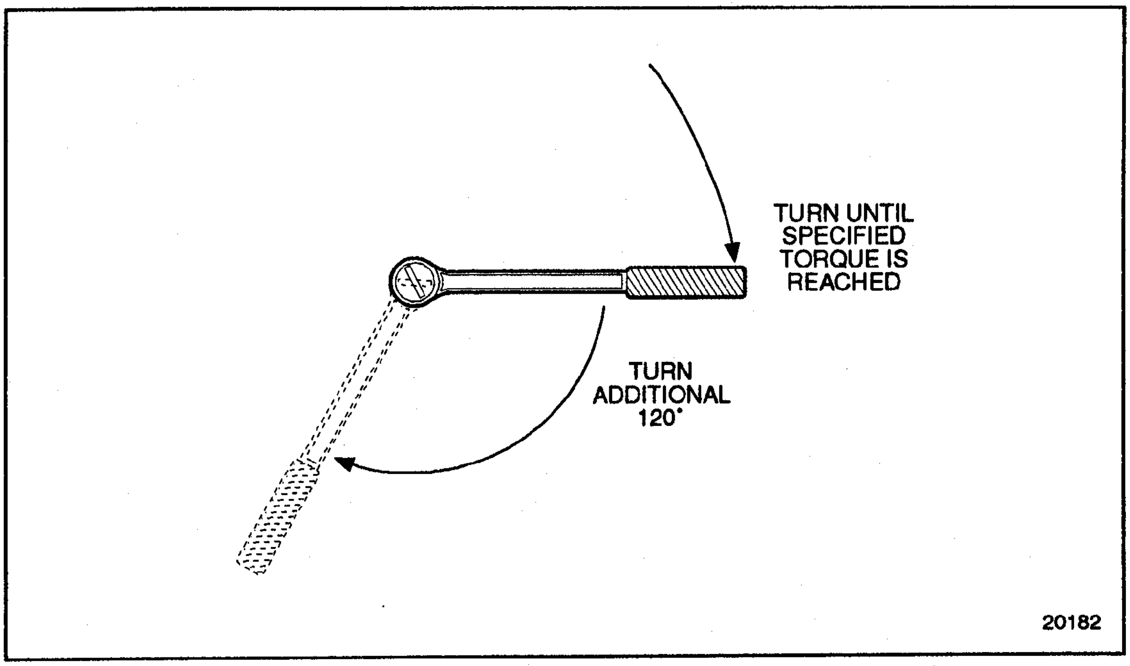

Figure 1-348 Torque Turn Limits

24. Remove the camshaft drive gear torque holding tool, J 35652-A.
25. Adjust the camshaft drive gear-to-adjustable idler gear lash. Refer to section 1.21.2.1.

NOTE:
Correct camshaft drive gear lash adjustment depends on the bolt and stud for No. 1 and 7 camshaft caps, the outboard bolt on No. 4 camshaft cap, and the camshaft drive gear-to-camshaft retaining bolt being tightened to the specified torque. However, the valve and injector spring pressures will not allow correct camshaft rotation. Therefore, do NOT install the rocker arm shaft assemblies before the camshaft gear lash has been measured and adjusted.

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1.23.5.1 Test of Camshaft End Play

Measure the camshaft end play, using a dial indicator and magnetic base, as follows:

1. Install the dial indicator so that the pointer is in contact with either the camshaft drive gear-to-camshaft retaining bolt, or at the rear end of the engine, in contact with the end of the camshaft. See Figure 1-349.

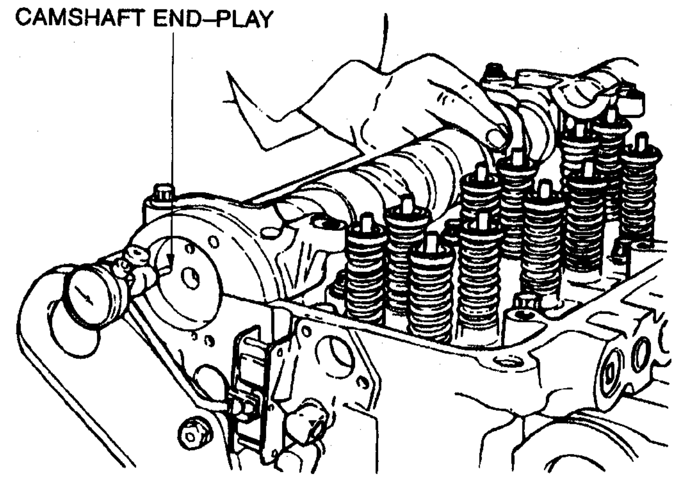

Figure 1-349 Camshaft End Play

2. Grasp the camshaft between the No. 1 and 4 camshaft caps, and move the cam as far forward as possible. Zero the dial indicator.
3. Move the camshaft as far as possible, to the rear. Read and record the total amount of end play as indicated.
4. Allowable camshaft end thrust specifications are 0.076 - 0.381 mm (0.003 -0.015 in.) and are listed in Table 1-25.
5. If the end play is beyond the maximum limit, loosen and re-torque the camshaft drive gear-to-camshaft retaining bolt, and the camshaft thrust plate retaining bolts, to ensure that the camshaft thrust plate is seated properly in the gear case.
6. If the end play is still beyond the maximum limit, remove and replace the camshaft thrust plate. Refer to section 1.23.2 for removal and refer to section 1.23.3 for installation.

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1.23.6 Installation of Camshaft and Camshaft Bearing

Continue installing camshaft and camshaft bearings as follows:

1. Install the bearing shells to the remaining No. 2, 3, 5, and 6 camshaft caps, noting the oil holes and locating tangs.
2. Coat the bearing shells with clean engine lubricating oil.
3. Install the remaining camshaft caps to their saddles on the cylinder head. Install the four outboard camshaft cap bolts for caps No. 2, 3, 5, and No. 6 finger-tight.
4. Coat the rocker arm assemblies and camshaft liberally with clean engine lubricating oil.
5. Install the rocker arm shaft assemblies to the cylinder head. Refer to section 1.3.3.
6. Install the remaining inboard camshaft cap bolts and spacers through the rocker arm shafts and into No. 2, 3, 4, 5, and 6 camshaft caps. Install the two nuts and spacers to the studs at No. 1 and 7 camshaft caps.
7. Torque the 11 bolts and two nuts to 101-116 N·m (75-85 lb·ft) using the sequence. See Figure 1-350.

NOTE:
It is not necessary to tighten bolts 9, 13, and 14 if a Jake Brake® is to be installed.

NOTE:
Jake Brakes® are not on a natural gas engine.

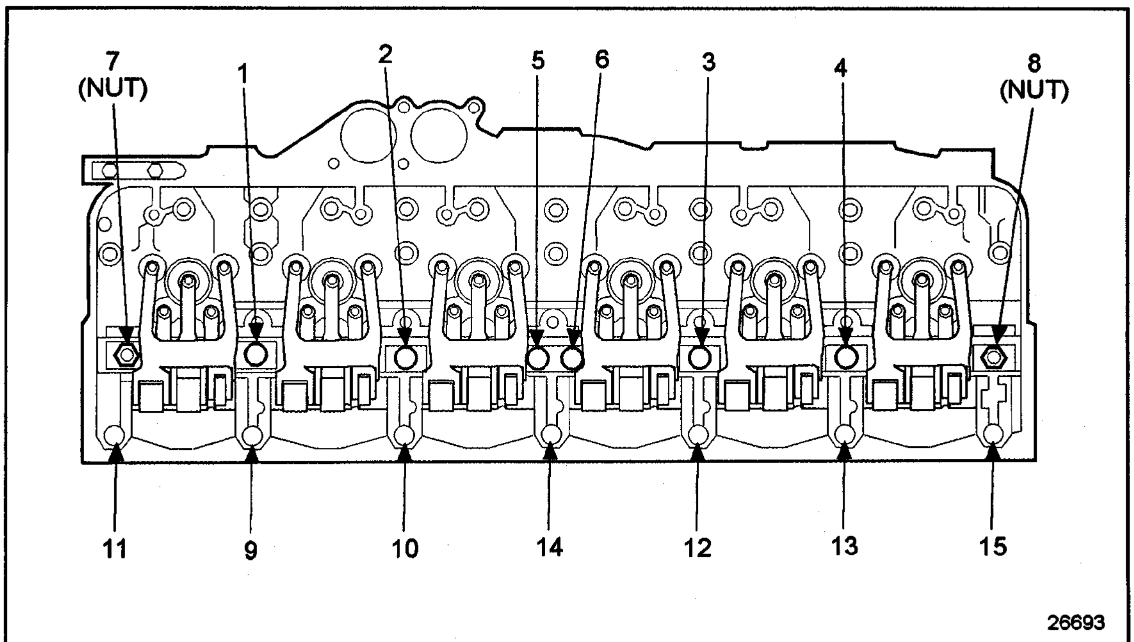

Figure 1-350 Camshaft Cap Bolts and Rocker Arm Shaft Nut Torque Sequence

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8. Clean all old gasket material from the mating surfaces of the rear camshaft cover and the cylinder head. Refer to section ADDITIONAL INFORMATION 1.A.
9. Apply a thin 1.5 mm (1/16 in.) bead of Gasket Eliminator, PT-7276 (Loctite® 518) or equivalent to the mating surface of the cover.
10. Install the cover and torque the three bolts to 30-38 N·m (22-28 lb·ft).
11. Clean all old gasket material from the mating faces of the camshaft drive gear access cover and the gear case cover.
12. Insert a new gasket between the camshaft drive gear access cover and the gear case.
13. Torque the bolts to 30-38 N·m (22-28 lb·ft), using the tightening sequence. See Figure 1-351.

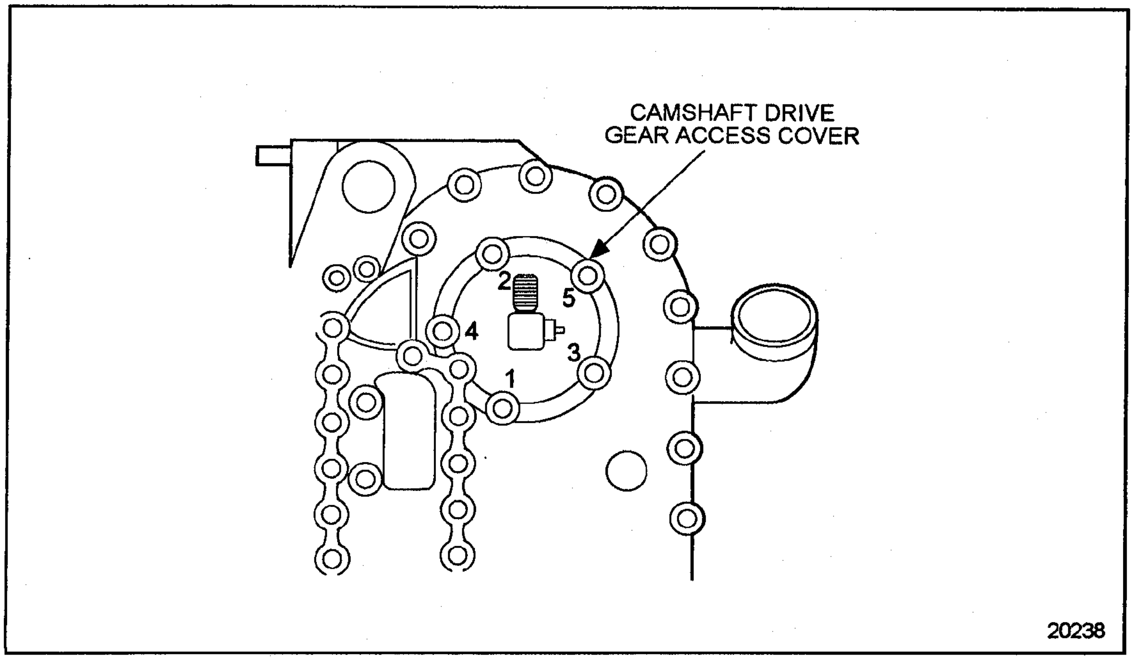

Figure 1-351 Camshaft Drive Gear Access Cover Torque Sequences

14. Adjust the intake and exhaust valve clearances and set the injector heights. Refer to section 12.2.
15. Install the fan hub, fan, (refer to section 4.7.6), and drive belts; refer to section 13.13.10.
16. Install any other components that were removed for this procedure.

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1.23.6.1 Testing of Camshaft Timing for Diesel Engines

Check the camshaft timing as follows:

NOTICE:
The camshaft must be in time with the crankshaft. An engine which is "out of time" may result in pre-ignition, uneven running or a loss of power.

1. Remove the valve cover. Refer to section 1.6.2 for one-piece rocker cover. Refer to section 1.6.3 for two-piece rocker cover. Refer to section 1.6.5for three-piece rocker cover.
2. Select any cylinder for the timing check.
3. Remove the rocker arm assembly for the cylinder selected. Refer to section 1.3.2.
4. Remove the injector for that cylinder. Refer to section 2.3.2.
5. Carefully slide a rod, approximately 304.8 mm (12 in.) long, through the injector tube hole until the end of the rod rests on top of the piston.
6. Using the 3/4 in. square drive hole in the center of the crankshaft pulley and a 3/4 in. drive breaker bar, turn the crankshaft slowly in the direction of engine rotation. See Figure 1-352. Stop when the rod reaches the end of its upward travel.

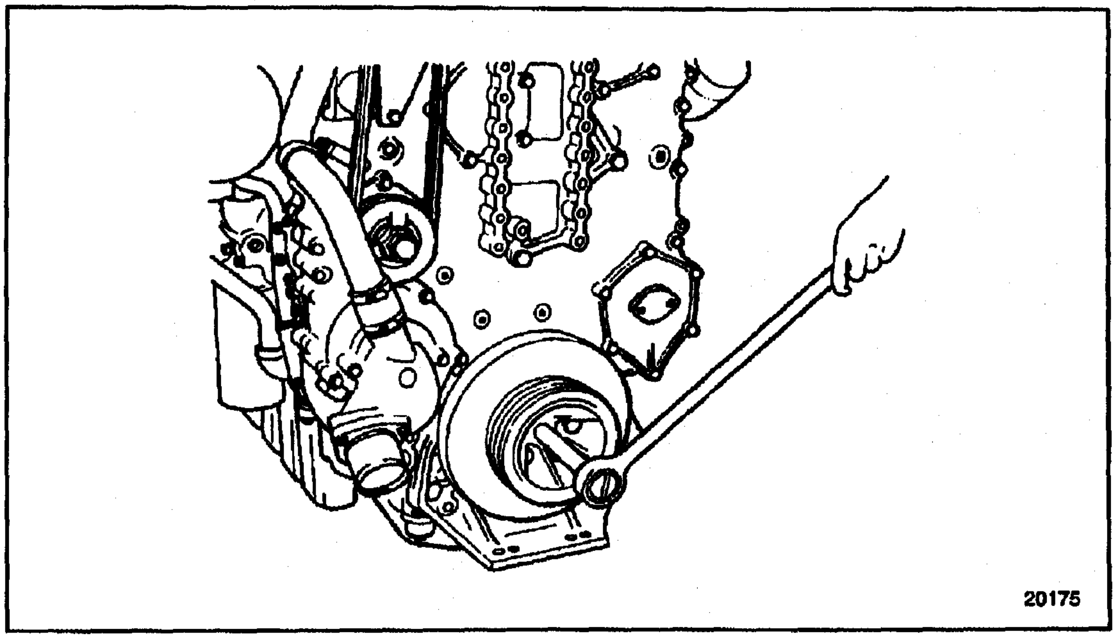

Figure 1-352 Barring Engine Over

NOTE:
The cylinder selected must be on the compression stroke when performing this check.

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7. Remove the rod and turn the crankshaft, opposite the direction of rotation, between 1/16 and 1/8 of a turn.
8. Select a dial indicator with 0.0254 mm (0.001 in.) graduations and a spindle movement of at least 25.4 mm (1 in.). Provide an extension for the indicator spindle. The extension must be long enough to contact the piston just before it reaches the end of its upward stroke.
9. Install a magnetic dial indicator base in a suitable place on the cylinder head and position the dial indicator over the injector hole tube.
10. Attach a suitable pointer to the gear case cover. The outer end of the pointer should extend over the vibration damper.
11. Turn the crankshaft slowly in the direction of engine rotation until the indicator hand just stops moving. Continue turning the crankshaft until the indicator hand starts to move again.
12. Reset the dial to zero.
13. Turn the crankshaft until the indicator reading is 0.254 mm (0.010 in.).
14. Scribe a line on the vibration damper in line with the end of the pointer.
15. Slowly turn the crankshaft opposite the direction of engine rotation until the indicator hand just stops moving. Continue turning the crankshaft until the indicator hand starts to move again.
16. Reset the dial to zero. Then turn the crankshaft in the same direction until the indicator reading is 0.254 mm (0.010 in.).
17. Scribe a second line on the vibration damper in line with the end of the pointer.
18. Scribe a third line half way between the first two lines. This is top dead center for the cylinder selected when the pointer is lined up with it.
19. Remove the dial indicator and base from the engine.
20. Install the injector that was removed. Refer to section 2.3.5.
21. Install the rocker arm assemblies. Refer to section 1.3.3.
22. Turn the crankshaft opposite the direction of engine rotation while watching the injector rocker arm cam follower for the cylinder selected. Turn the crankshaft until the cam follower is on the base circle of the injector lobe of the cam.
23. Install a magnetic dial indicator base on the cylinder head. Install a dial indicator so that the spindle rests directly on the injector cam follower roller for the cylinder selected.

NOTE:
The spindle should be on the center line of the injector cam follower roller pin in order to get an accurate measurement of cam lift.

24. Turn the crankshaft slowly, in the direction of engine rotation, until the center mark on the vibration damper lines up with the pointer.

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25. Check the dial indicator reading and compare the reading with the values listed in Table 1-8 to determine the correct indicator reading.

Engine	DDEC Version	Model	Camshaft Part No.	Model Year	Low Injector Cam Roller Lift at TDC	High Injector Cam Roller Lift at TDC
12.7 L	III	GK	23521680	1998	5.36 mm (0.211 in.)	6.76 mm (0.266 in.)
12.7 L	IV	PK, TK	23521680	1998	5.36 mm (0.211 in.)	6.76 mm (0.266 in.)
11.1 L	IV	EK	23522199	1998	5.46 mm (0.215 in.)	6.71 mm (0.264 in.)
11.1 L	III	SK	23518717	1993-1997	4.95 mm (0.195 in.)	6.53 mm (0.257 in.)
12.7 L	III	GK	23513565	1993-1997	4.95 mm (0.195 in.)	6.53 mm (0.257 in.)
11.1 L	III	WK	23513563	1993-1997	4.95 mm (0.195 in.)	6.53 mm (0.257 in.)
11.1 L	II	WU	8929484	1986-1993	4.39 mm (0.173 in.)	5.46 mm (0.215 in.)
12.7 L	II	GU	23505194	1986-1993	4.39 mm (0.173 in.)	5.46 mm (0.215 in.)
11.1 L	IV	LK	23524655	1999	5.21 mm (0.205 in.)	6.27 mm (0.247 in.)
11.1 L	IV	LK	23524914	1999	5.21 mm (0.205 in.)	6.27 mm (0.247 in.)
12.7 L	IV	BK	23524292	1999	5.03 mm (0.198 in.)	6.10 mm (0.240 in.)
12.7 L	IV	MK	23524292	1999	5.03 mm (0.198 in.)	6.10 mm (0.240 in.)
12.7 L	IV	MK, BK	23524912	1999-2000	5.03 mm (0.198 in.)	6.10 mm (0.240 in.)
14.0 L	IV	HK	23524912	1999-2000	5.03 mm (0.198 in.)	6.10 mm (0.240 in.)

Table 1-8 Camshaft Timing Setting Dimensions

26. If the camshaft lift is incorrect, re-time the engine. Refer to section 1.21.2.1.
27. Refer to section 11.8 for verification of proper camshaft and camshaft bearing installation.

1.23.6.2 Testing of Camshaft Timing for Natural Gas Engines

Check the camshaft timing as follows:

NOTICE:
The camshaft must be in time with the crankshaft. An engine which is "out of time" may result in pre-ignition, uneven running or a loss of power.

1. Remove the valve cover. Refer to section 1.6.2 for one-piece rocker cover. Refer to section 1.6.3 for two-piece rocker cover. Refer to section 1.6.5for three-piece rocker cover.
2. Select any cylinder for the timing check.
3. Remove the rocker arm assembly for the cylinder selected. Refer to section 1.3.2.
4. Remove the spark plug for that cylinder.

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5. Carefully slide a rod, approximately 304.8 mm (12 in.) long, through the spark plug hole until the end of the rod rests on top of the piston.
6. Using the 3/4 in. square drive hole in the center of the crankshaft pulley and a 3/4 in. drive breaker bar, turn the crankshaft slowly in the direction of engine rotation. See Figure 1-353. Stop when the rod reaches the end of its upward travel.

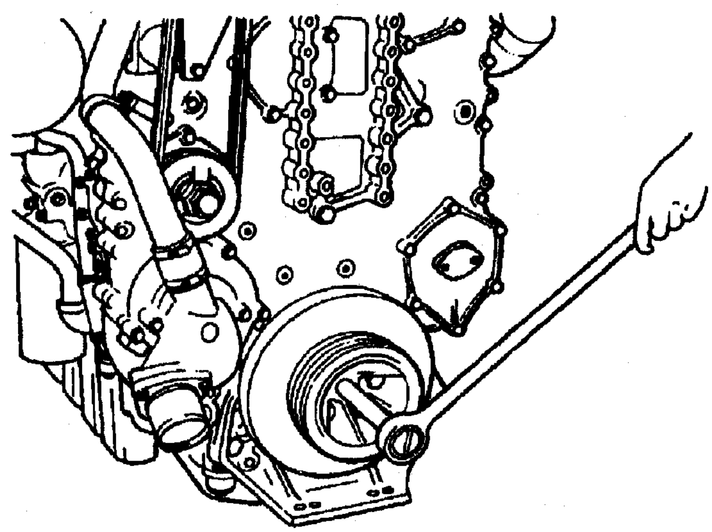

Figure 1-353 Barring Engine Over

NOTE:
The cylinder selected must be on the compression stroke when performing this check.

7. Remove the rod and turn the crankshaft, opposite the direction of rotation, between 1/16 and 1/8 of a turn.
8. Select a dial indicator with 0.0254 mm (0.001 in.) graduations and a spindle movement of at least 25.4 mm (1 in.). Provide an extension for the indicator spindle. The extension must be long enough to contact the piston just before it reaches the end of its upward stroke.
9. Install a magnetic dial indicator base in a suitable place on the cylinder head and position the dial indicator over the spark plug hole.
10. Attach a suitable pointer to the gear case cover. The outer end of the pointer should extend over the vibration damper.
11. Turn the crankshaft slowly in the direction of engine rotation until the indicator hand just stops moving. Continue turning the crankshaft until the indicator hand starts to move again.
12. Reset the dial to zero.
13. Turn the crankshaft until the indicator reading is 0.254 mm (0.010 in.).
14. Scribe a line on the vibration damper in line with the end of the pointer.

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15. Slowly turn the crankshaft opposite the direction of engine rotation until the indicator hand just stops moving. Continue turning the crankshaft until the indicator hand starts to move again.
16. Reset the dial to zero. Then turn the crankshaft in the same direction until the indicator reading is 0.254 mm (0.010 in.).
17. Scribe a second line on the vibration damper in line with the end of the pointer.
18. Scribe a third line half way between the first two lines. This is top dead center for the cylinder selected when the pointer is lined up with it.
19. Remove the dial indicator and base from the engine.
20. Install the spark plug that was removed.
21. Install the rocker arm assemblies. Refer to section 1.3.3.
22. Turn the crankshaft opposite the direction of engine rotation while watching the intake rocker arm cam follower for the cylinder selected. Turn the crankshaft until the cam follower is on the base circle of that intake lobe of the cam.
23. Install a magnetic dial indicator base on the cylinder head. Install a dial indicator so that the spindle rests directly on the intake cam follower roller for the cylinder selected.

NOTE:
The spindle should be on the center line of the intake cam follower roller pin in order to get an accurate measurement of cam lift.

24. Turn the crankshaft slowly, in the direction of engine rotation, until the center mark on the vibration damper lines up with the pointer.
25. Check the dial indicator reading:
    [a] The dial indicator reading for gas engines is 6.47 mm-7.54 mm (0.255 in. -0.297 in.).
26. If the camshaft lift is incorrect, re-time the engine. Refer to section 1.21.2.1.
27. Refer to section 11.8 for verification of proper camshaft and camshaft bearing installation.

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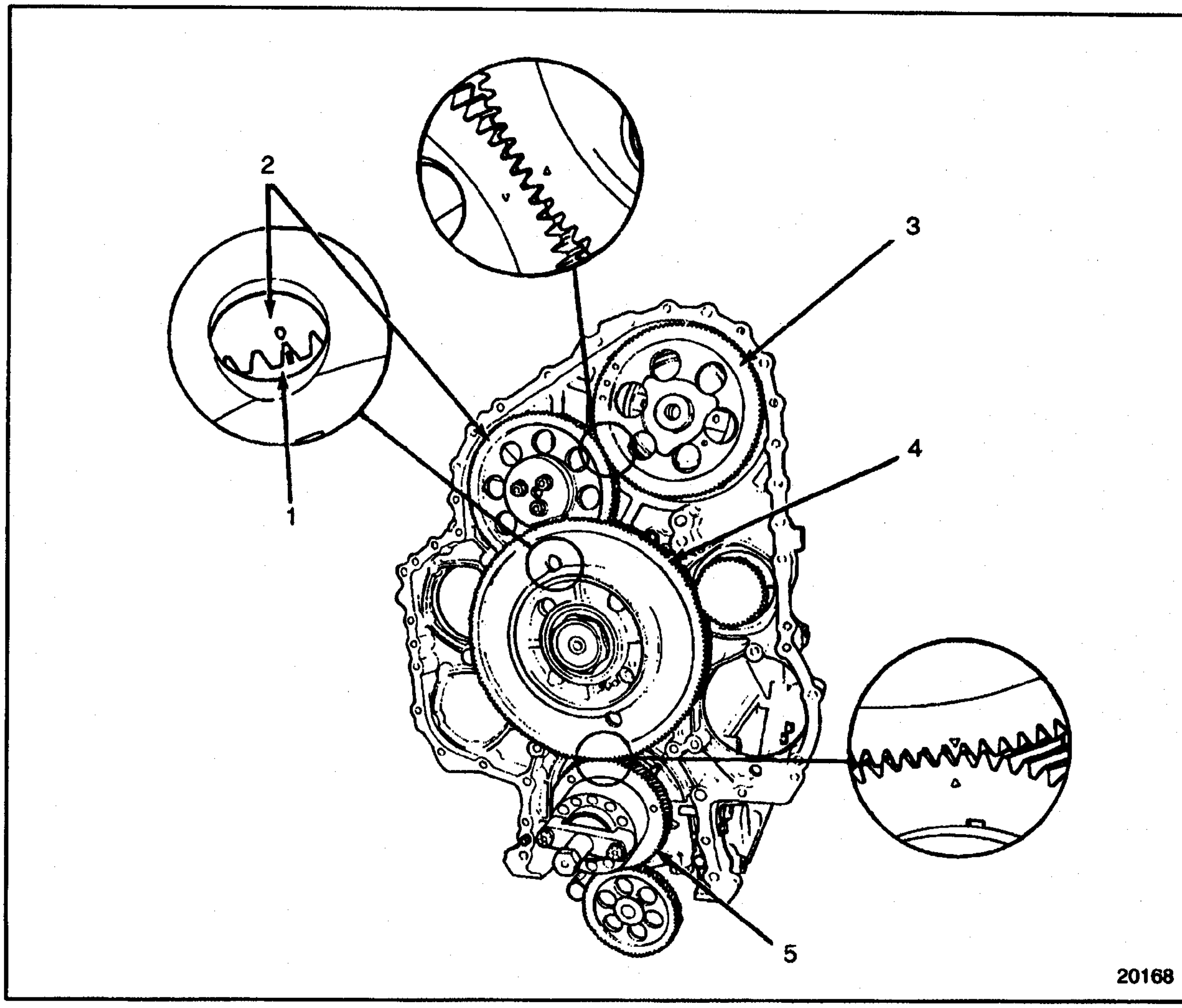
1.24 CAMSHAFT DRIVE GEAR

The camshaft drive gear, located at the front of the engine, under the gear case cover, is driven by the crankshaft through a series of intermediate gears. See Figure 1-354.



1. Idler Gear, Camshaft
2. Idler Gear, Adjustable
3. Drive Gear, Camshaft
4. Bull Gear
5. Timing Gear, Crankshaft

Figure 1-354 Engine Gear Train and Timing Marks

The gear train for the crankshaft drive consists of a crankshaft timing gear, mounted to the end of the crankshaft, meshing with a bull gear. To the rear of the bull gear is the camshaft idler gear, which is mounted on the same hub and rotates at the same speed as the bull gear. The camshaft idler gear meshes with an adjustable idler gear, which is mounted on a separate hub. The adjustable idler gear in turn meshes with the camshaft drive gear, which is mounted on the camshaft drive gear hub. The gears are designed so that the camshaft is driven at half crankshaft speed.

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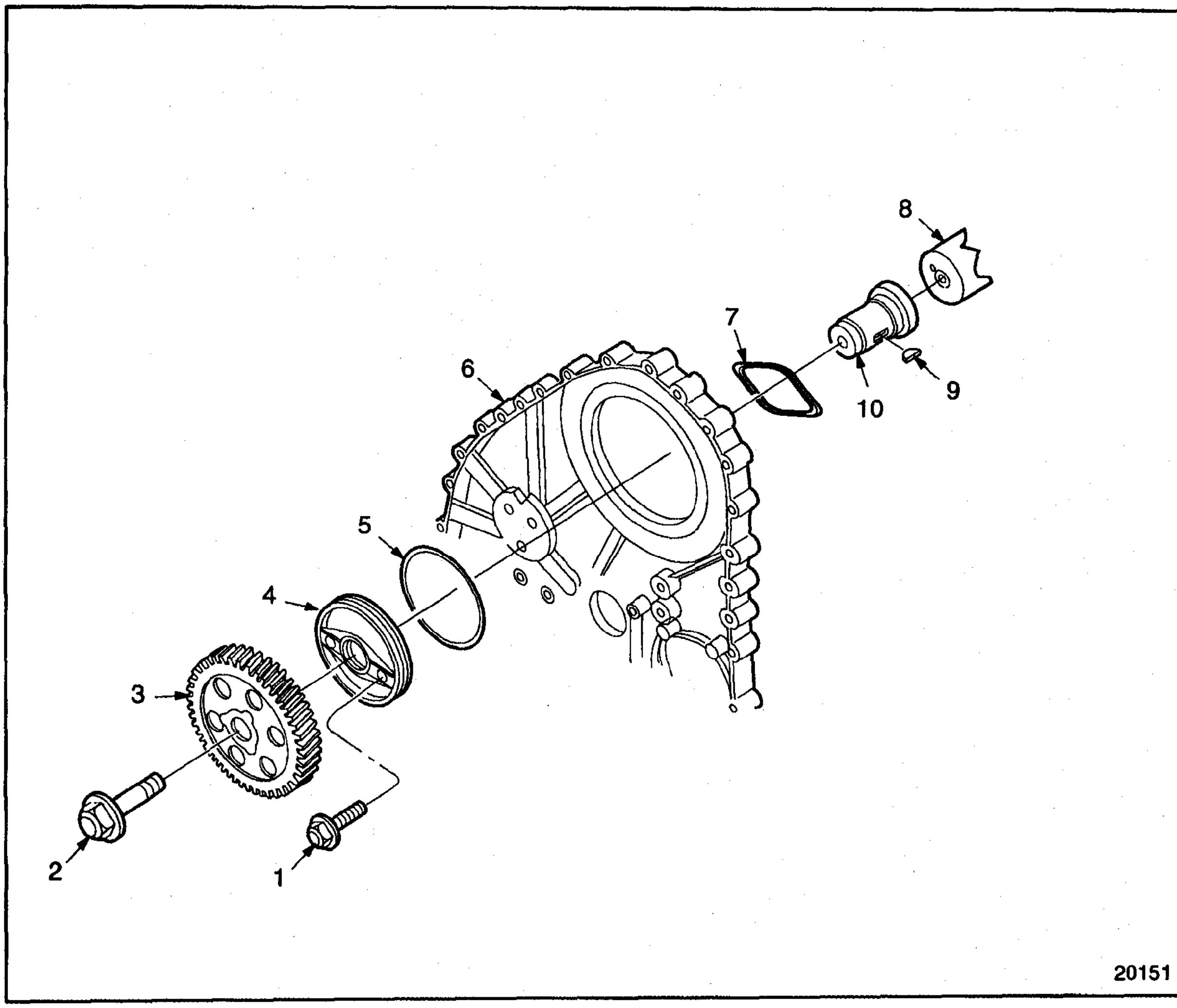
Since the camshaft must be timed exactly to the crankshaft, a series of timing marks are stamped or etched on the gear faces of these gears so that they may be installed in correct relationship to each other.

The camshaft drive gear is keyed and pressed onto a hub located in the thrust plate assembly at the end of the camshaft. The camshaft drive gear and hub are retained to the end of the camshaft by the camshaft drive gear retaining bolt which goes through the camshaft drive gear and the hub, and is threaded into the end of the camshaft. See Figure 1-355.



1. Bolt, Thrust Plate Retaining (2)
2. Bolt, Camshaft Hub Retaining
3. Drive Gear, Camshaft
4. Thrust Plate, Camshaft
5. O-ring
6. Gear Case
7. Seal, Thrust Plate
8. Camshaft
9. Key
10. Hub

Figure 1-355 Camshaft Drive Gear and Related Parts

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The camshaft is indexed to the hub by a dowel. The camshaft drive gear hub rides in a camshaft thrust plate, which is retained by two bolts. One of these bolts screws into the cylinder head, while the other bolt screws into the No. 1 camshaft bearing cap.

The camshaft thrust plate is sealed to the gear case by an O-ring which fits into a groove machined in the outer diameter of the thrust plate. A diamond shaped rubber seal that fits into a groove machined in the rear camshaft thrust plate face, seals the camshaft thrust plate to the cylinder head and No. 1 camshaft cap. The dimple in the thrust plate must be installed at the 12 o'clock position to allow alignment of the thrust plate bolt holes with those in the cylinder head and No. 1 camshaft cap. See Figure 1-356.

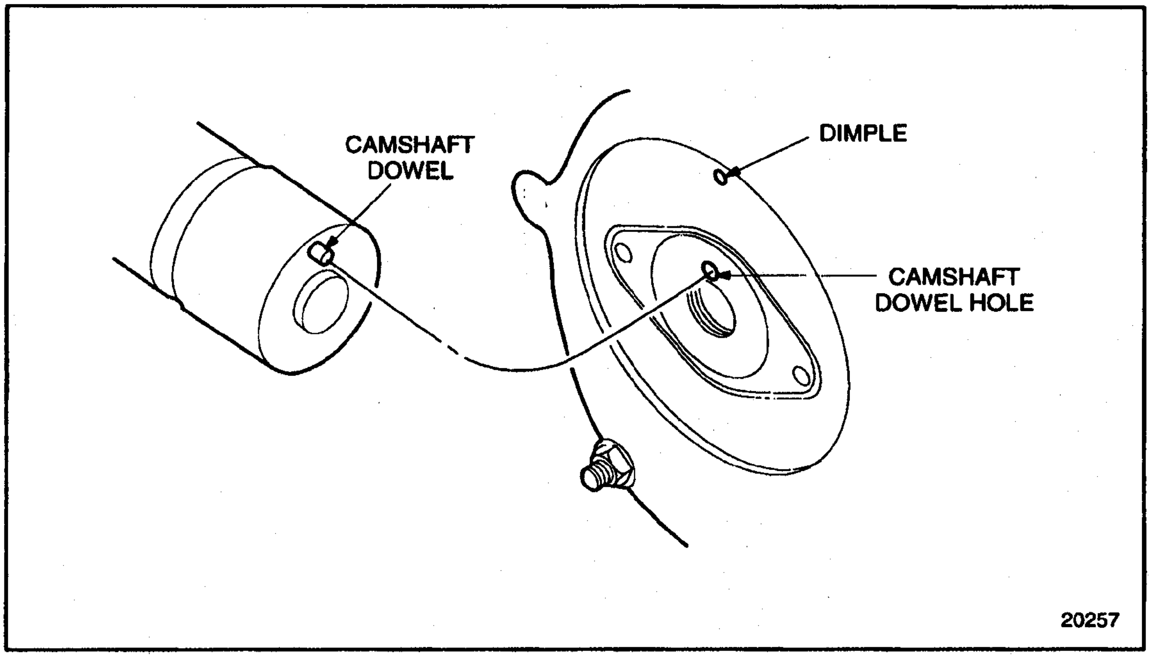

Figure 1-356 Camshaft Thrust Plate and Dowel Pin Location

The camshaft thrust plate can be moved horizontally in the gear case, to allow camshaft and cylinder head removal without damaging the thrust plate seal or removing the gear case cover. The camshaft drive gear will stay in mesh with its mating gear, and may be returned to its original position without re-timing the gears.

1.24.1 Repair or Replacement of Camshaft Drive Gear

To determine if repair or replacement of the camshaft drive gear is necessary, preform the following procedure. See Figure 1-357.

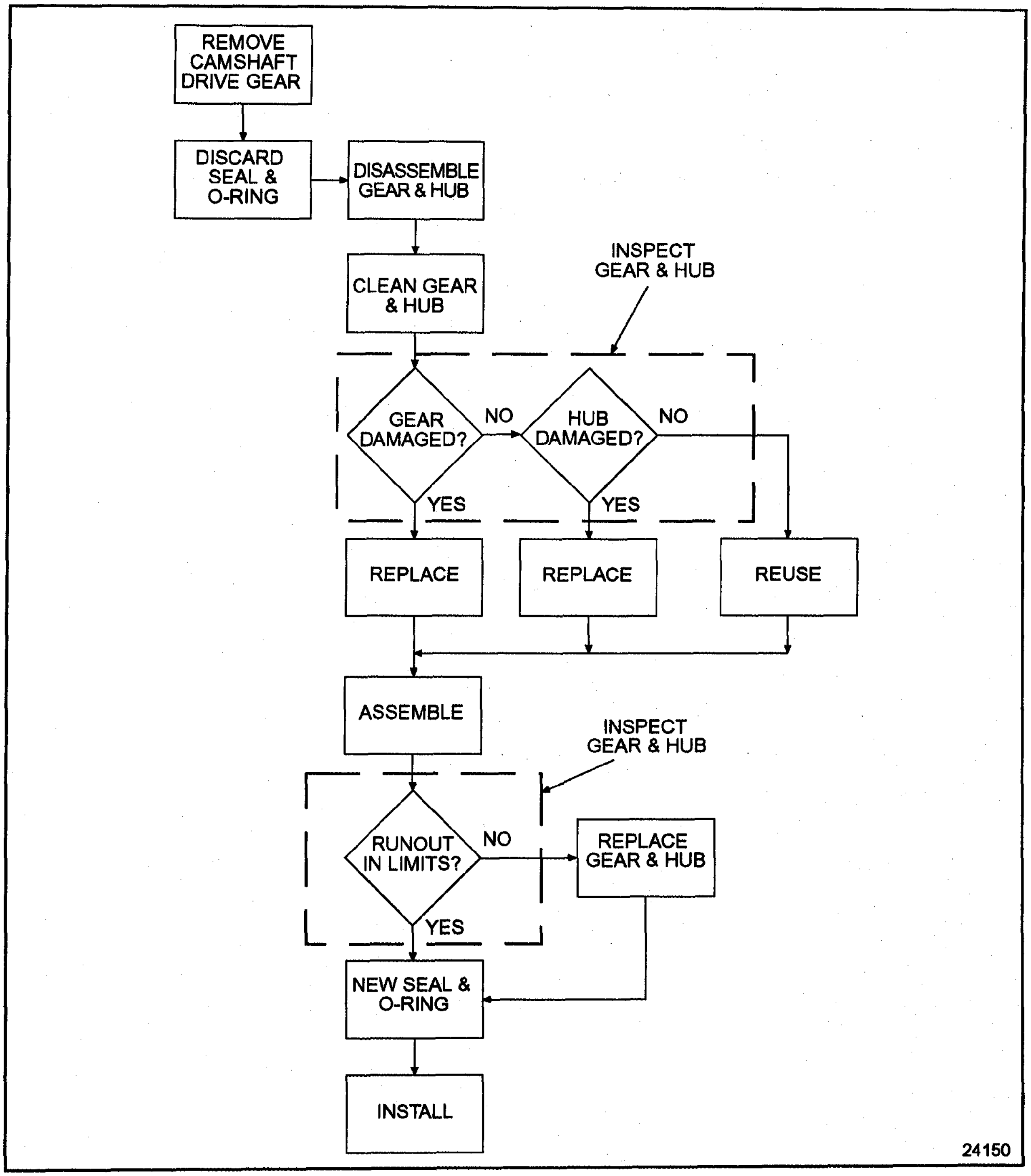

Figure 1-357 Flowchart for Repair or Replacement of Camshaft Drive Gear

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1.24.2 Removal of Camshaft Drive Gear

Remove the camshaft drive gear as follows:

1. Remove the engine valve rocker cover. Refer to section 1.6.2for one-piece rocker cover. Refer to section 1.6.3 for two-piece rocker cover. Refer to section 1.6.5for three-piece rocker cover.
2. Remove the camshaft drive gear access cover, fan bracket, (refer to section 4.7.3) and camshaft retaining bolt, refer to section 1.23.2.

NOTICE:
Use care when removing the camshaft thrust plate retaining bolts to prevent their accidental dropping into the gear case and causing engine damage.

3. Working through the access holes in the camshaft drive gear, remove the two bolts that retain the camshaft thrust plate to the cylinder head and No. 1 camshaft bearing cap. See Figure 1-358.

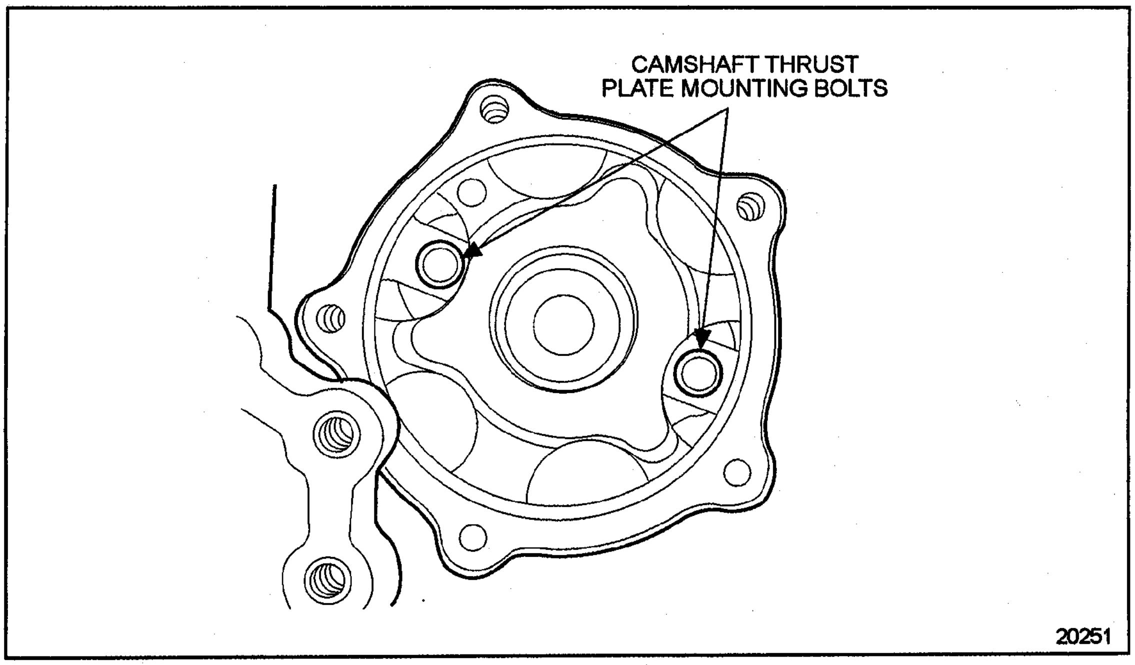

Figure 1-358 Camshaft Thrust Plate Mounting Bolts

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4. Pull the cam gear thrust plate assembly forward as far as possible to separate the assembly from the camshaft using, J 35906.
5. Remove the gear case cover. Refer to section 1.10.2.
6. Using a fiber mallet or plastic hammer, tap the rear face of the camshaft thrust plate forward until it is free of the gear case.
7. Remove the camshaft thrust plate, hub, and camshaft drive gear as an assembly. See Figure 1-359.

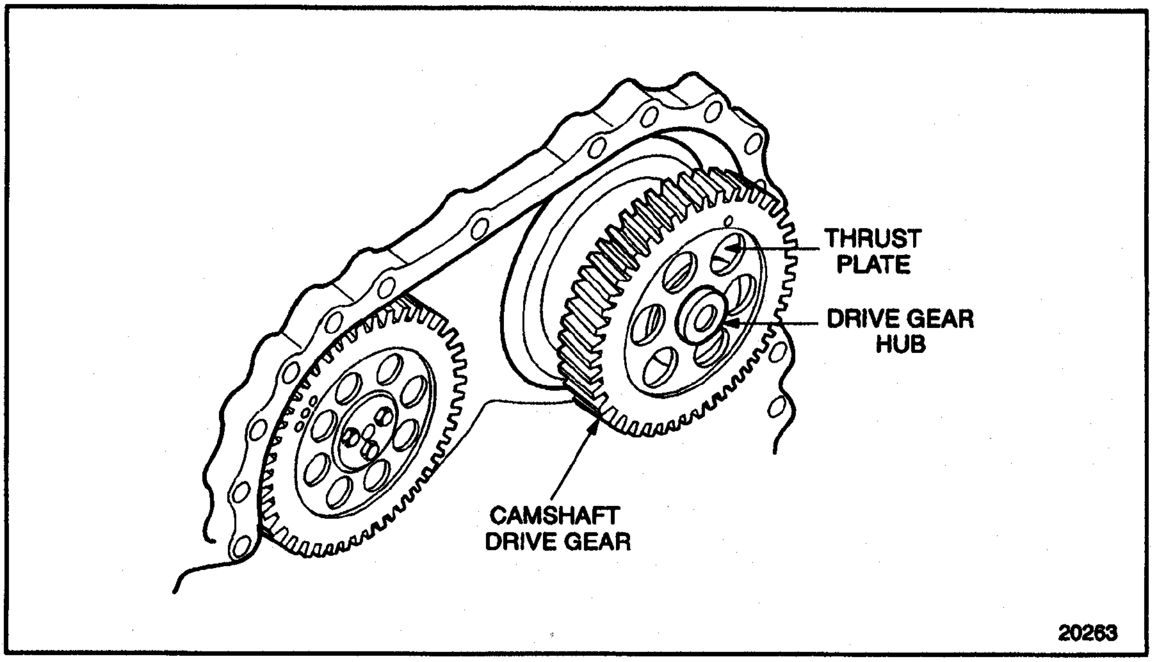

Figure 1-359 Camshaft Thrust Plate Assembly

8. Support the camshaft drive gear, with thrust plate facing down, on blocks.

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9. Press the hub out of the camshaft drive gear until the hub separates from the camshaft thrust plate. See Figure 1-360.

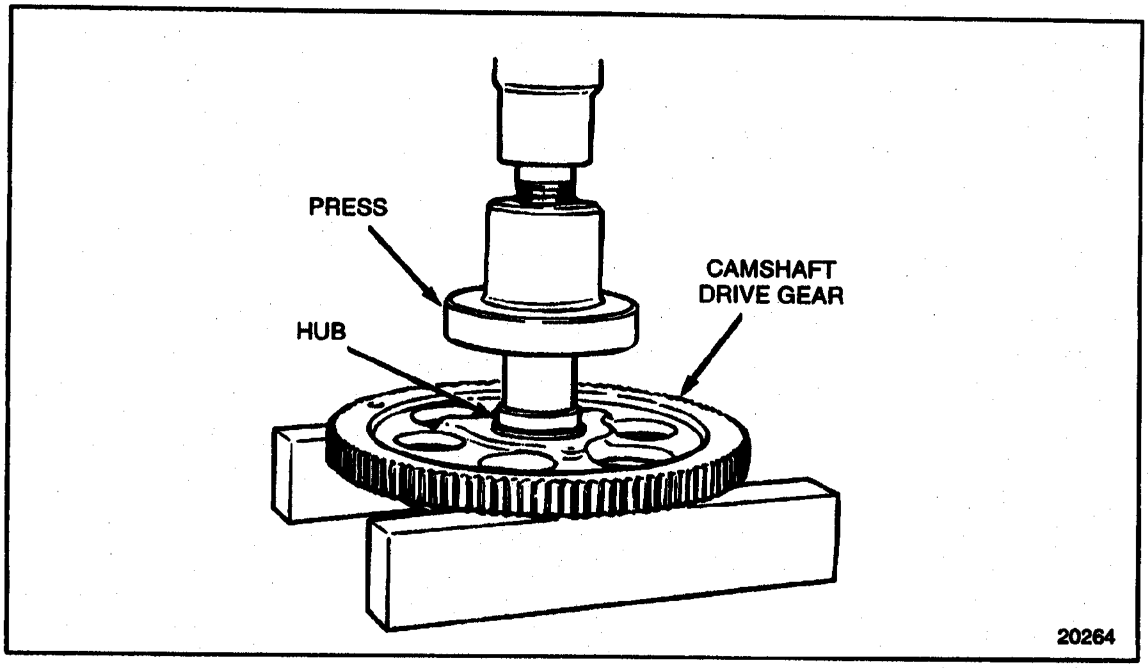

Figure 1-360 Camshaft Hub Removal

10. Remove the O-ring and seal from grooves in the camshaft thrust plate. Discard O-ring and seal.

11. Using a hooked seal extractor, remove the diamond seal from the thrust plate groove.

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1.24.2.1 Inspection of Camshaft Drive Gear

Inspect camshaft drive gear as follows:

1. Clean all parts with fuel oil.

CAUTION:
To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

2. Dry them with compressed air.
3. Examine the camshaft drive gear teeth for scoring, pitting, excessive wear and cracking, peening of the Woodruff Key slot. If damage is found, replace as required.
4. Visually examine the camshaft drive gear hub for scoring, pitting, galling or cracking. If damaged, replace drive gear hub.

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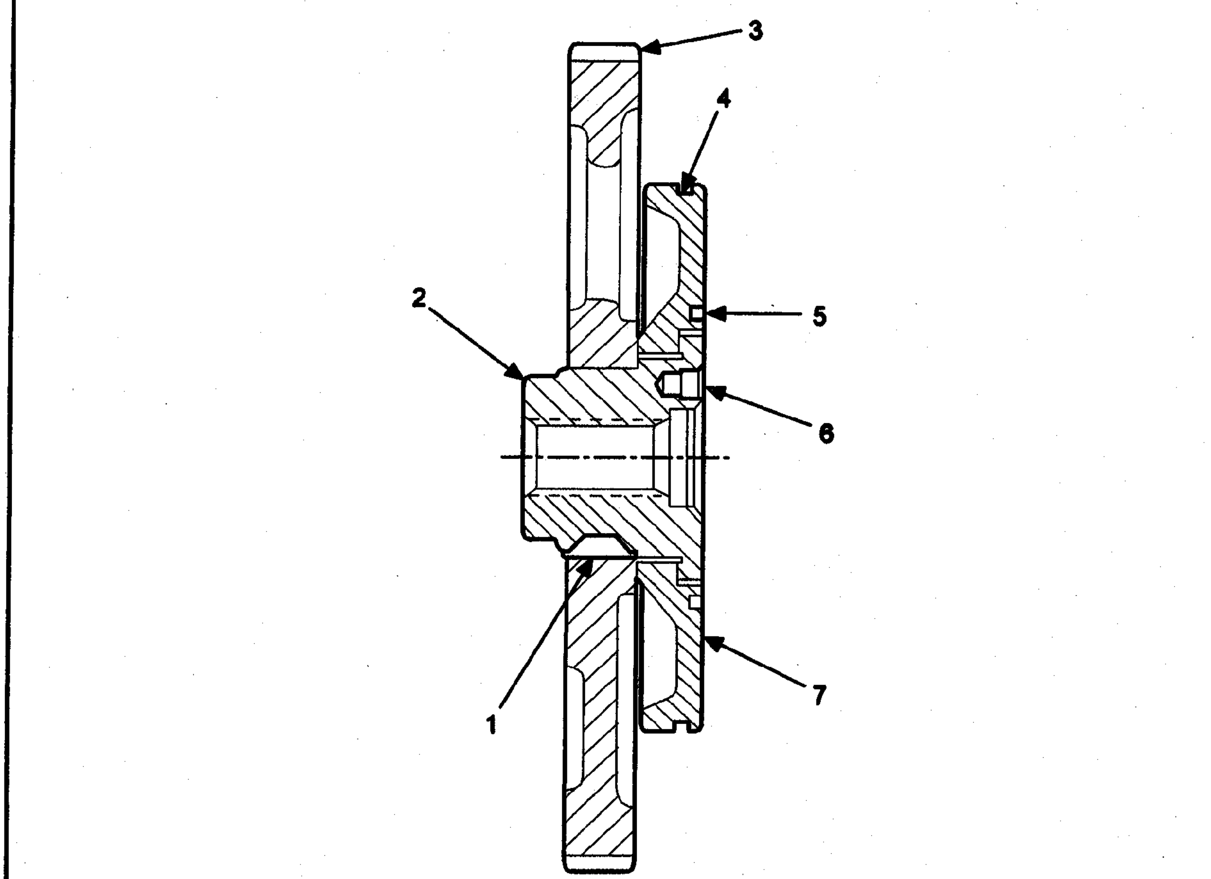
1.24.3 Installation of Camshaft Drive Gear

Install the camshaft drive gear, hub and thrust plate as follows:

1. Coat the contact surfaces of the hub and camshaft thrust plate with clean engine oil. See Figure 1-361.



1. Woodruff Key
2. Hub, Camshaft Drive Gear
3. Drive Gear, Camshaft
4. Groove, O-ring
5. Groove, Seal
6. Dowel Hole, Camshaft
7. Thrust Plate, Camshaft

Figure 1-361 Cross-Section of Camshaft Drive and Related Parts

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2. Install the hub to the camshaft thrust plate.
3. Install the key into the keyway on the hub.
4. Apply a thin film of Lubriplate to the bore of the camshaft gear.
5. Support the hub from the engine side.

NOTICE:
A minimum force of 20 kN (4500 lb) must be obtained when pressing the gear on the hub which can distort camshaft gear if applied off center. Only apply force to the inner hub of the gear when pressing.

6. Align the keyway in the camshaft drive gear with the key in the hub and press the gear, onto the hub until it is firmly seated against the shoulder.

1.24.3.1 Testing of Camshaft Drive Gear Assembly Run-out

Measure the camshaft drive gear assembly run-out as follows:

1. While supporting the camshaft thrust plate on blocks, position the camshaft drive gear assembly with the engine side facing down.
2. Assemble a dial indicator and magnetic base with the indicator stem resting on the face of the camshaft drive gear, just inboard of the drive gear teeth. Zero the dial indicator.
3. Rotate the drive gear two full rotations while reading the total indicated run-out.

NOTE:
The total amount the dial indicator needle moves to the left and right of zero, added together, gives the total indicated run-out Total Indicator Reading (TIR).

[a] If the measured value is 0.114 mm (0.0045 in.) or less, then the drive gear assembly can be reused.

[b] If the measured value is more than 0.114 mm (0.0045 in.), the drive gear assembly parts must be replaced.

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1.24.4 Installation of Camshaft Drive Gear - cont'd

Continue installing camshaft drive gear assembly as follows:

1. Coat the camshaft thrust plate O-ring with clean engine oil.
2. Install it into its groove in the camshaft thrust plate.
3. Install a new diamond seal in the camshaft thrust plate groove by pressing it in with the rounded end of the seal extractor or the flat end of a ruler.
4. Be sure the O-ring sealing surface of the gear case is clean and free of burrs.
5. Install the hub and camshaft thrust plate to the opening in the gear case. The depression in the rear face of the camshaft thrust plate must be positioned at 12 o'clock, see Figure 1-356, to align the retaining bolts in the thrust plate with those in the head and No. 1 camshaft cap.
6. Using a fiber mallet or plastic hammer, tap the camshaft drive gear at 90 degree intervals toward the engine, until the thrust plate bolts can be started in the cylinder head and No. 1 camshaft cap.

NOTICE:
Make sure camshaft dowel hole in camshaft drive hub is aligned with camshaft dowel prior to tightening thrust plate bolts. A misaligned hub can cause damage to the camshaft and thrust plate components

NOTICE:
Use care when installing the camshaft thrust plate retaining bolts to prevent accidentally dropping them into the gear case and causing damage to gear train.

7. Using a 13 mm socket and ratchet, tighten the thrust plate bolts alternately and evenly to draw the thrust plate straight into the gear case. Torque the bolts to 30 - 38 N·m (22-28 lb·ft).
8. Install the gear case cover. Refer to section 1.10.3.

NOTICE:
Always hold the camshaft drive gear stationary using camshaft drive gear retaining tool, J 35652 to prevent component damage, while loosening or tightening the camshaft drive gear-to-camshaft bolt.

NOTE:
Before installing the fan support bracket and camshaft drive gear access cover, it will be necessary to install and tighten the camshaft drive gear retaining bolt, and to measure and adjust the adjustable gear-to-camshaft drive gear lash.

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9. Install J 35652 and tighten the camshaft drive gear retaining bolt as follows:

NOTICE:
Failure to tighten the camshaft hub retaining bolt to the required torque may result in bolt loosening during engine operation, which may lead to camshaft alignment pin damage, altered engine timing, and erratic engine operation.

[a] Apply a small amount of International Compound #2®, or equivalent, to the bolt threads and underside of the bolt head.

[b] Install the bolt through the hub and thread into the camshaft.

[c] Torque bolt to 75 N·m (55 lb·ft).

[d] Turn the bolt an additional 120 degrees. See Figure 1-362.

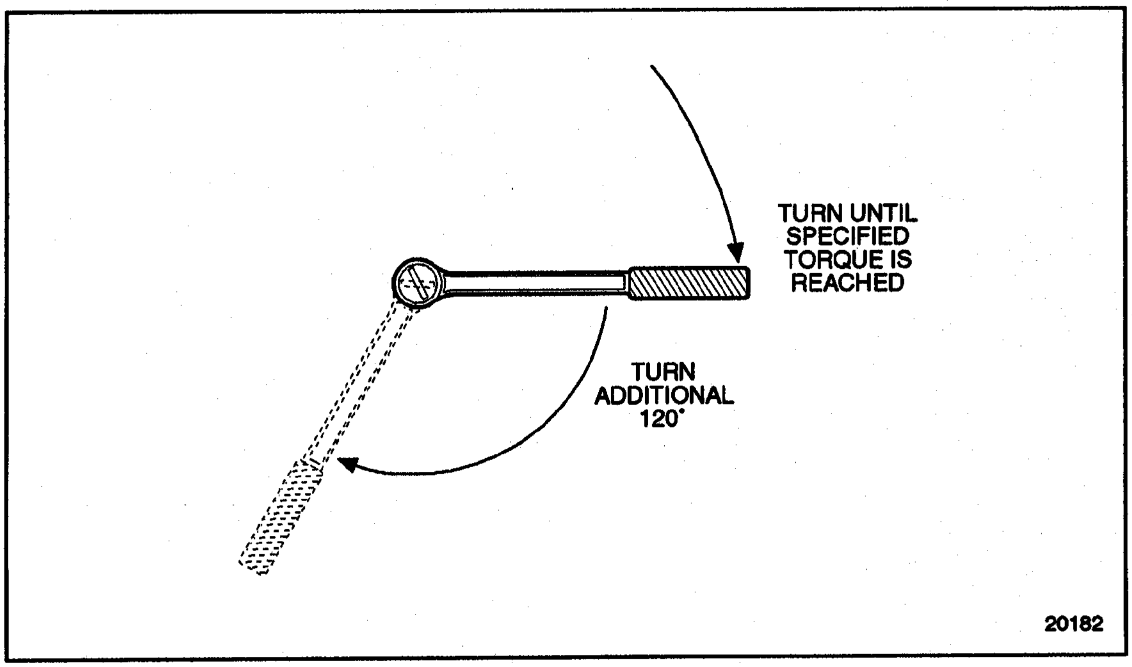

Figure 1-362 Torque Turn Limits

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10. Check the gear train timing and adjustable idler gear-to-camshaft drive gear lash. Refer to section 1.21.2.1.
11. Install the camshaft drive gear access cover. Refer to section 1.10.3.
12. Install the fan bracket. Refer to section 4.7.6.
13. Install any components that were removed for access to the gear case cover.
14. Check the lubricating oil. Refer to section 13.13.1.
15. Check the coolant level. Refer to section 13.13.4.
16. Refer to section 11.8 for verification of proper camshaft drive gear installation.

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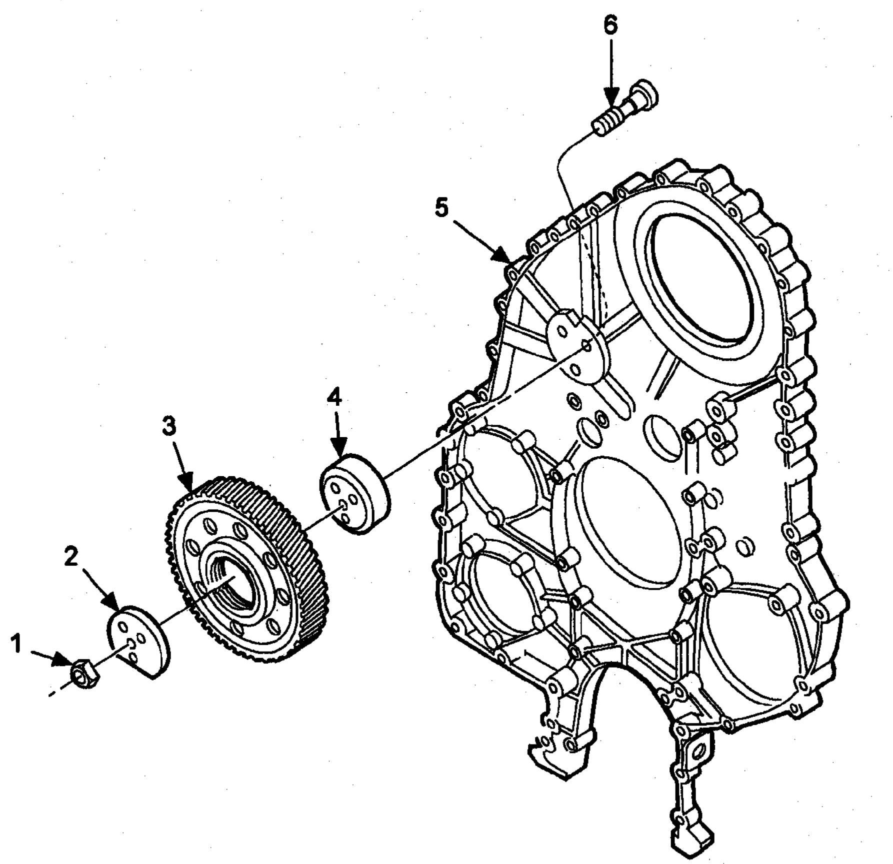
1.25 ADJUSTABLE IDLER GEAR ASSEMBLY

The adjustable idler gear is a straight-cut gear, mounted on a bushing pressed into the center of the gear, which in turn is supported on a stationary hub. The hub is secured to the gear case by a retaining plate, three studs, and locknuts. The studs are pressed into the gear case from the rear, and the flanged locknuts are installed after the gear, hub and hub retaining plate are installed. See Figure 1-363.



1. Locknut, Adjustable Idler Gear (3)
2. Retaining Plate, Adjustable Idler Gear Hub
3. Gear Assembly, Adjustable Idler
4. Idler Hub, Adjustable
5. Gear Case
6. Stud, Adjustable Idler Gear (3)

Figure 1-363 Adjustable Idler Gear and Related Parts

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The adjustable idler gear is pressure lubricated by engine oil fed to a gallery drilled into the gear case. This gallery indexes with the cylinder block oil gallery. See Figure 1-364.

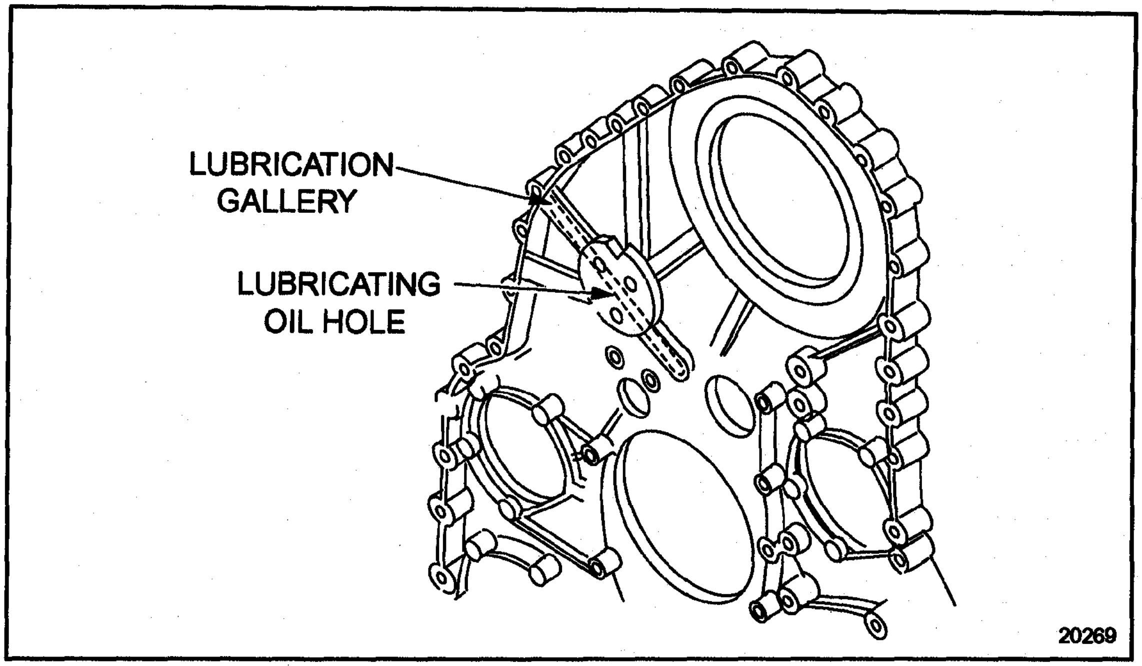

Figure 1-364 Adjustable Idler Gear Oil Gallery Location

The adjustable idler gear bushing has a series of machined grooves in the contact surface, for oil retention. The bushing is not serviced separately. If the bushing becomes worn or damaged, the gear and bushing must be replaced as an assembly.

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There are three bolt holes in the hub where it is inserted over the studs. See Figure 1-365.

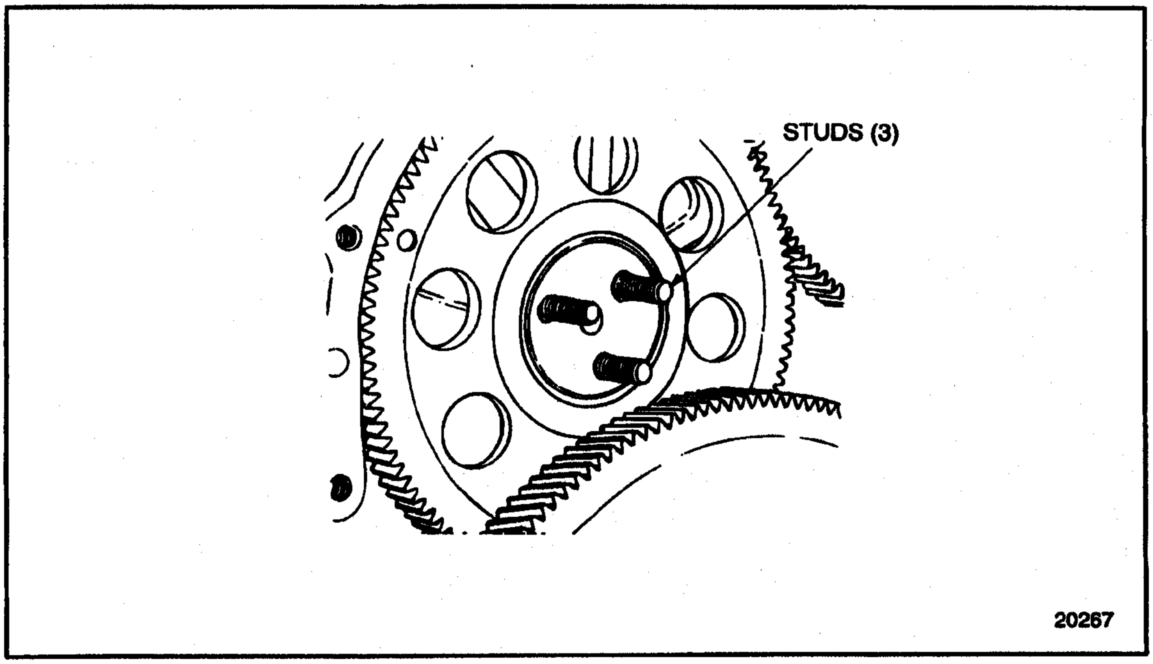

Figure 1-365 Adjustable Idler Gear Bolt Hole Location

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The top two holes are elongated, to allow the idler gear and hub assembly to be moved in relationship to the camshaft drive gear. The bottom stud hole is not elongated, and is a close fit to the stud. This allows the adjustable idler gear to pivot on the bottom stud, so the adjustable idler gear to camshaft drive gear lash can be adjusted without changing the clearance between the adjustable idler gear and camshaft idler gear. The adjustable idler gear retaining plate has a flat on the bottom to clear the bull gear for removal and installation. See Figure 1-366.

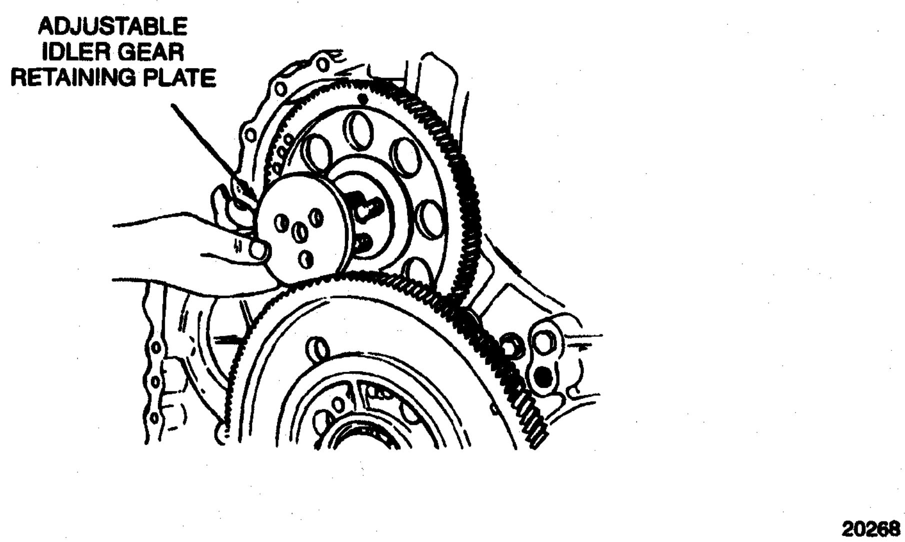

Figure 1-366 Adjustable Idler Gear Retaining Plate

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1.25.1 Repair or Replacement of Adjustable Idler Gear Assembly

To determine if repair or replacement of the adjustable idler gear assembly is necessary, perform the following procedure. See Figure 1-367.

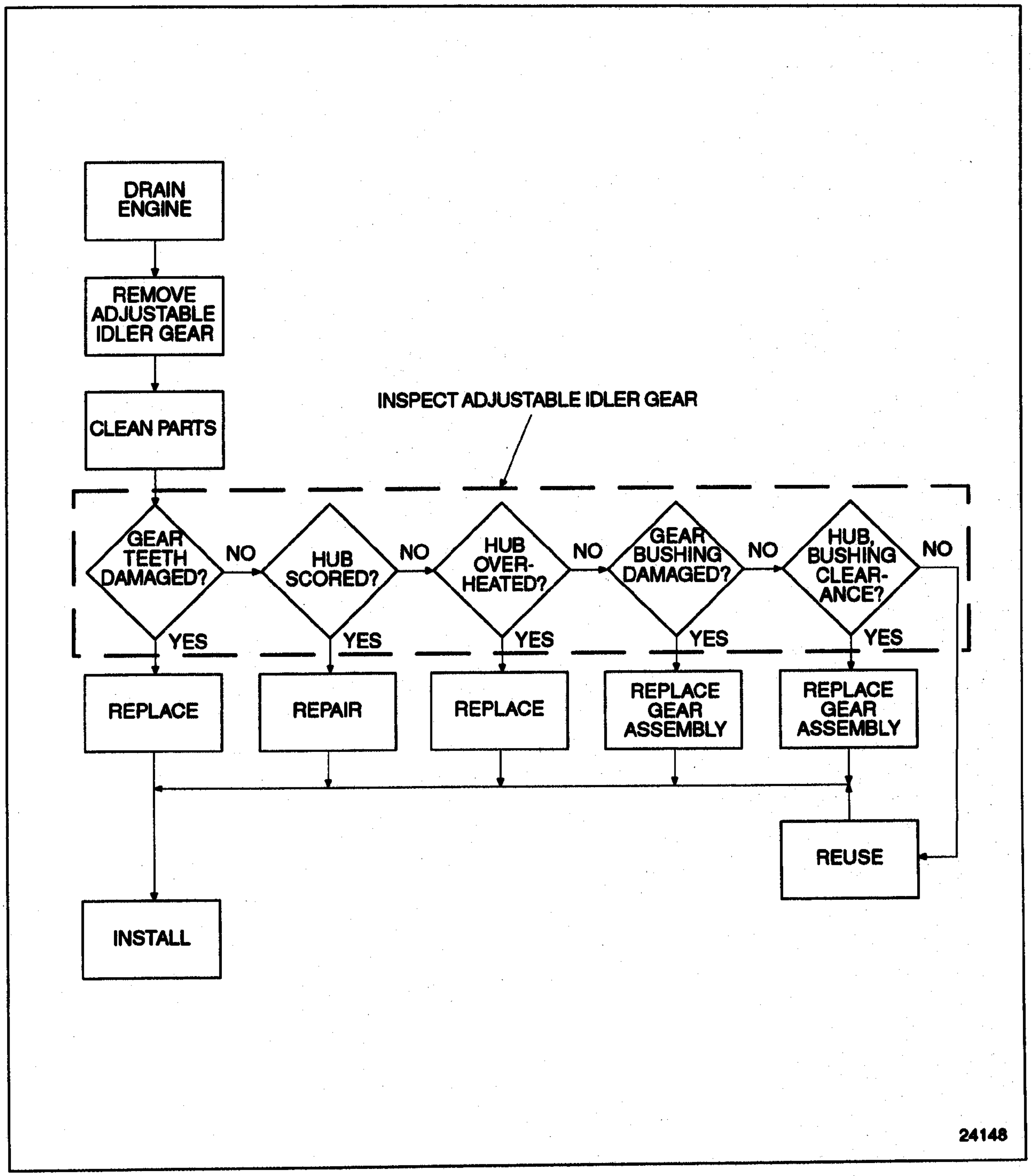

Figure 1-367 **Flowchart for Repair or Replacement of Adjustable Idler Gear Assembly**

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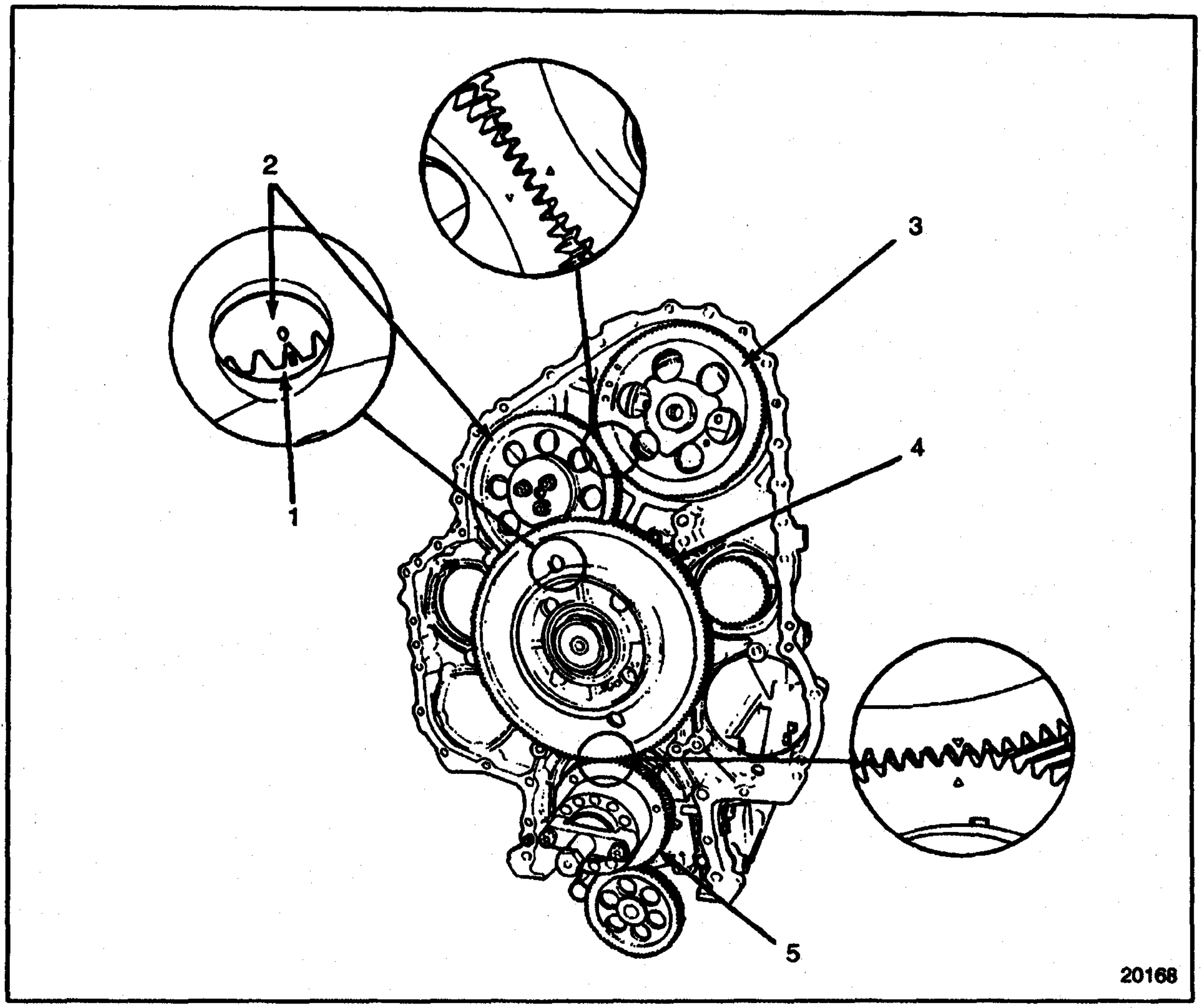
1.25.2 Removal of Adjustable Idler Gear Assembly

Align gear train timing marks. See Figure 1-368.

NOTE:
In order to maintain the proper timing between the crankshaft and the camshaft, a series of timing marks are stamped or etched on the gears in the gear train. With the timing marks aligned, the gears can be replaced exactly as removed.



1. Idler Gear, Camshaft
2. Idler Gear, Adjustable
3. Drive Gear, Camshaft
4. Bull Gear
5. Timing Gear, Crankshaft

Figure 1-368 Engine Gear Train and Timing Marks

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Remove the adjustable idler gear assembly as follows:

1. Drain the cooling system. Refer to section 13.13.4.
2. Drain the engine lubricating oil. Refer to section 13.13.1.
3. Remove the oil pan. Refer to section 3.11.2.
4. Remove the gear case cover. Refer to section 1.10.2.
5. Secure J 36237, to the front of the crankshaft. See Figure 1-369.

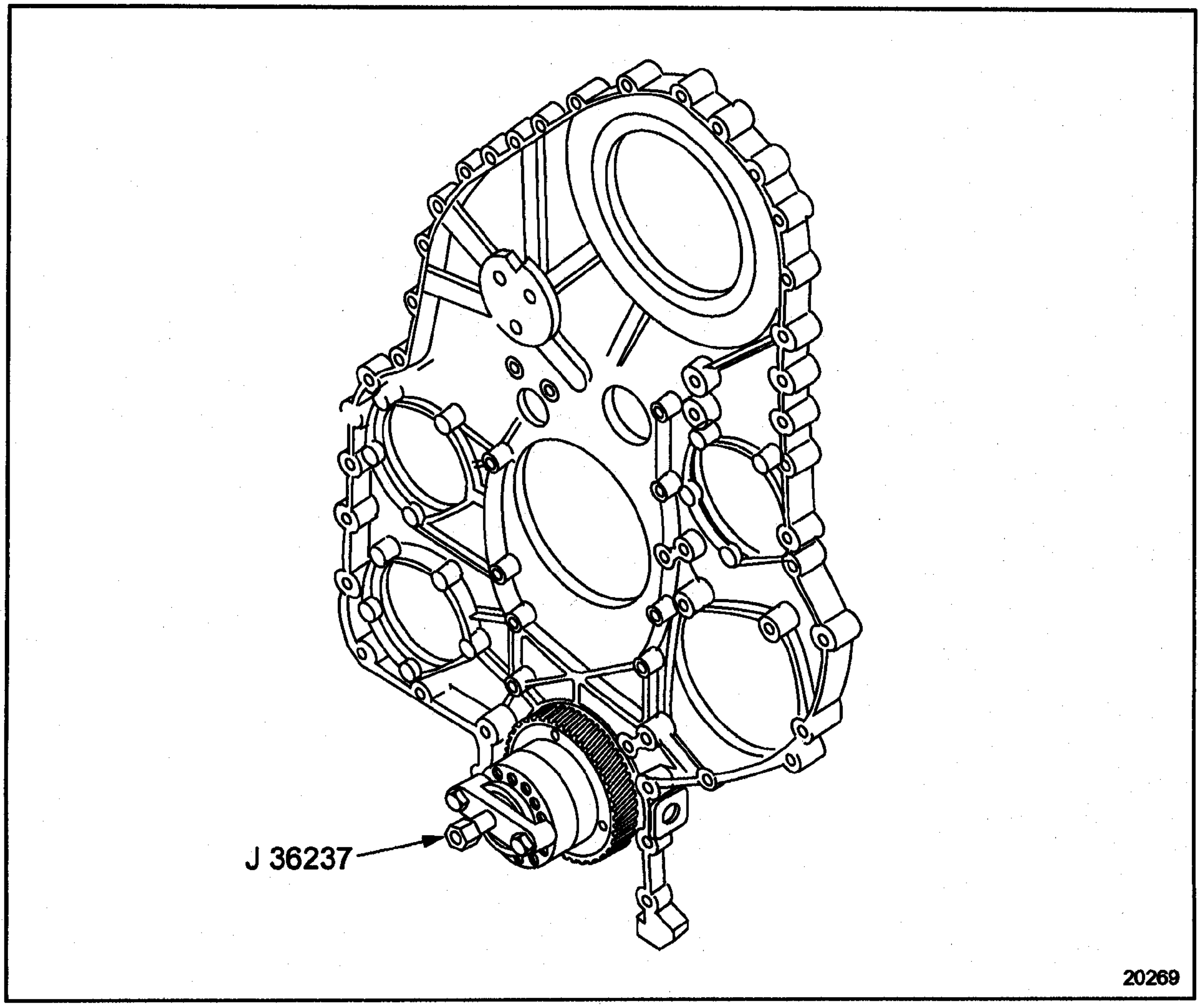

Figure 1-369 Barring Engine Over

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NOTICE:
Always use crankshaft protector, J 35994, to guard against damage to the oil seal area of the crankshaft. When removing the bull gear or camshaft idler gear and hub assembly, do not come in contact with the oil seal contact surface of the crankshaft. If sealing surface is scratched, an oil leak may result.

6. Install J 35994, to the oil seal contact area of the crankshaft.
7. Working through the four access holes in the bull gear and camshaft idler assembly, remove two of the four bolts that secure the bull gear and camshaft idler gear hub to the cylinder block. See Figure 1-370.

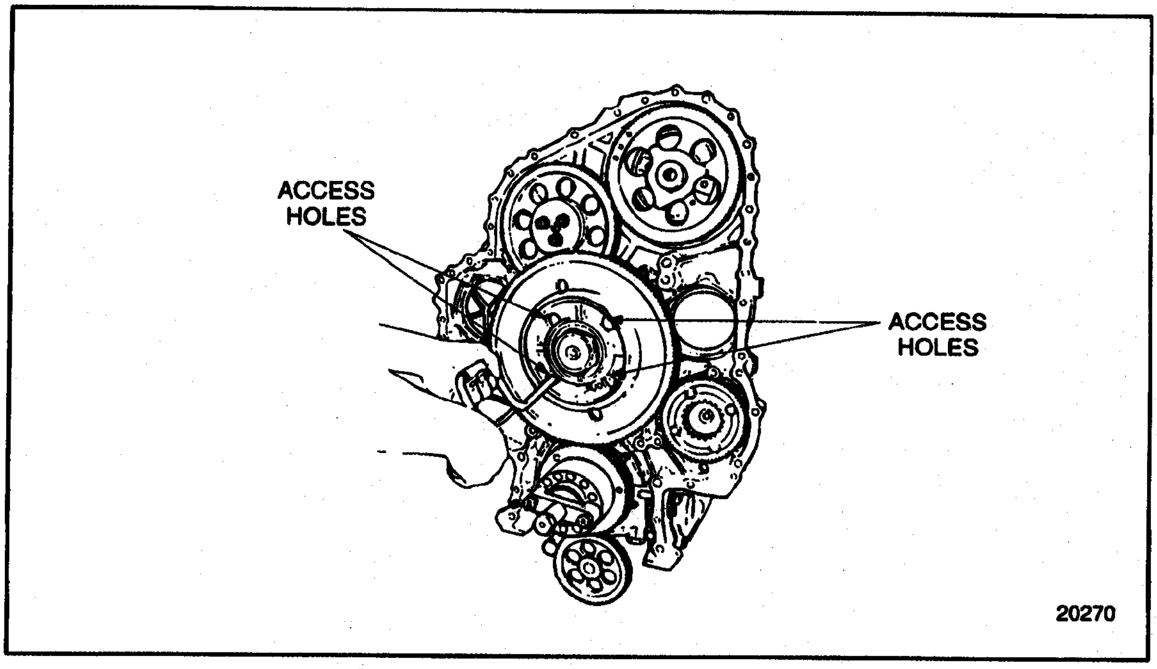

Figure 1-370 Removing Bull Gear and Camshaft Idler Gear Hub

8. Install J 35785, to the holes from where the bolts were removed.
9. Remove the remaining two bull gear and camshaft idler gear hub bolts.
10. Grasp the bull gear and remove the bull gear and camshaft idler gear and hub assembly from its recess in the cylinder block.
11. Remove the three adjustable idler gear flanged locknuts.
12. Remove the adjustable idler gear hub retaining plate.
13. Remove the adjustable idler gear and hub.

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1.25.2.1 Inspection of Adjustable Idler Gear Assembly

Inspect the adjustable idler gear assembly as follows:

1. Wash the adjustable idler gear, hub, and retaining plate thoroughly in clean fuel oil.

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

2. Dry with compressed air.
3. Examine the gear teeth for evidence of scoring, pitting and wear.

NOTE:
If gear teeth are damaged, also inspect the other gears in the gear train.

   [a] If severely damaged or worn, replace the gear.

   [b] If no damage is found, reuse the gear.

4. Inspect the contact surface of the hub for scoring or evidence of overheating (blue discoloration).

   [a] If hub has blue discoloration, replace the hub.

   [b] If hub has no blue discoloration, reuse the hub.

   [c] If slight irregularities are present, use a fine stone or emery cloth to remove them.

5. Check the lubrication hole and gallery in the gear case for blockage.

   [a] If the lubrication hole is blocked, clear the lubrication hole.

   [b] If the lubrication hole is not clogged, no cleaning is required.

6. Inspect the bushing contact surface of gear and bushing assembly for signs of scoring, discoloration due to overheating, or excessive wear.

   [a] If the surface of the bushing is not acceptable, replace the gear and bushing as an assembly.

   [b] If the surface has no damage, reuse the bushing assembly.

7. Measure the clearance between the bushing and hub.

   [a] If the clearance is more than 0.033 - 0.076 mm (0.0013 -0.0030 in.), replace the gear and bushing as an assembly.

   [b] If the clearance is to specification, 0.033 - 0.076 mm (0.0013 -0.0030 in.), reuse the gear and bushing assembly.

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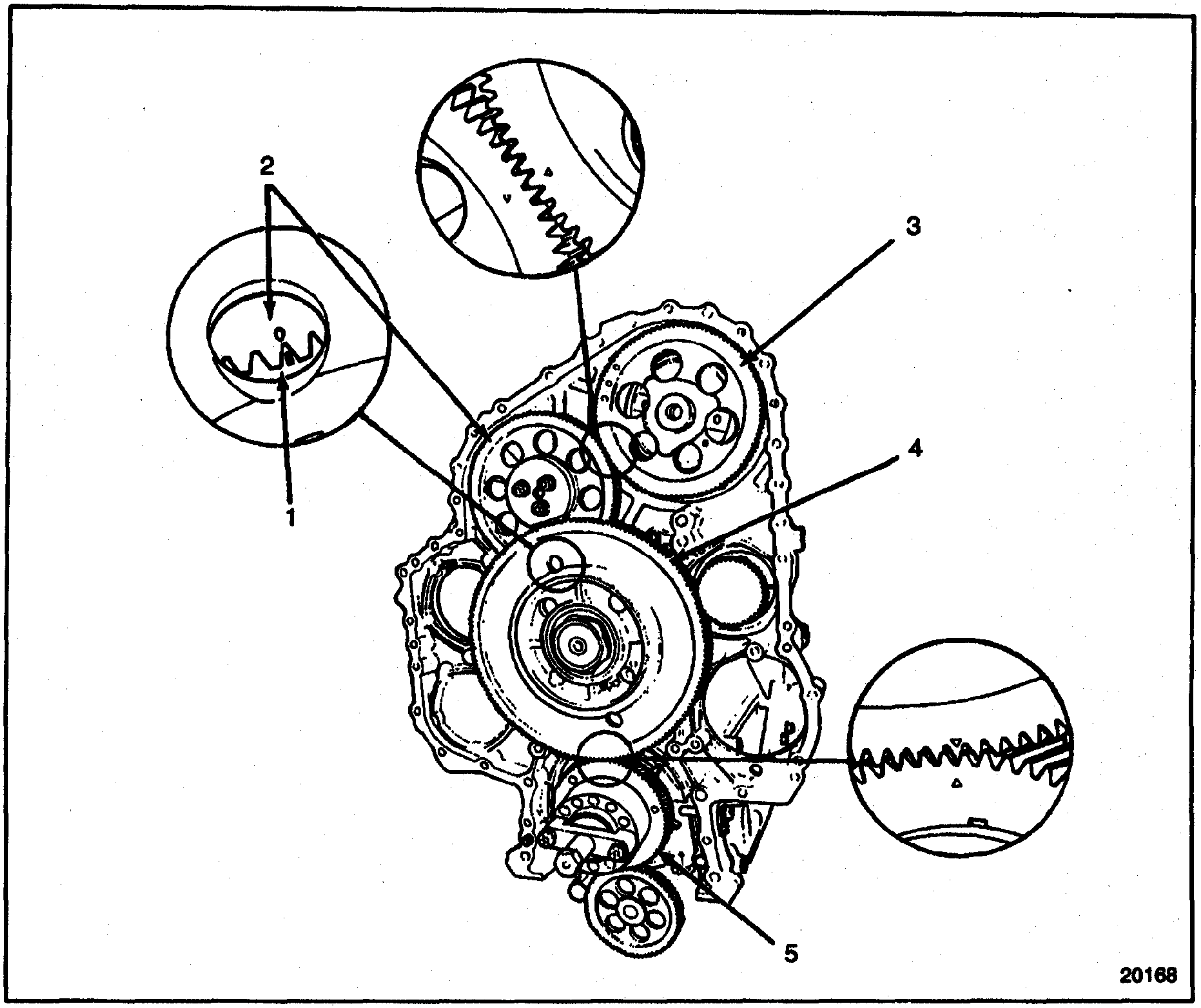
1.25.3 Installation of Adjustable Idler Gear Assembly

Install the adjustable idler gear and related parts as follows:

1. Coat the contact surfaces of the hub and idler gear bushing with clean engine oil.
2. Install the hub, with the word "OUT" facing outward, to the three studs in the gear case with the oil supply hole in the hub towards the gear case.
3. Align the timing marks on the face of the adjustable idler gear and camshaft drive gear and install the adjustable idler gear to its hub. See Figure 1-371.



1. Idler Gear, Camshaft
2. Idler Gear, Adjustable
3. Drive Gear, Camshaft
4. Bull Gear
5. Timing Gear, Crankshaft

Figure 1-371 Engine Gear Train and Timing Marks

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4. Install thrust plate with the relief at the bottom. See Figure 1-370.
5. Install the three flanged locknuts, finger-tighten.
6. Install J 35785, and J 35994 to the cylinder block.
7. Coat the bearings and contact surfaces of the bull gear assembly with clean engine oil.
8. Looking through the inspection hole in the bull gear, align the timing marks on the camshaft idler gear (mounted to the rear of the bull gear) with the adjustable idler gear. Align the timing marks on the bull gear and crankshaft timing gear. Refer to section 1.21.2.1. Install the bull gear hub assembly to the cylinder block. See Figure 1-371.
9. Install the bull gear hub assembly to the cylinder block. Refer to section 1.26.3.
10. Install the gear case cover. Refer to section 1.10.3.
11. Adjust the gear lash between the adjustable idler gear and camshaft drive gear. Refer to section 1.21.2.1.
12. Install any other components that were removed for access to the gear case cover.
13. Refer to section 11.8 for verification of proper adjustable idler gear assembly installation.

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1.26 BULL GEAR AND CAMSHAFT IDLER GEAR ASSEMBLY

The bull gear and camshaft idler gear assembly is centrally located beneath the gear case cover. The larger bull gear is directly driven by the crankshaft timing gear. The bull gear directly drives all of the gear-driven engine accessories (except the oil pump), meshing with drive gears for the fuel pump drive, air compressor drive and power steering pump (if so equipped), raw water pump (if so equipped), water pump and accessory and alternator drive. See Figure 1-372.

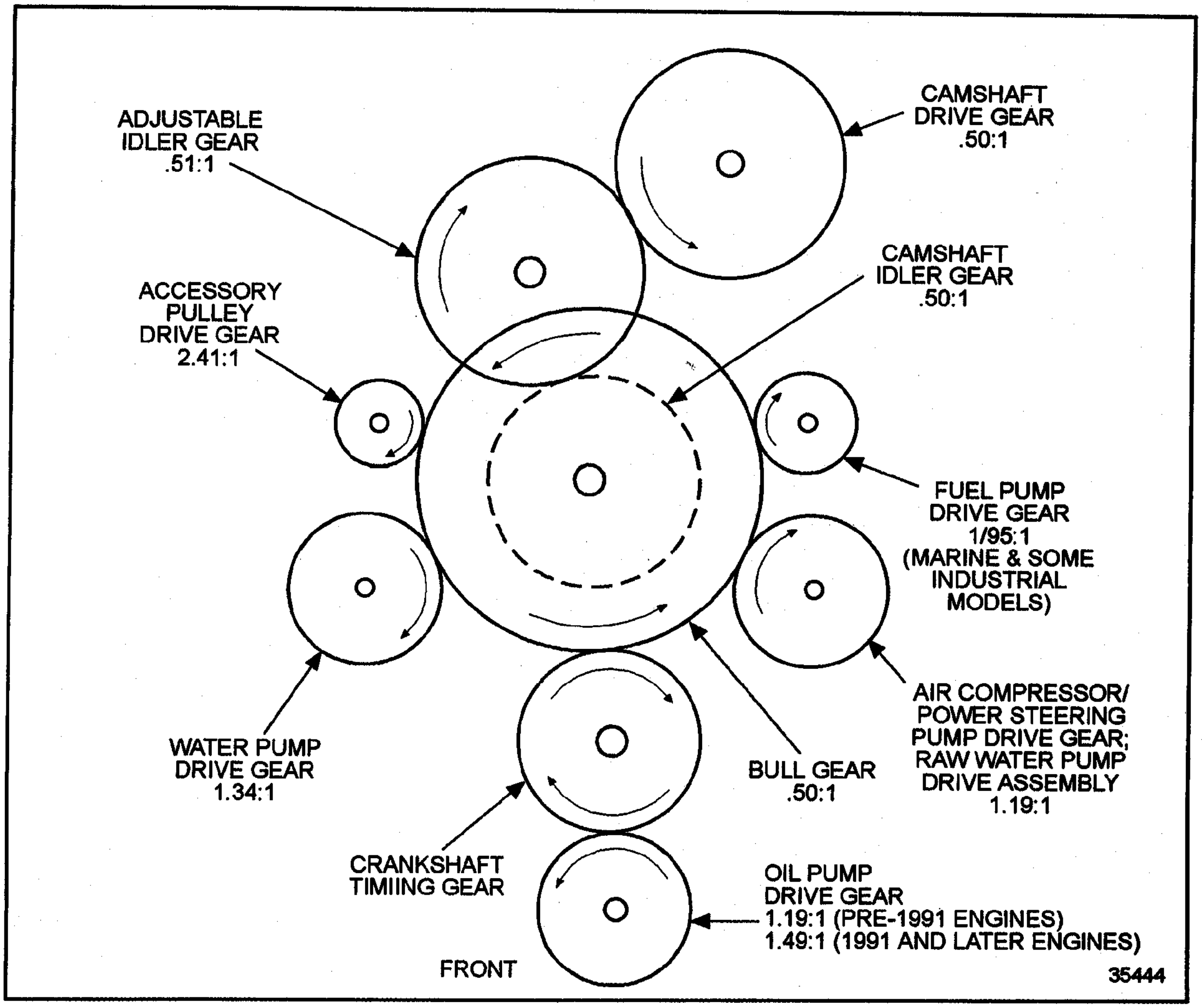

Figure 1-372 Engine Gear Train

The smaller camshaft idler gear is located behind the bull gear on the same carrier, and turns at the same speed as the bull gear. The camshaft idler gear drives an adjustable idler gear, mounted on a separate hub in the gear case. The adjustable idler gear drives the camshaft drive gear. The gear ratio of each gear in relationship to the crankshaft timing gear is shown directly below the gear title.

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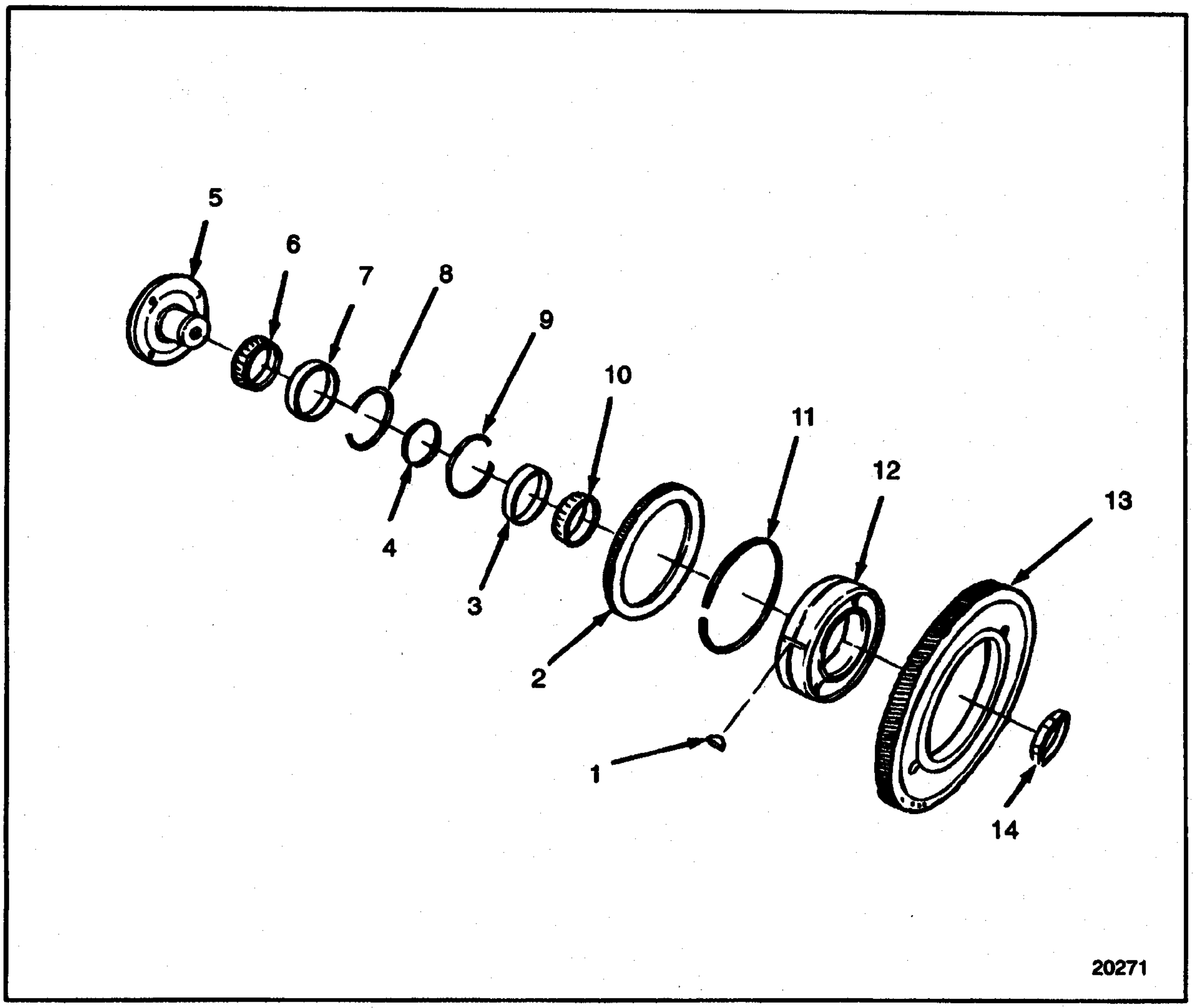
The bull gear and camshaft idler gear are a press-fit to the bull gear and camshaft idler gear carrier. See Figure 1-373.



1. Woodruff Key
2. Camshaft, Idler Gear
3. Bearing Race, Outer
4. Spacer Ring, Small
5. Hub
6. Bearing, Inner
7. Bearing Race, Inner
8. Snap Ring, Inner
9. Snap Ring, Outer
10. Bearing, Outer
11. Spacer Ring, Large
12. Carrier
13. Bull Gear
14. Thread Nut, Left Hand

Figure 1-373 Bull Gear and Related Parts

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Both gears are keyed to the carrier by the same key. For units built prior to 6R11886, a spacer ring fits in a groove in the carrier between the bull gear and the camshaft idler gear. For units built after 6R11887, this spacer was incorporated in the carrier. The carrier is supported by two tapered roller bearing assemblies that ride on a hub bolted to the engine block by four bolts. A selective-size spacer between the two bearing assemblies is used to obtain the correct bearing preload.

NOTE:
The bull gear and camshaft idler gear assembly is retained to the hub by a left-hand threaded nut.

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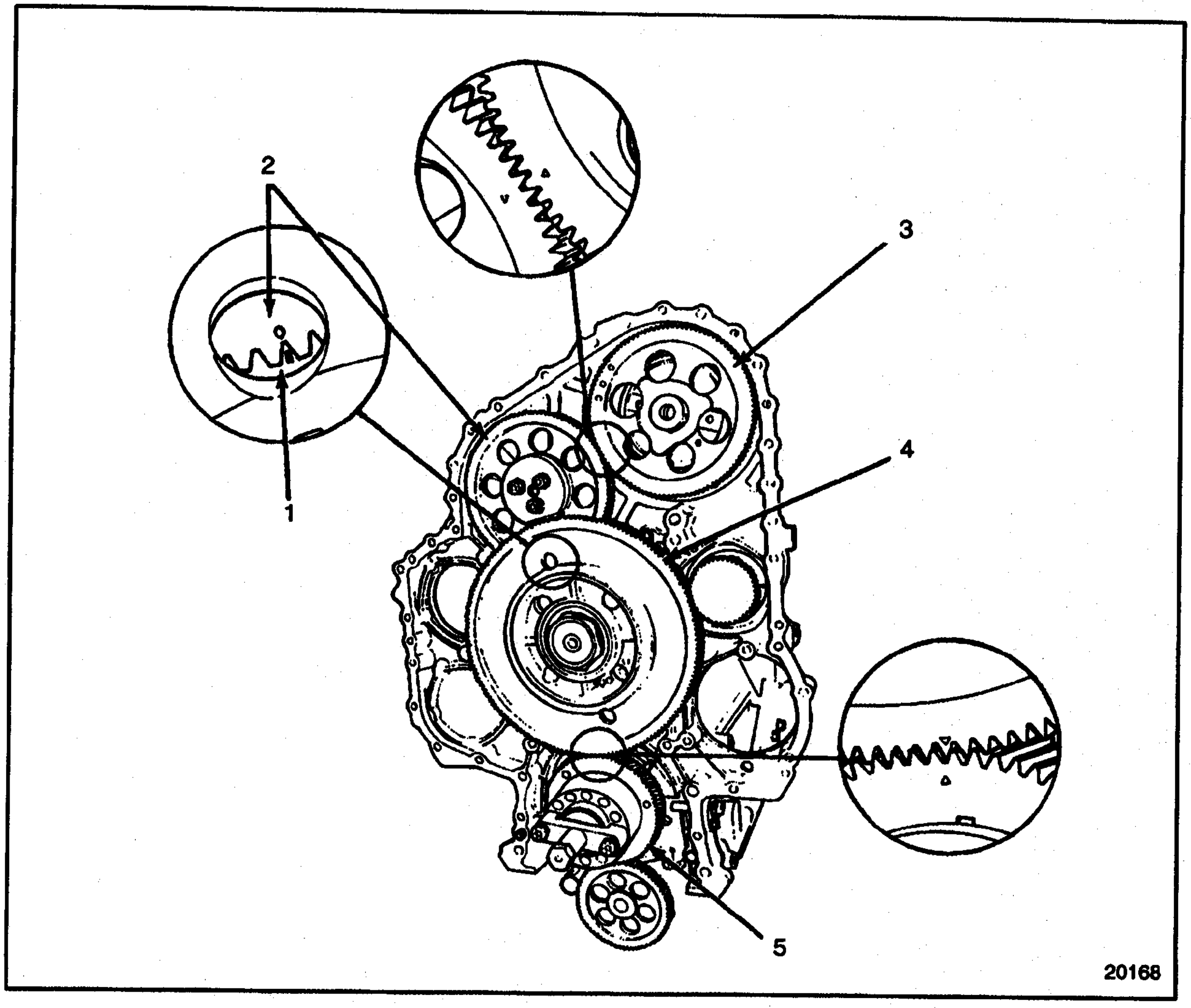
The camshaft must be in time with the crankshaft timing gear. Since there are three gears between them, timing marks have been stamped or etched on the face of the gears to facilitate correct gear train timing. Refer to section 1.21.2.1 for gear train timing procedures. See Figure 1-374.



1. Idler Gear, Camshaft
2. Idler Gear, Adjustable
3. Drive Gear, Camshaft
4. Bull Gear
5. Timing Gear, Crankshaft

Figure 1-374 Engine Gear Train and Timing Marks

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The backlash between the various mating gears in the gear train should be 0.051-0.229 mm (0.002 -0.009 in.), and should not exceed 0.305 mm (0.012 in.) backlash between worn gears. Refer to section 1.21.2.1.

NOTE:
All gear lash measurements should be taken with engine in an upright position.

The bull gear and camshaft idler gear assembly is pressure-fed lubricating oil through two holes in the bull gear recess area of the engine block. See Figure 1-375.

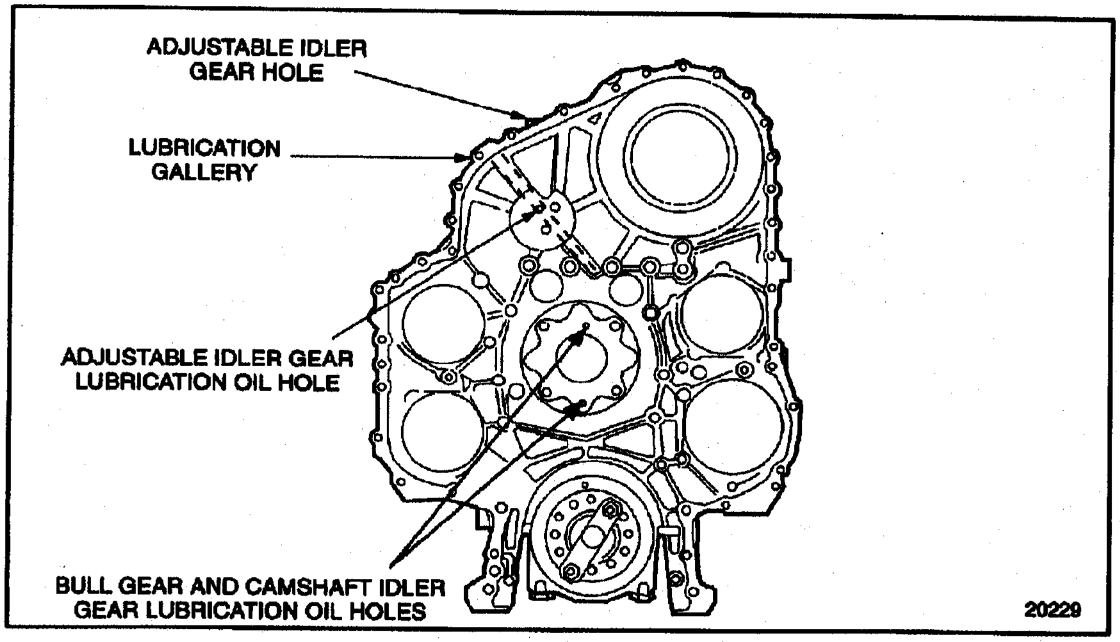

Figure 1-375 Bull Gear and Camshaft Idler Gear Lubricating Oil Hole Locations

These two holes are drilled into a main oil gallery. An internal oil passage, cast into the bull gear and camshaft idler gear hub relief at the rear of the hub indexes with these two oil holes to supply oil through a drilled passage to the two roller bearing assemblies.

1.26.1 Repair or Replacement of Bull Gear and Camshaft Idler Gear Assembly

To determine if repair or replacement of the bull gear and camshaft idler gear assembly is necessary, perform the following procedure. See Figure 1-376.

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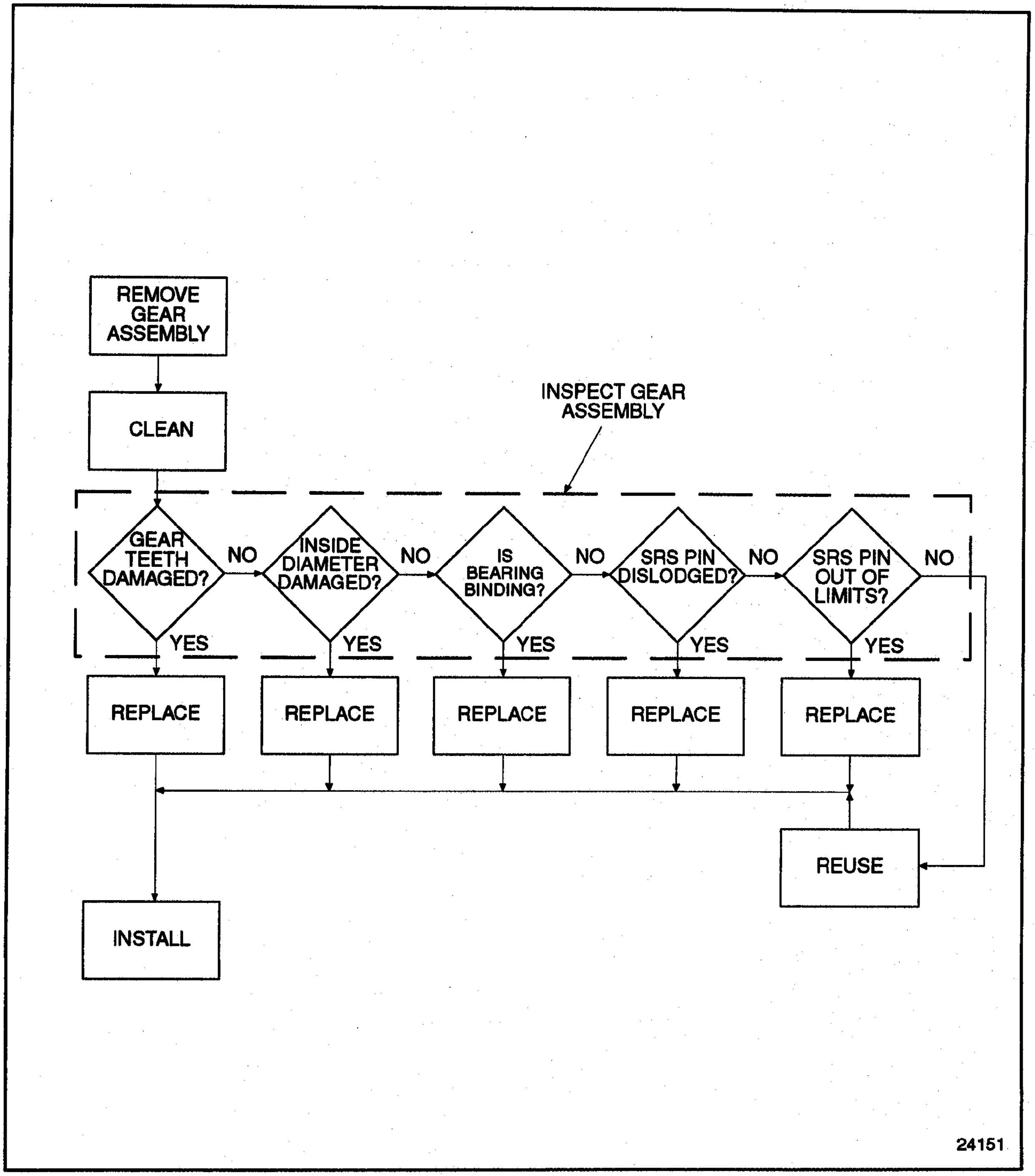

Figure 1-376 Flowchart for Repair or Replacement of Bull Gear and Camshaft Idler Gear Assembly

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1.26.2 Removal of Bull Gear and Camshaft Idler Gear Assembly

Remove the bull gear and camshaft idler gear assembly as follows:

1. Remove the engine gear case cover. Refer to section 1.10.2.
2. Install J 35994, to the oil seal contact area of the crankshaft. See Figure 1-377.

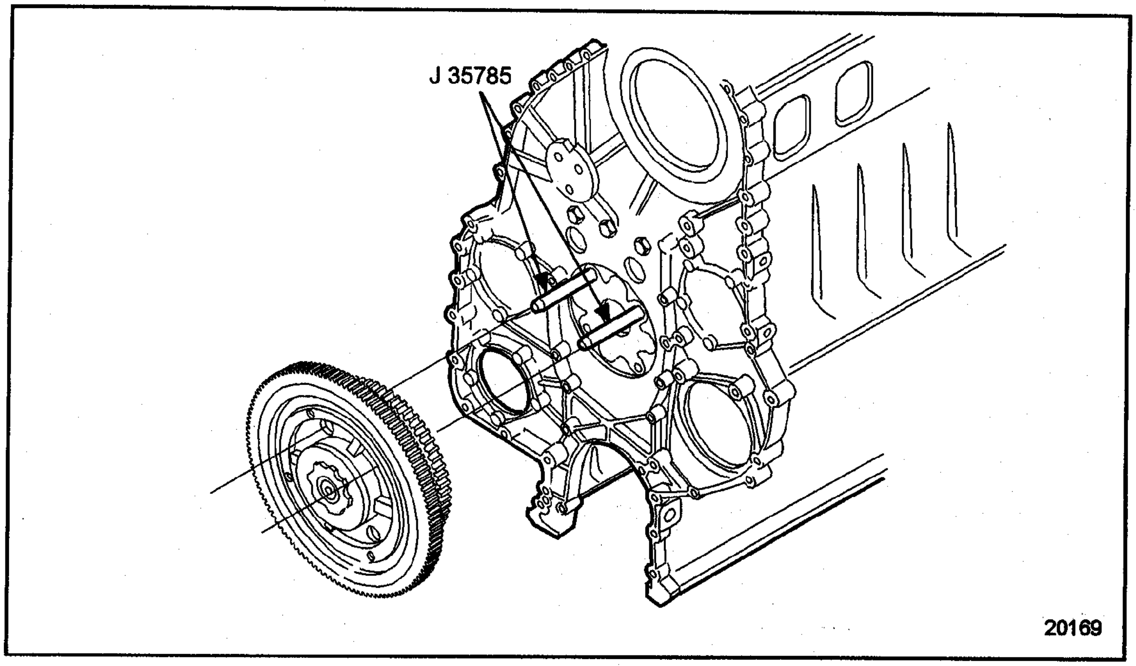

Figure 1-377 Bull Gear Guide Studs

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NOTICE:
Use care when removing the bull gear and camshaft idler gear assembly from the engine so that it does not come in contact with the oil seal contact surface of the crankshaft. If this sealing surface is scratched, an oil leak may result.

3. Working through the four access holes in the bull gear carrier, loosen and remove two of the four bolts that secure the bull gear assembly to the cylinder block. See Figure 1-378.

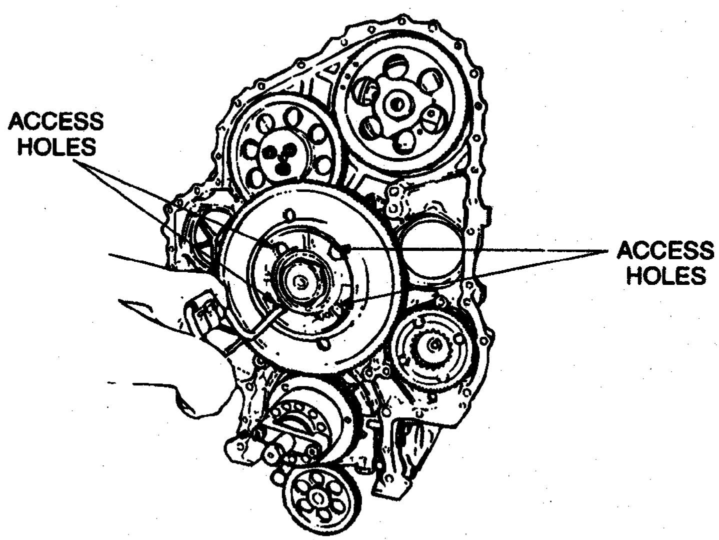

Figure 1-378 Removing Bull Gear Assembly Retaining Bolts

4. Install J 35785, into the holes the bolts from where they were removed.
5. Remove the two remaining bull gear retaining bolts.
6. Grasp the bull gear and pull the assembly straight out of the recess in the cylinder block.

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1.26.2.1 Inspection of Bull Gear and Camshaft Idler Gear Assembly

Inspect the bull gear and camshaft idler gear assembly as follows:

1. Clean the bull gear and idler gear assembly in clean fuel oil.

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

2. Dry the bull gear and idler gear assembly with compressed air.
3. Visually examine the gear teeth on both the bull gear and idler gear for evidence of scoring, cracking, pitting, and wear.
   [a] If either gear is damaged, replace the bull gear and idler gear assembly.
   [b] If either gear is not damaged, reuse the bull gear and idler gear assembly.
4. Visually examine the inner diameter of both gears, where they are pressed on the carrier for evidence of gear movement.
   [a] If there is any evidence of gear movement, replace the bull gear and idler gear assembly.
   [b] If damage is not found, reuse the bull gear and idler gear assembly.
5. Place the bull gear and idler gear assembly on a bench, resting on the hub. Inspect the bearings for signs of distress or overheating.
   [a] If there is any bearing distress, replace the bull gear and idler gear assembly.
   [b] If damage is not found, reuse the bull gear and idler gear assembly.
6. Coat the bearings with clean engine oil.
7. Slowly rotate the gears on the hub looking for binding of the bearing.
   [a] If the gears do not rotate freely on the hub, replace the bull gear and idler gear assembly.
   [b] If the gears rotate freely, reuse the bull gear and idle gear assembly.

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NOTICE:

Care should be taken not to damage or dislocate the pin. The pin is installed at a set dimension which is used by the Synchronous Reference Sensor (SRS). Damage to pin will cause loss of engine performance.

Inspect the SRS pin in the bull gear as follows. See Figure 1-379.

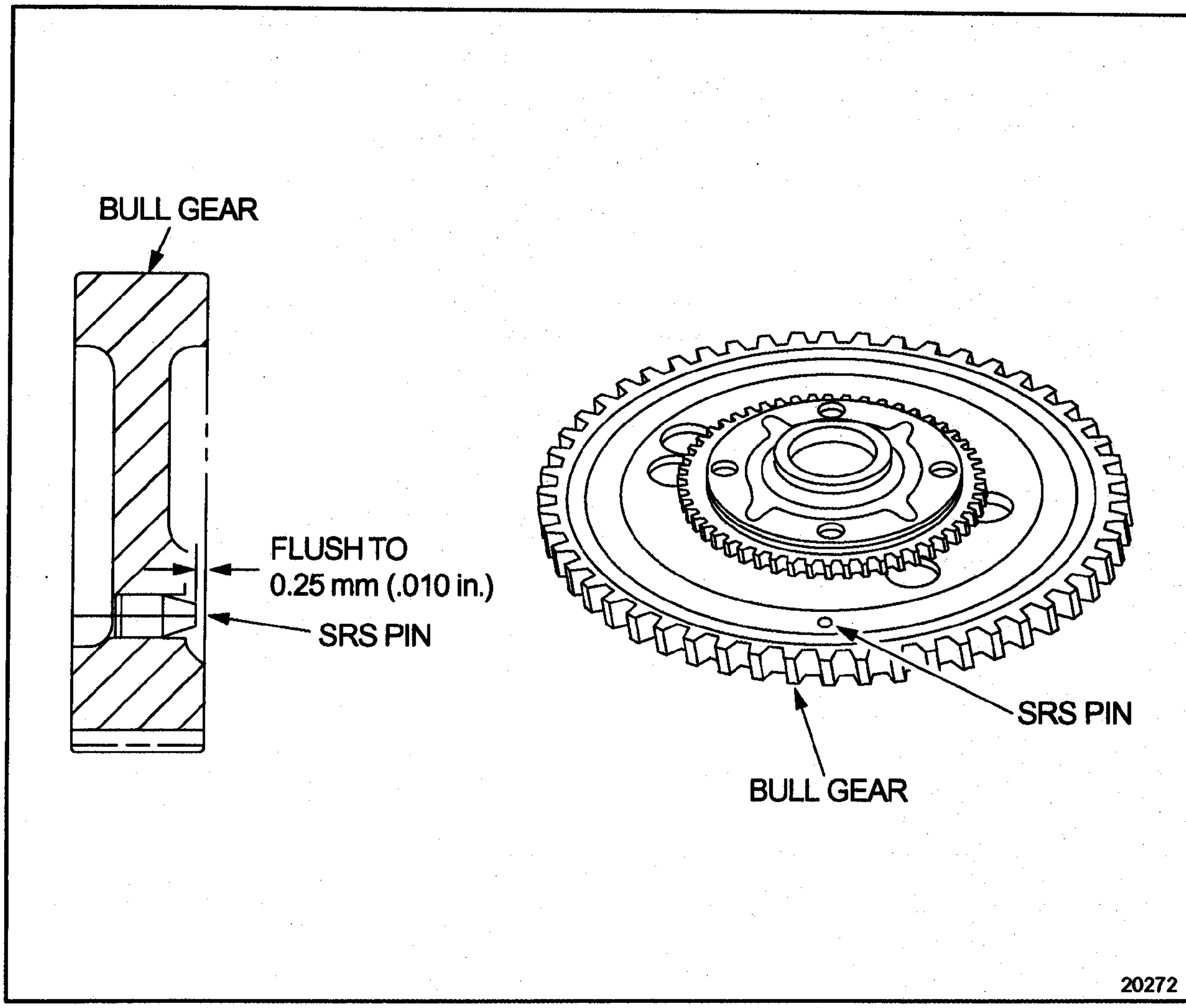

Figure 1-379 SRS Pin Location

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1. Check the SRS pin for damage or looseness. If the SRS pin is damaged or dislodged, replace the pin as follows:

   [a] Press the SRS pin from the bull gear. Discard pin.

NOTICE:
Do NOT reuse or readjust a pin once it has been installed. Damage to pin will cause loss of engine performance.

   [b] Apply Loctite® 609 (PT 7260) to pin.

   [c] Press pin flush to 0.25 mm (0.010 in.) below bull gear surface.

   [d] If no damage is found, reuse the bull gear assembly.

2. Using straight edge and thickness gages, measure recess of SRS pin.

   [a] If pin is not flush to 0.25 mm (0.010 in.) below bull gear surface, replace the pin.

   [b] If the pin is to specifications 0.25 mm (0.010 in.), reuse the part.

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1.26.3 Installation of Bull Gear and Camshaft Idler Gear Assembly

Install bull gear assembly and camshaft assembly as follows:

1. Inspect the bull gear and camshaft idler gear access opening in the gear case and remove any foreign material. Be sure the lubrication oil holes are clear and free.
2. Install two Bull Gear Guide Studs, J 35785, to the cylinder block. See Figure 1-380.

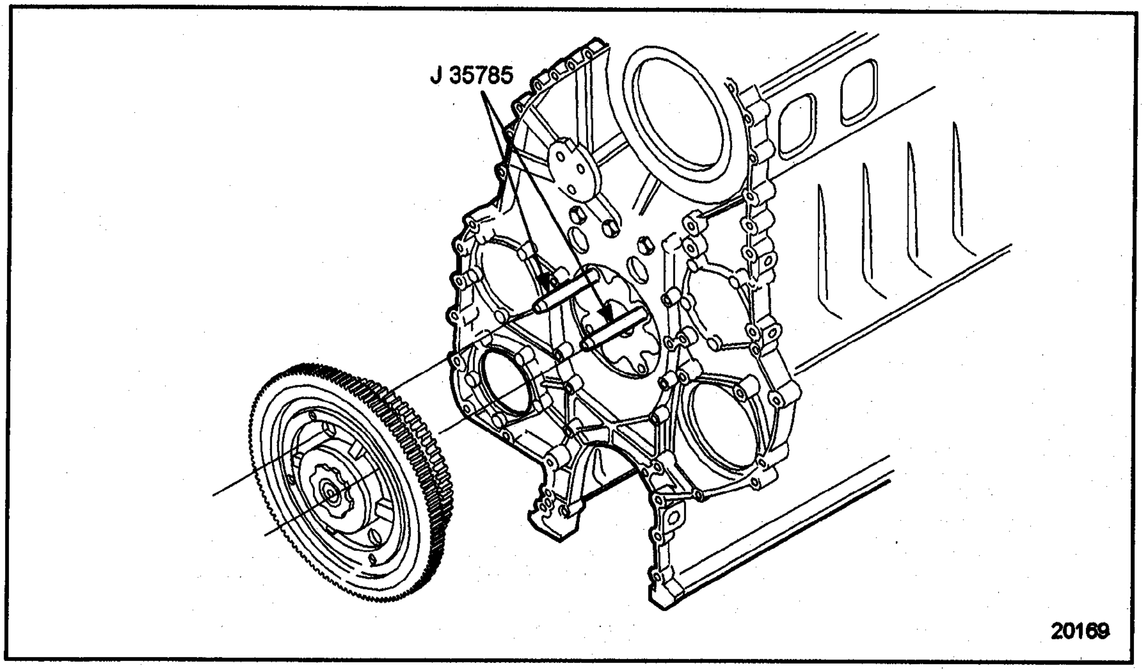

Figure 1-380 Bull Gear Guide Stud Installation

3. Install J 35994, to the oil seal contact area of the crankshaft.

NOTE:
The crankshaft seal surface will be protected using J 35994, when installing the bull gear and camshaft idler gear assembly to the cylinder block.

4. Install the bull gear and camshaft idler gear assembly to the guide studs in the cylinder block.

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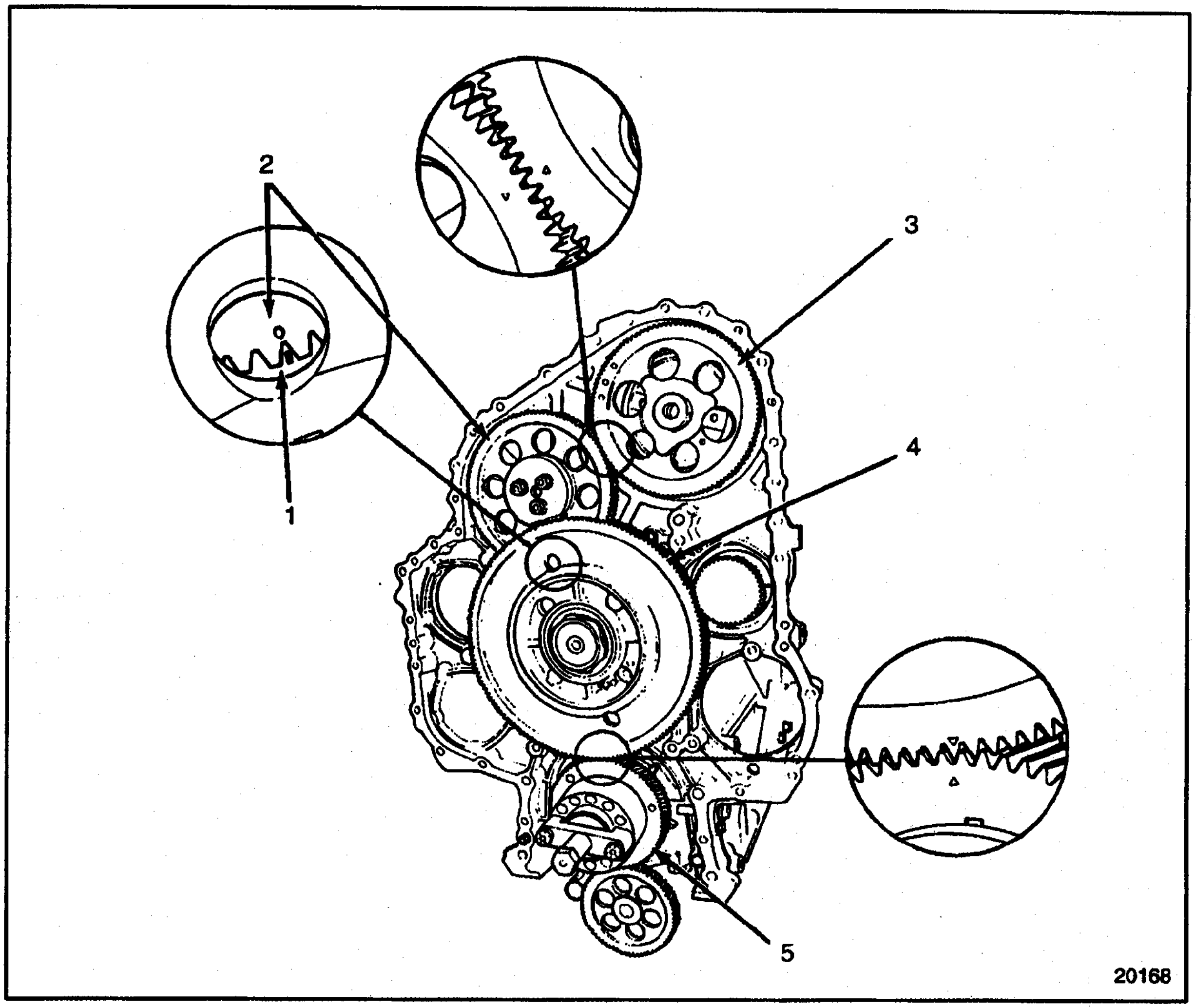
5. Bar the engine over until the timing mark on the crankshaft timing gear is at the 12 o'clock position. See Figure 1-381.



1. Idler Gear, Camshaft
2. Idler Gear, Adjustable
3. Drive Gear, Camshaft
4. Bull Gear
5. Timing Gear, Crankshaft

Figure 1-381 Engine Gear Train and Timing Marks

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6. Align the timing marks on the camshaft drive gear and the adjustable idler gear as shown. See Figure 1-381.
7. Slide the bull gear and camshaft idler gear assembly towards the engine, but do not engage any of the gears on the engine.
8. Looking through the access hole in the bull gear, align the timing marks on the adjustable idler gear and the camshaft idler gear as shown. See Figure 1-381.
9. Check the timing marks on the bull gear and crankshaft timing gear to ensure they will align when the bull bear assembly is seated in the cylinder block.

NOTE:
The injector and valve spring pressures will not allow easy rotation of the camshaft and adjustable idler gears. Therefore, it may be necessary to remove the rocker arm shaft assemblies to facilitate aligning all three sets of timing marks. Refer to section 1.3.2.

10. When all three sets of timing marks are aligned, slide the bull gear and camshaft idler gear towards the engine completely and seat it in the recess in the gear case and cylinder block.

NOTICE:
Use care when installing the bull gear and camshaft idler gear assembly to prevent damaging the crankshaft oil seal contact surface.

11. Working through the lightening holes in the bull gear, install two of the bull gear assembly mounting bolts through the hub and into the cylinder block. Tighten the bolts finger-tight.
12. Remove the two bull gear guide studs.
13. Install the remaining two bull gear assembly mounting bolts. Torque all four mounting bolts to 101-116 N·m (75-86 lb·ft) in a clockwise direction.
14. Check the timing marks on the gears to ensure the gear train is properly timed. See Figure 1-381.
15. Check the gear lash for all of the gears that mate with the bull gear and camshaft idler gear. Refer to section 1.21.
16. Install the gear case cover. Refer to section 1.10.3.
17. Check bull gear to accessory drive gear lash. Refer to section 1.21.2.1.
18. Refer to section 11.8 for verification of proper bull gear and camshaft idler gear assembly installation.

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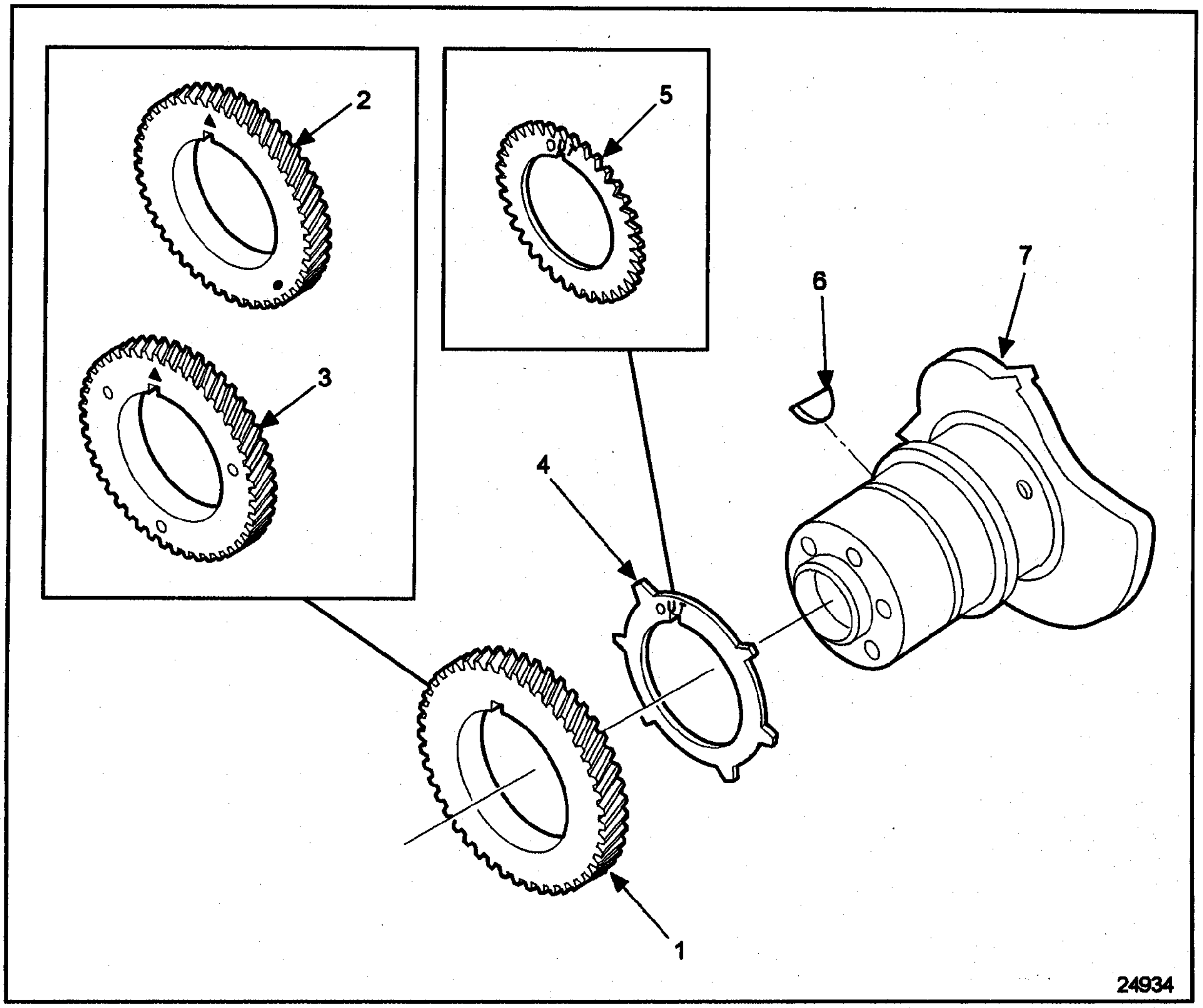
1.27 CRANKSHAFT TIMING GEAR AND TIMING WHEEL

The crankshaft timing gear is a helical gear that is indexed to the crankshaft by a key. It is pressed onto the end of the crankshaft. The inside diameter of the 12.7 liter engine crankshaft timing gear is slightly larger than the 11.1 liter engine gear. The current 12.7 liter engine gear can be identified by an "O" on the front face of the gear. See Figure 1-382.

NOTE:
The former 12.7 liter engine gear had a groove on the front face.



1. Timing Gear, Crankshaft
2. 12.7L Gear
3. 11.1L Gear
4. Timing Wheel, DDEC II
5. Timing Wheel, DDEC III
6. Woodruff Key
7. Crankshaft

Figure 1-382 Crankshaft Timing Gear and Related Parts

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The crankshaft timing gear directly drives the bull gear and oil pump drive gear. The bull gear drives the various accessories, and drives the camshaft through the idler gear. See Figure 1-383.

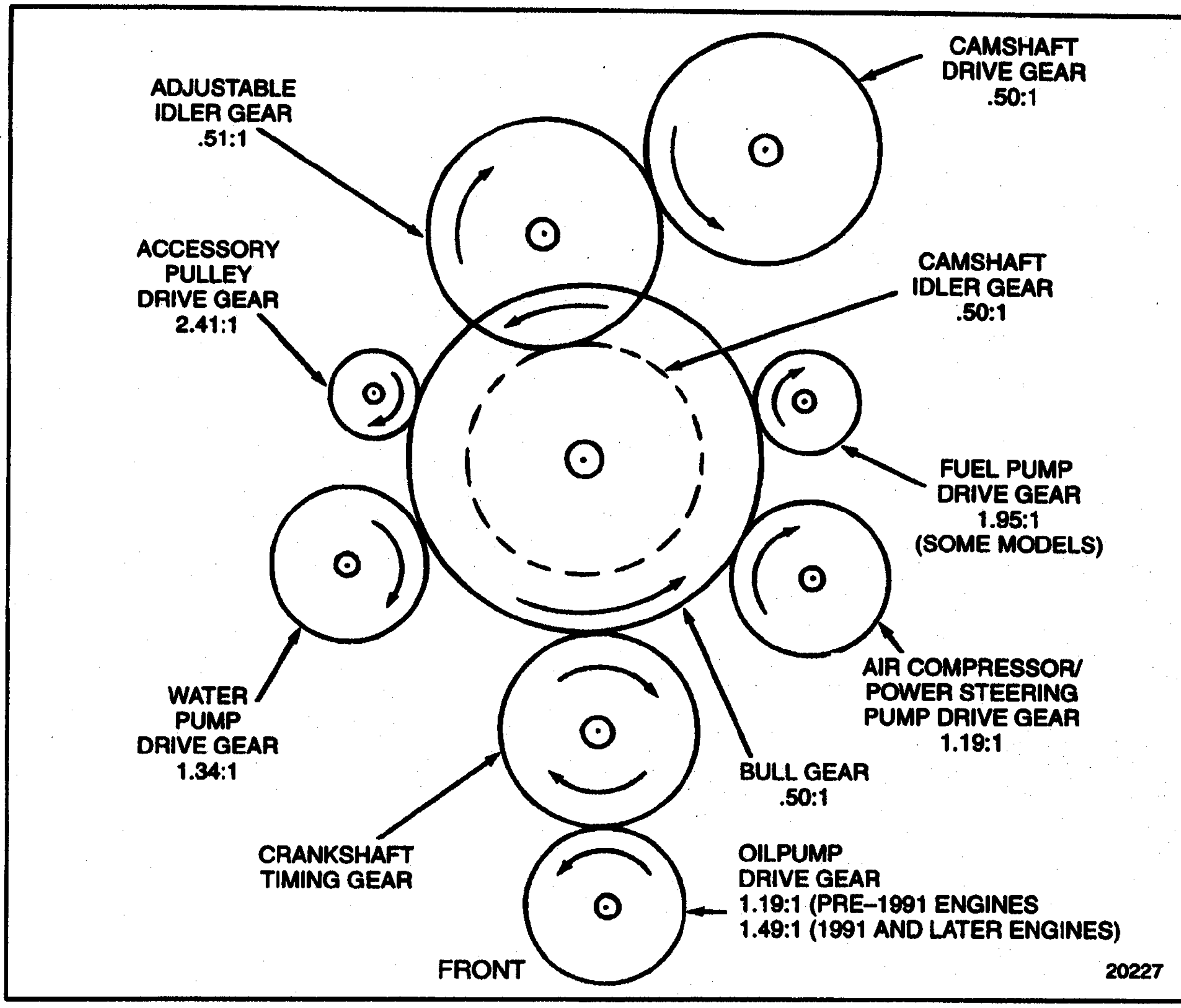

Figure 1-383 Engine Gear Train

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A timing wheel is installed on the crankshaft directly behind the crankshaft timing gear. The timing wheel is indexed to the crankshaft by the same key as the crankshaft timing gear, and is retained to the crankshaft by the crankshaft timing gear. The timing wheel is marked with the word OUT on the outboard side, and should be installed with this mark facing you as you install the wheel. See Figure 1-384.

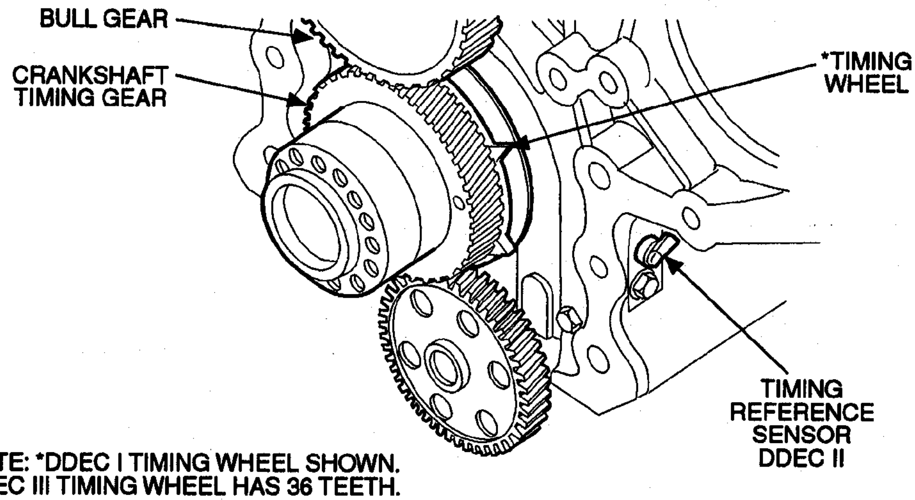

Figure 1-384 Crankshaft Timing Gear and Related Parts Location

The timing wheel induces a voltage signal in the Timing Reference Sensor (TRS), as the teeth of the pulse wheel passes by the TRS. This signal is sent to the Electronic Control Module (ECM) to determine injector firing.

Since the crankshaft and camshaft must be in time with each other, a series of timing marks are stamped or etched on the faces of the gears in the gear train. Refer to section 1.21.2.1, for gear train timing information. The balance shafts and crankshaft must also be in time with each other.

The crankshaft timing gear is lubricated by splash from the engine oil pan, and excess oil returning to the oil pan from the other gears.

1.27.1 Repair or Replacement of Crankshaft Timing Gear and Timing Wheel

To determine if repair or replacement of the crankshaft timing gear and timing wheel are necessary, perform the following procedure. See Figure 1-385.

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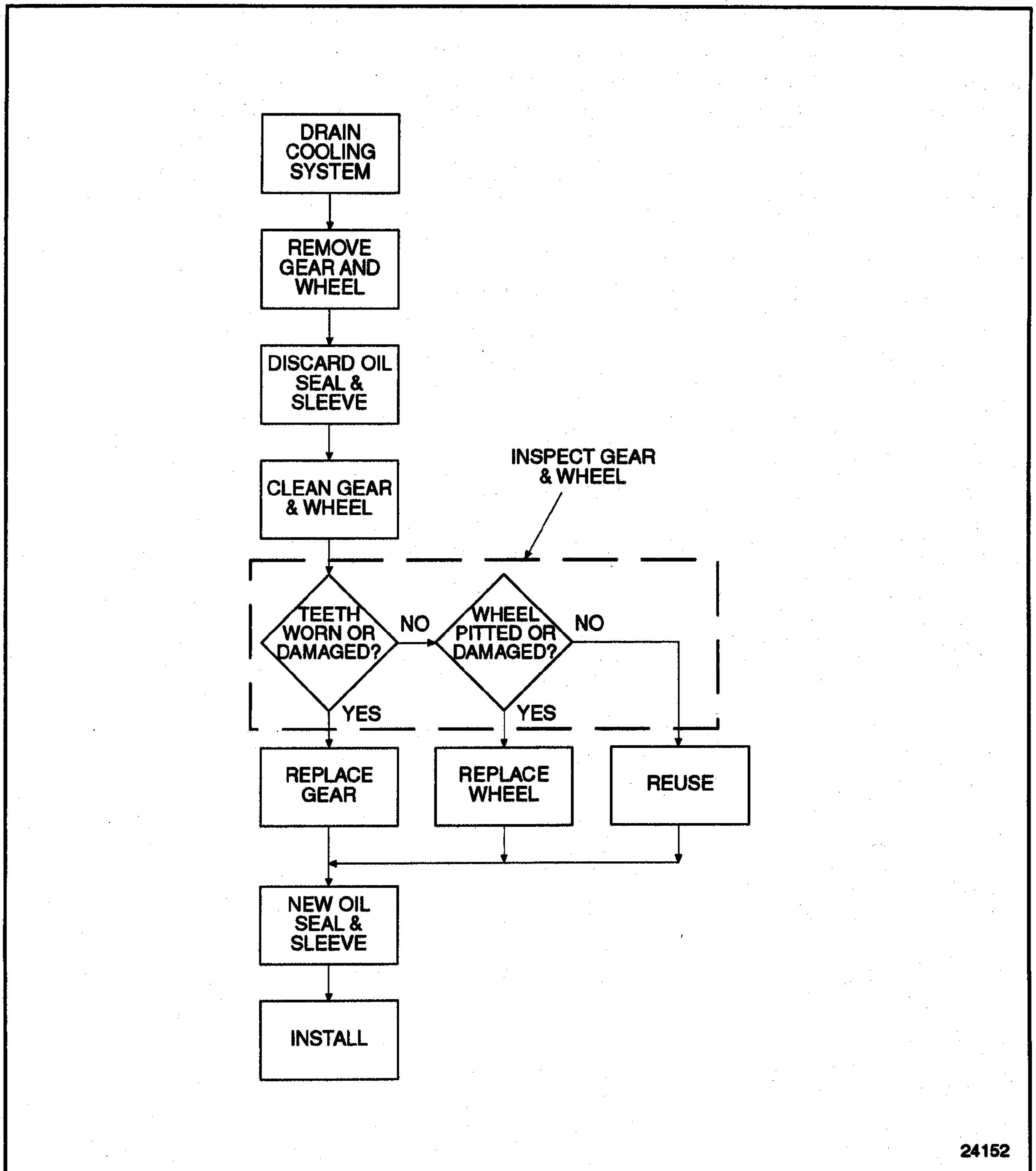

Figure 1-385 Flowchart for Repair or Replacement of Crankshaft Timing Gear and Timing Wheel

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1.27.2 Removal of Crankshaft Timing Gear and Timing Wheel

Remove the gear and the timing wheel as follows:

1. Drain the cooling system. Refer to section 13.13.4.
2. Remove the radiator to engine coolant hoses. Refer to OEM guidelines.
3. Remove the timing reference sensor. Refer to section 2.30.2.
4. Remove components as necessary to gain access to the gear case cover.
5. Remove the gear case cover. Refer to section 1.10.2.
6. If an oversize crankshaft front oil seal sleeve is used, peen the outside diameter of the sleeve until it stretches sufficiently and slip the sleeve off of the crankshaft. Discard sleeve.
7. Remove the oil pump inlet and outlet tubes. Refer to section 3.2.2.
8. Remove the oil pump. Refer to section 3.2.2.

NOTICE:
Use care when removing the bull gear assembly. To prevent damaging the crankshaft oil seal contact surface, use Crankshaft Protector, J 35994 on end of crankshaft or oil leaks may result.

9. Remove the bull gear and camshaft idler gear assembly. Refer to section 1.26.2.

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10. Using two of the crankshaft pulley bolts, secureJ 35642-1 part of J 35642 to the end of the crankshaft. Torque the bolts to 190-203 N·m (140-150 lb·ft). See Figure 1-386.

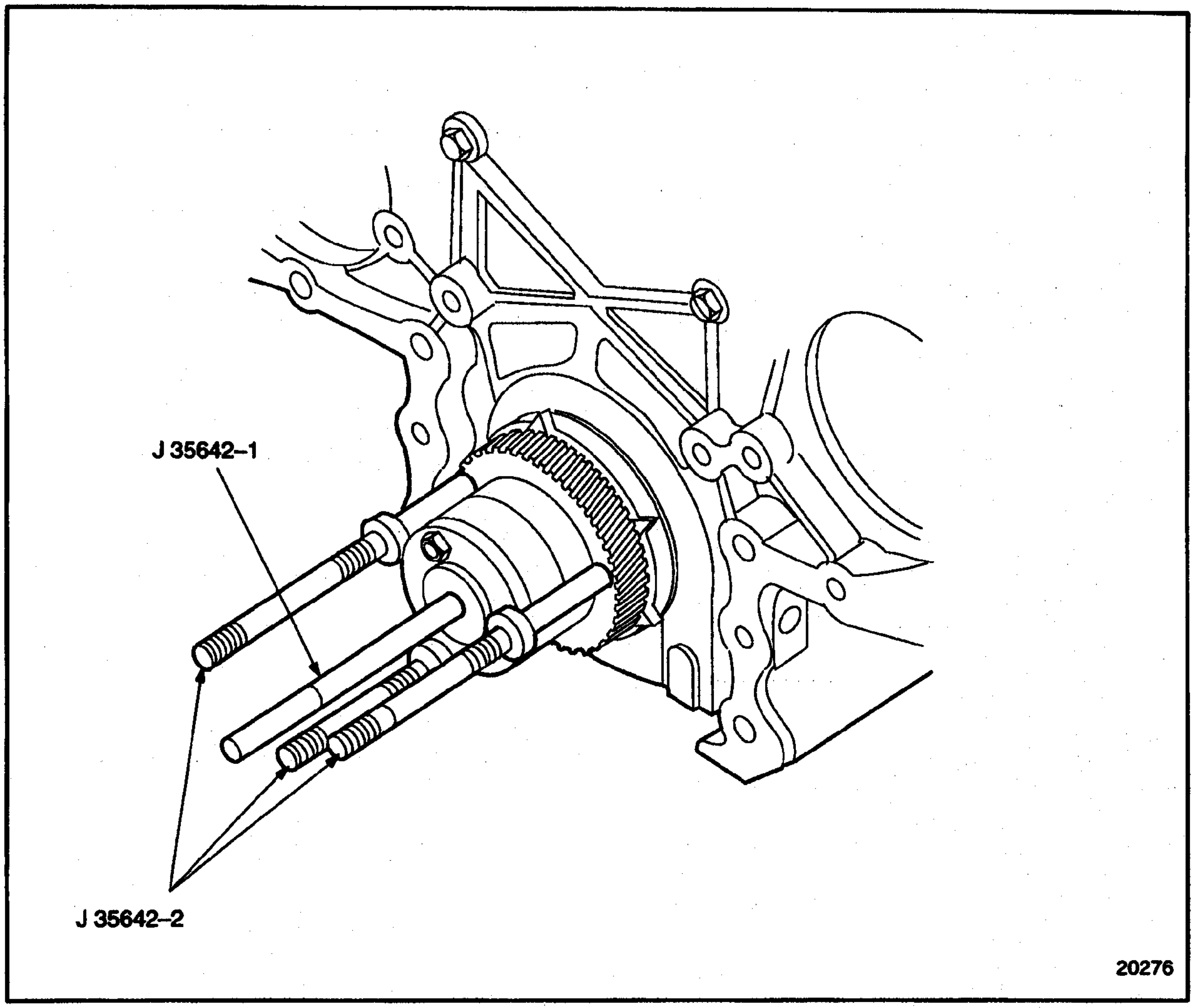

Figure 1-386 Installation of Crankshaft Timing Gear Removal Tools

NOTE:
The crankshaft removal values are shown with the crankshaft installed in the engine. The crankshaft timing gear may be removed with the crankshaft in or out of the engine.

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11. Thread the three guide studs,J 35642-2 part of J 35642 into the three threaded holes in the crankshaft timing gear. finger-tighten the legs.
12. Slide the hydraulic ram, J 35951-175, over the center rod of, J 35642-1 part of J 35642 and all the way to the base. See Figure 1-387.

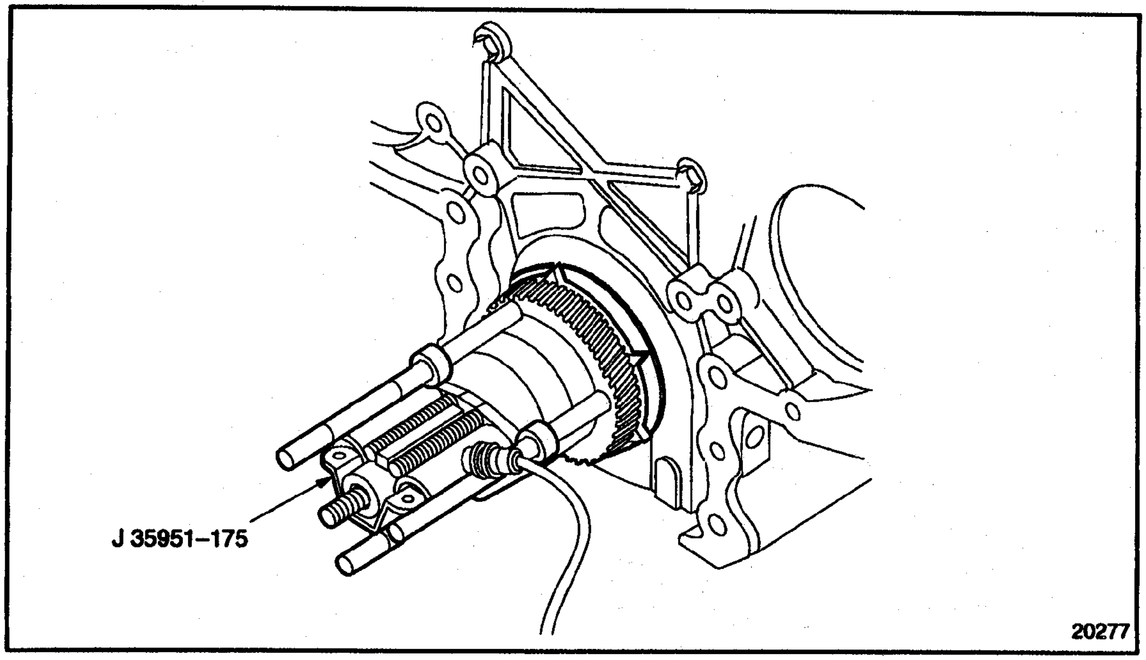

Figure 1-387 Hydraulic Ram Installation

13. Install J 35642-4 part of J 35642, to the three guide studs, J 35642-2 part of J 35642 . See Figure 1-388.

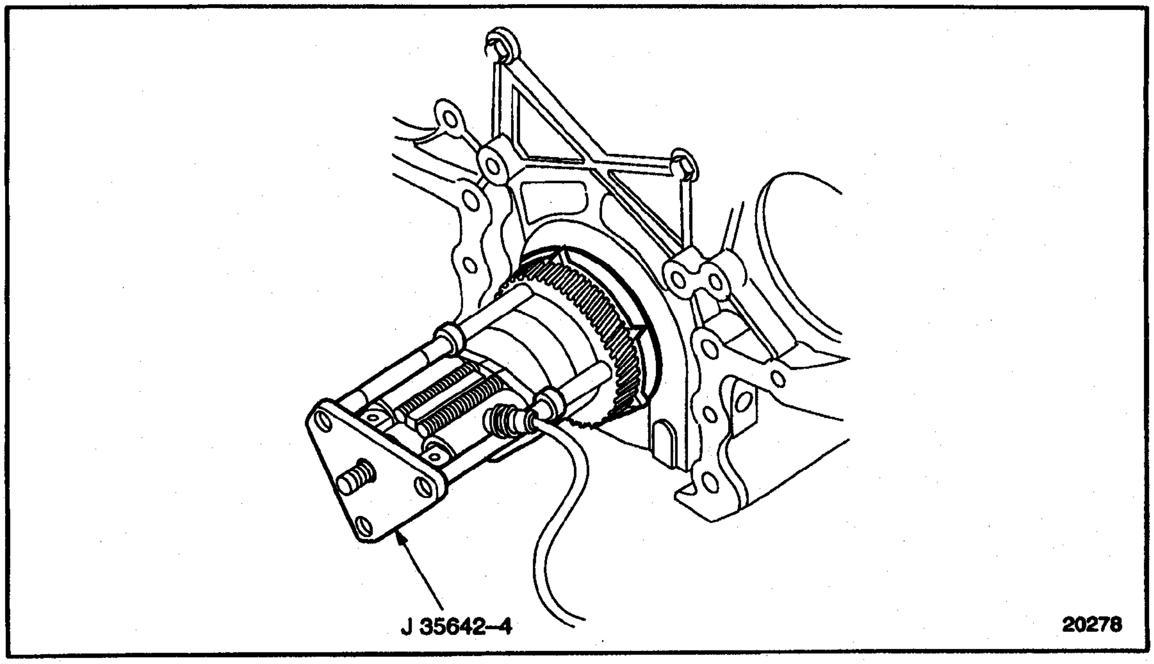

Figure 1-388 Pressure Plate Installation

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14. Install the three retaining nuts to the legs. Tighten the nuts to the pressure plate. Finger-tighten the nuts. See Figure 1-389.

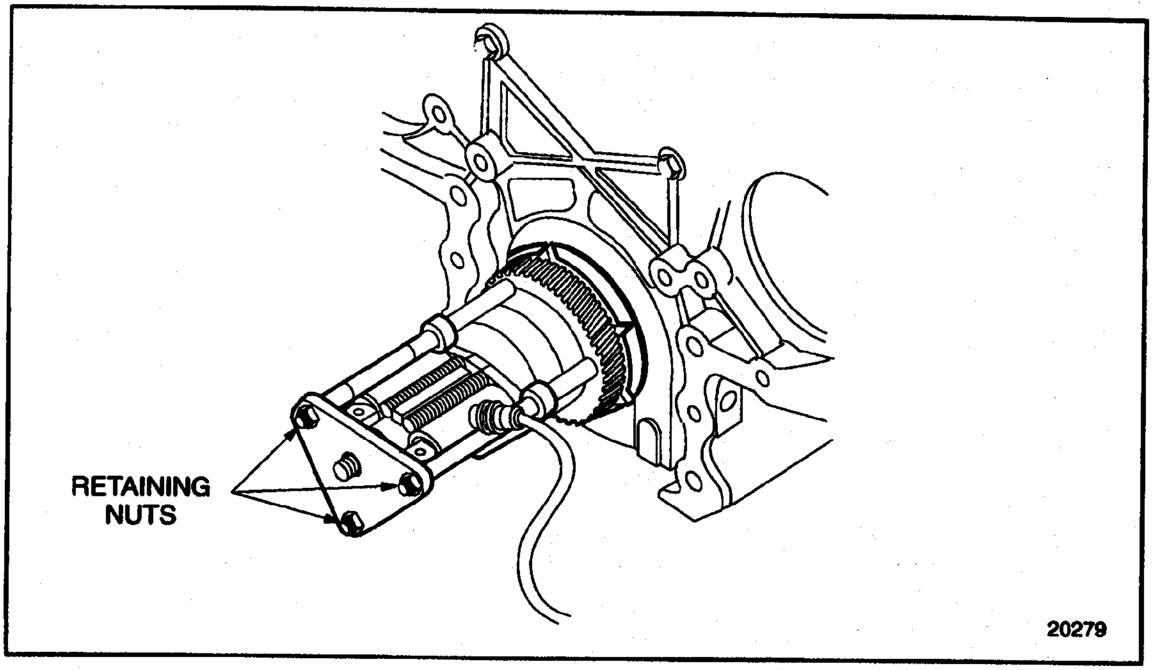

Figure 1-389 Retaining Nuts Installation

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15. Close the valve on J 35951-175. Pump the lever to build pressure and remove the crankshaft timing gear. See Figure 1-390.

NOTE:
Considerable pressure is required to remove the crankshaft timing gear. Due to manufacturer's tolerances, it may take as much as 80 kN (9 tons) of force to remove the crankshaft timing gear.

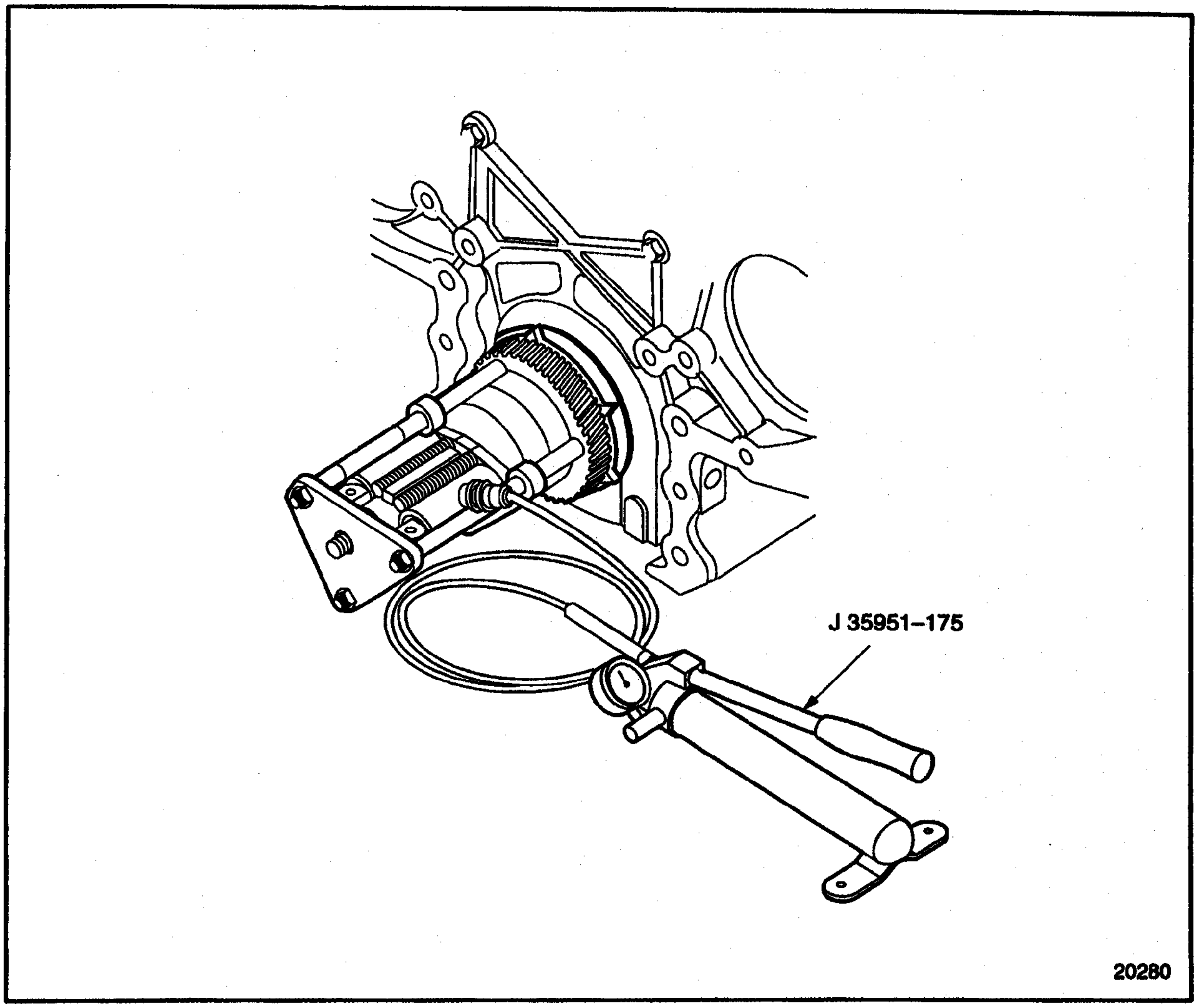

Figure 1-390 Crankshaft Timing Gear Removal

16. Remove the tools from the engine and timing gear as follows:
    [a] Open the valve on J 35951-175, to relieve the pressure. See Figure 1-390.
    [b] Loosen and remove the three retaining nuts on, J 35642-2 part of J 35642 against the pressure plate. See Figure 1-387.
    [c] Remove J 35642-2 part of J 35642.
    [d] Remove J 35951-175. See Figure 1-388.
    [e] Loosen and remove the three guide studs, J 35642-2 part of J 35642.
    [f] Loosen and remove the two crankshaft pulley bolts and remove the Base Post, J 35642-1 part of J 35642, part of Tool Kit J 35642.

NOTICE:
Care should be exercised when removing the timing wheel. Do NOT use sharp tools to pry on the timing wheel. Damage to the crankshaft seal contact surface may cause oil leaks.

17. Slide the timing wheel off the end of the crankshaft.

NOTE:
The timing wheel is a slip fit to the crankshaft, and no special tools are required for removal. A three-jaw adjustable puller, however, may be necessary.

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1.27.2.1 Inspection of Crankshaft Timing Gear and Timing Wheel

Inspect the crankshaft timing gear and timing wheel as follows:

1. Clean the crankshaft timing gear and timing wheel with clean fuel oil.

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

2. Dry all parts with compressed air.
3. Visually examine the gear teeth of the crankshaft timing gear for evidence of scoring, pitting, or excess wear.

NOTE:
The 11.2 and 12.7 liter crankshaft gears have different inside diameters. The 12.7 L crank gear can be identified by a groove on the outer face of the gear. These gears cannot be interchanged.

NOTE:
If gear teeth are damaged or severely worn, also check the other gears in the gear train. Refer to section 1.21.2.

   [a] If gear teeth are damaged or worn, install a new gear.

   [b] If the gear teeth are not damaged, reuse the part.

4. Visually examine the timing wheel for evidence of pitting and the gear teeth for bending or damage.

   [a] If wheel is pitted or gear teeth damaged, replace timing wheel.

   [b] If the wheel is not damaged, reuse the part.

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1.27.3 Installation of Crankshaft Timing Gear and Timing Wheel Removal

Install the crankshaft timing gear and timing wheel as follows:

1. Install J 35642-1 part of J 35642 to the end of the crankshaft, using two crankshaft pulley retaining bolts. Torque the bolts to 190 - 203 N·m (140 - 150 lb·ft). See Figure 1-391.

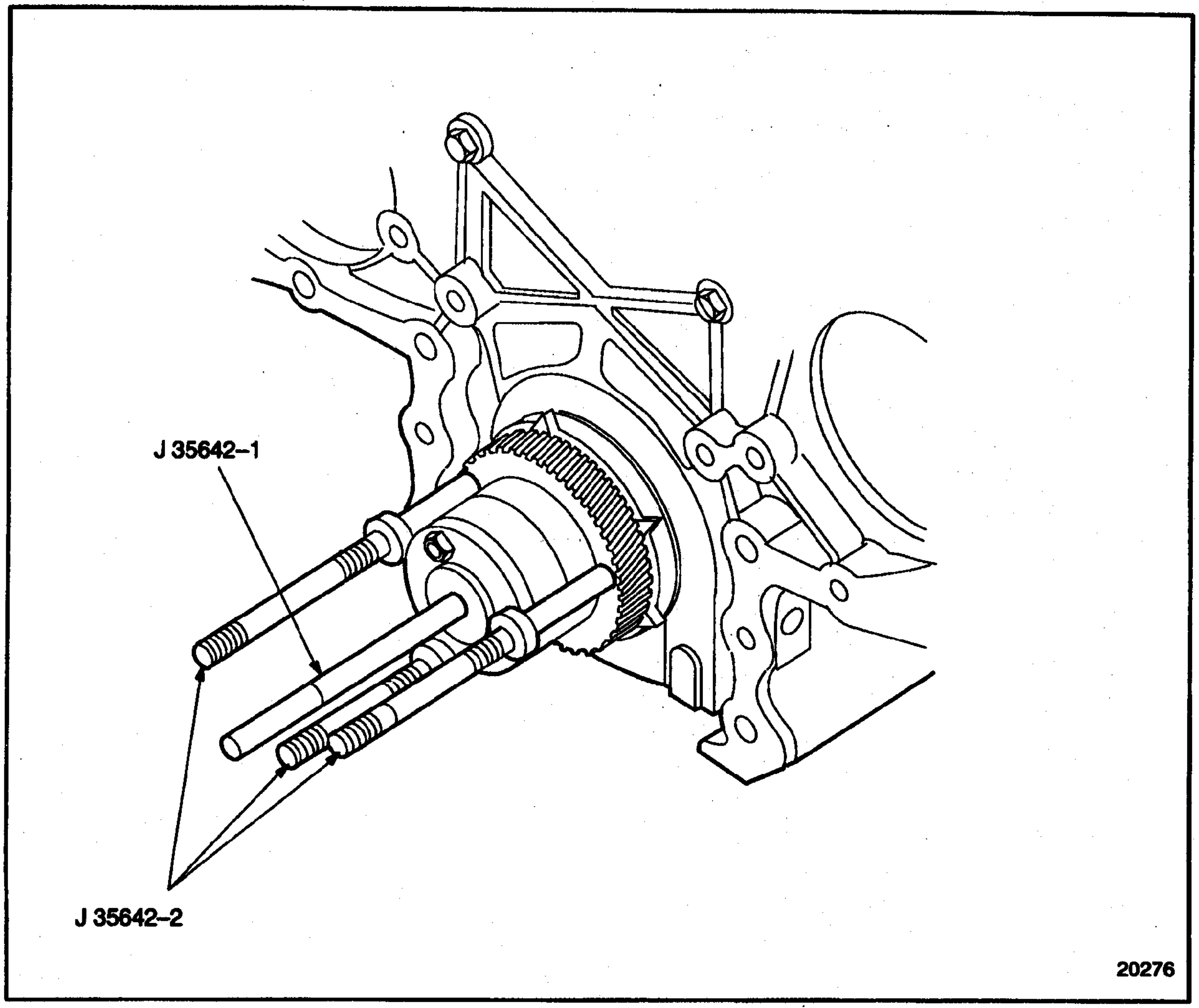

Figure 1-391 Installation of Crankshaft Timing Gear Removal Tools

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2. If removed, install the key to the keyway. Tap the key with a plastic mallet or brass hammer to seat. See Figure 1-392.

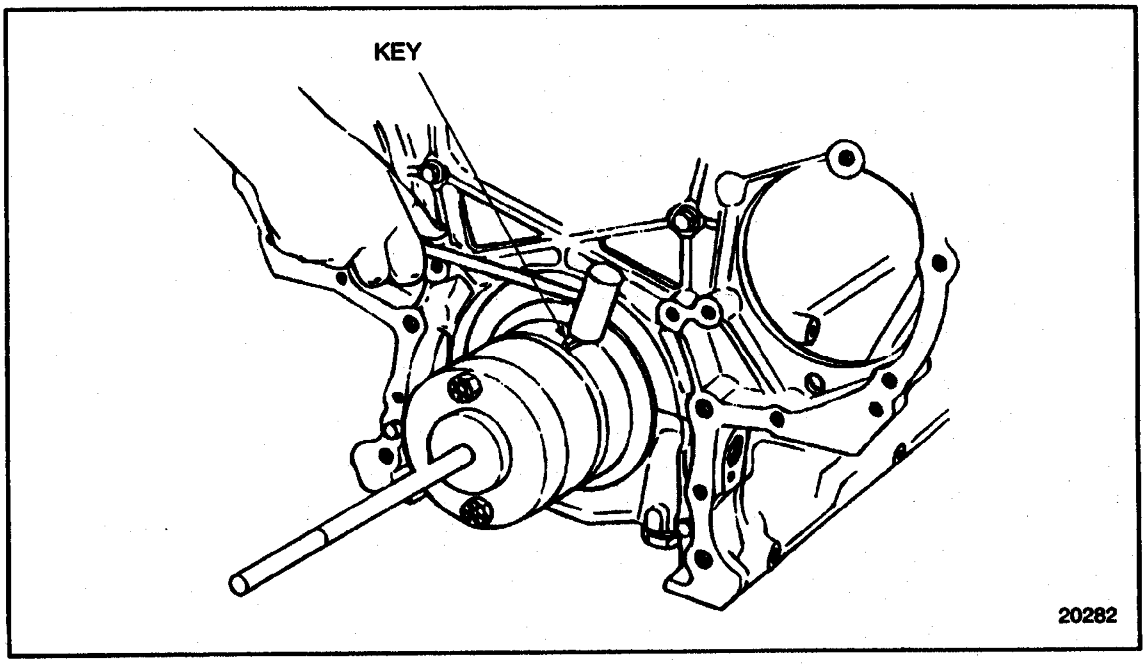

Figure 1-392 Key-to-Keyway Installation

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3. Index the keyway of the timing wheel with the key in the crankshaft. Slide the timing wheel onto the crankshaft, with the word OUT on the timing wheel facing you, as far as it will go without forcing it. See Figure 1-393.

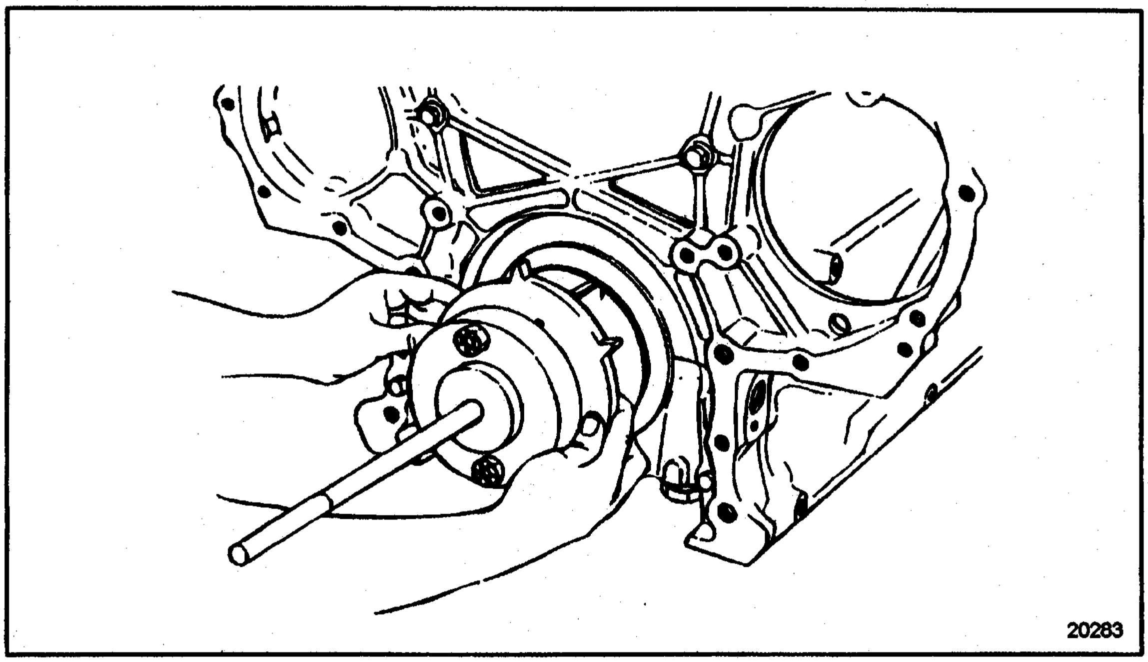

Figure 1-393 Timing Wheel Installation

4. Coat the bore of the crankshaft timing gear with a film of Lubriplate.

5. Index the keyway of the crankshaft timing gear with the Woodruff key in the crankshaft. Tap the gear with a plastic hammer or fiber mallet, to ensure that the key is started in the keyway. See Figure 1-394.

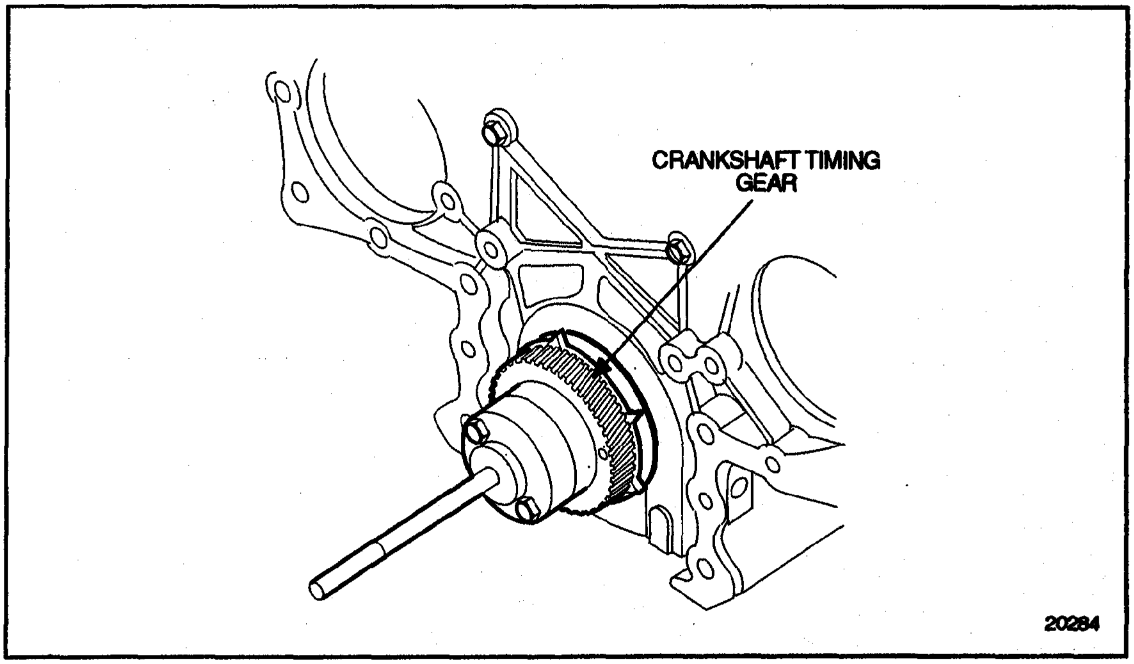

Figure 1-394 Crankshaft Timing Gear Indexing

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6. Install the three guide studs, J 35642-2 part of J 35642 to the threaded holes in the crankshaft timing gear. Tighten the three legs, but do not torque. See Figure 1-395.

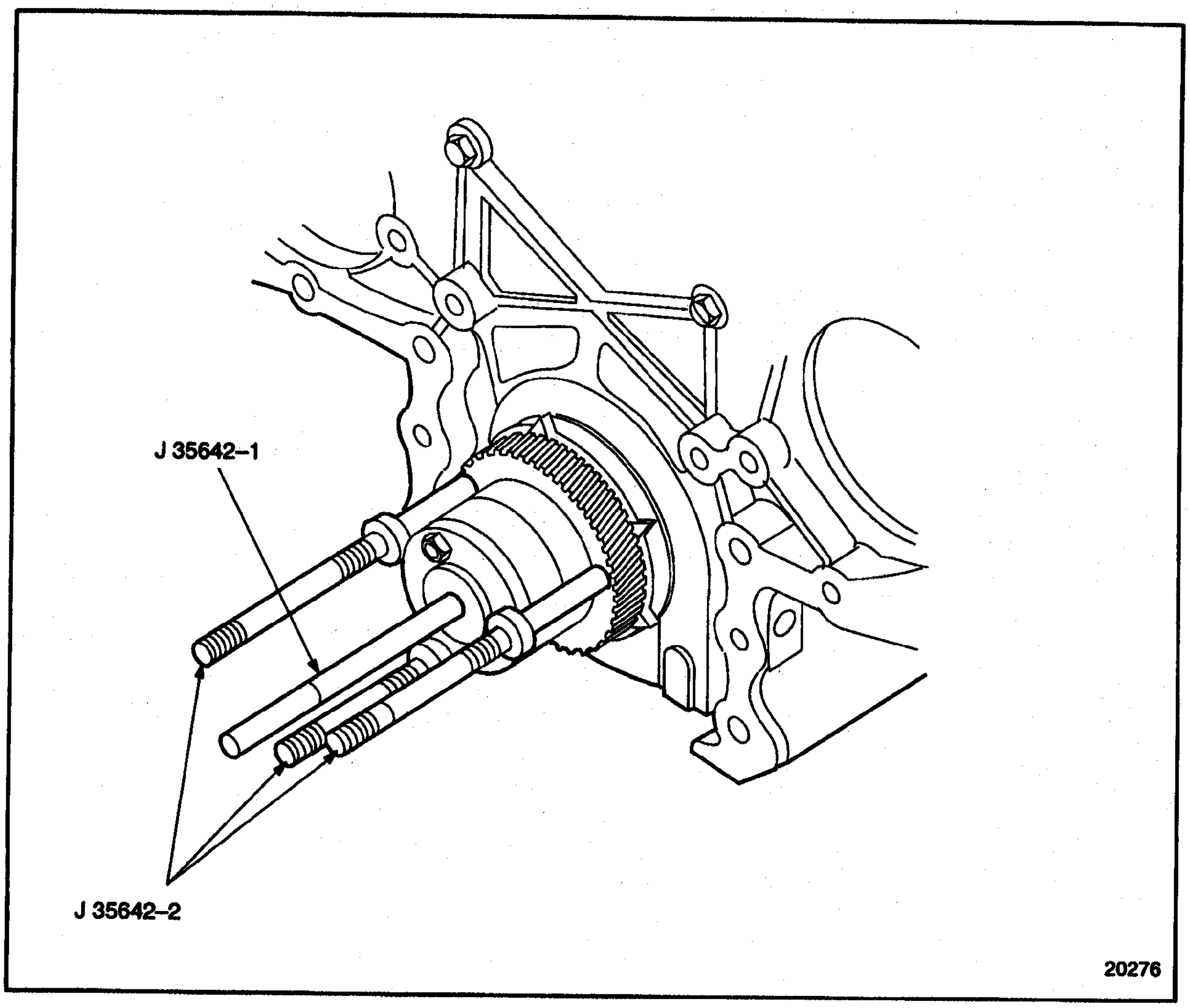

Figure 1-395 Puller and Leg Installation

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7. Install J 35642-4 part of J 35642 to the three pulley legs. Seat the pressure plate against the flanges on the puller legs. See Figure 1-396.

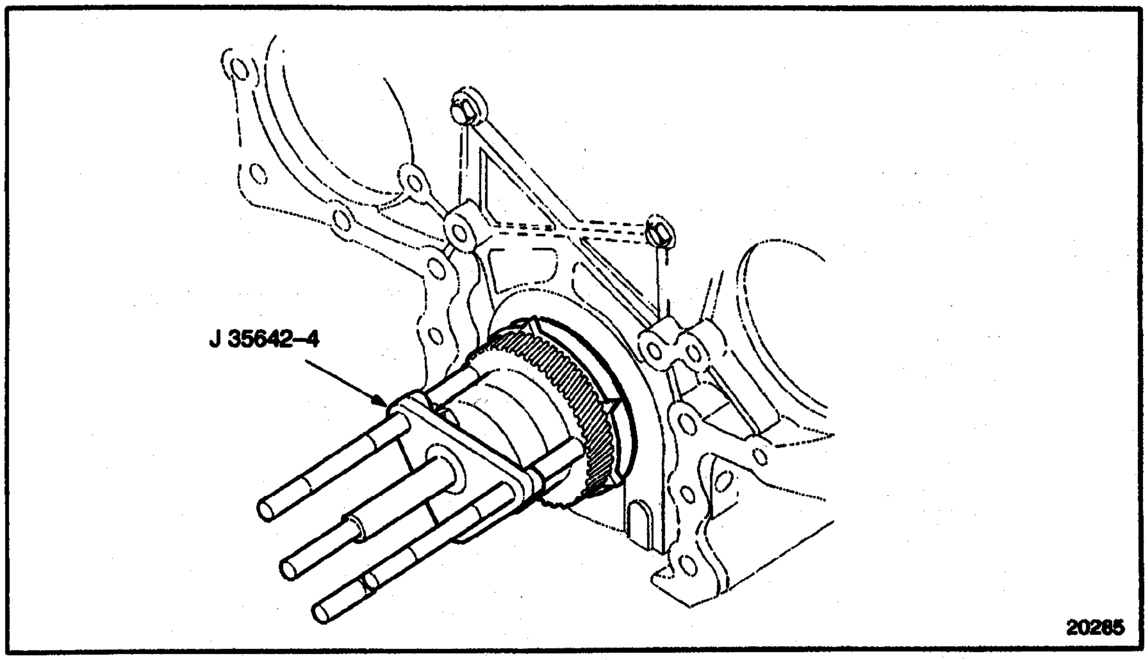

Figure 1-396 Pressure Plate Installation

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8. Install the three retaining nuts to the puller legs. Thread the nuts past the first set of threads on the legs. Slide the nuts past the unthreaded portion of the shafts, and engage the second set of threads. Tighten but do not torque the retaining nuts. See Figure 1-397.

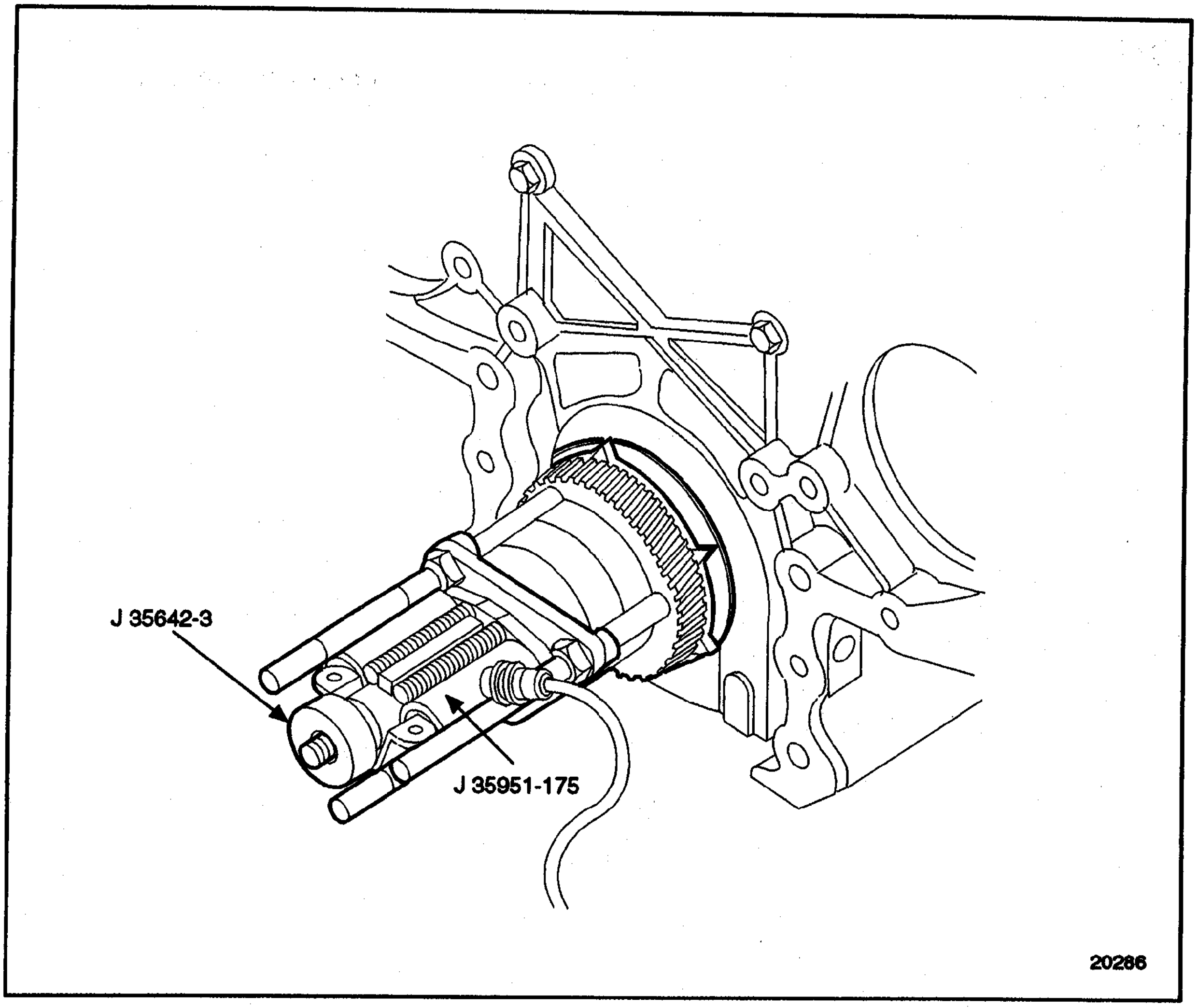

Figure 1-397 Crankshaft Timing Gear Installation Tools

9. InstallJ 35951-175 to the base post rod. See Figure 1-397.
10. Install J 35642-3 part of J 35642 to the end of the base post threaded rod. Tighten the stop nut.

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11. Close the valve on J 35951-175. Work the pump handle to supply hydraulic pressure to the ram. Make sure that the slot in the crankshaft timing gear indexes with the key in the crank. Pump until the crankshaft timing gear is seated firmly against the timing wheel and the timing wheel is seated firmly against the crankshaft flange. See Figure 1-398.

NOTE:
A minimum force of 30 kN (3.37 tons) must be obtained when pressing the gear on the crankshaft.

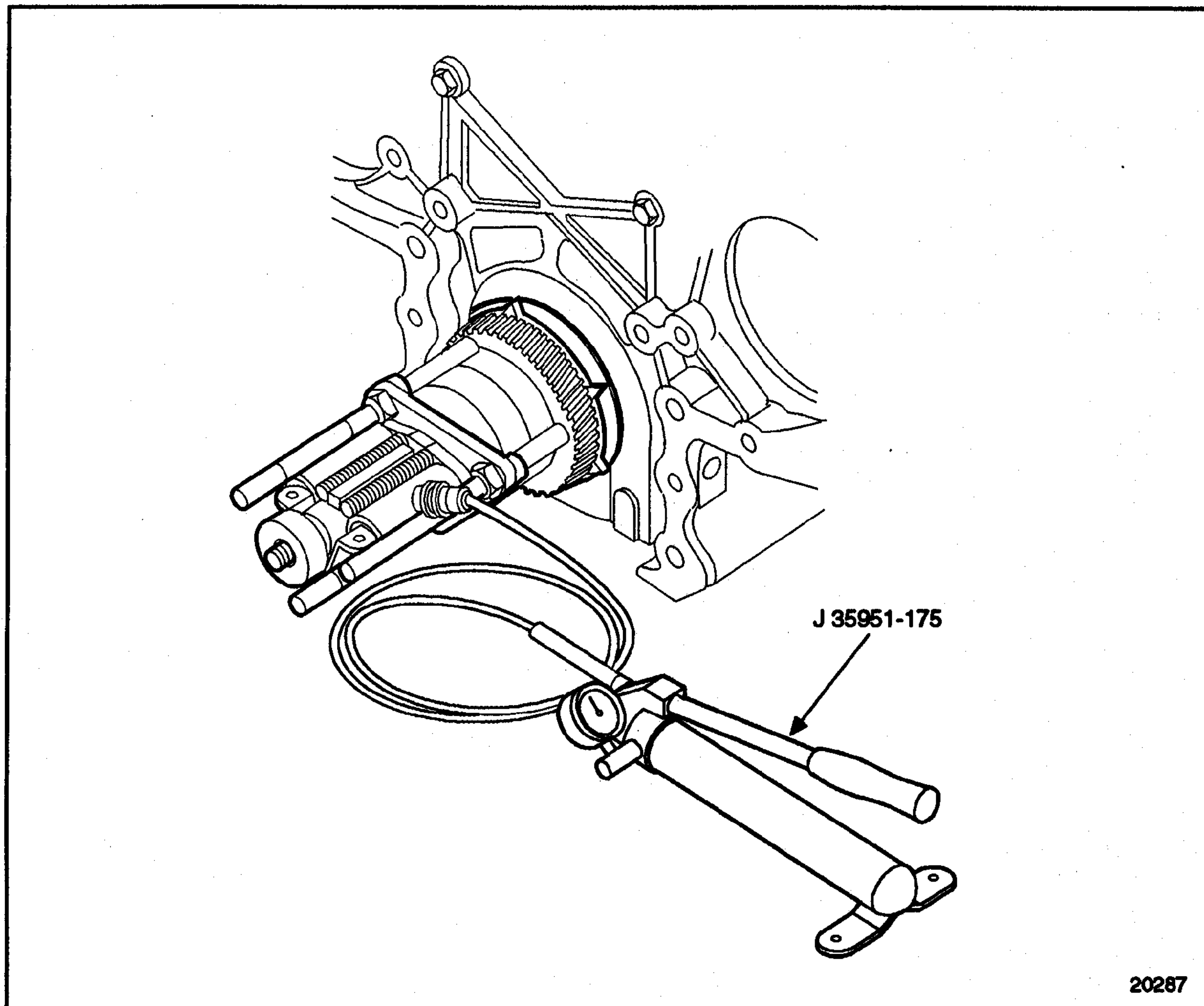

Figure 1-398 Crankshaft Timing Gear Installation

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12. Remove the special tools as follows:
    [a] Open the valve on the hydraulic pump.
    [b] Remove J 35642-3 part of J 35642 from the end of the base post threaded rod.
    [c] Remove the hydraulic ram from the base post rod.
    [d] Remove the three retaining nuts from the puller legs ofJ 35642-2 part of J 35642.
    [e] Remove J 35642-4 part of J 35642 from the three pulley legs.
    [f] Remove the three legs ofJ 35642-2 part of J 35642 from the threaded holes in the crankshaft timing gear.
    [g] RemoveJ 35642-1 part of J 35642 and two crankshaft pulley retaining bolts from the end of the crankshaft.
13. Install the bull gear and camshaft idler gear assembly to the gear case. Refer to section 1.26.3.

NOTE:
Be sure to time the gears as instructed.

14. Install the lubricating oil pump, inlet and outlet pipes. Refer to section 3.2.6.
15. Measure the gear lash between the crankshaft timing gear and oil pump drive gear. Refer to section 1.21.2.1.
16. Measure the lash between the crankshaft timing gear and the bull gear. Refer to section 1.21.2.1.
17. Install the gear case cover. Refer to section 1.10.3.
18. Install a new crankshaft seal and sleeve. Refer to section 1.8.7.
19. Install the timing reference sensor (TRS). Refer to section 2.30.3.
20. Install any components that were removed for access to the gear case cover.
21. Refer to section 11.3 for verification of proper crankshaft timing gear and timing wheel installation.

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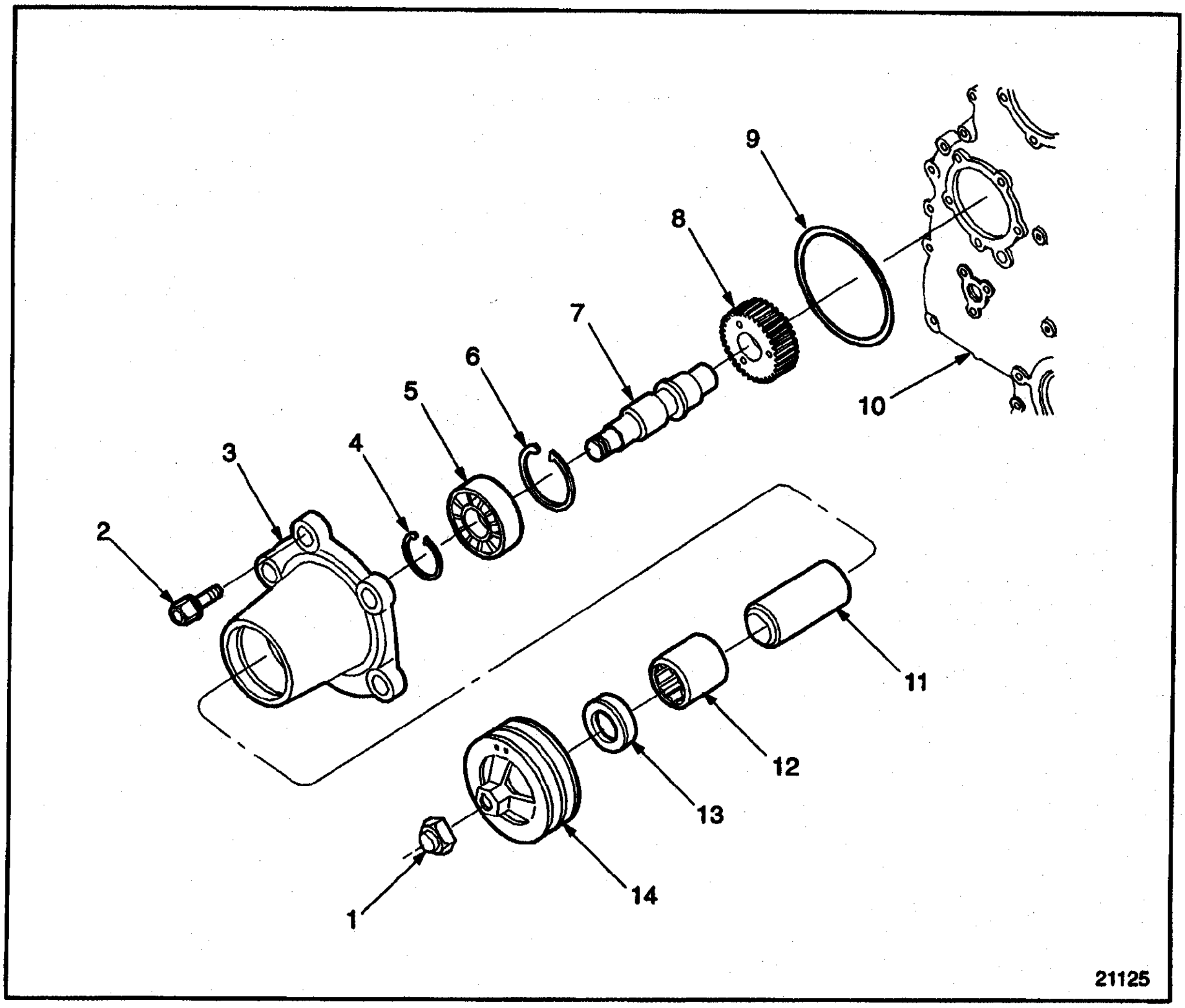
1.28 ACCESSORY DRIVE

The accessory drive assembly is mounted to the front of the gear case cover and utilizes a two-groove pulley to drive the alternator. See Figure 1-399, and see Figure 1-400.



1. Locknut
2. Mounting Bolts (5)
3. Drive Housing
4. Snap Ring (Small)
5. Ball Bearing
6. Snap Ring (Large)
7. Drive Shaft
8. Drive Gear
9. O-ring
10. Gear Case Cover
11. Bearing Inner Race
12. Needle Bearing
13. Oil Seal
14. Pulley

Figure 1-399 Accessory Drive Assembly Related Parts (Former Design)

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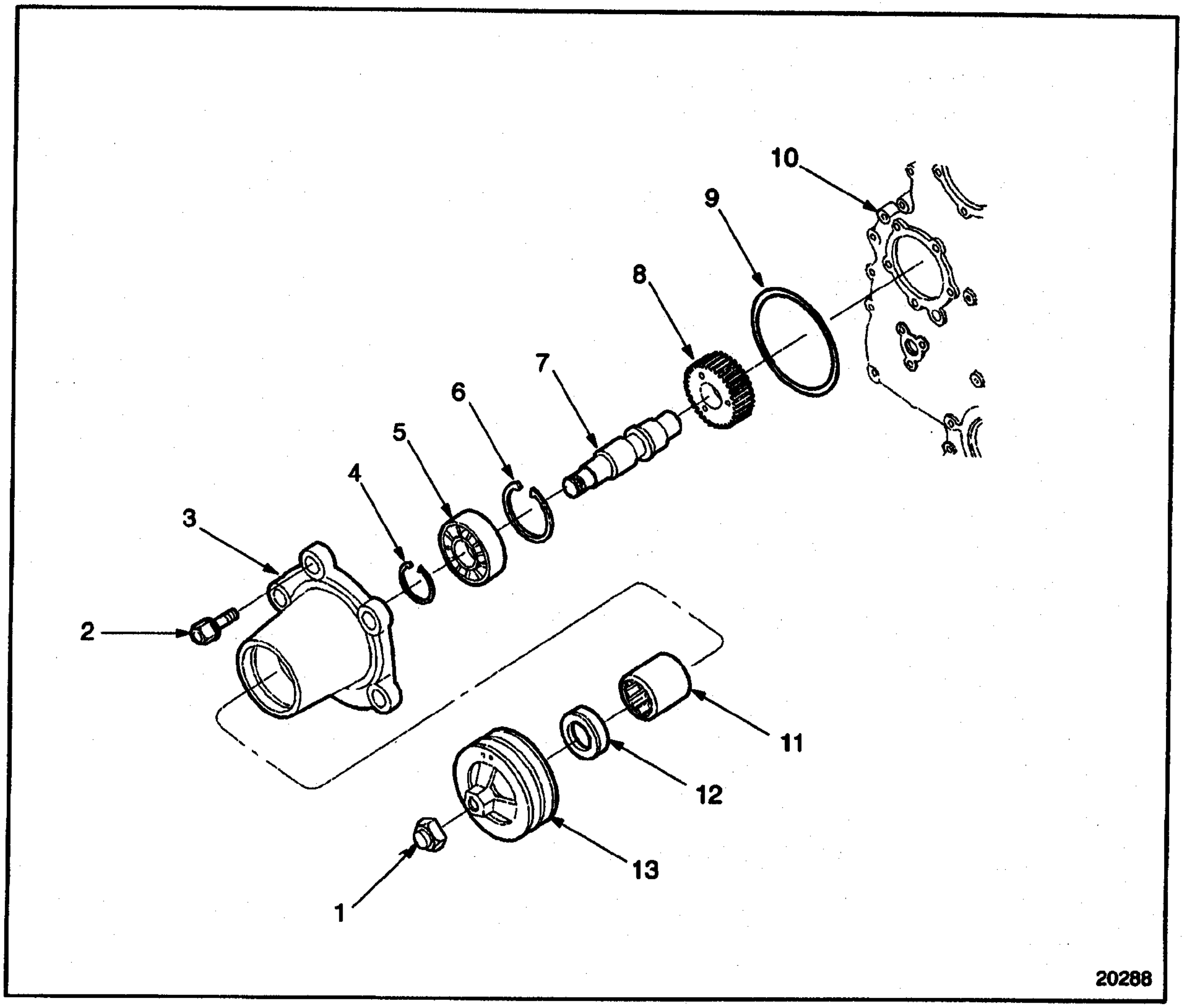

1. Locknut
2. Mounting Bolts (5)
3. Drive Housing
4. Snap Ring (Small)
5. Ball Bearing
6. Snap Ring (Large)
7. Drive Shaft
8. Drive Gear
9. O-Ring
10. Gear Case Cover
11. Needle Bearing
12. Oil Seal
13. Pulley

Figure 1-400 Accessory Drive Assembly Related Parts (Current Design)

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The accessory drive assembly is splash fed oil through two holes in the casting of the accessory drive housing. The oil returns to the crankcase via the gear case.

The accessory drive is driven by a drive gear which is pressed onto the drive shaft. The drive gear meshes with the bull gear and is driven at 2.41 times engine speed.

The drive shaft is supported by a ball bearing at the drive end and a needle bearing at the pulley end.

NOTE:
A design change has been made to the accessory drive assembly. The needle bearing inner race is now incorporated into the drive shaft. See Figure 1-399, and see Figure 1-400.

An O-ring is used to seal the accessory drive housing to the gear case cover.

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1.28.1 Repair and Replacement of the Accessory Drive

To determine if repair is possible or replacement is necessary, perform the following procedures. See Figure 1-401.

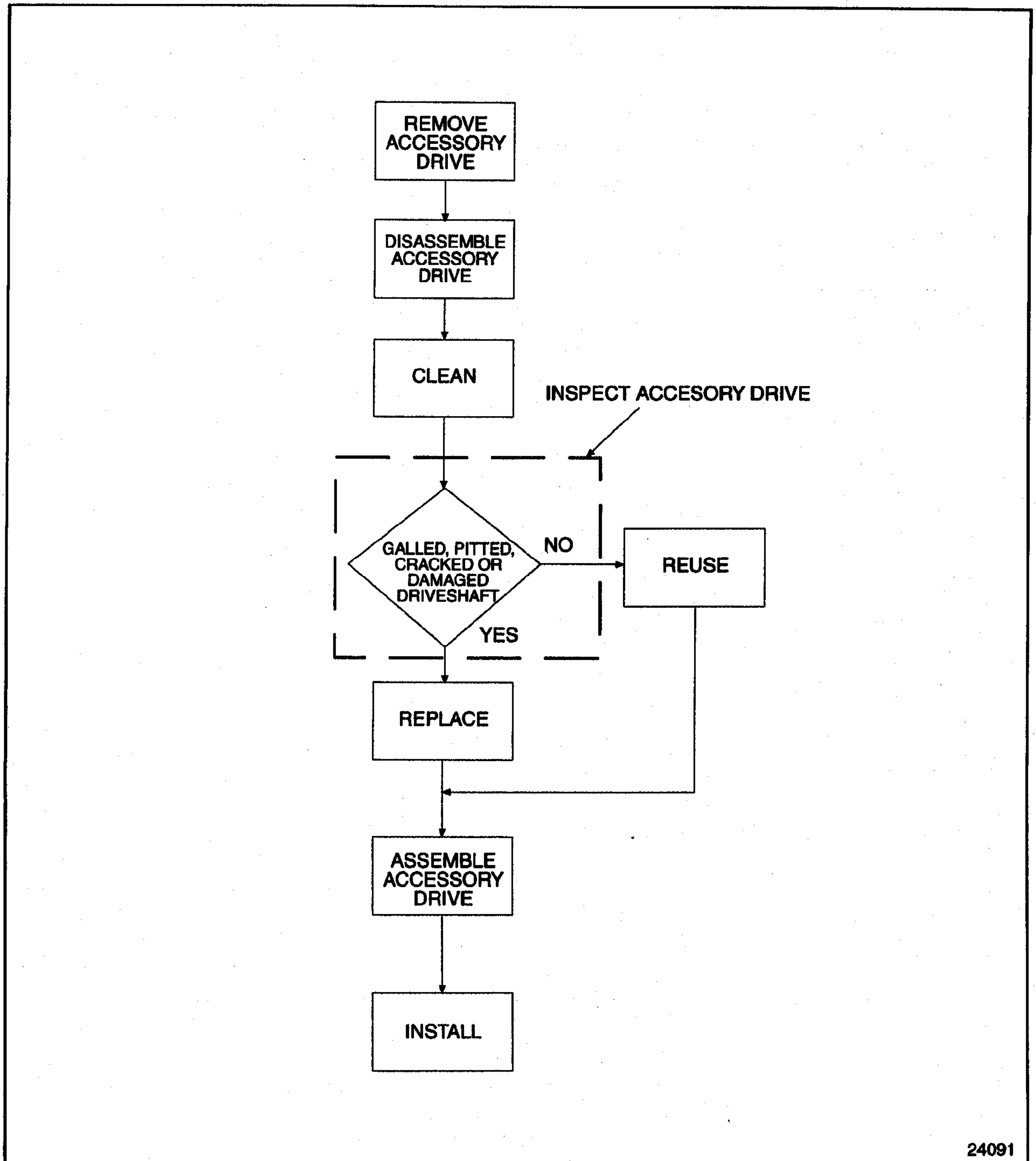

Figure 1-401 Flowchart for Repair or Replacement of Accessory Drive

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1.28.2 Removal and Cleaning of the Accessory Drive

Precleaning is not necessary.

Remove the accessory drive as follows:

1. Loosen the alternator mounting bolts and the adjusting rod nuts to get slack in the alternator drive belts. Remove the alternator drive belts. Refer to section 13.13.10.
2. Remove the five bolts that secure the accessory drive assembly to the gear case cover.
3. Remove the accessory drive assembly by pulling it straight out of the gear case cover to avoid damaging the rubber O-ring. See Figure 1-402.

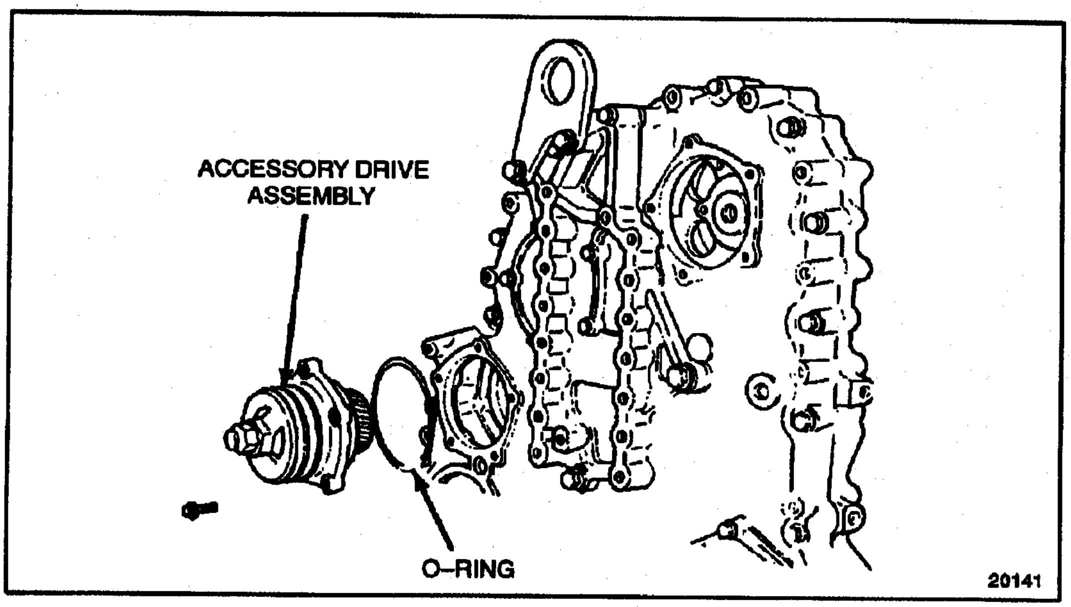

Figure 1-402 Accessory Drive Assembly Removal

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1.28.3 Disassembly of the Accessory Drive

Disassemble the accessory drive as follows:

NOTE:
For disassembly and assembly of the accessory drive use J 36024-C . See Figure 1-403.

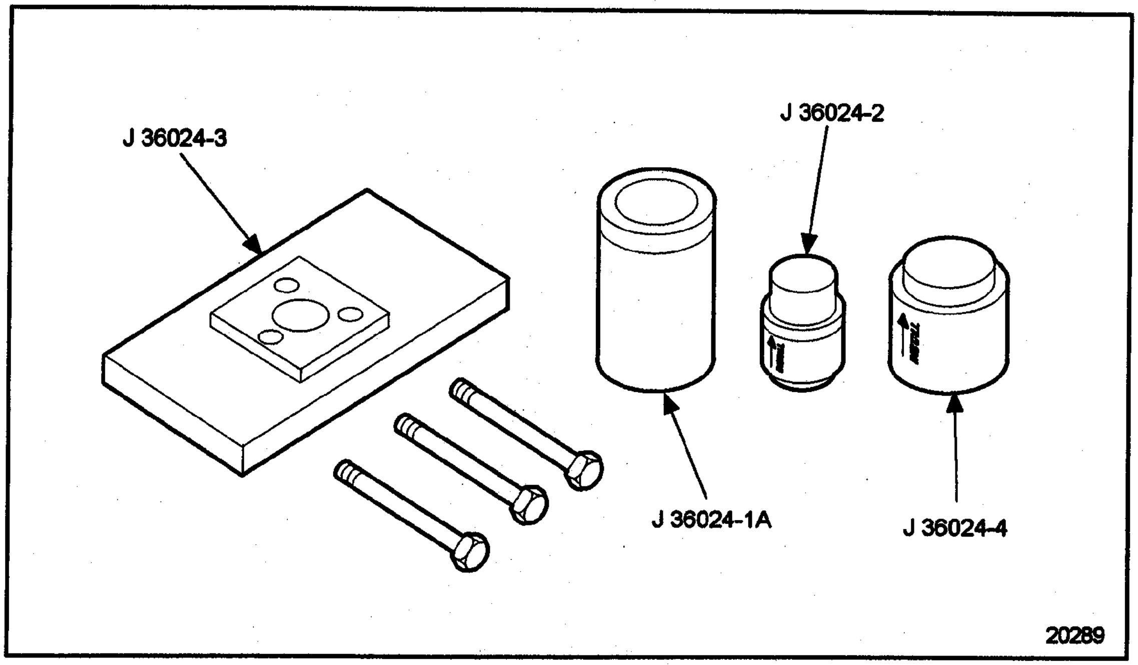

Figure 1-403 Accessory Drive Service Tool Set

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1. Attach the accessory drive gear to the holding fixture, J 36024-3 part of J 36024–C , using the three bolts provided. See Figure 1-404.

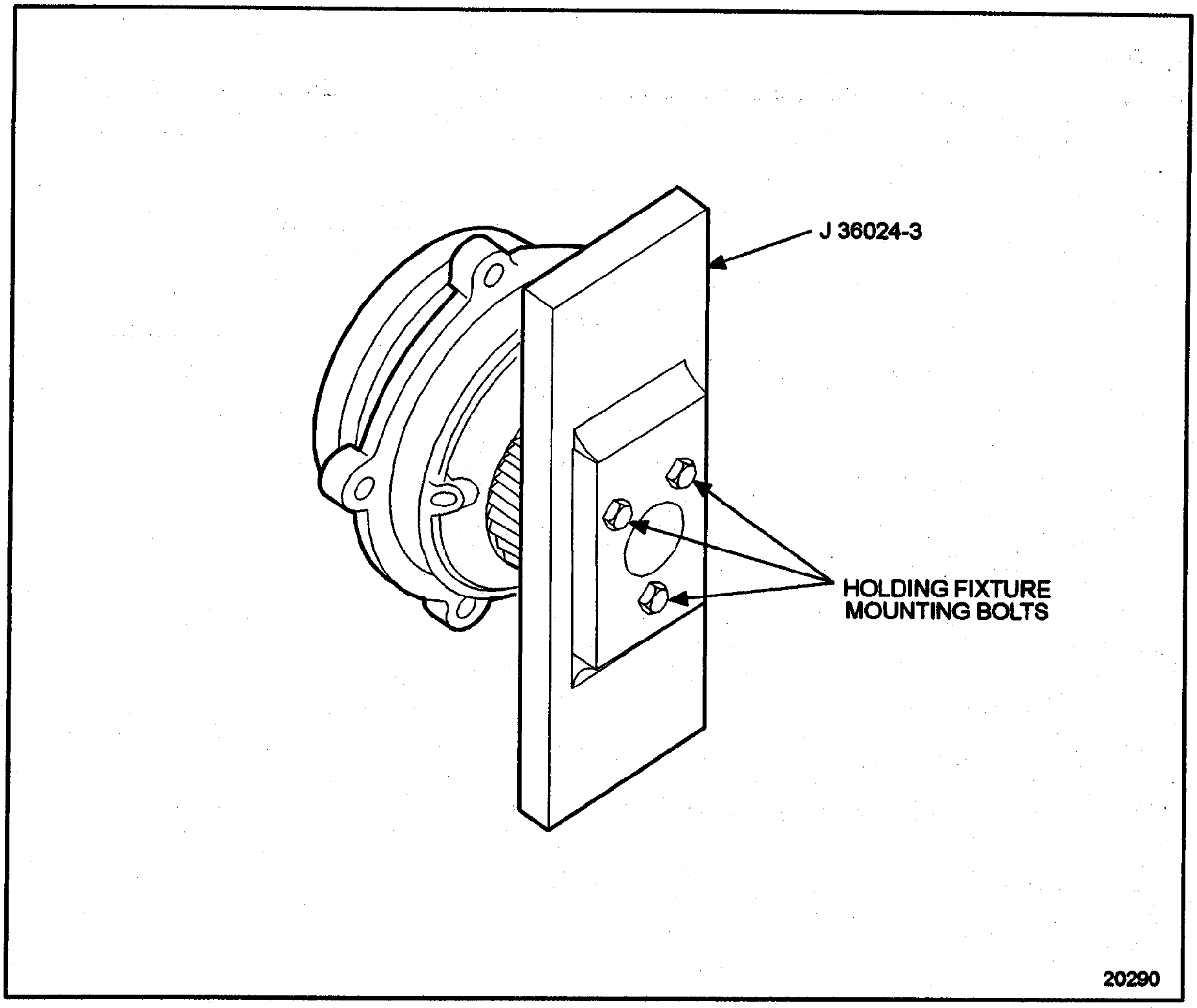

Figure 1-404 Holding Fixture

2. Place the accessory drive assembly holding fixture into a vise. See Figure 1-405.

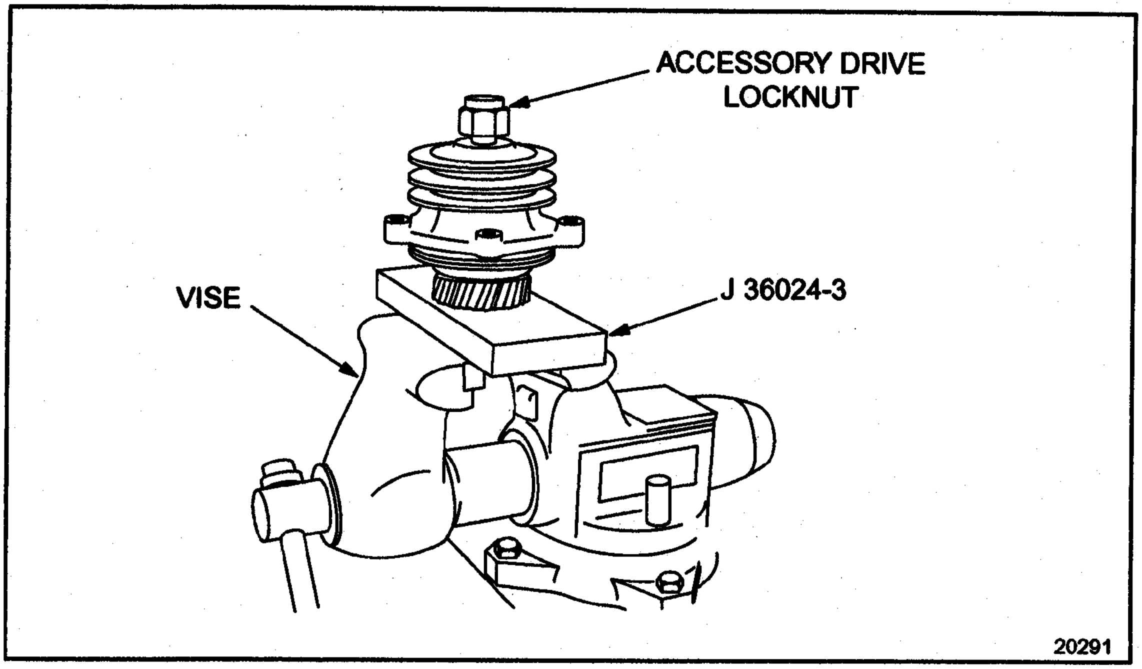

Figure 1-405 Accessory Drive Pulley Locknut Removal

3. Remove the accessory drive pulley locknut. See Figure 1-405.
4. Remove the accessory drive pulley by tapping it with a rubber hammer or fiber mallet. If the pulley does not come off easily, use a puller to remove it.

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5. Position the accessory drive assembly on a press bed with the holding fixture supported. See Figure 1-406.

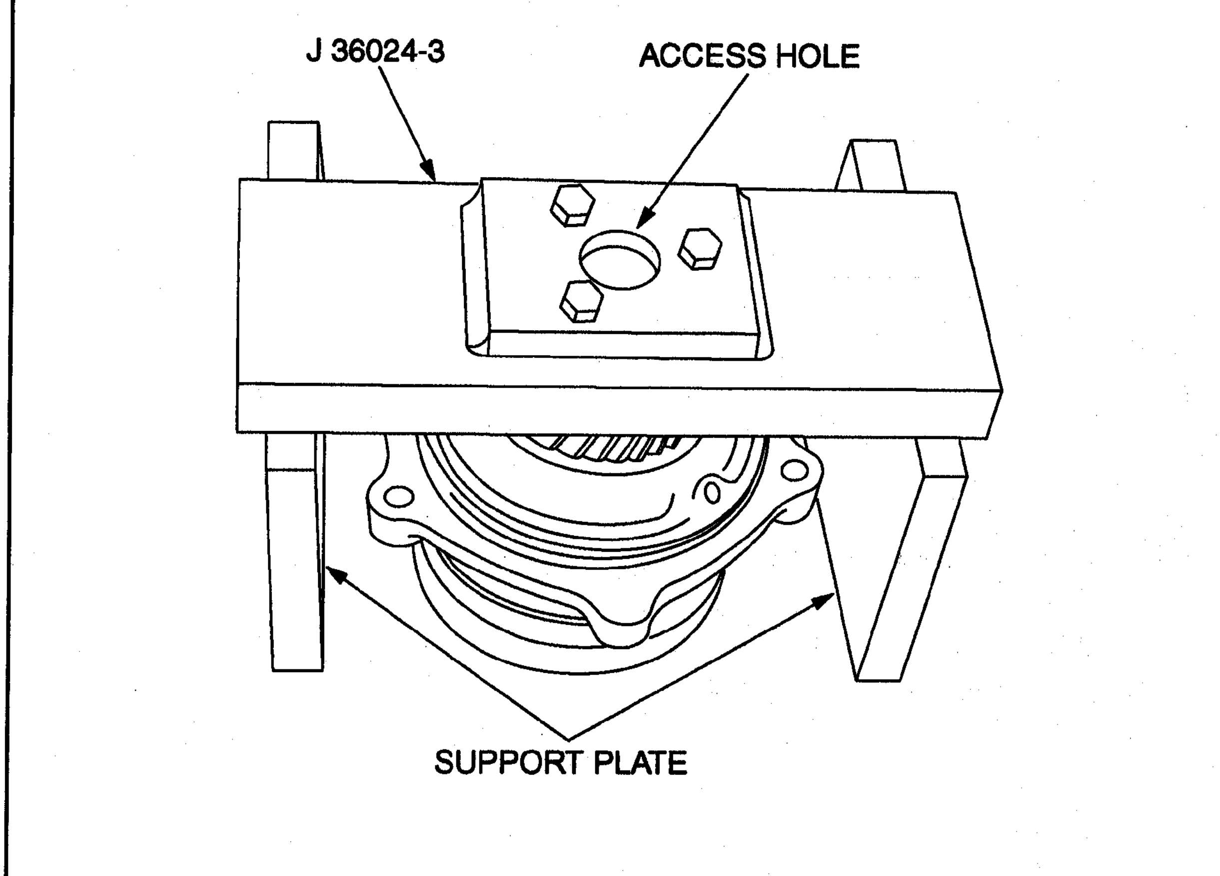

Figure 1-406 Accessory Drive Gear Removal

6. Using a press, apply pressure through the access hole in the holding fixture, J 36024-3 part of J 36024–C, and press the drive shaft out of the gear. See Figure 1-406.

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7. Remove the snap ring from the accessory drive housing. See Figure 1-407.

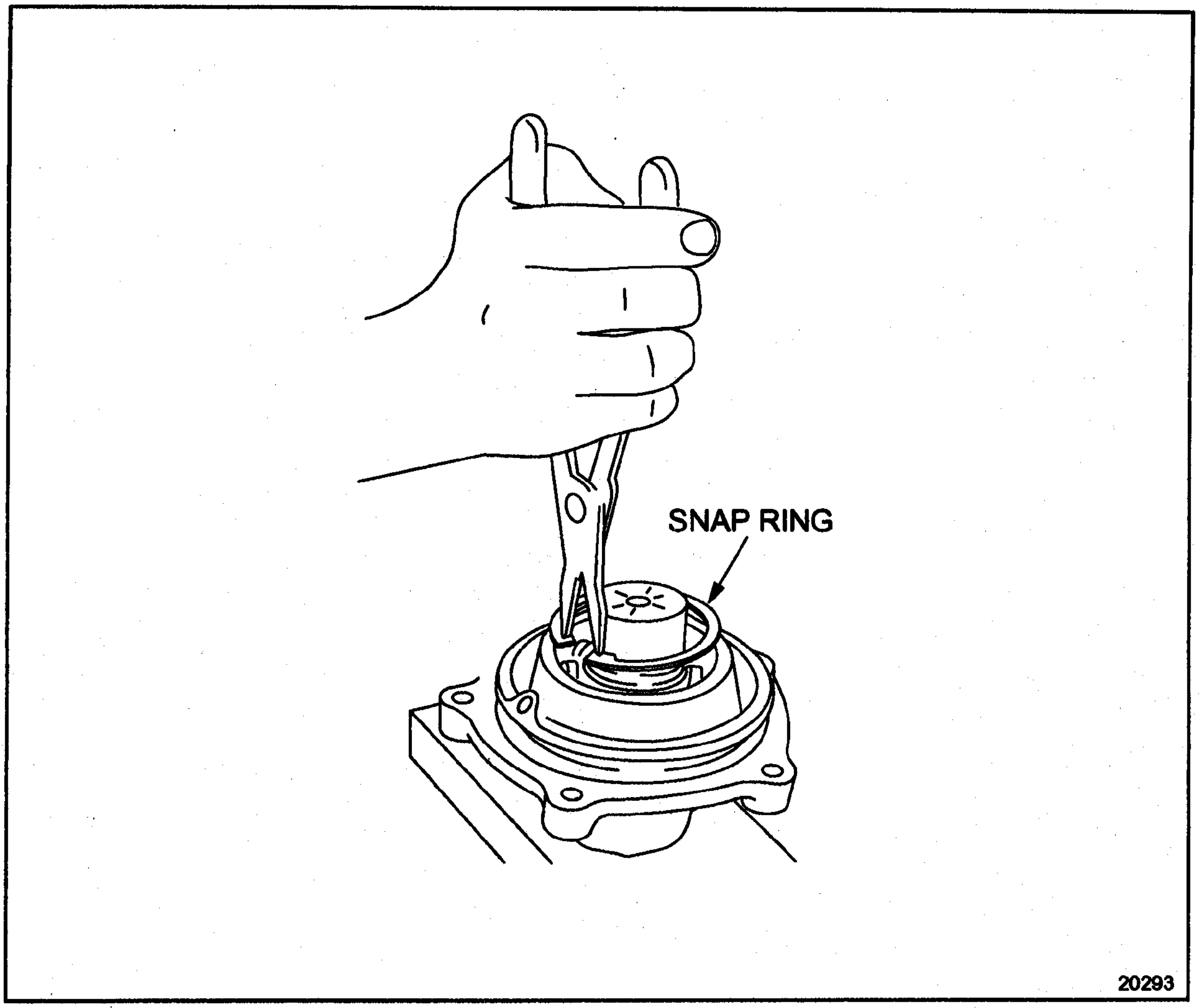

Figure 1-407 Snap Ring Removal

8. Turn the housing over and support the accessory drive housing on the machined surface using V-blocks.
9. Using a press, apply pressure to the pulley end of the shaft and remove the shaft and bearing assembly.
10. Turn the accessory drive housing over, and support it on the attaching bolt bosses using V-blocks.

NOTE:
On current design, the shaft serves as the inner race for the needle bearing.

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NOTICE:
For assemblies with inner race for needle bearing, place the accessory drive shaft in a vise with soft jaws taking care not to damage the shaft surface.

11. Install J 36024-2 part of J 36024–C and apply pressure to J 36024-2 part of J 36024–C , to remove the needle bearing. See Figure 1-408.

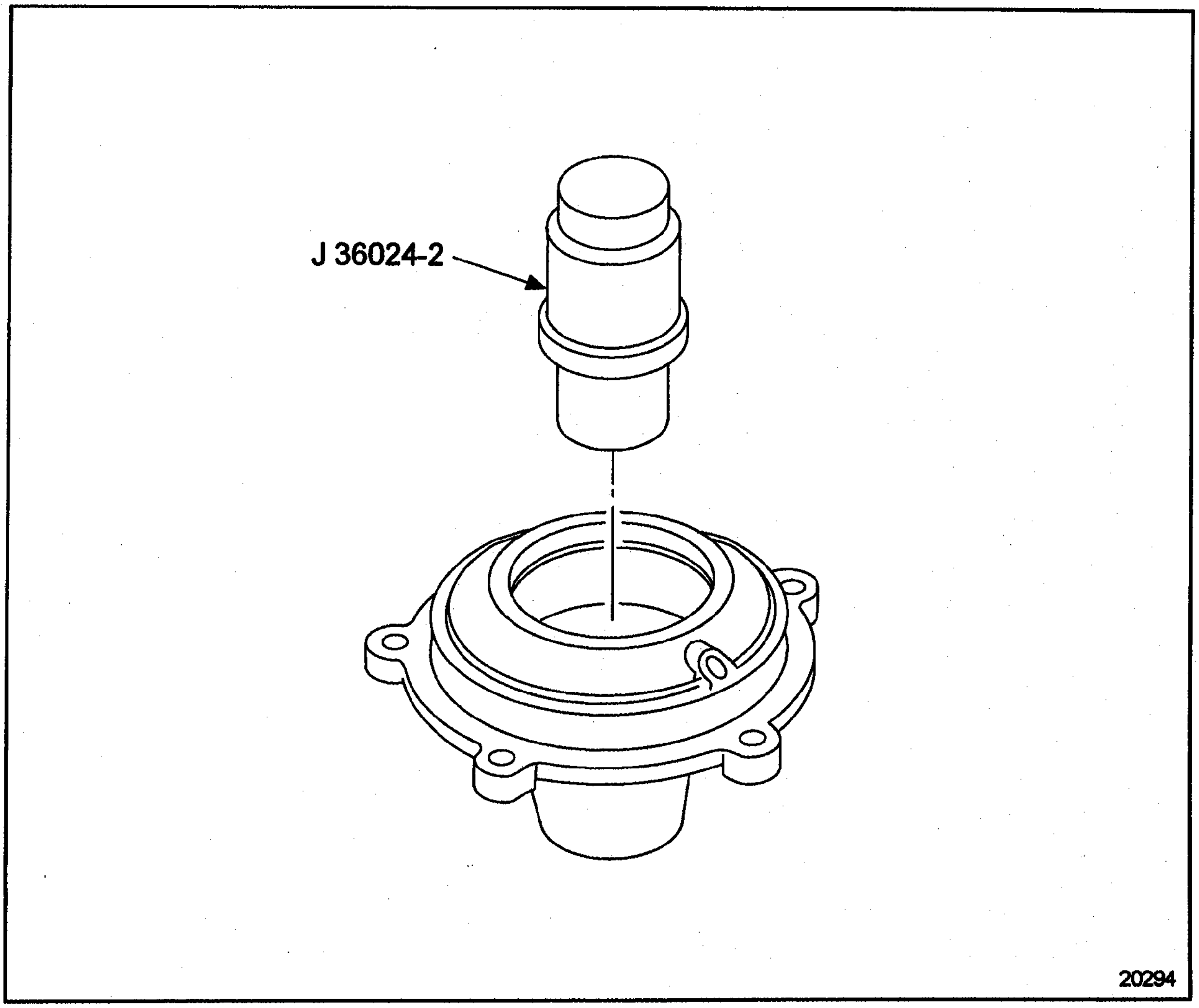

Figure 1-408 Needle Bearing Removal

12. Remove the needle bearing inner race from the accessory drive shaft with a two jaw puller utilizing the slots provided in the shaft. See Figure 1-409.

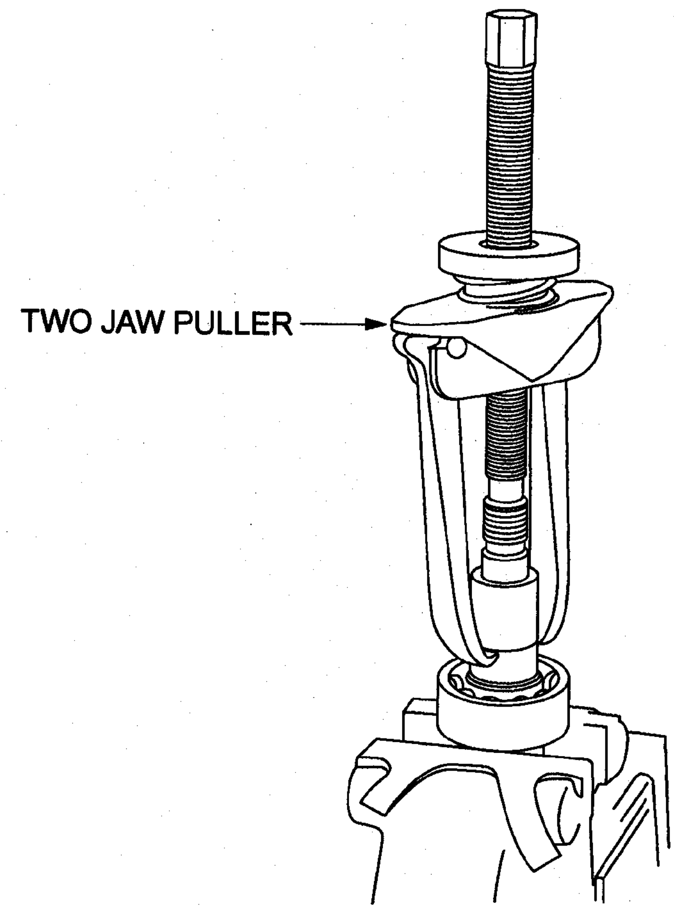

Figure 1-409 Bearing Inner Race Removal

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13. Remove the snap ring from the accessory drive shaft. See Figure 1-410.

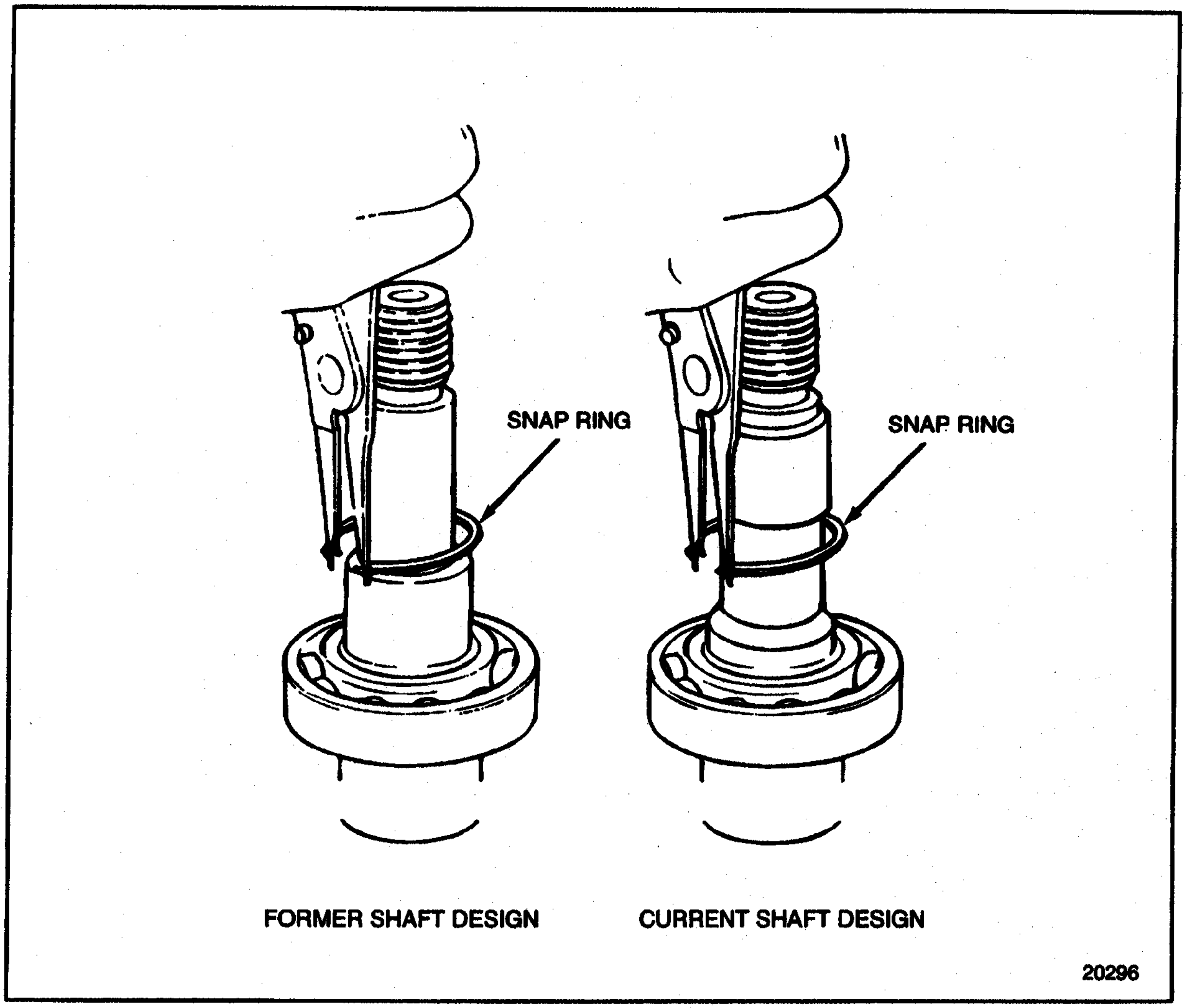

Figure 1-410 Snap Ring Removal

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14. Position two steel press plates under the ball bearing outer race. See Figure 1-411.

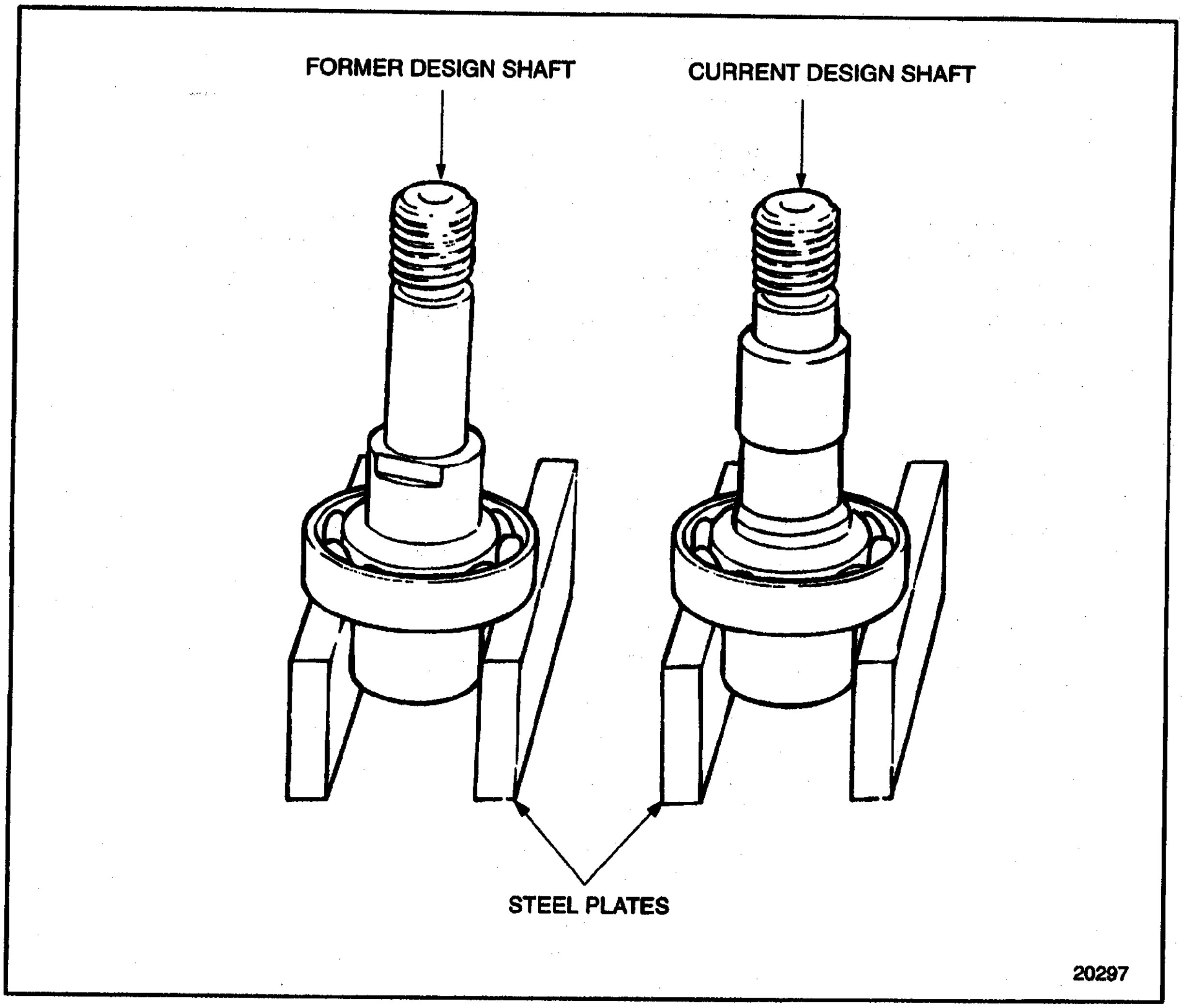

Figure 1-411 Position of the Steel Press Plates

NOTE:
Whenever the needle or ball bearing is removed from the shaft, they MUST be replaced with new bearing assemblies.

15. Use a press to apply pressure to the top of the shaft and remove the ball bearing from the shaft.

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1.28.3.1 Inspection of the Accessory Drive

Clean the accessory drive prior to inspection as follows:

1. Clean all of the parts with clean fuel oil.

CAUTION:
To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

2. Dry parts with compressed air.

Inspect the accessory drive as follows:

1. Visually examine the drive shaft for damage check the drive shaft for galling, pitting, cracks, or other damage.
   [a] If any damage is detected, replace with a new part.
   [b] If no damage is found, reuse the part.

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1.28.4 Assembly of the Accessory Drive

Assemble the accessory drive as follows:

1. Place a new ball bearing on the accessory drive shaft. Use tool J 36024-1A and a press to install the bearing onto the shaft until it bottoms out against the shoulder of the drive shaft. See Figure 1-412.

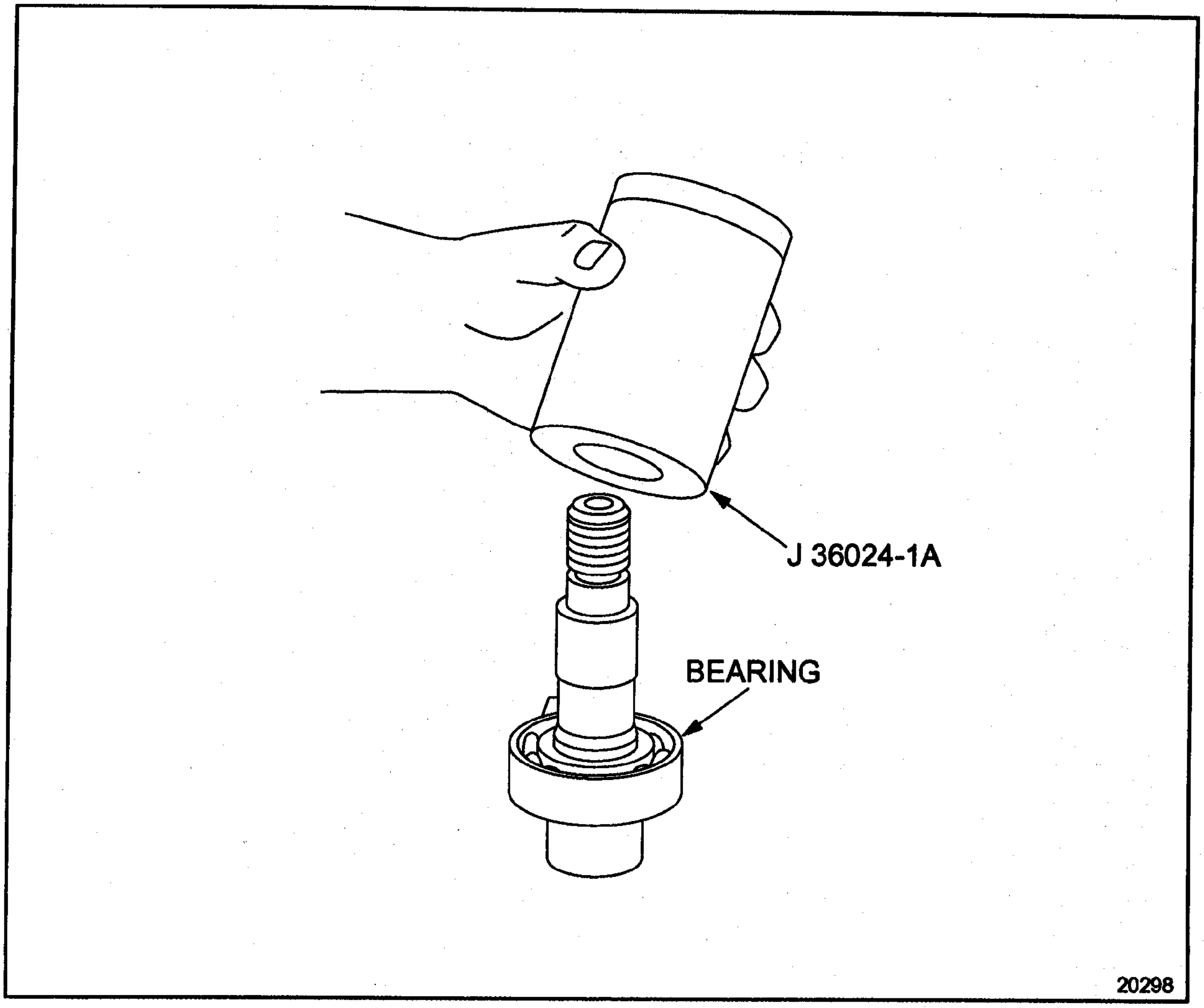

Figure 1-412 Bearing Installation

2. Install the snap ring to the accessory drive shaft making sure it is fully seated in the groove a full 360 degrees See Figure 1-413.

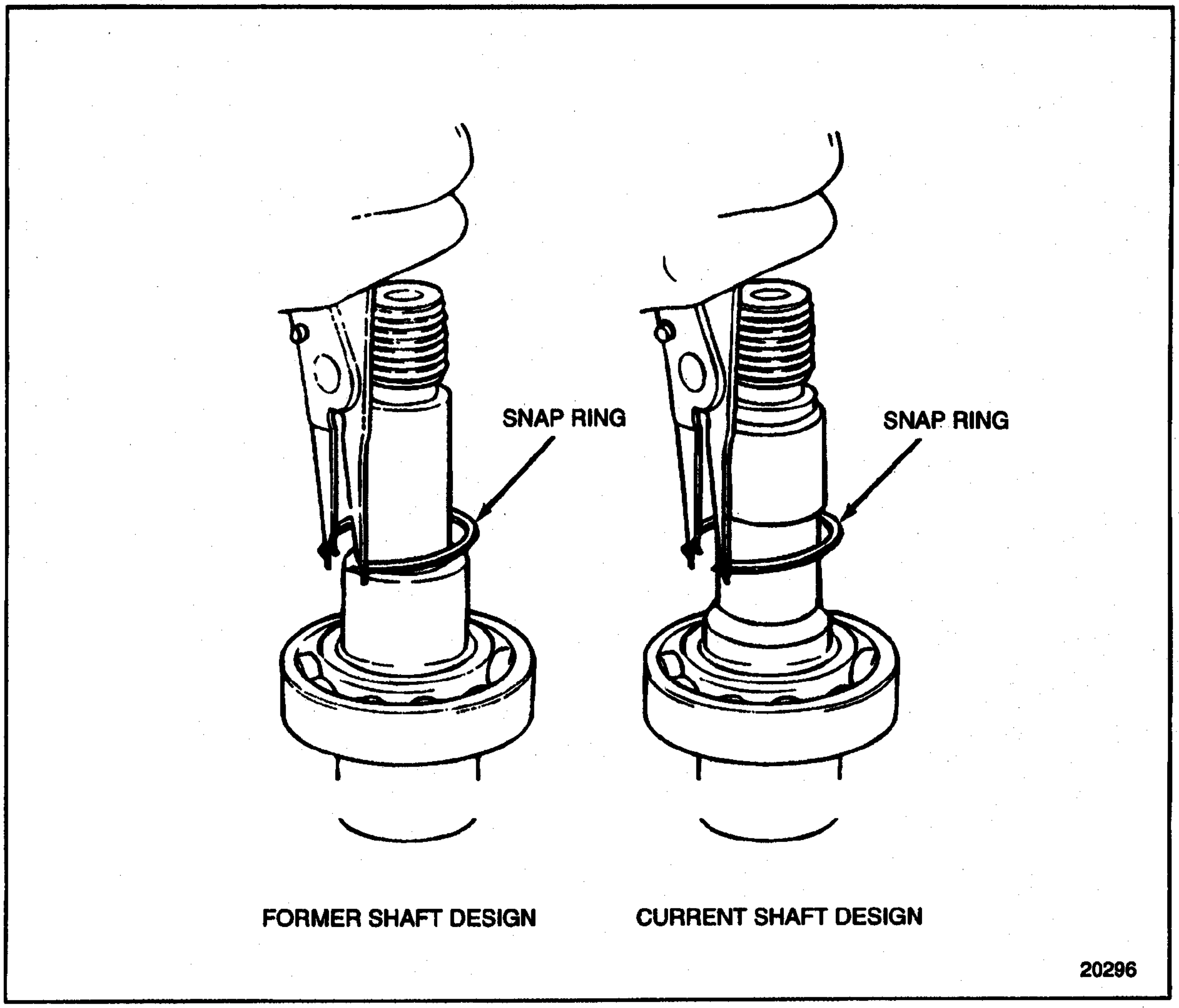

Figure 1-413 Snap Ring Installation

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3. Place the needle bearing inner race on the accessory drive shaft. Use tool J 36024-1 part of J 36024–C and a press to install the bearing inner race to the shaft until it is tight against the shoulder. See Figure 1-414.

NOTE:
On current design accessory drive shaft, the needle bearing inner race is incorporated into the shaft.

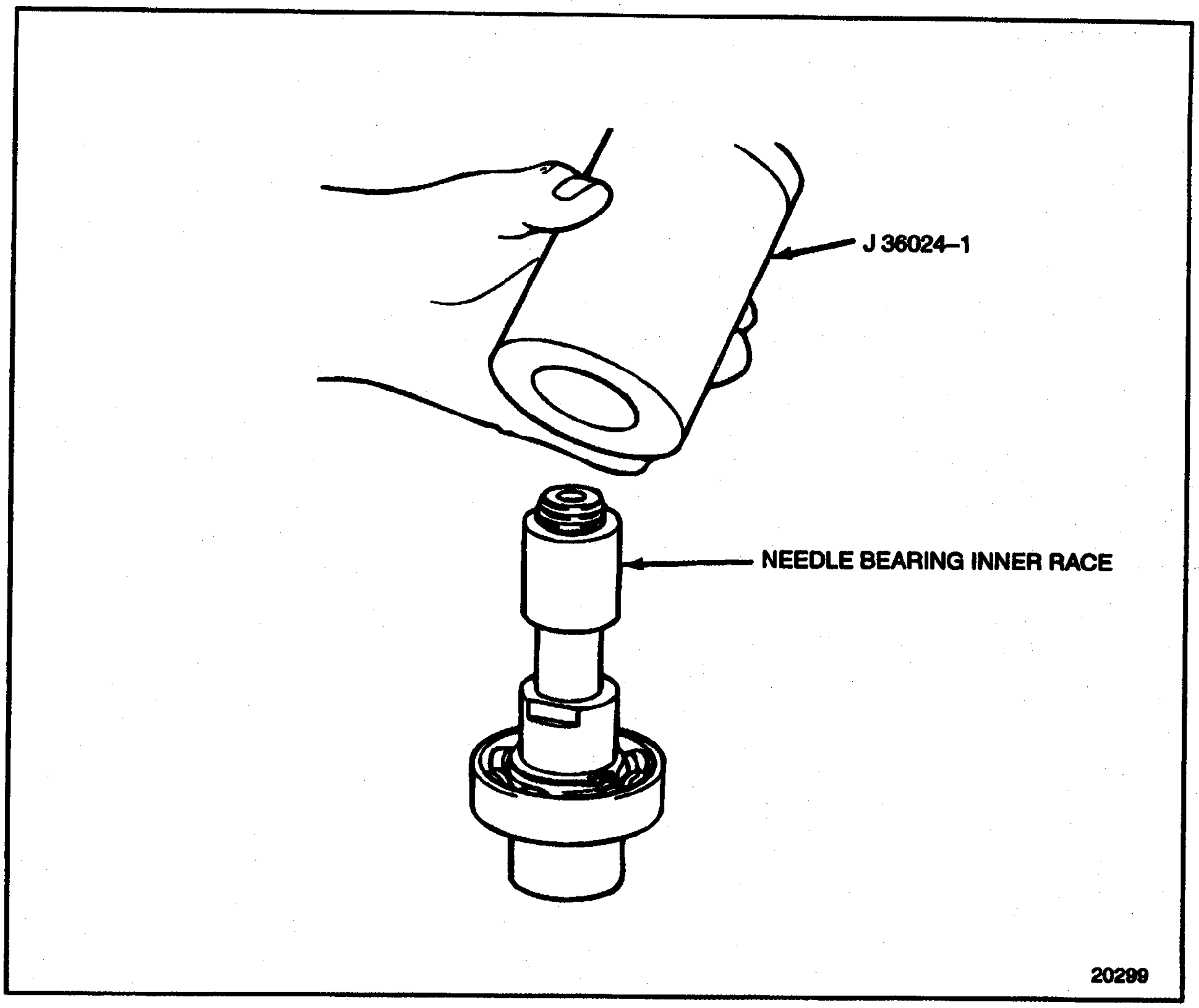

Figure 1-414 Needle Bearing Inner Race Installation

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4. Install the needle bearing to the accessory drive housing using tool J 36024-2. See Figure 1-415.

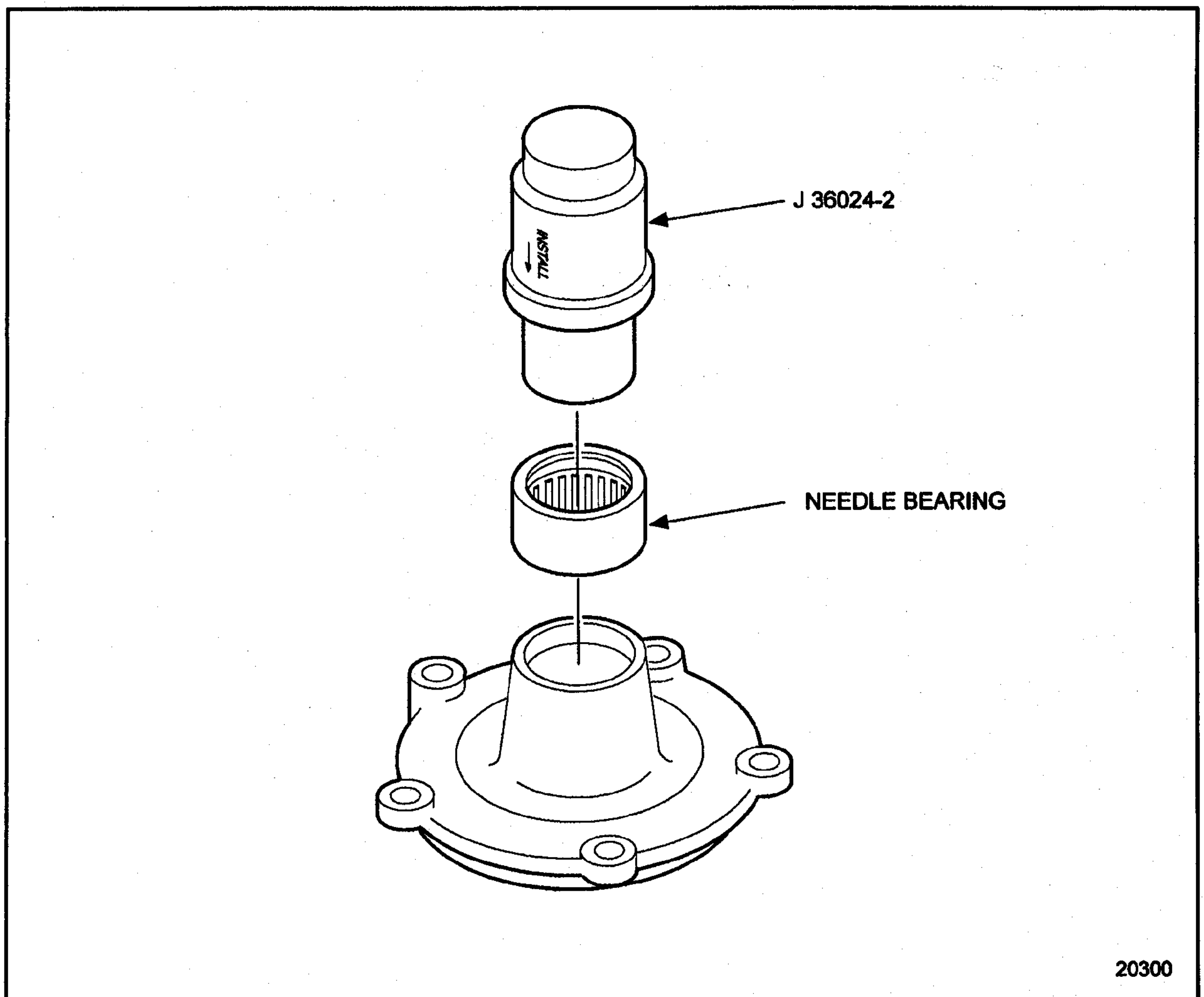

Figure 1-415 Needle Bearing Installation

NOTE:
The end of the bearing with the identification numbers must be against the installer.

NOTE:
The word INSTALL and an arrow are etched into the tool, J 36024-2 part of J 36024–C, to facilitate correct bearing installation.

5. Lubricate the oil seal contact area of the accessory drive housing with a thin film of engine oil.
6. Install the accessory drive oil seal to the accessory drive housing using the seal installer, J 36024-4 part of J 36024–C, and a plastic hammer or fiber mallet. The oil seal must be installed flush to 0.25 mm (0.010 in.) below the face of the housing. See Figure 1-416.

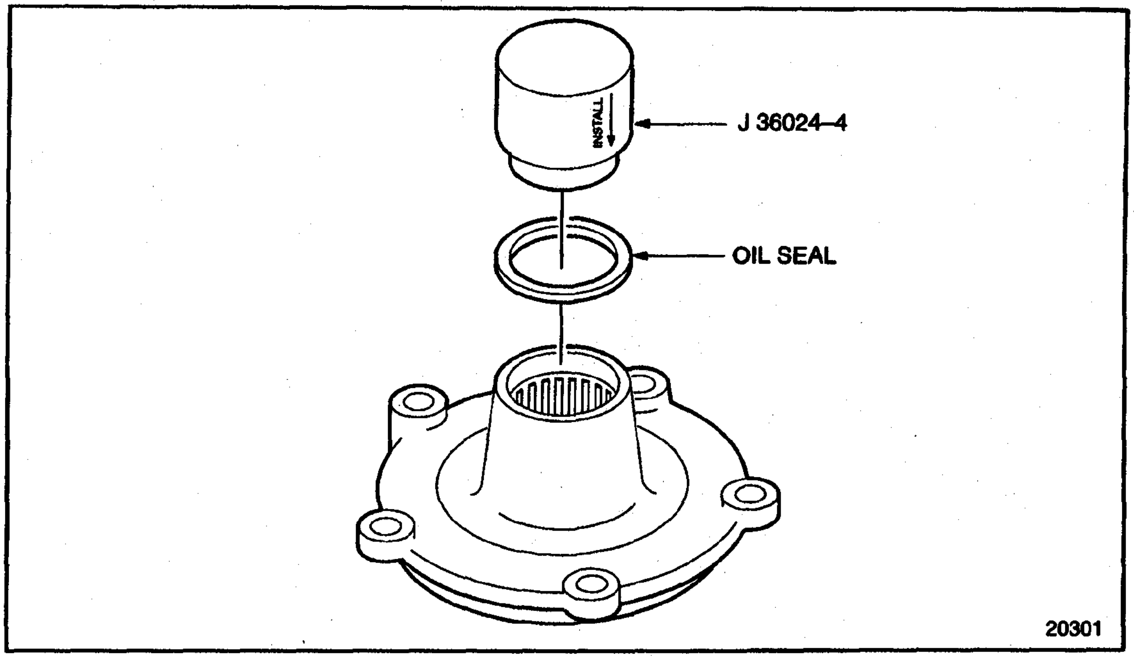

Figure 1-416 Accessory Drive Oil Seal Installation

7. Lubricate the oil seal with a thin film of engine oil.
8. Support the holding fixture, J 36024-3 on two steel plates and position the accessory drive housing into the hole in the fixture. See Figure 1-407.

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9. Install the drive shaft to the housing. See Figure 1-417.

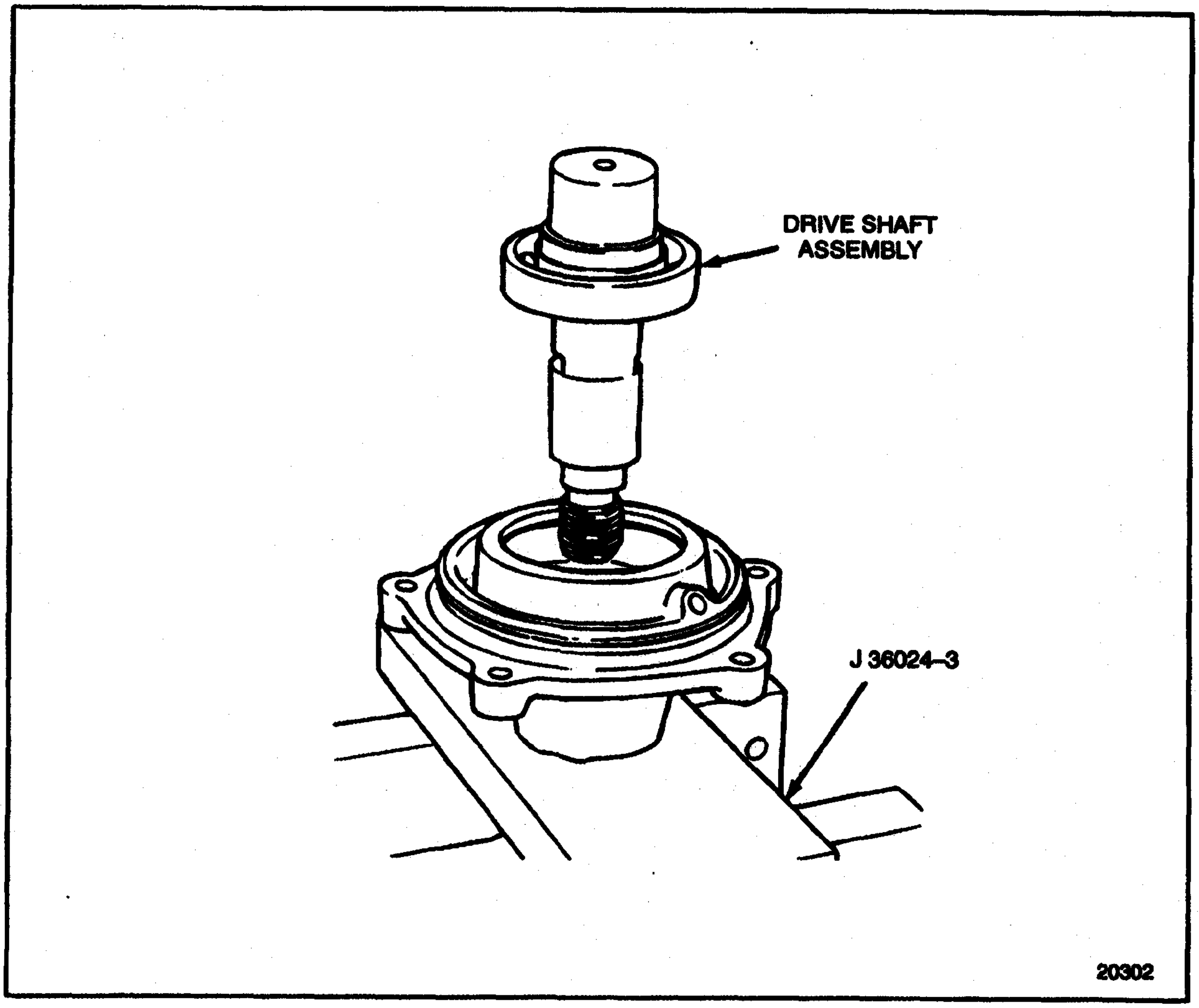

Figure 1-417 Drive Shaft Installation

10. Press the drive shaft into the housing by placing tool, J 36024-1A part of J 36024–C , on the bearing outer race.

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11. Press the bearing into the housing until the bearing is seated against the shoulder of the housing. See Figure 1-418.

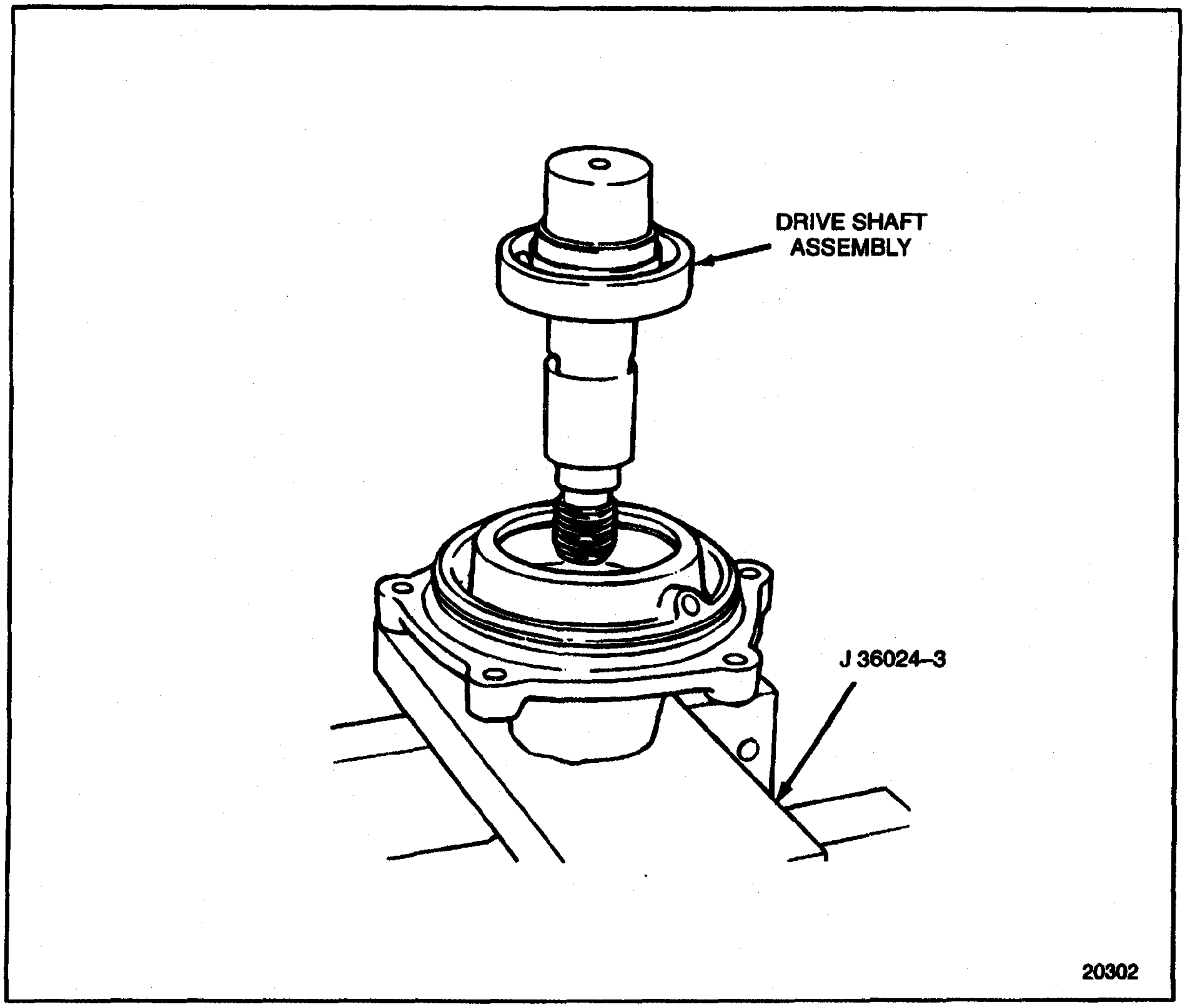

Figure 1-418 Bearing Installation

12. Install the snap ring to the accessory drive housing making sure the snap ring is fully seated in the groove a full 360 degrees See Figure 1-419.

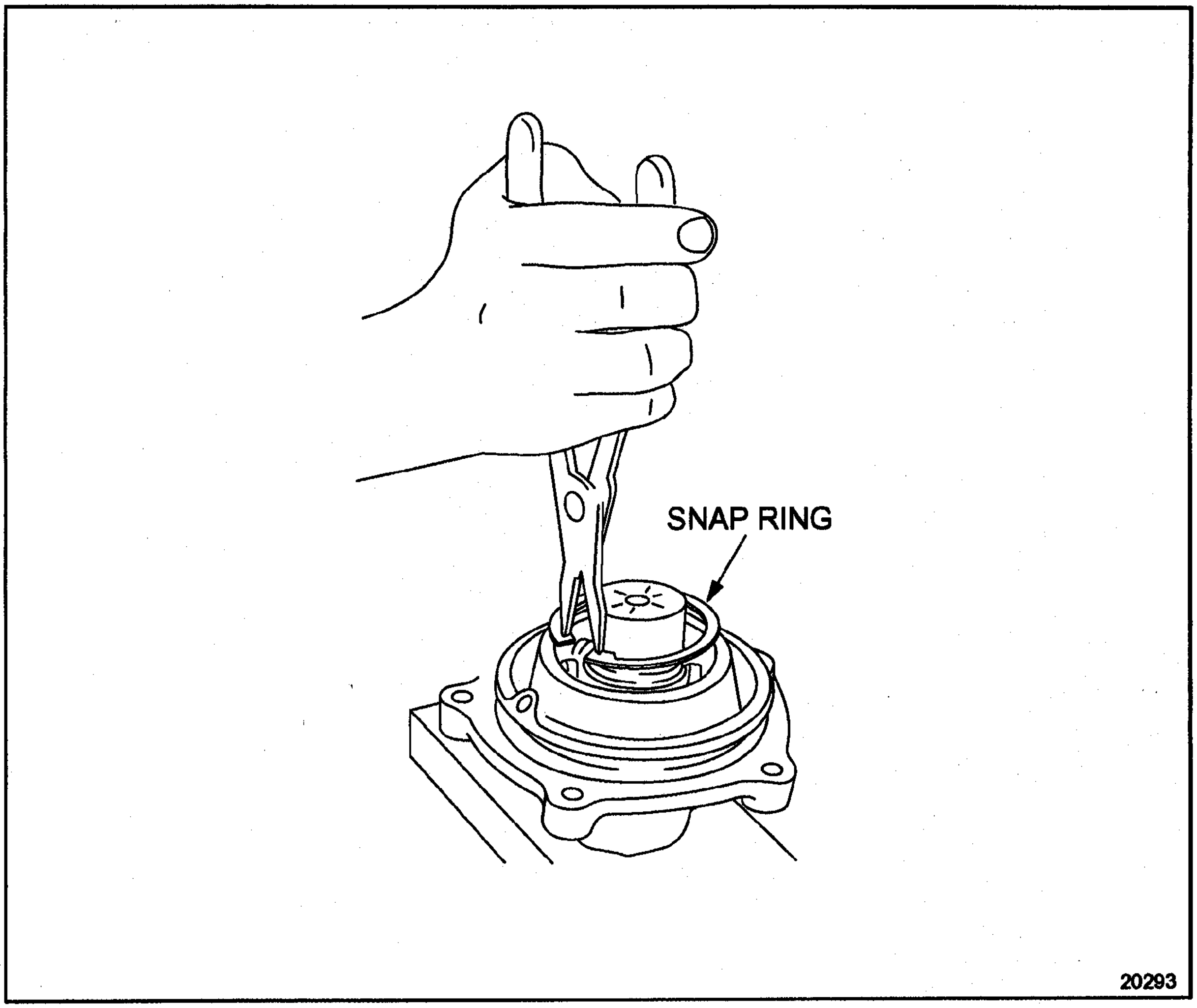

Figure 1-419 Snap Ring Installation

13. Lubricate the contact surfaces of the bearing with clean engine lubricating oil.

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14. A film of lubriplate must be applied to the drive gear end of the accessory drive shaft. See Figure 1-420.

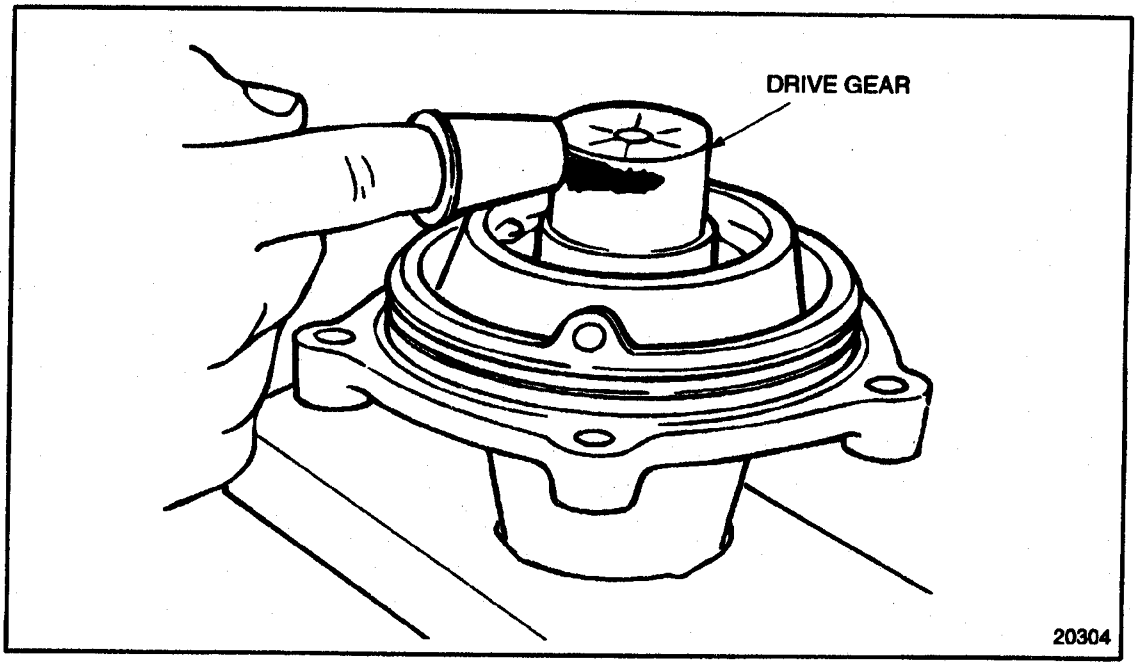

Figure 1-420 Drive Gear Installation Preparation

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15. Use a press to install the drive gear on the accessory drive shaft until it is flush with the drive shaft end. Make sure the three threaded holes are facing up. See Figure 1-421.

NOTE:
Support the opposite end of the drive shaft on the press bed when pressing the gear on the shaft. A minimum press load of 17.8 kN (4000 lb) must be obtained when pressing the gear on the shaft.

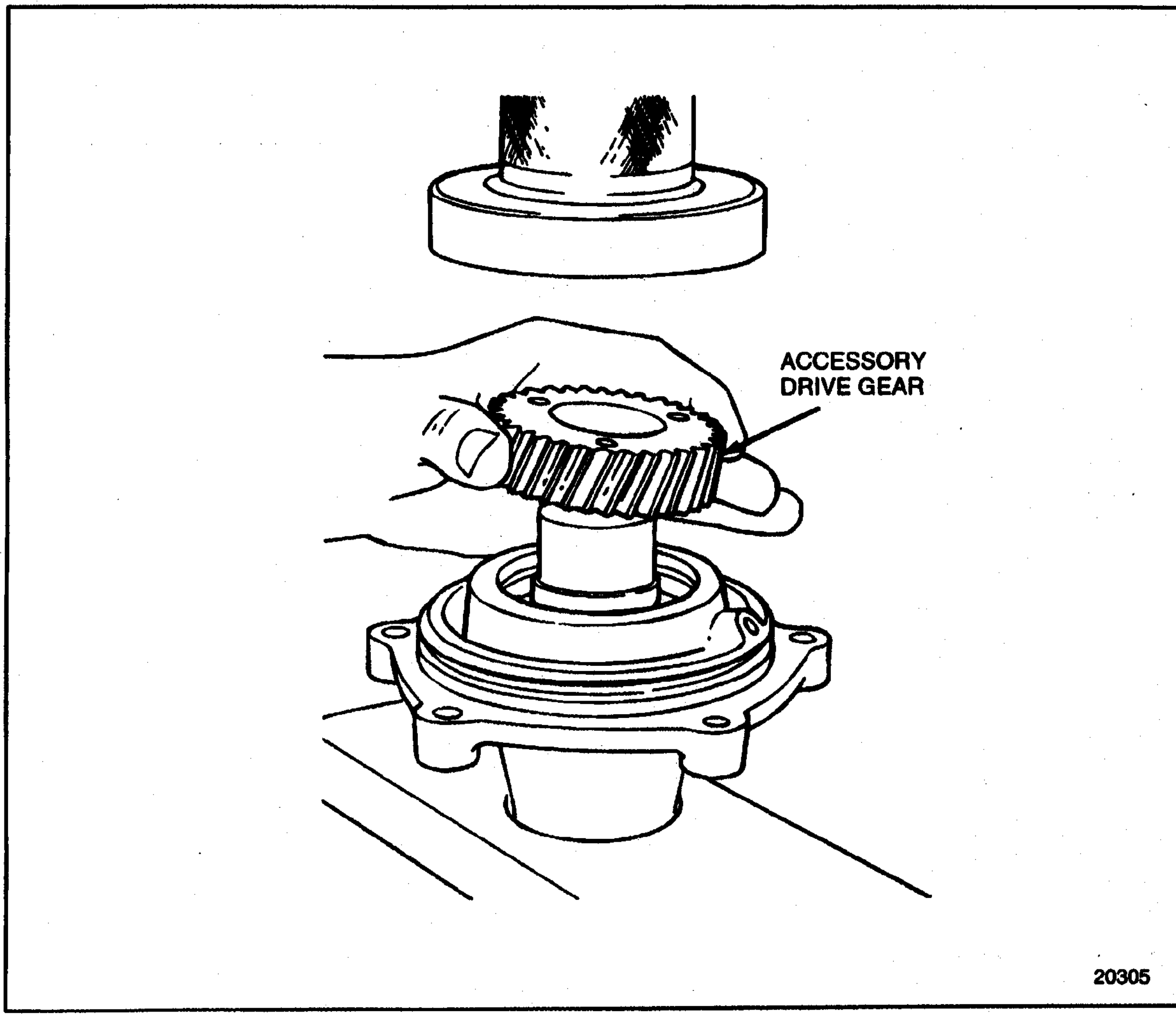

Figure 1-421 Accessory Drive Gear Installation

16. Install the accessory drive pulley to the shaft.

NOTE:
If necessary, use tool J 36024-1 to seat the pulley on the shaft. If pressing is necessary, the opposite (gear) end of the shaft must be supported during the pressing operation.

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17. Attach J 36024-3 part of J 36024–C, to the drive gear. See Figure 1-403.
18. Place the accessory drive assembly holding fixture into a vise. See Figure 1-422.
19. Install and torque the accessory drive pulley locknut to 360-400 N·m (266-295 lb·ft). See Figure 1-422.

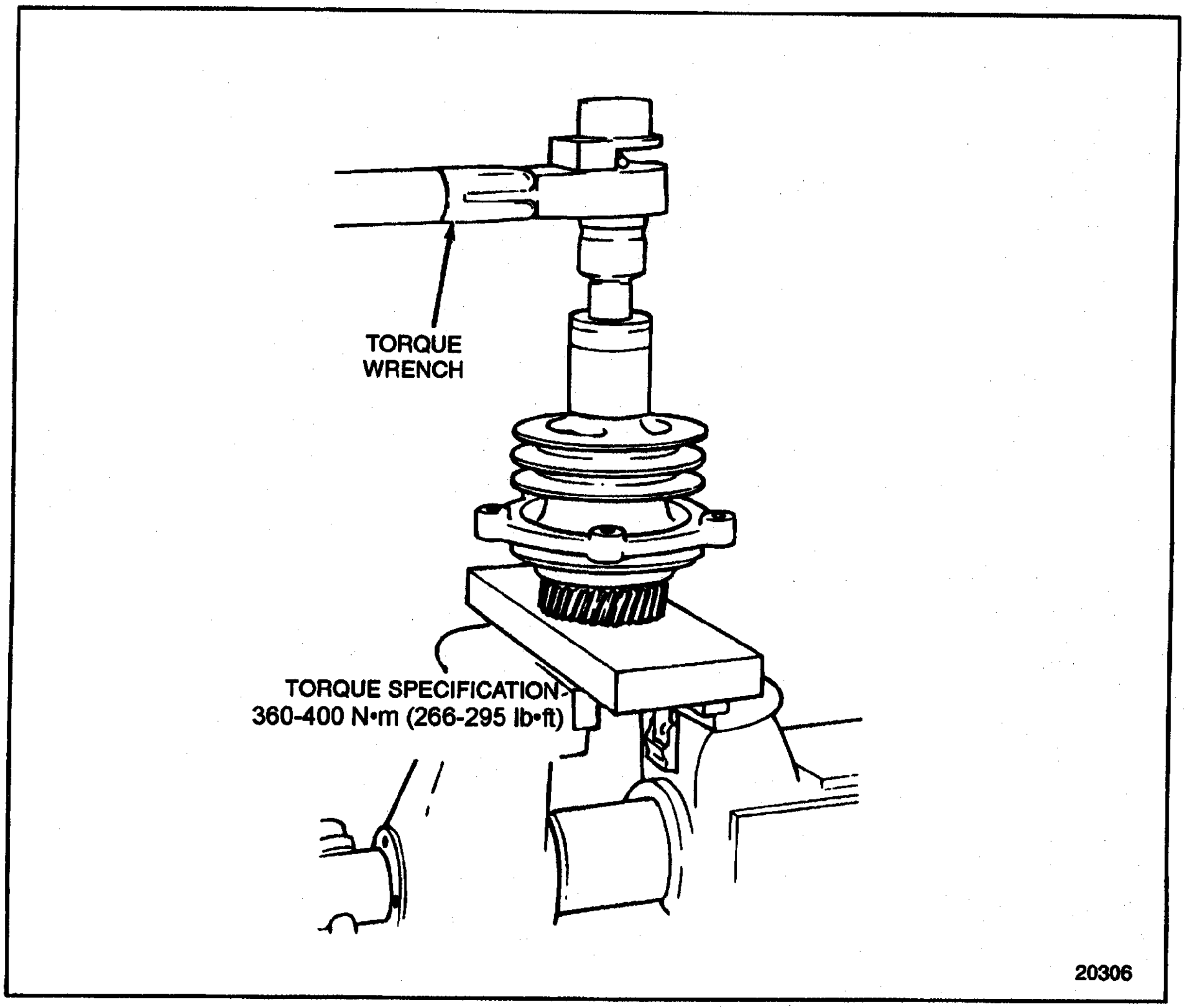

Figure 1-422 Accessory Drive Pulley Locknut Tightening

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20. Support the accessory drive assembly. See Figure 1-423.

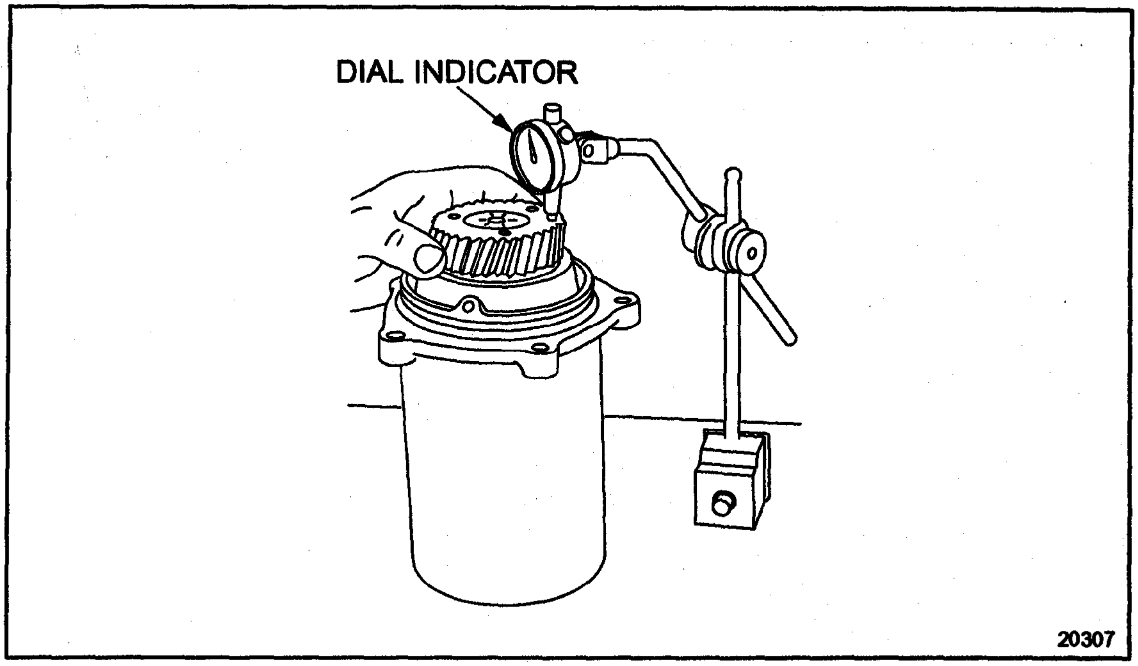

Figure 1-423 Accessory Drive Gear TIR Measurement

21. Assemble a dial indicator and magnetic base, so that the indicator stem rests on the face of the accessory drive gear just inboard of the drive gear teeth. See Figure 1-423.
22. Zero the dial indicator.
23. Rotate the drive gear two full rotations. See Figure 1-423. As the gear is rotated, the dial indicator needle may register both to the left and right of zero.
24. The total amount the dial indicator needle moves to the left and right of zero, added together, gives the total indicated run-out (TIR). The specified TIR is 0.04 mm (0.0015 in.).

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1.28.5 Installation of the Accessory Drive

Install the accessory drive as follows:

1. Install the O-ring seal in the groove on the drive housing.
2. Lubricate the O-ring with petroleum jelly.
3. Install the accessory drive housing to its original position in the gear case cover.

NOTE:
The word "UP" is cast into the drive housing.

4. Install the bolts that secure the accessory drive housing to the gear case cover and torque to 30-38 N·m (22-28 lb·ft) using the pattern shown. See Figure 1-424.

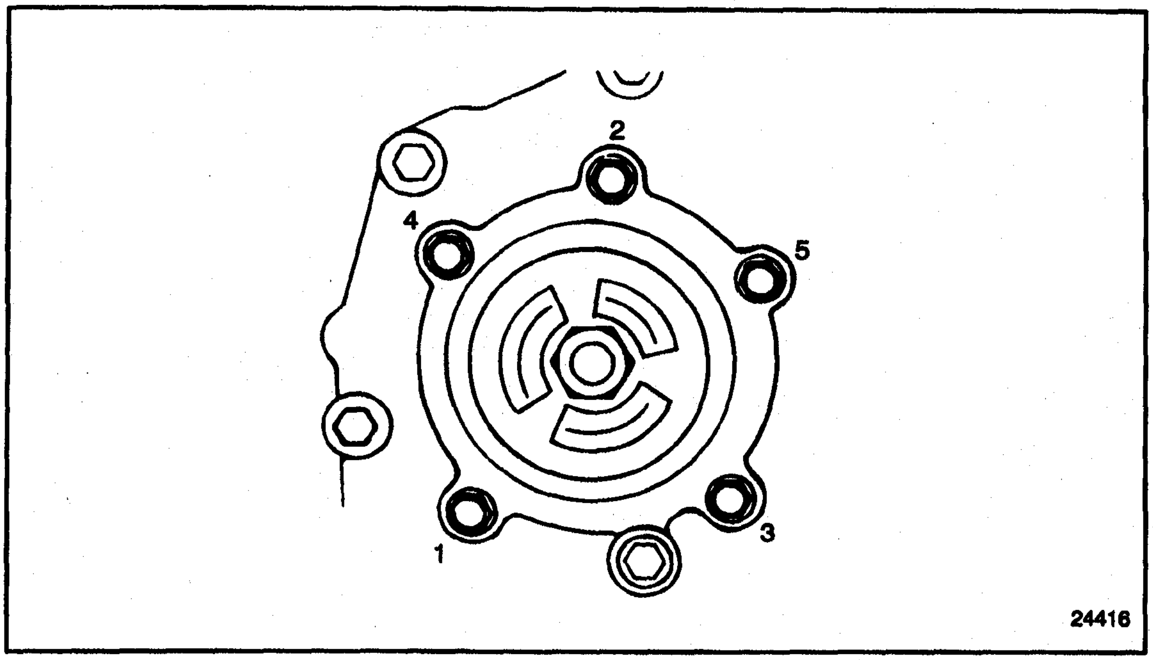

Figure 1-424 Accessory Drive Housing Bolt Torque Sequence

5. Check the bull gear-to-accessory drive gear backlash. Refer to section 1.21.2.1.
6. Adjust the alternator belts. Refer to section 13.13.10.
7. Tighten the alternator mounting bolts.
8. Install any other components removed for this procedure.
9. Refer to section 11.3 for verification of proper accessory drive installation.

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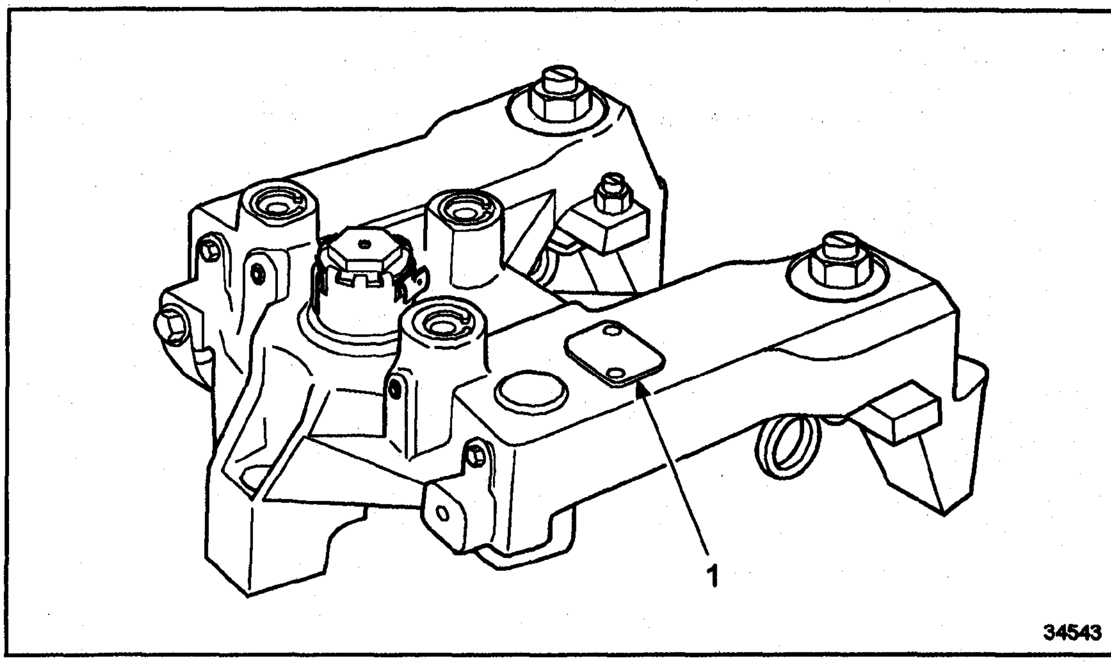
1.29 JAKE BRAKE®

The engine brake has been designed to fit on the Series 60 engine with no additional valve cover spacers. There are three styles of valve covers for the Series 60 engine. On engines equipped with a two-piece aluminum valve cover, it is NOT necessary to remove the lower valve cover to install the engine brake. However, one style of upper valve cover may require modification at the breather housing location (inside) for engine brake clearance.

The model, part number and serial number are located on the nameplates at the top of each housing. See Figure 1-425.



1. Identification Plate

Figure 1-425 Nameplate Location on Housing

NOTICE:
Only the specific brake model can be used with the engine model it was designed for. Also, the correct slave piston adjustment specification must be used. Failure to follow these instructions may result in serious engine or engine brake damage.

Listed in Table 1-9 are the different Jake Brake® models used and the slave piston adjustment specification.

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Model Number	Model Year	Engine Displacement	Engine Brake	Slave Piston Adjustment
6067WU40	Pre-1991	11.1L	760/760A	0.660 mm (0.026 in.)
6067GU40	Pre-1991	12.7L	760/760A	0.508 mm (0.020 in.)
6067WU60	1991	11.1L	760/760A	0.660 mm (0.026 in.)
6067GU40	1991	12.7L	765	0.660 mm (0.026 in.)
6067GU28	1991	12.7L	765	0.660 mm (0.026 in.)
6067GU91	1991	12.7L	765	0.660 mm (0.026 in.)
6067WK60	1994	11.1L	760A	0.660 mm (0.026 in.)
6067GK60	1994	12.7L	765	0.660 mm (0.026 in.)
6067GK28	1994	12.7L	765	0.660 mm (0.026 in.)
6067EK60	1998	11.1L	760B	0.584 mm (0.023 in.)
6067PK60	1998	12.7L	765A	0.584 mm (0.023 in.)
6067TK60	1998	12.7L	765A	0.584 mm (0.023 in.)
6067TK45	1998	12.7L	765A	0.584 mm (0.023 in.)
6067MK60	1998	12.7L	770	0.660 mm (0.023 in.)
6067BK60	1998	12.7L	770	0.660 mm (0.023 in.)
6067HKXX	1998 (Non-Line Haul)	14L	770	0.660 mm (0.023 in.)
6067MK28, 6067MK45, 6067MK57, 6067MK60	2000	12.7L Standard	790	0.660 mm (0.026 in.)
6067BK28, 6067BK45, 6067BK57, 6067BK60	2000	12.7L Premium	790	0.660 mm (0.026 in.)
6067HK45, 6067HK60	2000	14L U.S.	790A	0.660 mm (0.026 in.)
6067WK28, 6067WK60	2000	11.1L	790B	0.660 mm (0.026 in.)
6067LK28, 6067LK45, 6067LK60	2000	11.1L	790B	0.660 mm (0.026 in.)
6063GK60, 6067GK28, 6067GK45, 6067GK91, 6067PK62, 6067TK28, 6067TK60, 6067TK62	2000	12.7L	790B	0.660 mm (0.026 in.)
6067HK62	2000	14L Australian	790C	0.660 mm (0.026 in.)

All slave piston adjustments shown here are current as of the date of this manual and supersede all previous adjustments.

XXXX = Model numbers to be determined.

Table 1-9 Jake Brake® Model Information

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NOTE:
All engines built after serial number 06R0004455 have the correct engine parts for engine brake installation. The model numbers have changed because of design changes in the engine brakes.

NOTE:
All Series 60 engines with serial numbers 06R0004455 or higher are Jake Brake® ready. Do not install a Jake Brake® on engines with lower serial numbers.

Effective December 16,1999, Model 790 Jake Brakes® are used on all Series 60 engines requiring an engine brake.

Former Jake Brake® production models for the Series 60 engine were the 760A (which replaced model 760), 760B, 765, 765A, and 770.

Detroit Diesel engine model Nos. 6067GU28 and 6067GK28 are for bus/coach applications. Due to interference fits on some coach chassis, a two-housing Jake Brake® kit may be required. Contact your Detroit Diesel Distributor for information on these kits.

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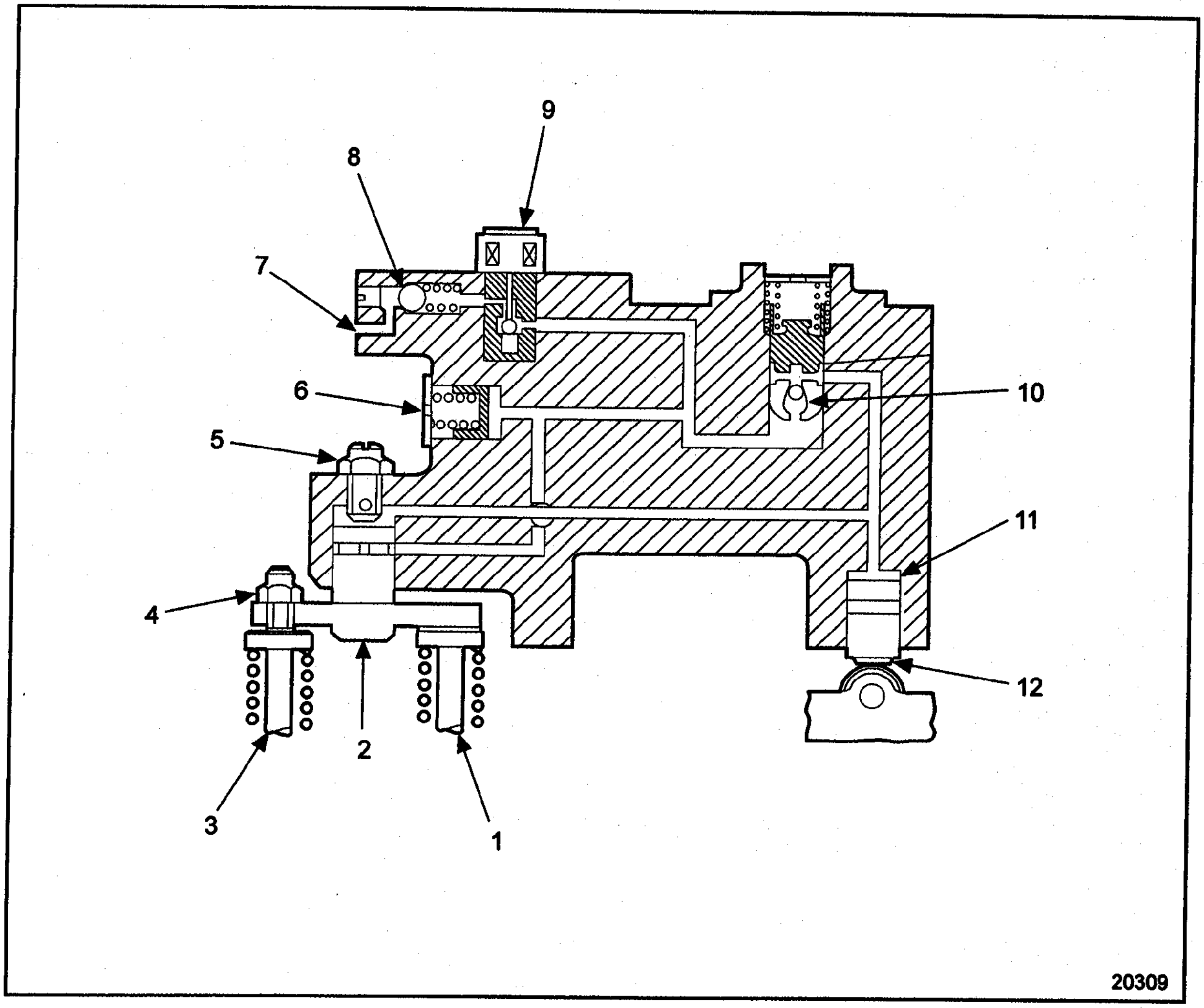
Energizing the engine brake effectively converts a power-producing diesel engine into a power-absorbing air compressor. This is accomplished through motion transfer using a master-slave piston arrangement which opens cylinder exhaust valves near the top of the normal compression stroke, releasing the compressed cylinder charge to exhaust. See Figure 1-426.



1. Exhaust Valve
2. Slave Piston Assembly
3. Exhaust Valve
4. Leveling Screw
5. Slave Piston Adjusting Screw
6. Accumulator
7. Oil In
8. Check Valve (Model 760)
9. Solenoid Valve
10. Control Valve
11. Master Piston
12. Injector Pin and Roller

Figure 1-426 Jake Brake® Schematic

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The blowdown of compressed air to atmospheric pressure prevents the return of energy to the engine piston on the expansion stroke, the effect being a net energy loss, since the work done in compressing the cylinder charge is not returned during the expansion process.

Exhaust blowdown occurs as the energized solenoid valve permits engine lube oil to flow under pressure through the control valve to both the master piston and the slave piston. See Figure 1-426.

Oil pressure causes the master piston to move down, coming to rest on the injector rocker arm roller.

The injector rocker arm begins its travel as in the normal injection cycle, moving the master piston upward and directing high-pressure oil to the slave piston. The ball check valve in the control valve traps high-pressure oil in the master-slave piston system.

High pressure oil causes the slave piston to move down, momentarily opening the exhaust valves, while the engine piston is near its top-dead-center position, releasing compressed cylinder air to the exhaust manifold.

At the bottom of its stroke, the slave piston separates from the valve in the slave piston adjusting screw, allowing high pressure oil to flow into the accumulator. This reduces the pressure in the high pressure circuit, permitting the slave piston to retract and the exhaust valves to close in preparation for the normal exhaust valve cycle. The oil pressure reserved in the accumulator ensures that the hydraulic circuit is fully charged for the next cycle. Compressed air escapes to the atmosphere, completing a compression braking cycle.

The Jake Brake® is electronically controlled. Jake Brake® control system wiring will vary depending on the vehicle manufacturer. For a general overview of the Jake Brake®, see Figure 1-427 and see Figure 1-428.

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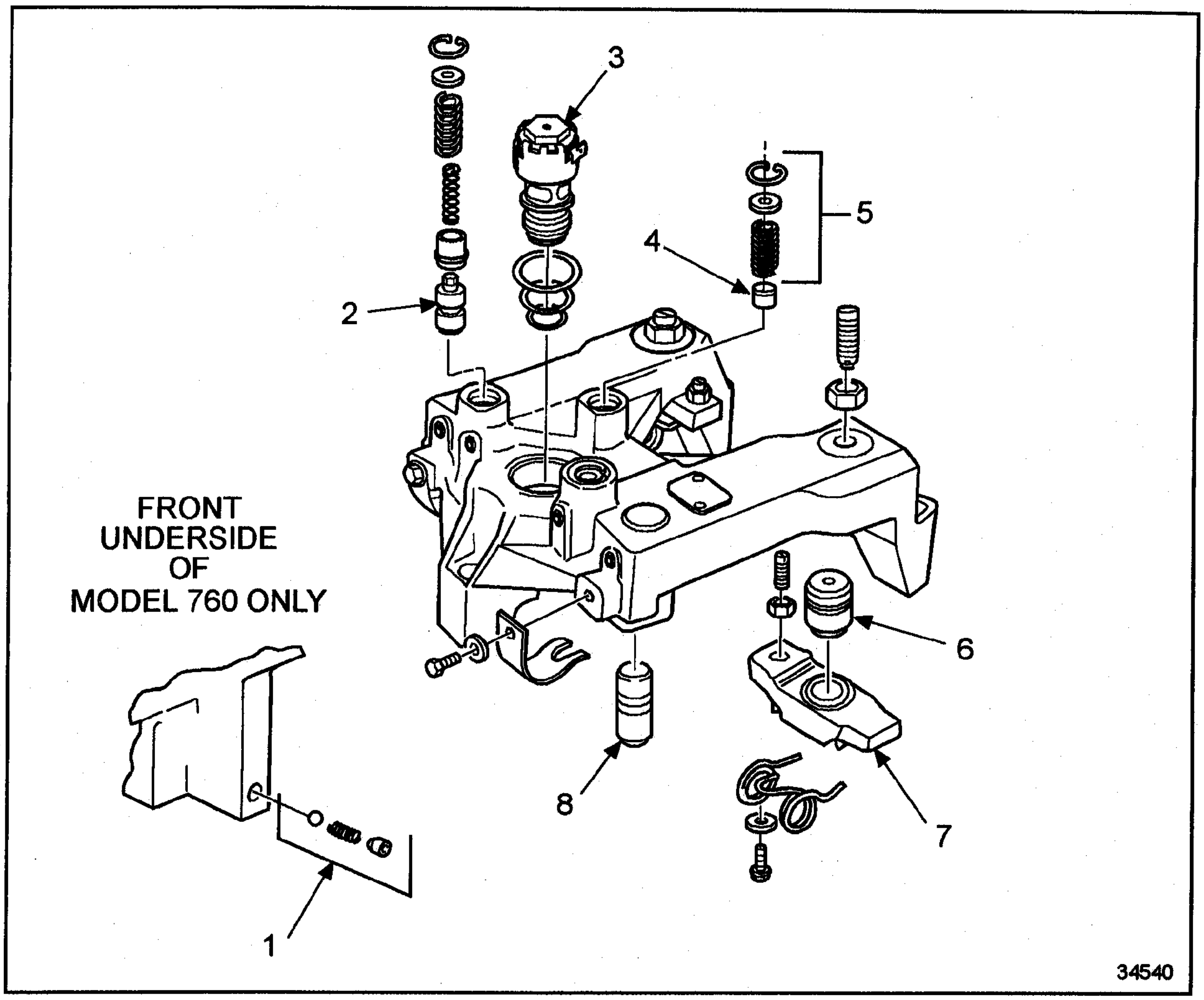

1. Ball Check Valve (Model 760 Only)
2. Control Valve
3. Solenoid Valve
4. Accumulator Piston
5. Power Lash Assembly
6. Slave Piston
7. Bridge
8. Master Piston

Figure 1-427 Typical Model 760, 765, or 770 Jake Brake® Assembly

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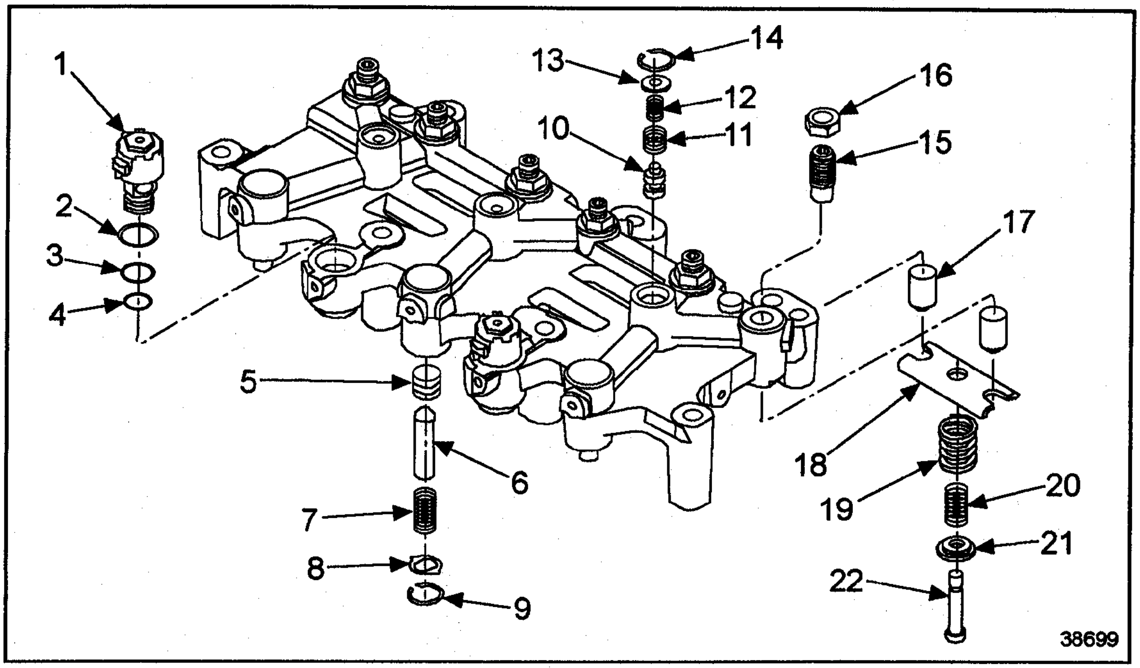

1. Solenoid Valve
2. Upper Seal
3. Center Seal
4. Lower Seal
5. Master Piston
6. Master Piston Pushrod
7. Master Piston Spring
8. Washer
9. Retaining Ring
10. Control Valve
11. Outer Control Valve Spring
12. Inner Control Valve Spring
13. Washer
14. Retaining Ring
15. J-Lash® Screw
16. Locknut
17. Slave Piston
18. Slave Piston Bridge
19. Outer Slave Piston Spring
20. Inner Slave Piston Spring
21. Slave Piston Spring Seat
22. Shoulder Bolt

Figure 1-428 Typical Model 790 Jake Brake® Assembly

NOTICE:
This application and adjustment information must be strictly followed. Failure to follow these instructions may result in serious engine or engine brake damage.

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1.29.1 Repair or Replacement of Jake Brake®

To determine if repair is possible or replacement is necessary, perform the following procedure. See Figure 1-429.

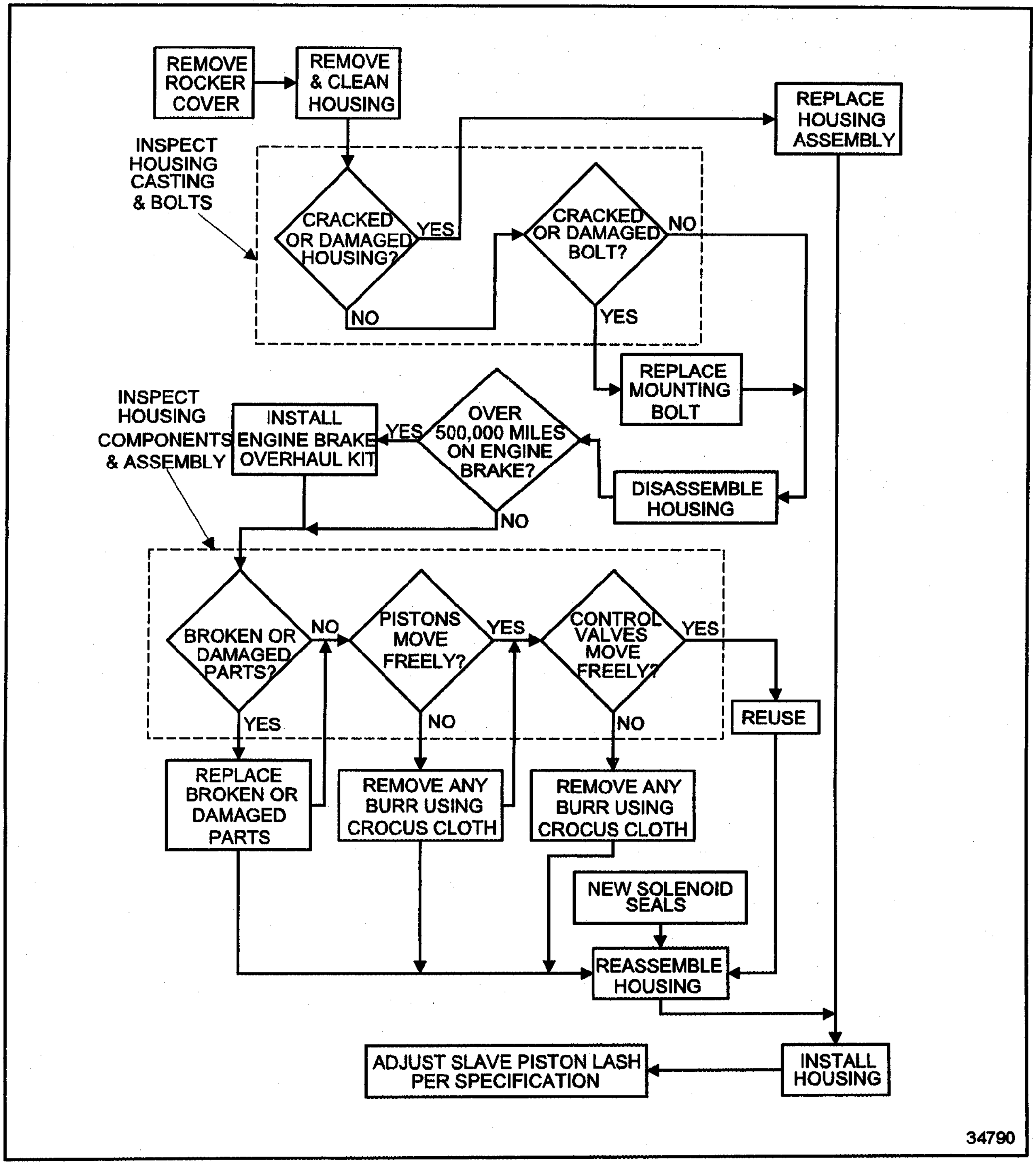

Figure 1-429 Jake Brake® Repair or Replacement Flowchart

1.29.2 Removal of Model 760, 765, or 770 Jake Brake®

Remove the model 760, 765, or 770 Jake Brake® as follows:

NOTE:
The following procedures apply to Model 760, 765, and 777 Jake Brakes®. For Model 790 Jake Brake® removal procedures, refer to section 1.29.6.

CAUTION:

To avoid injury, never remove any engine brake component with engine running.

1. Disconnect starting power for engine. Refer to OEM guidelines.
2. Remove the engine rocker cover. Refer to section 1.6.2 for one-piece, refer to section 1.6.3 for two-piece and refer to section 1.6.5 for three-piece.

NOTE:
If the engine is equipped with an aluminum two-piece valve cover, remove only the upper valve cover when installing the engine brake.

3. Note the location of the rocker arm shaft, the exhaust valve rocker arm, the fuel injector rocker arm, and the intake valve rocker arm.
4. Disconnect the solenoid wiring harness connectors from the engine brake solenoids. See Figure 1-430.

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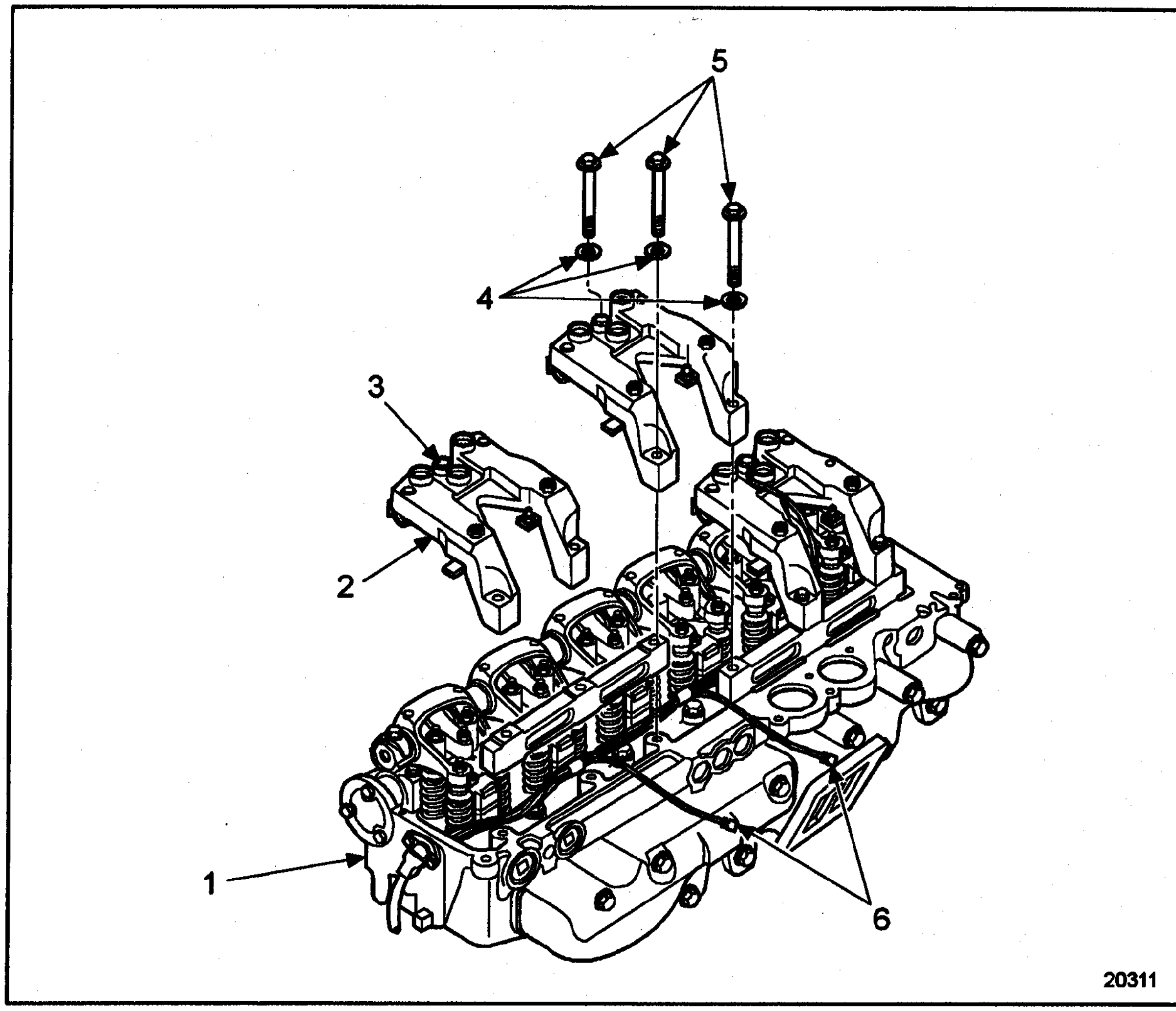


1. Cylinder Head
2. Jake Brake® Assembly
3. Solenoid
4. Washers (3 each)
5. Mounting Bolts (3 each)
6. Engine Brake Harness

Figure 1-430 Jake Brake® Assembly

5. Remove the nine mounting bolts and washers that secure the engine brake assemblies to the cylinder head. See Figure 1-430.

NOTE:
Only the Model 760 Jake Brake® uses two different length mounting bolts. Six bolts, 120 mm (4.72 in.) long, are used on the exhaust side of the engine. Three bolts, 110 mm (4.33 in.) long, are used on the intake side of the engine. These bolts must be reinstalled in their correct positions.

6. Remove the engine brake assemblies and the spacer bar.

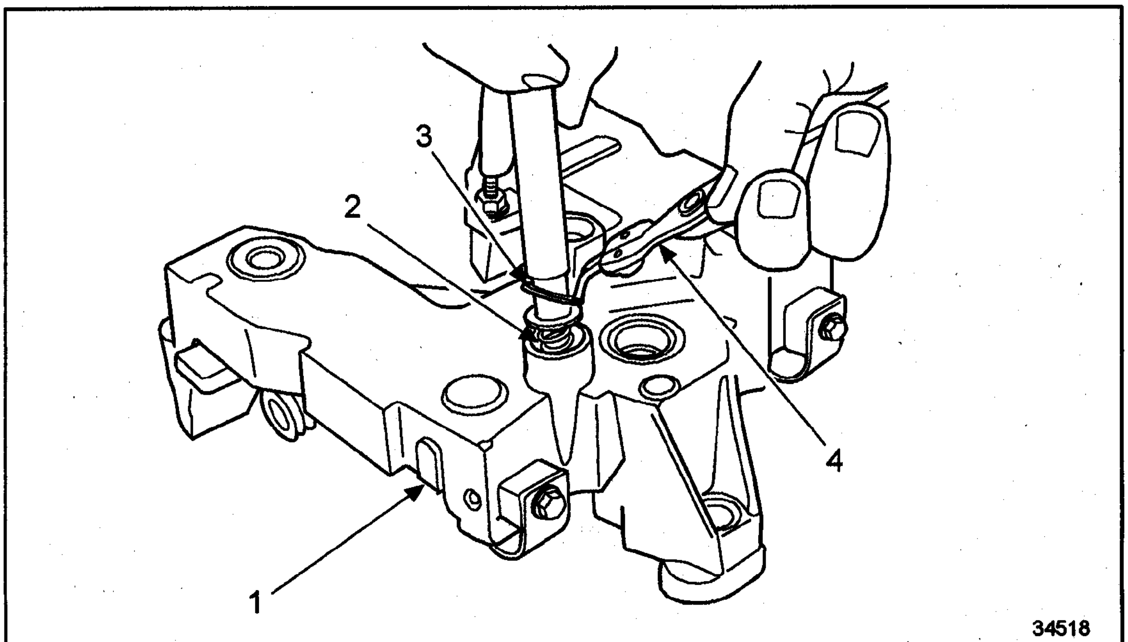
1.29.3 Disassembly of Model 760, 765, or 770 Jake Brake®

Remove the control valve as follows:

CAUTION:

To avoid injury from flying parts when working with components under spring tension, wear adequate eye protection (face shield or safety goggles).

1. Press down on control valve washer using an appropriate diameter rod to relieve spring pressure. See Figure 1-431.



1. Jake Brake® Assembly
2. Spring
3. Snap Ring Retainer
4. Snap Ring Pliers

Figure 1-431 Relieving Spring Pressure

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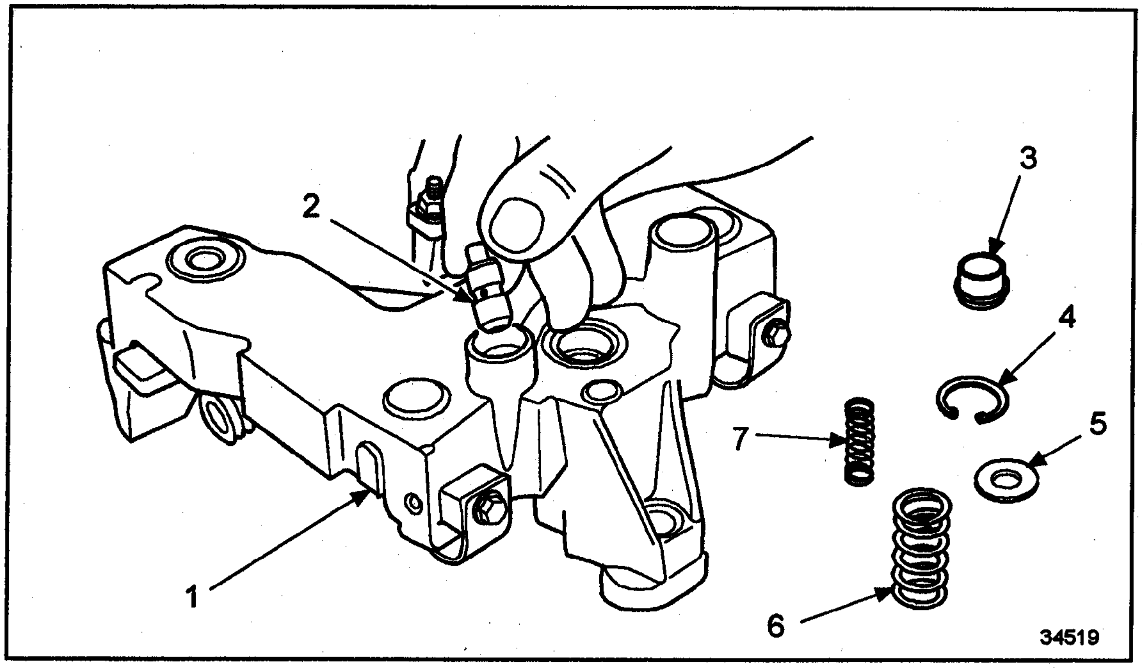
2. Using retaining ring pliers, remove retaining ring.
3. Slowly remove cover until spring pressure ceases, then remove the two control valve springs and collar. See Figure 1-432.



1. Jake Brake® Assembly
2. Control Valve
3. Collar
4. Snap Ring Retainer
5. Washer
6. Collar Spring
7. Control Valve Spring

Figure 1-432 Removing Control Valve Springs and Collar

4. Using needle-nose pliers, reach into the bore and grasp the stem of the control valve. Remove control valve.

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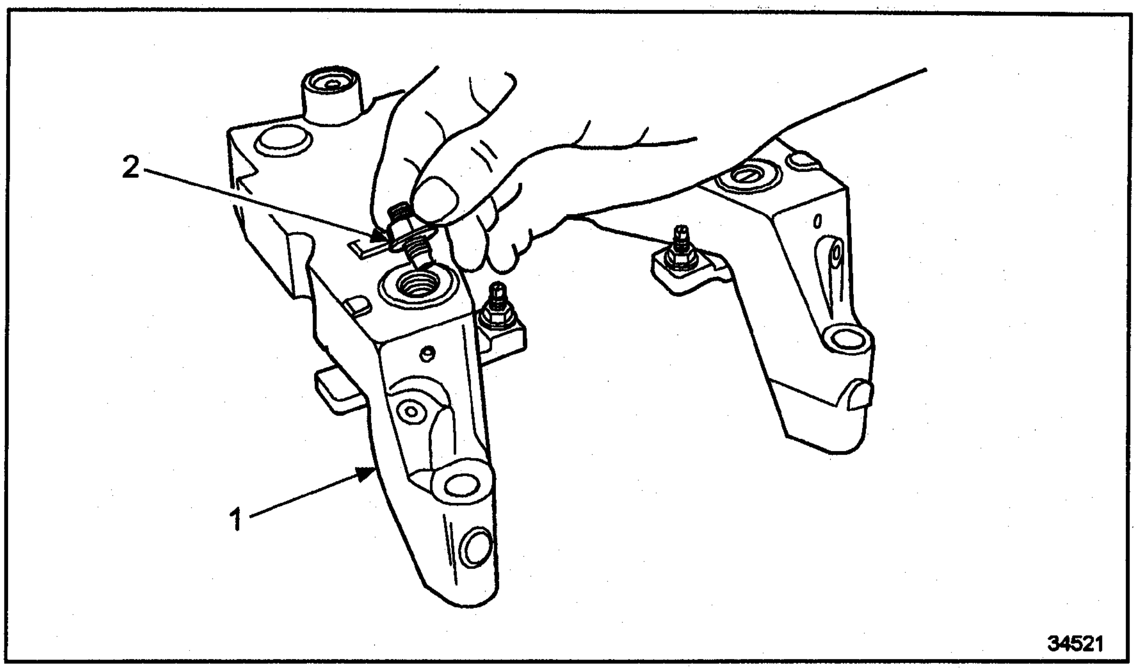
Remove the slave piston adjusting screw as follows:

1. Loosen slave piston adjusting screw locknut.
2. Remove adjusting screw from housing. See Figure 1-433.



1. Jake Brake® Assembly
2. Slave Piston Adjusting Screw

Figure 1-433 Removing Slave Piston Adjusting Screw

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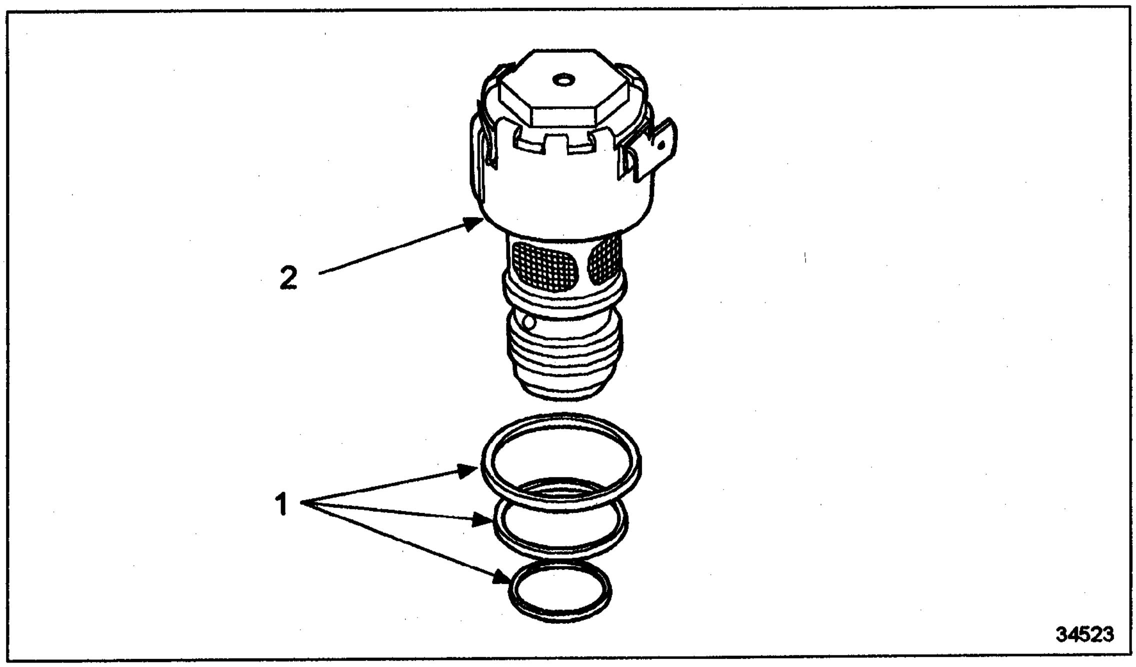
Remove the solenoid valve as follows:

NOTICE:
To avoid possible engine damage, do not disassemble or tamper with the solenoid valve.

1. Disconnect solenoid valve harness.
2. Using a 7/8 in. socket and extension for former solenoids or a 3/4 in., 6 point socket and extension for current solenoids, unscrew solenoid valve.
3. Remove and discard the three rubber seal rings. See Figure 1-434.



1. Seal Rings (3)
2. Solenoid

Figure 1-434 Removing Rubber Seal Rings

4. If the lower ring stays in the bottom of the housing bore, remove with a piece of wire.

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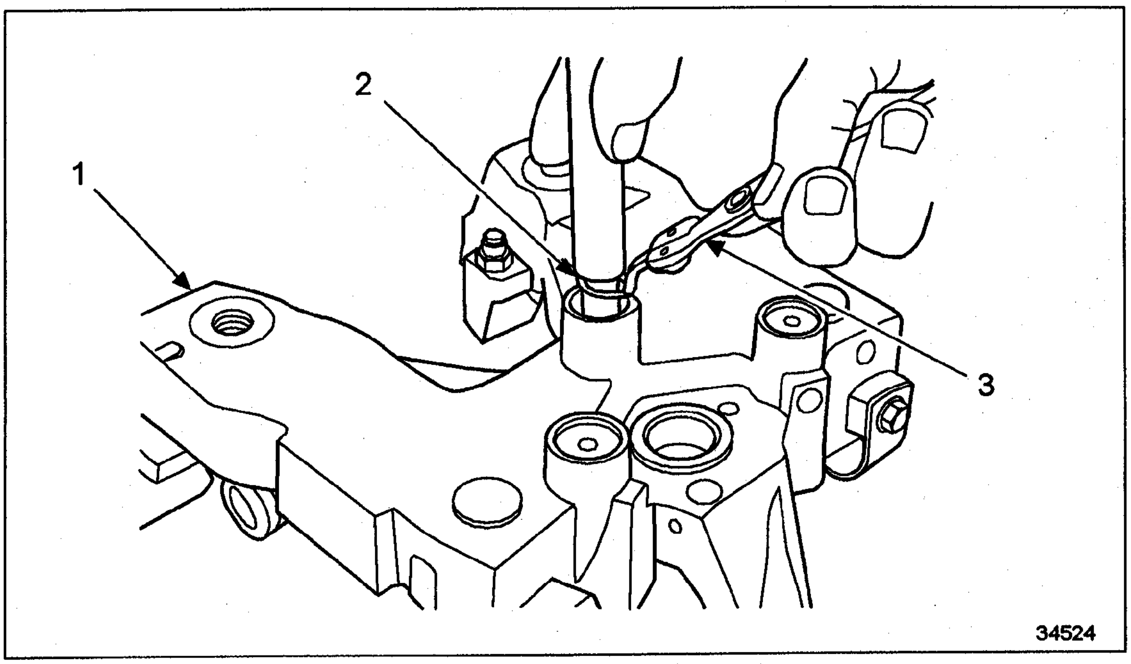
Remove the accumulator as follows:

CAUTION:

To avoid injury from flying parts when working with components under spring tension, wear adequate eye protection (face shield or safety goggles).

1. Push down on the accumulator cover using the appropriate diameter rod, and remove the retaining ring. See Figure 1-435.



1. Jake Brake® Assembly
2. Retaining Ring
3. Retaining Ring Pliers

Figure 1-435 Removing Retaining Ring

2. Relieve pressure on the accumulator cover.
3. Remove the cover and spring.

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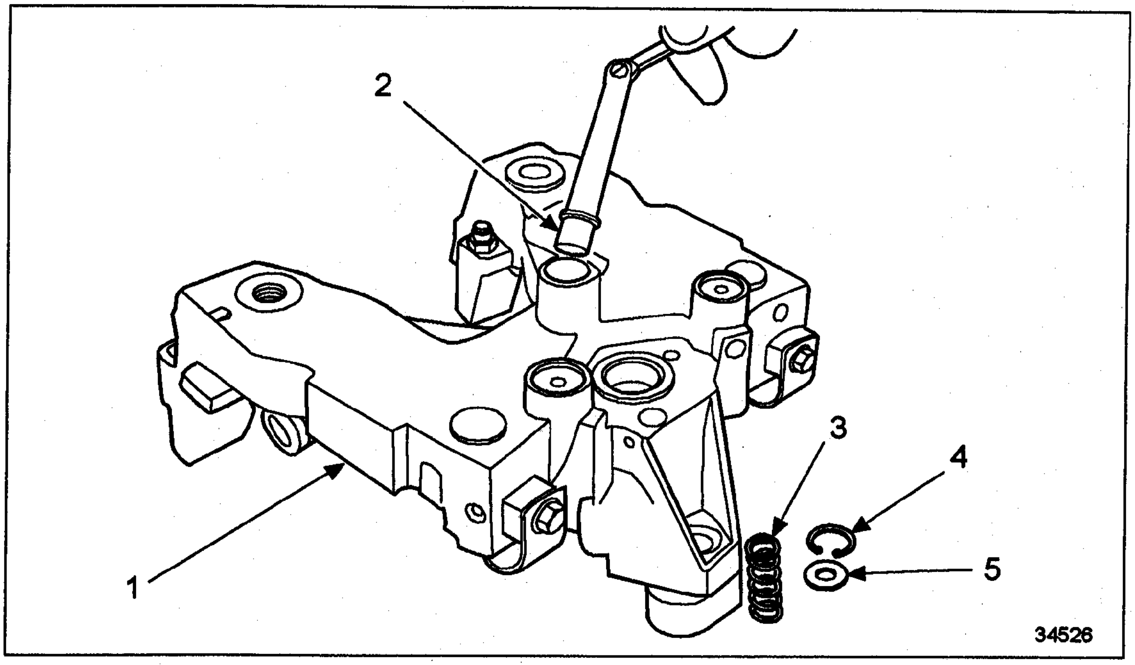
4. Use a magnet to remove the piston from the accumulator bore. See Figure 1-436.



1. Jake Brake® Assembly
2. Piston
3. Spring
4. Retaining Ring
5. Washer

Figure 1-436 Removing Piston from Accumulator Bore with Magnet

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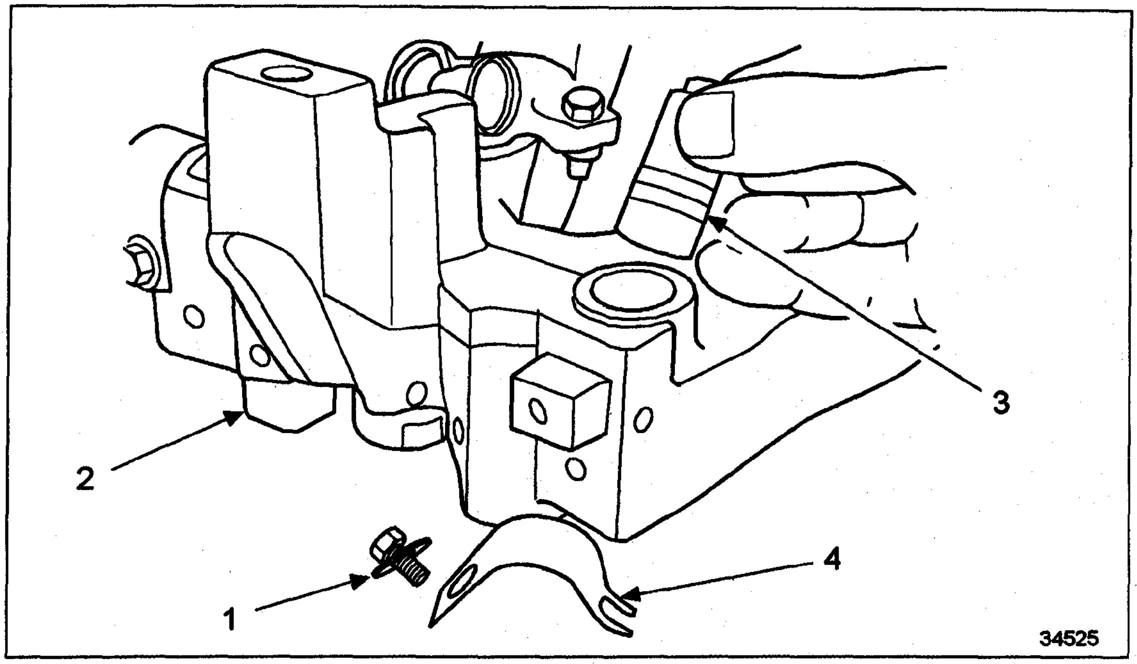
Remove the master piston as follows:

1. Remove the screw, washer, and master piston spring from the housing.
2. Remove the master piston. See Figure 1-437.

NOTE:
Use needle-nose pliers, if necessary.



1. Washer and Screw Assembly
2. Jake Brake® Assembly
3. Master Piston
4. Master Piston Spring

Figure 1-437 Removing The Master Piston

On Model 760 only, remove the ball check valve as follows:

1. Remove the plug.
2. Remove the ball check valve and spring.

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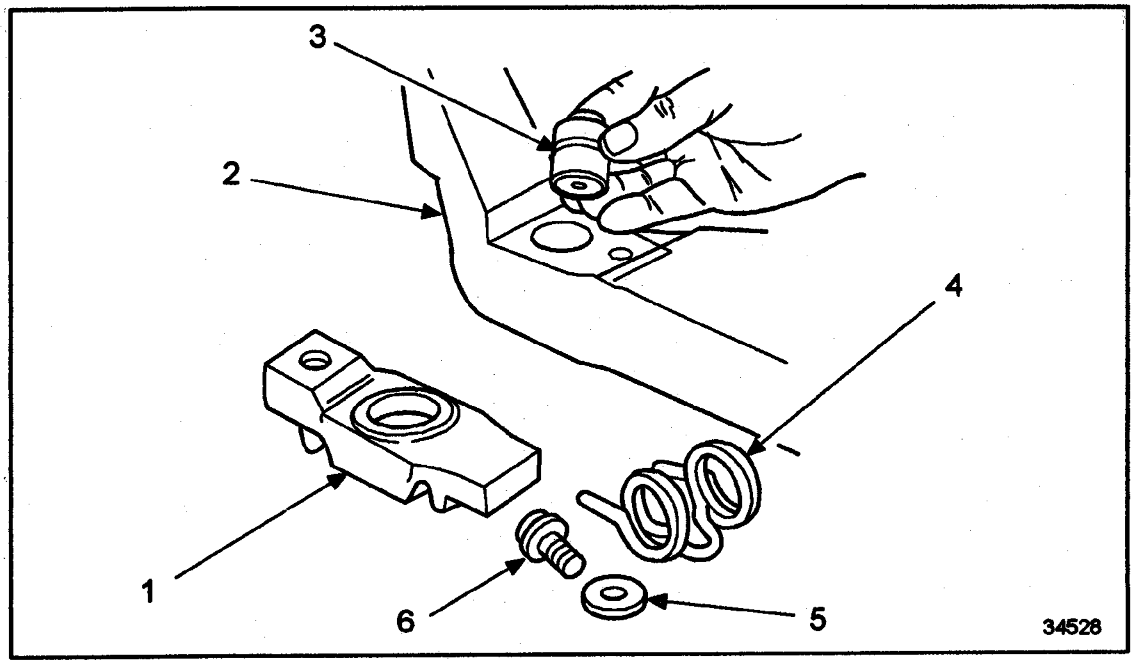
Remove the slave piston as follows:

1. Remove the screw and spring that retains the slave piston return spring.
2. Remove the bridge and the slave piston. See Figure 1-438.



1. Slave Piston Bridge
2. Jake Brake® Housing
3. Slave Piston
4. Return Spring
5. Washer
6. Screw

Figure 1-438 Removing Bridge and Slave Piston

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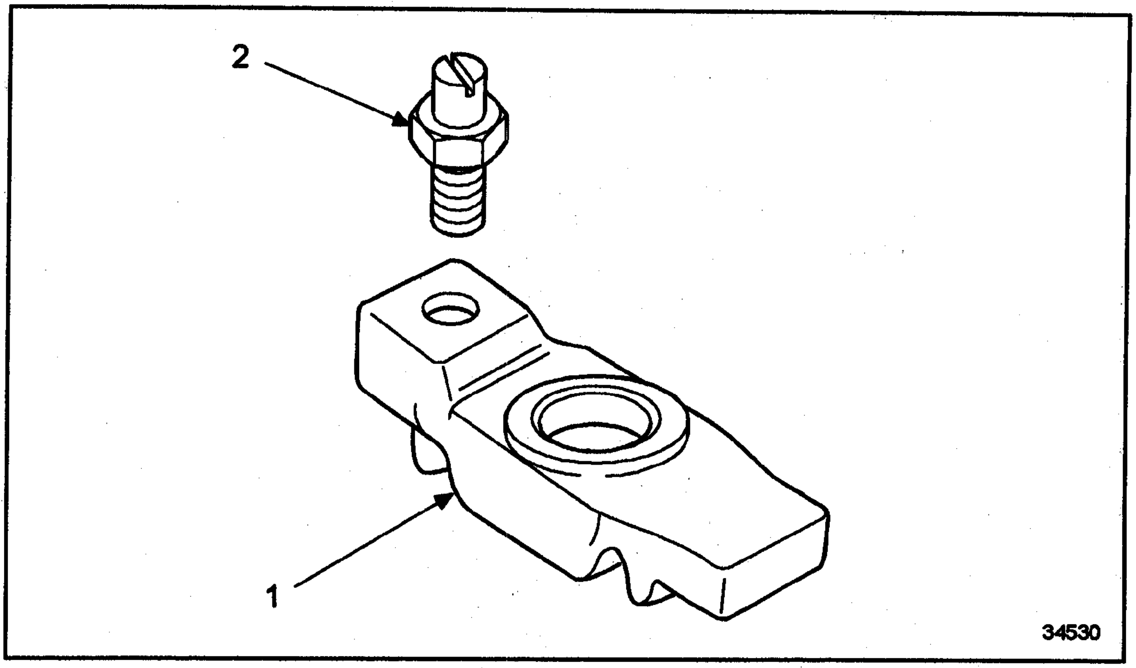
3. Loosen the leveling screw locknut and remove the leveling screw from the bridge. See Figure 1-439.



1. Slave Piston Bridge
2. Slave Piston Leveling Screw

Figure 1-439 Removing the Leveling Screw from the Bridge

The injector rocker arm contains a pin and roller for actuating the engine brake master piston. If excessive wear or damage to the roller is present, replace the rocker arm assembly. Refer to section 1.6.2

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1.29.3.1 Cleaning of Model 760, 765, or 770 Jake Brake®

Clean the Jake Brake® as follows:

NOTE:
Use an OSHA-approved cleaning solvent when washing parts. Be sure to coat parts with clean engine oil when reinstalling them.

1. Wash the control valves with approved cleaning solvent.
2. Push a wire through the hole in the base of the valve to the distance required to ensure that the ball check is free.

NOTE:
The ball should lift with light pressure on the wire.

CAUTION:
To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

3. Dry the valve with compressed air, and wipe clean with a paper towel.
4. Thoroughly clean the control valve bore in the housing using clean paper towels.
5. Clean slave piston adjusting screw in an approved cleaning solvent.
6. Clean out the solenoid valve bore in the housing.

NOTICE:
Use clean paper towels to clean the solenoid valve bore. Never use rags, as they may leave lint and residue which can plug the oil passageways, causing Jake Brake® malfunction.

7. Clean the master piston in approved cleaning solvent.

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1.29.3.2 Inspection of Model 760, 765, or 770 Jake Brake®

The Jacobs engine brake is typically a trouble-free device. However, inspections are necessary and some maintenance is required. Use the following procedures to keep the engine brake in top condition.

Inspect the Jake Brake® as follows:

1. Inspect slave piston adjusting screw for protrusion, spring pressure and freedom of movement.

NOTE:
The plunger should protrude from the bottom of the screw, have light spring pressure apparent when depressed, and move freely. Be sure the retaining ring is fully engaged in its groove (groove is located on the bottom of the reset screw and top of the POWER-LASH assembly).

   [a] If the plunger does not protrude, the spring does not have light pressure or does not move freely, replace the entire screw assembly. Refer to section 1.29.4

   [b] If the slave piston adjusting screw meets specifications, continue with inspection.

2. Inspect the accumulator for wear or damage.

   [a] If worn or damaged, replace the accumulator. Refer to section 1.29.4.

   [b] If accumulator is not worn or damaged, continue with inspection.

3. Inspect the master piston bore for wear or damage.

NOTE:
Some wear marks are permissible.

   [a] If worn or damaged, replace the master piston. Refer to section 1.29.4.

   [b] If not worn or damaged, continue with inspection.

4. Apply clean lube oil to the piston, and insert into bore.

NOTE:
Master piston should move in and out freely with no binding.

   [a] If binding occurs, replace master piston and/or housing. Refer to section 1.29.4.

   [b] If no binding occurs, continue with inspection.

5. Inspect master piston spring for relaxation.

NOTE:
The spring should hold the master piston completely in the housing.

   [a] If relaxed, replace the spring. Refer to section 1.29.4.

   [b] If spring holds tightly, continue with inspection.

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6. Inspect the ball check valve (Model 760 only) for wear or damage.
   [a] If worn or damaged, replace ball check valve. Refer to section 1.29.4.
   [b] If not worn or damaged, proceed with inspection.
7. Inspect slave piston components for excessive wear or damage.
   [a] If worn or damaged, replace slave piston component.
   [b] If not worn or damaged, proceed with inspection.

1.29.3.3 Inspection of Control Valve

Inspect the control valve as follows:

1. Dip the control valves in clean lube oil.
2. Holding the control valve by the stem, let it drop into the bore.
   [a] If binding occurs or if the ball sticks in the valve, replace the control valve. Refer to section 1.29.4.
   [b] If no binding occurs and the ball does not stick in the control valve, assemble the Jake Brake®. Refer to section 1.29.4.

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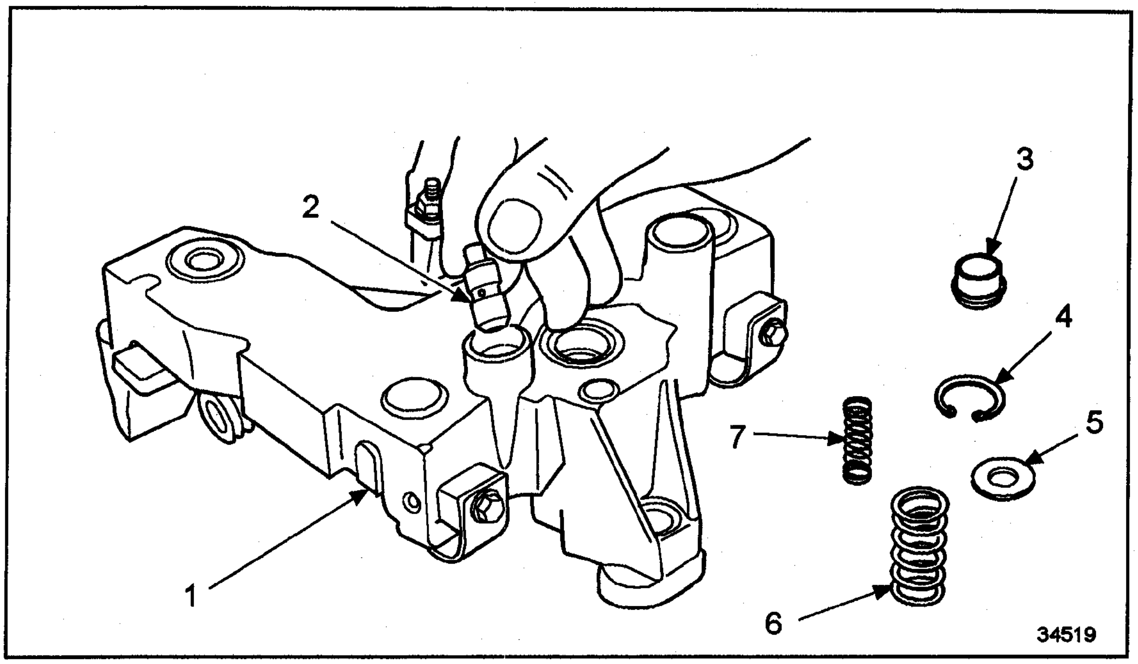
1.29.4 Assembly of Model 760, 765, or 770 Jake Brake®

Install the control valve as follows:

1. Slip the control valve into the bore. See Figure 1-440.

NOTE:
Make sure the control valve collar is installed with the longer sleeve area facing up. If the collar is installed upside down, the engine brake cylinder will not operate.



1. Jake Brake® Assembly
2. Control Valve
3. Collar
4. Snap Ring Retainer
5. Washer
6. Collar Spring
7. Control Valve Spring

Figure 1-440 Installing the Control Valve

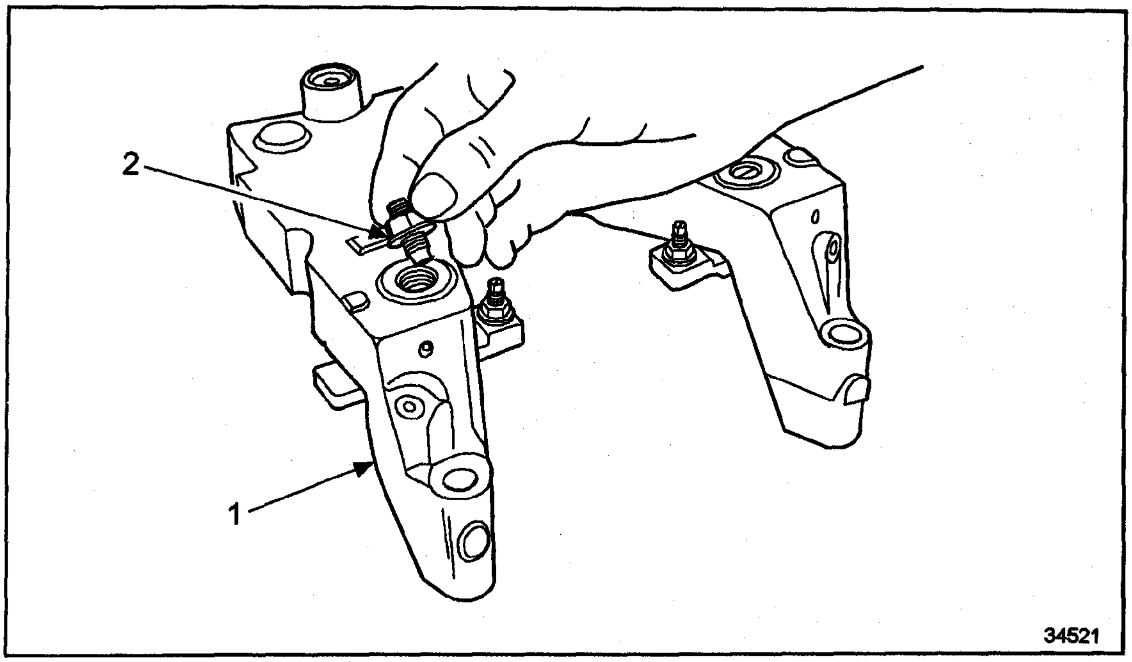
2. Install the control valve collar and two springs.

NOTE:
Ensure the collar is installed with the longer sleeve area facing up. If the collar is installed upside down, the engine brake cylinder will not operate.

3. Press the cover (washer) into place.
4. While holding the cover tightly in place, install the retaining ring.
5. Rotate retaining ring ears 90 degrees to assure ring is seated in groove.

Install the slave piston adjusting screw as follows:

1. Place the screw in the housing. See Figure 1-441.



1. Jake Brake® Assembly
2. Slave Piston Adjusting Screw

Figure 1-441 Installing the Slave Piston Adjusting Screw

2. Torque the slave piston adjusting screw locknut to 35 N·m (25 lb·ft).

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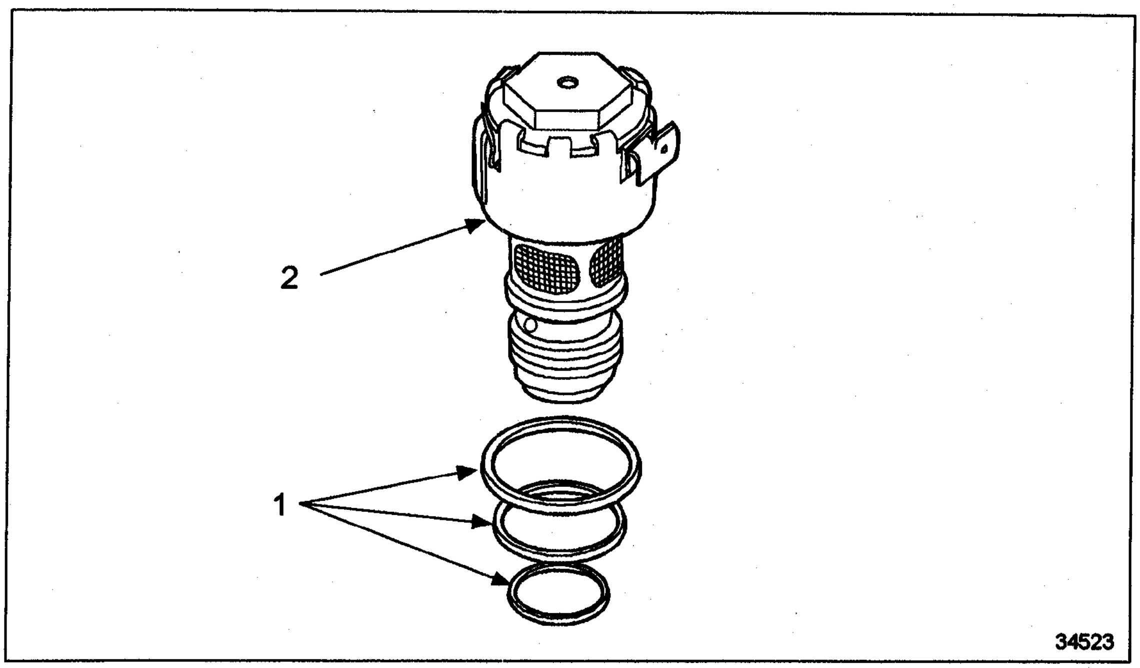
Install the solenoid valve as follows:

NOTE:
As of October 19, 1997, former solenoids have been replaced with the current improved solenoids. The current solenoids have an increased installation torque and improved durability. The current solenoid is interchangeable with the former.

1. Coat new solenoid valve seal rings with clean lube oil.

NOTE:
Use current upper seals when installing current solenoids. New seals are identified with yellow stripes.

2. Install the upper and center seal rings on the solenoid valve body and the lower seal ring into the bottom of the bore in the housing. See Figure 1-442.



1. Seal Rings (3)
2. Solenoid

Figure 1-442 Installation of Solenoid Valve Seal Rings

3. Make sure the seals are seated properly.
4. Using a 7/8 in. socket and extension for former solenoids or a 3/4 in., 6 point socket and extension for current solenoids, carefully screw the solenoid valve into the housing without unseating the seals.

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5. Torque the former solenoid to 12.4 N·m (9 lb·ft). Torque the current solenoid to 20 N·m (15 lb·ft.)

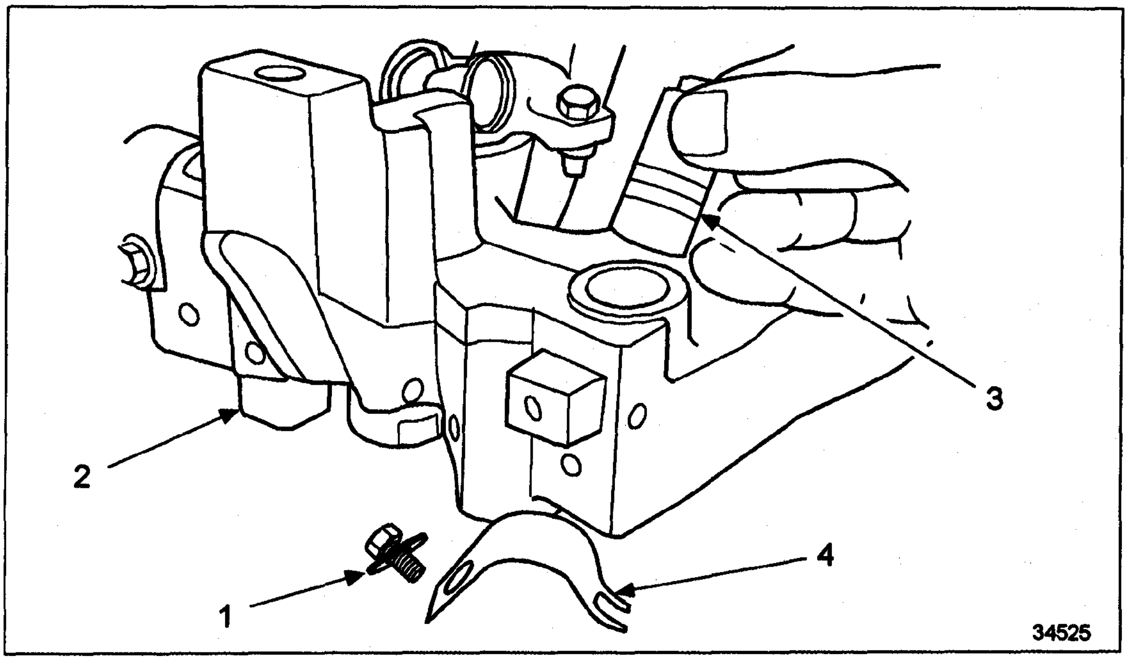
NOTE:
Be careful not to twist the seals while installing.

Install the accumulator as follows:

1. Place the piston into the accumulator bore.
2. Insert the spring, and install the cover.
3. Push down the accumulator cover, and insert retaining ring.

Install the master piston as follows:

1. Apply clean lube oil to the piston.
2. Insert master piston into bore. See Figure 1-443.



1. Washer and Screw Assembly
2. Jake Brake® Assembly
3. Master Piston
4. Master Piston Spring

Figure 1-443 Inserting Master Piston into Bore

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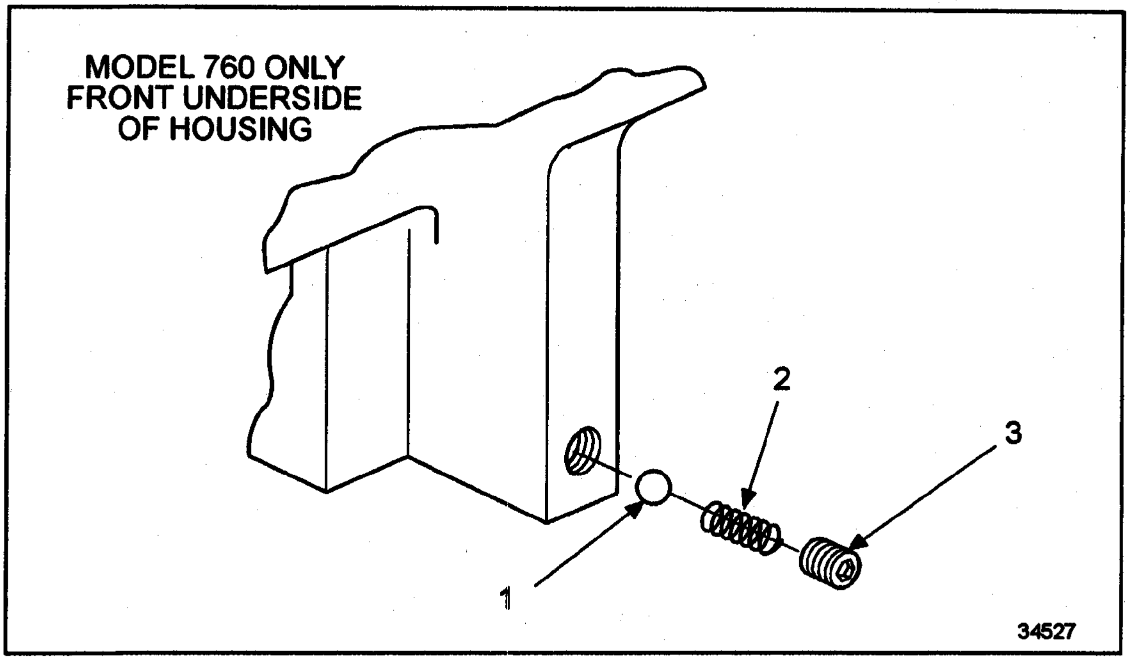
3. Install spring, washer, and screw.

NOTE:
Make sure spring legs are centered around master piston boss.

4. Torque screw to 10 N·m (7.4 lb·ft).

On model 760 only, install the ball check valve as follows:

1. Install the ball check valve and spring. See Figure 1-444.



1. Ball Check Valve
2. Spring
3. Pipe Plug

Figure 1-444 Installation of Ball Check Valve

2. Insert the plug. Torque pipe plug to 11.2 N·m (8.3 lb·ft).

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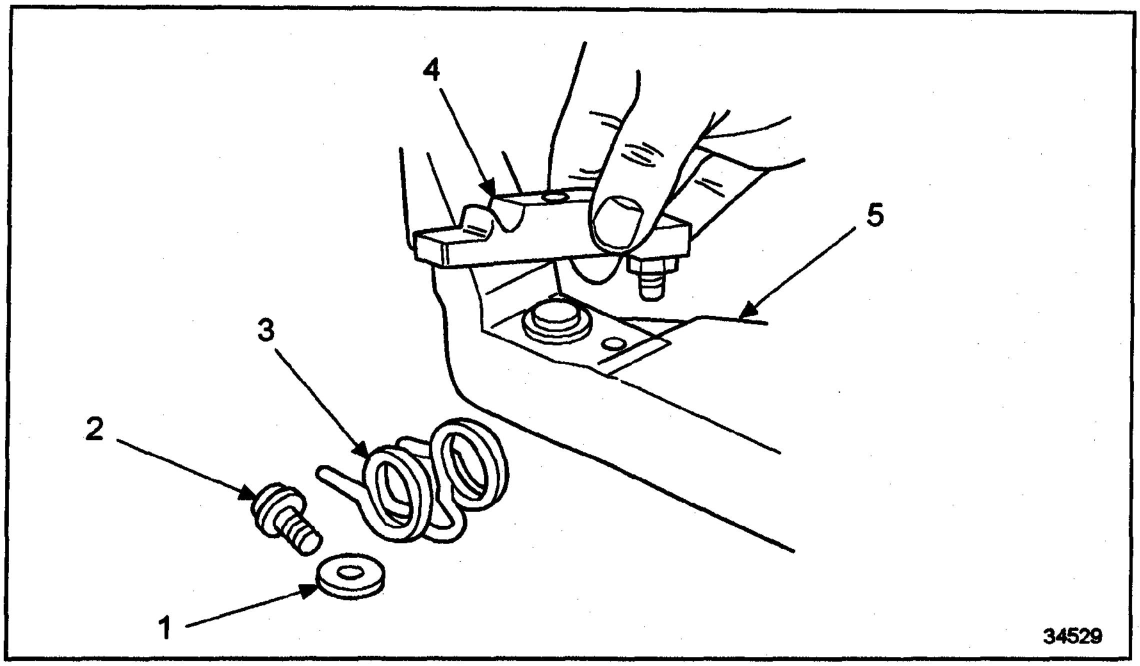
Install the slave piston as follows:

1. Install the screw from the slave piston side of the bridge.
2. Install the leveling screw locknut.
3. Install the bridge with the leveling screw toward the center of the housing. See Figure 1-445.



1. Washer
2. Screw
3. Torsion Spring
4. Bridge Assembly
5. Jake Brake® Housing

Figure 1-445 Installing Bridge with Leveling Screw Toward Center of Housing

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4. Install the slave piston assembly torsion spring with the ends over the bridge. See Figure 1-446.

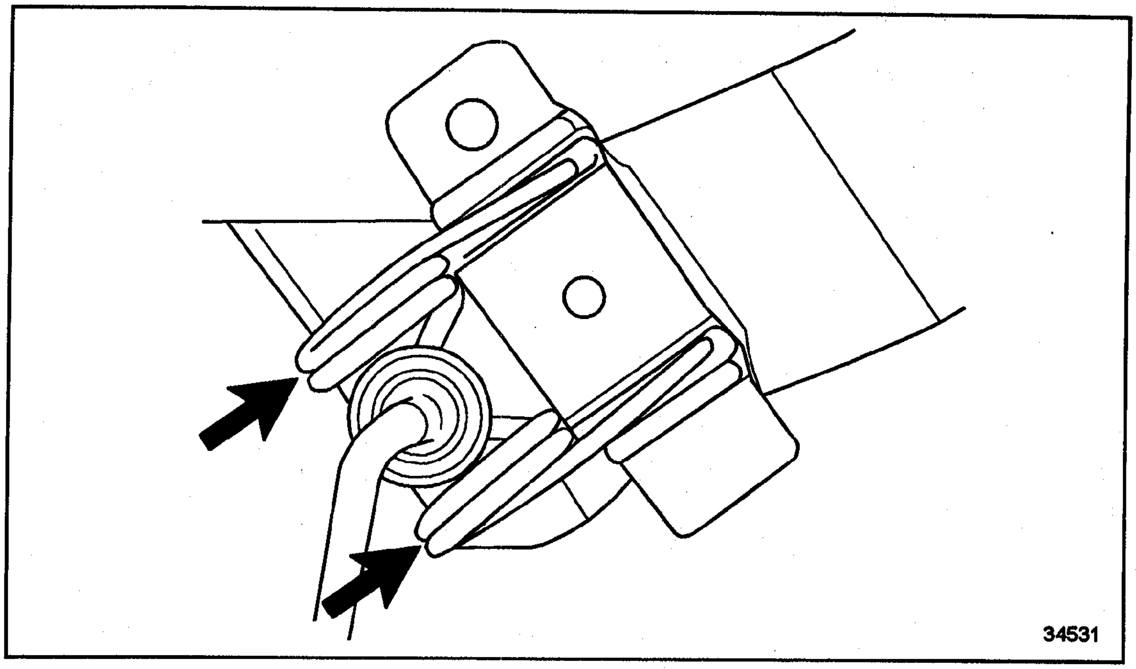

Figure 1-446 Installing the Slave Piston Assembly Torsion Spring

5. Install the screw over the center part of the spring.

NOTICE:
While tightening the screw on the torsion spring, push the spring toward the slave piston assembly. Failure to do so may result in contact between the intake valve adjusting screw and torsion spring. Serious engine damage may result.

6. Torque the screw to 20 N·m (15 lb·ft.).
7. Torque the slave piston leveling screw locknut to 47 N·m (35 lb·ft.).

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1.29.5 Installation of Model 760, 765, or 770 Jake Brake®

Install the model 760, 765, or 770 Jake Brake® as follows:

NOTE:
The following procedures apply to Model 760, 765, and 770 Jake Brakes®. For Model 790 Jake Brake® installation procedures, refer to section 1.29.10.

1. Adjust the intake and exhaust valve clearances and set the injector heights. Refer to section 12.2.

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

2. Attach the length of tubing to a blow gun nozzle, and blow out the oil from the bolt holes.
3. Cover the holes with hand towels to minimize oil spray.

NOTE:
Removing the oil from the bolt holes prevents the cylinder head from cracking when tightening the bolts.

4. Place the spacer bar on the exhaust manifold side of the cylinder head with the "OUT" markings adjoining each other and facing the exhaust manifold. See Figure 1-447, and see Figure 1-448.

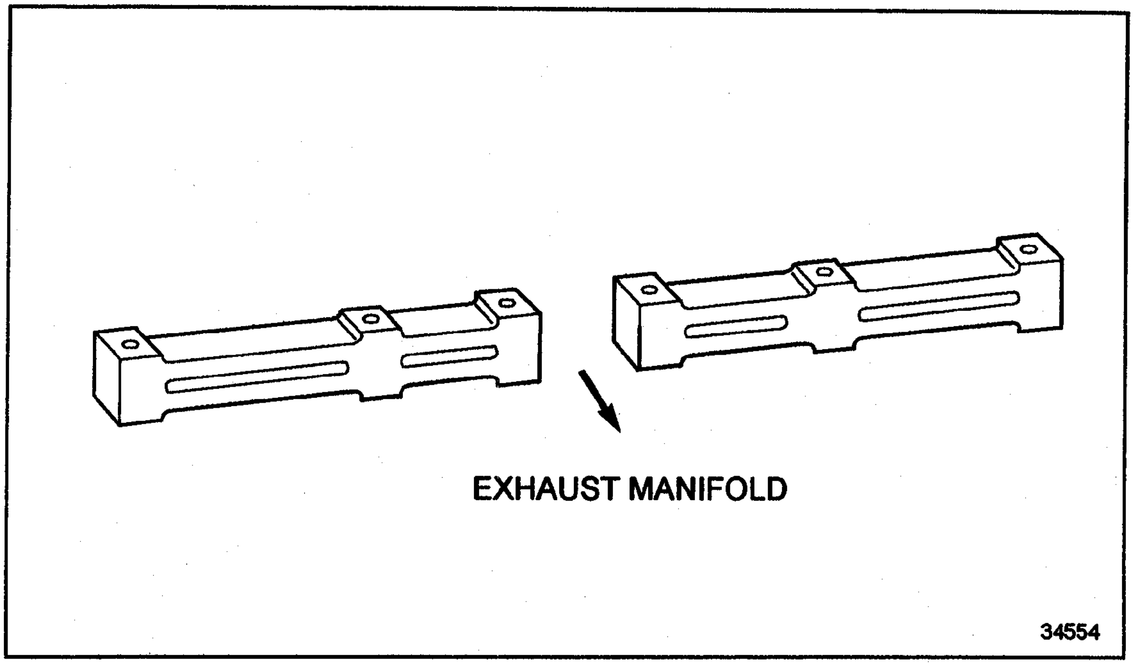

Figure 1-447 Spacer Bars with "Out" Marks Adjoined

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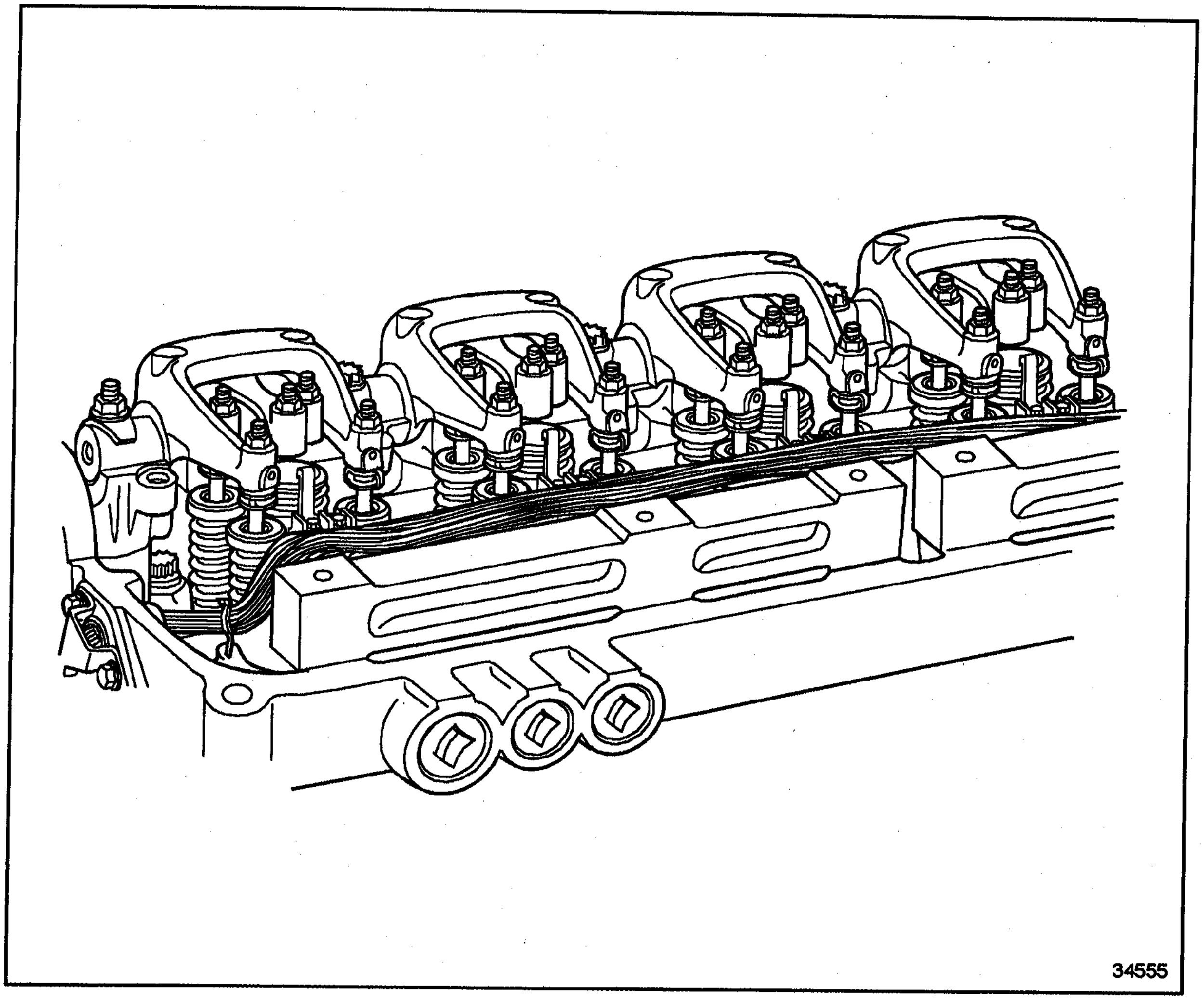

Figure 1-448 Location of Spacer Bars

5. Place the three engine brake housings over the rocker shafts with the solenoid valves toward the camshaft side of the engine.

NOTE:

Be sure housings do not interfere with wiring harness.

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NOTICE:
Do not mix the rocker arm shaft bolts and the Jake Brake® mounting bolts. If the rocker arm shaft bolt is mistakenly used to mount the Jake Brake® housing, the longer shoulder on the bolt will block the oil supply to the Jake Brake® on the camshaft side of the housing. The brake will not retard the engine as designed. This condition could cause loss of vehicle braking control on downgrades, which may create a risk of personal injury to the vehicle operator or other persons and damage to the vehicle or property of others.

NOTE:
The rocker arm shaft mounting bolt and Jake Brake® mounting bolt, part of the Jake Brake® assembly, are similar in appearance. Both are M12 x 110 mm (4.33 in.) long and have 12–point heads.

NOTE:
In the event of a housing hold down bolt failure on a Jacobs engine brake housing, replace all bolts on that particular housing.

NOTICE:
Use bolts that have the Jacobs logo, circled "J". Installation of bolts that do not have the circled "J" may result in damage to the engine, engine brake or both.

[a] The Jake Brake® bolt has the Jacobs logo (circled "J") and the letters "EF" marked on the head. The bolt length is no longer marked atop the bolt head.

[b] The DDC rocker arm shaft bolt has the DDC logo (spinning arrows) and the vendor I.D. (F-C) on its head.

[c] Jake Brake® model 760 requires two bolts along with one bolt and new washers.

NOTE:
Be sure that only Jake Brake® bolts, see Figure 1-449, are installed in the Jake Brake® housing.

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[d] The DDC bolt shoulder is much longer, 17.0 mm (0.669 in.) versus 4 mm (0.157 in.) than the Jake Brake® bolt. See Figure 1-449.

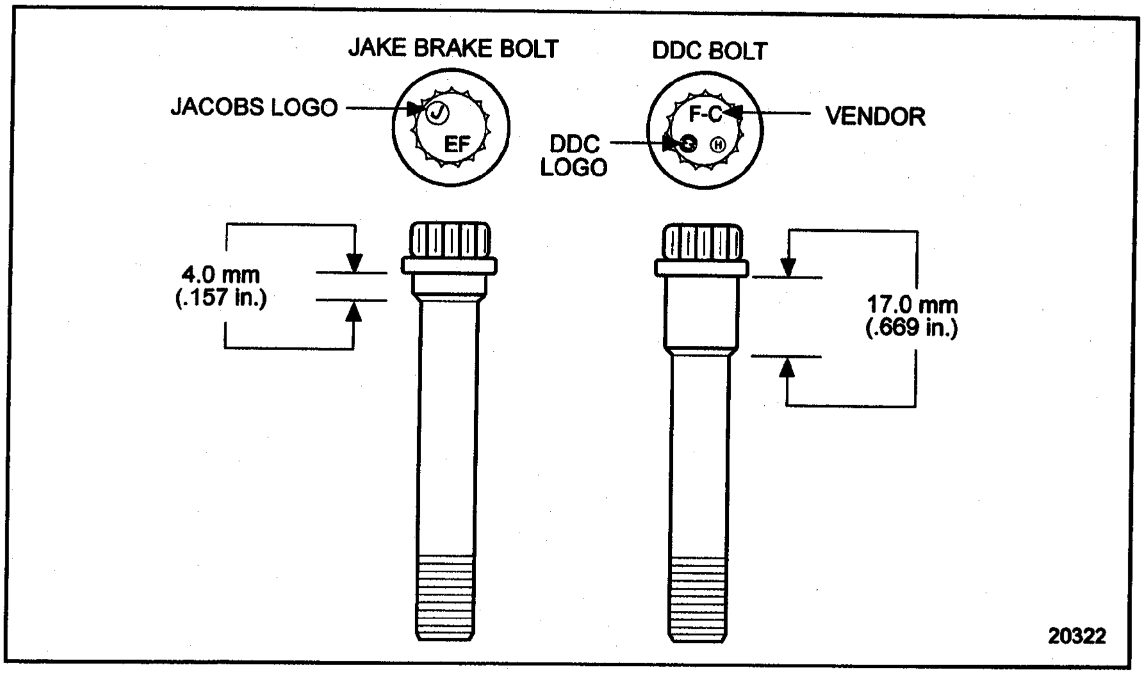

Figure 1-449 Jake Brake® and DDC Bolt Identification

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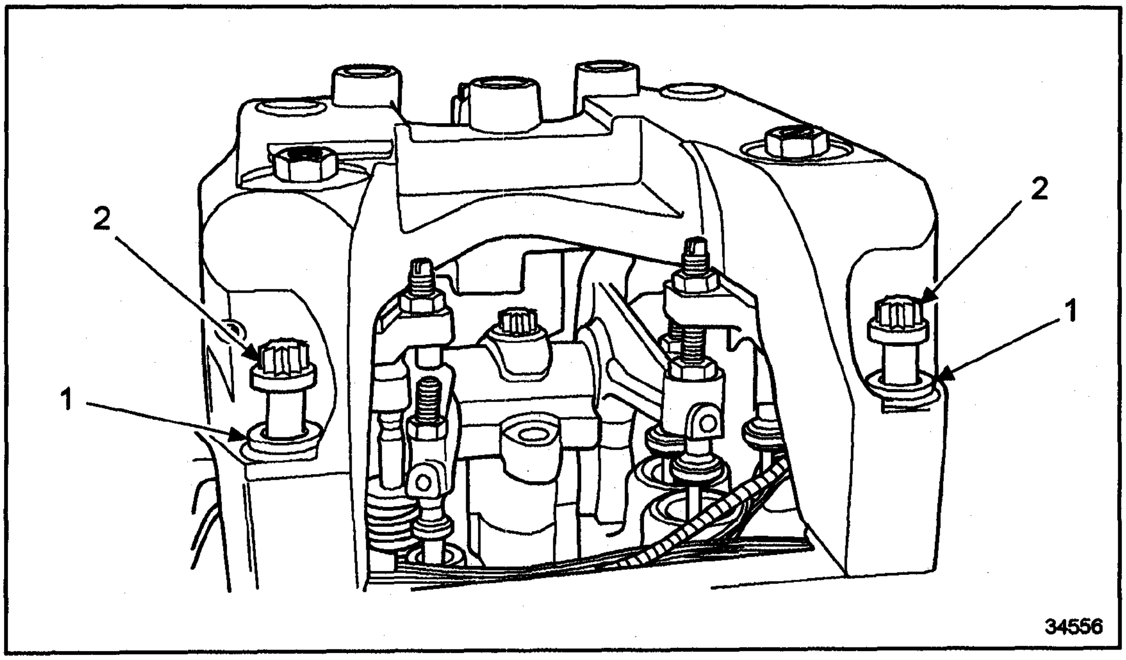
NOTICE:

The model 760 uses two lengths of mounting bolts. Six 120 mm bolts should be installed on the exhaust side of the engine. Three 110 mm bolts should be installed on the camshaft side of the engine. Failure to do so will result in engine damage.

6. On model 760, install one washer onto each 120 mm (4.75 in.) bolt, and insert into brake housing on the exhaust manifold side (two per housing). See Figure 1-450.



1. Washer
2. Long Bolt

Figure 1-450 Installation of Brake Housing Bolts on Exhaust Manifold Side

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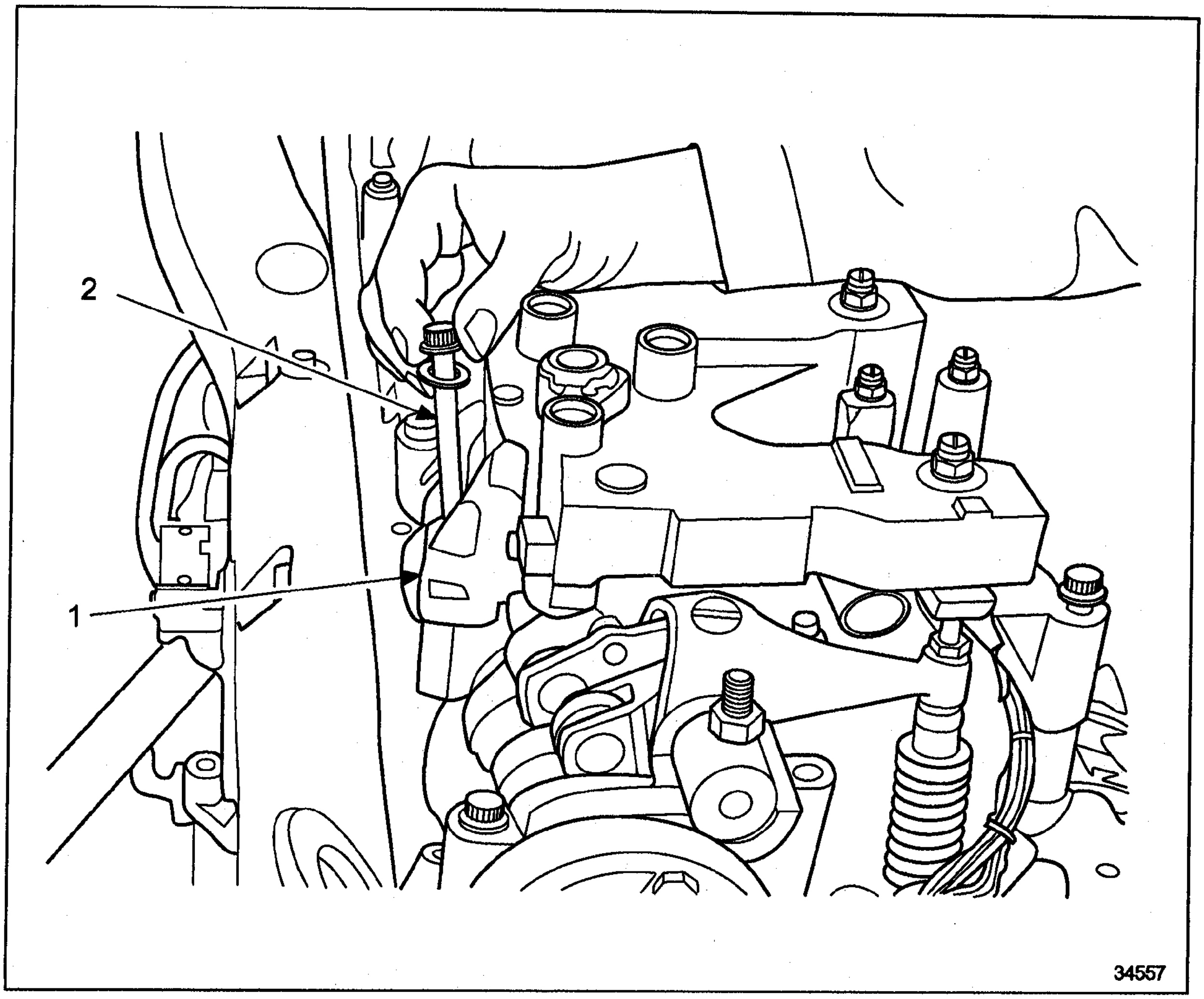
7. On model 760, install one washer on the 110 mm (4.375 in.) bolt, and insert into brake housing at the camshaft side (one per housing). See Figure 1-451.



1. Jake Brake® Housing Assembly
2. Mounting Bolt

Figure 1-451 Installation of Brake Housing Bolts on Camshaft Side

8. On models 760A, 760B, 765, and 765A, lubricate each hold down bolt with clean engine oil.

NOTE:
All the housing mounting bolts for these models are the same length of 110 mm (4.375 in.).

9. On models 760A, 760B, 765, and 765A, install a washer on each bolt, and install into housings (three bolts per housing).

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10. On models 760A and 765, move the housing from side to side, and locate the housing in the center position of the movement. See Figure 1-452.

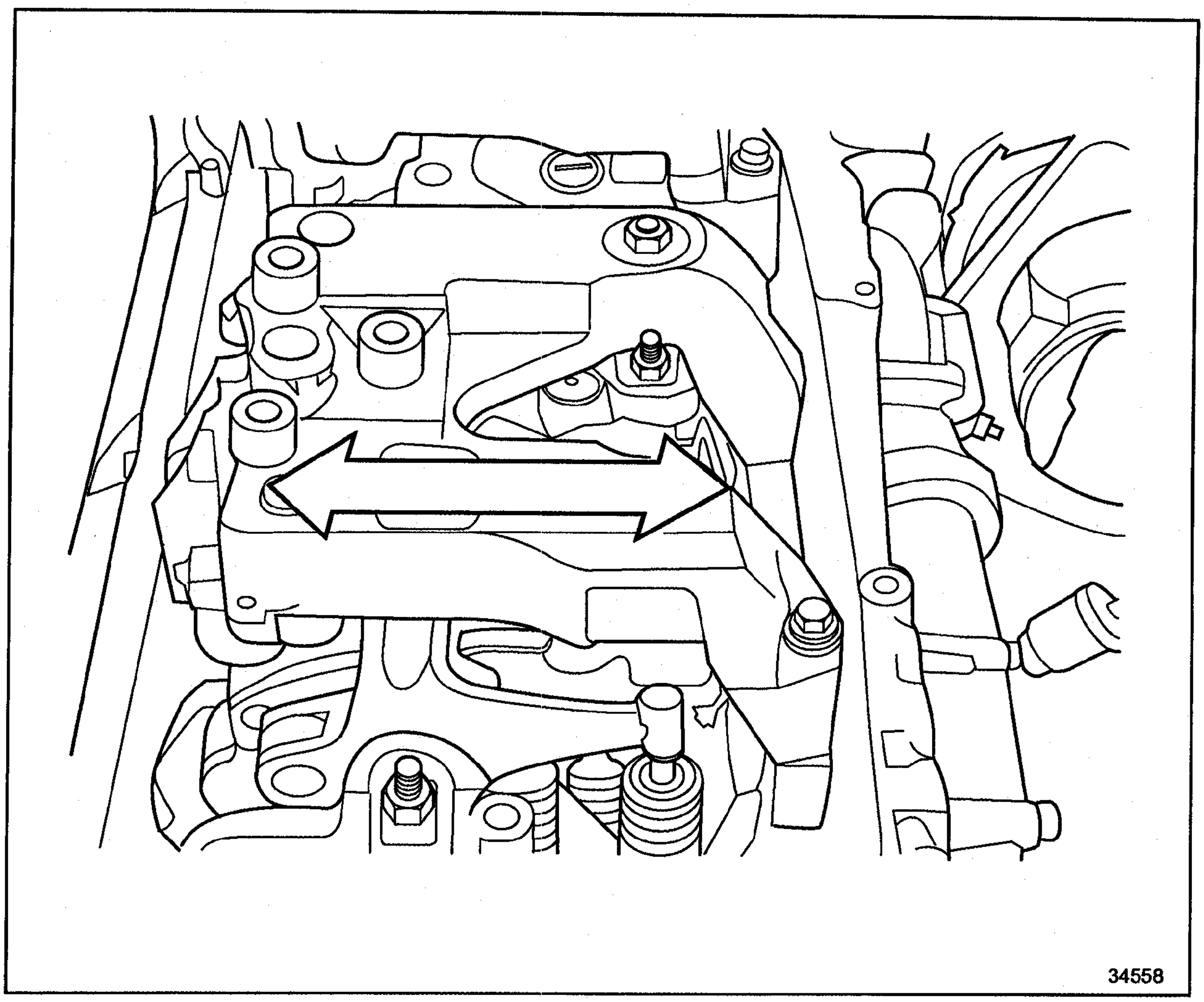

Figure 1-452 Locating Center Position of Housing

11. On models 760B and 765A, move the housing from side to side, and locate as far toward the camshaft side of the engine as possible.
12. On all models, torque the engine brake mounting bolts using the following sequence:
    [a] Torque the three bolts on the camshaft side of the engine to 55 N·m (40 lb·ft).
    [b] Torque the six bolts on the exhaust manifold side of the engine to 55 N·m (40 lb·ft).
    [c] Repeat the tightening sequence and re-torque all bolts to 136 N·m (100 lb·ft).
    [d] Check the torque to 136 N·m (100 lb·ft).
13. Secure wire harness to spacer bars with plastic ties.
14. Connect wiring harness solenoid connectors to solenoids.

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1.29.5.1 Adjustment of Slave Piston on Model 760, 765, or 770 Jake Brake®

Make the following adjustment with the engine stopped and cold, and the oil temperature at 60°C (140°F) or below. The exhaust valves on the cylinder *must* be in the closed position (rocker arm roller on the base circle of the camshaft). When setting the engine brake lash, the exhaust valves must be in the closed position. Adjust the slave piston on all models as follows:

NOTE:
The following procedures apply to Model 760, 765, and 770 Jake Brakes®. For Model 790 Jake Brake® slave piston lash setting procedures, refer to section 1.29.10.1.

NOTE:
Model 770 Jacobs engine brake requires a special procedure for adjusting the slave piston. The procedure is clearly indicated in the following adjustment steps.

NOTICE:
Improper slave piston adjustment can result in engine or brake housing damage.

NOTICE:
Strictly follow the slave piston adjustment procedure. Failure to use the proper adjustment procedure will result in poor engine brake performance and/or serious engine damage.

1. Refer to section 1.29for proper slave piston clearance setting.

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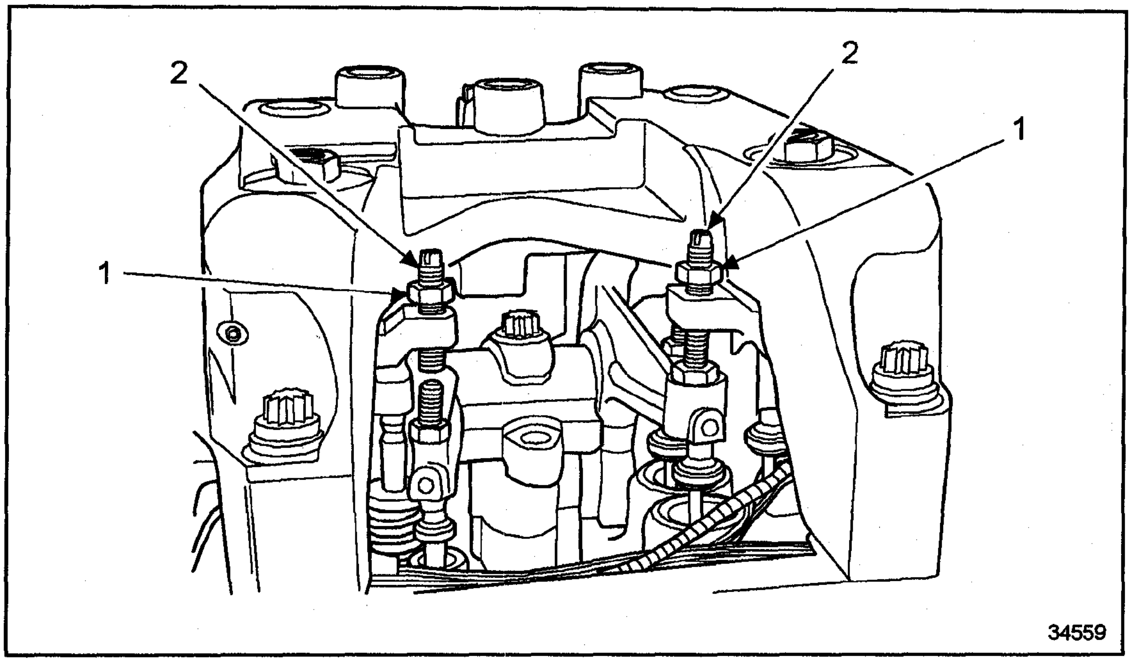
2. Back out the leveling screw in the slave piston assembly until the end of the screw is beneath the surface of the bridge in the slave piston assembly. See Figure 1-453.

NOTE:
The leveling screw is located in the bridge member of the slave piston assembly.



1. Leveling Screw
2. Locknut

Figure 1-453 Location of Leveling Screw

3. On models 760, 760A, 760B, 765, and 765A, place the correct size feeler gage between the solid side of the slave piston (the side without the leveling screw) and the exhaust rocker arm adjusting screw. Feeler gage sizes are listed in Table 1-9.

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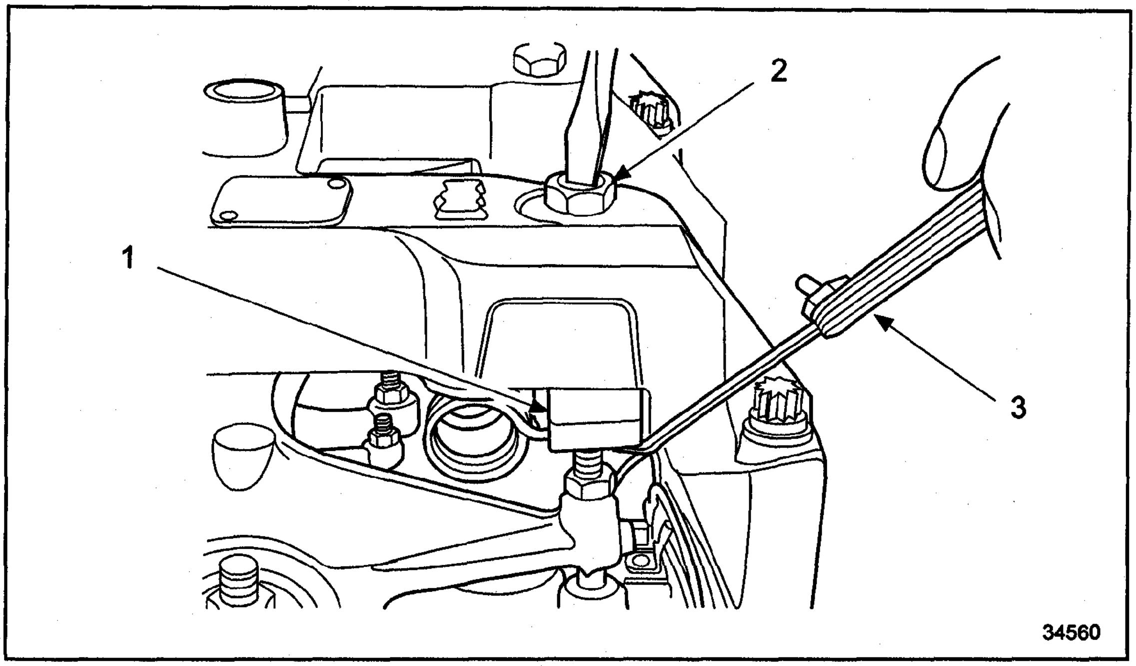
4. On models 760, 760A, 760B, 765, and 765A, turn the slave piston adjusting screw clockwise until a slight drag is felt on the feeler gage. See Figure 1-454.



1. Slave Piston Bridge
2. Slave Piston Adjusting Screw
3. Feeler Gage

Figure 1-454 Turn Slave Piston Adjusting Screw Clockwise

5. Perform the following additional steps on model 770:

   [a] Turn in the J-Lash® adjusting screw until the solid side of the slave piston bridge assembly contacts the exhaust valve and the valve springs begin to compress. Turn in one additional turn.

NOTICE:
All oil must be purged from the J-Lash adjusting screw. Oil remaining in the J-Lash screw will cause inaccurate clearance adjustment, resulting in possible engine or engine brake damage. If oil is below room temperature (below 60°F), wait at least two minutes for oil to be purged from the J-Lash adjusting screw.

NOTE:
Wait at least 30 seconds for oil to be purged from the J-Lash adjusting screw.

   [b] Back out the adjusting screw **only** until the correct size feeler gage can be inserted between the solid side of the slave piston bridge assembly and the exhaust valve.

   [c] Adjust the J-Lash so that a light drag is felt on the feeler gage.

NOTE:
Do not back out the J-Lash more than required to obtain a light drag on the feeler gage.

   [d] Use a screwdriver to hold the J-Lash in place, and torque the lock nut to 34 N·m (25 lb·ft).

NOTE:
If the J-Lash screw is backed out until it no longer compresses the slave piston spring, oil will enter the screw and the adjustment will be incorrect. If this occurs, repeat the J-Lash adjustment procedure.

   [e] Recheck the lash settings. If clearance setting is incorrect, repeat the J-Lash adjustment procedure.

NOTE:
Once the engine brake has been run, oil enters the J-Lash screw making the engine brake adjustment unreadable. If unsure of the adjustment, repeat the J-Lash adjustment procedure.

6. On all models, hold the screw in position, and torque the locknut to 34 N·m (25 lb·ft).
7. Check the adjustment, and repeat if necessary.

NOTE:
Do not disassemble the slave piston adjusting screws.

8. Place the correct feeler gage between the leveling screw and the rocker arm adjusting screw.

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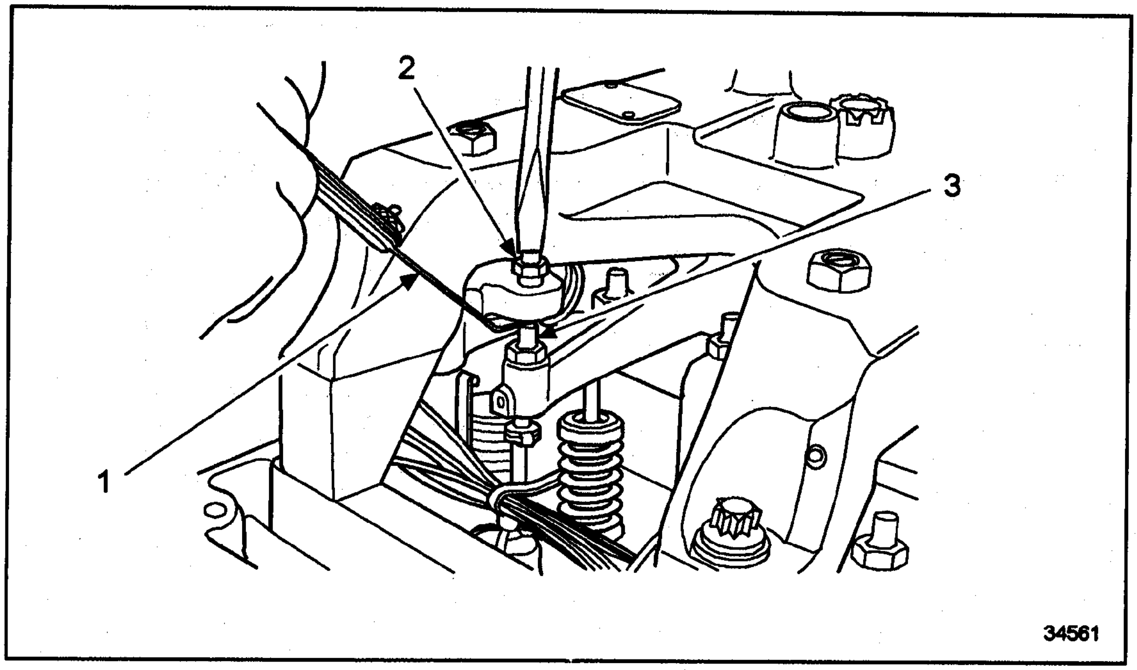
9. Turn the leveling screw clockwise until a slight drag is felt on the feeler gage. See Figure 1-455.



1. Feeler Gage
2. Slave Piston Leveling Screw
3. Rocker Arm Adjusting Screw

Figure 1-455 Setting Clearance on Leveling Screw and Rocker Arm Adjusting Screw

10. Hold the leveling screw in position, and torque the locknut to 47 N·m (35 lb·ft).
11. Check adjustment, and repeat if necessary.
12. Repeat the adjustment procedures for the remaining cylinders. Refer to step 2 through step 11.

NOTE:
Bar over the engine when necessary to place the exhaust valves in the closed position for slave piston adjustment.

13. Install the engine rocker cover. Refer to section 1.6.2 for one-piece, refer to section 1.6.3 for two-piece, and refer to section 1.6.5 for three-piece.
14. Install all remaining components that were removed for this procedure.
15. Connect starting power for the engine.
16. Verify proper Jake Brake® installation by driving the vehicle, then checking engine brake performance.

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1.29.6 Removal of Model 790 Jake Brake® Assembly

Remove the Model 790 Jake Brake® as follows:

CAUTION:
To avoid injury from hot surfaces, allow engine to cool before removing any component. Wear protective gloves.

CAUTION:
To avoid injury from accidental engine startup while servicing the engine, disconnect/disable the starting system.

1. With the engine at ambient temperature and power to the starting system disconnected, refer to section 1.6 and remove the engine rocker cover.
2. Note the location of the rocker arm shaft, the exhaust valve rocker arm, the fuel injector rocker arm, and the intake valve rocker arm.
3. Disconnect the solenoid wiring harness connectors from the Jake Brake® solenoids.

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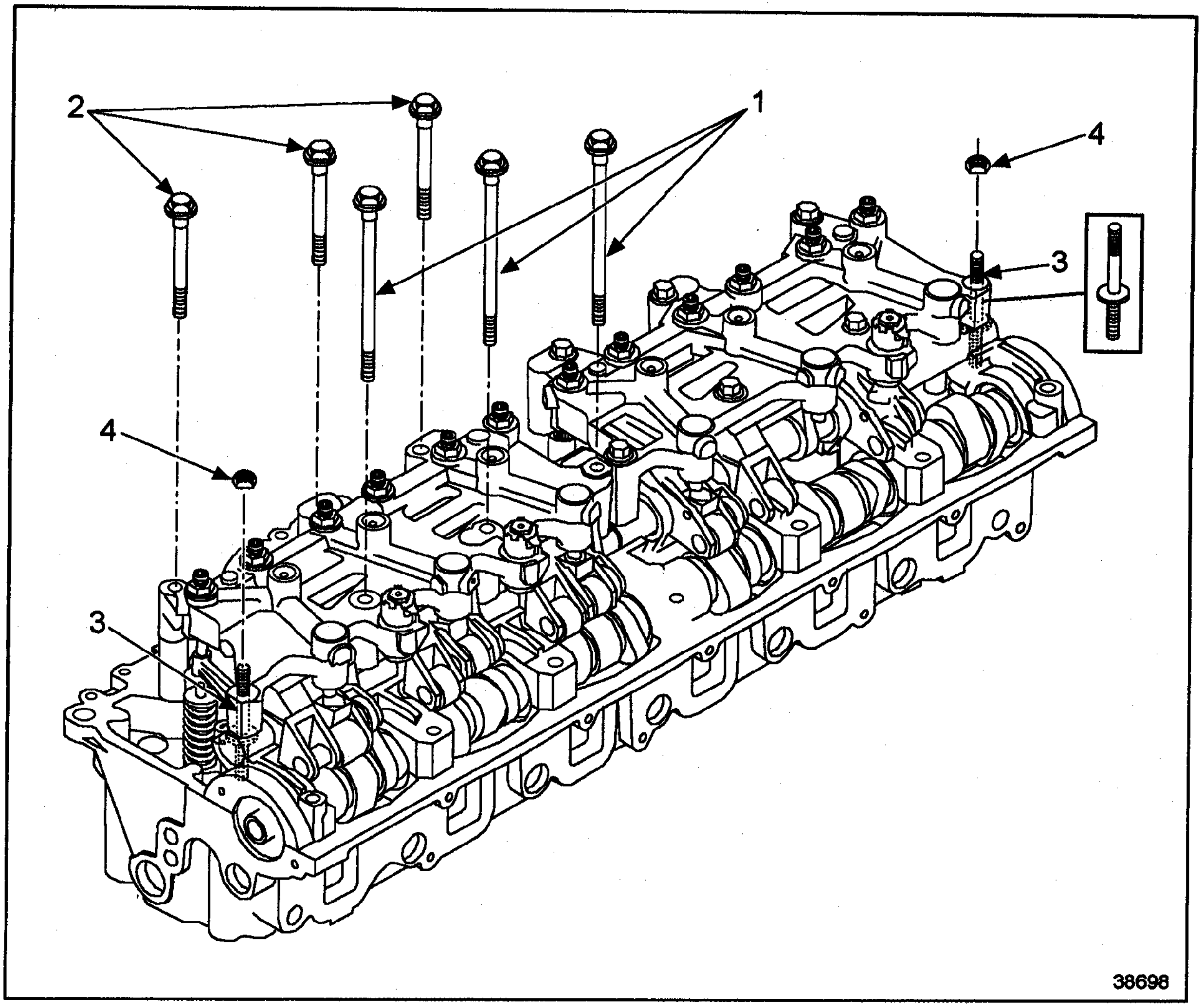
4. Remove the three (3) 140 mm long mounting bolts that secure the engine brake to the cylinder head. See Figure 1-456.



1. Mounting Bolt — 170 mm Long
2. Mounting Bolt — 140 mm Long
3. Stud Bolt
4. Nut

Figure 1-456 Model 790 Jake Brake® Fasteners

5. Remove the three (3) 170 mm long mounting bolts and the two (2) nuts that secure the engine brake to the cylinder head.
6. Remove the engine brake assembly.
7. Repeat steps 1 through step 5 and remove the second Jake Brake® assembly from the engine.

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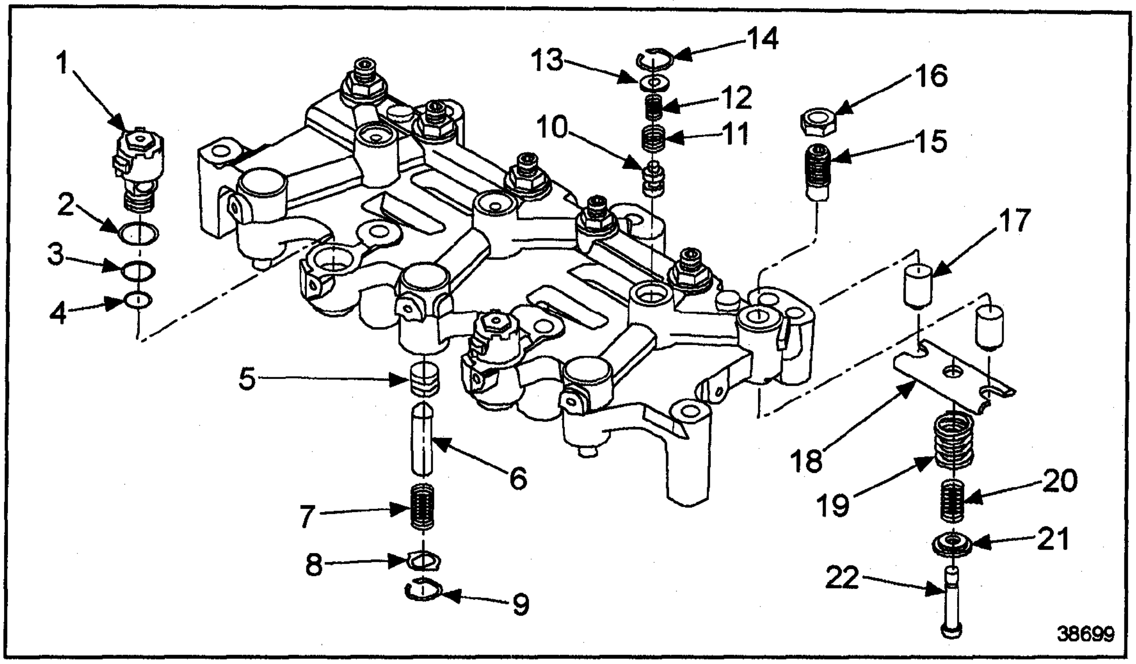
1.29.6.1 Disassembly of Model 790 Jake Brake®

Instructions for disassembly of Model 790 Jake Brakes® are incomplete at time of publication, but will be provided at a future date. For components of Model 790 Jake Brakes®, see Figure 1-457.



1. Solenoid Valve
2. Upper Seal
3. Center Seal
4. Lower Seal
5. Master Piston
6. Master Piston Pushrod
7. Master Piston Spring
8. Retaining Ring
9. Control Valve
10. Outer Control Valve Spring
11. Inner Control Valve Spring
12. Washer
13. Retaining Ring
14. J-Lash® Screw
15. Locknut
16. Slave Piston
17. Slave Piston Bridge
18. Outer Slave Piston Spring
19. Inner Slave Piston Spring
20. Slave Piston Spring Seat
21. Shoulder Bolt
22. Shoulder Bolt

Figure 1-457 Typical Model 790 Jake Brake® Assembly

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1.29.7 Cleaning of Model 790 Jake Brake®

Instructions for cleaning of Model 790 Jake Brake® are incomplete at the time of publication, but will be provided at a future date.

1.29.8 Inspection of Model 790 Jake Brake®

Instructions for inspection of Model 790 Jake Brake® are incomplete at the time of publication, but will be provided at a future date.

1.29.9 Assembly of Model 790 Jake Brake®

Instructions for assembly of Model 790 Jake Brake® are incomplete at the time of publication, but will be provided at a future date.

1.29.10 Installation of Model 790 Jake Brake® Assembly

The installation procedures for the model 790 Jake Brake® assemblies differ slightly from the former engine brakes. Two brake housings are used, instead of three, and spacer bars are not required. Install the model 790 Jake Brake® assemblies as follows:

1. With the engine at ambient temperature, install front Jake Brake® housing (with two solenoids) over the front three cylinders. Position with solenoids on camshaft side of engine.
2. Install the rear housing (with one solenoid) over the rear three cylinders. Position with solenoid on camshaft side of engine.

NOTE:
There is one extra mounting hole drilled on the slave piston side of each housing. These holes are for manufacturing purposes only and are not used for installation.

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3. Install six (6) 170 mm bolts through the housings into the rocker shafts in locations 1 through 6, and install two (2) nuts in locations 7 and 8. See Figure 1-458.

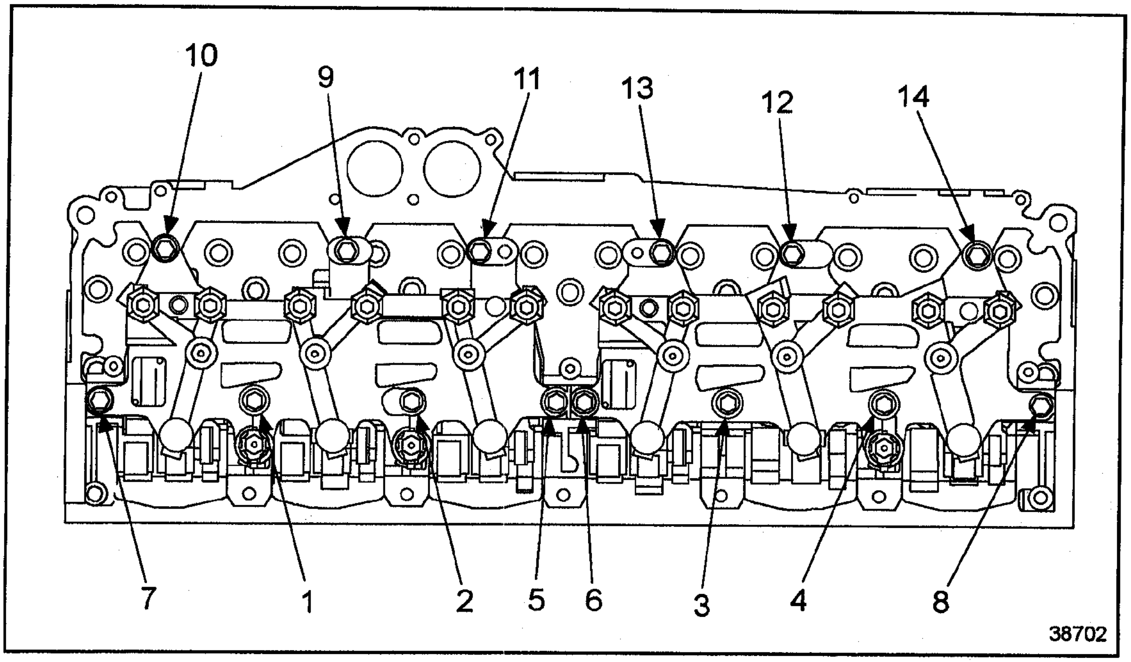

Figure 1-458 Housing Hold-Down Bolt Locations

NOTICE:
To ensure proper engine brake housing installation, Jake Brake® mounting bolts (identified by a circle "J" on the heads) and required one-piece spacers *must* be used when mounting the brake assemblies.

4. Install six (6) 140 mm bolts into each housing and through the spacers in locations 9 through 14.
5. Torque all mounting bolts to 136 N·m (100 lb-ft) in bolt location number sequence shown. See Figure 1-458.
6. Route the wire to the solenoid for cylinder 1 through the front retaining clip on the front housing and connect to the solenoid. Torque screw to 1.13 N·m (10 lb·in.).
7. Route wire to the solenoid for cylinders 3 and 4 through the rear retaining clip on the front housing and connect to the solenoid. Torque screw to 1.13 N·m (10 lb·in.).
8. Route wire to the solenoid for cylinders 4, 5 and 6 through the single retaining clip on the rear housing and secure to the terminal screw on the solenoid. Torque screw to 1.13 N·m (10 lb·in.).
9. Secure any excess wire to the injector harness with wire ties.

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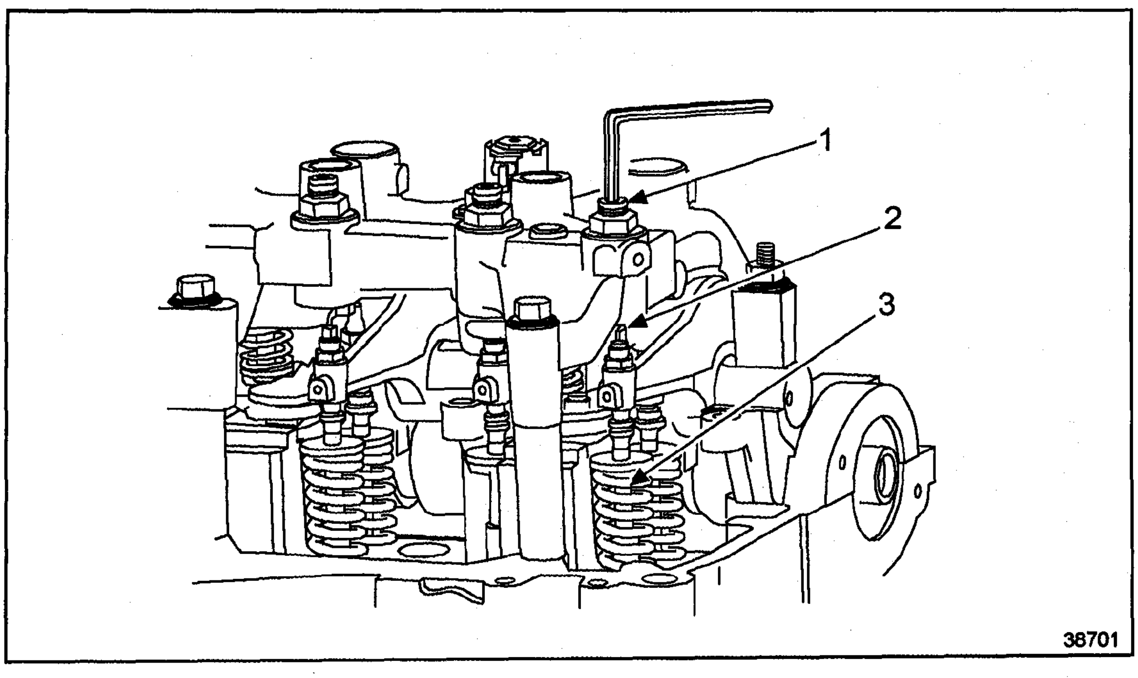
1.29.10.1 Set Slave Piston Lash

The slave piston lash must be set after Jake Brake® housings are installed. Adjustments must be made with the engine stopped and cold and the oil temperature at 60°C (140°F) or below. Exhaust valves on the cylinder must be in the closed position (rocker arm roller should be on the base circle of the camshaft).

NOTICE:
The slave piston adjustment procedure *must* be followed exactly. Failure to properly adjust Jake Brakes® will result in inefficient engine brake performance and may lead to severe engine or Jake Brake® damage.

Adjust Jake Brake® Model 790 slave piston lash as follows:

1. Loosen the locknut. Then, using a 5/16 in. Allen wrench, turn the J-Lash adjusting screw counter-clockwise until a 0.660 mm (0.026 in.) feeler gauge can be inserted between the slave piston and the exhaust rocker adjusting screw. Insert the feeler gauge.
2. Using the 5/16 in. Allen wrench, turn the J-Lash adjusting screw in (clockwise) until the slave piston contacts the feeler gauge and the exhaust rocker adjusting screw. When the valve spring begins to compress, turn the screw clockwise *one* additional turn. *Wait at least 30 seconds for oil to be purged from the J-Lash adjusting screw.* See Figure 1-459.



1. J-Lash Adjusting Screw
2. Slave Piston
3. Exhaust Valve Spring

Figure 1-459 Turn the Adjusting Screw Until the Valve Spring Compresses

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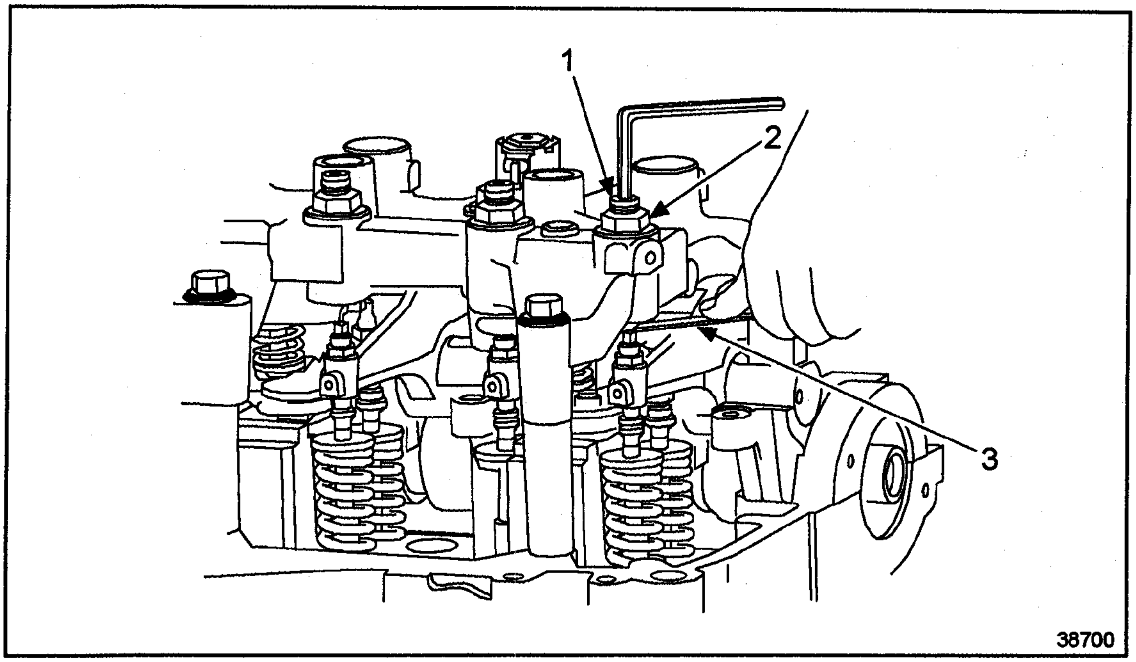
NOTICE:

Oil *must* be purged from the J-Lash adjusting screw. Oil remaining in the J-Lash screw will cause inaccurate clearance adjustment, which could result in damage to the engine or Jake Brake®. ***If oil is below room temperature (below 16° C or 60° F), wait at least two minutes for oil to be purged from the J-Lash adjusting screw.***

3. After waiting the required interval to purge oil from the J-Lash adjusting screw, back out the adjusting screw (turn counter-clockwise) ***only*** until a 0.660 mm (0.026 in.) feeler gage can be moved with a slight resistance. See Figure 1-460. *Do not back out the J-Lash adjusting screw more than required to obtain a light drag on the feeler gage.* Using the Allen wrench to hold the J-Lash adjusting screw in place, torque the lock nut to 35 N·m (25 lb-ft).



1. J-Lash Adjusting Screw
2. Locknut
3. Feeler Gage

Figure 1-460 Adjusting Slave Piston Lash

NOTE:

If the J-Lash adjusting screw is backed out until it no longer compresses the slave piston spring, oil will enter the screw and the adjustment will be incorrect. If this occurs, repeat step 1 and step 2.

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4. After torquing the adjusting screw lock nut, recheck lash setting. If lash is incorrect, repeat step 1 and step 2.

NOTE:
Once the engine brake has been run, you will not be able to check Jake Brake® adjustment. This is because of oil retained in the J-Lash adjusting screw. If unsure of the adjustment, you must repeat step 1 through step 3.

5. Repeat step 1 through step 3 for the remaining slave piston on the same cylinder.
6. Repeat step 1 through step 4for the remaining cylinders.
7. Complete the installation by installing the rocker cover. Refer to section 1.6 of the service manual.
8. Install all remaining components that were removed for this procedure.
9. Connect starting power for the engine.
10. Start and drive the vehicle to verify proper Jake Brake® performance.

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1.A ADDITIONAL INFORMATION

Description **Page**

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SHOP NOTES

Shop notes contains information on checking bearing clearances, the crankshaft remanufacturing procedures and a glossary.

Cylinder Block Liner Boring

Further information will be printed as it is developed.

Checking Bearing Clearance

A strip of soft plastic squeezed between the crankshaft journal and the connecting rod bearing or main bearing may be used to measure the bearing clearances.

The strip is a specially molded plastic "wire manufactured commercially and is available in three sizes and colors. Type PG-1 (green) has a clearance range of 0.0254-0.0762 mm (0.001 -0.003 in.). Type PR-1 (red) has a range of 0.0508-0.1524 mm (0.002 -0.006 in.). Type PB-1 (blue) has a range of 0.1016-0.2286 mm (0.004 -0.009 in.).

The plastic strip may be used for checking the bearing clearances as follows:

1. Remove the bearing cap and wipe the oil from the bearing shell and the crankshaft journal to be checked.

NOTE:
Check the main bearing clearances with the weight of the crankshaft supported by a jack under the counterweight adjoining the bearing being checked. If the engine is positioned with the main bearing caps supporting the crankshaft and flywheel, an erroneous reading could result.

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2. Place a piece of plastic strip the full width of the bearing shell, about 1/4 inch off center. See Figure 1-461.

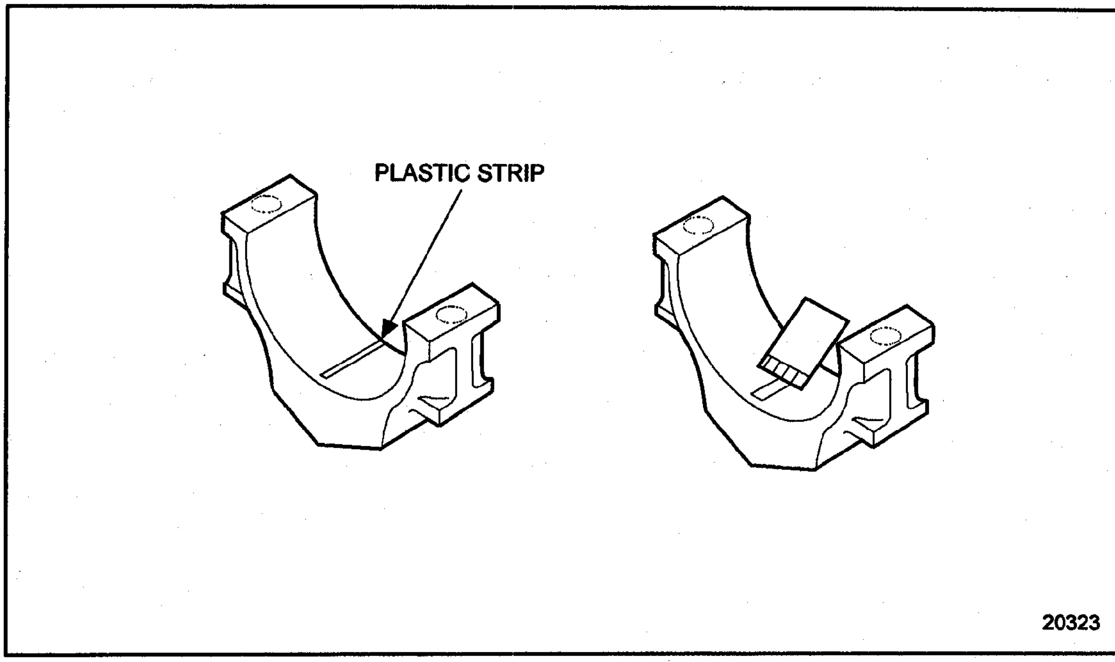

Figure 1-461 Using Plastic Strip to Measure Bearing-to-Crankshaft Clearance

3. Install the bearing cap. Torque the bolts to 470-530 N·m (347-391 lb·ft).
4. Remove the bearing cap. The flattened plastic strip will be found adhering to either the bearing shell or the crankshaft.
5. Compare the width of the flattened plastic strip at its widest point with the graduations on the envelope. See Figure 1-461. The value within the graduation on the envelope indicates the bearing clearance in thousands of an inch. To obtain metric specifications:
   [a] Multiply the reading obtained (in thousandths) by 25.4. Taper may be indicated when one end of the flattened plastic strip is wider than the other.
   [b] Measure each end of the plastic strip. The difference between the two readings is the approximate amount of taper.

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CRANKSHAFT REMANUFACTURING PROCEDURES

This section describes the procedures used to remanufacture crankshafts.

Crankshaft Grinding

In addition to the standard size main and connecting rod bearings, 0.254 mm, 0.508 mm and 0.762 mm (approximately 0.010 in., 0.020 in., and 0.030 in.), undersize bearings listed in Table 1-10 are available.

Crankshafts which exhibit surface irregularities may be reground to utilize these bearings. Listed in Table 1-10, are guidelines to determine if the crankshaft is suitable for regrinding:

Bearing Size	11 & 12L Connecting Rod Journal Diameter	14L Connecting Rod Journal Diameter	Main Bearing Journal Diameter
Standard	85.000 - 84.975 mm (3.346 in. - 3.345 in.)	95.000 - 94.975 mm (3.740 in. - 3.739 in.)	125.000 - 124.975 mm (4.921 in. - 4.920 in.)
0.254 mm (0.010 in.) Undersize	*84.750 - 84.775 mm (3.336 in. - 3.337 in.)	94.750 - 94.775 mm (3.730 in. - 3.731 in.)	*124.750 - 124.725 mm (4.911 in. - 4.910 in.)
0.508 mm (0.020 in.) Undersize	*84.500 - 84.475 mm (3.327 in. - 3.326 in.)	94.500 - 94.475 mm (3.720 in. - 3.719 in.)	*124.500 - 124.475 mm (4.902 in. - 4.901 in.)
0.762 mm (0.030 in.) Undersize	*84.250 - 84.225 mm (3.317 in. - 3.316 in.)	94.250 - 94.225 mm (3.711 in. - 3.709 in.)	*124.250 - 124.225 mm (4.892 in. - 4.891 in.)

* Dimension of reground crankshaft.

Table 1-10 Crankshaft Journal Specifications

Inspection

Perform the following steps for part inspection:

1. Determine if the crankshaft is from an 11.1 liter engine or a 12.7 liter engine. Listed in Table 1-11 are the forging number history for Series 60 crankshafts.

Model	Series 60 Crankshaft Forging Part Number	Part Number History Year Released	Fillet Finishing
11.1 Liter	8929238	1986	Induction Hardened
12.7 Liter	8929239	1986	Induction Hardened
14 Liter	23522887	1998	Induction Hardened

Table 1-11 Crankshaft Part Number History

2. Inspect connecting rod and main bearing journals for discoloration due to excessive overheating from bearing failure.

NOTE:
Crankshafts with discoloration are not acceptable for rework.

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3. Inspect keyway conditions using width gages and micrometers. Compare with the specifications. See Figure 1-462.

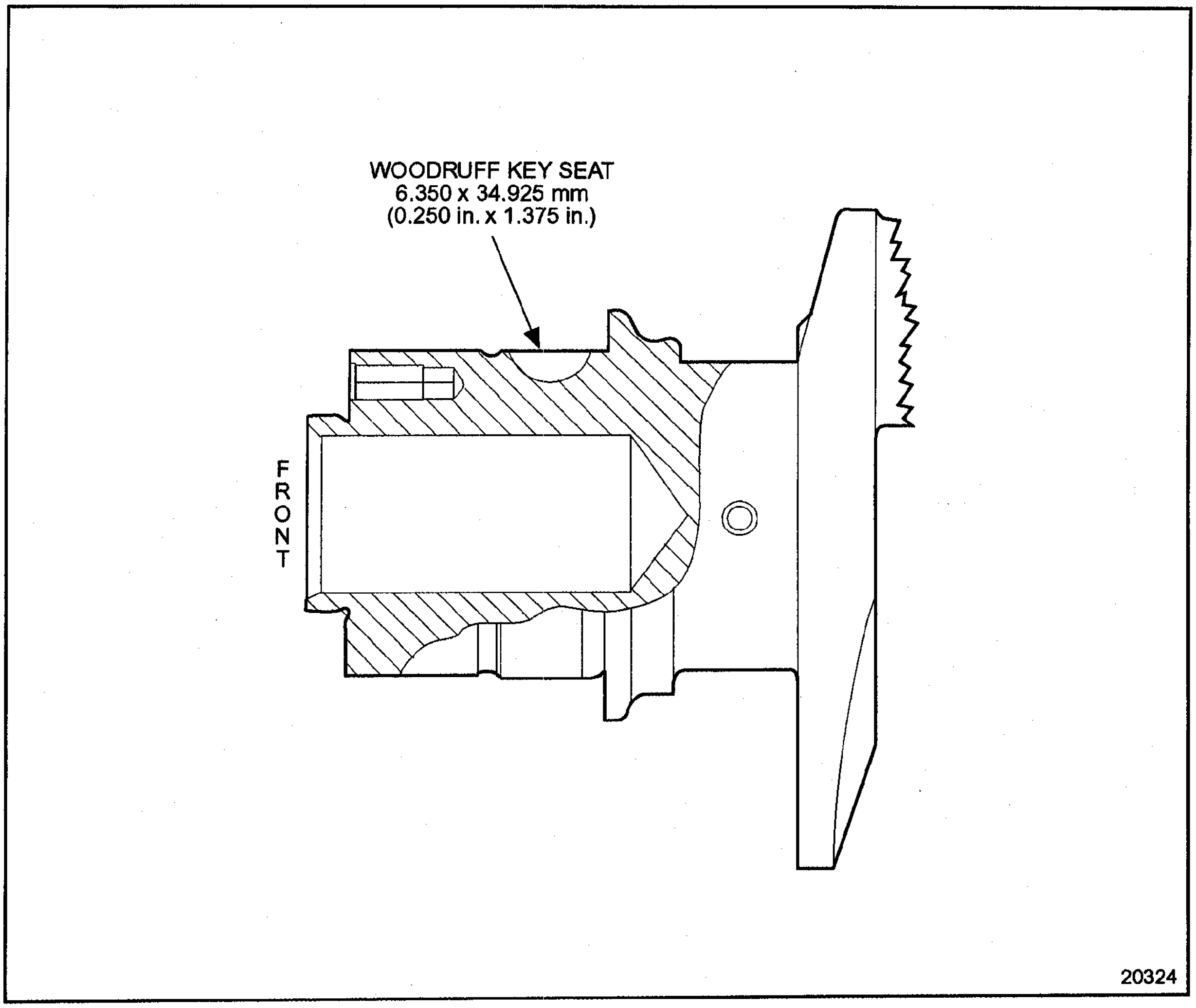

Figure 1-462 Standard Crankshaft Keyway Dimensions

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4. Inspect flange bolt holes visually and determine if any necessary repairs can be made by chasing threads or installing heli-coil(s).
5. Regardless of seal area wear condition, a new sleeve and seal must be installed.
6. Read and record all "bearing" total indicator reading (TIR) measurements with the crankshaft mounted in vee blocks. Listed in Table 1-12 are TIR limits.

NOTE:
Run-out tolerance listed in Table 1-12 are given for guidance when regrinding crankshaft. When the run-out on adjacent journals is in the opposite direction, the sum must not exceed 0.076 mm (0.003 in.) total indicator reading. When the run-out on adjacent journals is in the same direction, the difference must not exceed 0.076 mm (0.003 in.) total indicator reading.

Journals Supported On	Journals Measured	Maximum Run-Out (Total Indicator Reading)
No. 1 and No. 7	No. 2 and No. 6	0.076 mm (0.003 in.)
No. 1 and No. 7	No. 3 and No. 5	0.127 mm (0.005 in.)
No. 1 and No. 7	No. 4	0.152 mm (0.006 in.)

Table 1-12 Bearing Total Indicator Reading (TIR) Specifications

7. Whether run-out on adjacent journals is in the same or opposite directions, the sum shall not exceed 0.076 mm (0.003 in.) TIR.
8. When high spots of run-out adjacent journals are at right angles to each other, the sum shall not exceed 0.10 mm (0.004 in.) TIR or 0.05 mm (0.002 in.) on each journal.

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9. In the event of bearing seizure, bearing overlay must be removed. Check the width of journals to determine whether the sidewalls can be reground. See Figure 1-463 for location of crankshaft dimensions. Crankshaft specifications are listed in Table 1-13.

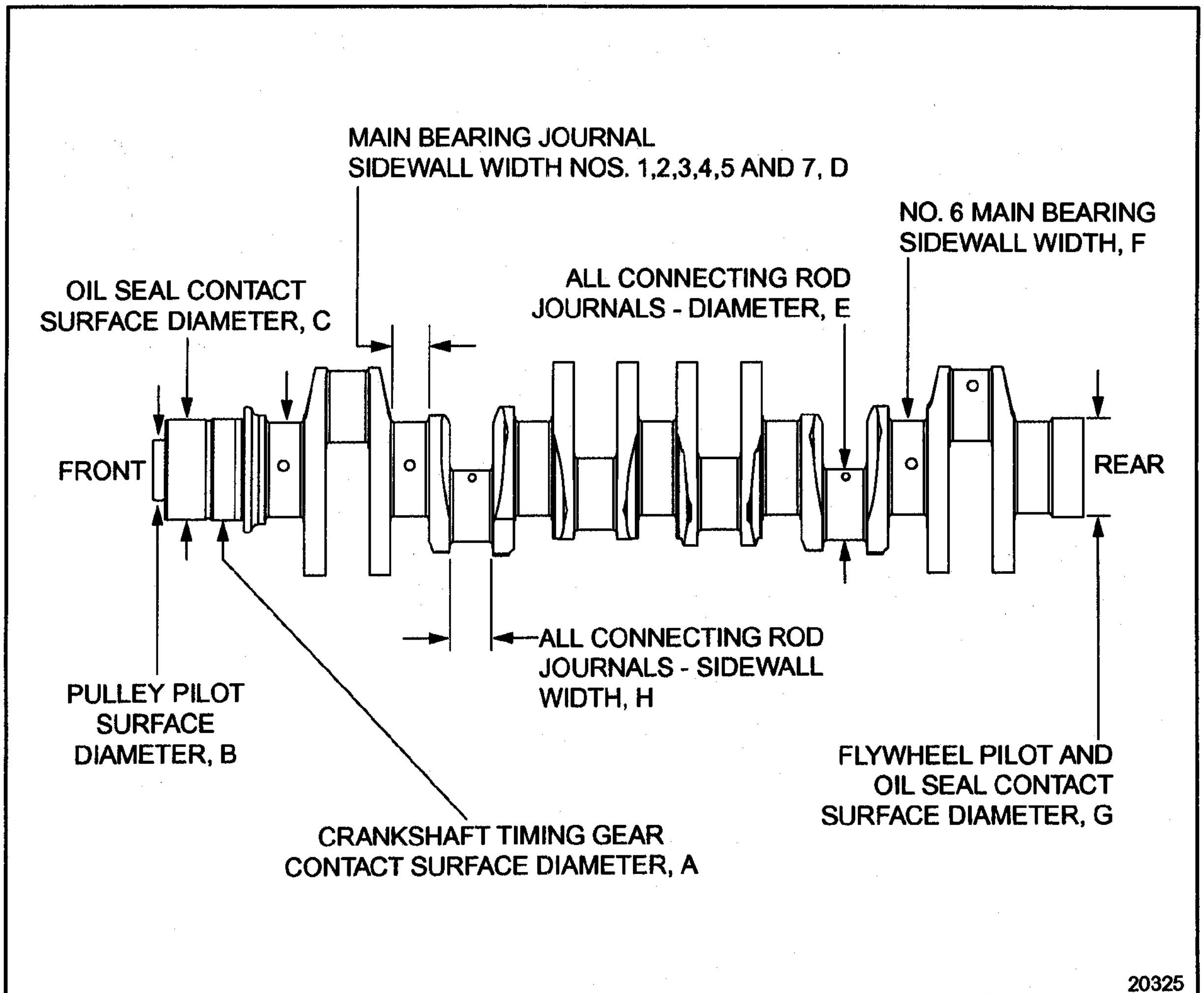

Figure 1-463 Standard Crankshaft Dimensions

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Location	Diameter, mm (in.)
A	11.1 L 132.970-133.000 mm (5.235-5.236 in.) 12.7 L 133.670-133.770 mm (5.263-5.264 in.)
B	80.19-80.22 mm (3.157-3.158 in.)
C	131.72-131.78 mm (5.185-5.188 in.)
D	49.35-49.65 mm (1.943-1.955 in.)
E (11 & 12 L)	84.975-85.000 mm (3.345-3.346 in.)
E (14 L)	94.975-95.000 mm (3.742-3.743 in.)
F	49.45-49.55 mm (1.947-1.950 in.)
G	131.72-131.78 mm (5.186-5.188 in.)
H	55.77-56.07 mm (2.196-2.208 in.)

Table 1-13 Crankshaft Specifications

10. Visually inspect the entire crankshaft for any serious deviations from normal wear patterns, cracks, nicks or other damage.
11. If the crankshaft has been ground undersize prior to present receiving inspection, check fillets, thrust, and all widths to determine whether or not enough stock remains to warrant regrinding. See Figure 1-463 for location of crankshaft dimensions. Listed in Table 1-14 are crankshaft remanufacturing tolerances.

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Crankshaft Specifications	Minimum	Maximum	Tolerance
Journal Diameter - Main Bearing	124.975 mm (4.920 in.)	125.000 mm (4.921 in.)	0.025 mm (0.001 in.)
Journal Diameter - Connecting Rod Bearing	84.975 mm (3.345 in.)	85.000 mm (3.346 in.)	0.025 mm (0.001 in.)
14L Journal Diameter - Connecting Rod Bearing	94.975 mm (3.742 in.)	95.000 mm (3.743 in.)	0.025 mm (0.001 in.)
Journal Out-of-Round - Main Bearing	-	0.015 mm (0.0006 in.)	0.015 mm (0.0006 in.)
Journal Out-of-Round - Connecting Rod Bearing	-	0.010 mm (0.0004 in.)	0.010 mm (0.0004 in.)
Journal Taper - Main Bearing - Full Length	-	0.013 mm (0.0005 in.)	0.013 mm (0.0005 in.)
Journal Taper - Connecting Rod - Full Length	-	0.010 mm (0.0004 in.)	0.010 mm (0.0004 in.)
Journal Taper Connecting Rod Half - Length	-	0.005 mm (0.0002 in.)	0.005 mm (0.0002 in.)
Gear Fit Run-out TIR (Total Indicated Reading)	-	0.030 mm (0.0012 in.)	0.030 mm (0.0012 in.)
Journal Alignment - Main and Connecting Rod - Per Length of Pin	-	0.012 mm (0.0005 in.)	0.012 mm (0.0005 in.)
Axial Profile Slope - Main - Full Length	-	0.008 mm (0.0003 in.)	0.008 mm (0.0003 in.)
Axial Profile Slope - Mains Per 5.0 mm (0.197 in.) of Length	-	0.006 mm (0.00024 in.)	0.006 mm (0.00024 in.)
Axial Profile Slope - Connecting Rod Journals - Full Length	-	0.006 mm (0.0002 in.)	-
Axial Profile Slope - Connecting Rod Journals - Per 5.0 mm (0.197 in.) of Length	-	0.003 mm (0.0001 in.)	-
Main and Connecting Rod Fillet Radius Main and Connecting Rod Fillet Radius	3.5 mm (0.1378 in.)	4.0 mm (0.1575 in.)	-
Surface Finish - Main and Connecting Rod Journals	-	0.3 µ m 12 AA	0.3 µ m 12 AA
Surface Finish - Thrust Wall	-	0.4 µ m 16 AA	0.4 µ m 16 AA
Surface Finish - Oil Seal Area	0	2.0 µ m 80 AA	2.0 µ m 80 AA
Journal Hardness (Rockwell C)	47 Rc	55 Rc	8 Rc
Crankshaft Dynamic Balance - (Ounce - Inch)	-	1.5	1.5
Main and Connecting Rod Journal Alignment Per Length of Pin	-	0.012 mm (0.0004 in.)	-
Crankshaft - Convex	-	0.013 mm (0.0005 in.)	0.043 mm (0.0017 in.)
Butt Face Concave	-	0.03 mm (0.0011 in.)	0.043 mm (0.0017 in.)

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Crankshaft Specifications	Minimum	Maximum	Tolerance
Pin Width	55.77 mm (2.196 in.)	56.07 mm (2.208 in.)	0.30 mm (0.012 in.)
Timing Gear Diameter (must maintain 0.003 -0.005 in. press fit)	133.67 (5.263 in.)	133.70 mm (5.264 in.)	0.030 mm (0.0012 in.)

Table 1-14 Series 60 Crankshaft Remanufacturing Tolerances

12. Journal O.D. score marks must be:
    [a] Circumferential-not axial.
    [b] Maximum of 0.254 mm (0.010 in.) wide.
    [c] At least 3.175 mm (0.125 in.) from fillet tangent point.
    [d] Smooth, no proud metal.
    [e] Maximum of one mark per journal.
13. No journal dimpling permitted for removal of defects.
14. Nicks, dents or pits in journal O.D. must be 3.175 mm (0.125 in.) maximum diameter, no proud metal, maximum (3) per journal.
15. Pins and bearing journals which exhibit discoloration due to excessive overheating from bearing failure are not acceptable for rework.
16. If one or more main or connecting rod journals require grinding, then grind all of the main journals or all of the connecting rod journals to the same required size.
17. Inspect the hardness of all journals. Crankshafts to be 47-55 Rc.

18. Clean the crankshaft as follows:

    [a] Clean all oil passages with a brush. Power probing is recommended.

    [b] Remove all copper, brass and lead, etc., from journal surfaces. Scrub the crankshaft until clean in a detergent bath.

    [c] Extremely rusted shafts can be soaked in hot rust stripper.

    [d] Scrub all webs and counterweights with a wire brush to remove all blackened residue. Use industrial detergent at proper ratios or regular hot degreaser.

NOTICE:
A crack in any vital area of the crankshaft cannot be repaired or removed. That is why magnetic particle inspection of the entire crankshaft before regrinding is mandatory. Crankshafts that are cracked MUST BE SCRAPPED.

19. After a visual inspection, the crankshaft should be magnetically inspected using one of the two following methods:

    [a] Magnetic Particle Method: Refer to section 1.7.2.6.

    [b] Fluorescent Magnetic Particle Method: Refer to section 1.7.2.8.

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MACHINING OPERATIONS

The following topics cover machining operations:

Main and Connecting Rod Journals

Main and Connecting Rod Journals:

1. Connecting rod and main bearing journal grinding should be performed with crankshaft rotation opposite to actual engine rotation. See Figure 1-464.

NOTE:
Crankshaft and main journal grinding should be performed with crankshaft rotation opposite to actual engine rotation. While polishing should be performed with the crankshaft rotation in the same direction as engine rotation.

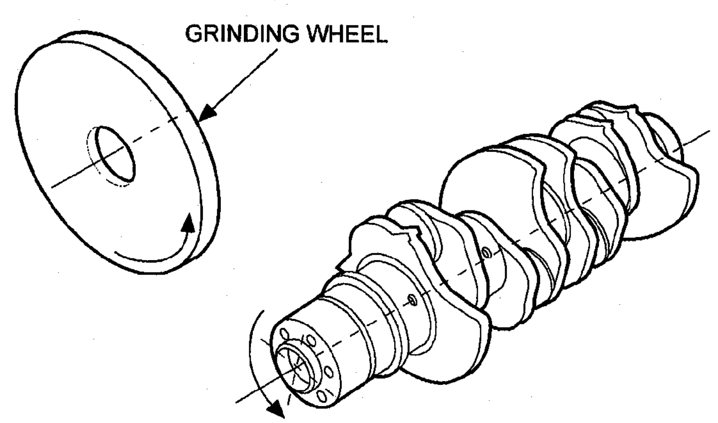

Figure 1-464 Crankshaft Grinding Rotation

2. Crankshaft polishing should be performed with the crankshaft rotation in the same direction as engine rotation.
3. All connecting rod journal fillets must have a 5.75 mm (0.226 in.) radius between the crank cheek and the journal.
4. All connecting rod journal fillets must have a 5.75 mm (0.226 in.) radius between the crank cheek and the journal. All main journal fillets must have a 3.75 mm (0.148 in.) radius between the crank cheek and the journal.
5. No journal may have any sharp grind marks. The fillet must blend smoothly into the journal and the crank cheek and must be free of scratches.

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6. The radius may be checked with a fillet gage. See Figure 1-465.

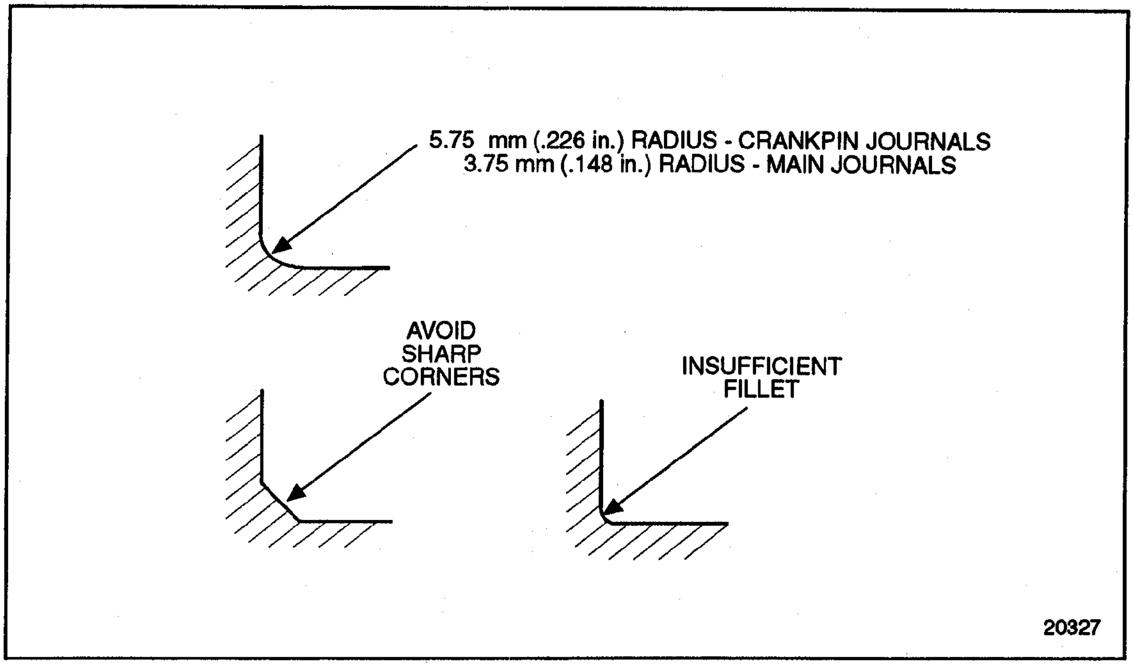

Figure 1-465 Crankshaft Journal Fillets

7. Lobing and Chatter: The number of lobes around the journal circumference, times the average peak to valley lobe height in micrometers, shall not exceed 42 micrometers. Peak to valley excursions exceeding 1.0 micrometers shall be considered lobing or chatter.
8. Excursions can be measured on a circular chart of the circumferential profile.

Grinding Connection Rod Journals (Pins)

Perform the following steps for grinding connection rod journals:

1. Grind the pin O.D. surface to the specified undersize. The undersize conditions are 0.254 mm, 0.508 mm or 0.762 mm (approximately 0.010 in., 0.020 in. or 0.030 in.).
2. ALL connecting rod journals must be ground to the same undersize condition.
3. Journal taper on a radial basis shall not exceed 0.008 mm (0.0003 in.) overall, or exceed 0.004 mm (0.00016 in.) on half-length.

NOTE:
Avoid localized heating, which often produces grinding cracks. Cool the crankshaft generously with coolant while grinding. Do not crowd the grinding wheel into the work.

4. Grind sidewalls wide enough to clean up the basic face surface, not to exceed pin width allowable. See Figure 1-463.
5. If there are deep interruptions, gouges or nicks that do not extend into fillets, smooth the edges with 120 grit emery cloth.

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Grinding Main Bearing Journals

Perform the following steps for grinding main bearing journals:

1. Grind the main bearing O.D. surface to the specified undersize. The undersize conditions are 0.254, 0.508 or 0.762 mm (approximately 0.010, 0.020, or 0.030 in.).

NOTE:
Avoid localized heating, which often produces grinding cracks. Cool the crankshaft generously with coolant while grinding. Do not crowd the grinding wheel into the work.

2. ALL main bearing journals must be ground to the same undersize conditions.
3. Journal taper on a radial basis shall not exceed 0.012 (0.0005 in.) overall or exceed 0.006 mm (0.00024 in.) on half-length.

Other Machining Operations:

Perform the following steps for other machining operations:

1. Examine the thrust wall (No. 4 main bearing):
   [a] If the thrust wall surface is scored, scratched or groove worn, the thrust wall must be "bump ground."
   [b] The maximum run-out of the thrust wall is 0.038 mm (0.0015 in.) TIR.

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[c] If wear is 0.0508 mm (0.002 in.) or more, regrind to restore flatness to the thrust wall. See Figure 1-466.

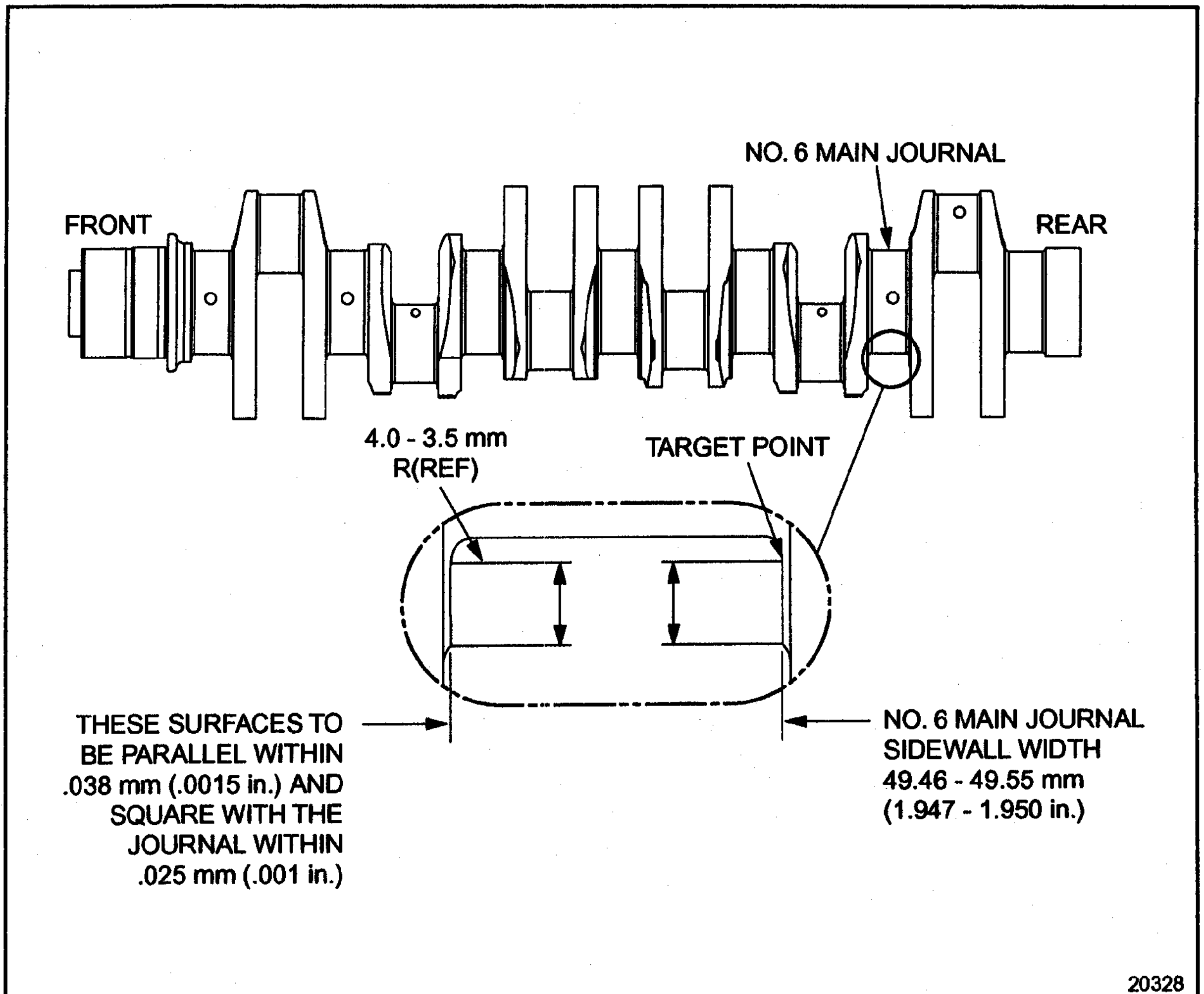

Figure 1-466 No. 6 Main Journal Thrust Wall Dimensions

[d] An oversize thrust wall is to be "bump ground" in multiples of 0.127 mm (0.005 in.), with a maximum of 0.250 mm (0.010 in.) to be removed from each side. Record oversize for installations.

NOTE:
Avoid localized heating, which often produces grinding cracks. Cool the crankshaft generously with coolant while grinding. Do not crowd the grinding wheel into the work.

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2. Chamfer all oil holes to remove grinding burrs to the limit shown on illustrations. See Figure 1-467. See Figure 1-468. See Figure 1-469. See Figure 1-470.

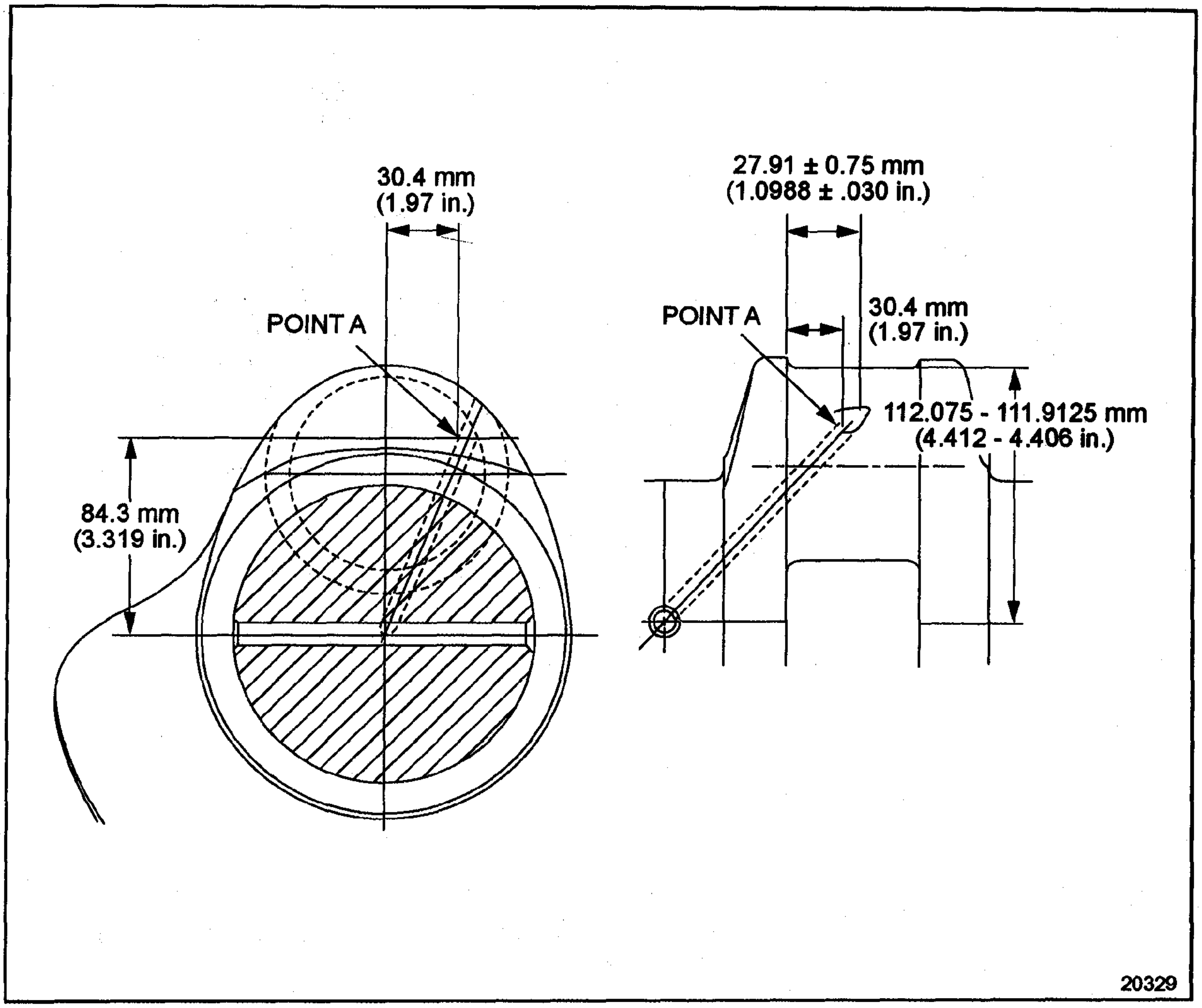

Figure 1-467 **Oil Hole Specifications - Connecting Rod Journals - 11.1 L Crankshaft (139 mm stroke)**

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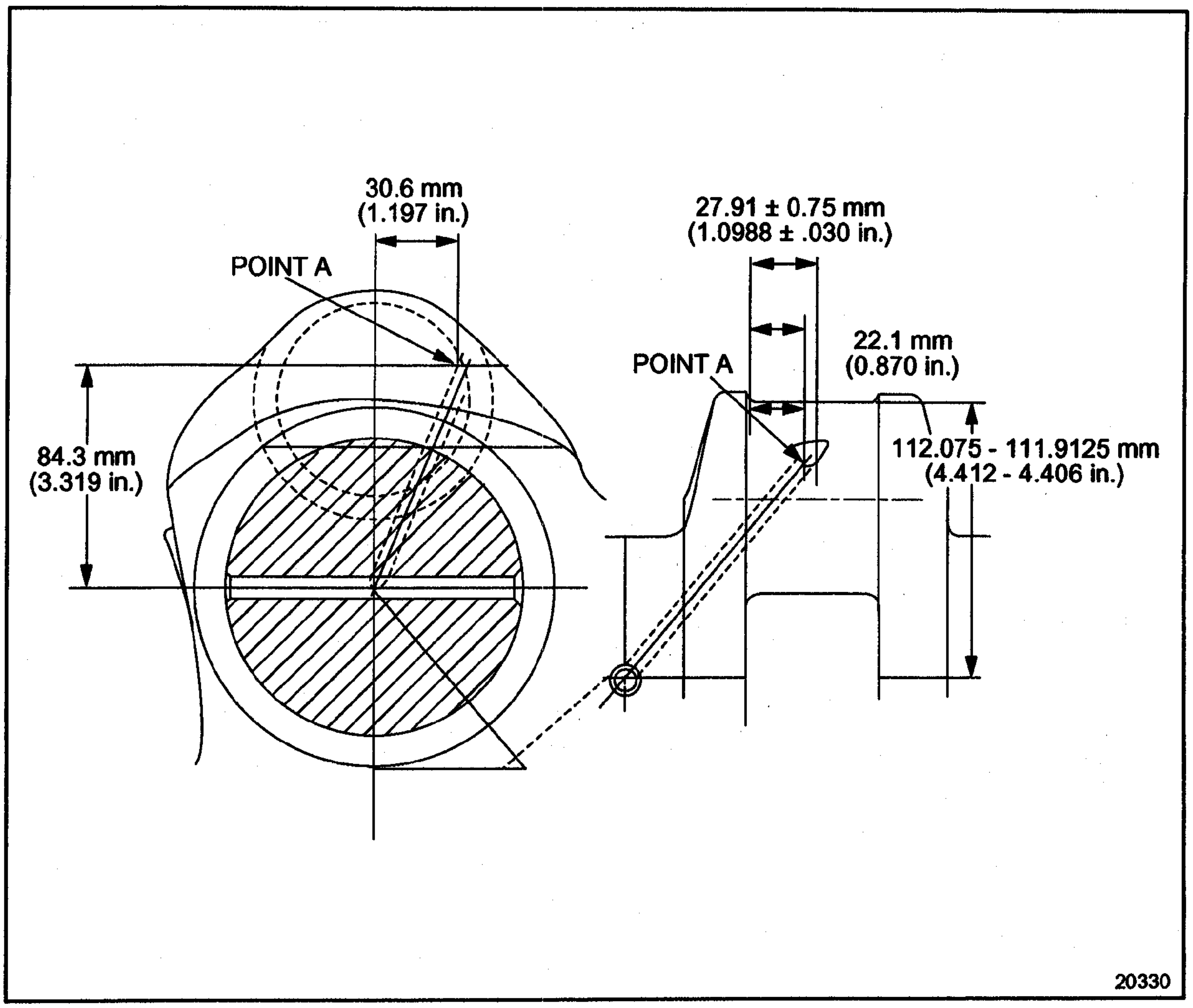

Figure 1-468 Oil Hole Specifications - Connecting Rod Journals - 12.7 L Crankshaft (160 mm stroke)

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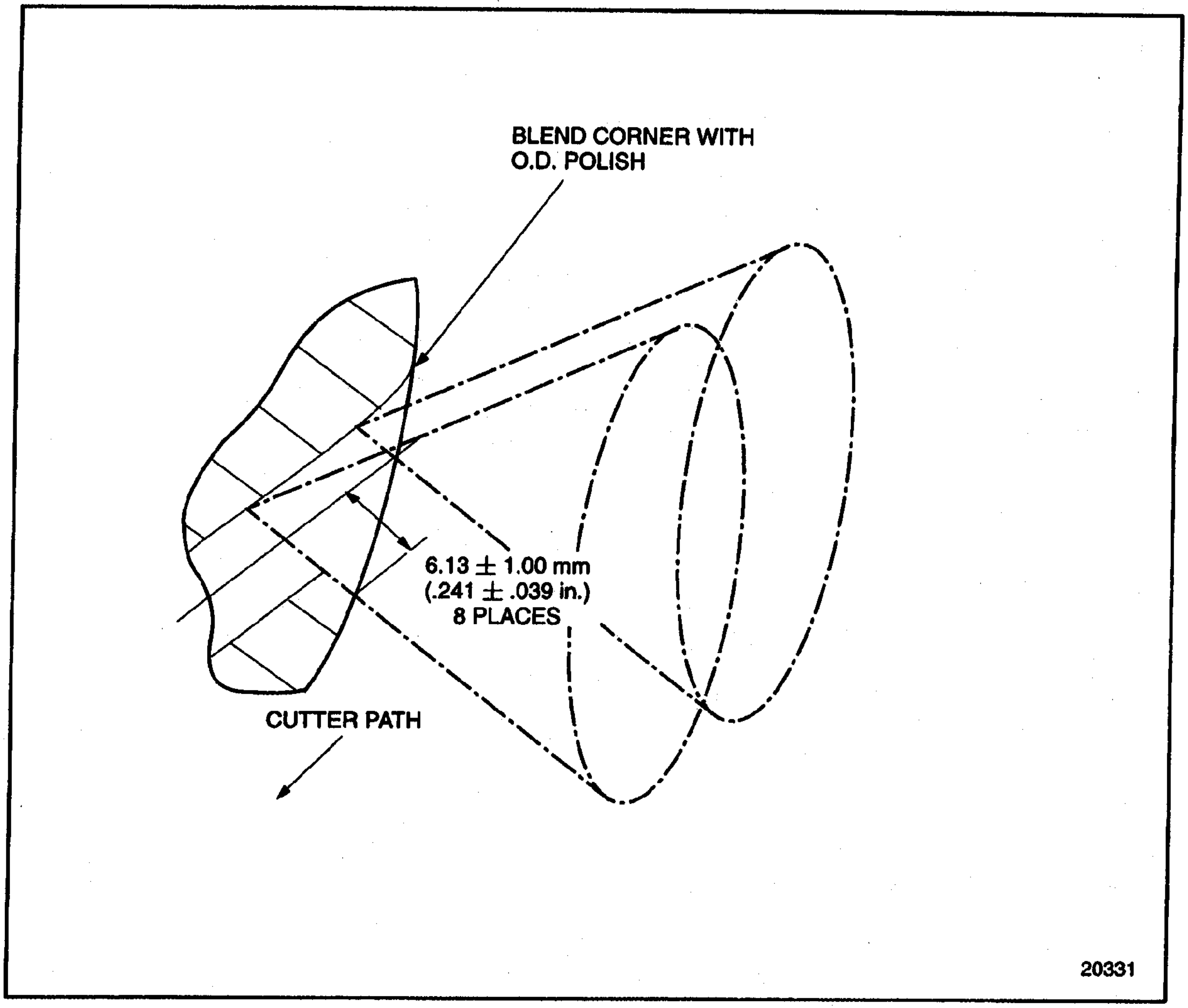

Figure 1-469 Connecting Rod Journal Oil Hole Chamfer Limits

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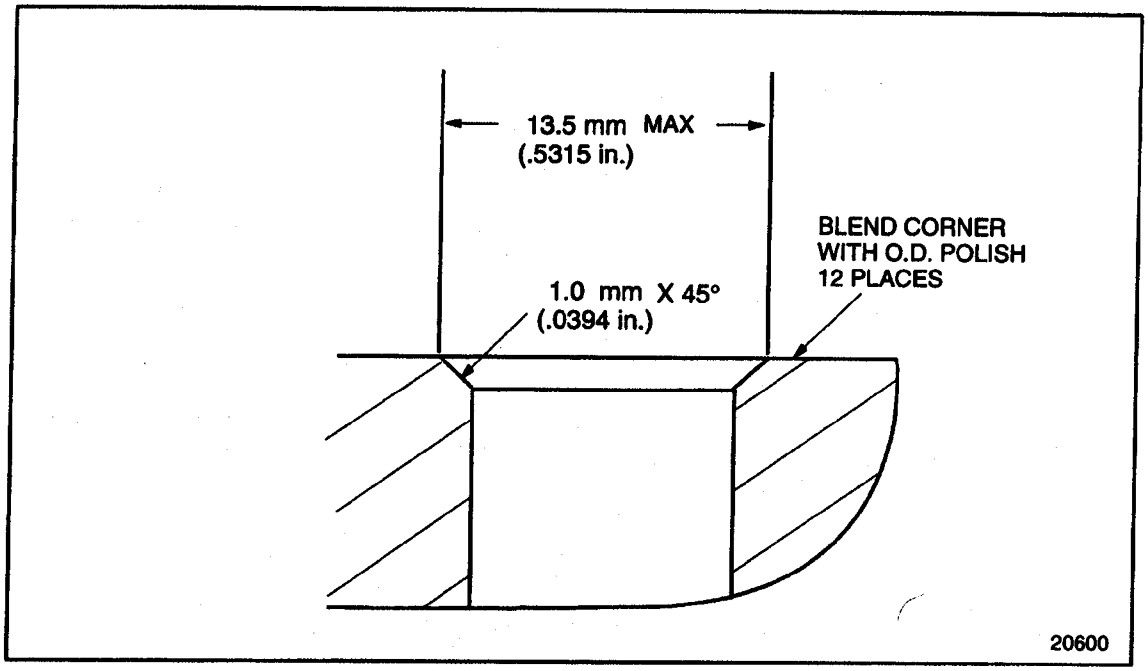

Figure 1-470 Main Journal Oil Hole Chamfer Limits

3. Repair the flywheel and pulley contact faces of the crankshaft to clean up the surface of any nicks, gouges or raised metal. The crankshaft face must be 0.013 mm (0.0005 in.) convex to 0.025 mm (0.001 in.) concave.

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After-Grinding Inspection

Perform the following steps for after grinding:

1. Inspect the crankshaft by the magnetic particle method after grinding has been completed to determine whether the grinding operation has produced cracks.
2. Re-tap and check all internal threads with plug gages to determine acceptability. If necessary, heli-coil pulley and flywheel flange bolt holes with the following restrictions: Heli-coil 2 holes maximum per crankshaft end (front or rear). Heli-coil of two adjacent holes at rear (forward end) is not permitted.
3. Demagnetize the crankshaft.
4. Clean the crankshaft and oil passages thoroughly with clean fuel oil.

> **CAUTION:**
>
> **To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.**

5. Dry the crankshaft with compressed air.

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GLOSSARY

The following glossary terms support the Series 60 Engine.

Glossary Terms

AA - ARITHMETICAL AVERAGE: The average total sum of the heights and depths of the ridges and valleys above and below the mean reference line. Limits for journal surfaces are 0.3 µm (12 AA).

AXIAL PROFILE: The deviation of the journal surface from a reference line. Total peak to valley variation per full length of journal.

AXIAL PROFILE SLOPE: The amount of variation tolerable from the mean reference line of the journal in a particular distance (example: 0.0025 mm [0.0001 in.] deviation / 2.54 mm [0.100 in.] length maximum). This specification indicates that any deviation in excess of 0.0025 mm (0.0001 in.) inside a 2.54 mm (0.100 in.) length is not acceptable.

GOULD 1200: Surfanalyzer 1200 surface texture measuring system is used to determine surface parameters such as profile, roundness and waviness. A diamond stylus having a radius of 0.0025-0.013 mm (0.0001 -0.0005 in.) is moved at a constant speed over the surface. Vertical displacements of this stylus are converted into a voltage signal through a linear variable differential transformer.

OIL HOLE WASHOUT: The localized removal of material below the reference surface of an idealized round and straight journal at the trailing edge of the oil hole. This condition is the result of excessive polishing with a soft black apparatus (nut cracker, soft show, rawhide) with lapping paper or cloth in an attempt to improve the surface finish.

A depression (washout) extending beyond the oil hole blend out ellipse reduces the effective bearing area appreciably. This type of polishing is not recommended.

PIN and CRANKPIN: The cylindrical piece to which the connecting rod is attached.

RADIAL CHATTER: This term relates to surface irregularities which are of greater magnitude or spacing than those indicated by the term roughness. Chatter might be the result of vibration or deflection of a cutting tool, of some part of the machine, or the work itself.

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ENGINE PLUG AND DOWEL CHARTS

Following figures support the Series 60 Engine plugs and dowels.

1991 Model Year and Later

See Figure 1-471; see Figure 1-472; see Figure 1-473; see Figure 1-474; see Figure 1-475; and see Figure 1-476 for plug and dowel information supporting 1991 model year and later Series 60 Engines.

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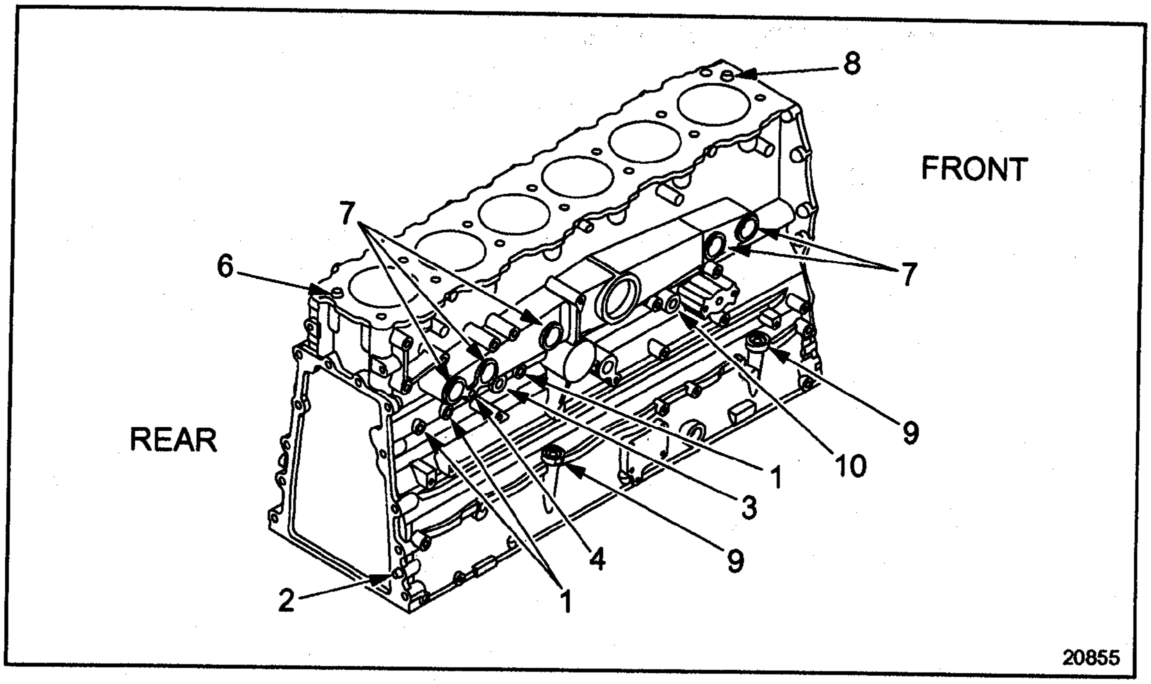


1. 8922327 1/4 in. Pipe Plug (4 places). Torque to 19-24 N·m (14 -18 lb·ft).
2. 8929015 Dowel (Round) * ‡
3. 8929594 3/8 in. Pipe Plug (2 places). Torque to 24-31 N·m (18-23 lb·ft).
4. 8924140 Draincock
5. 8929022 Dowel (Diamond) (2 places)* ‡ §
6. 8929163 Dowel (Diamond) * † §
7. 5139991 Cup Plug (5 places) | |
8. 8929152 Dowel (Round) * †
9. 8922327 1/4 in. Pipe Plug (1 place). Opposite Oil Level Dipstick Location.
10. 8929594 3/8 in. Pipe Plug (2 places). Torque to 24-31 N·m (18-23 lb·ft).

*Installed to a height of 12.0 mm ± 0.5 mm (0.472 in. ± 0.002 in.).

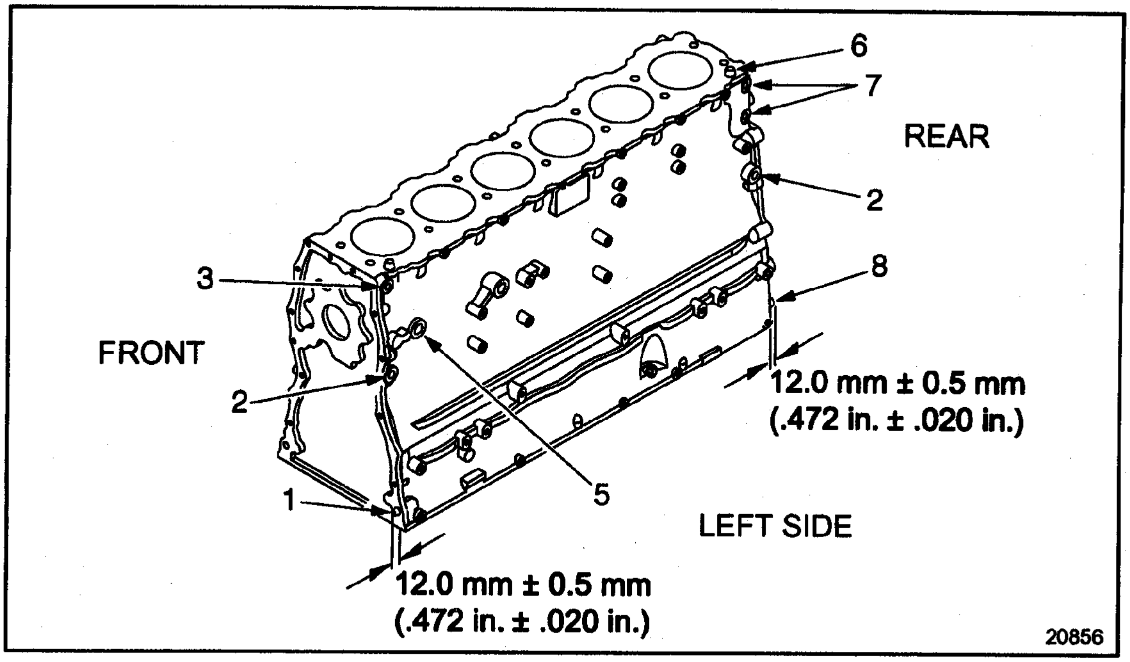
† Use tool J 36244-1 to install.

‡ Use tool J 36224-2 to install.

§ Refer to illustration for orientation of dowels.

| | Cup plug 7 are installed 2.5-3.0 mm (0.098 in. -0.118 in.) below the machined surface. Use tool set J 35653 to install the cup plugs. Coat the outside sealing edge of the cup plugs with a good grade of non-hardening sealant such as Loctite® 620 (or equivalent) before installing.

Figure 1-471 Right Side View



1. 8929022 Dowel (Diamond) (2 places)* ‡ §

2. 8924517 3/8 in. Pipe Plug (2 places). Torque to 24-31 N·m (18-23 lb·ft).

3. 8922327 1/4 in. Pipe Plug (4 places). Torque to 19-24 N·m (14 -18 lb·ft).

4. 8929152 Dowel (Round) * †

5. 8923916 1/2 in. Pipe Plug (1 place). Torque to 31-39 N·m (23-29 lb·ft).

6. 8929163 Dowel (Diamond) * † §

7. 8922327 1/4 in. Pipe Plug (2 places). Required only for pressure testing of cylinder block. In service, these plugs are replaced by the oil pressure sensor (OPS), refer to section 2.24.1, and the oil temperature sensor (OTS), refer to section 2.25.1.

8. 8929015 Dowel (Round) * ‡

*Installed to a height of 12.0 mm ± 0.5 mm (0.472 in. ± 0.002 in.).

† Use tool J 36244 to install.

‡ Use tool J 36244-2 to install.

§ Refer to illustration for orientation of dowels.

Figure 1-472 Left Side View

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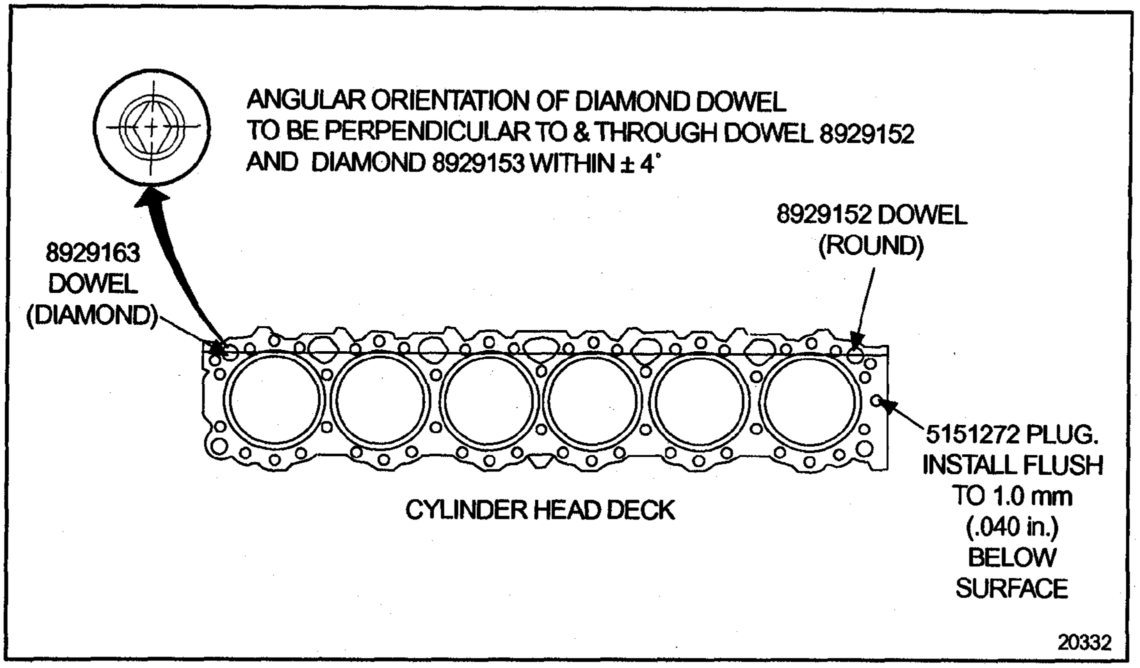

Figure 1-473 Cylinder Head Deck

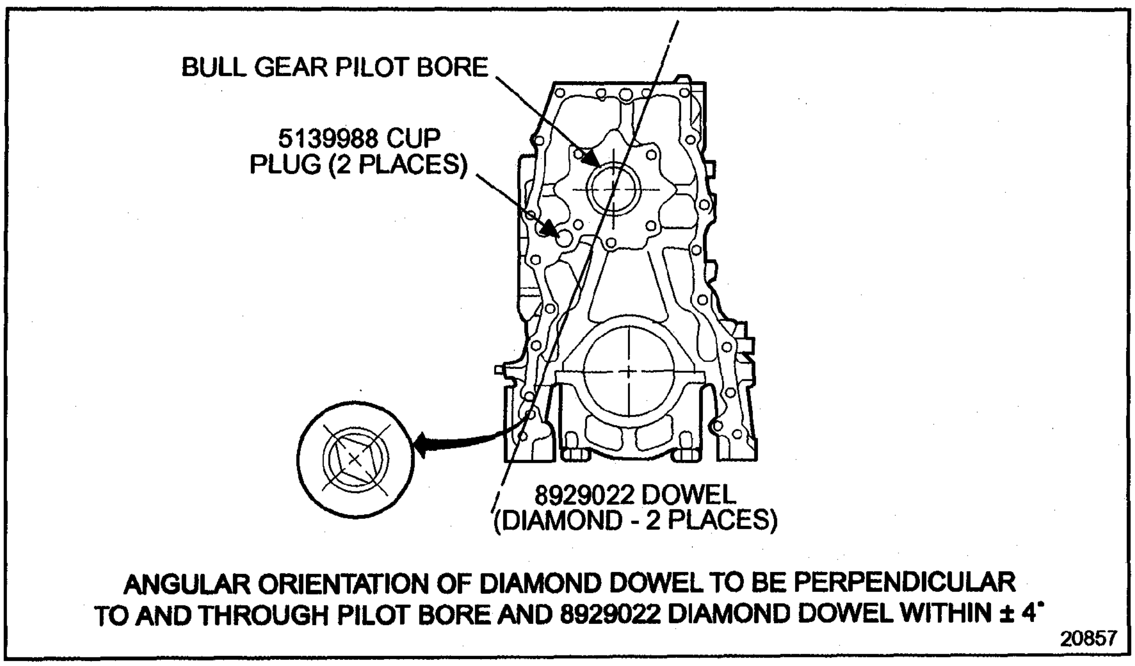

Figure 1-474 Front View

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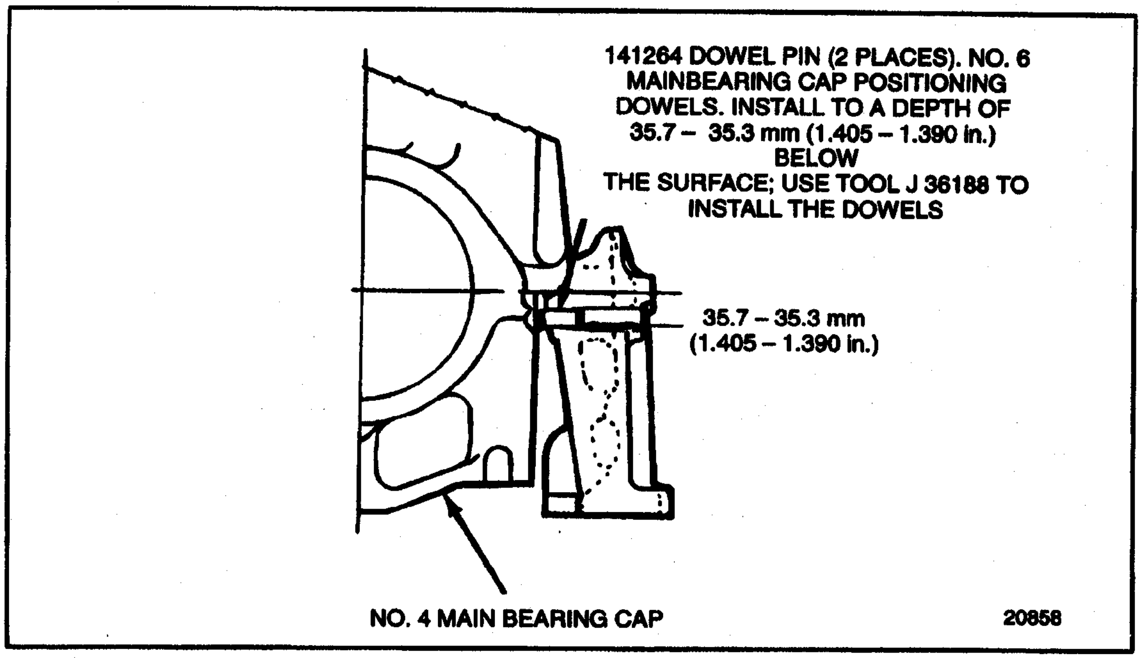
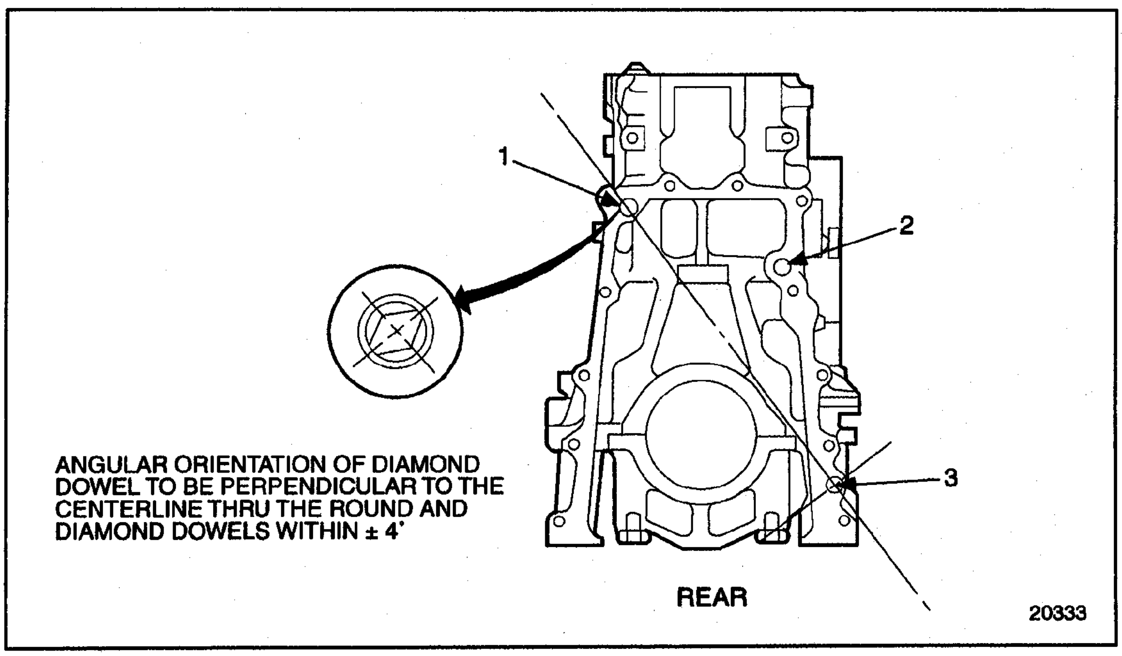


Figure 1-475 No. 6 Main Bearing Cap



1.8929022 Dowel (Diamond-2 Places)

2.5139988 Cup Plug (2 Places)

3.8929015 Dowel (Round)

Figure 1-476 Rear View

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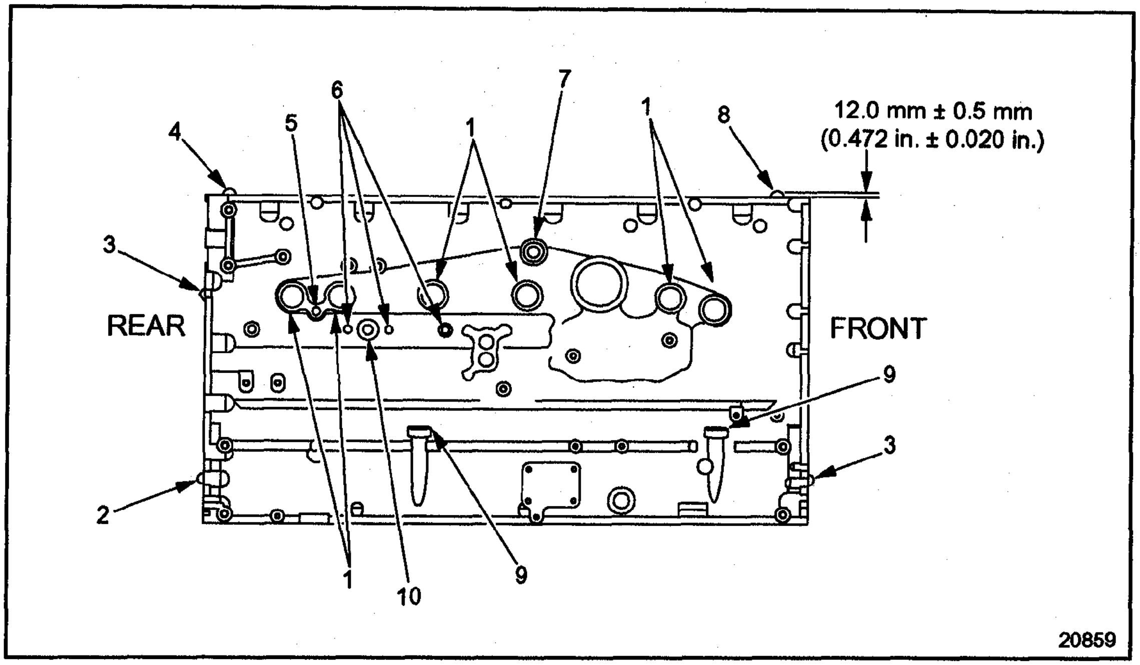
Pre-1991 Engines

See Figure 1-477; see Figure 1-478; see Figure 1-479; see Figure 1-480; see Figure 1-481; see Figure 1-482; see Figure 1-483; see Figure 1-484; and see Figure 1-485 for plug and dowel information supporting pre-1991 model year Series 60 Engines.



1. 5139991 Cup Plug (6 places) ||
2. 8929015 Dowel (Round) * ‡
3. 8929022 Dowel (Diamond) (2 places)* ‡ §
4. 8929153 Dowel (Diamond)
5. 8924140 Draincock
6. 8922327 1/4 in. Pipe Plug (4 places). Torque to 19-24 N·m (14-18 lb·ft).
7. 8923312 3/4 in. Pipe Plug (1 place). Torque to 45-56 N·m (31-39 lb·ft).
8. 8929152 Dowel (Round) * †
9. 8922327 1/4 in. Pipe Plug (4 places). Torque to 19-24 N·m (14-18 lb·ft).
10. 8929594 3/8 in. Pipe Plug (2 places). Torque to 24-31 N·m (18-23 lb·ft).

*Installed to a height of 12.0 mm ± 0.5 mm (0.472 in. ± 0.002 in.).

† Use tool J 36244-1 to install.

‡ Use tool J 36244-2 to install.

§ Refer to illustration for orientation of dowels.

|| Cup plug 7 are installed 2.5-3.0 mm (0.098 -0.118 in.) below the machined surface. Use tool set J 35653 to install the cup plugs. Coat the outside sealing edge of the cup plugs with a good grade of non-hardening sealant such as Loctite® 620 (or equivalent) before installing.

Figure 1-477 Right Side View

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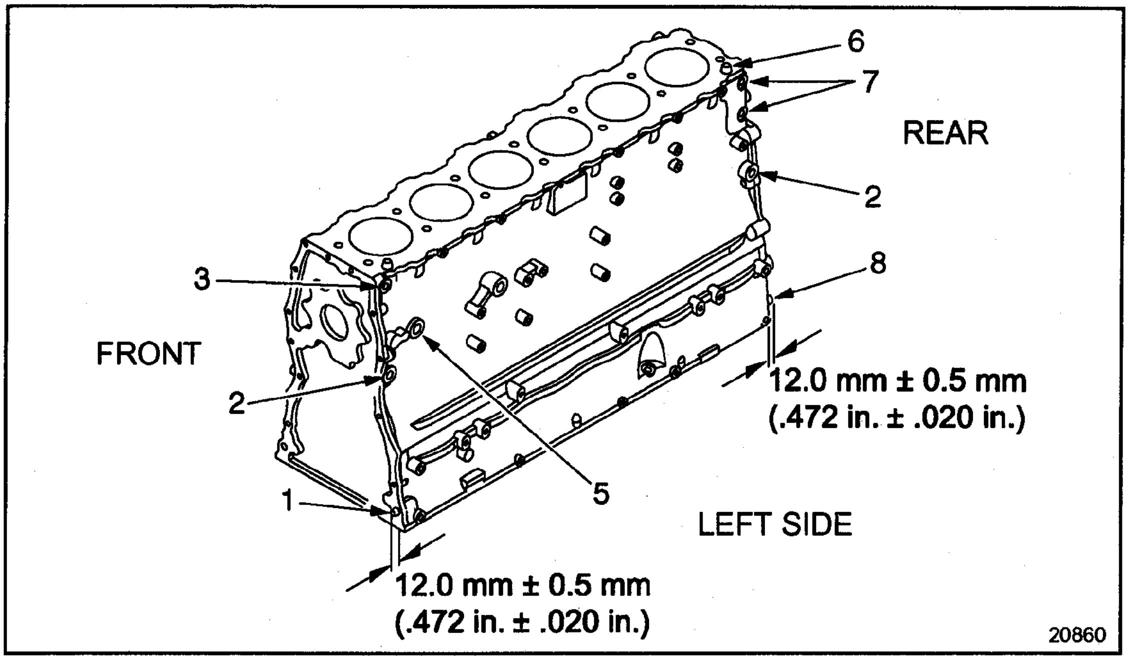

1. 8929022 Dowel (Diamond) (2 places)* ‡ §
2. 8929594 3/8 in. Pipe Plug (2 places) Torque to 24-31 N·m (18-23 lb·ft).
3. 8922327 1/4 in. Pipe Plug (4 places). Torque to 19-24 N·m (14-18 lb·ft).
4. 8929152 Dowel (Round) * †
5. 8923916 1/2 in. Pipe Plug (1 place). Torque to 31-39 N·m (23-29 lb·ft).
6. 8929153 Dowel (Diamond) * † §
7. 8922327 1/4 in. Pipe Plug (2 places). Required only for pressure testing of cylinder block. In service, these plugs are replaced by the oil pressure sensor (OPS).
8. 8929015 Dowel (Round) * ‡

*Installed to a height of 12.0 mm ± 0.5 mm (0.472 in. ± 0.002 in.)

† Use toolJ 36224-1 to install.

‡ Use tool J 36224-2 to install.

§ Refer to illustration for orientation of dowels.

Figure 1-478 Left Side View

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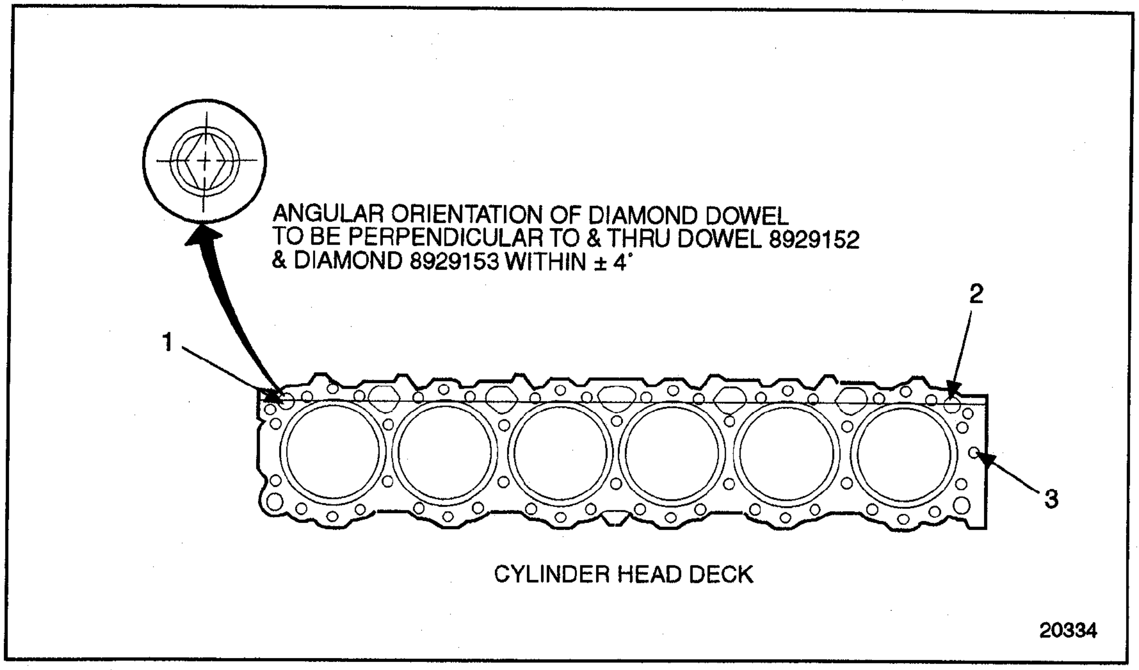
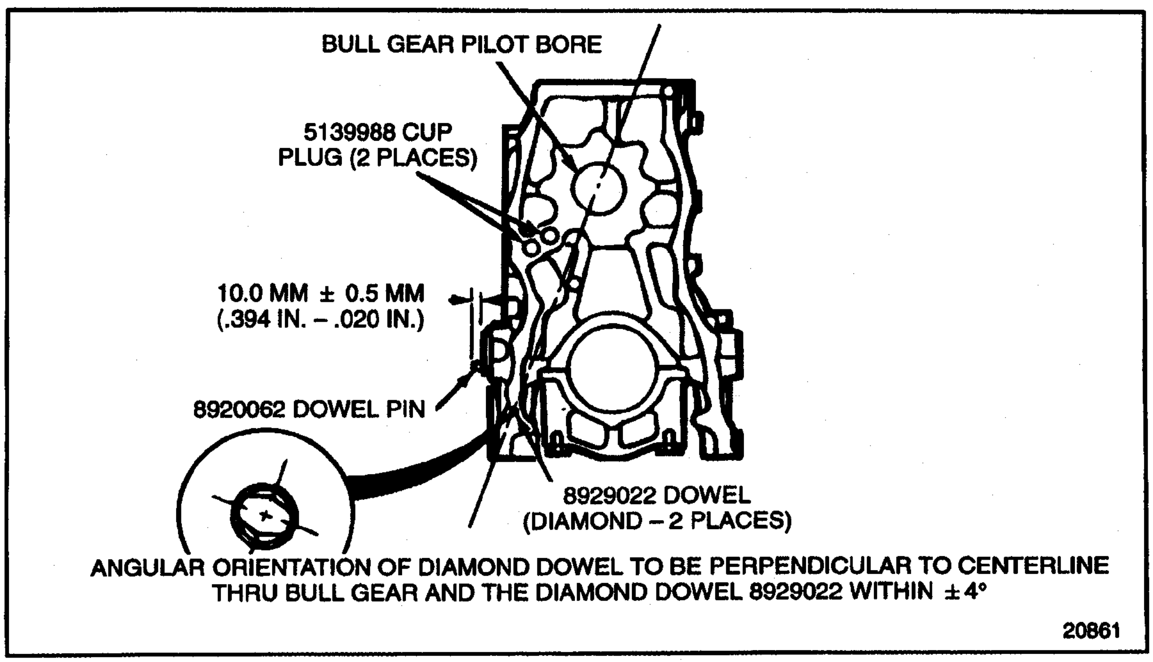


1. 8929163 Dowel (Diamond)
2. 8929152 Dowel
3. 5151272 Plug (1.0 mm [0.040 in.] below surface)

Figure 1-479 Cylinder Head Deck



1. 8929022 Dowel (Diamond-2 Places)
2. 8920062 Dowel Pin
3. 5139988 Cup Plug (2 Places)
4. Bull Gear Pilot Bore

Figure 1-480 Front View

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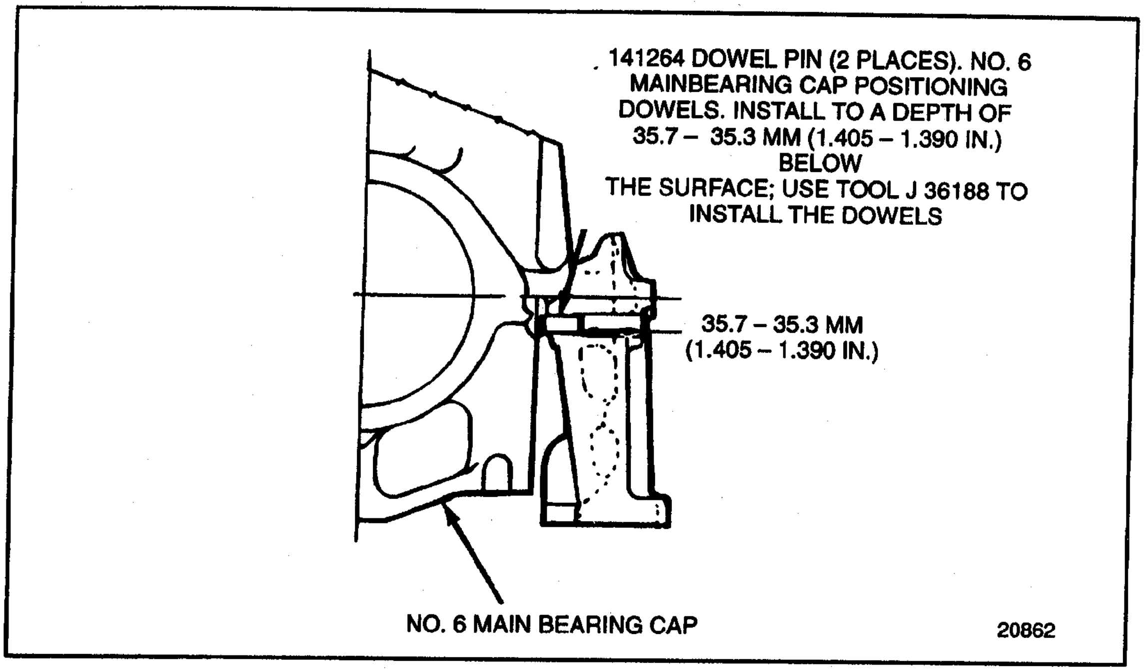
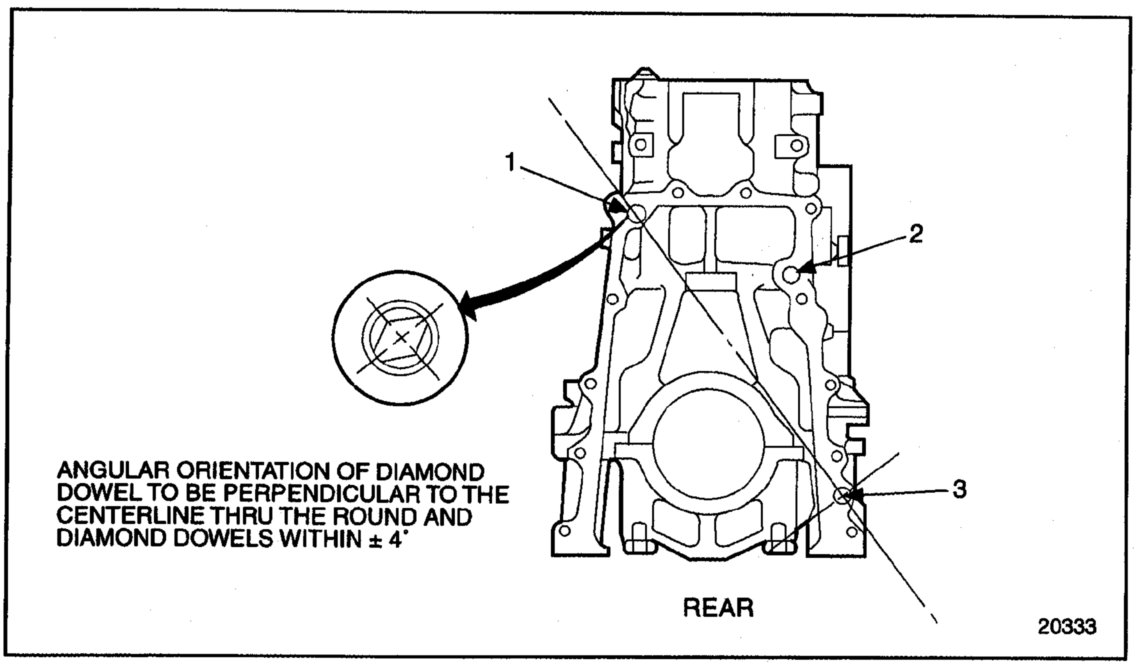


Figure 1-481 No. 6 Main Bearing Cap



1. 8929022 Dowel (Diamond-2 Places)
2. 5139988 Cup Plug (2 Places)
3. 8929015 Dowel (Round)

Figure 1-482 Rear View

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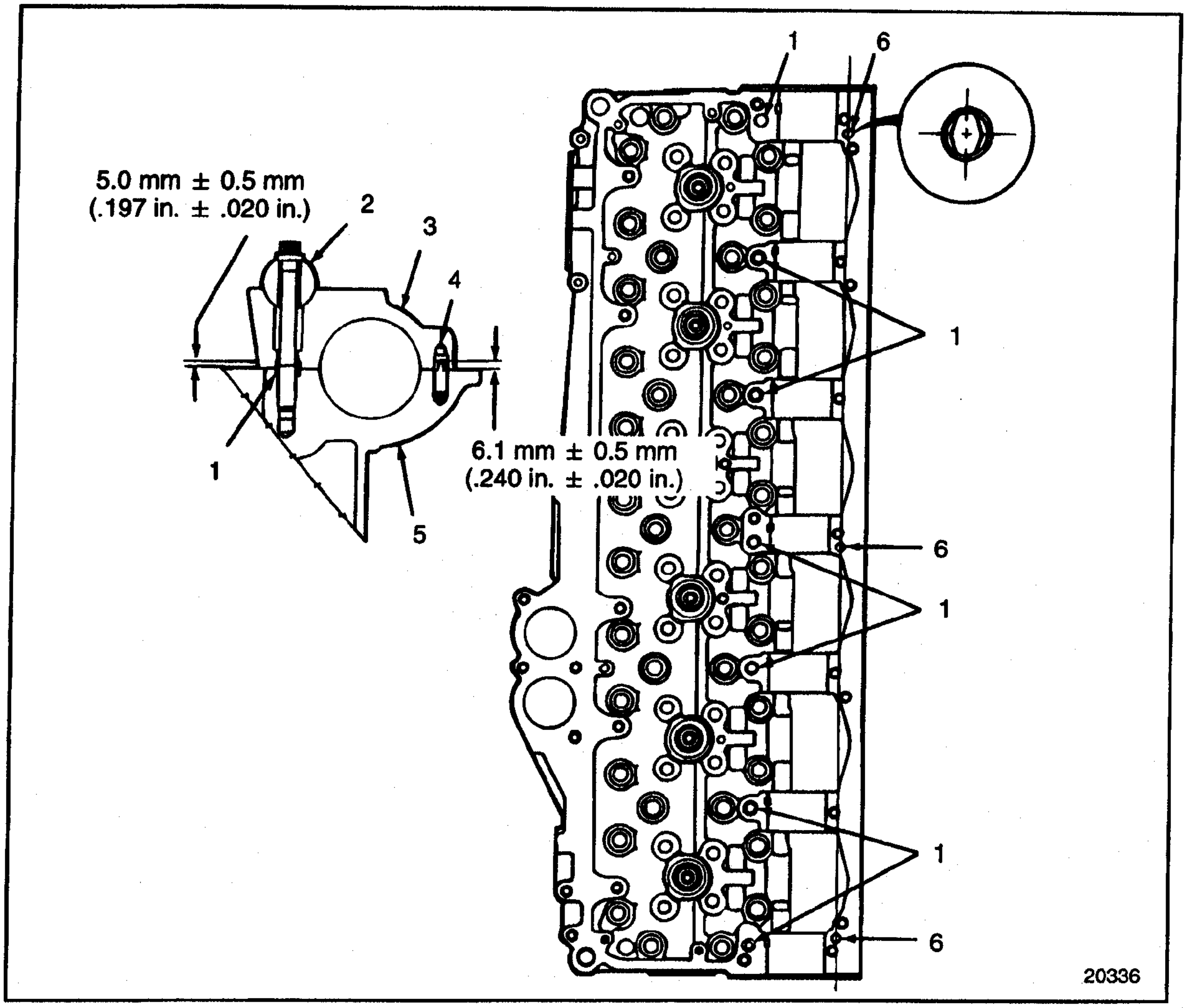

1. 5138638 Dowel (Hollow) (7 places). Install to a height of 5.000 mm ± 0.254 mm (0.197 in. ± 0.010 in.). Bearing Cap
2. Rocker Arm Shaft
3. Camshaft Cap
4. Cylinder Head Dowel
5. Cylinder Head
6. 5143033 Dowel (Diamond) (3 places). Install to a height of 6.1 mm ± 0.5 mm (0.240 in. ± 0.010 in.)

Figure 1-483 Cylinder Head Dowel Chart

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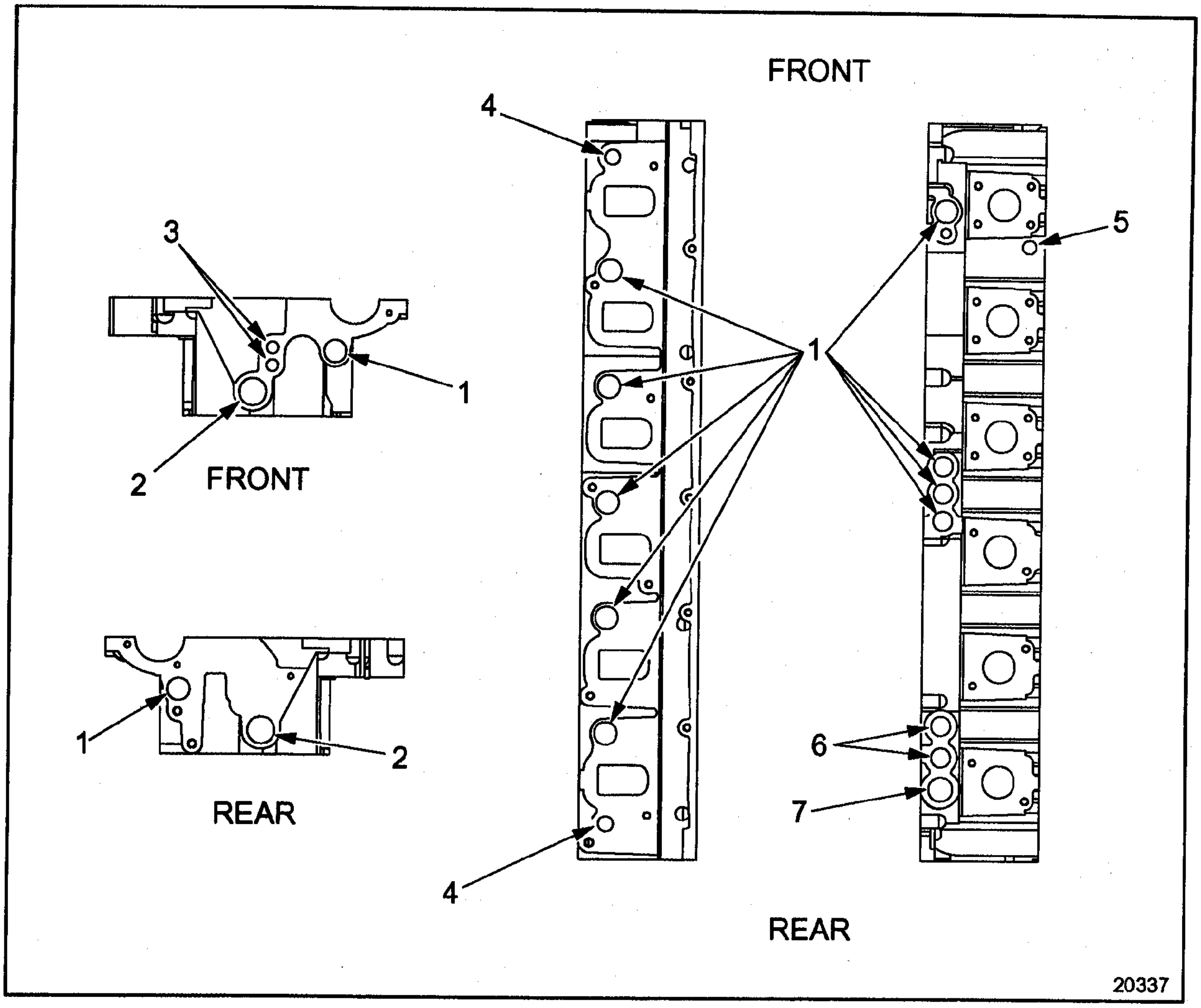

1. 5109157 Cup Plug (11 places) * †

2. 5139991 Cup Plug (2 places) * †

3. 23513197 3/8 in. Pipe Plug (Square Drive) (2 places). Torque to 30-33 N·m (22-24 lb·ft).

4. 8923916 1/2 in. Pipe Plug (2 places). Torque to 31-39 N·m (23-29 lb·ft).

5. 8926991 Fuse Plug. Torque to 19-24 N·m (14-18 lb·ft).

6. 8923313 3/4 in. Pipe Plug (2 places). Torque to 45-56 N·m (33-41 lb·ft).

7. 8924750 1 in. Pipe Plug (1 place). Torque to 102-127 N·m (75-94 lb·ft).

*Cup plugs 1 and 2 are installed 2.5-3.0 mm (0.098 in. -0.118 in.) below the machined surface.

† Use tool set J 35653 to install the cup plugs. Coat the outside sealing edge of the cup plugs with a good grade of non-hardening sealant such as Loctite® 620 (or equivalent) before installing.

Figure 1-484 Cylinder Head Cup, Pipe Plug, and Dowel Chart

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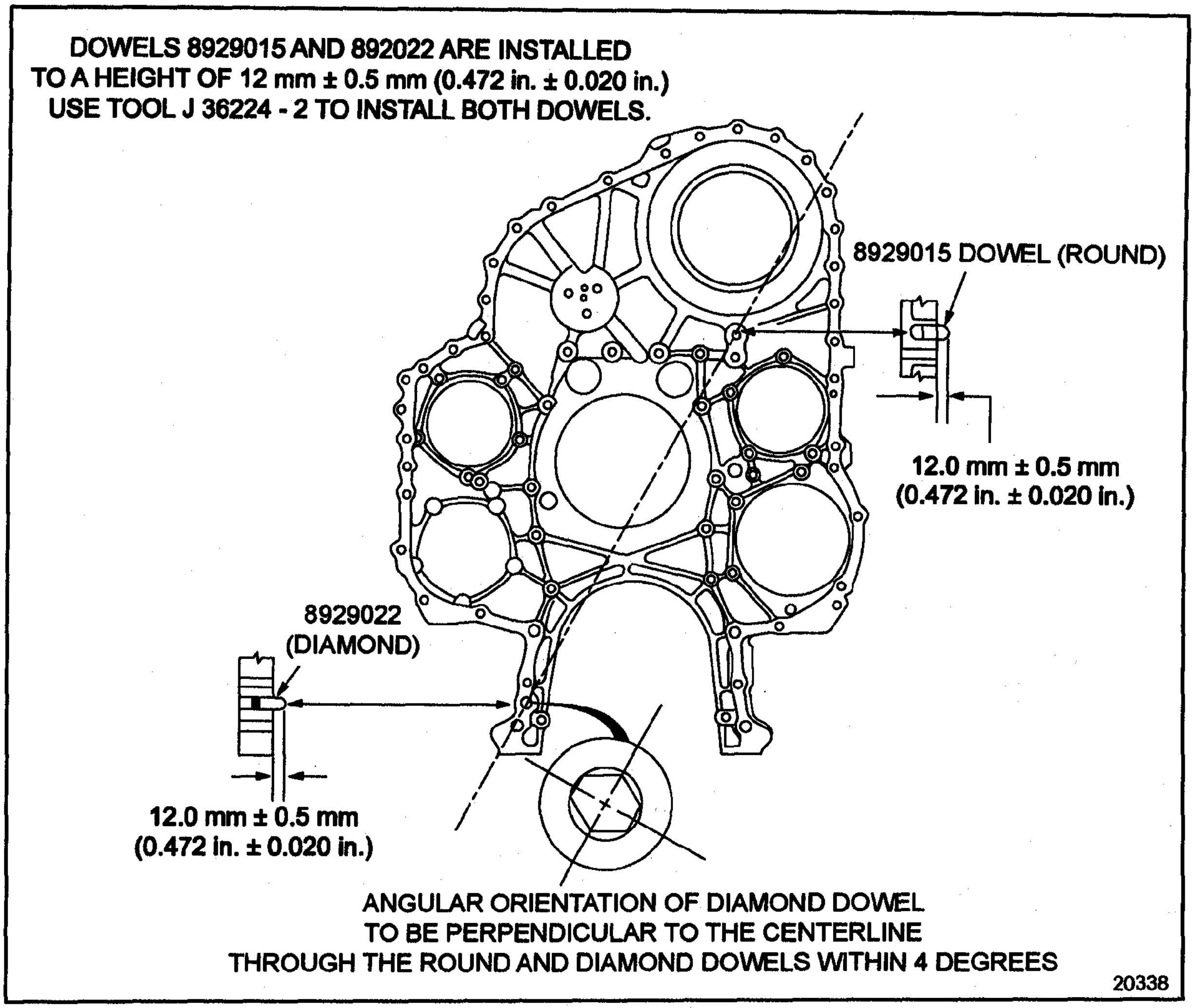

Figure 1-485 Gear Case Dowel Chart

SPECIFICATIONS

Specifications, clearances and wear limits are listed below. It should be specifically noted that the clearances apply only when all new parts are used at the point where the various specifications apply. This also applies to references within the text of the manual. The column entitled "Limits" in this chart lists the amount of wear or increase of clearance which can be tolerated in used engine parts and still ensure satisfactory performance. It should be emphasized that the figures given as "Limits" must be qualified by the judgment of personnel responsible for installing new parts. These wear limits are, in general, listed only for the parts more frequently replaced in engine overhaul work. For additional information, refer to the text.

Table of Specifications, New Clearances, and Wear Limits

These limits also apply to oversize and undersize parts.

Refer to the following tables to obtain specifications, new clearances, and wear limits for the Series 60 Engine:

1. Cylinder block is listed in Table 1-15.
2. Cylinder liner is listed in Table 1-16.
3. Cross-head piston and piston rings are listed in Table 1-17.
4. Articulated 14L piston and piston rings are listed in Table 1-18.
5. Cross-head cast-iron piston pin is listed in Table 1-19.
6. Articulated 14L piston pin is listed in Table 1-20.
7. Crankshaft is listed in Table 1-21.
8. Connecting rod bearing is listed in Table 1-22.
9. Closed—end connecting rod bushing is listed in Table 1-23.
10. Main bearing is listed in Table 1-24.
11. Camshaft is listed in Table 1-25.
12. Camshaft bearing is listed in Table 1-26.
13. Camshaft drive gear is listed in Table 1-27.
14. Idler gear is listed in Table 1-28.
15. Crankshaft timing gear is listed in Table 1-29.
16. Bull gear is listed in Table 1-30.
17. Cylinder head is listed in Table 1-31.
18. Intake valve (diesel) seat insert is listed in Table 1-32.
19. Intake valve (natural gas) seat insert is listed in Table 1-33.
20. Exhaust valve (diesel) seat insert is listed in Table 1-34.
21. Exhaust valve (natural gas) seat insert is listed in Table 1-35.

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22. Intake valves (diesel) are listed in Table 1-36.
23. Intake valves (natural gas) are listed in Table 1-37.
24. Exhaust valves (diesel) are listed in Table 1-38.
25. Exhaust valves (natural gas) are listed in Table 1-39.
26. Valve guides (diesel) are listed in Table 1-40.
27. Valve guides (natural gas) are listed in Table 1-41.
28. Rocker arms and shaft (diesel) are listed in Table 1-42.
29. Rocker arms and shaft (natural gas) are listed in Table 1-43.
30. Cam follower roller is listed in Table 1-44.

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Engine Part (Standard Size, New)	Minimum	Maximum	Limits
Block Bore: Diameter - 15.0 mm (0.60 in.) form top of block	149.050 mm (5.868 in.)	149.120 mm (5.871 in.)	-
Diameter - 235.0 mm (9.25 in.) from top of block	146.050 mm (5.750 in.)	146.125 mm (5.753 in.)	0.076 mm (0.003 in.)
Diameter - 270.0 mm (10.63 in.) from top of block	146.050 mm (5.750 in.)	146.125 mm (5.753 in.)	0.076 mm (0.003 in.)
Out-of-round	-	-	0.0254 mm (0.001 in.)
Taper (lower bore)	-	-	0.0254 mm (0.001 in.)
Cylinder Liner Counter Bore:	-	-	-
Diameter	157.15 mm (6.186 in.)	157.25 mm (6.191 in.)	-
* Depth	8.9256 mm (0.3514 in.)	8.9746 mm (0.3533 in.)	-
Main Bearing Bore:	-	-	-
Inside diameter (vertical axis)	133.00 mm (5.236 in.)	133.020 mm (5.237 in.)	-
Top Surface of Block:	-	-	-
Center of main bearing bore to top of block	436.50 mm (17.1850 in.)	436.62 mm (17.1897 in.)	-
Flatness (transverse)	-	-	0.076 mm (0.003 in.)
Flatness (longitudinal)	-	-	0.127 mm (0.005 in.)

* The bottom of the counterbore must not vary in depth more than 0.04 mm (0.0015 in.). No two adjacent counterbores can vary in depth more than 0.025 mm (0.001 in.) when gaged longitudinally.

Table 1-15 Cylinder Block

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Engine Part (Standard Size, New)	Minimum	Maximum	Limits
Outside Diameter (below flange)	148.95 mm (5.864 in.)	149.00 mm (5.866 in.)	-
Outside Diameter (below crevice seal groove)	145.975 mm (5.747 in.)	146.025 mm (5.749 in.)	-
Outside Diameter (between "D" ring grooves)	145.975 mm (5.747 in.)	146.025 mm (5.749 in.)	-
Flange Thickness	8.960 mm (0.3527 in.)	9.00 mm (0.3543 in.)	-
Inside Diameter	130.00 mm (5.118 in.)	130.05 mm (5.120 in.)	-
14 L - Inside Diameter	133.00 mm (5.240 in.)	133.05 mm (5.242 in.)	-
Out-of-Round (inside diameter)	-	-	0.025 mm (0.001 in.)
Taper	-	-	
Height of Flange Above Block	0.000 mm (0.000 in.)	0.076 mm (0.003 in.)	-
Variation in Height between Adjacent Liners	-	-	0.05 mm (0.002 in.)

Table 1-16 Cylinder Liner

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Engine Part (Standard Size, New)	Minimum	Maximum	Limits
At top (above firing ring)	128.63 mm (5.064 in.)	128.83 mm (5.072 in.)	-
Below (2nd) compression ring	129.776 mm (5.1093 in.)	129.845 mm (5.112 in.)	-
Compression Rings	-	-	-
Gap (2.5 mm [.0985 in.] chrome fire ring)	0.40 mm (0.016 in.)	0.87 mm (0.034 in.)	-
Gap (3.5 mm plasma [.1379 in.] fire ring) (High sulfur fuel export engines)	0.51 mm (0.020 in.)	0.87 mm (0.034 in.)	-
Gap (No. 2 compression ring)	0.79 mm (0.031 in.)	1.30 mm (0.051 in.)	-
Clearance ring-to-groove:	-	-	-
Top (keystone fire ring)	must be checked with Piston Ring Land gage J 35884-A	-	-
No. 2 (keystone compression ring)	must be checked with Piston Ring Land Gage J 38689	-	-
Oil Control Rings	-	-	-
Gap	0.40 mm (0.016 in.)	0.81 mm (0.032 in.)	-
Clearance	0.03 mm (0.001 in.)	0.11 mm (0.004 in.)	-
* Piston Pin Bore in Dome (3-piece bushing)	51.000 mm (2.0078 in.)	51.025 mm (2.0088 in.)	-
Piston Skirt to Liner Clearance (thrust faces)	0.050 mm (0.0020 in.)	0.183 mm (0.0072 in.)	-

* Both ends must be measured on vertical and horizontal planes.

Table 1-17 Cross-head Piston and Piston Rings

Engine Part (Standard Size, New)	Minimum	Maximum	Limits
At top (above firing ring)	131.60 mm (5.185 in.)	131.70 mm (5.189 in.)	-
Below (2nd) compression ring	132.685 mm (5.2278 in.)	132.715 mm (5.2290 in.)	-
Compression Rings	-	-	-
Gap (3.0 mm chrome fire ring)	0.60 mm (0.0236 in.)	0.80 mm (0.0315 in.)	-
Gap (No. 2 compression ring)	0.63 mm (0.0248 in.)	.98 mm (0.0386 in.)	-
Clearance ring-to-groove:	-	-	-
Top (keystone fire ring)	must be checked with Piston Ring Land J 35884-A	-	-
No. 2 (keystone compression ring)	must be checked with Piston Ring Land J 38689	-	-
Oil Control Rings	-	-	-
Gap	0.21 mm (0.0083 in.)	0.51 mm (0.0201 in.)	-
Clearance	0.03 mm (0.001 in.)	0.11 mm (0.004 in.)	-
* Piston Pin Bore in Dome	55.05 mm (2.1990 in.)	55.065 mm (21696 in.)	-
Piston Skirt to Liner Clearance (thrust faces)	0.050 mm (0.0020 in.)	0.183 mm (0.0072 in.)	-

* Both ends must be measured on vertical and horizontal planes.

Table 1-18 Articulated 14L Piston and Piston Rings

Engine Part (Standard Size, New)	Minimum	Maximum	Limits
Cast Iron Piston Pin Diameter	44.99 mm (1.7712 in.)	45.00 mm (1.7716 in.)	44.96 mm (1.770 in.)

Table 1-19 Cross-head Cast Iron Piston Pin

Engine Part (Standard Size, New)	Minimum	Maximum	Limits
Steel Piston Pin Diameter	54.992 mm (2.1667 in.)	55.000 mm (2.1670 in.)	54.96 mm (2.164 in.)

Table 1-20 Articulated Steel Piston Pin

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Engine Part (Standard Size, New)	Minimum	Maximum	Limits
Journal Diameter (main bearing)	124.968 mm (4.920 in.)	125.000 mm (4.921 in.)	-
Journal Diameter (connecting rod bearing)	84.963 mm (3.345 in.)	85.000 mm (3.346 in.)	-
14L - Journal Diameter (connecting rod bearing)	94.975 mm (3.739 in.)	95.000 mm (3.740 in.)	-
Journal Out-of-Round (ROD)	-	-	0.008 mm (0.0003 in.)
Journal Out-of-Round (MAIN)	-	-	0.0127 mm (0.0005 in.)
Journal Taper: Main Bearing	-	-	0.0127 mm (0.0005 in.)
Connecting Rod (full length)	-	-	0.008 mm (0.0003 in.)
Connecting Rod (half length)	-	-	0.004 mm (0.00016 in.)
* Run-out on Journals-Total Indicator Reading (mounted on No. 1 and 7 Journals): At Journals No. 2 and 6	-	-	0.075 mm (0.003 in.)
At Journals No. 3 and 5	-	-	0.127 mm (0.005 in.)
At Journal No. 4	-	-	0.152 mm (0.006 in.)
No. 6 Main Bearing Journal Thrust Width	49.45 mm (1.947 in.)	49.53 mm (1.950 in.)	-
Thrust Washer Thickness	3.48 mm (0.137 in.)	3.56 mm (0.140 in.)	-
End Play (end thrust clearance)		0.419 mm (0.0165 in.)	-

* Run-out tolerance given for guidance when regrinding crankshaft. When the run-out on adjacent journals is in the opposite direction, the sum must not exceed 0.076 mm (0.003 in.) total indicator reading. When the run-out on adjacent journals is in the same direction, the difference must not exceed 0.076 (0.003 in.) total indicator reading.

Table 1-21 Crankshaft

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Engine Part (Standard Size, New)	Minimum	Maximum	Limits
Bearing-to-Journal Clearance	0.040 mm (0.0016 in.)	0.127 mm (0.005 in.)	0.152 mm (0.006 in.)
Bearing Thickness 90 degrees from Parting Line	3.108 mm (0.1224 in.)	3.125 mm (0.1230 in.)	3.086 mm (0.1215 in.)
14L Bearing Thickness 90 degrees from Parting Line	3.111 mm (0.1225 in.)	3.124 mm (0.1230 in.)	-

Table 1-22 Connecting Rod Bearing

Engine Part (Standard Size, New)	Minimum	Maximum	Limits
Diameter	55.055 mm (2.16752 in.)	55.070 mm (2.16811 in.)	55.100 mm (2.16929 in.)

Table 1-23 Closed-End Connecting Rod Bushing

Engine Part (Standard Size, New)	Minimum	Maximum	Limits
Bearing-to-Journal Clearance	0.040 mm (0.0016 in.)	0.127 mm (0.005 in.)	0.151 mm (0.006 in.)
Bearing Thickness 90 degrees from Parting Line	3.960 mm (0.1559 in.)	3.977 mm (0.1566 in.)	3.937 mm (0.1550 in.)

Table 1-24 Main Bearing

Engine Part (Standard Size, New)	Minimum	Maximum	Limits
Diameter (bearing journals)	64.974 mm (2.558 in.)	65.000 mm (2.5559 in.)	-
Run-out at Center Bearing (when mounted on end bearings should not exceed)	-	-	0.050 mm (0.002 in.)
End Thrust	0.076 mm (0.003 in.)	0.381 mm (0.015 in.)	-

Table 1-25 Camshaft

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Engine Part (Standard Size, New)	Minimum	Maximum	Limits
Bearing-to-Journal Clearance	0.089 mm (0.0035 in.)	0.166 mm (0.0065 in.)	0.191 mm (0.0075 in.)
Bearing Thickness (90 degrees from Parting Line)	1.941 mm (0.0764 in.)	1.954 mm (0.0769 in.)	-

Table 1-26 Camshaft Bearing

Engine Part (Standard Size, New)	Minimum	Maximum	Limits
Camshaft Drive Gear Bore	52.00 mm (2.0472 in.)	52.03 mm (2.0484 in.)	-
Outside Diameter:	-	-	-
Camshaft Hub	52.10 mm (2.0511 in.)	52.13 mm (2.0523 in.)	-
* Interference (gear-to-hub)	0.07 mm (0.0027 in.)	0.13 mm (0.0051 in.)	-
Backlash -(cam gear-to-adjustable idler)	0.051 mm (0.002 in.)	0.229 mm (0.009 in.)	0.305 mm (0.012 in.)

Table 1-27 Camshaft Drive Gear

Engine Part (Standard Size, New)	Minimum	Maximum	Limits
Backlash (adjacent idler-to-cam idler)	0.051 mm (0.002 in.)	0.229 mm (0.009 in.)	0.305 mm (0.012 in.)

* A minimum force of 20.0 kN (4500 lb.) must be obtained when pressing the camshaft drive gear to the drive gear hub.

Table 1-28 Idler Gear

Engine Part (Standard Size, New)	Minimum	Maximum	Limits
11.1 Liter Engine	132.860 mm (5.2307 in.)	132.900 mm (5.2322 in.)	-
12.7 Liter Engine	133.561 mm (5.2583 in.)	133.600 mm (5.2598 in.)	-
* Interference (gear-to-crankshaft)	0.076 mm (0.003 in.)	0.102 mm (press) (0.004 in.) (press)	-
Backlash:	-	-	-
Crank Gear-to-Bull Gear	0.051 mm (0.002 in.)	0.229 mm (0.009 in.)	0.305 mm (0.012 in.)
Crankshaft Gear-to-Oil Pump Drive Gear	0.051 mm (0.002 in.)	0.229 mm (0.009 in.)	0.305 mm (0.012 in.)

*A minimum force of 30 kN (6750 lb) must be obtained when pressing the crankshaft timing gear on the crankshaft.

Table 1-29 Crankshaft Timing Gear

Engine Part (Standard Size, New)	Minimum	Maximum	Limits
Backlash (Bull Gear-to-Water Pump, Accessory, Fuel Pump or Air Compressor Drive Gears)	0.051 mm (0.002 in.)	0.229 mm (0.009 in.)	0.305 mm (0.012 in.)

Table 1-30 Bull Gear

Engine Part (Standard Size, New)	Minimum	Maximum	Limits
Flatness (transverse)	-	-	0.076 mm (0.003 in.)
Flatness (longitudinal)	-	-	0.279 mm (0.011 in.)
Distance between Rail and Fire Deck (new)	164.85 mm (6.490 in.)	165.13 mm (6.501 in.)	-
Valve Insert Counterbore:	-	-	-
Intake Valve:	-	-	-
Diameter	46.12 mm (1.8157 in.)	46.15 mm (1.8169 in.)	-
Depth	11.46 mm (0.4511 in.)	11.76 mm (0.4629 in.)	-
Valve Insert Counterbore:	-	-	-
Exhaust Valve:	-	-	-
Diameter	41.26 mm (1.6244 in.)	41.29 mm (1.6255 in.)	-
Depth	10.70 mm (0.4212 in.)	11.00 mm (0.4330 in.)	-

Table 1-31 Cylinder Head

Engine Part (Standard Size, New)	Minimum	Maximum	Limits
Outside Diameter	46.20 mm (1.8188 in.)	46.22 mm (1.8196 in.)	-
Seat Width	0.48 mm (0.019 in.)	2.14 mm (0.084 in.)	-
Valve Seat Run-out	-	-	0.05 mm (0.002 in.)
Standard Seat Thickness	5.55 mm (0.282 in.)	7.256 mm (0.2857 in.)	-

Table 1-32 Intake Valve Seat Inserts (Diesel)

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Engine Part (Standard Size, New)	Minimum	Maximum	Limits
Outside Diameter	46.20 mm (1.8188 in.)	46.23 mm (1.820 in.)	-
Seat Width	0.83 mm (0.033 in.)	4.24 mm (0.167 in.)	-
Valve Seat Run-out	-	-	0.05 mm (0.002 in.)
Standard Seat Thickness	6.756 mm (0.266 in.)	6.858 mm (0.133 in.)	-

Table 1-33 Intake Valve Seat Inserts (Natural Gas)

Engine Part (Standard Size, New)	Minimum	Maximum	Limits
Outside Diameter	41.34 mm (1.627 in.)	41.36 mm (1.628 in.)	-
Seat Width	0.67 mm (0.026 in.)	2.66 mm (0.105 in.)	-
Valve Seat Run-out	-	-	0.05 mm (0.002 in.)
Standard Valve Seat Thickness	6.261 mm (0.2465 in.)	6.362 mm (0.2505 in.)	-

Table 1-34 Exhaust Valve Seat Inserts (Diesel)

Engine Part (Standard Size, New)	Minimum	Maximum	Limits
Outside Diameter	41.34 mm (1.627 in.)	41.36 mm (1.628 in.)	-
Seat Width	0.92 mm (0.036 in.)	3.37 mm (0.133 in.)	-
Valve Seat Run-out	-	-	0.05 mm (0.002 in.)
Standard Valve Seat Thickness	5.958 mm (0.234 in.)	6.060 mm (0.238 in.)	-

Table 1-35 Exhaust Valve Seat Inserts (Natural Gas)

Engine Part (Standard Size, New)	Minimum	Maximum	Limits
Stem Diameter	8.679 mm (0.3417 in.)	8.699 mm (0.3425 in.)	-
Valve Head-to-Cylinder Head 30 degrees (recess)	1.4 mm (0.055 in.)	1.8 mm (0.071 in.)	-

Table 1-36 Intake Valves (Diesel)

Engine Part (Standard Size, New)	Minimum	Maximum	Limits
Stem Diameter	8.725 mm (0.3435 in.)	8.745 mm (0.3443 in.)	-
Valve Head-to-Cylinder Head 30 degrees (recess)	0.80 mm (0.031 in.)	1.47 mm (0.058 in.)	-

Table 1-37 Intake Valves (Natural Gas)

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Engine Part (Standard Size, New)	Minimum	Maximum	Limits
Stem Diameter	P/N 23506350 8.679 mm (0.3417 in.) P/N 23524521 8.701 mm (0.3426 in.)	P/N 23506350 8.699 mm (0.3425 in.) P/N 23524521 8.721 mm (0.3433 in.)	-
Valve Head-to-Cylinder Head 30 degrees (recess)	1.4 mm (0.055 in.)	1.8 mm (0.071 in.)	-

Table 1-38 Exhaust Valves (Diesel)

Engine Part (Standard Size, New)	Minimum	Maximum	Limits
Stem Diameter	8.712 mm (0.3430 in.)	8.732 mm (0.3438 in.)	-
Valve Head-to-Cylinder Head 20 degrees (recess)	0.82 mm (0.032 in.)	1.34 mm (0.053 in.)	-

Table 1-39 Exhaust Valves (Natural Gas)

Engine Part (Standard Size, New)	Minimum	Maximum	Limits
Height Above Cylinder Head	37.5 mm (1.476 in.)	38.0 mm (1.496 in.)	-
Diameter (inside)	8.763 mm (0.345 in.)	8.785 mm (0.346 in.)	-
Clearance (valve-to-guide, maximum)	-	-	Intake Valve P/N 8929590 0.152 mm (0.006 in.) Exhaust Valve P/N 23506350 0.152 mm (0.006 in.) Exhaust Valve P/N 23524521 0.101 mm (0.004 in.)

Table 1-40 Valve Guides (Diesel)

Engine Part (Standard Size, New)	Minimum	Maximum	Limits
Height Above Cylinder Head	37.5 mm (1.476 in.)	38.0 mm (1.496 in.)	-
Diameter (inside)	8.759 mm (0.345 in.)	8.785 mm (0.346 in.)	-
Clearance (valve-to-guide, maximum)	-	-	0.060 mm (0.002 in.) Intakes 0.073 mm (0.003 in.) Exhaust

Table 1-41 Valve Guides (Natural Gas)

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Engine Part (Standard Size, New)	Minimum	Maximum	Limits
Rocker Shaft Diameter	35.992 mm (1.417 in.)	36.017 mm (1.418 in.)	35.941 mm (1.415 in.)
Steel Rocker Arm Bushing Diameter (inside)	36.017 mm (1.418 in.)	36.118 mm (1.422 in.)	36.195 mm (1.425 in.)
Clearance (shaft to bushing) (maximum): Bronze Bushing	-	-	0.057 mm (0.0022 in.)
Steel Bushing	-	-	0.254 mm (0.010 in.)

Table 1-42 Rocker Arms and Shafts (Diesel)

Engine Part (Standard Size, New)	Minimum	Maximum	Limits
Rocker Shaft Diameter	35.992 mm (1.417 in.)	36.017 mm (1.418 in.)	35.941 mm (1.415 in.)
Clearance (shaft to bushing) (maximum): Bronze Bushing	-	-	0.057 mm (0.0022 in.)

Table 1-43 Rocker Arms and Shafts (Natural Gas)

Engine Part (Standard Size, New)	Minimum	Maximum	Limits
Diameter	37.95 mm (1.494 in.)	38.05 mm (1.498 in.)	-
Rollers and Pins:	-	-	-
Clearance (pin-to-bushing) (maximum) (horizontal)	-	-	0.08 mm (0.003 in.)
Side Clearance (roller-to-follower) (maximum)	-	-	0.40 mm (0.015 in.)

Table 1-44 Cam Follower Roller

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Exceptions to Standard Fastener Torque Specifications

Listed in Table 1-45 are exceptions to standard fastener torque specifications supporting the Series 60 Engine.

Section	Fastener	Size	N · m	(lb·ft)
Refer to section 1.6.3.1	Breather Housing to Rocker Cover Cap	-	2.5	1.833
Refer to section 1.2.5	Cylinder Head Bolt (torque twice)	M16 X 2.0	250 - 285	(185 - 210)
Refer to section 2.3.5	Bolt, Inj. Harness Mounting Flange	M8 X 1.25	10-15	(7-11)
Refer to section 1.6.8 and refer to section 1.6.9	Bolt, Rocker Cover-to Cylinder Head	3/8-16	20-25	(15-18)
Refer to section 1.9.3	Bolt, Main Bearing Cap	M20 X 2.5	470-530	(347-391)
Refer to section 1.10.3	Plug, Gear Case Adj. Idler Oil Hole	5/16-24	15-20	(11-15)
Refer to section 1.13.3	Bolt, Front Pulley	9/16-18	182-210	(134-155)
Refer to section 1.16.3	Bolt, Flywheel Hsg. Mounting	M12 X 1.75	112-126	(83-93)
Refer to section 1.14.3	Bolt, Flywheel	9/16-18	68(+120°)	(50)(+120°)
Refer to section 1.19.4	Nut, Connecting Rod	M14 X 1.5	160-185	(118-137)
Refer to section 1.23.6	Bolt, Camshaft Bearing Cap	M12 X 1.75	126-146	(93-108)
Refer to section 1.3.3	Bolt, Rocker Arm Shaft	M12 X 1.75	126-146	(93-108)
Refer to section 1.23.6	Nut, Nos. 1&7 Camshaft Cap	M12 X 1.75	126-146	(93-108)
Refer to section 1.23.6	Stud, Nos. 1&7 Camshaft Cap	M12 X 1.75	126-146	(93-108)
Refer to section 1.24.4	Bolt (Solid), Camshaft Drive Gear	M18 X 1.5	75	(55 + 120°)
Refer to section 1.25.3	Nut, Adjustable Idler Assy.	M12 X 1.75	57-67	(42-49)
Refer to section 1.26.3	Bolt, Bull Gear Assy-to-Block	M12 X 1.75	101-116	(75-86)
Refer to section 1.26.3	Nut, Bull Gear Assy (LH thread)	2-1/2-18	940-1000	(693-738)
Refer to section 1.28.4	Nut, Accessory Drive Pulley	M24 X 1.0	220-250	(162-185)

Table 1-45 Exceptions to Standard Fastener Torque Specifications

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2 FUEL SYSTEM

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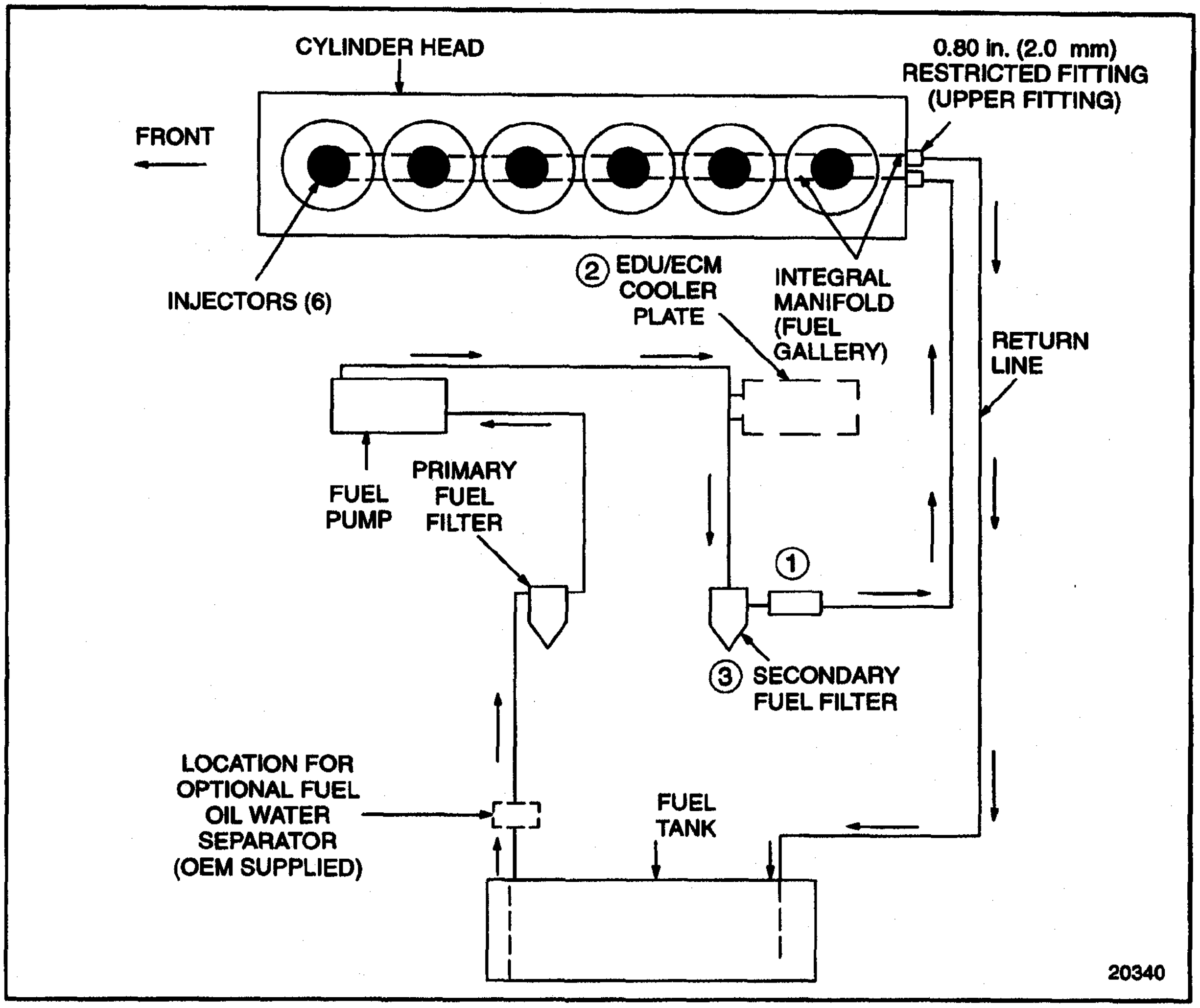
2.1 DIESEL FUEL SYSTEM OVERVIEW

For a schematic diagram of a typical diesel fuel system, see Figure 2-1.



1. Effective with 6R56762, a manually operated fuel shutoff valve replaced a check valve. A PRO-CHEK ® valve may be installed at this location to remove air.
2. Effective with 6R8950, the ECM/EDU cooler unit was removed from all Series 60 engines used in on-highway applications.
3. Effective with unit 6R13060, a fuel system check valve is installed in the secondary fuel filter head to prevent fuel drainback when filters are changed.

Figure 2-1 Schematic Diagram of the Diesel Fuel System

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The fuel system includes injectors, integral fuel manifold in the cylinder head, fuel pump, a cooling plate for the Electronic Control Module (ECM) or Electronic Distributor Unit (EDU), a primary fuel filter, a secondary fuel filter, and a fuel check valve if equipped. An 0.080 in. (2.0 mm) restrictive orifice is located in the fuel return fitting at the rear of the cylinder head to maintain the pressure in the fuel system. See Figure 2-1 for fuel recommendations.

CAUTION:

To avoid injury from fire caused by heated diesel-fuel vapors:

- **Keep those people who are not directly involved in servicing away from the engine.**
- **Stop the engine immediately if a fuel leak is detected.**
- **Do not allow open flames or smoke when working on an operating engine.**
- **Wear adequate protective clothing (face shield, insulated gloves and apron, etc.).**
- **To prevent a buildup of potentially volatile vapors, keep the engine area well ventilated during operation.**

Diesel fuel is relatively harmless at ambient temperatures.

Fuel is drawn from the fuel tank through an optional fuel water separator, into the primary fuel filter and enters the pump. After leaving the fuel pump under pressure, the fuel flows through the EDU/ECM cooler plates (if equipped) through the secondary fuel filter to the cylinder head. For units prior to 6R56762, the fuel flows through a check valve prior to entering the cylinder head.

An optional PRO-CHEK® check valve that removes air from the fuel supply line may be installed between the secondary filter and the cylinder head. The fuel flows to the injectors in the cylinder head through passages integral with the head. Surplus fuel exits at the rear of the head just above the inlet, through a restrictive return fitting which maintains fuel pressure in the system and returns back to the fuel tank.

NOTE:

Effective with unit 6R8950, the cooler plate was removed from all Series 60 engines used in on-highway applications. Effective with unit 6R13060, a fuel system check valve is installed in the secondary fuel filter to prevent fuel drainback when filters are changed.

NOTE:

Effective with 6R56762, a manually operated fuel shutoff valve has replaced the former valve.

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2.2 VEHICLE SAFETY FOR THE NATURAL GAS ENGINE

Today, a wide variety of vehicles from passenger cars to pickup trucks to school busses operate on one of the most plentiful fuels available, compressed natural gas. There are some very good reasons for this.

Natural gas is one of the most environmentally friendly fuels available. When burned, it produces far fewer air pollutants than conventional gasoline - up to 90 percent less carbon monoxide and up to 85 percent less reactive hydrocarbons - and contains no particulates. Further, it produces far less carbon dioxide (a "greenhouse gas") than conventional fuels. This makes natural gas an ideally friendly fuel for the environment.

2.2.1 Natural Gas Vehicles - The Safe Alternative

Safety is probably among the chief concerns when adding NGVs to a fleet. Although gasoline and diesel seem safer because they have been around for a very long time, natural gas has many characteristics that actually make it safer than these more familiar fuels.

First of all, natural gas is lighter than air, so it will not pool on or near the ground. When accidentally released in an unconfined space, it quickly disperses in the atmosphere, away from the scene of an accident.

Natural gas also has a high ignition temperature, igniting at around 1,350°F, compared to between 400°F and 900°F for gasoline and diesel. What's more, natural gas has a narrower flammability range than other fuels including liquid petroleum gas (LPG). Natural gas is only flammable in concentrations above 5.3 percent in air. Gasoline, diesel and LPG, on the other hand, are flammable at much lower concentrations, above 0.5 percent to 2 percent.

The upper limit of the flammability range of natural gas at about 15 percent, is a bit higher than other fuels. Because natural gas disperses quickly it is highly unlikely it will collect in a flammable concentration in the open air.

Natural gas is a safe fuel for other reasons as well. Unlike gasoline or diesel, it is nontoxic, non-caustic and poses no threat to land or water in the case of a spill. Also, several studies relating to the safety of operating NGVs in tunnels, in parking garages and on ferries have shown that natural gas poses no greater hazard than conventional fuels.

But what if natural gas is released in a confined space? Won't it float to the ceiling in a garage, for example? That is a concern. Experts recommend, and regulations in some cases require, that shops servicing NGVs install a methane detector and ensure there are not areas in the service area where natural gas could collect in dangerous concentrations if released. Adequate ventilation is also important, but natural gas's lighter-than-air properties make it easier to ventilate than the heavier vapors of gasoline, diesel and LPG. Check with your gas company or contractor to be certain, but you shouldn't have to augment your existing air-handling system to service NGVs.

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2.2.2 Safety Standards

Products manufactured for the NGV industry - from under-hood components to fuel-pump nozzles - are governed by a variety of standards to ensure safety. For example, onboard components including pressure regulators, valves, fueling nozzles and connectors, etc., must be certified by International Approval Services, jointly sponsored by American Gas Association Labs and Canadian Gas Association Labs. The National Fire Protection Association (NFPA) has created a safety standard (NFPA 52) for equipment installation and fueling infrastructure. The Uniform Fire Code (Article 52, Standard No. 52-1) also addresses NGV safety issues relating to fueling stations, including fueling indoors. The Compressed Gas Association has numerous standards pertaining to cylinders.

Through several NGV Coalition committees, the industry has created a series of strict voluntary standards and continues to improve and add to these. Standards for fueling connectors and cylinders are already on the books (known as ANSI/NGV1 and ANSI/NGV2, respectively).

As a fleet operator, you needn't become a NGV standards expert, but you can rest assured the industry is working hard to address safety concerns and ensure NGVs perform as safe and safer than conventional vehicles. As you introduce NGVs to your fleet and need to know more about which safety standards apply to your operation, consult your gas company representative. Your gas company probably has several NGVs in its fleet and has worked with local officials on meeting codes. If your local fire marshal isn't familiar with NGVs, your gas company representative in many cases can put him or her in touch with someone who is.

2.2.3 Cylinder Safety

Fuel for NGVs is stored in cylinders under pressure, typically at 3,000 or 3,600 pounds per square inch (psi). To the uninitiated this sounds hazardous just by definition. As one industry report notes, "There is no doubt that carrying a highly pressurized fuel onboard a vehicle represents a 'high perceived risk' which simply does not occur on conventionally fueled vehicles." The NGV industry, to its credit, has made addressing any risks, perceived or real, a top priority, and this is particularly evident in the area of storage container (cylinder) safety.

In recent years the industry has developed strict voluntary standards for cylinders in conjunction with governmental bodies such as the American National Standards Institute (ANSI). In 1994, the National Highway Traffic Safety Administration (NHTSA) adopted a set of regulations (known as DOT 304) governing cylinder durability, strength and pressure relief. The regulations also set testing criteria and generally follow the industry's existing ANSI/NGV2 standard. In the future NHTSA will codify additional standards, including cylinder resistance to chemical corrosion.

Cylinders undergo a variety of rigorous tests. In the bonfire test, as its name suggests, a pressurized cylinder is subjected to flames of around 1,200°F (649°C) to determine its resistance to bursting. To pass the test, the cylinder must remain intact long enough to safely release its contents. A pressure-relief device, required by NHTSA rules, vents the contents when the cylinder reaches about 210°F (98°C) to 220°F (104°C), and the cylinder typically remains intact for another 100 degrees beyond that. Cylinders must also pass a pressure test that subjects them to 18,000 cycles of pressurization and depressurization.

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Manufacturers also test cylinders for resistance to rough handling and impact by dropping them from a certain height, hitting them with a heavy weight or gouging them. The cylinders are then cycled the equivalent of a million miles of operation. In the gunfire test, manufacturers test the resistance of a cylinder to fragmentation by shooting it. Cylinders have also shown their durability in crash tests featured in informational videos produced by the NGV Coalition and others. In these tests, cylinders are mounted in a vehicle that is then dropped from several feet. The cylinders come through unscathed, even though the car is demolished.

Commenting on cylinder safety, one industry expert notes that the science of designing safe pressurized cylinders is by no means new, and the safety record is excellent. For example, some 1.4 million cylinders have been used by firemen for more than 15 years with only two catastrophic accidents, he notes, and those cylinders, pressurized to 4,500 lb/in.^{2}, are not mounted in a vehicle but carried on a person's back.

2.2.4 Fueling Safety

When designing for safety, companies manufacturing fuel dispensers for compressed natural gas typically concentrate on two areas: hardware and what engineers call the "fill routine." For example, some dispenser valves are designed to shut off the flow of fuel if needed or vent the gas away from the dispenser in a closed-loop return system. Dispensers also have what is called "driveway protection." If someone drives away while fueling, a breakaway device on the dispenser ensures that the hose won't rupture or topple the dispenser. By the way, the breakaway force, according to code, for compressed natural gas dispensers is about 44 pounds vs. 250 pounds for gasoline pumps.

To guard against overfilling or any other kind of uncontrolled fill, dispensers are designed to monitor, either mechanically or electronically, whether the vehicle is receiving the amount of fuel it should. If the fill pressure rises beyond a predetermined level, the dispenser shuts off automatically. By the same token, if there's no pressure or a sudden loss in pressure - as in the case of an aborted fill or a hose being cut, - it also shuts off.

Natural gas fuel dispensers are designed to be as easy to use and as similar to conventional fuel dispensers as possible, with safety and convenience in mind. With a minimum of training, anyone who can pump gasoline can safely dispense natural gas.

2.2.5 Safety Training

When it comes to dealing with any fuel, it is important that technicians and vehicle drivers learn about safety. Technicians working with liquid fuels have learned to keep them contained, keep them off their skin, and keep them away from any source of ignition. They have learned, too, what to do in the event of a spill or leak.

In the same way, NGV technicians and drivers need to learn how to safely handle a gaseous fuel, natural gas. While working with a gaseous fuel that's under pressure may be no more inherently hazardous than working with a liquid fuel, it is different. To do their jobs safely, your technicians and drivers need to know what the differences are and how to work with them.

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2.2.6 Fueling Vehicles

Unlike liquid fuels which are simply poured into a fuel tank, CNG fuel systems require a closed fuel dispensing system that allows the natural gas to flow into the fuel cylinder without leaking into the atmosphere. Such a system must use ANSI (American National Standards Institute) NGV1-standard fuel nozzles which will not allow the CNG to flow unless the nozzle is properly connected to the vehicle fuel inlet. Such a system will also comply with the NFPA (National Fire Protection Association) standards for fueling station construction and safety.

The typical commercial natural gas dispenser looks a lot like a gasoline pump. It has a hose that connects easily to the vehicle fuel inlet with a snap-type coupling device and a meter that indicates how much fuel has been pumped. Once the cylinders are full, the pump shuts off automatically.

Most stations can fill fuel cylinders on a "quick fill basis" or on a "timed fill" basis. With a "quick fill" system cylinders can be filled in about five minutes. Stations with "timed fill" systems may take longer, depending on the number of vehicles being fueled and the size or capacity of the fueling unit. Many fleets operate their own timed fill stations because this allows them to fill their vehicles unattended at night.

Home dispensers for natural gas are also available. These are about the size of a window air conditioner and can be hooked up directly to the natural gas supply of the home. Home dispensers normally use the "timed fill" principle so a vehicle can be fueled overnight.

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2.3 ELECTRONIC UNIT INJECTOR

The Electronic Unit Injector (EUI) is a lightweight, compact unit that injects diesel fuel directly into the combustion chamber. See Figure 2-2. The amount of fuel injected and the beginning of injection timing is determined by the ECM. The ECM sends a command pulse which activates the injector solenoid. The EUI performs four functions:

- ☐ Creates the high-fuel pressure required for efficient injection.
- ☐ Meters and injects the exact amount of fuel required to handle the load.
- ☐ Atomizes the fuel for mixing with the air in the combustion chamber.
- ☐ Permits continuous fuel flow for component cooling.

Engine combustion is obtained by injecting, under pressure, a small quantity of accurately metered and finely atomized fuel oil into the cylinder. Metering and timing of the fuel is accomplished by the ECM which actuates the solenoid poppet valve to stop the free flow of fuel through the injector. When the solenoid poppet valve closes, fuel is trapped in the injector body and under the plunger. The continuous fuel flow through the injector prevents air pockets in the fuel system and cools those injector parts subjected to high combustion temperatures.

NOTE:
Do not test new or reliabilt® remanufactured electronic unit injectors prior to installation in the engine. The Kent-Moore® POP stand should only be used as a diagnostic tool on fuel injectors that have been removed from an engine.

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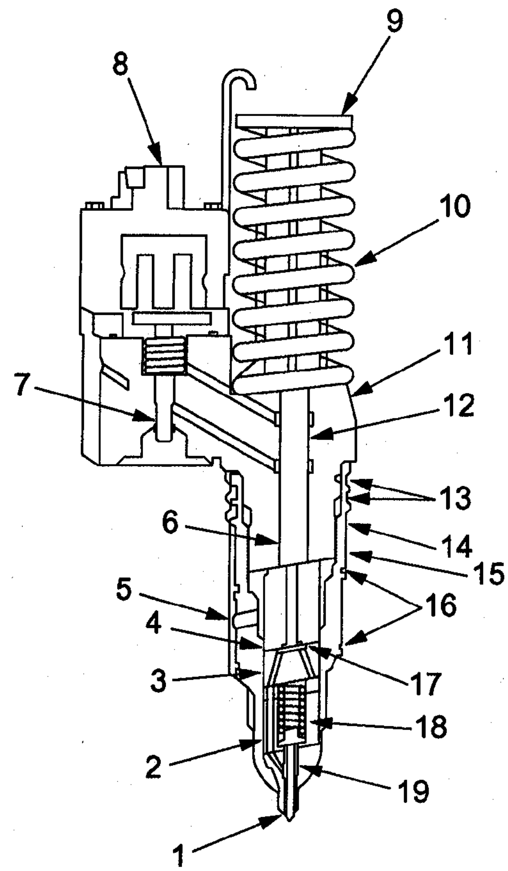

1. Spray Tip
2. Spring Cage
3. Check Valve Cage
4. Spacer
5. Fuel Inlet Opening
6. Fuel Supply Chamber
7. Poppet Control Valve
8. Solenoid
9. Injector Follower
10. Injector Follower Spring
11. Injector Body
12. Plunger
13. Upper O-ring Grooves and Seals
14. Fuel Outlet Openings
15. Injector Nut
16. Lower O-rings Grooves and Seals
17. Flat Disk Check Valve
18. Injector Needle Valve Spring
19. Needle Valve

Figure 2-2 Electronic Unit Injector Cross-section

Fuel enters the injector through the two fuel inlet filter screens located around the injector body. See Figure 2-3. Filter screens are used at the fuel inlet openings to prevent relatively coarse foreign material from entering the injector.

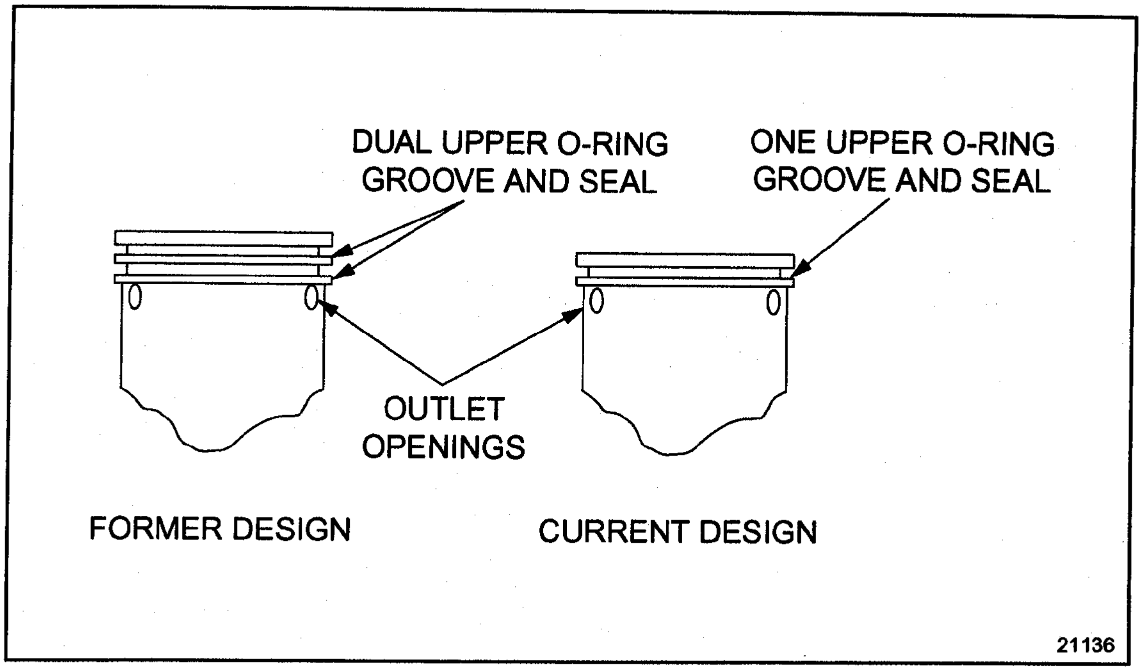

Figure 2-3 Fuel Injector Body

NOTE:
Effective with September, 1988 production, Series 60 engine EUI nuts incorporate one upper seal ring groove and seal ring, instead of two. See Figure 2-4.

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Outlet openings, through which the excess fuel oil returns to the fuel return manifold and then back to the fuel tank, are located around the injector nut. See Figure 2-4.

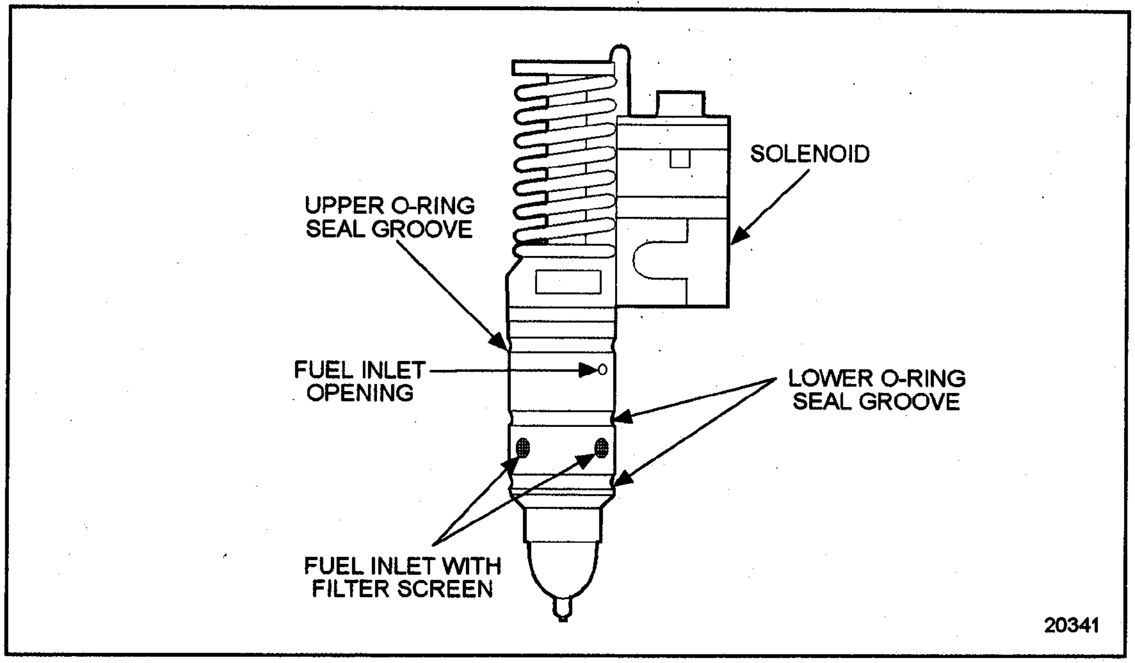

Figure 2-4 Electronic Unit Injector

After entering the nut cavity, the fuel passes through a drilled passage into the poppet control valve and plunger area. See Figure 2-2.

The plunger operates up and down in the body bore of the injector. The motion of the injector rocker arm is transmitted to the plunger and follower that bears against the follower spring.

As the piston moves approximately two-thirds of the way up in the cylinder on the compression stroke, the injector cam lobe begins to lift causing the injector rocker arm to push down on the follower and the plunger. Just before injection begins, the ECM sends an electronic pulse which turns on the injector solenoid. The energized solenoid creates a magnetic force which pulls the armature up, closing the poppet valve and trapping fuel under the plunger and passages leading down to the needle valve. The fuel pressure increases as the plunger continues its downward stroke.

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A flat disk check valve is built into the injector fuel passages between the plunger and the tip. This check valve normally has no effect on the injection process but will function to prevent cylinder gases from blowing back into the injector and fuel system if a particle of debris should become lodged between the needle and seat or the tip assembly fails.

This fuel pressure acts on the needle valve. When it creates a force high enough to overcome the valve spring force holding the needle on its seat, the needle valve moves up, allowing the high pressure fuel to spray into the combustion chamber. The high pressure of the fuel passing through the small holes in the tip creates a finely atomized spray for combustion within the cylinder.

After the pulse width time has passed, the ECM turns off the current to the injector solenoid. The de-energized solenoid allows a spring to open the poppet valve, permitting the trapped fuel to spill down, dropping the pressure within the injector. When the pressure is low enough the needle valve closes and ends injection.

The beginning of injection and metering of the fuel in relation to the crankshaft position are controlled by the ECM. Injection begins soon after the poppet valve is closed. The valve closing point information, known as the response time feedback, is returned to the ECM. This information is used to monitor and adjust injection timing, thus removing injector-to-injector variation influences on timing. The amount of fuel injected depends on the pulse width stored in the calibration which determines how long the poppet valve remains closed; the larger the pulse width the longer the valve is closed and the more fuel is injected.

When the injector rocker arm has completed its downward travel the injector follower spring returns it to the starting position. As the plunger moves up fuel enters the injector pumping cavity for another injection cycle. The constant circulation of fuel through the injector renews the fuel supply in the chamber and aids the cooling of the injector.

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2.3.1 Repair or Replacement of Electronic Unit Injector

To determine if repair is possible or replacement is necessary perform the following procedure. See Figure 2-5.

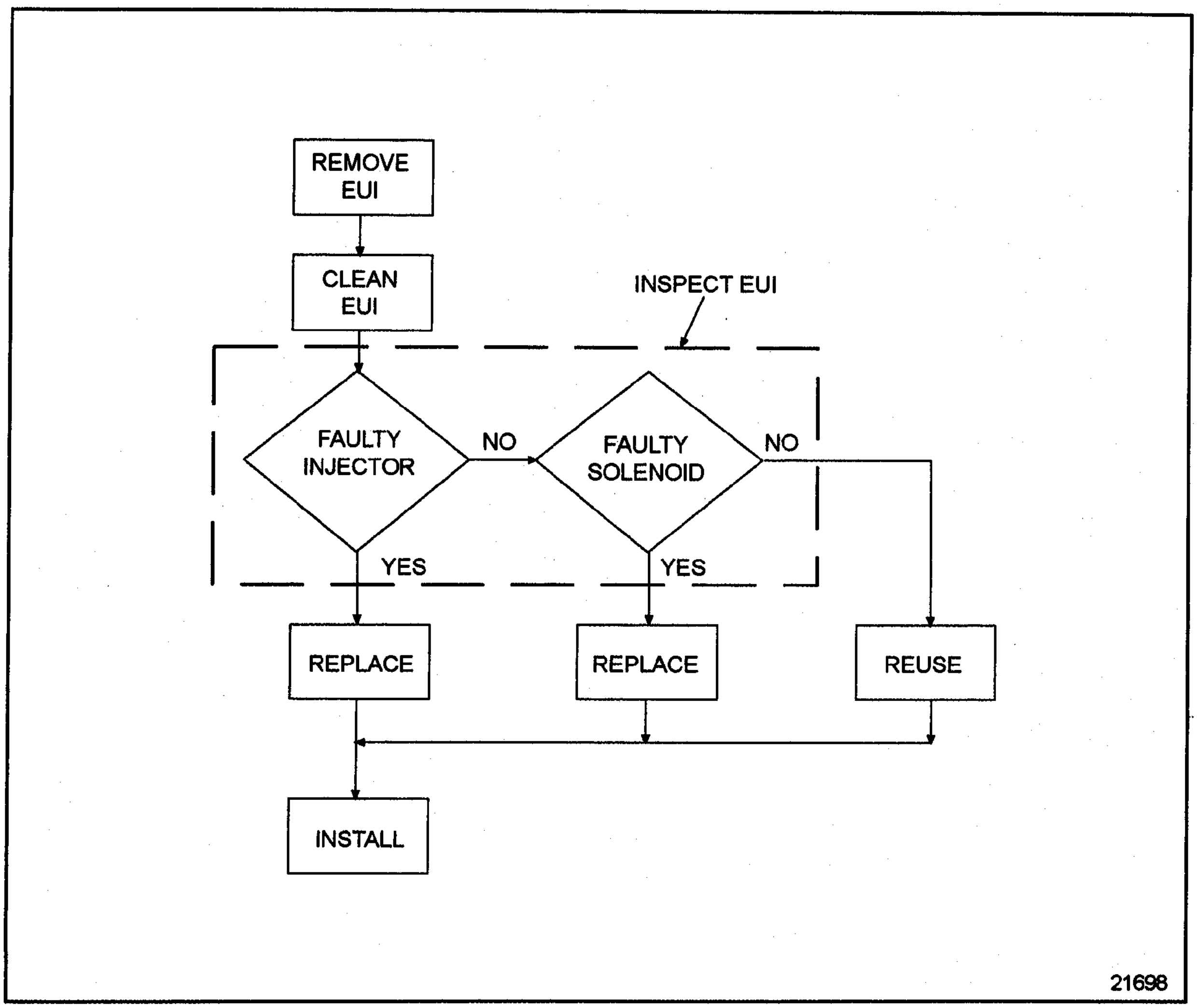

Figure 2-5 Flowchart for Repair or Replacement of Electronic Unit Injector

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2.3.2 Removal of Electronic Unit Injector

The following steps must be performed prior to removing an injector:

NOTE:
The solenoid can be replaced without removing the injector. Refer to section 2.3.4.

1. Clean the valve rocker cover around its seat on the head, and in the attaching bolt recesses.
   [a] To remove the *one-piece* rocker cover, refer to section 1.6.2.
   [b] To remove the *two-piece* rocker cover, refer to section 1.6.3.
   [c] To remove the *three-piece* rocker cover, refer to section 1.6.5.

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

NOTICE:

All the fuel must be removed from the cylinder head before removing an injector to prevent the fuel from entering the cylinder and causing hydrostatic lock or washdown. If the head is not thoroughly purged of fuel before an injector is removed, fuel remaining in the fuel manifold will drain into the cylinder filling the piston dome recess. It cannot drain from the dome and, if not removed, can cause hydrostatic lock and bend the connecting rod.

2. Drain the cylinder head fuel gallery by removing the inlet and outlet lines from the fittings at the rear of the cylinder head. Blow low pressure compressed air into the inlet fitting for 20 to 30 seconds or until all of the fuel is purged from the cylinder head. See Figure 2-6.

NOTE:
Front and rear rocker shaft assemblies look identical but are not interchangeable because of different bolt hole center distances. The outboard end of each rocker shaft assembly is marked with the DDC logo for identification. Care should be taken to identify and return assemblies to the proper location if both overhead assemblies are removed.

NOTE:
Loosening the fuel line at the inlet fitting will allow fuel to flow faster. Carefully collect the drained fuel in an appropriate container.

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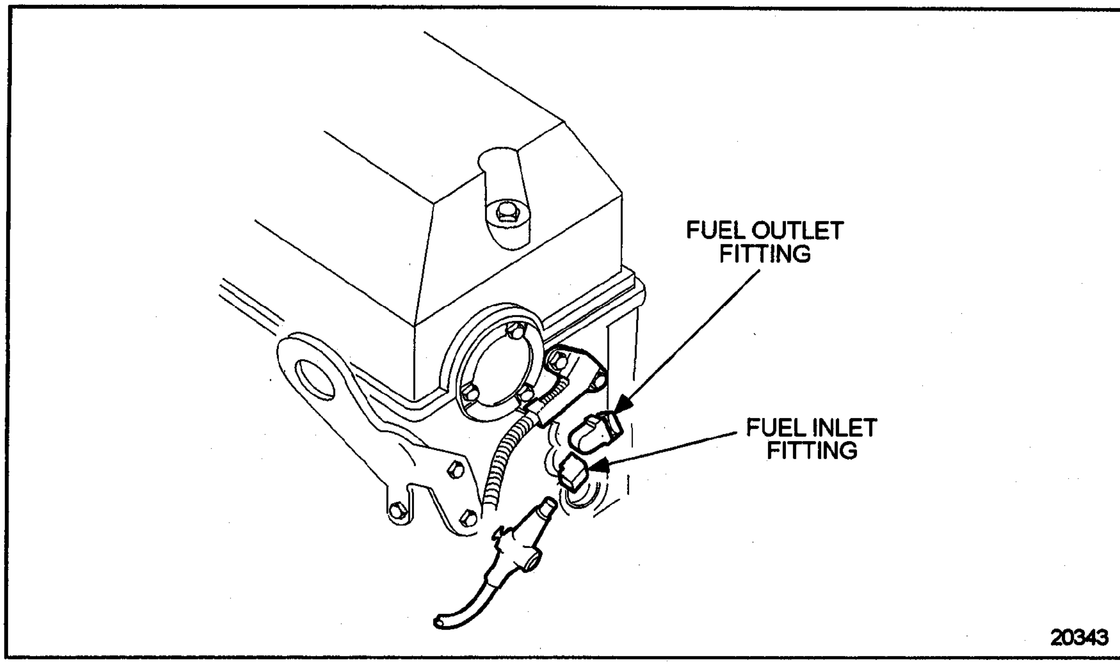

Figure 2-6 Cylinder Head Fuel Fitting Locations

3. Remove the two rocker shaft through-bolts and one nut for each rocker shaft assembly, and lift the rocker shaft assembly off the engine. Refer to section 1.3.2.

To remove the injector, complete the following steps:

NOTICE:
Do not remove the screws from the injector. The wire terminals have keyhole slots to fit over the screw head. Turning the screws too far will damage the threads in the injector solenoid housing.

1. Loosen the injector wire terminal screws two full turns and remove the terminal wires.
2. Remove injector hold down crab.

NOTICE:
Extreme care should be used when handling an EUI to avoid costly damage by dropping or otherwise mishandling the EUI.

NOTE:
When replacing an EUI, always replace the injector O-rings.

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3. Lift the injector from its seat in the cylinder head by inserting a pry bar under the injector body. See Figure 2-7.

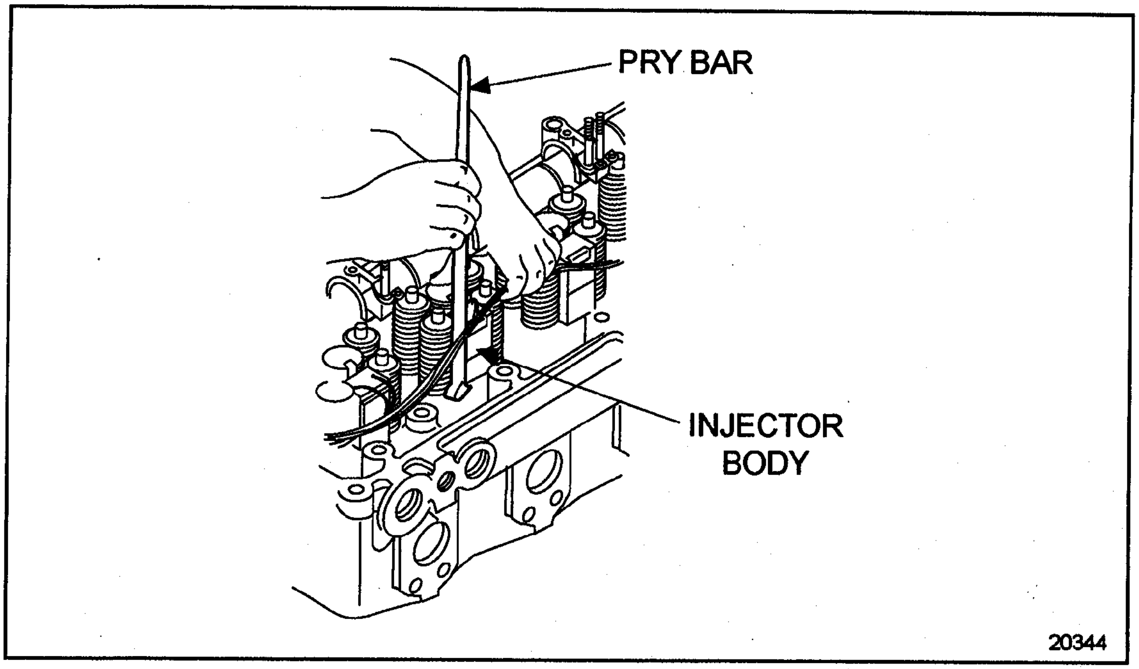

Figure 2-7 Removing Electronic Unit Injector

NOTICE:
Avoid wire brushing the spray holes to prevent damage.

4. Cover the injector hole in the cylinder head to keep out foreign material. Remove carbon from the injector exterior in the area where the tip joins the nut, using wire buffing wheel, J 7944.

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2.3.3 Disassembly of Electronic Unit Injector

On a Series 60 engine EUI, only the injector solenoid and seal rings are serviceable. The injector must not be disassembled.

2.3.3.1 Inspection of the Electronic Unit Injector

To clean and inspect the injector, complete the following steps:

NOTE:
The injector can be tested either on or off of the engine.

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

1. Clean the exterior of the injector with clean solvent and dry it with compressed air.

NOTE:
Do not test new or reliabilt® remanufactured electronic unit injectors prior to installation in the engine. The Kent-Moore® POP stand should only be used as a diagnostic tool on fuel injectors that have been removed from an engine.

2. Test the EUI using J 34760. Follow procedures supplied with this tool. Reuse or replace injector or injector and solenoid as indicated by testing.
3. Inspect the O-rings for damage or foreign material. Replace O-rings.
4. Inspect the fuel injector tubes at the injector seat. If required, replace the fuel injector tubes.

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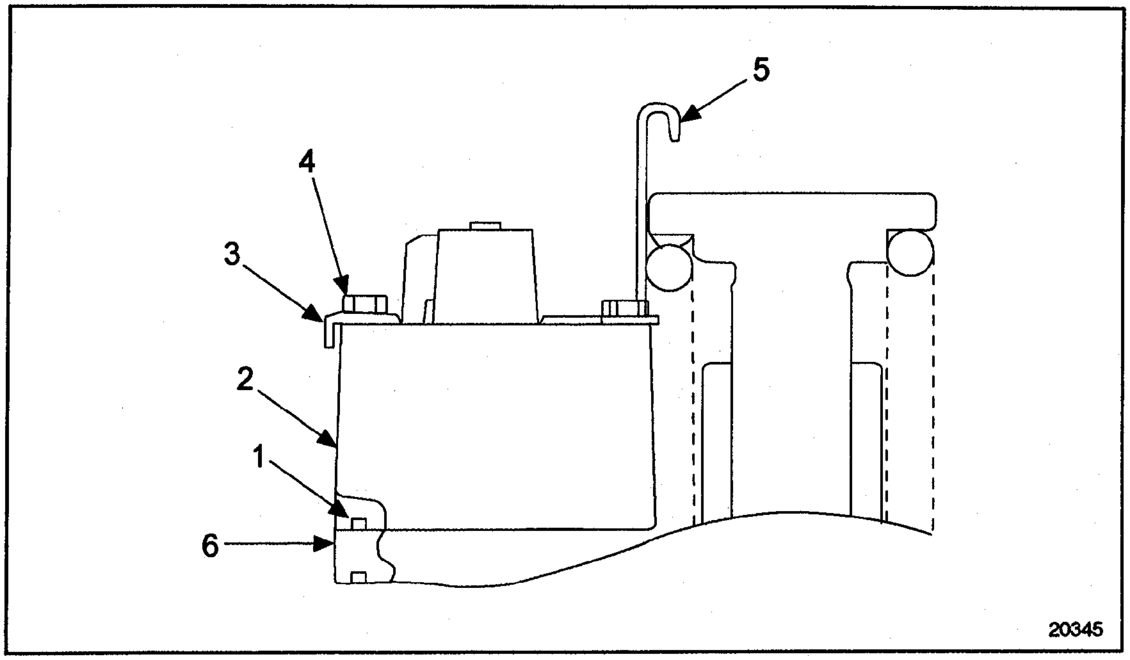
2.3.4 Repair of Electronic Unit Injector Solenoid and Seals

Perform the following steps for solenoid replacement:

1. Loosen the injector wire terminal screws two turns and remove terminal wires.
2. Loosen four hex-head screws and remove old solenoid. See Figure 2-8.



1. Spacer Seals
2. Solenoid
3. Load Plate
4. Screw
5. Follower Retainer
6. Spacer

Figure 2-8 Electronic Unit Injector Solenoid Assembly

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3. Perform the appropriate step for the DDEC unit used.
   [a] For DDEC I and DDEC II, discard the solenoid, load plate, follower retainer, and screws. Do not reuse old screws.
   [b] For DDEC III/IV, discard the solenoid, follower retainer, and screws. Do not reuse old screws. The load plate must be reused.

NOTICE:
The spacer is a matched component with the armature and must remain with its respective injector.

4. Remove spacer and seals from injector body.
5. Discard seals, but do not discard spacer.
6. Install new seal in spacer groove and position spacer on body with seal facing down. See Figure 2-8. Seal may be retained in groove with small quantity of grease.
7. Install new seal in solenoid groove.
8. Install solenoid on spacer.

NOTICE:
The load plate on each DDEC III injector is unique and must remain with the injector. The DDEC III load plate carries the injector part number, the injector serial number in bar code format, and the injector calibration code number.

9. Install new screws through the load plate and follower retainer, solenoid, and spacer.

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10. Thread screws into body and tighten all screws until heads contact retainer and load plate with a slight force (less than 0.6 N·m [5 lb·in.] torque) in the sequence shown. See Figure 2-9.

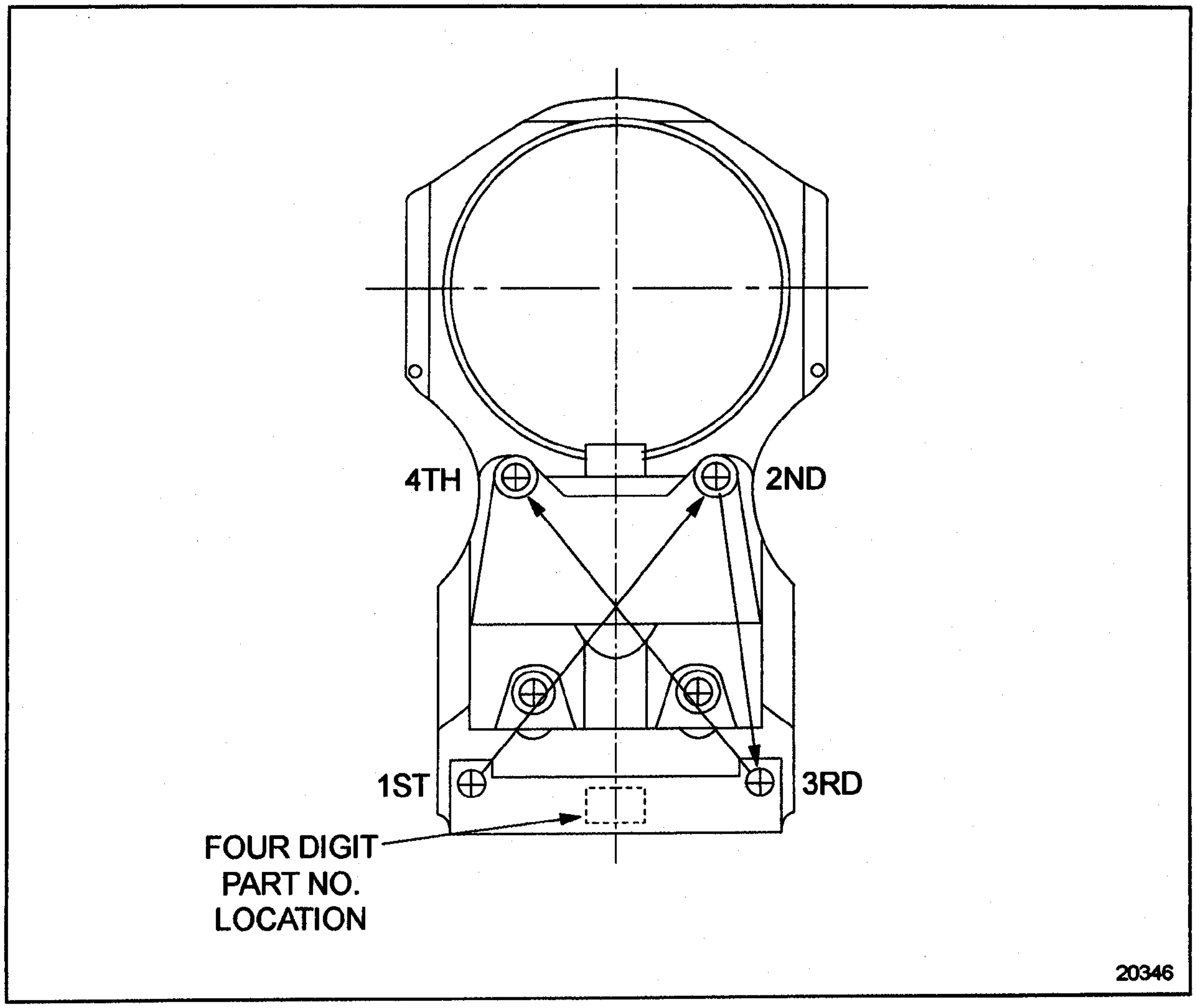

Figure 2-9 Electronic Unit Injector Solenoid Torque Sequence

11. Torque screws to 2 N·m (19 lb·in.) in the sequence shown. See Figure 2-9.
12. On DDEC II injectors only, etch the last four digits of injector part number on the load plate. See Figure 2-9.

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2.3.5 Installation of the Electronic Unit Injector

Perform the following steps:

1. If the fuel system is contaminated with coolant:
   - [a] Drain the fuel tanks and refill with clean fuel. Refer to section 13.13.2.
   - [b] Replace both filters with new, and clean the fuel/water separator, if equipped. Refer to section 13.13.14.
   - [c] Inspect fuel injectors for damage and replace as required.
2. If the coolant system is contaminated with fuel, flush and reverse flush the system. Refer to section 13.13.4.

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

NOTICE:

Leftover fuel must be removed from the injector bore before injector installation. If fuel is trapped between the top of the injector hole tube and the lower injector O-ring seal, it may seep down to the injector hole tube seal ring, causing swelling and possible seal leakage.

3. Using clean compressed air, blow out any fuel remaining in the injector bore.

NOTE:

If the engine is equipped with an auxiliary injector tube seal, replace it with a new seal when the injector is removed.

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NOTICE:
Do not use a metal dowel as this may damage the seal.

NOTICE:
Injector seals are considered one-use items and cannot be reused. Any time an injector is removed, all three injector nut O-ring seals must be replaced with new seals. Failure to replace seals can result in seal leakage.

4. Detroit Diesel encourages the use of an additional service seal (5104701) that is impervious to both coolant and fuel. This seal should be used in situations where injector tube seal leakage or deterioration is suspected or confirmed. Place the auxiliary seal in the injector hole and seat it against the top of the injector tube with a 41.3 mm (1-5/8 in.) diameter wood or plastic dowel.
5. Check to make sure the injector bore is thoroughly clean.
6. Apply a thin coat of clean ethylene glycol to the injector seal rings and install them in the injector nut ring grooves. Make sure seals are properly seated.
7. Insert the injector into its respective injector tube bore. Visually align the injector body for equal clearance between valve springs (there is no locating dowel pin on the underside of the EUI). After locating the injector, press down on the top of the injector body with the heel of your hand to seat it in the injector tube.

NOTE:
The injector tube bore should be cleaned and inspected for damage before installation of the electronic unit injector. Refer to section 2.4.3.

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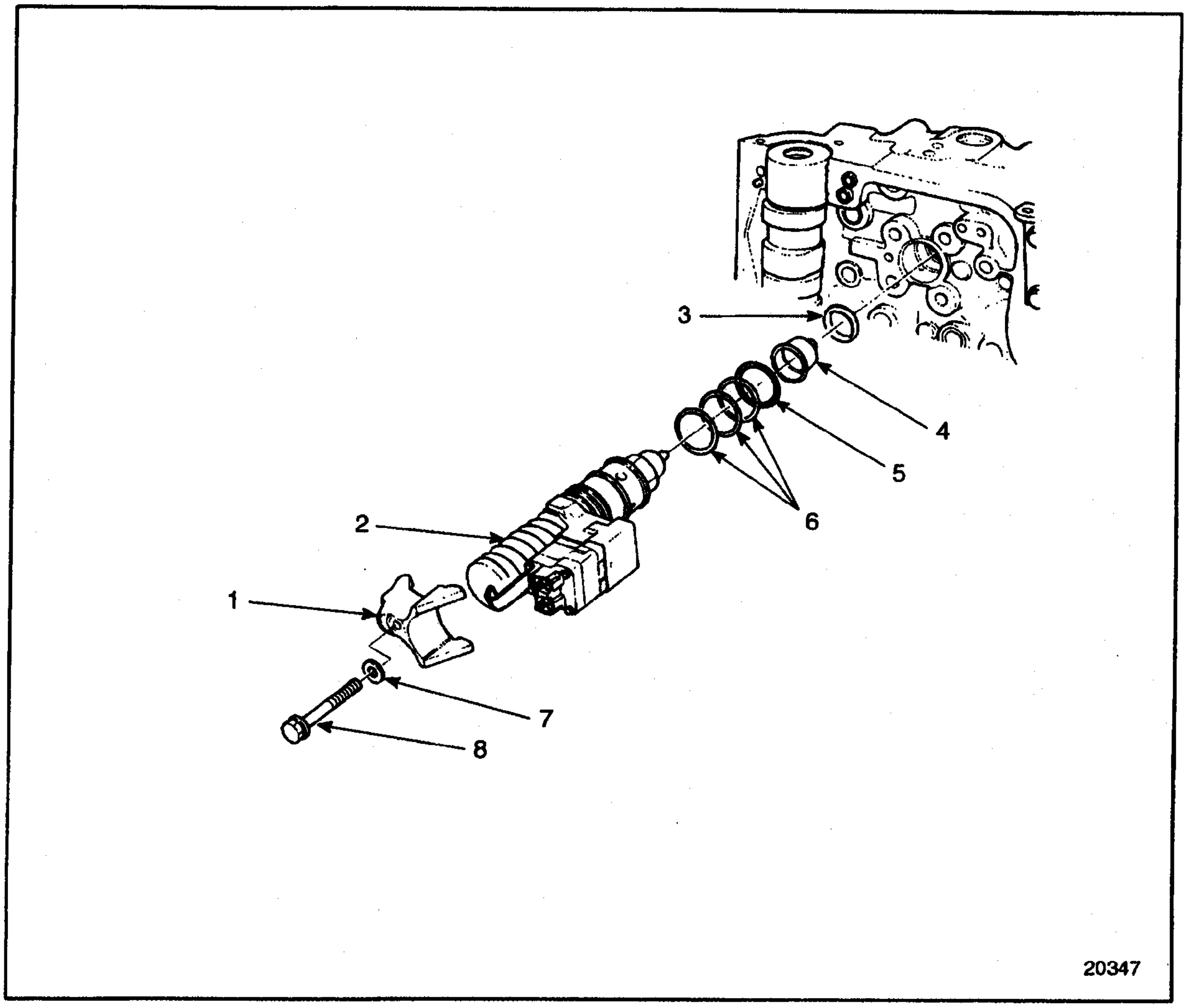
NOTICE:

The hemispherical portion of the hold-down crab washers must be installed facing the crab (pointing down) in order to prevent damage to the washers. See Figure 2-10.



1. Injector Hold-down Crab
2. Electronic Unit Injector
3. Injector Tube O-ring
4. Injector Tube
5. Auxiliary Injector Seal
6. Injector O-rings
7. Hold-down Crab Washer
8. Hold-down Crab Bolt

Figure 2-10 Electronic Unit Injector and Related Parts

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8. Determine which type of hold-down crab is used by measuring the overall height.
   [a] If the overall height is 54 mm (2.125 in.), proceed to step 9.
   [b] If the overall height is 52 mm (2.047 in.), skip to step 10.
9. Position a 0.762 mm (0.030 in.) feeler gage between the crab and injector spring on the side of the spring that faces the intake manifold.
10. Install the hold-down crab, hemispherical crab washer (flat surface up against bolt) and hold-down bolt to the injector. See Figure 2-11. Ensure the clamp does not interfere with the injector spring or valve springs.
11. Torque the hold-down bolt to 58-66 N·m (43-49 lb·ft).

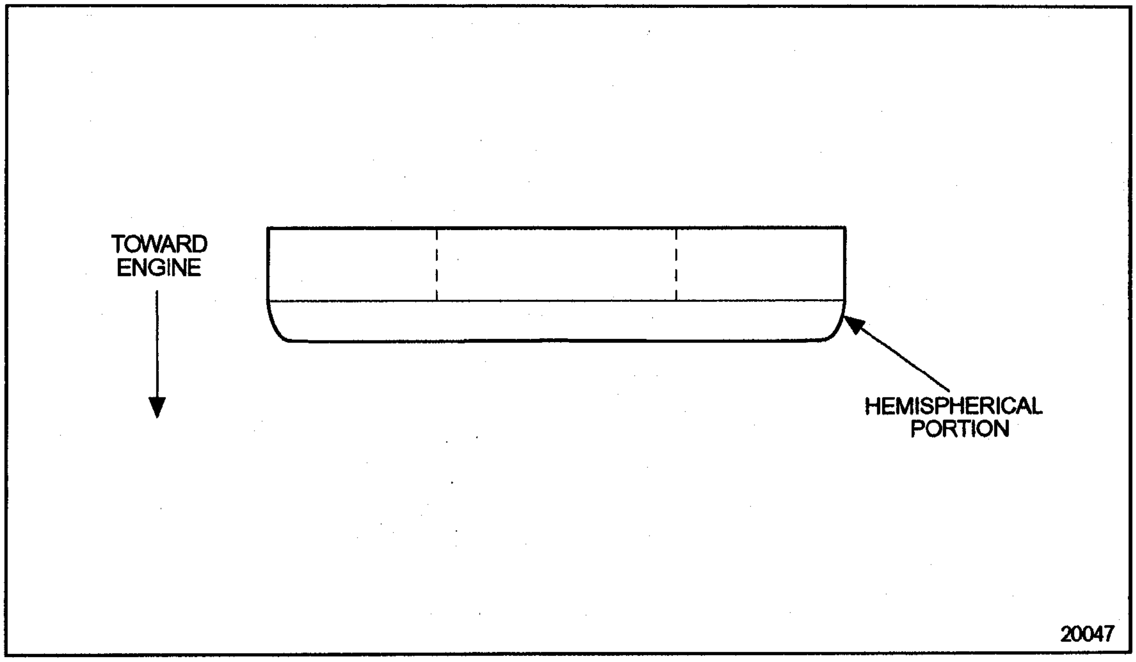

Figure 2-11 Hold-down Crab Washer Installation

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12. Install the EUI terminal wires by positioning the keyhole in the terminal over the screw in the injector solenoid housing. Pull the terminal end down so that the screw rests in the smaller slot in the terminal. Torque the terminal screws to 1.08–1.13 N·m (9.5–10.0 lb·in.). Do not bend the terminals down after installation. See Figure 2-12.

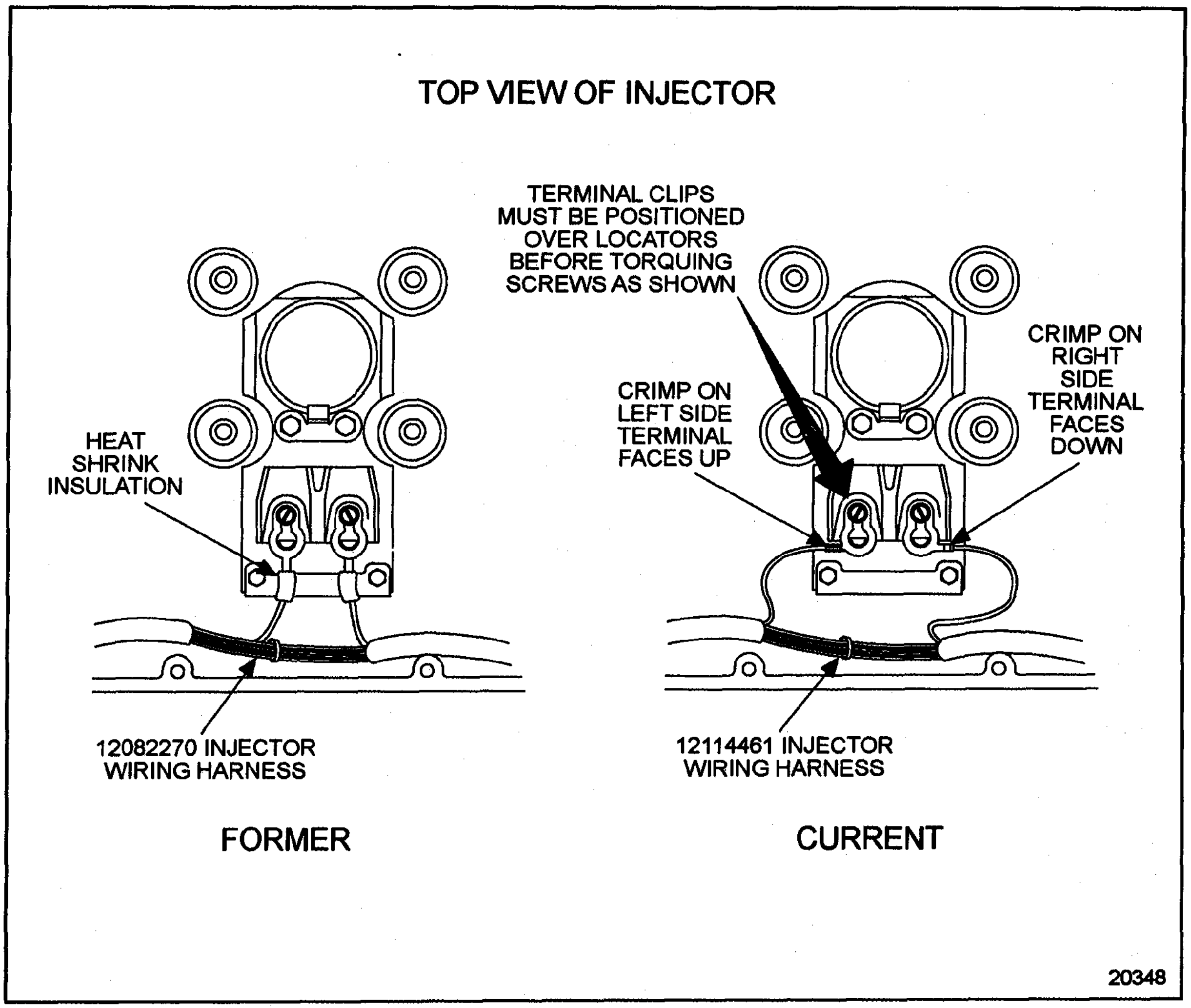

Figure 2-12 Electronic Unit Injector Terminal Installation

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13. Install the rocker arm shafts, with rocker arms in place. Refer to section 1.3.3.

NOTE:
Front and rear rocker shaft assemblies look identical but are *not interchangeable* due to different bolt-hole center distances. The outboard end of each rocker shaft assembly is marked with the DDC logo for identification. Care should be taken to identify and return assemblies to the proper location if both overhead assemblies were removed.

14. Adjust the intake and exhaust valve clearances and injector height. Refer to section 12.2
15. Install the inlet and outlet fuel lines to the fittings at the rear of the cylinder head. See Figure 2-6.
16. On DDEC III/IV engines, record the injector calibration code from the load plate with the proper cylinder location.
17. Install the valve rocker cover. Refer to section 1.6.7.
18. For one-piece valve rocker cover, refer to section 1.6.8. For two-piece and three-piece valve rocker cover, refer to section 1.6.9.
19. Verify repair of electronic unit injector. Refer to section 11.8.

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2.4 FUEL INJECTOR TUBE AND O-RING

The bore in the cylinder head for the EUI is directly through the cylinder head water jacket. To prevent coolant from contacting the injector and still maintain maximum cooling of the injector, a copper tube is pressed into the injector bore. The tube has a ring seal at the top and is flared at the bottom, on the lower side of the cylinder head, to create water and gas-tight joints at the top and bottom.

NOTE:
It is recommended that the injector tube be replaced with new parts at the time of engine overhaul.

2.4.1 Repair or Replacement of Fuel Injector Tube

To determine if repair or replacement of the fuel injector tube is necessary. See Figure 2-13.

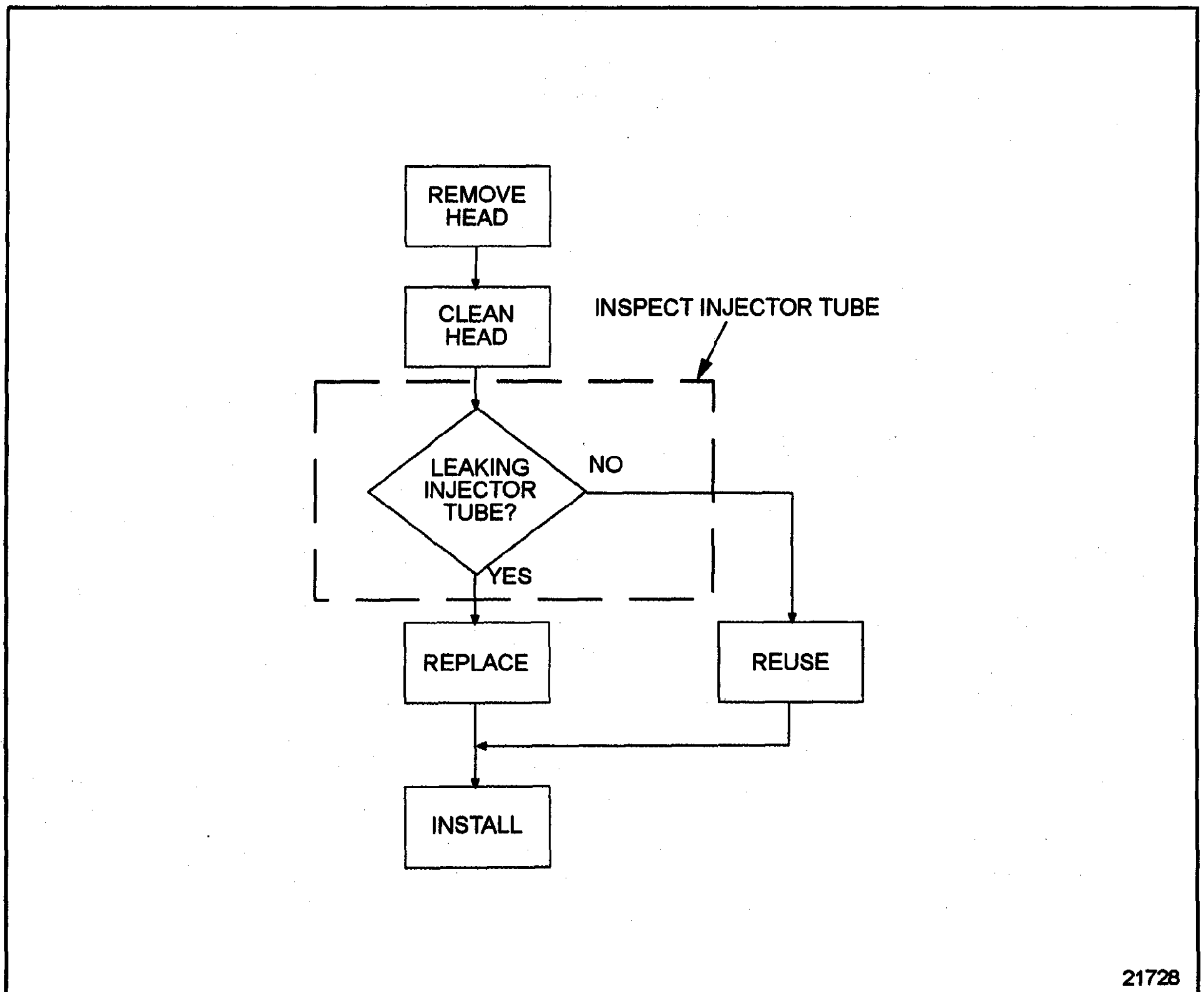

Figure 2-13 Flowchart for Repair or Replacement of Fuel Injector Tube

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2.4.2 Removal of the Injector Tube and O-ring

When removing an injector tube, use J 33880-4, part of J 33880 and J 5286-5.

1. Remove, disassemble, and clean the cylinder head. Refer to section 1.2.2.
2. Place J 33880-4, in the injector tube. Insert J 5286-5, through the small opening of the injector tube and thread the pilot into the tapped hole in the end of the installation/removal tool. See Figure 2-14.

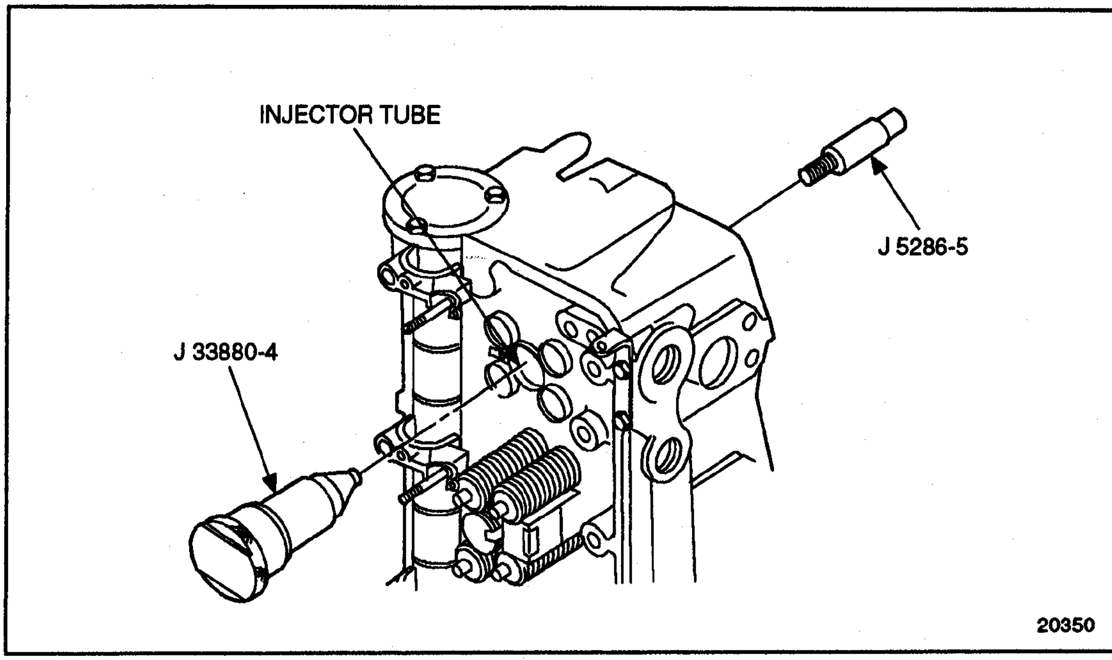

Figure 2-14 Removal of Injector Tube

3. Tap on the end of the pilot using a brass hammer or fiber mallet. Carefully drive and lift the injector tube, J 33880-4 and J 5286-5 from the cylinder head. If the injector tube O-ring is not removed with the injector tube, remove the O-ring from the cylinder head casting at the upper end of the injector tube bore. Discard O-ring.

2.4.3 Cleaning of Injector Tube

Thoroughly clean the injector tube hole in the cylinder head to remove any dirt, burrs, or foreign material that may prevent the new tube from seating at the lower end or sealing at the upper end. Excess material in the form of a small copper ring may be left at the lower end of the injector tube counterbore after the injector tube has been removed. This copper ring will have to be removed using a suitable sharp-pointed tool.

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2.4.4 Installation of Auxiliary Injector Seal

Perform the following for installation of auxiliary injector seal.

NOTICE:
If a cylinder head has a damaged injector hole tube seal, coolant may seep past the seal after injector removal. Drain down the injector tube hole, and fill the combustion chamber. If this condition goes undiscovered and the coolant is not removed from the cylinder before the injector is replaced, the engine may be damaged at startup. Always check cylinders for possible coolant seepage before replacing injectors and use care to prevent coolant or fuel from contaminating the engine lubricating oil.

NOTICE:
Do not use a metal dowel to install the auxiliary injector seal, as this may damage the seal.

1. Place the auxiliary seal in the injector hole.
2. Seat it against the top of the injector tube with a 1-5/8 in. diameter wood or plastic dowel. See Figure 2-15.

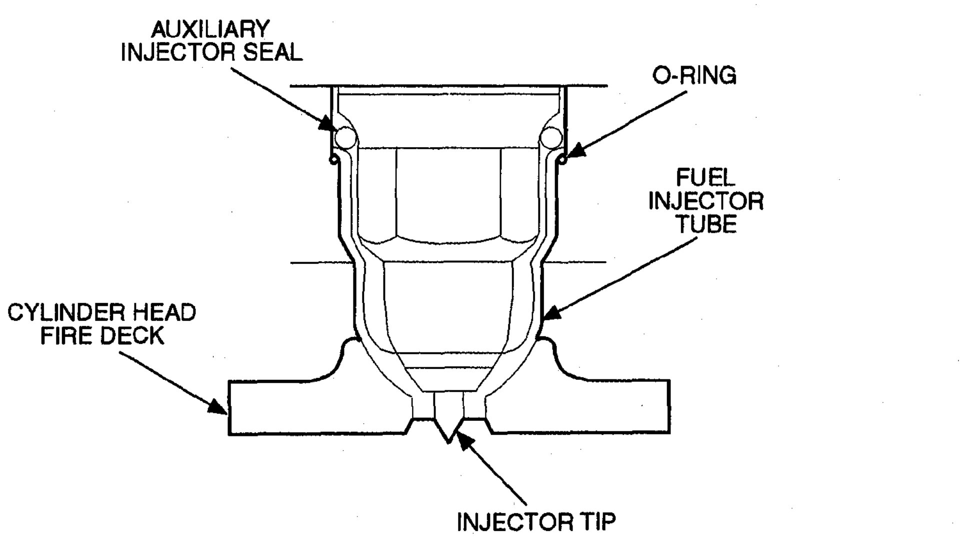

Figure 2-15 Auxiliary Injector Seal Location

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2.4.5 Installation of Injector Tube and O-ring

Perform the following steps for injector tube installation:

NOTICE:
DO NOT lubricate the outside of the injector tube or inside the cylinder head injector tube bore to facilitate installation of the tube. Lubricant may cause the tube to turn during reaming or flaring operations possibly damaging the injector tube or reamers.

NOTE:
This ring was formerly made of fluoroelastomer and had a blue coating for identification. It is now made of a special blended fluorocarbon material with a green teflon coating for identification. Former and current-design seal rings are completely interchangeable, and only the current green-coated seal ring will be serviced.

1. Place the O-ring over the injector tube, sliding it up to the lip. See Figure 2-16.
2. Install the injector tube on J 33880-4. See Figure 2-16.

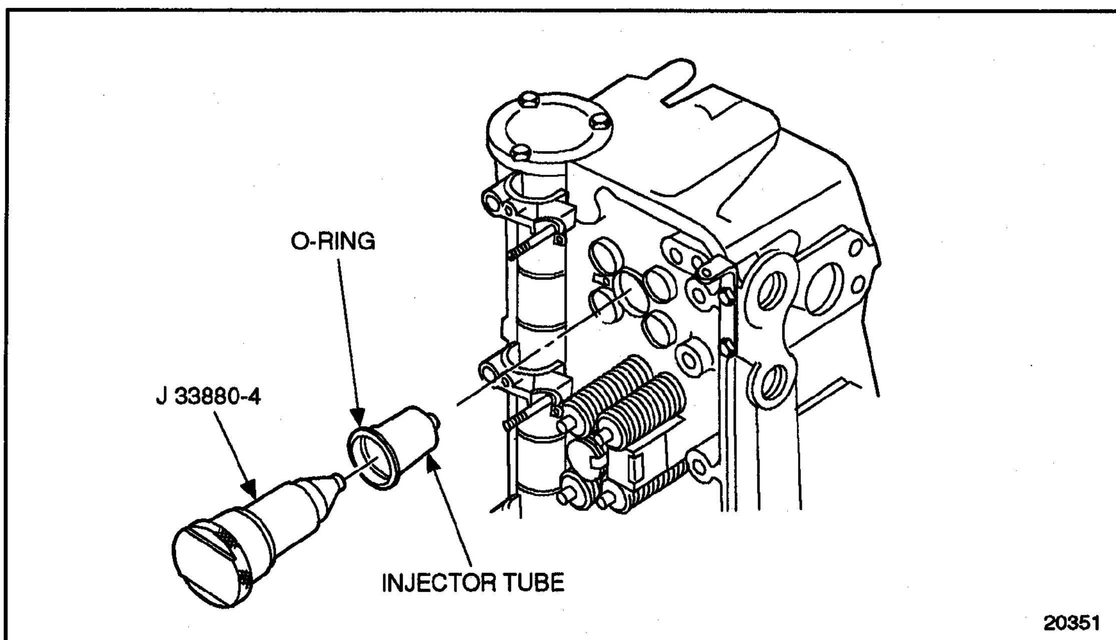

Figure 2-16 Installing O-ring and Injector Tube

3. Install both J 33880-4 and injector tube into the injector bore. Ensure the tip of the injector tube goes through the small hole in the fire deck. Tap lightly on the end of the tool, if necessary, to seat the tube.

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4. Install the EUI hold-down clamp and bolt it in place over J 33880-4. See Figure 2-17.

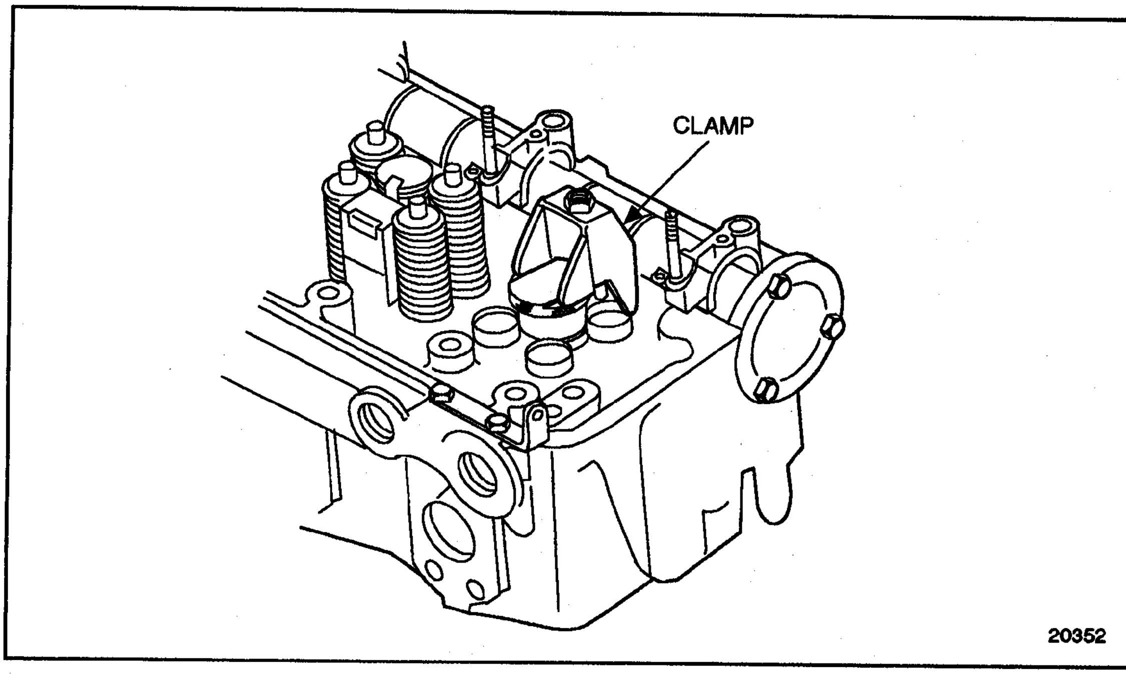

Figure 2-17 Installing Injector Hold-down Clamp

5. Torque the EUI hold-down clamp bolt 58-66 N·m (43-49 lb·ft). This will seat the injector tube at the desired depth.After an injector tube has been installed in a cylinder head, it must be finished.

   Perform the following steps for a flaring injector tube:

6. Insert J 5286-6, through the small hole in the bottom of the tube, rotating to engage the threads in the installation/removal tool.

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7. Using a torque wrench and 12-point, 29/32 in. socket, screw J 5286-6 into J 33880-4 until it begins to flare the tube. See Figure 2-18.

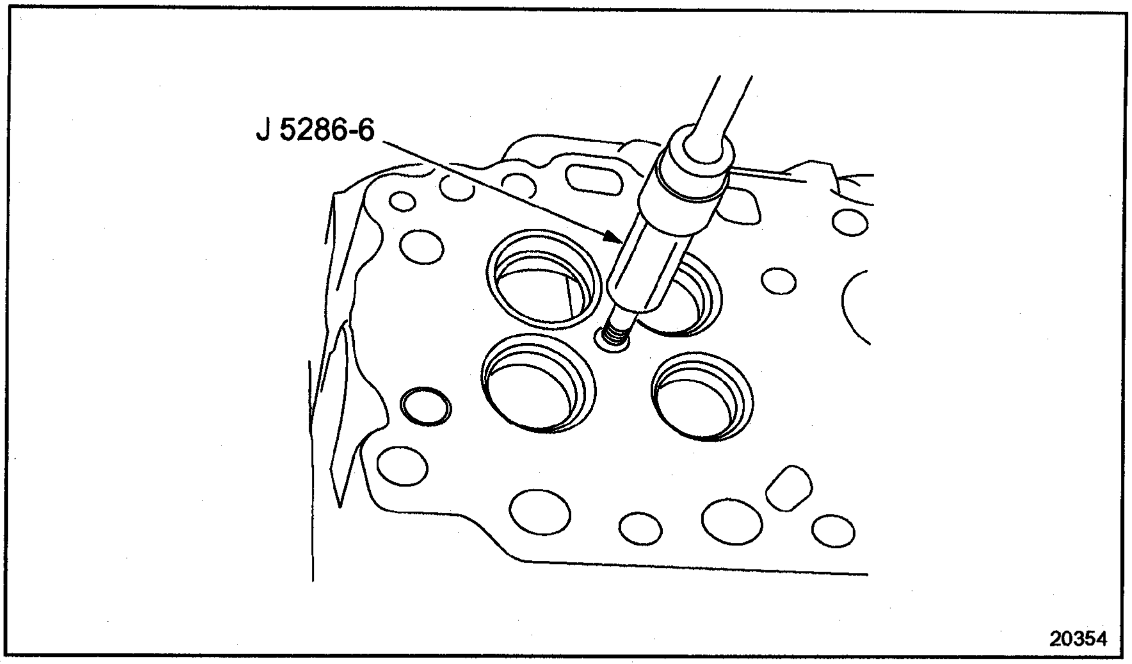

Figure 2-18 Flaring Injector Tube Tip

8. Continue to rotate J 5286-6 and apply pressure to the flare end of the tube firmly against the cylinder head casting tube opening. Do not exceed 41 N·m (30 lb·ft) torque. See Figure 2-19.

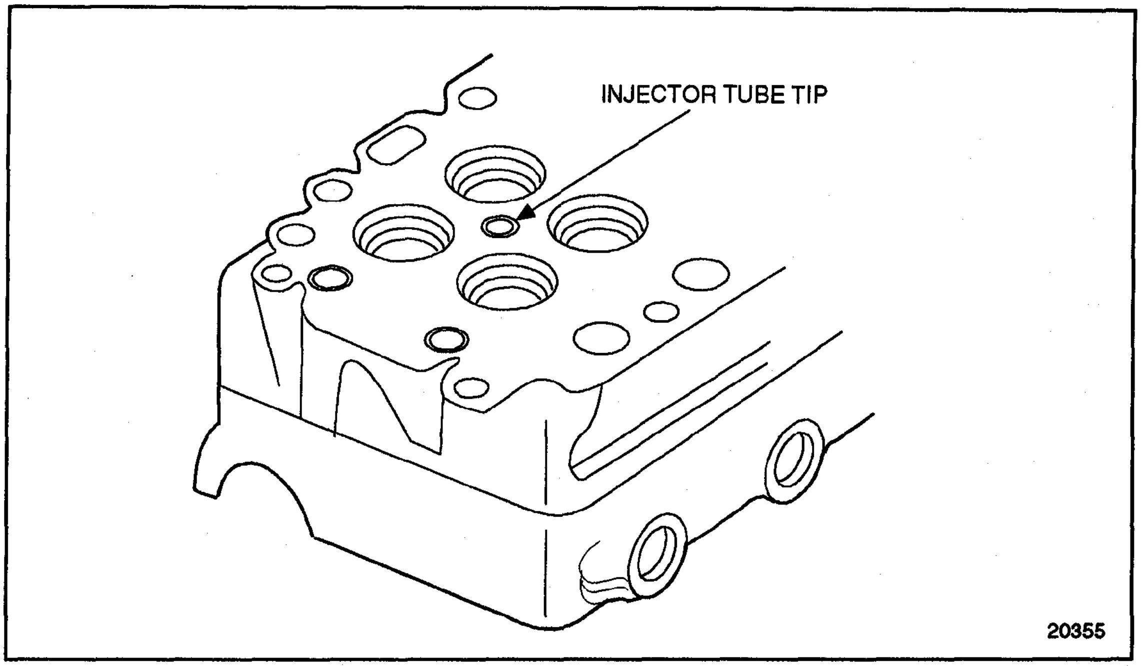

Figure 2-19 Properly Flared Injector Tube Tip

9. Remove the J 5286-6 and J 33880.The tapered lower end of the injector tube must provide a smooth and true seat for the lower end of the injector nut to effectively seal the cylinder pressures and properly position the injector tip into the combustion chamber. To ream the injector tube, complete the following steps:
10. Install J 33880-3, into the injector bore until it contacts the cylinder head. See Figure 2-20.
11. Install J 33880-10, into the seat reamer pilot until it bottoms. See Figure 2-20.

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NOTICE:
Turn the reamer in a clockwise direction only (both when inserting and withdrawing the reamer) because movement in the opposite direction will dull the cutting edges of the flutes.

12. Place a few drops of cutting oil on the cutting edges of J 33880-5, and install it in J 33880-10. See Figure 2-20.

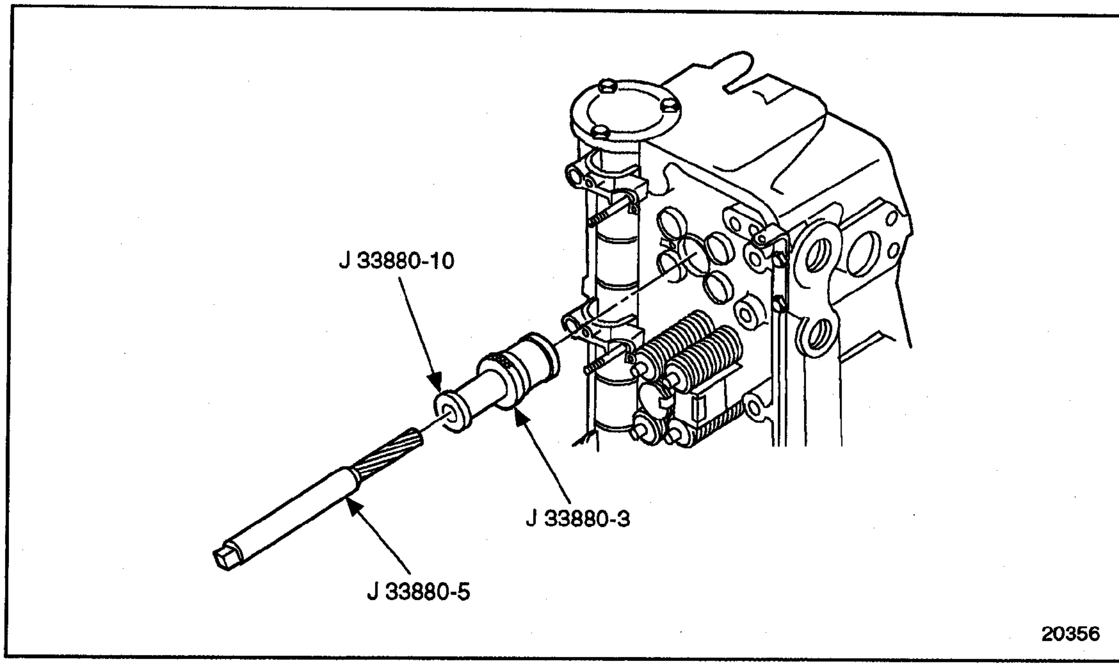

Figure 2-20 Reaming Injector Tube

13. Using a speed handle with 7/16 in. socket attached, turn the tip reamer in a clockwise direction using light pressure until it goes completely through the end of the injector tube.

CAUTION:
To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

14. Remove J 33880-5 and J 33880-10. Blow out the injector tube and tip with compressed air to remove all metal shavings.

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15. Install J 33880-20, to the firedeck of the cylinder head using two existing head bolts. Tighten the head bolts, but do not torque. Position the cut out portion of the stop block beneath the injector tube. See Figure 2-21.

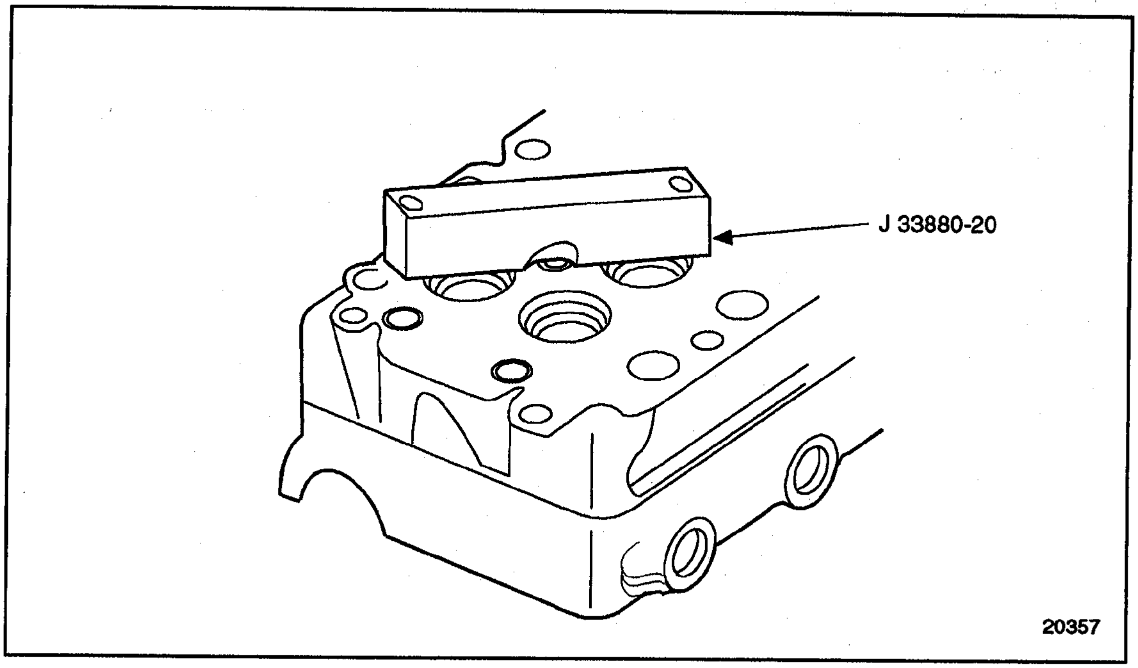

Figure 2-21 Stop Block Installation

16. Install J 33880-3, into the injector tube bore until it contacts the cylinder head. See Figure 2-22.

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NOTICE:

If the seat reamer is dropped into the pilot, or is allowed to strike the injector, chatter marks may result in the injector tube seat. Use extreme care when inserting the seat reamer to prevent damaging the tube.

17. Place a few drops of cutting oil on the edges of J 33880-1, and gently place it in the pilot. See Figure 2-22.

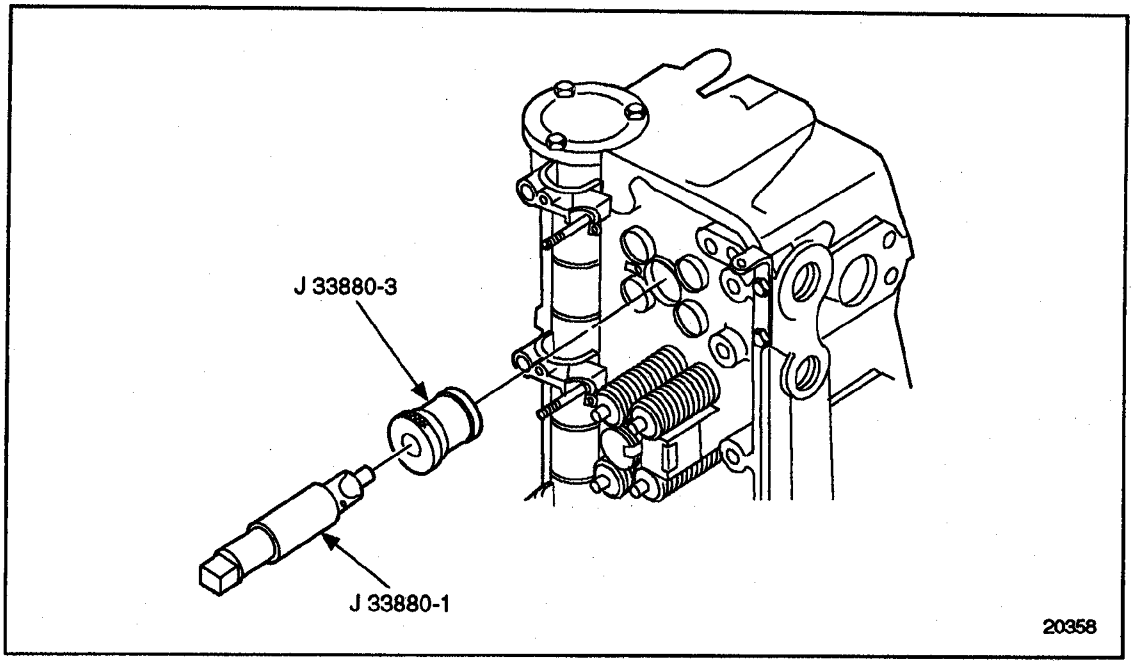

Figure 2-22 Reaming Injector Tube Seat

NOTICE:

Turn the reamer in a clockwise direction only, because movement in the opposite direction will dull the cutting edges of the flutes.

18. Using a speed handle with 15/16 in. socket attached, turn the seat reamer in a clockwise direction with light pressure. Continue until J 33880-1 part of J 33880 bottoms against J 33880-20 part of J 33880.

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19. Inspect the tube seating surface to ensure that there are no irregularities or chatter marks in the seating surface. If irregularities or chatter marks are found, remove and replace the injector tube. See Figure 2-23.

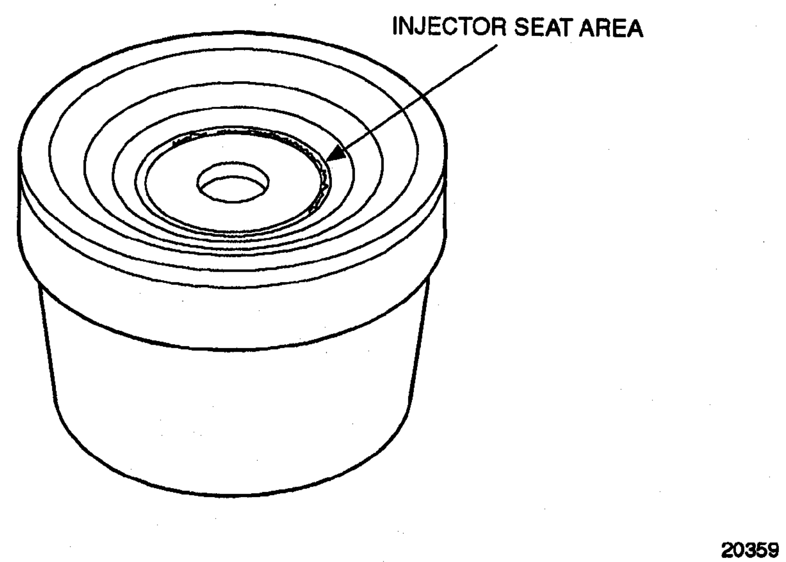

Figure 2-23 Injector Tube Seat Irregularities

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

20. Remove the reamer and pilot. Clean out the injector tube with compressed air.
21. Remove the two head bolts and J 33880-20 from the cylinder head.

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22. Spot-face the injector tube as follows:

[a] With the cylinder head firedeck in a workable position, insert the tube tip refinisher tool, J 5286-8, into the injector tube. See Figure 2-24.

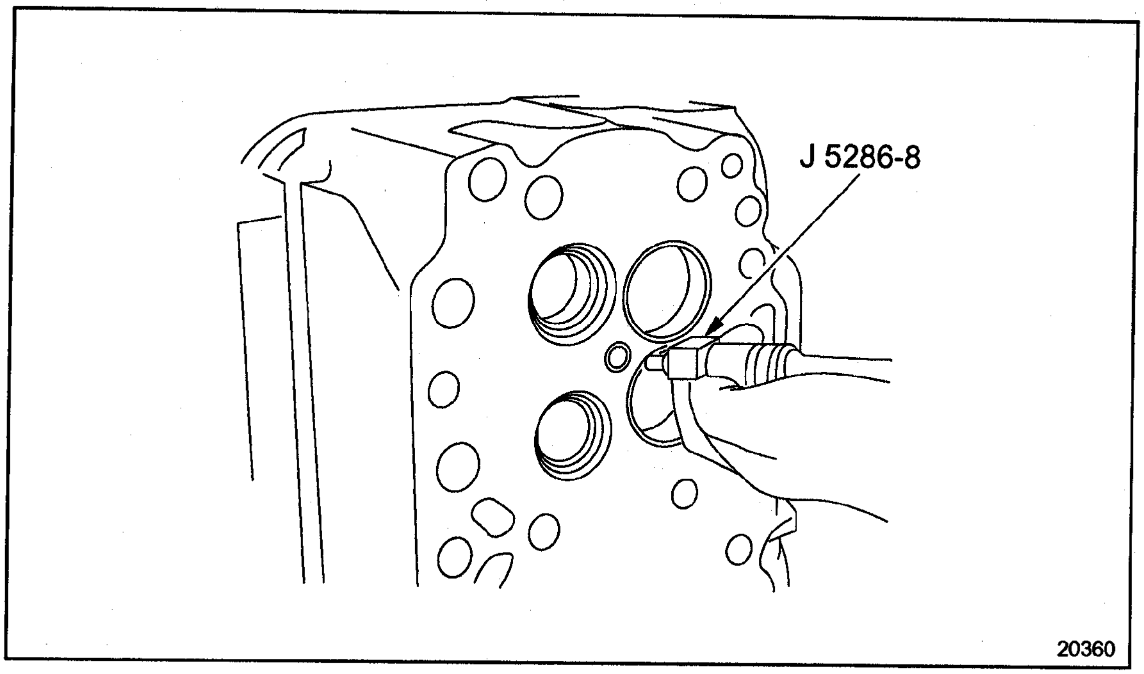

Figure 2-24 Refinishing Injector Tube Recess

[b] Using a 12-point socket and speed handle, turn the refinisher to remove excess stock so that the lower end of the injector tube is from flush to -0.20 mm (-0.008 in.) below the firedeck surface of the cylinder head.

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

[c] Remove the chips from the injector tube with compressed air. See Figure 2-24.

2.4.5.1 Check Injector Tip Protrusion

To check the injector tip protrusion:

1. Insert J 33880-3 part of J 33880, into injector tube bore of cylinder head. See Figure 2-20.
2. Insert J 33880-7 part of J 33880, into pilot. See Figure 2-25.

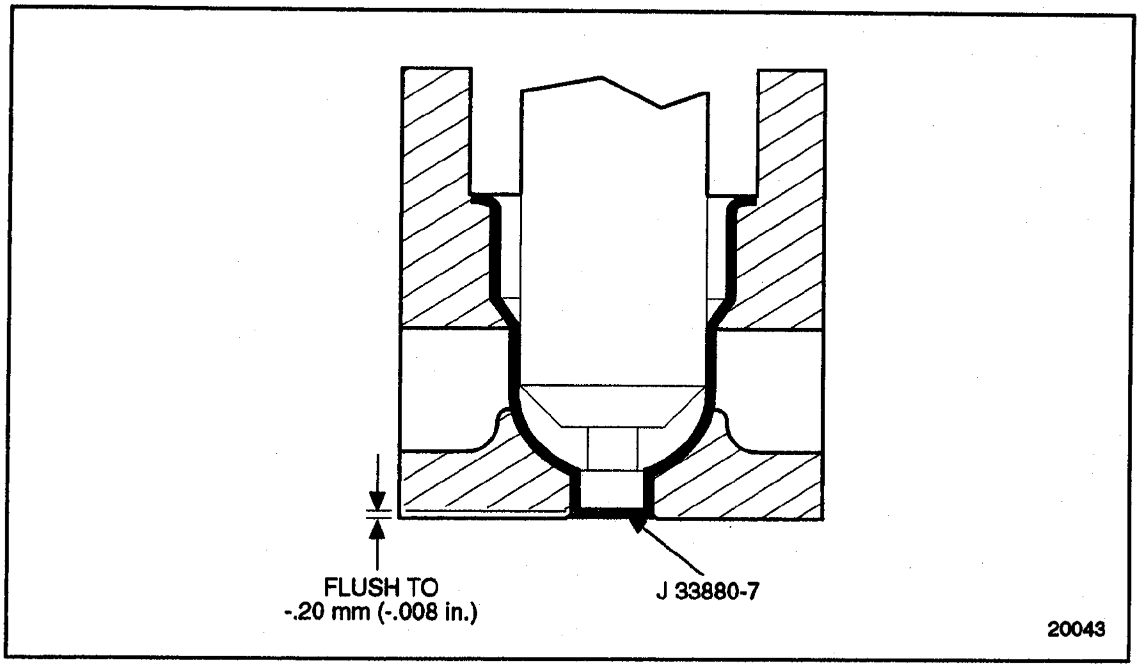

Figure 2-25 Checking Injector Tip Protrusion

3. Check injector tip protrusion using J 22273-01. Hold protrusion gage against pilot while measuring tip protrusion. This measurement should be flush to -0.20 mm (-0.008 in.).

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2.5 FUEL PUMP WITH SEPARATE DRIVE SHAFT AND HUB

The former fuel pump system consists of the following components:

- ☐ Barnes positive displacement type fuel pump; separate drive shaft
- ☐ Air compressor drive hub
- ☐ Gear train mounting adaptorThis pump has been replaced, effective July 1995, with an improved fuel pump. The pumps are similar, except the improved pump has a one-piece drive. These pump assemblies are completely interchangeable. Components are not interchangeable.

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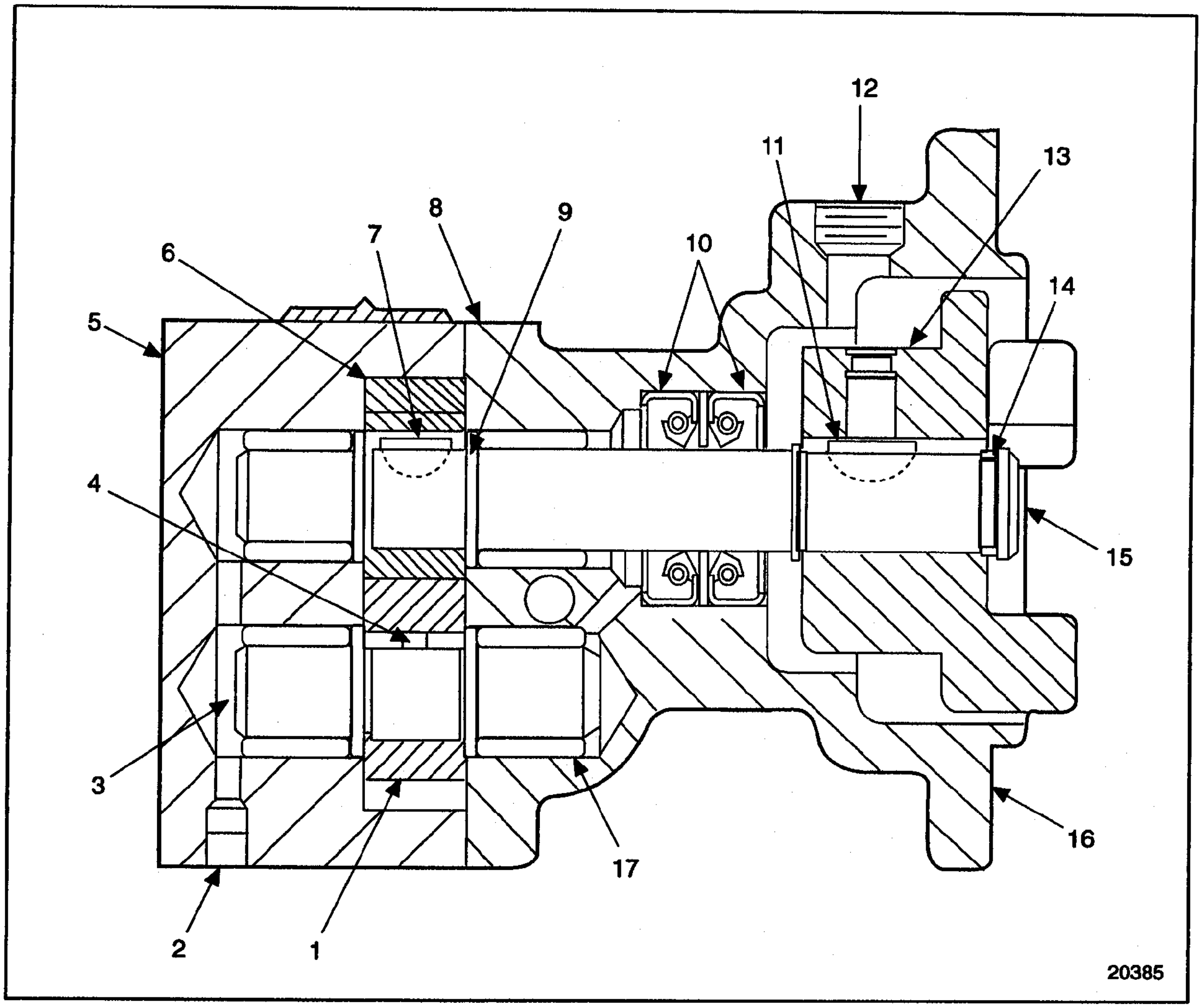
See Figure 2-26for the former positive displacement gear-type fuel pump.



1. Driven Gear
2. Plug
3. Driven Shaft
4. Pin
5. Cover
6. Drive Gear
7. Key
8. Gasket
9. C-clip
10. Oil Seals
11. Key
12. Plug, Relief Valve
13. Drive Hub
14. C-clip
15. Drive Shaft
16. Pump Body
17. Needle Bearing

Figure 2-26 Former Fuel Pump Assembly with Separate Drive Shaft and Hub Assembly

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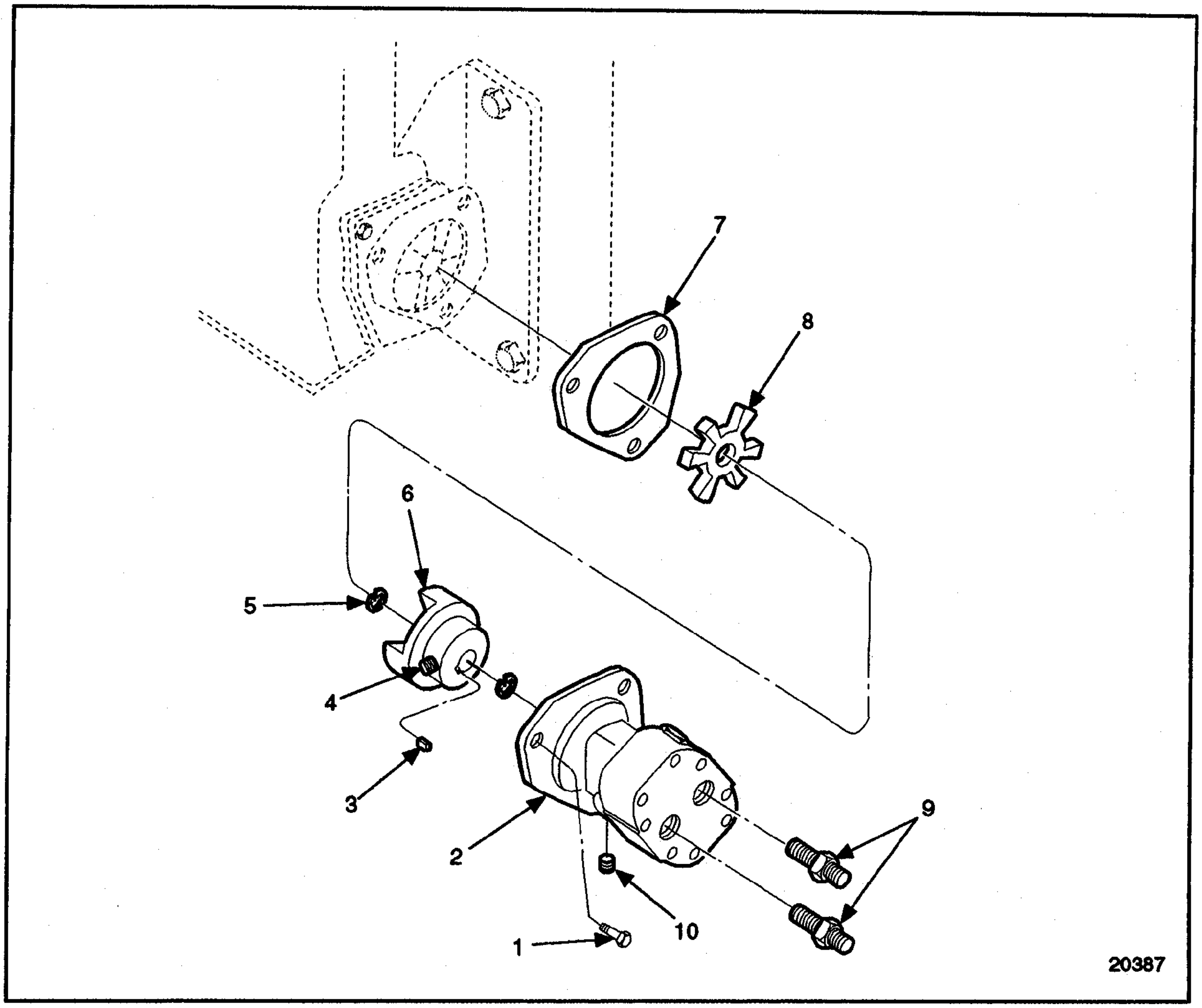
The fuel pump transfers fuel from the supply tank to the fuel injectors. The pump circulates an excess supply of fuel through the injectors which purges the air from the system and cools the injectors. The unused portion of fuel returns to the fuel tank by means of a fuel return line.

The fuel pump is attached to either a drive assembly mounted on the rear side of the gear case, see Figure 2-27, or driven off of the rear of the air compressor. See Figure 2-28.



1. Bolt
2. Fuel Pump Assembly
3. Key
4. Set Screw
5. C-clip
6. Drive Hub
7. Gasket
8. Fuel Pump Coupling
9. Fuel Fitting
10. Plug

Figure 2-27 Fuel Pump Drive Coupling

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The fuel pump cover and body are positioned by two dowels. The dowels aid in maintaining alignment between the body, cover and shafts. The mating surfaces of the pump body and cover are perfectly flat ground surfaces. A gasket is used between the cover and body.

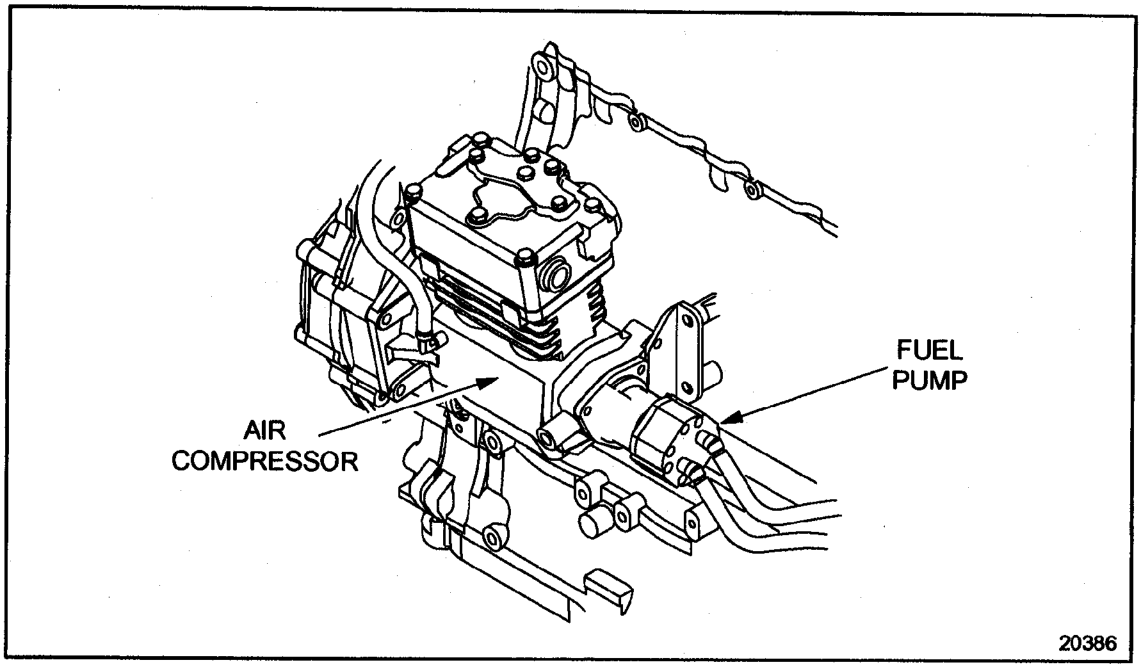

Figure 2-28 Fuel Pump Mounting

The fuel pump body is recessed to provide running space for the pump gears. Recesses are also provided at the inlet and outlet positions of the gears. The small relief valve vent (5) (see Figure 2-29) permits the fuel oil in the inlet side of the pump to lubricate the relief valve at its outer end. This eliminates the possibility of a hydrostatic lock which would render the relief valve inoperative. Pressurized fuel contacts the relief valve through the passage to the head of the relief valve (1) and provides for relief of excess discharge pressures.

Fuel re-enters the inlet side of the pump through the passage to head of the relief valve (6) when the discharge pressure is great enough to move the relief valve back from its seat. Part of the relief valve may be seen through the passage to the head of the relief valve (6).

The gear teeth vent cavity (7) provides escape for the fuel oil that is squeezed out of the gear teeth as they mesh together on the discharge side of the pump. Otherwise, fuel trapped at the root of the teeth would tend to force the gears apart, resulting in undue wear on the gears, shafts, body, and cover. See Figure 2-29.

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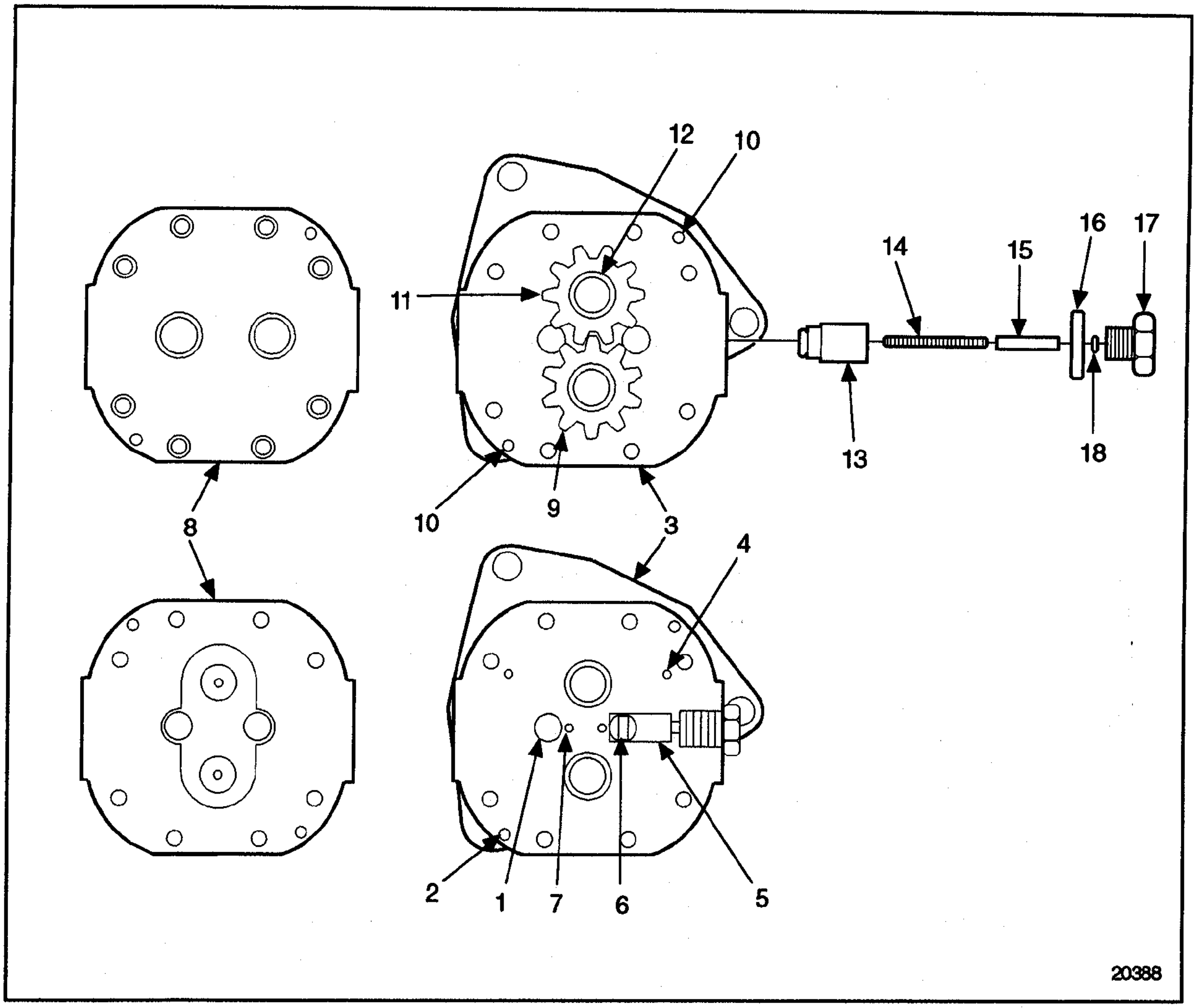

1. Passage to Head of Relief Valve-Pressure Side
2. Dowel Hole
3. Body
4. Oil Seal Vent to Suction Side
5. Relief Valve Vent to Suction Side
6. Passage to Head of Relief Valve-Suction Side
7. Gear Teeth Vent Cavity
8. Cover
9. Driven Gear
10. Dowel
11. Drive Gear
12. Drive Shaft Gear
13. Relief Valve
14. Spring
15. Pin
16. O-ring
17. Plug
18. Spacer

Figure 2-29 Fuel Pump

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Two oil seals are pressed into the bore in the flanged side of the pump body to retain the fuel oil in the pump and the lubricating oil in the fuel pump drive and gear case. The oil seal vent (4) (see Figure 2-29) serves as a vent passageway in the body between the inner oil seal and the suction side of the pump. This prevents building up any fuel oil pressure around the shaft ahead of the inner seal. The oil seals are installed with the lips of the seals facing each other. See Figure 2-30.

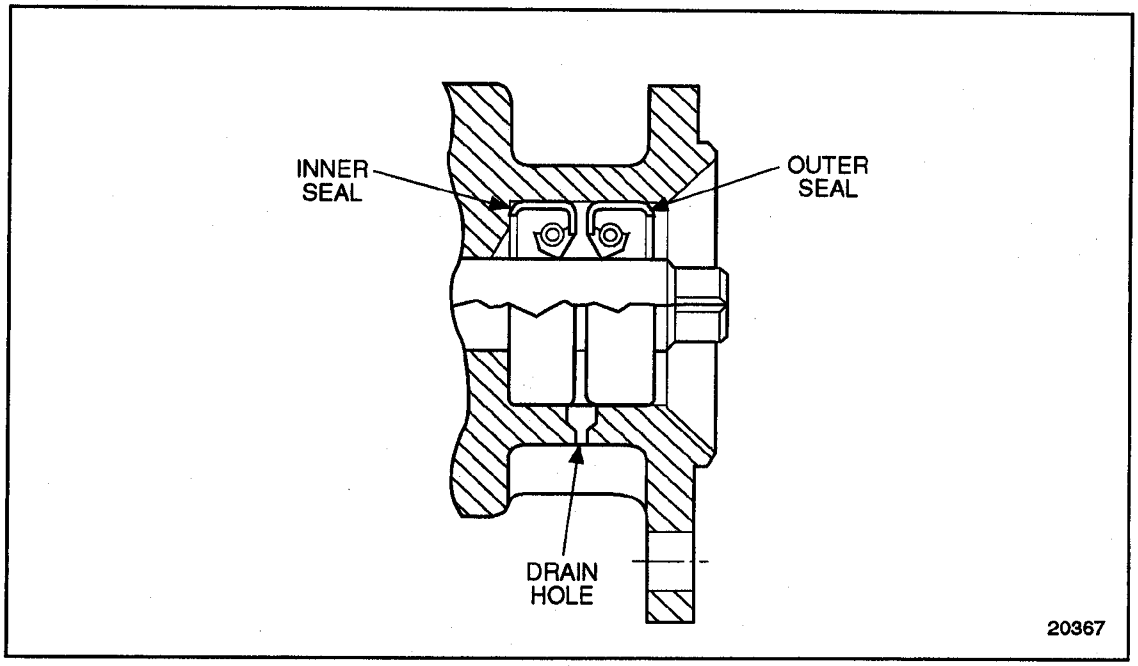

Figure 2-30 Fuel Pump Oil Seal Arrangement

Some fuel oil seepage by the fuel pump can be expected with a running engine and immediately after an engine has been shut down. This is especially true with a new fuel pump, new pump seals, or both, as the seals have not yet conformed to the pump drive shaft. Fuel pump seals will always allow some seepage. A drain hole in the pump body is provided to prevent fuel oil from being retained between the seals. Excessive fuel retention between the seals could provide enough pressure to cause engine oil dilution by fuel; therefore, drainage of the excess fuel oil is mandatory. However, if leakage exceeds one drop per minute, replace the seals. The drain hole should be checked for plugging at normal scheduled maintenance.

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A spring-loaded relief valve incorporated in the pump body normally remains in the closed position, operating only when pressure on the outlet side (to the fuel filter) reaches approximately 448 kPa (65 lb/in.^{2}).

In operation, fuel enters the pump on the suction side and fills the space between the gear teeth that are exposed at that instant. The gear teeth then carry the fuel oil to the discharge side of the pump and, as the gear teeth mesh in the center of the pump, the fuel is forced out the outlet cavity. Since this is a continuous cycle and fuel is continually being forced into the outlet cavity, the fuel flows from the outlet cavity into the fuel lines and through the engine fuel system under pressure.

The pressure relief valve relieves the discharge pressure by bypassing the fuel from the outlet side of the pump to the inlet side when the discharge pressure reaches approximately 448 to 517 kPa (65 to 75 lb/in.^{2}). The fuel pump should maintain the fuel pressure as shown in the maintenance section. Refer to section 11.5.

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2.5.1 Repair or Replacement of Former Fuel Pump

To determine if repair or replacement of the fuel pump is necessary. See Figure 2-31.

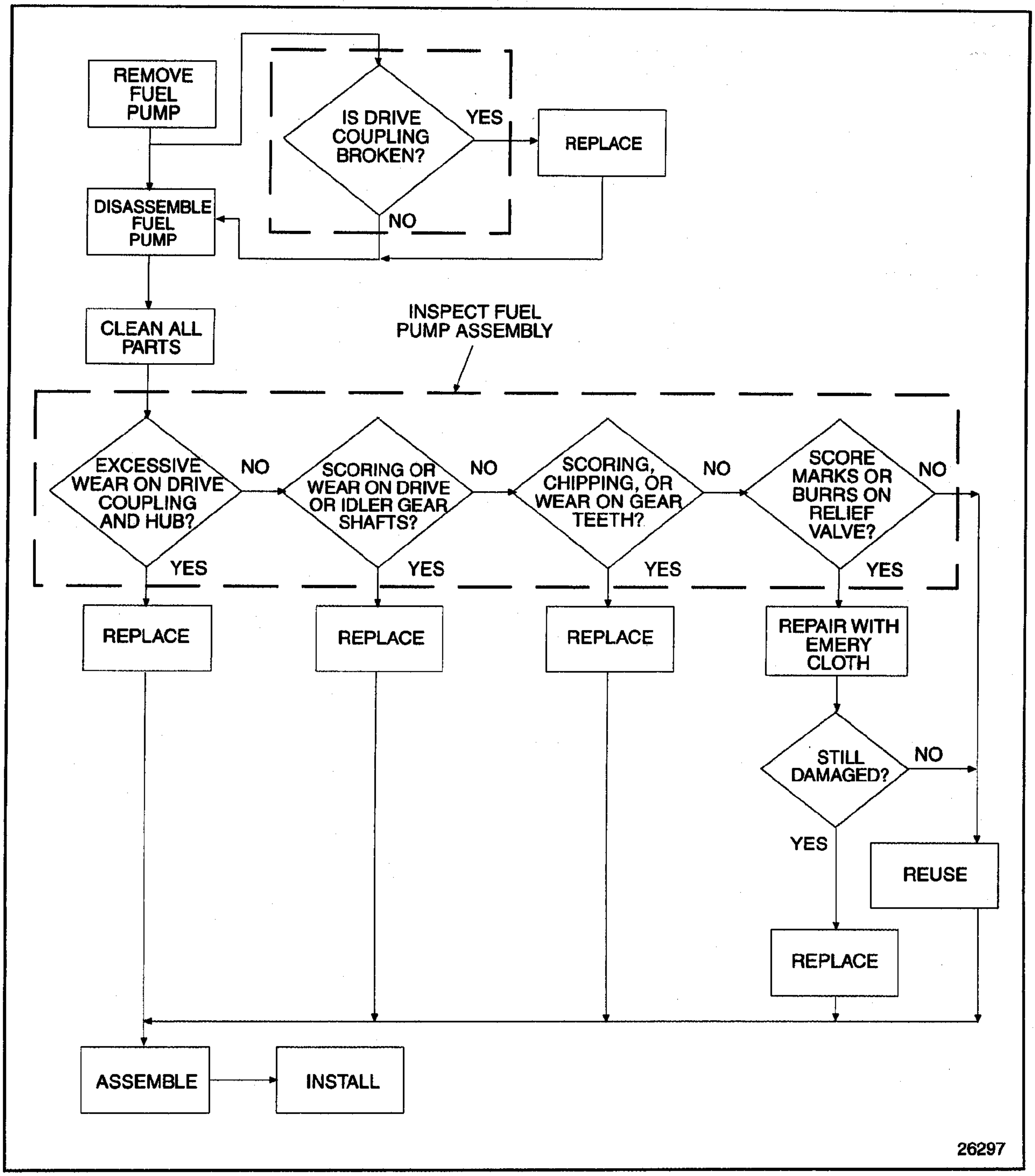

Figure 2-31 Flowchart for Repair or Replacement of Former Fuel Pump

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2.5.2 Removal of Former Fuel Pump

Perform the following steps for fuel pump removal:

1. Disconnect the fuel lines from the inlet and outlet openings of the fuel pump.
2. Remove the three fuel pump attaching bolts and withdraw the pump from the mounting adaptor on the gear case or air compressor.
3. Check the drive coupling and, if broken or worn, replace it with a new coupling.

2.5.3 Disassembly of Former Fuel Pump

Perform the following steps for fuel pump disassembly:

1. With the fuel pump removed from the engine, clamp the pump in a bench vise equipped with soft jaws.
2. Remove fuel inlet and outlet fittings from fuel pump cover.
3. Remove access hole plug.
4. Use snap ring pliers, J 4880, and remove outer drive hub positioning C-clip.

NOTE:
It may be necessary to rotate the drive hub and shaft to align the set screw with access hole.

5. Working through access hole, loosen but do not remove set screw securing drive hub to drive key.
6. Slide drive hub off shaft and remove drive key from shaft.
7. Use snap ring pliers, J 4880, and remove inner drive hub positioning C-clip.

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8. Position pump on holding fixture, J 38767-1, hub side down. See Figure 2-32.

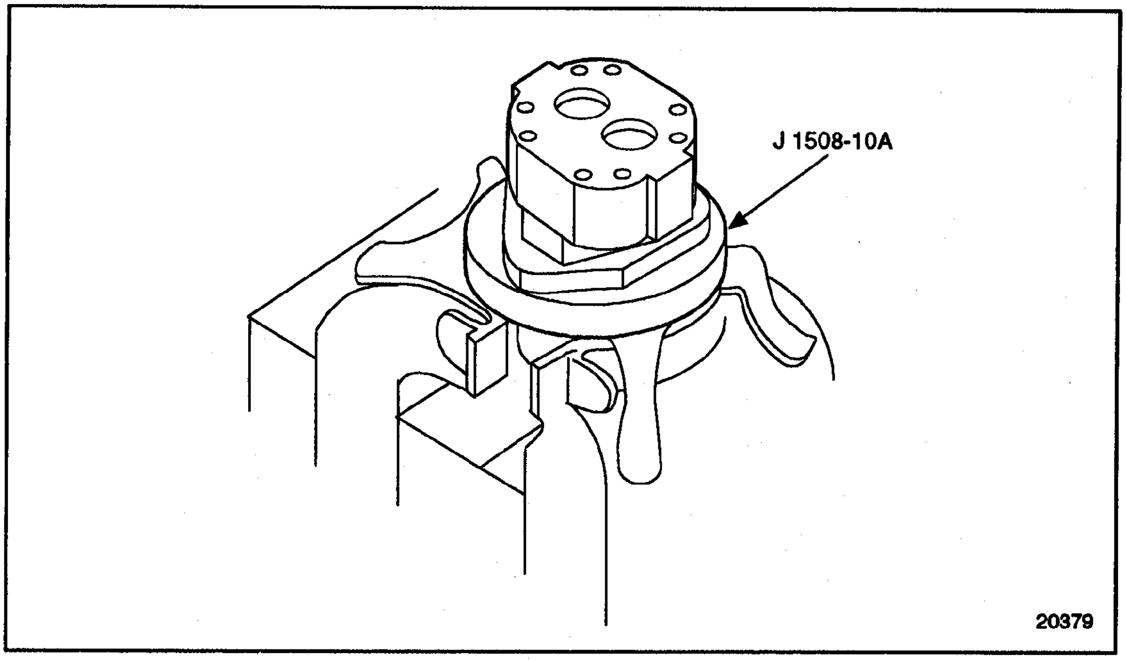

Figure 2-32 Fuel Pump Holding Fixture

9. Using a No. E-8 torx socket, J 25359-11, remove eight (8) bolts securing the pump cover to body.

NOTE:
Note the color of the foil gasket, gold or silver. If the pump is reassembled, the same color foil gasket must be used. The gaskets are of different thickness and establish correct internal clearance.

10. Separate the pump cover from the body by lifting it off the shafts and dowels. Remove and discard the foil gasket between the cover and body.

NOTE:
When the drive shaft is removed from the pump, the oil seals must be replaced.

11. Withdraw the driven shaft, drive shaft, and gear assemblies from the pump body.
12. Remove the C-clips that retain the gears on the shafts, taking care not to misplace the drive pin from the drive shaft or the key from the drive shaft.
13. Remove the gears from the shafts.

NOTE:
When the drive shaft is removed, the drive shaft needle bearing assembly in the pump body must also be removed to allow installation of the oil seal protector used during reassembly.

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14. Use needle bearing remover, J 33853, with slide hammer and remove the needle bearing assemblies from the pump body and cover. See Figure 2-33.

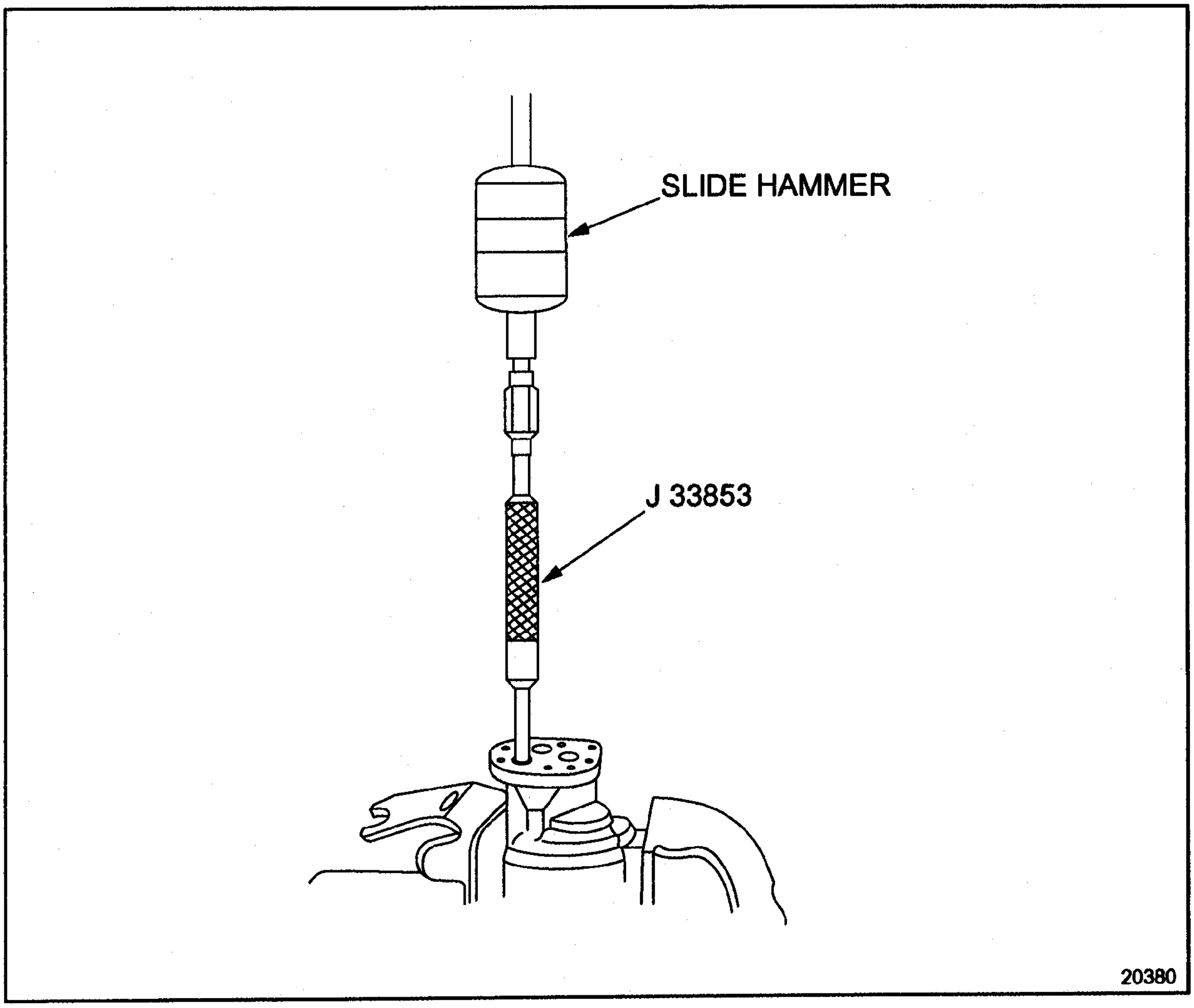

Figure 2-33 Needle Bearing Removal

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15. Position pump on fixture, J 38767-1, and insert lip of seal remover, J 1508-13, between the inner and outer oil seals. Tap the tool with a light hammer to drive the outer seal out of the pump body. See Figure 2-34. Discard the seal.

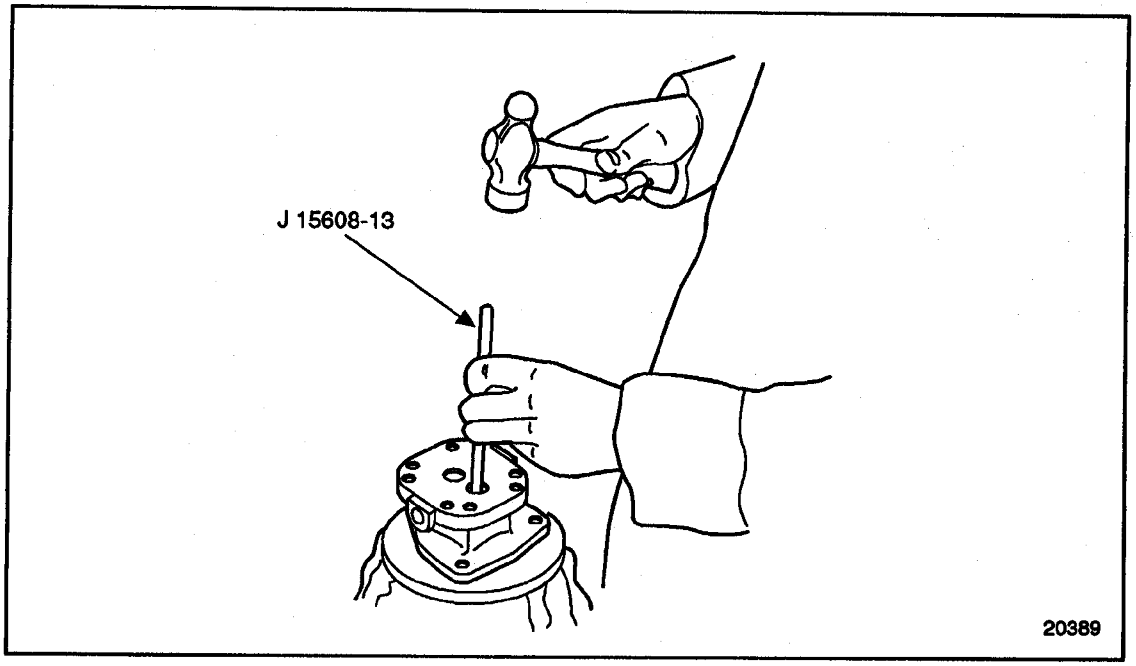

Figure 2-34 Oil Seal Removal

16. Repeat the process removing the inner seal by placing the tool lip against the inside of the seal case. Discard the seal.
17. Unscrew and remove the relief valve plug and remove the relief valve plunger, spring and pin from the bore.
18. Remove the spacer from the relief valve plug.
19. Remove and discard the O-ring seal under the head of the plug.

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2.5.3.1 Cleaning and Inspection of Former Fuel Pump

Perform the following steps to clean and inspect the fuel pump parts:

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

1. Clean all parts with clean fuel oil, before inspection.
2. Dry the parts with compressed air.
3. Visually inspect the drive coupling and hub for wear or damage.
   [a] If wear or damage is found, replace the drive coupling and hub.
   [b] If no wear or damage is found. Reuse the drive coupling and hub.
4. Oil seals, once removed, must be discarded and replaced with new seals. Oil seals must be removed whenever the fuel pump drive shaft is withdrawn.
5. Visually inspect the drive and idler gear shafts for scoring or wear.
   [a] If scoring or wear is found, replace the drive and idler gear shafts.
   [b] If no scoring or wear is found, reuse the drive and idler gear shafts.
6. Visually check the gear teeth for scoring, chipping or wear.
   [a] If gear teeth are scored, chipped or worn, replace the parts as necessary.
   [b] If gear teeth are not scored, chipped or worn, reuse the parts.
7. Visually inspect the relief valve. The valve must be free of score marks and burrs.
   [a] If the relief valve is scored and cannot be cleaned up with fine emery cloth, replace the relief valve.
   [b] If the relief valve is not damaged, reuse the part.

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2.5.4 Assembly of Former Fuel Pump

Perform the following steps for fuel pump assembly:

1. Lubricate the lips of the oil seals and pilot of oil seal installer, J 1508-8, with a light film of clean engine oil.
2. Place oil seal adaptor, J 34158, on the pilot with the wide end of the adaptor against the installer handle.
3. Place oil seal on installer pilot with seal case against the adaptor.
4. Support the pump body on wood blocks, hub side up, and insert the pilot into the shaft bore positioning the seal on the bore. Use a light hammer and drive the seal into the bore until the adaptor is bottomed against the pump body. See Figure 2-35.

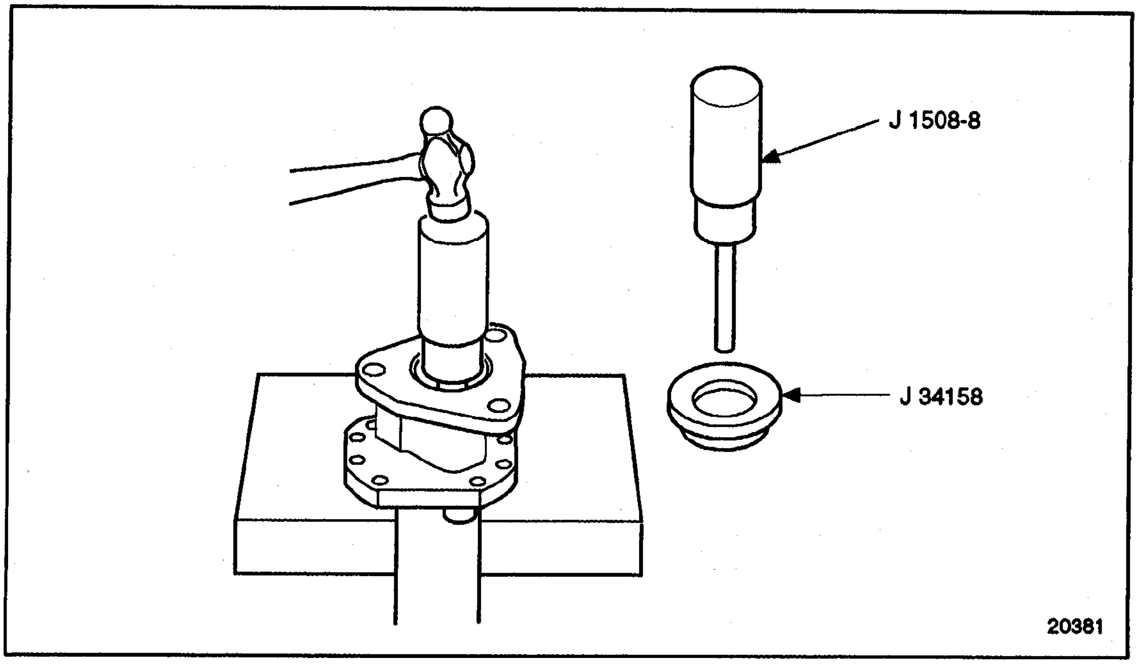

Figure 2-35 Installing Inner Oil Seal

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5. Remove the installer and reverse the adaptor, placing the narrow end against the installer handle. See Figure 2-36.

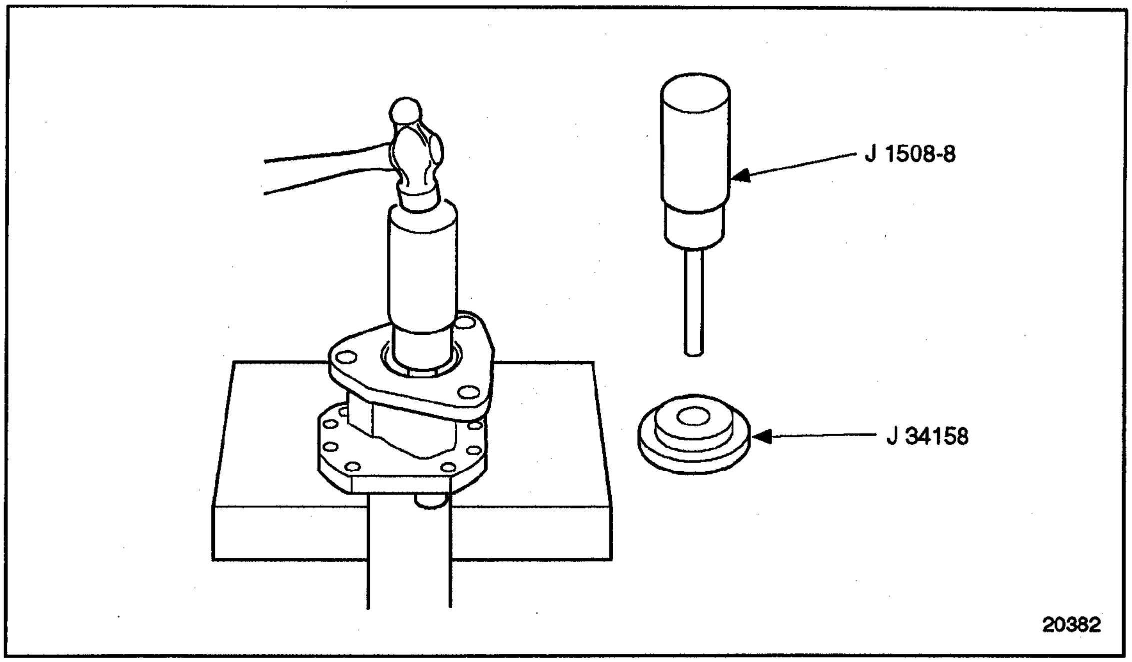

Figure 2-36 Installing Outer Oil Seal

6. Place a second seal on the installer pilot with the seal case faced away from the adaptor.
7. Carefully reinsert the installer pilot through the inner seal and position the second outer seal on the bore. Use a light hammer and drive the seal into the bore until the adaptor is bottomed against the pump body.
8. Press a fuel pump gear positioning C-clip directly into inner groove of fuel pump drive shaft opposite the drive hub end of the shaft.
9. Install drive key in slot on the drive shaft and slide the gear on the shaft indexing the keyway in the gear with the key.
10. Press a second C-clip directly into the groove behind the gear to retain it in position.
11. As the driven shaft is reversible, press a C-clip directly into either groove on the shaft.
12. Insert driven gear pin into its hole in the driven shaft with the square head of the pin parallel to the shaft. Slide the gear on the shaft indexing the keyway in the gear over the square head of the pin.
13. Press a second C-clip directly into the groove behind the gear to retain it in position.

NOTE:
The bearing numbers should always be against the tool during installation.

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14. With the pump cover on a bench, inside face up, position a new needle bearing assembly on bearing installer, J 33854, with the bearing numbers against the installer. Position the bearing carefully on a shaft bore in the cover and with a light hammer drive the bearing into the bore until the installer is flush against the cover surface. See Figure 2-37. Repeat the procedure, installing a new bearing assembly in the remaining shaft bore.

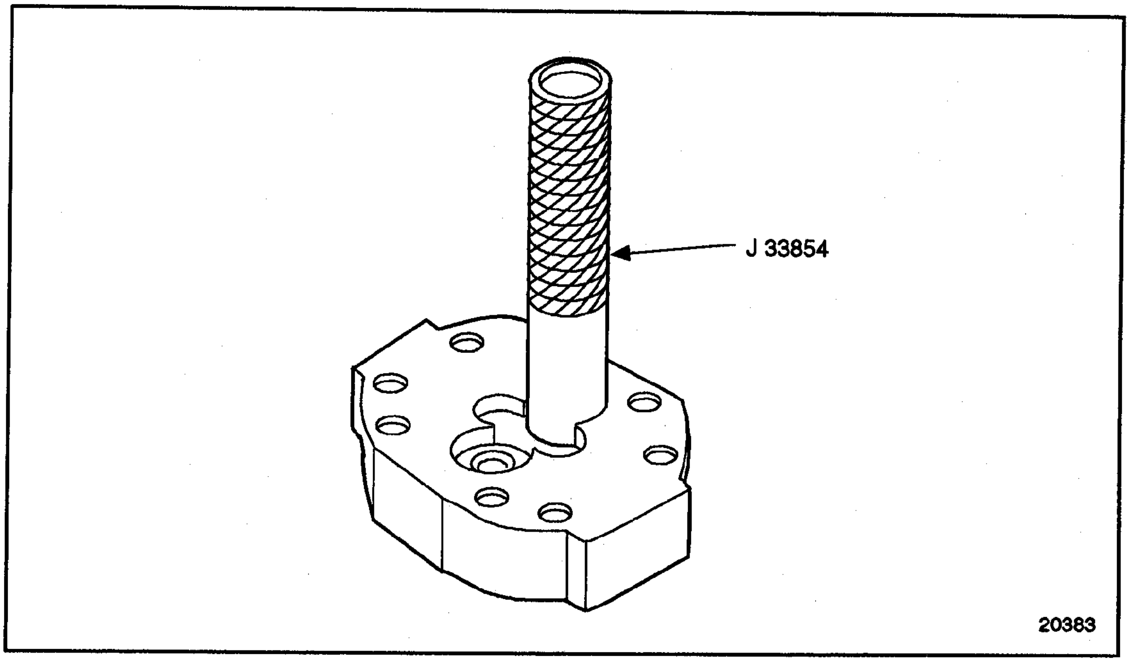

Figure 2-37 Bearing Assembly Installation

NOTE:
Do not install a needle bearing assembly in the drive shaft bore until all other needle bearings have been installed and the oil seal protector has been positioned in the seals.

15. Position the pump body on a bench, hub side down, and following the same bearing installation procedure, install a new needle bearing assembly in the driven shaft bore in the body.

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NOTICE:
The seal protector must remain in place on both seals during installation of the needle bearing assembly in the drive shaft bore. If the protector is allowed to come out before the drive shaft is installed, the bearing must be removed and discarded and the protector reinstalled. The protector will be pushed out during drive shaft installation.

16. With the pump body on a bench, hub side down, lubricate the outside of seal protector, J 33021-A, with clean engine oil. Install the solid end of the protector down through both seals until it contacts the bench. See Figure 2-38. Approximately 3 mm (1/8 in.) of the open end of the protector should remain above the inner seal.

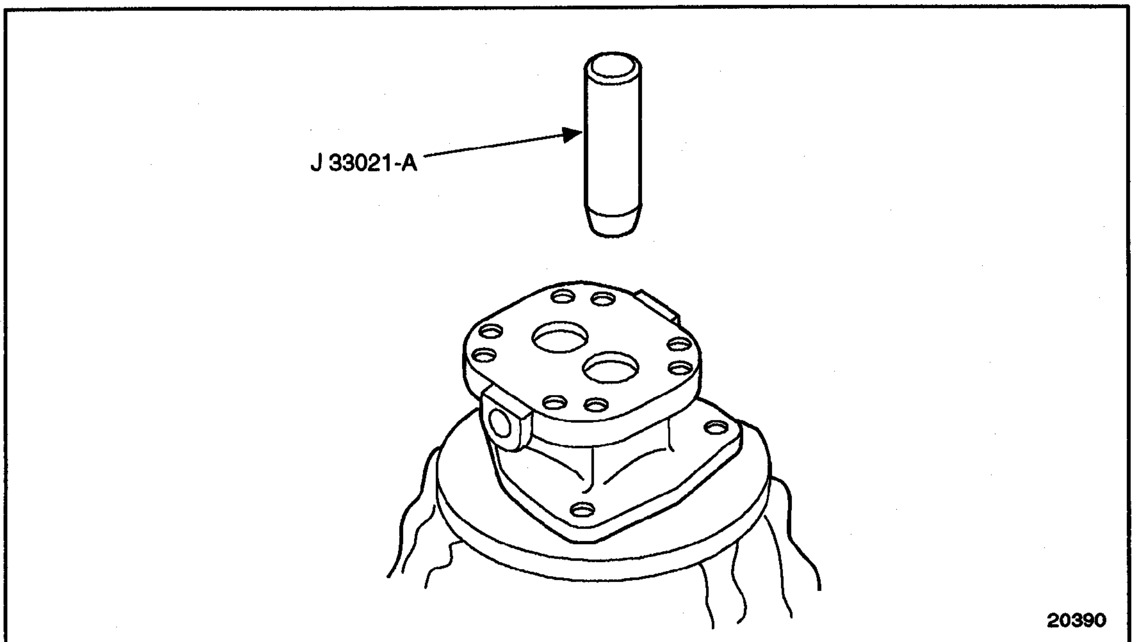

Figure 2-38 Seal Protector Installation

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17. Install a new needle bearing assembly in the drive shaft bore. See Figure 2-39.

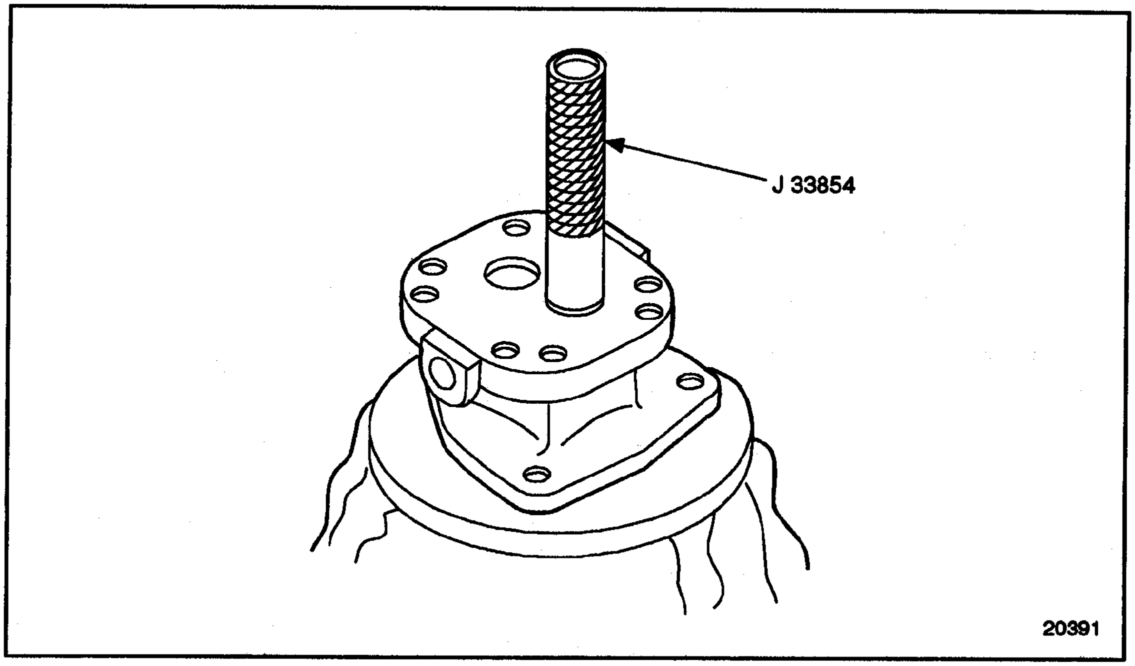

Figure 2-39 Drive Shaft Bearing Installation

18. Carefully insert the drive hub end of the drive shaft through the needle bearing assembly and into the seal protector. Ensure the shaft is fully seated in the seal protector.
19. Hold the shaft down in the seal protector and lift the pump body up against the gear. With the gear in contact with the pump body, lift the body and remove the seal protector from the drive shaft.

NOTE:
Hold the shaft in position with the gear against the pump body to ensure the drive hub C-clip grooves do not contact the oil seals.

20. Position the pump body on the holding fixture, J 38767-1 part of J 38767–A, hub side down.

NOTE:
When assembling pump, always use the same color foil gasket that was originally installed and is listed in Table 2-1. If the color is unknown, measure the depth of the gear cavity in the pump cover and install the required gasket.

Gear Cavity Depth	Color Gasket Used
0.24885-0.24905 in. (6.320-6.325 mm)	Blue
0.24906-0.24925 in. (6.326-6.331 mm)	Amber
0.24935-0.24955 in. (6.333-6.338 mm)	Gold
0.24956-0.24975 in. (6.339-6.344 mm)	Silver

Table 2-1 Gasket Color vs. Gear Cavity Depth Chart (Former Fuel Pump)

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21. Place a new foil gasket on the face of the pump. With a finger tip, carefully smooth the gasket against the face to ensure there are no wrinkles, creases or bubbles. If present, and they cannot be removed with the finger, remove the gasket and repeat the procedure.
22. Carefully insert the driven shaft and gear assembly in the needle bearing in the pump body.

NOTE:
When positioning the cover, the fuel inlet (stamped on cover) must be on the side of the relief valve bore in the pump body.

23. Position the needle bearing assemblies in the pump cover on the ends of the driven and drive shafts and slide the cover against the pump body.
24. Install eight (8) cover retaining bolts. Use No. E-8 torx socket, J 25359-11 part of J 25359–C , and torque bolts to 12-15 N·m (9-11 lb·ft).

NOTE:
As the outside of the pump body and cover are not machined and to prevent possible distortion, ensure that only the pump cover is gripped and that the vise jaws do not contact both body and cover.

25. Clamp the fuel pump cover in a soft-jawed vise with the relief valve bore in the pump body positioned up.
26. Lubricate the relief plunger with clean engine oil and insert the plunger into the bore with the hollow end up. Insert the relief spring inside the plunger and the pin inside the spring.
27. Install the spacer in the bottom of the spring seat in the plug and install a new O-ring seal under the head of the plug. Thread the plug into the pump body and torque to 8-14 N·m (6-10 lb·ft).
28. Place the pump assembly on a bench, hub side up. Coat the surface of the outer seal with a small amount of lithium base all purpose grease.
29. Use snap ring pliers, J 28507, and install inner drive hub positioning C-clip in its groove in the shaft.
30. Remove the set screw from the drive hub and apply one drop of Loctite® 242 (or equivalent) to the threads and reinstall the set screw two or three turns.
31. Install the hub drive key in the groove on the shaft and slide the hub on the shaft indexing the keyway in the hub with the key in the shaft.
32. Use snap ring pliers and install outer hub retaining C-clip in groove.
33. Rotate the drive shaft and hub to align the hub set screw with the access hole in the pump body. Torque the set screw to 3.8 N·m (2.8 lb·ft).
34. Install access hole plug.
35. Install fuel inlet and outlet fittings in the pump cover.

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2.5.5 Installation of Former Gear Train-Driven Fuel Pump

Install the fuel pump as follows:

NOTICE:
It may be necessary to use a brass hammer or fiber mallet to seat the drive assembly. Be careful not to damage the O-ring on installation.

1. Install the drive assembly on the gear case.
2. Install the fuel pump drive bolts and torque to 30-34 N·m (22-25 lb·ft) using the torque pattern. See Figure 2-40.

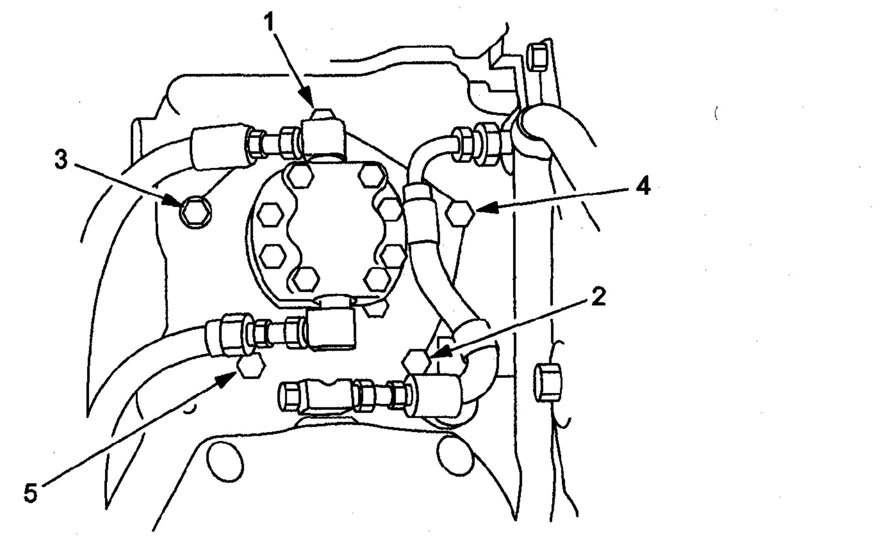

Figure 2-40 Fuel Pump Drive Retaining Bolt Torque Sequence

3. Using a new gasket, install the fuel pump and torque bolts to 30-38 N·m (22-28 lb·ft).
4. Install any other components that were removed for this procedure.
5. Connect fuel inlet and outlet lines to the fuel pump and tighten.
6. Prime the fuel system before starting the engine.

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CAUTION:

Diesel engine exhaust and some of its constituents are known to the State of California to cause cancer, birth defects, and other reproductive harm.

- **Always start and operate an engine in a well ventilated area.**
- **If operating an engine in an enclosed area, vent the exhaust to the outside.**
- **Do not modify or tamper with the exhaust system or emission control system.**

7. Start the engine and check for leaks.
8. Shut down the engine upon completion of tests.

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2.5.6 Installation of Former Air Compressor-Driven Fuel Pump

Perform the following steps for fuel pump installation:

NOTE:
New fittings have sealant already applied. If reusing fittings, coat the threads lightly with Loctite® Pipe Sealant, PT-7260 , or equivalent, before installing. To prevent sealant from entering fuel system, do not apply it to the first two (2) threads of the fitting. Do not use Teflon tape or paste on the fittings.

1. If removed, install inlet and outlet fittings in the rear cover of the fuel pump.
2. Install drive coupling in drive hub of the fuel pump and affix a new gasket to the mounting flange of the pump.

NOTE:
When correctly positioned, the outlet fitting on the pump should be in approximately 8 o'clock position when viewed from the rear, and the drain opening in the pump body facing down.

3. Index the drive coupling with the drive hub on the end of the air compressor crankshaft and align the pump mounting bolt holes with those in the air compressor rear cover.
4. Seat the fuel pump squarely against the air compressor piloting the flange on the pump body in the opening in the rear cover of the compressor. Install three (3) fuel pump mounting bolts and torque them to 30-38 N·m (22-28 lb·ft).
5. Connect the fuel inlet and outlet lines to the fuel pump and tighten.
6. Prime engine fuel system before starting engine to ensure pump seal lubrication and prompt engine starting.

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2.6 FUEL PUMP WITH ONE-PIECE DRIVE SHAFT AND HUB ASSEMBLY

An improved fuel pump replaced the former fuel pump, effective with July 1995 engine production. The improved and former pumps are similar, except that the improved pump has a one-piece drive shaft and hub assembly. See Figure 2-41. The former pump has a separate drive shaft and drive hub. See Figure 2-42. Former and improved pump assemblies are completely interchangeable. However, components of former and improved pump assemblies are not interchangeable.

The current fuel pump system consists of the following components:

- ☐ Barnes positive displacement type fuel pump with one-piece drive shaft and hub assembly
- ☐ Gear train mounting adaptor

NOTE:
Effective with engine serial number 06R0549855 built on October 19, 1999, gear case-mounted fuel pumps have a splined drive shaft and splined gear coupling assembly. See Figure 2-42. The former and current fuel pump and fuel pump drive assemblies are not interchangeable. Both current assemblies must be used together. Components of former and current pump assemblies and drive assemblies are not interchangeable.

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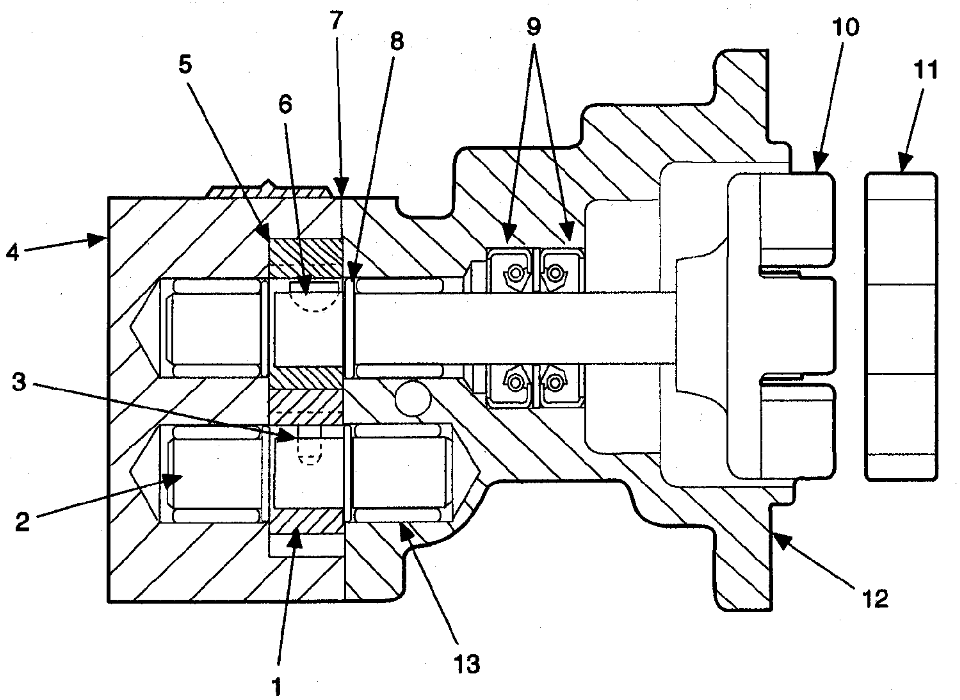

1. Driven Gear
2. Driven Shaft
3. Pin, Drive
4. Cover
5. Drive Gear
6. Key
7. Gasket
8. Snap Ring
9. Oil Seals
10. Drive Shaft and Hub Assembly
11. Coupling
12. Pump Body
13. Needle Bearing

Figure 2-41 **Current Compressor-Mounted Fuel Pump Assembly with One-Piece Drive Shaft and Hub Assembly**

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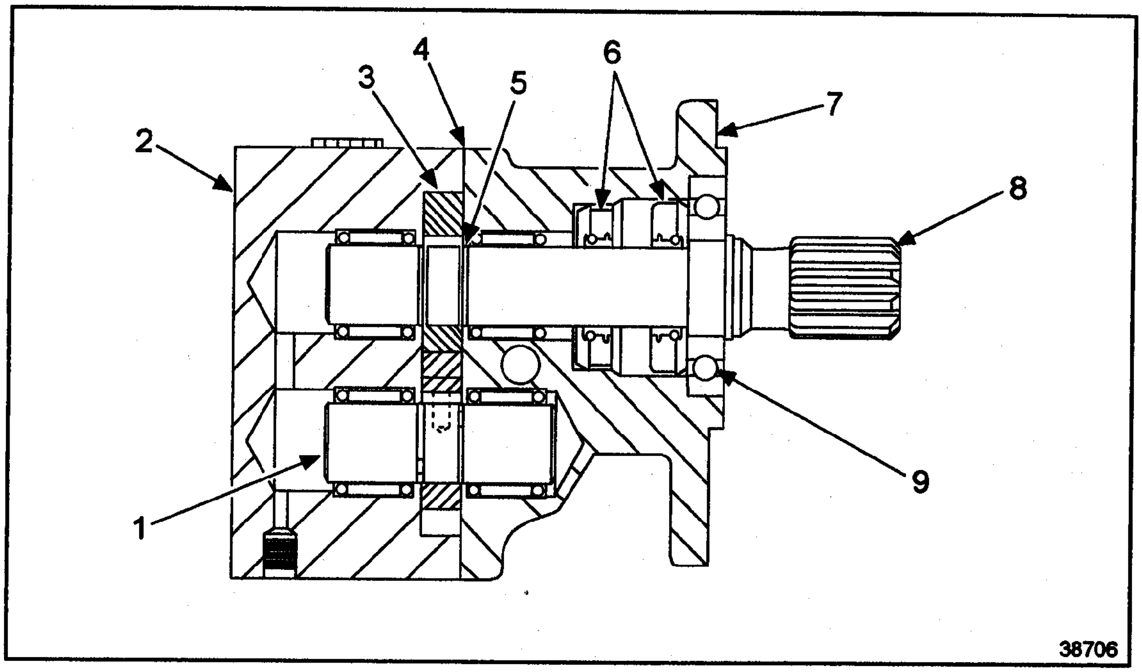

1. Driven Shaft
2. Cover
3. Drive Gear
4. Gasket
5. Snap Ring
6. Oil Seal
7. Pump Body
8. Spline Drive Shaft
9. Steel Cage Ball Bearing

Figure 2-42 Current Gear Case-Mounted Fuel Pump Assembly

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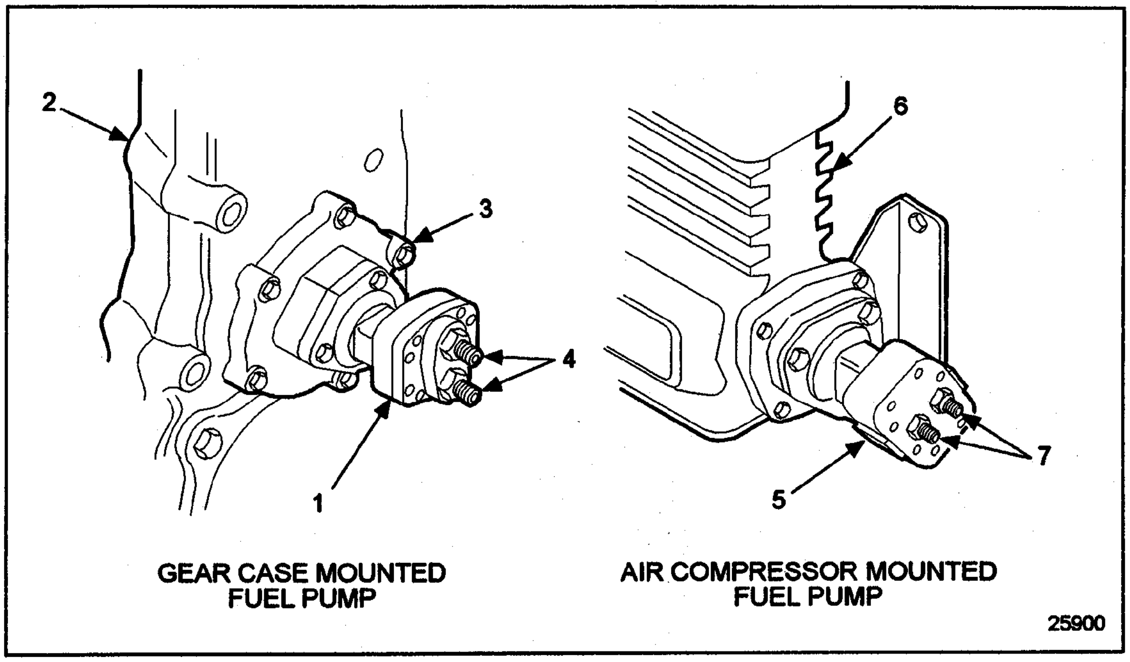
See Figure 2-43for the current positive displacement gear-type fuel pump is shown in the next illustration.



1. Gear Case-Mounted Fuel Pump Assembly
2. Gear Case Housing
3. Fuel Pump Drive Adaptor
4. Brass Fittings
5. Air Compressor-Mounted Fuel Pump
6. Air Compressor Assembly
7. Brass Fittings

Figure 2-43 Gear Case and Air Compressor-Mounted Fuel Pumps

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The fuel pump transfers fuel from the supply tank to the fuel injectors. The pump circulates an excess supply of fuel through the injectors, which purges the air from the system and cools the injectors. The unused portion of fuel returns to the fuel tank by means of a fuel return line.

The fuel pump is either attached to a drive assembly mounted on the rear side of the gear case, or driven off of the rear of the air compressor. See Figure 2-43.

The fuel pump cover and body are positioned by two dowels. The dowels aid in maintaining alignment between the body, cover and shafts. The mating surfaces of the pump body and cover are perfectly flat ground surfaces. A gasket is used between the cover and body.

The fuel pump body is recessed to provide running space for the pump gears. Recesses are also provided at the inlet and outlet positions of the gears. The small relief valve vent (5) (see Figure 2-44) permits the fuel oil in the inlet side of the pump to lubricate the relief valve at its outer end. This eliminates the possibility of a hydrostatic lock which would render the relief valve inoperative. Pressurized fuel contacts the relief valve through the passage to the head of the relief valve (1) and provides for relief of excess discharge pressures. Fuel re-enters the inlet side of the pump through the passage to the head of the relief valve (6) when the discharge pressure is great enough to move the relief valve back from its seat. Part of the relief valve may be seen through the passage to the head of the relief valve (6). The gear teeth vent cavity (7) provides escape for the fuel oil that is squeezed out of the gear teeth as they mesh together on the discharge side of the pump. Otherwise, fuel trapped at the root of the teeth would tend to force the gears apart, resulting in undue wear on the gears, shafts, body, and cover. See Figure 2-44.

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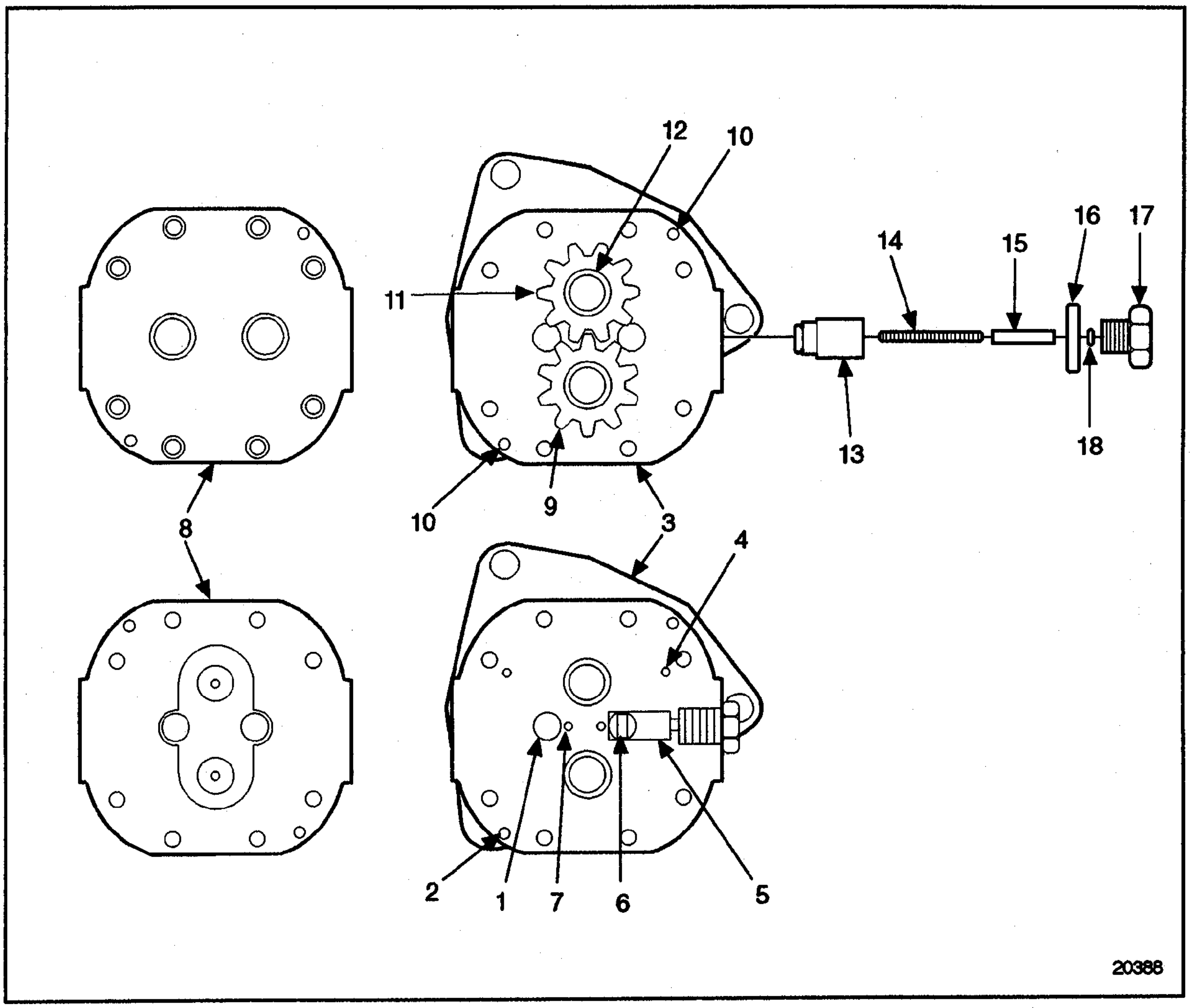

1. Passage to Head of Relief Valve, Pressure Side
2. Dowel Hole
3. Body
4. Oil Seal Vent to Suction Side
5. Relief Valve Vent to Suction Side
6. Passage to Head of Relief Valve, Suction Side
7. Gear Teeth Vent Cavity
8. Cover
9. Driven Gear
10. Dowel
11. Drive Gear
12. Drive Shaft Gear
13. Relief Valve
14. Spring
15. Pin
16. O-ring
17. Plug
18. Spacer

Figure 2-44 Fuel Pump

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Two oil seals are pressed into the bore in the flanged side of the pump body to retain the fuel oil in the pump and the lubricating oil in the fuel pump drive and gear case. The oil seal vent (4) (see Figure 2-44) serves as a vent passageway in the body, between the inner oil seal and the suction side of the pump, which prevents building up any fuel oil pressure around the shaft ahead of the inner seal. The oil seals are installed with the lips of the seals facing each other. See Figure 2-45.

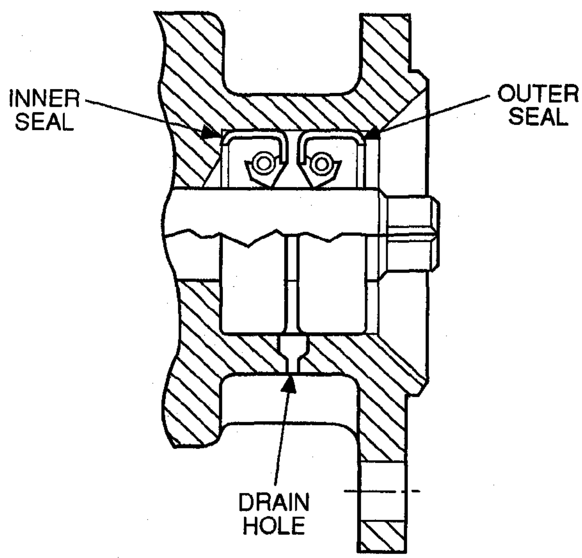

Figure 2-45 Fuel Pump Oil Seal Arrangement

Some fuel oil seepage by the fuel pump can be expected with a running engine and immediately after an engine has been shut down. This is especially true with a new fuel pump, new pump seals, or both, as the seals have not yet conformed to the pump drive shaft. Fuel pump seals will always allow some seepage. A drain hole in the pump body is provided to prevent fuel oil from being retained between the seals. Excessive fuel retention between the seals could provide enough pressure to cause engine oil dilution by fuel; therefore, drainage of the excess fuel oil is mandatory. However, if leakage exceeds one drop per minute, replace the seals. The drain hole should be checked for plugging at normal scheduled maintenance.

A spring-loaded relief valve incorporated in the pump body normally remains in the closed position, operating only when pressure on the outlet side (to the fuel filter) reaches approximately 448 kPa (65 lb/in.^{2}).

In operation, fuel enters the pump on the suction side and fills the space between the gear teeth that are exposed at that instant. The gear teeth then carry fuel oil to the discharge side of the pump and as the gear teeth mesh in the center of the pump, the fuel is forced out the outlet cavity. Since this is a continuous cycle and fuel is continually being forced into the outlet cavity, the fuel flows from the outlet cavity into the fuel lines and through the engine fuel system under pressure.

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The pressure relief valve relieves the discharge pressure by bypassing the fuel from the outlet side of the pump to the inlet side when the discharge pressure reaches approximately 448 to 517 kPa (65 to 75 lb/in.^{2}).

The fuel pump should maintain the fuel pressure as listed in Table 2-2.

Fuel System Parameter Limits	Operating Limits at 2100 r/min	Operating Limits at 1800 r/min
Fuel pressure at secondary filter outlet - kPa (lb/in.^{2}):		
Normal with 2.03 mm (0.080 in.) restriction	517 (75)	517 (75)
Minimum	345 (50)	345 (50)
Fuel spill minimum at no-load - L/min (gal/min):		
Normal with 2.03 mm (0.080 in.) restriction	4.9 (1.3)	4.1 (1.0)
Fuel pump suction at pump inlet, maximum - kPa (in. Hg):		
Clean system	20 (6)	20 (6)
Dirty system	41 (12)	41 (12)

Table 2-2 Series 60 Engine Fuel System Parameters

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2.6.1 Repair or Replacement of Fuel Pump

To determine if repair or replacement of the fuel pump is necessary. See Figure 2-46.

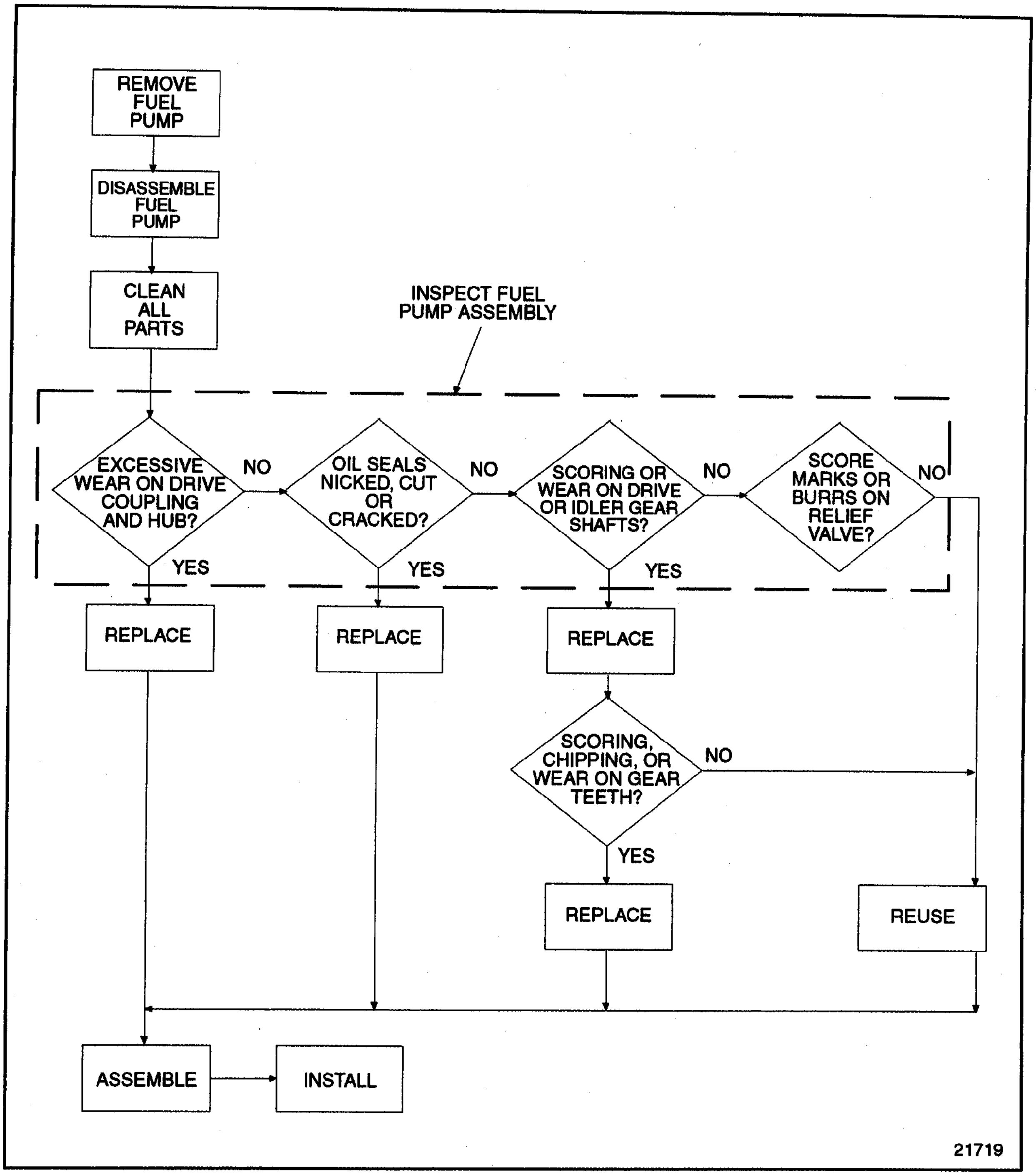

Figure 2-46 Flowchart for Repair or Replacement of Fuel Pump

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2.6.2 Removal of Fuel Pump (One-piece Drive Shaft)

Perform the following steps for fuel pump removal:

1. Disconnect the fuel lines from the inlet and outlet openings of the fuel pump.
2. Remove the three fuel pump attaching bolts and withdraw the pump from the mounting adaptor on the gear case or air compressor.
3. Check the drive coupling and, if broken or worn, replace it with a new coupling.

2.6.3 Disassembly of Fuel Pump (One-piece Drive Shaft)

Perform the following steps for fuel pump disassembly:

1. With the fuel pump removed from the engine, clamp the pump in a bench vise equipped with soft jaws.
2. Remove fuel inlet and outlet fittings from fuel pump cover.
3. Remove the pump from the vise and position pump on holding fixture J 38767-1, hub side down. See Figure 2-47. Clamp the holding fixture in the vise.

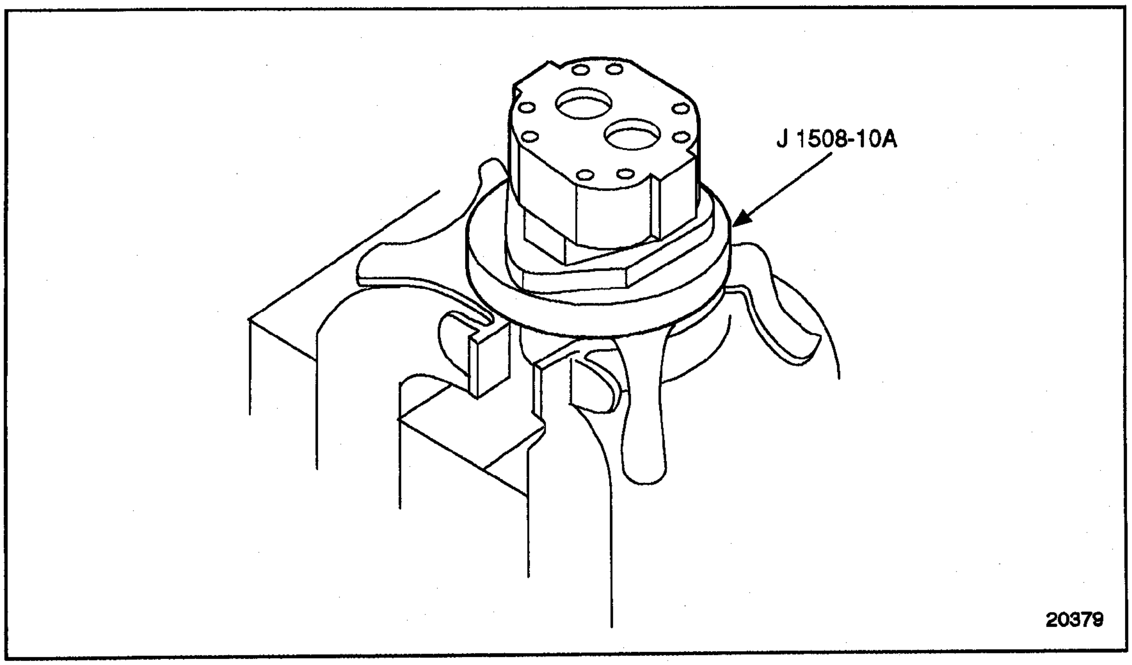

Figure 2-47 Fuel Pump Holding Fixture

4. Using a No. E-8 torx socket, J 25359-11, remove eight (8) bolts securing the pump cover to body.

NOTE:
Note the color of the foil gasket, gold or silver. If the pump is reassembled, the same color foil gasket must be used. The gaskets are of different thickness and establish correct internal clearance.

5. Separate the pump cover from the body by lifting it off the shafts and dowels. Remove and discard the foil gasket between the cover and body.

NOTE:
When the drive shaft is removed from the pump, the oil seals must be replaced.

6. Withdraw the driven shaft and gear and the drive shaft and gear assemblies from the pump body.
7. Remove the C-clips, and key from the drive shaft. Remove the C-clips and pin from the driven shaft.
8. Remove the gears from the shafts.

NOTE:
When the drive shaft is removed, the drive shaft needle bearing assembly in the pump body must also be removed to allow installation of the oil seal protector used during reassembly.

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9. Use needle bearing remover, J 33853, with slide hammer and remove the needle bearing assemblies from the pump body and cover. See Figure 2-48.

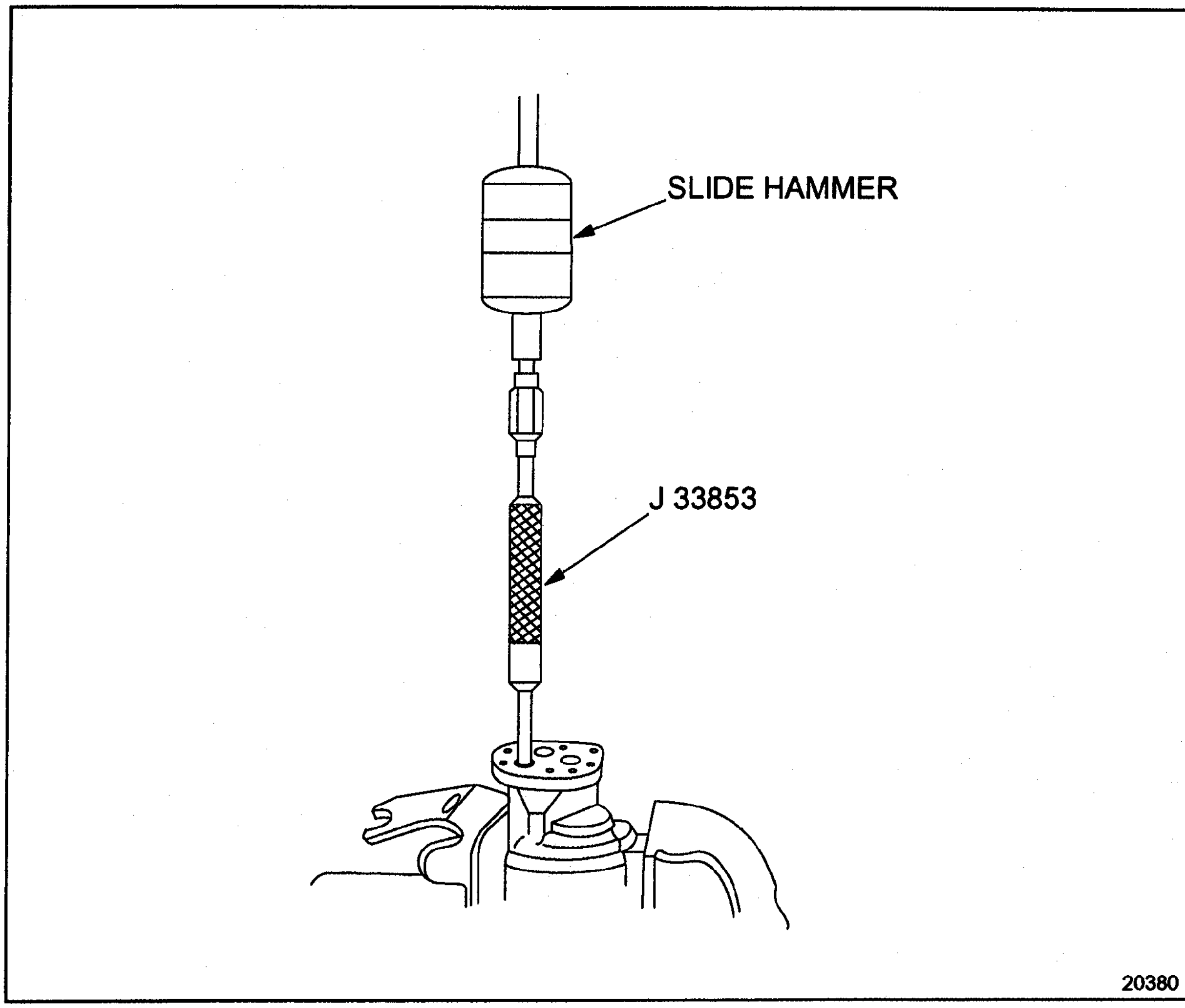

Figure 2-48 Needle Bearing Assembly Removal

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10. Position pump on fixture, J 38767-1, and insert the lip of seal remover, J 1508-13, between the inner and outer oil seals. Tap the tool with a light hammer to drive the outer seal out of the pump body. See Figure 2-49. Discard the outer seal.

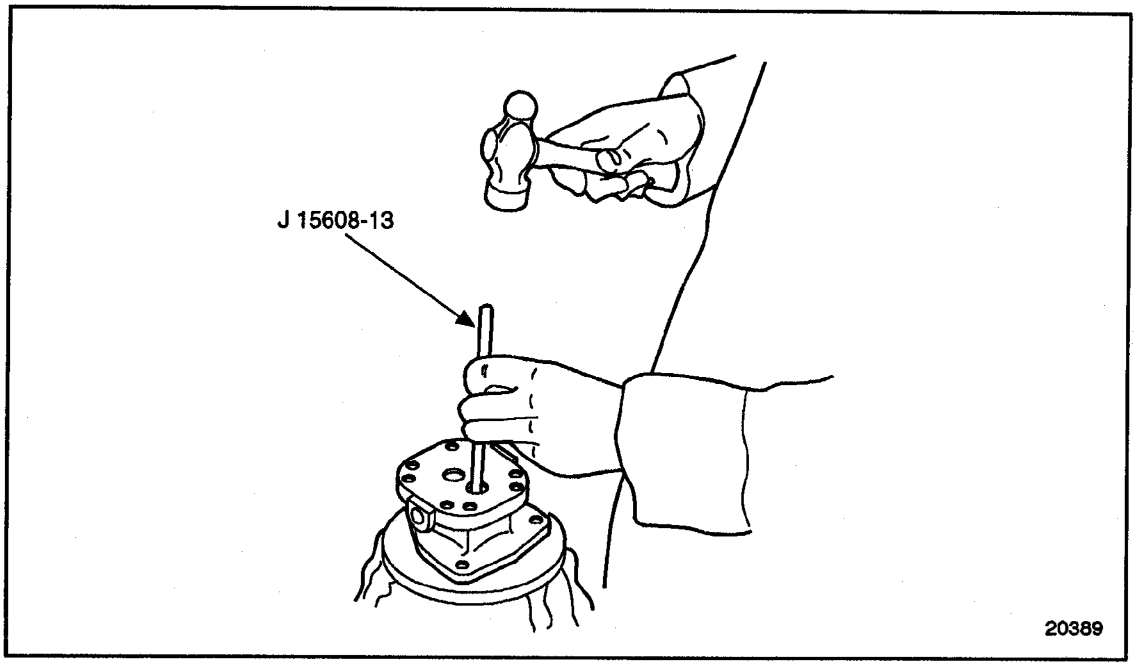

Figure 2-49 Oil Seal Removal

11. Repeat the process, removing the inner seal by placing the tool lip against the inside of the seal case. Discard the inner seal.
12. Unscrew and remove the relief valve cover and remove the relief valve plunger, spring and pin from the bore.
13. Remove the spacer from the relief valve cover.
14. Remove and discard the O-ring seal under the head of the cover.

2.6.3.1 Cleaning and Inspection of Fuel Pump (One-piece Drive Shaft)

Perform the following steps to clean and inspect the fuel pump parts:

1. Clean all parts with clean fuel oil before inspection.

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

2. Dry the parts with compressed air.
3. Visually inspect the drive coupling for wear or damage.
   [a] If wear or damage is found, replace the drive coupling.
   [b] If no wear or damage is found, reuse the drive coupling.

NOTE:
Oil seals, once removed, must be discarded and replaced with new seals. Oil seals must be removed whenever the fuel pump drive shaft is withdrawn.

4. Visually inspect the drive shaft and hub assembly and idler gear shaft for scoring or wear.
   [a] If scoring or wear is found, replace the drive shaft and hub assembly and idler gear shaft.
   [b] If no scoring or wear is found, reuse the drive shaft and hub assembly and idler gear shafts.
5. Visually check the gear teeth for scoring, chipping or wear.
   [a] If gear teeth are scored, chipped or worn, replace the parts as necessary.
   [b] If gear teeth are not scored, chipped or worn, reuse the parts.
6. Visually inspect the relief valve. The valve must be free of score marks and burrs.
   [a] If the relief valve is scored and cannot be cleaned up with fine emery cloth, replace the relief valve.
   [b] If the relief valve is not damaged, reuse the part.

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2.6.4 Assembly of Fuel Pump (One-piece Drive Shaft)

Perform the following steps for fuel pump assembly:

1. Lubricate the lips of a new inner oil seal and pilot of oil seal installer, J 1508-8, with a light film of clean engine oil.
2. Place the oil seal adaptor, J 34158, on the pilot, J 1508-8, with the wide end of the adaptor against the handle.
3. Place inner oil seal on the pilot, J 1508-8, with seal case against the adaptor.
4. Support the pump body on wood blocks, hub side up, and insert the pilot into the shaft bore positioning the seal on the bore. Use a light hammer and drive the inner seal into the bore until the adaptor is bottomed against the pump body. See Figure 2-50.

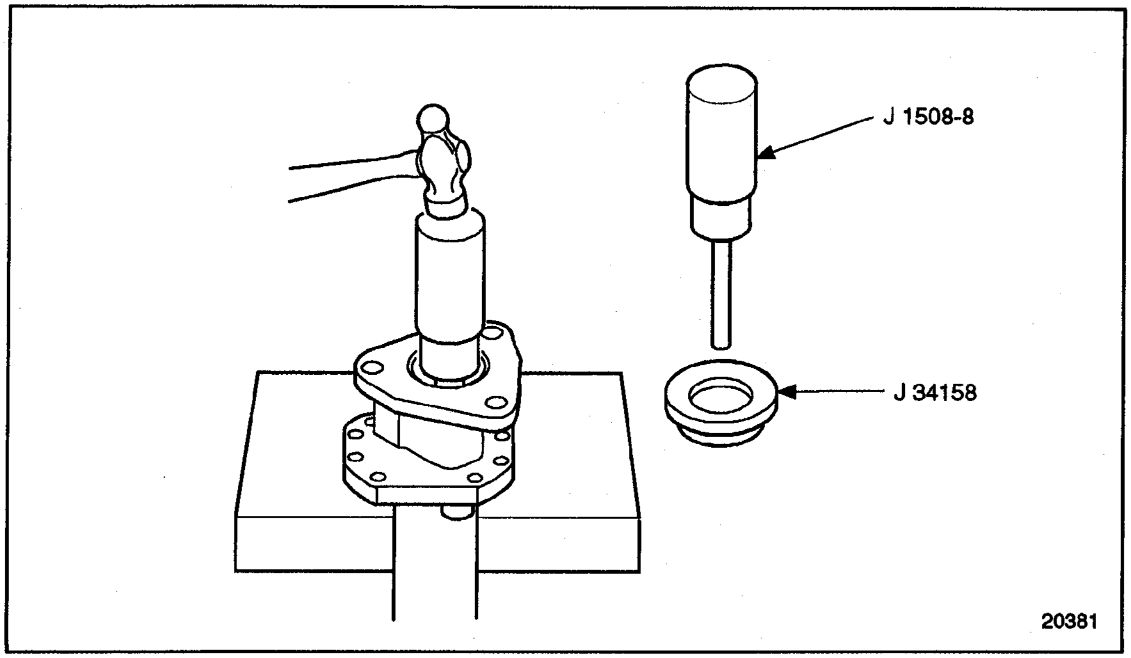

Figure 2-50 Installing Inner Oil Seal

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5. Remove the installer J 1508-8 and pilot J 34158 and place the narrow end against the installer handle. See Figure 2-51.

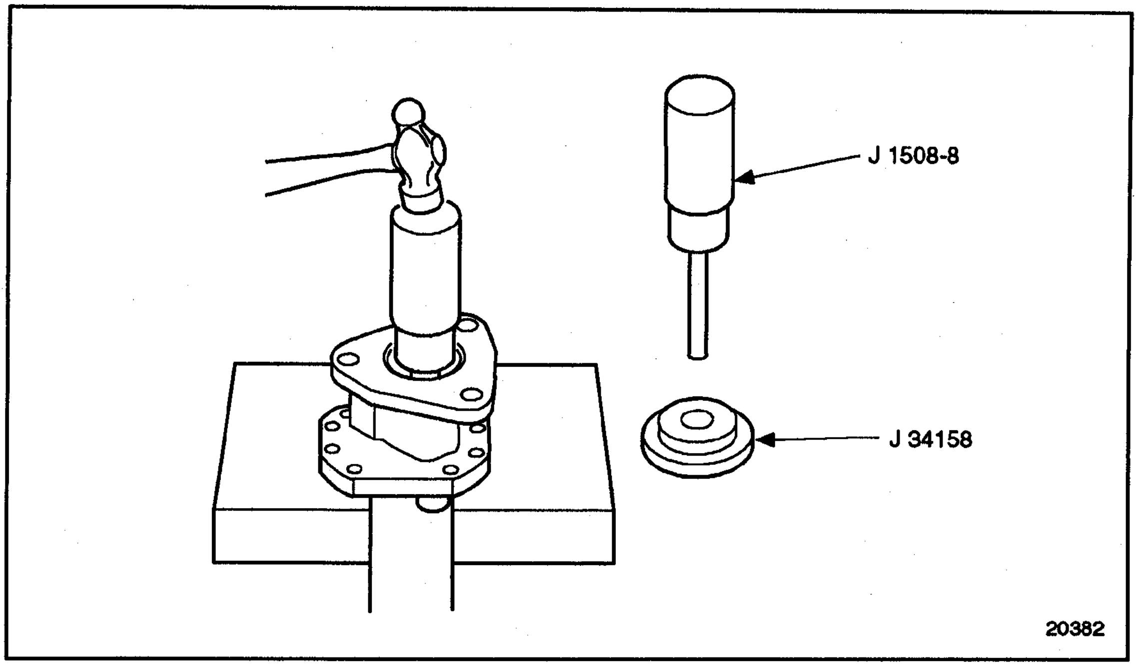

Figure 2-51 Installing Outer Oil Seal

6. Place a new outer seal on J 1508-8 with J 34158, faced away from the adaptor.
7. Carefully reinsert the installer pilot (J 1508-8) through the inner seal and position the outer seal on the bore. Use a light hammer and drive the seal into the bore until the adaptor is bottomed against the pump body.

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8. Install seal protector, J 33021-A, on drive shaft and hub assembly and install through seal. Remove seal protector. See Figure 2-52.

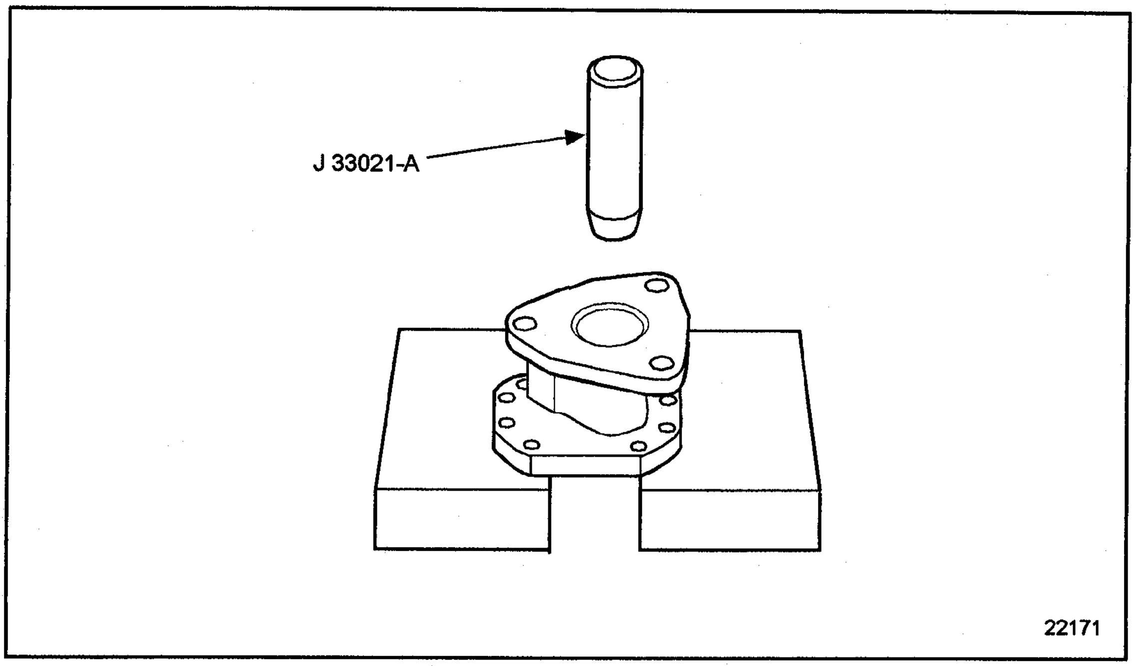

Figure 2-52 Seal Protector Installation

NOTE:
The bearing numbers should always be against the tool during installation.

9. Install drive shaft needle bearings, using J 38767-8 part of J 38767–A. The new tool permits bearing installation over drive shaft. Tool J 33854 can and should be used to install the other three bearings as shown. See Figure 2-53(this tool will support the bearing cages).

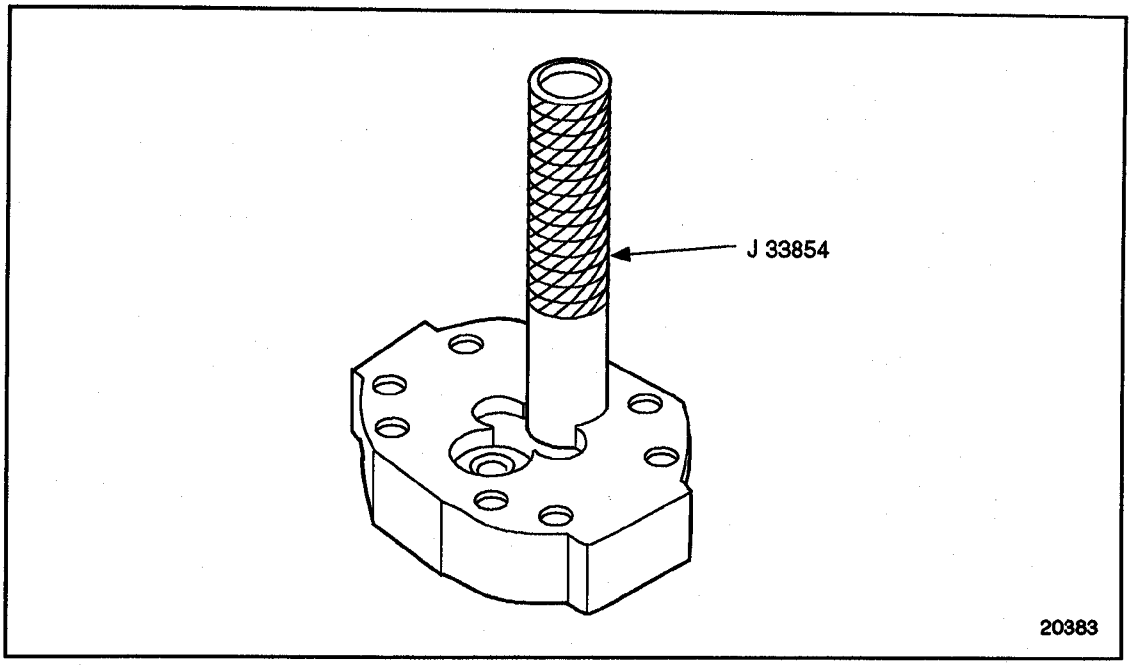

Figure 2-53 Drive Shaft Bearing Installation

10. Install C-clip, key, gear, the final C-clip on drive shaft.

NOTE:
Hold the shaft in position with the gear against the pump body while handling to ensure the drive hub C-clip grooves do not contact the oil seals.

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11. Position the pump body on the holding fixture,J 38767-1, hub side down.

NOTE:
When assembling pump, always use the same color foil gasket that was originally installed. Required gaskets for gear driven pump are listed in Table 2-3. Required gaskets for air compressor-driven pumps are listed in Table 2-4. If the color is unknown, measure the depth of the gear cavity in the pump cover and install the required gasket.

Gear Cavity Depth	Color Gasket Used
0.24885 - 0.24905 in. (6.320-6.325 mm)	Blue
0.24906 - 0.24925 in. (6.326-6.331 mm)	Amber
0.24935 - 0.24955 in. (6.333-6.338 mm)	Gold
0.24956 - 0.24975 in. (6.339-6.344 mm)	Silver

Table 2-3 Gasket Color vs. Gear Cavity Depth Chart (Gear Driven Pumps)

Gear Cavity Depth	Color Gasket Used
0.37385-0.37405 in. (9.495-9.500 mm)	Blue
0.37406-0.37425 in. (9.501-9.505 mm)	Amber
0.37435-0.37455 in. (9.508-9.513 mm)	Gold
0.37456-0.37475 in. (9.514-9.518 mm)	Silver

Table 2-4 Gasket Color vs. Gear Cavity Depth Chart (Air Compressor-Driven Pumps)

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12. Place a new foil gasket on the face of the pump. With a finger tip, carefully smooth the gasket against the face to ensure there are no wrinkles, creases, or bubbles.
    [a] If wrinkles, creases, or bubbles are present, and they cannot be removed with the finger, remove the gasket and repeat the procedure.
13. Assemble the driven gear shaft assembly by installing the C-clip on the shaft, and then installing the square-headed location pin in the hole in the shaft. Next, slide the driven gear on the shaft, aligning the pin on the shaft with the slot in the gear. Finally, install the C-clip on the shaft to hold the gear in place.
14. Carefully insert the driven shaft and gear assembly in the needle bearing in the pump body.

NOTE:
When positioning the cover, the fuel inlet (stamped on cover) must be on the same side as the relief valve bore in the pump body.

15. Position the needle bearing assemblies in the pump cover on the ends of the driven and drive shafts and slide the cover against the pump body.
16. Install eight cover retaining bolts. Use No. E-8 torx socket, J 25359-11, and torque bolts to 12-15 N·m (9-11 lb·ft).

NOTE:
As the outside of the pump body and cover are not machined and to prevent possible distortion, ensure that only the pump cover is gripped and that the vise jaws do not contact both body and cover.

17. Clamp the fuel pump cover in a soft-jawed vise with the relief valve bore in the pump body facing up.
18. Lubricate the relief plunger with clean engine oil and insert the plunger into the bore with the hollow end up. Insert the relief spring inside the plunger and the pin inside the spring.
19. Install the spacer in the bottom of the spring seat in the plug and install a new O-ring seal under the head of the plug. Thread the plug into the pump body and torque to 8-14 N·m (6-10 lb·ft).
20. Place the pump assembly on a bench, hub side up. Install the coupling onto the hub.
21. Install fuel inlet and outlet fittings in the pump cover.

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2.6.5 Installation of Gear Train-Driven Fuel Pump (One-piece Drive Shaft)

Install the fuel pump as follows:

NOTICE:
It may be necessary to use a brass hammer or fiber mallet to seat the drive assembly. Be careful not to damage the O-ring on installation.

NOTE:
Effective with engine serial number 06R0549855 built on October 19, 1999, gear case-mounted fuel pumps have a splined drive shaft and splined gear coupling assembly. See Figure 2-42. The former and current fuel pump and fuel pump drive assemblies are not interchangeable. Both current assemblies must be used together. Components of former and current pump assemblies and drive assemblies are not interchangeable.

1. Using a new O-ring seal, install the drive assembly on the gear case.
2. Install the fuel pump drive bolts and torque to 30-34 N·m (22-25 lb·ft) using the torque pattern shown. See Figure 2-54.

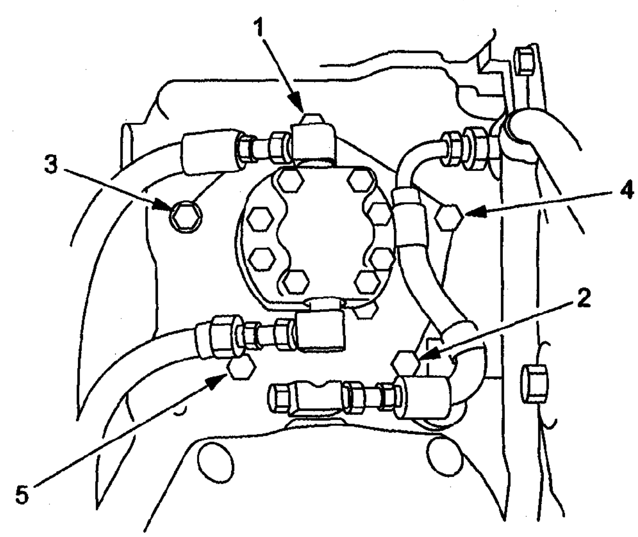

Figure 2-54 Fuel Pump Drive Retaining Bolt Torque Sequence

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3. Using a new gasket, install the fuel pump and torque bolts to 30-38 N·m (22-28 lb·ft).
4. Install any other components that were removed for this procedure.

CAUTION:

To avoid injury before starting and running the engine, ensure the vehicle is parked on a level surface, parking brake is set, and the wheels are blocked.

CAUTION:

Diesel engine exhaust and some of its constituents are known to the State of California to cause cancer, birth defects, and other reproductive harm.

- **Always start and operate an engine in a well ventilated area.**
- **If operating an engine in an enclosed area, vent the exhaust to the outside.**
- **Do not modify or tamper with the exhaust system or emission control system.**

5. Reconnect fuel inlet and outlet hoses, prime the fuel system, start the engine, and check for leaks.
6. Shut down engine upon completion.

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2.6.6 Installation of Air Compressor-Driven Fuel Pump (One-piece Drive Shaft)

Perform the following steps for air compressor-driven fuel pump installation:

NOTE:
New fittings have sealant already applied. If reusing fittings, coat the threads lightly with Loctite® Pipe Sealant, PT-7260 , or equivalent before installing. To prevent sealant from entering fuel system, do not apply it to the first two (2) threads of the fitting. Do not use teflon tape or paste on the fittings.

1. If removed, install inlet and outlet fittings in the rear cover of the fuel pump.
2. Install drive coupling in drive hub of the fuel pump and affix a new gasket to the mounting flange of the pump.

NOTE:
When correctly positioned, the outlet fitting on the pump should be in approximately the 8 o'clock position when viewed from the rear, and the drain opening in the pump body facing down.

3. Index the drive coupling with the drive hub on the end of the air compressor crankshaft and align the pump mounting bolt holes with those in the air compressor rear cover.
4. Seat the fuel pump squarely against the air compressor. Install three (3) fuel pump mounting bolts and torque them to 30-38 N·m (22-28 lb·ft).
5. Connect the fuel inlet and outlet lines to the fuel pump and tighten.
6. Prime the fuel system before starting engine.
7. Refer to section 2.6.5 for the exhaust caution before preceeding. Start and run the engine. Visually observe fuel pump for any leaks. Repair as necessary.
8. Shut down engine upon completion of test.

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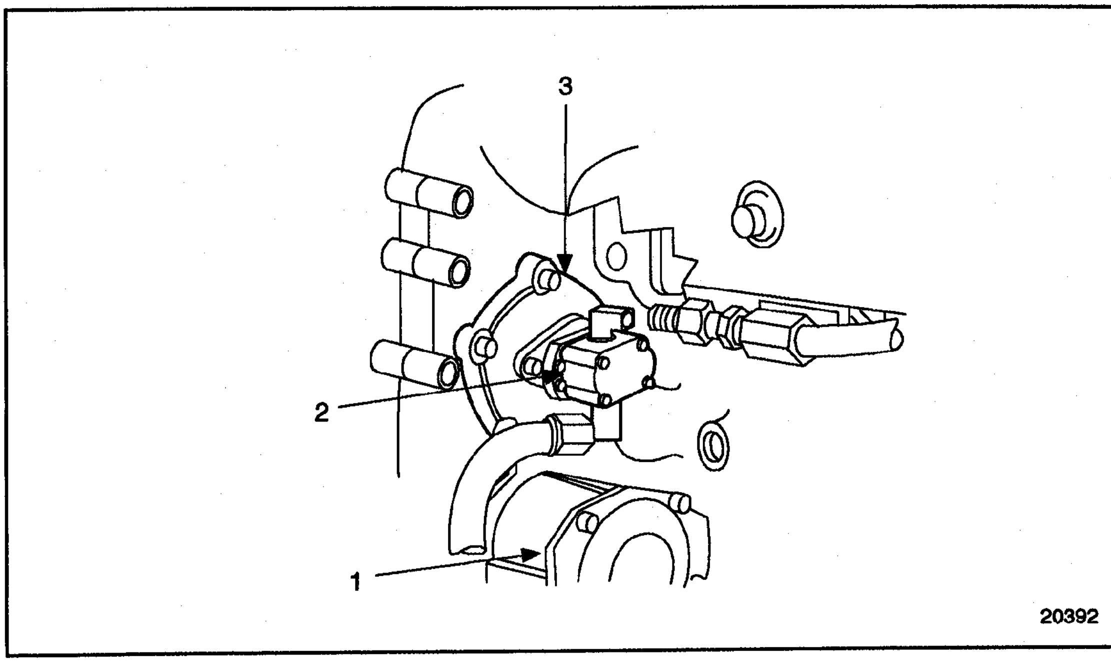
2.7 FUEL PUMP DRIVE

On certain Series 60 engines, the fuel pump is mounted on a fuel pump drive assembly. The fuel pump drive assembly is mounted to the gear case with five bolts. If installed on vehicle engines, the fuel pump drive assembly is located just above the air compressor drive assembly on the intake (left) side of the engine. See Figure 2-55.

NOTE:
Effective with engine serial number 06R0549855 built on October 19, 1999, gear case mounted fuel pumps have a splined drive shaft and splined gear coupling assembly, see Figure 2-56. The former and current fuel pump drive assemblies are not interchangeable. Both current assemblies must be used together. Components of former and current pump assemblies and drive assemblies are not interchangeable.



1. Air Compressor Drive Assembly
2. Fuel Pump
3. Fuel Pump Drive

Figure 2-55 Fuel Pump Drive Location

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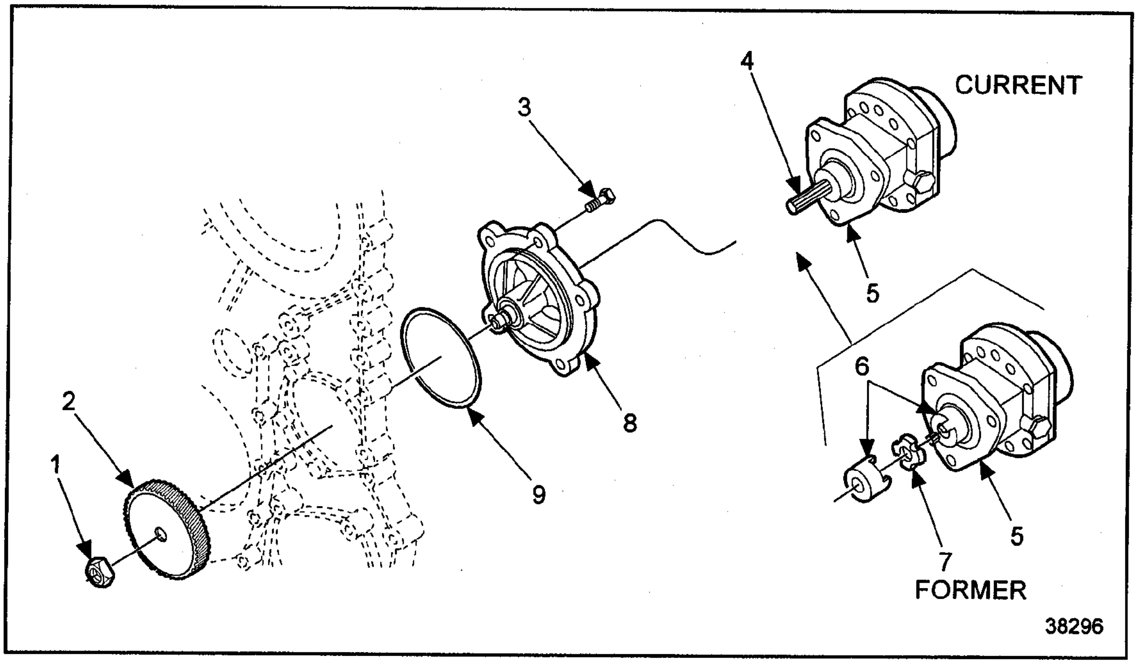
The fuel pump drive assembly consists of an aluminum housing, a helical gear driven off the bull gear, a drive shaft supported in the middle by a double-row ball bearing, and a forked hub that mates with a drive coupling. The fuel pump drive is supplied as an assembly, so components are not serviced. The drive gear and hub are pressed onto the drive shaft. A rubber O-ring located in a groove machined into the mounting surface of the drive is used to seal the fuel pump assembly to the gear case. An internal-type snap ring is fitted to a groove in the fuel pump drive housing to retain the bearing and shaft. see Figure 2-56

NOTE:
Effective with engine serial number 06R0549855 built on October 19, 1999, gear case mounted fuel pumps have a splined drive shaft and splined gear coupling assembly, see Figure 2-56. The former and current fuel pump drive assemblies are not interchangeable. Both current assemblies must be used together. Components of former and current pump assemblies and drive assemblies are not interchangeable.



1. Nut
2. Gear
3. Bolt
4. Splined Shaft
5. Fuel Pump
6. Hub
7. Coupling
8. Fuel Pump Drive Assembly
9. O-ring

Figure 2-56 Current and Former Fuel Pumps

The coupling between the fuel pump and fuel pump drive hubs is plastic, and acts as a shock absorber in the fuel pump drive line.

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2.7.1 Lubrication of Fuel Pump Drive Bearing

The fuel pump drive bearing is lubricated by engine oil splash-fed by the gears rotating in the gear case. This oil feeds the bearing and drive shaft through a hole in the fuel pump drive housing.

2.7.2 Removing Fuel Pump Drive Assembly

Remove the fuel pump drive assembly as follows:

1. Remove the bolts retaining the assembly to the gear case.

NOTICE:
Failure to remove the fuel pump drive assembly by pulling it straight may damage the O-ring.

2. Remove the fuel pump drive assembly by pulling it straight out of the gear case.

2.7.2.1 Clean the Fuel Pump Drive Assembly

Clean the fuel pump drive assembly as follows:

1. Clean the mating surfaces of the fuel pump drive assembly and gear case with fuel oil.

CAUTION:
To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

2. Dry the fuel pump drive assembly with compressed air.

2.7.2.2 Inspection of Fuel Pump Drive Assembly

Perform the following to inspect the fuel pump drive assembly:

1. The fuel pump drive assembly is nonserviceable if the bearing is worn or scored. Replace the fuel pump drive assembly.

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2.7.3 Installation of Fuel Pump Drive Assembly

Perform the following steps to install the fuel pump drive assembly:

1. Replace the O-ring as necessary.
2. Lubricate the O-ring with a light coating of petroleum jelly.
3. Install the O-ring on the fuel pump housing.
4. Install the drive assembly on the gear case.

NOTE:
It may be necessary to use a brass hammer or fiber mallet to seat the drive assembly. Be careful not to damage the O-ring during installation.

5. Install the fuel drive bolts and torque to 30-34 N·m (22-25 lb·ft) using the torque pattern shown. See Figure 2-57.

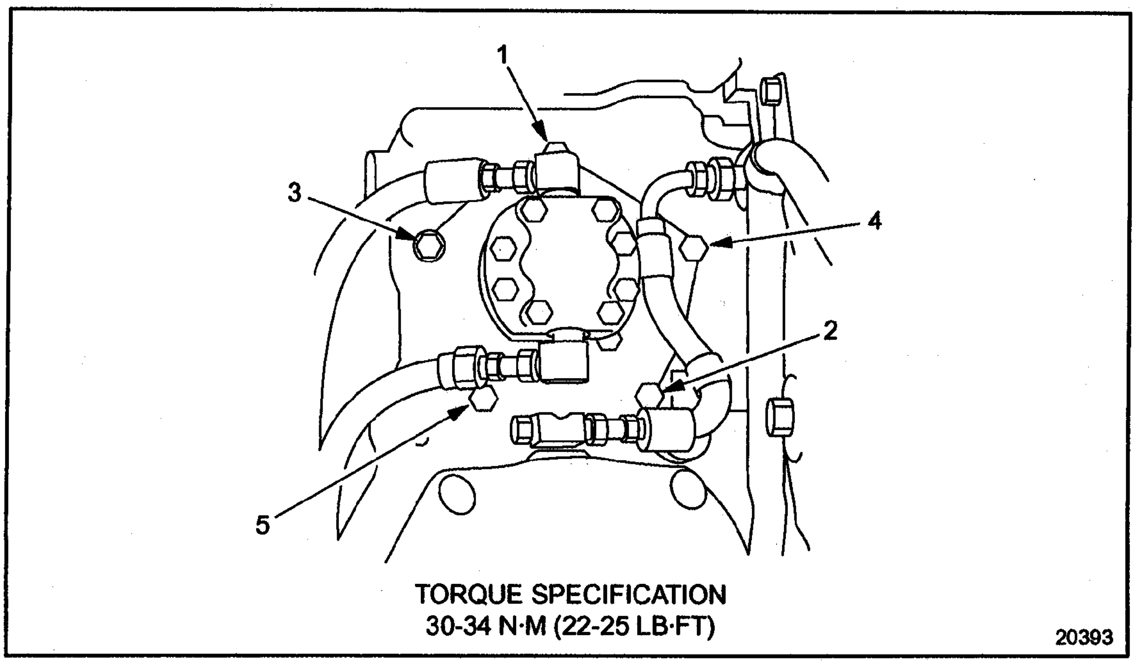

Figure 2-57 Fuel Pump Drive Assembly Torque Sequence

6. Install the fuel pump. Refer to section 2.6.5 for gear train-driven fuel pump. Refer to section 2.6.6 for air compressor-driven fuel pump.
7. Install any other components that were removed for this procedure.

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CAUTION:

To avoid injury before starting and running the engine, ensure the vehicle is parked on a level surface, parking brake is set, and the wheels are blocked.

CAUTION:

Diesel engine exhaust and some of its constituents are known to the State of California to cause cancer, birth defects, and other reproductive harm.

- **Always start and operate an engine in a well ventilated area.**
- **If operating an engine in an enclosed area, vent the exhaust to the outside.**
- **Do not modify or tamper with the exhaust system or emission control system.**

8. Start the engine and check for leaks. If leaks are found. Repair as necessary.
9. Shut down the engine upon completion of inspection.

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2.8 DIESEL FUEL FILTERS (SPIN-ON)

Two spin-on type filters are used on the Series 60 engine. The first in the fuel flow is a strainer, and the second is a filter. Although they are not marked as such, the threaded sleeves that accept the cartridges are different sizes to prevent mismatching. The primary filter has a 1 in. x 12 thread. The secondary filter has a 13/16 in. x 12 thread. The word "Primary" or "Secondary" is cast onto the top of the respective adaptor. See Figure 2-58.

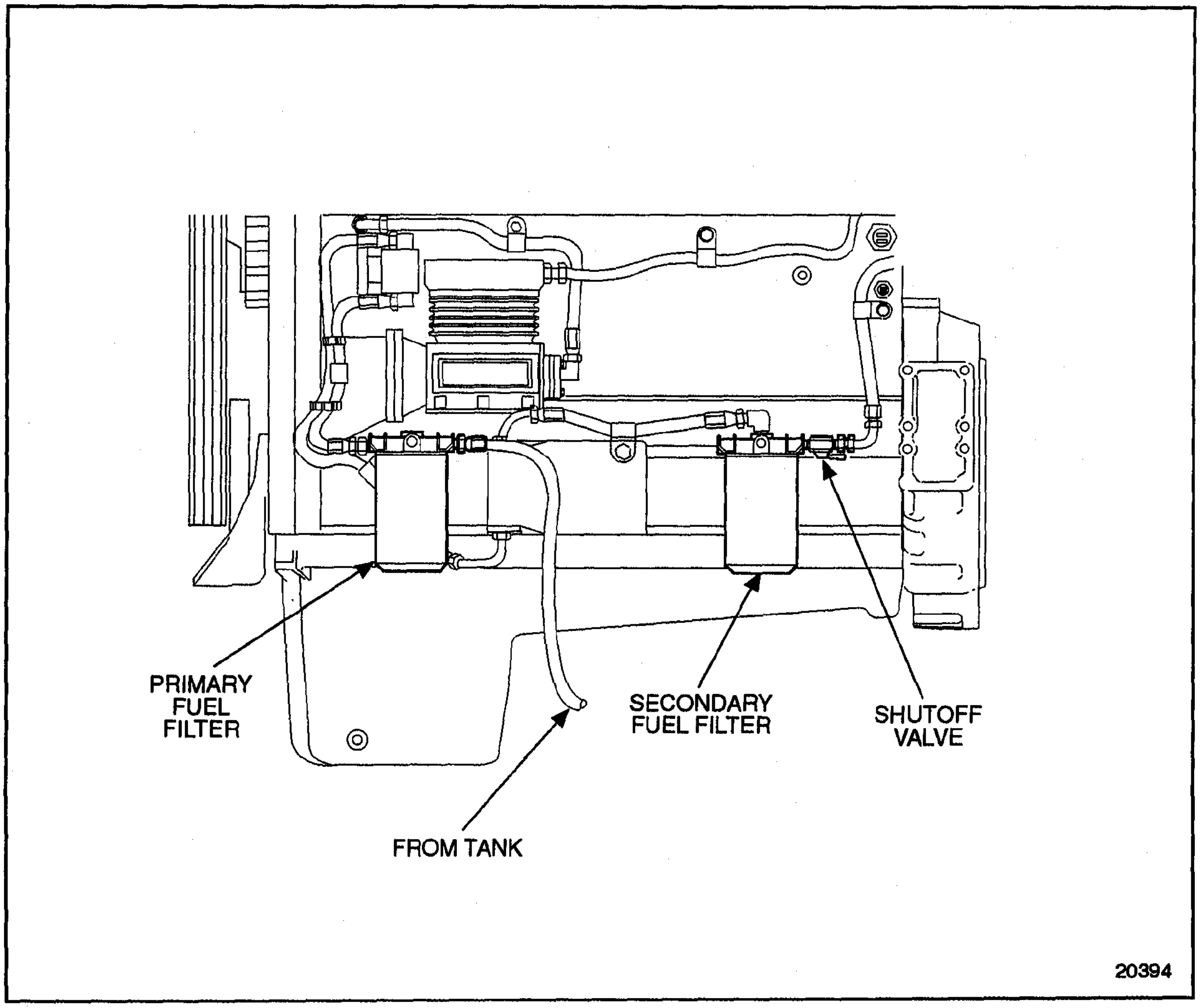

Figure 2-58 Fuel Filters

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For marine fuel filter information, refer to section 2.10 for Sea Pro 150/300 or refer to section 2.11for Sea Pro 152.

The spin-on filter cartridges consist of a shell, element, and gasket combined into a unitized replacement assembly. No separate springs or seats are required to support the filters. Effective with 1993 engine production, an optional fuel filter and water separator assembly may be installed in place of the strainer. A fuel shutoff valve or check valve may be installed on the outlet side of the secondary filter.

NOTICE:
Do not overtorque the external threaded end of the shutoff valve when installing it in the fuel filter adaptor. The connection must be tight enough to prevent leakage but not tightened to the point where the adaptor will crack.

The fuel filter adaptors are attached to the block with two bolts each. Torque these bolts to 58-73 N·m (43-54 lb·ft).

The fuel filter system consists of the following:

- Spin-on primary fuel filter
- Primary fuel filter adaptor
- Spin-on secondary fuel filter
- Secondary fuel filter adaptor
- Fuel shutoff valve or check valve

2.8.1 Replacement of Fuel Filter

As contaminants build up on the filter medium, a number of factors start to affect vehicle performance:

- The fuel delivery rate is reduced, making less fuel available for combustion.
- The fuel pump is forced to work harder to move the same volume of fuel. This subjects internal seals to abnormal conditions which may lead to seal leakage. In extreme cases air can be drawn into the fuel system.
- With the rate of flow slowed, fuel stays in the cylinder head for a longer period of time, allowing its temperature to rise above normal. Because fuel temperature has an affect on engine power, higher fuel temperatures normally result in reduced power.
- If the restriction is severe enough, fuel vaporization can occur, resulting in pockets of air that can further reduce fuel delivery.

All of these conditions can lead to power loss and subsequent operator complaints of "low power" and "reduced vehicle fuel economy" requiring more frequent downshift on grades.

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To determine if replacement of fuel filter element is necessary. See Figure 2-59.

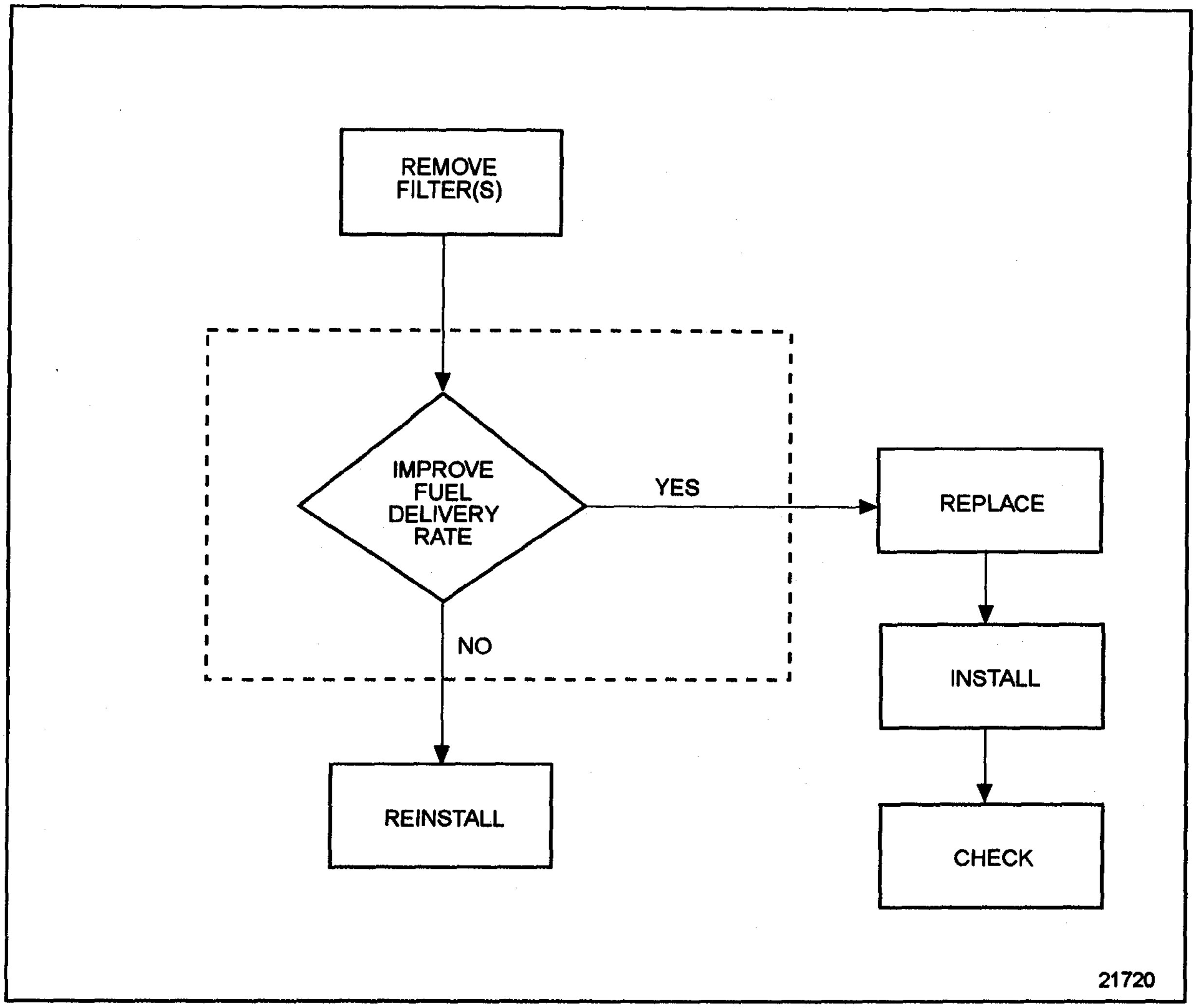

Figure 2-59 Flowchart for Replacement of Fuel Filter Element

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2.8.2 Replacement of Fuel Filter

Replace spin-on primary and secondary fuel filters at the following intervals or earlier, if plugging is indicated:

- ☐ Truck and Parlor Coach — 15,000 Miles (24,000 Km)
- ☐ Transit Coach — 6,000 Miles (9,600 Km)
- ☐ Fire Fighting Apparatus — 6,000 Miles (9,600 Km)
- ☐ Industrial, Agricultural — 150 Hours
- ☐ Marine — 250 Hours

Replace Fuel Pro® and Sea Pro® 152 primary filter elements when the fuel level in the see-thru filter cover reaches the top of the filter element or after one year of service, whichever comes first. Replace Sea Pro 150 or 300 spin-on primary filter element every 250 hours.

Replace spin-on secondary filter element at regular 250 hour intervals.

A method of determining when filters are plugged to the extent that they should be changed is based on the fuel pressure at the cylinder head fuel inlet fitting and the inlet restriction at the fuel pump. In a clean system, the maximum pump inlet restriction should not exceed 6 in. Hg (20.3 kPa) and must not exceed 12 in. Hg (41 kPa) with a dirty system.

At normal operating speeds and with the standard 0.080 in. (2.03 mm) restriction fittings, the fuel pressure at the cylinder head inlet is 345-577 kPa (50-83 lb/in.^{2}). Change the fuel filters whenever the inlet restriction at the fuel pump reaches 12 in. Hg (41 kPa) at normal operating speeds and whenever the fuel pressure at the cylinder head inlet fitting falls to the minimum fuel pressure shown above.

Spin-on type primary and secondary fuel filters used on Series 60 engines consist of a shell, element, and gasket unitized into the single cartridge and a filter cover, that includes a threaded sleeve to accept the spin-on filter cartridge. An optional fuel and water separator may be installed in place of the standard primary filter.

The Sea Pro 150 and 300 Fuel Processor Systems have a primary spin-on type filter mounted at the top of the processor body. This filter element and secondary filter element must be replaced every 250 hours or every year, whichever comes first. The Fuel Pro and Sea Pro 152 Fuel Processor Systems have primary cartridge-style filter elements installed in see-thru covers mounted on top of the fuel processor bodies. These filter elements must be changed when the fuel level in the see-thru cover reaches the top of the element. The secondary filter element must be replaced every 250 hours or every year, whichever comes first.

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Replace spin-on type primary or secondary filter elements as follows:

1. With the engine shut down, place a suitable container under the filter.
2. A fuel shutoff valve may be installed on the discharge side of the secondary fuel filter. If installed, turn the handle on the shutoff valve to the **closed** position (perpendicular to the valve).
3. Using a suitable band-type filter wrench, remove the primary and secondary fuel filters. Dispose of the filters in an environmentally responsible manner, according to state and federal (EPA) recommendations.
4. Fill new replacement filters with clean fuel oil, and coat the gaskets lightly with clean fuel oil.

NOTICE:
Overtightening may crack or distort the adaptors.

5. Thread the new filters onto the adaptors until they make full contact with the gasket and no side movement is evident. Then rotate an additional one-half turn **by hand.**
6. Turn the handle on the shutoff valve (if installed) to the **open** position (in line with the valve).

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NOTICE:

To improve engine starting, have replacement filters filled with fuel and ready to install immediately after used filters are removed. This will prevent possible siphoning and fuel system aeration.

CAUTION:

Diesel engine exhaust and some of its constituents are known to the State of California to cause cancer, birth defects, and other reproductive harm.

- **Always start and operate an engine in a well ventilated area.**
- **If operating an engine in an enclosed area, vent the exhaust to the outside.**
- **Do not modify or tamper with the exhaust system or emission control system.**

7. Start the engine, and check for leaks.

NOTICE:

Under no circumstances should the starting motor and fuel pump be used to prime the fuel filters. Prolonged use of the starting motor and fuel pump to prime the fuel system can result in damage to the starter, fuel pump, and injectors and cause erratic running of the engine because of air in the lines and filters.

If the engine fails to start after filter replacement, the fuel system will require priming using tool J 5956. Authorized Detroit Diesel service outlets are properly equipped to perform this service.

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Replace the fuel and water separator as follows:

1. Drain off some fuel by opening the drain valve.
2. Using a strap wrench, remove the element and bowl together. Remove the bowl from the element. The filter and bowl have standard right-hand threads, so turn counterclockwise to remove.
3. Clean the bowl and the O-ring seal.

NOTICE:
To avoid damaging the bowl or the filter, do not use tools when tightening.

4. Apply a light coating of clean fuel or grease to the O-ring seal, spin the bowl onto the new filter, and *tighten by hand.*
5. Apply a light coating of clean fuel or grease to the new O-ring seal on the top of the filter. Spin the filter and bowl assembly onto the filter head, and *tighten by hand* until snug.
6. To eliminate air from the filter, operate the primer pump on the filter head (if equipped) until the fuel purges at the filter assembly.
7. Refer to section 2.8.2 for the exhaust caution before preceeding. Start the engine, and check for leaks. Correct any leaks with the engine off.

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2.8.3 Installation of Fuel Filter

Perform the following steps to install the fuel filter:

NOTICE:
Mechanical tightening of the fuel filters is not recommended, and may result in seal damage, cartridge damage, or both. Tighten the fuel filters by hand only.

1. Refer to section 13.13.14 for fuel filter installation.

NOTE:
There is a fuel system shutoff valve on the discharge side of the secondary fuel filter. This check valve is designed to prevent loss of fuel prime at time of filter replacement.

2. Refer to section 2.8.2 for the exhaust caution before preceeding. Start and run the engine. Check for leaks.
3. Shut down engine upon completion of test.

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2.9 FUEL PRO 380/380E FUEL FILTER SYSTEM

The Fuel Pro® 380/380E diesel fuel filter system is used in place of a separate spin-on primary fuel filter. See Figure 2-60. This system uses a high efficiency five-micron fuel filter element which requires replacement when the fuel level in the see-through filter cover reaches the top of the element or after one year of service, whichever comes first.

NOTE:
The secondary fuel filter *must* be changed at regular mile or hour intervals, depending on the engine application. Refer to section 13.13.14.

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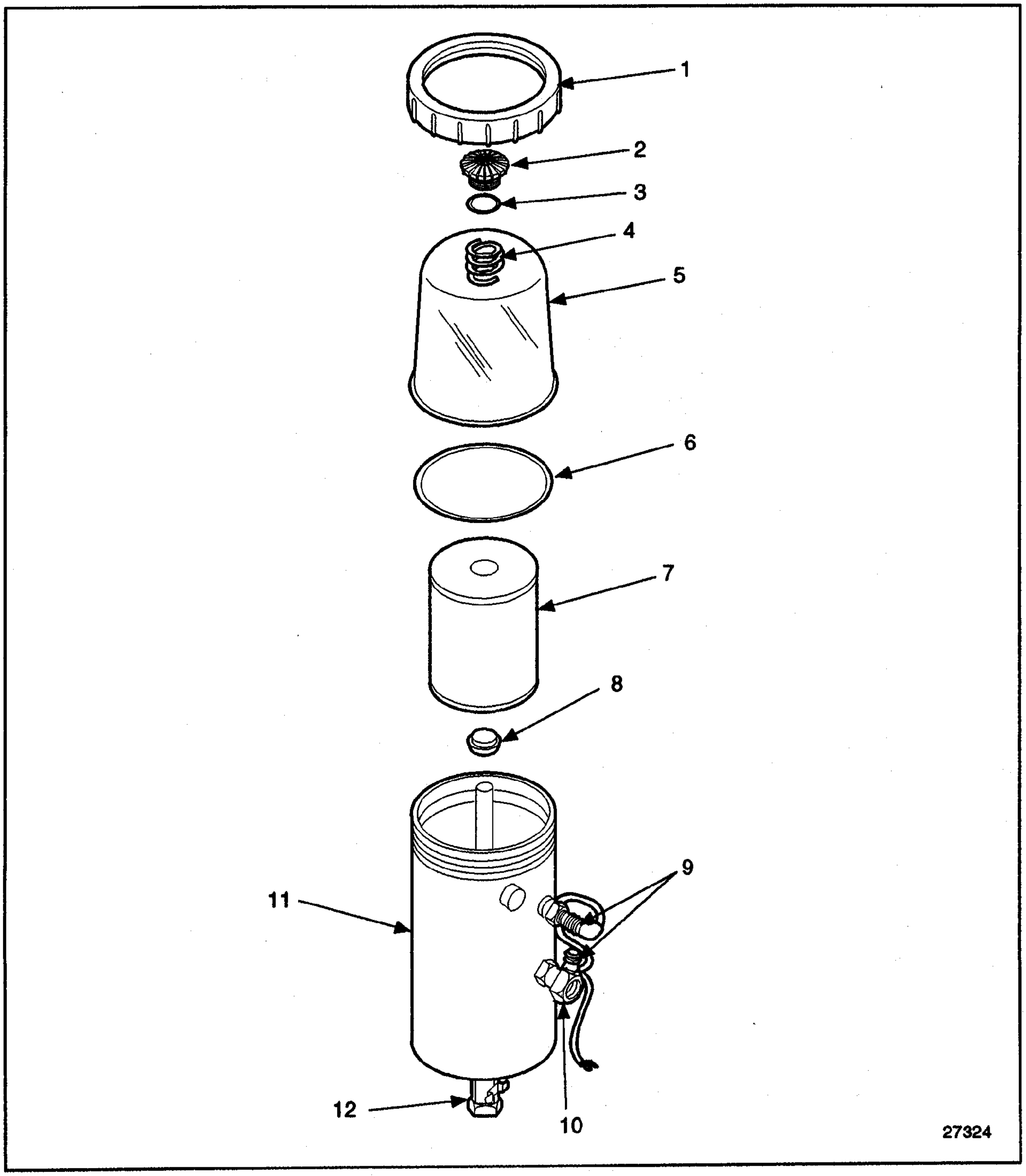

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1. Collar
2. Vent Cap
3. Vent Cap Seal
4. Spring (Part of Cover)
5. Cover
6. Cover Seal
7. Filter Element
8. Filter Seal Grommet (Part of Element)
9. Wiring Harness (380E System Only)
10. Check Valve and Thermostat
11. Fuel Processor Assembly
12. Drain Valve

Figure 2-60 Fuel Pro 380E Fuel Processor Assembly

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The Fuel Pro 380/380E diesel fuel filter system consists of the following:

- ☐ A permanently mounted fuel processor
- ☐ A replaceable five-micron filter element and sealing grommet assembly
- ☐ A filter spring
- ☐ A see-through filter cover and O-ring seal
- ☐ A cover locking collar
- ☐ A cover vent cap and seal

The Fuel Pro 380E system also includes the following:

- ☐ A fuel heater element
- ☐ A thermostat switch
- ☐ A wiring harness

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2.9.1 Replacement of Fuel Pro 380E Fuel Filter Element

Replace the Fuel Pro filter element as follows:

CAUTION:

To avoid injury from fire caused by heated diesel-fuel vapors:

- **Keep those people who are not directly involved in servicing away from the engine.**
- **Stop the engine immediately if a fuel leak is detected.**
- **Do not allow open flames or smoke when working on an operating engine.**
- **Wear adequate protective clothing (face shield, insulated gloves and apron, etc.).**
- **To prevent a buildup of potentially volatile vapors, keep the engine area well ventilated during operation.**

Diesel fuel is relatively harmless at ambient temperatures.

1. With the engine shut down and cool, place a suitable container under the fuel processor.
2. A fuel shutoff valve may be installed on the discharge side of the fuel filter. If installed, turn the handle on the shutoff valve to the closed position (perpendicular to the valve).
3. Open the drain valve at the base of the fuel processor, and drain the fuel until it is below the level of the filter. Close the drain valve.
4. Using filter collar wrench, Part No. 23516731 or equivalent, remove the collar by turning counterclockwise. Remove the cover, filter spring, and cover seal ring by lifting straight up and over the filter element. Remove the element from the center stud (fuel outlet pipe) by pulling upward and twisting slightly.

NOTE:
Current filter elements include an integral sealing grommet. Former filter elements used a separate sealing grommet. If a former element is replaced, ensure the separate sealing grommet is removed from the center stud.

5. Dispose of the used filter element and grommet in an environmentally responsible manner, according to state and/or federal (EPA) recommendations.

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2.9.2 Installation of Fuel Pro 380E Fuel Filter Element

Install the Fuel Pro filter element as follows:

1. Ensure a sealing grommet is included in the base of the replacement element, then install the element onto the center stud.

NOTICE:
Do not use a wrench of any kind to tighten the collar, since this may lead to overtightening which can damage the collar and the cover.

2. Ensure the filter spring is installed at the top of the cover. If missing, the spring *must* be replaced to insure proper filter operation. Wipe the cover lip and cover seal clean. After ensuring the seal is properly positioned at the base of the cover, install the cover and collar onto the fuel processor. Tighten the collar *by hand* until secure.

NOTICE:
To avoid cover or vent plug damage, do not use tools to tighten the vent cap.

3. Remove the vent cap from the top of the cover by turning the cap counterclockwise. Fill the cover *full* of clean fuel. After ensuring the O-ring seal is installed on the vent cap, reinstall the cap and *tighten by hand only.*

CAUTION:

Diesel engine exhaust and some of its constituents are known to the State of California to cause cancer, birth defects, and other reproductive harm.

- **Always start and operate an engine in a well ventilated area.**
- **If operating an engine in an enclosed area, vent the exhaust to the outside.**
- **Do not modify or tamper with the exhaust system or emission control system.**

4. Open the fuel shutoff valve (if installed) and start the engine. When the lubrication system reaches its normal operating pressure, increase engine speed to high idle for 2 to 3 minutes.

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NOTICE:
Do not allow the fuel level in the see-thru cover to fall below the top of the collar, since this may lead to interruption of the fuel flow and engine stalling.

5. After the air is purged and with the engine still running, *slowly* loosen the vent cap on the filter cover. The fuel level in the cover will start falling. When the fuel level falls to the top of the collar, tighten the vent cap quickly by hand.

NOTICE:
Do not use a wrench of any kind to tighten the collar, since this may lead to overtightening which can damage the collar and the cover.

6. Shut down the engine and *hand-tighten* the collar again.
7. Refer to section 2.9.2 for the exhaust caution before preceeding. Restart the engine and check for leaks.

NOTE:
The clear filter cover will not fill completely during engine operation. It will gradually fill over time as the filter medium becomes clogged. The filter element does not require changing until the fuel level has risen to the top of the element, or after one year of service, whichever comes first.

NOTE:
The secondary fuel filter *must* be changed at regular mile or hour intervals, depending on the engine application. Refer to section 13.13.14.

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2.10 SEA PRO 150/300 DIESEL FUEL PROCESSOR SYSTEM (MARINE)

The Sea Pro® 150 fuel processor system (recommended by DDC) consists of a primary fuel processor assembly secured to a mounting plate with two U-bolts, washers, and nuts. The Sea Pro® 300 diesel fuel processor system consists of two primary fuel processor assemblies secured to a mounting plate with four U-bolts, washers, and nuts. Each processor assembly consists of a replaceable spin-on filter element assembly with a vent cap, seal ring, and reusable element splash guard. Each processor also has a water-in-fuel (WIF) switch that requires an optional module for activation. The Sea Pro 150 and 300 systems may also include an optional electric primer pump. See Figure 2-61 for the Sea Pro 150 and see Figure 2-62 for the Sea Pro 300. The Sea Pro system is installed between the fuel tank and the fuel pump.

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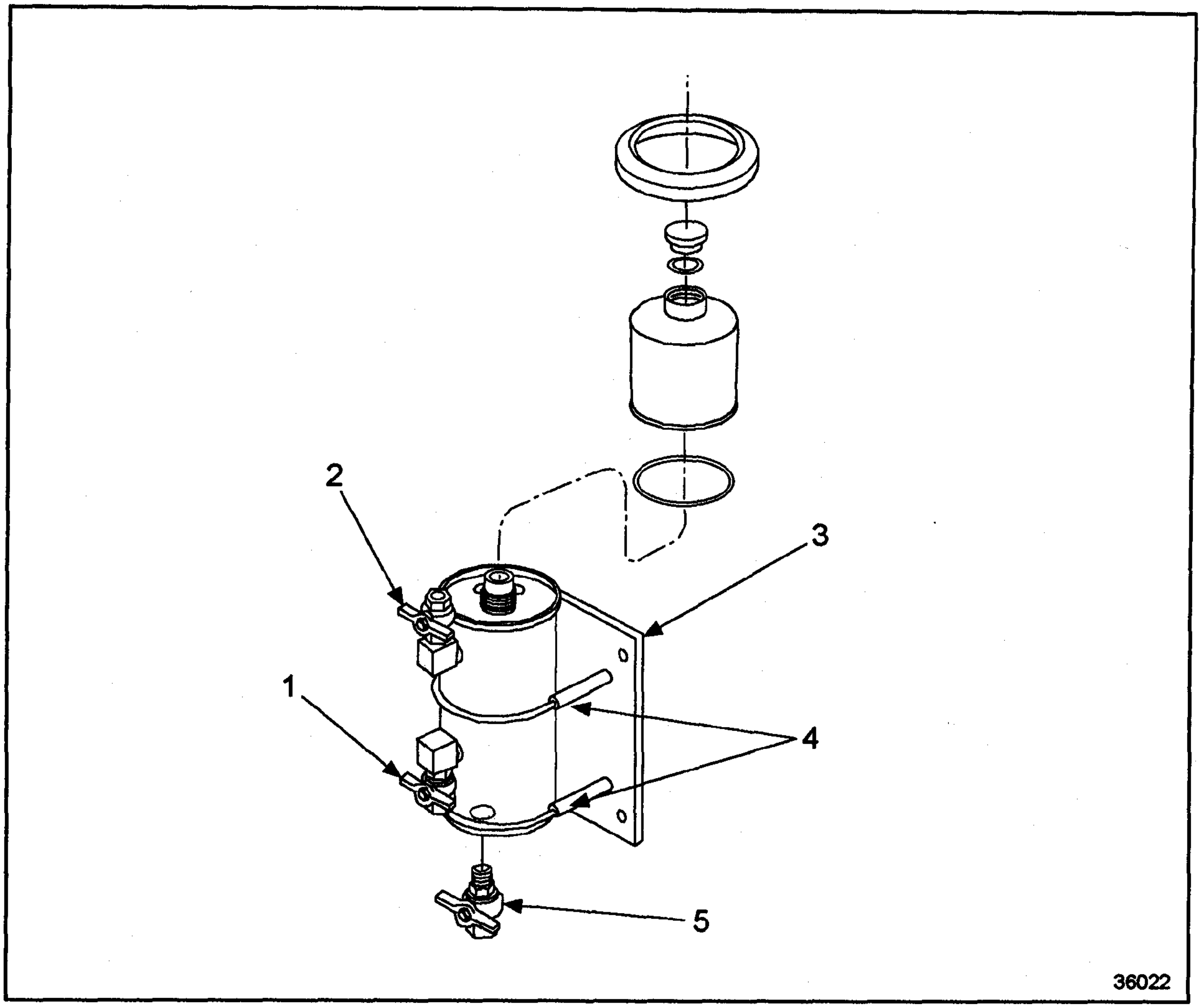

1. Fuel Inlet Valve
2. Fuel Outlet Valve
3. Mounting Plate
4. U-bolts
5. Drain valve

Figure 2-61 Sea Pro 150 Diesel Fuel Processor System

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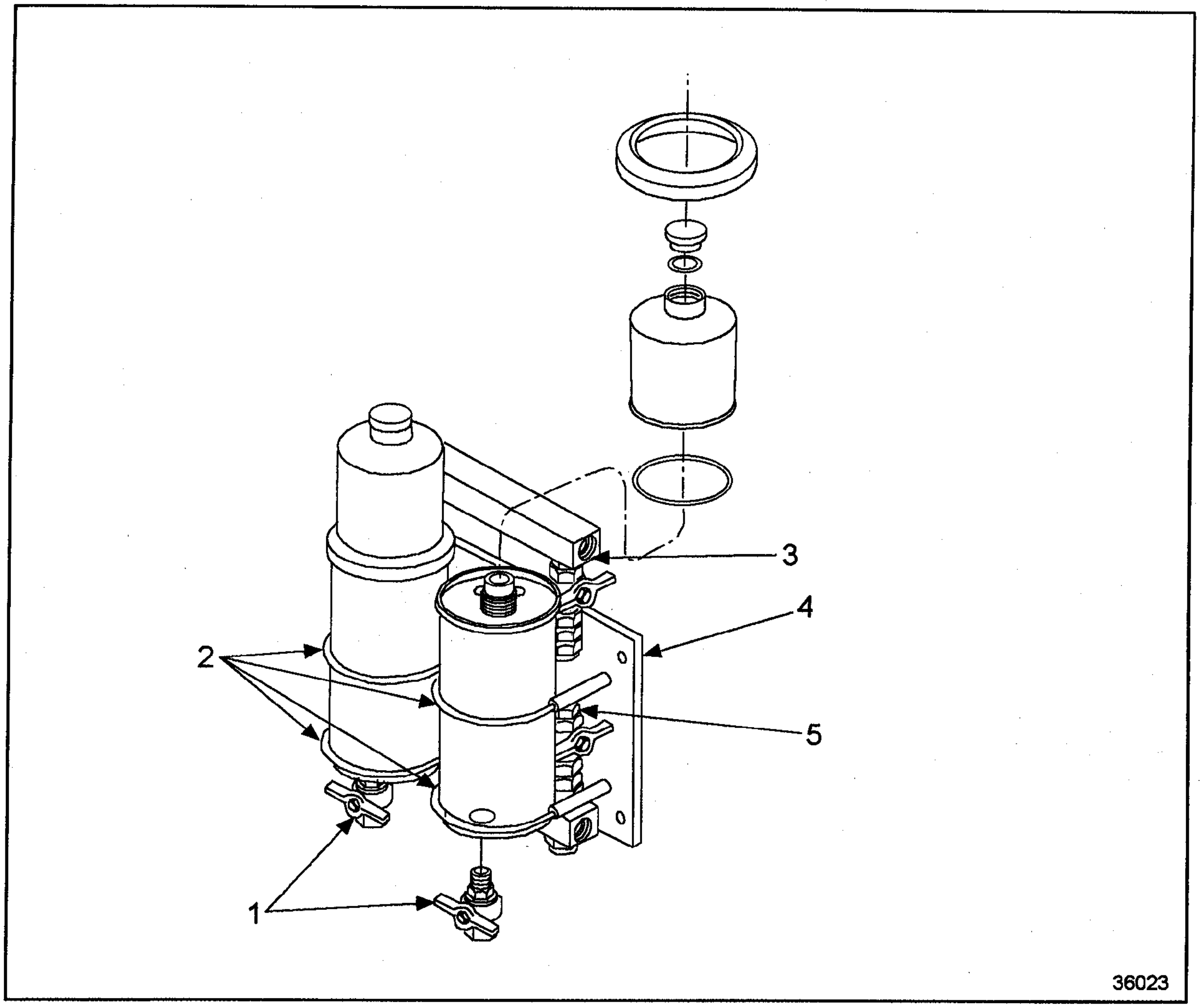

1. Drain Valves
2. U-bolts
3. Fuel Outlet Valve
4. Mounting Plate
5. Fuel Inlet Valve

Figure 2-62 Sea Pro 300 Fuel Processor System

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2.10.1 Replacement of the Sea Pro 150 or 300 Filter Element

To determine if repair is possible or replacement is necessary perform the following procedure. See Figure 2-63.

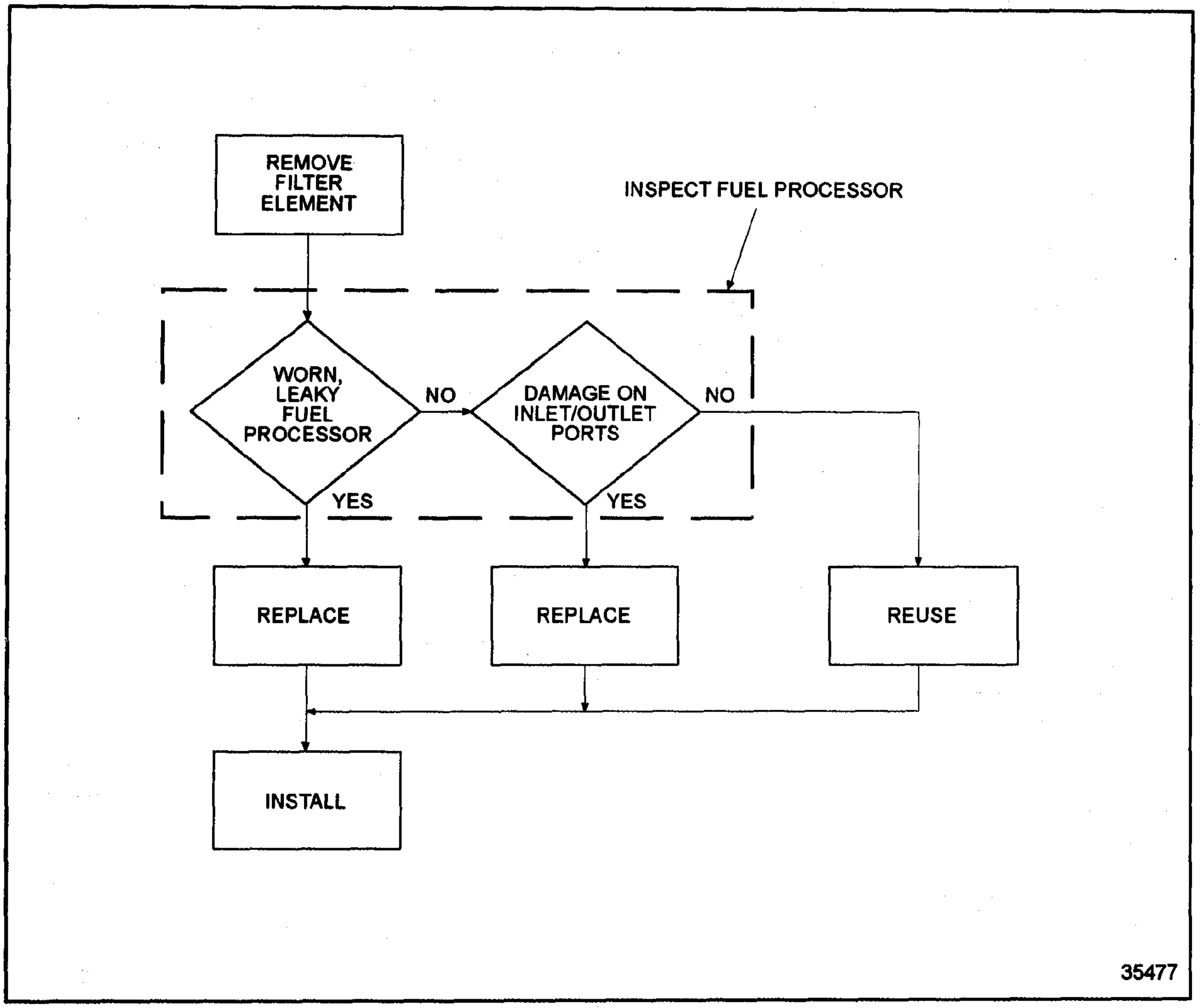

Figure 2-63 Flowchart of Repair or Replacement of the Sea Pro 150 or 300 Filter Element

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2.10.2 Removal of the Sea Pro 150 or 300 Fuel Filter Element

Detroit Diesel recommends shutting down the engine and allowing it to cool to engine room temperature before replacing fuel filter elements.

CAUTION:

To avoid injury from fire caused by heated diesel-fuel vapors:

- **Keep those people who are not directly involved in servicing away from the engine.**
- **Stop the engine immediately if a fuel leak is detected.**
- **Do not allow open flames or smoke when working on an operating engine.**
- **Wear adequate protective clothing (face shield, insulated gloves and apron, etc.).**
- **To prevent a buildup of potentially volatile vapors, keep the engine area well ventilated during operation.**

Diesel fuel is relatively harmless at ambient temperatures.

1. Close fuel inlet and outlet valves on the fuel processor. If changing a Sea Pro 300 filter "on the run", open the fuel manifold inlet and outlet valve of the new filter before closing the inlet and outlet valve of the used filter.

NOTE:

On some Sea Pro 300 models this is accomplished by moving the selector valve lever on the fuel manifold to the "Service Right Can" or "Service Left Can" position.

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2. Open the vent plug on top of the element being serviced, place a suitable container under the processor, and remove the drain valve plug (if installed). Open the bottom valve and allow about a pint of fuel to drain out.

NOTE:
This will help drain the filter element of fuel.

NOTE:
Dispose of the used element in an environmentally friendly manner, according to state and federal (EPA) recommendations.

3. Close the valve, and install the valve drain plug.

NOTICE:
The center hole of the processor is the clean fuel outlet to the cylinder head. To avoid possible contamination of the clean fuel, cover the top of the processor with a clean cloth immediately after the filter element is removed.

4. Using a suitable strap-type filter wrench, rotate the filter element counterclockwise, and spin it off the fuel processor body.

NOTE:
Any fuel left in the filter element will be caught by the deep well in which the element sits and will drain back into the fuel processor.

5. Remove the reusable plastic splash seal from the element and retain for reuse.

NOTE:
Dispose of the used element in an environmentally friendly manner, according to state and federal (EPA) recommendations.

2.10.2.1 Inspection of the Sea Pro 150 or 300 Fuel Processor

Inspection the Sea Pro 150 or 300 as follows:

1. Inspect the fuel processors for worn, damaged, or leaky fittings.
   [a] If damage was found, replace the component.
   [b] If no damage was found, reuse the component.
2. Inspect threaded inlet and outlet ports on the fuel processors and fuel manifold for damage.
   [a] If damage was found, replace the component.
   [b] If no damage was found, reuse the component.

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2.10.3 Installation of the Sea Pro 150 or 300 Filter Element

Install the Sea Pro 150 or 300 filter element as follows:

1. Check the new spin-on element to ensure the O-ring seal is just inside the center opening and the perimeter seal is installed at the base.

NOTE:
Do not install the element if either seal is missing, since this will result in fuel leakage.

NOTICE:
Do not use a strap wrench or other tool to tighten the element. Over-tightening may result in filter element or fuel processor damage or both.

2. Wipe the perimeter seal contact surface on top of the processor with a clean cloth.
3. Using clean engine oil, lubricate the center O-ring and perimeter seal.
4. Install the element onto the processor center stud by pressing down, on the element and rotating clockwise to engage the threads. ***Tighten by hand only.***
5. Install the plastic splash guard onto the element and push down until firmly seated over the fuel processor well.

NOTICE:
Do not use a tool to tighten the vent plug. Over-tightening may result in vent plug or fuel processor damage or both.

6. If the fuel processor assembly is not equipped with a fuel primer pump, remove the vent plug at the top of the filter and fill the element with clean fuel. Replace the plug and ***tighten by hand only.***
7. If the processor is equipped with a fuel primer pump, prime the system as follows:
   [a] Remove the vent on the filter.
   [b] Turn the fuel flow valve to "Prime System".
   [c] Push the momentary switch mounted above primer pump until fuel is visible in the sight glass on the processor body.
   [d] Continue to push switch for an additional 5 to 10 seconds to fill the filter.
   [e] Replace vent on the filter and ***tighten by hand*** until secure.
8. Open fuel inlet and outlet valves on the fuel processor manifold. If equipped, put primer pump selector valve in the "Run Position".

CAUTION:

Diesel engine exhaust and some of its constituents are known to the State of California to cause cancer, birth defects, and other reproductive harm.

- **Always start and operate an engine in a well ventilated area.**
- **If operating an engine in an enclosed area, vent the exhaust to the outside.**
- **Do not modify or tamper with the exhaust system or emission control system.**

9. Start the engine and check for leaks.

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2.11 SEA PRO 152 FUEL FILTER SYSTEM (MARINE ENGINE)

The Sea Pro® 152 diesel fuel processor system is used in place of a separate spin-on primary fuel filter. See Figure 2-64. This system uses a high efficiency five-micron fuel filter element which requires replacement when the fuel level in the see-thru filter cover reaches the top of the element or after one year of service, whichever comes first.

NOTE:
The secondary fuel filter *must* be changed at regular hour intervals.
Refer to section 13.13.14.

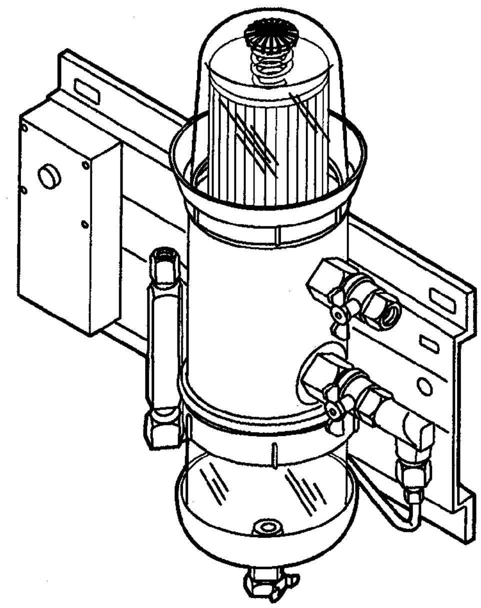

Figure 2-64 Sea Pro 152 Fuel Processor System

The Sea Pro 152 diesel fuel processor system consists of the following:

- A permanently mounted fuel processor
- A replaceable five-micron filter element and sealing grommet assembly
- A filter spring
- A see-thru filter cover and O-ring seal
- A cover-locking retainer collar/deflector
- A cover vent cap and seal
- An electric fuel primer pump
- Fuel inlet and outlet valves
- A see-thru water filter bowl and collar assembly

2.11.1 Replacement of Sea Pro 152 Fuel Filter Element

Replace the Sea Pro 152 filter element as follows:

1. With the engine shut down and at ambient temperature (cool to the touch), place a suitable container under the fuel processor.
2. Turn the fuel inlet and outlet valves on the fuel processor to the closed position (perpendicular to the valves) and loosen the vent cap on the see-thru cover. See Figure 2-65.

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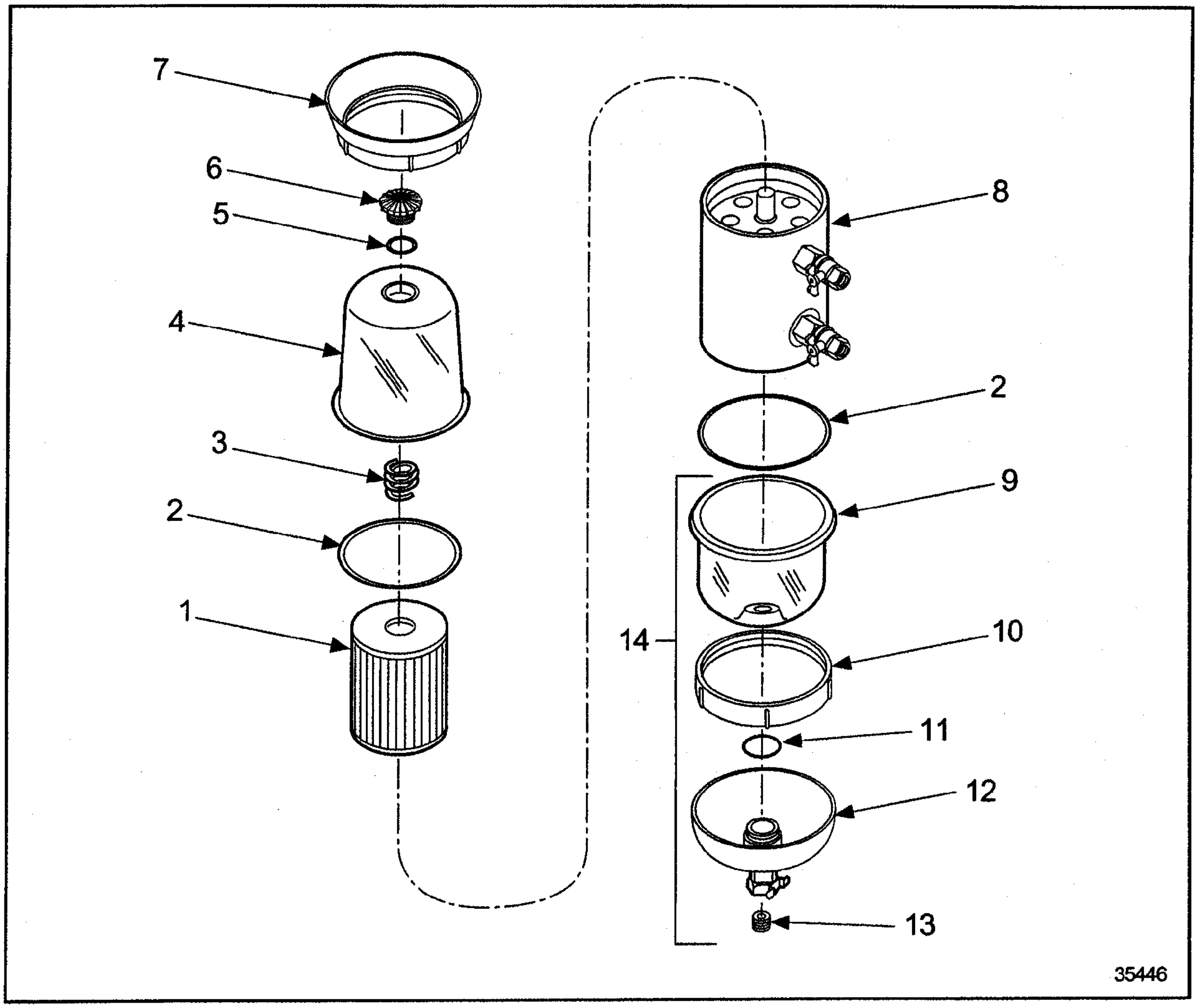

1. Filter Element
2. Cover Seal
3. Spring (part of cover assembly)
4. See-Thru Cover Assembly
5. Vent Cap Seal
6. Vent Cap
7. Retainer/Deflector Collar
8. Fuel Processor Assembly
9. See-Thru Water Separator Bowl
10. Retainer Collar
11. Deflector/Drain Valve Assembly
12. Drain Valve Plug
13. Water Filter Bowl and Collar Assembly

Figure 2-65 Sea Pro 152 Fuel Processor/Filter Assembly

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3. Remove the plug from the drain valve at the base of the water-separator bowl, open the valve, and drain the fuel until it is below the level of the retainer/deflector collar on the see-thru cover. Close the drain valve and replace the plug.
4. Using the offset wrench supplied with the Sea Pro 152 fuel processor assembly, turn the cover retainer/deflector collar counterclockwise and remove. Then remove the cover, filter spring, and cover seal ring by lifting straight up and over the filter element. Remove the element from the center stud by pulling upward and twisting slightly.

NOTE:
Any remaining fuel dripping from the element will be caught by the deep well in which the element sits and will drain into the processor body.

5. Dispose of the used element in an environmentally responsible manner, according to state and/or federal (EPA) recommendations.

2.11.2 Installation of Sea Pro 152 Fuel Filter Element

Install the Sea Pro 152 element as follows:

1. Before installing the new filter element, ensure the sealing surface on top of the processor body is clean by wiping with a clean cloth or paper towel.
2. Ensure a sealing grommet is included in the base of the replacement filter, then install the element onto the center stud by pushing down and twisting slightly to seat the element.
3. Ensure the filter spring is installed at the top of the cover. If missing, the spring must be replaced to insure proper filter operation. Wipe the cover lip and cover seal clean. After ensuring the seal is properly positioned at the base of the cover, install the cover over the filter and onto the fuel processor. Install the retainer/deflector collar. Then, using the wrench supplied with the fuel processor assembly, tighten the collar securely.

NOTICE:
To avoid cover or vent cap damage, do not use tools to tighten the vent cap.

4. Remove the vent cap from the top of the cover by turning counterclockwise, then open the fuel inlet valve on the processor body. Do not open the outlet valve. Fill the cover to the top of the filter element with clean fuel by operating the electric primer pump. After ensuring the O-ring seal is installed on the vent cap, reinstall the cap and tighten by hand only. Open the fuel outlet valve.

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CAUTION:

Diesel engine exhaust and some of its constituents are known to the State of California to cause cancer, birth defects, and other reproductive harm.

- **Always start and operate an engine in a well ventilated area.**
- **If operating an engine in an enclosed area, vent the exhaust to the outside.**
- **Do not modify or tamper with the exhaust system or emission control system.**

5. Start the engine. When the lubrication system reaches its normal operating pressure, increase engine speed to high idle for 2 to 3 minutes.

NOTICE:

To avoid possible cover or vent cap damage, do not use tools to tighten the vent cap.

NOTICE:

Do not allow the fuel level in the see-thru cover to fall *below* the top of the retainer collar/deflector, since this may lead to interruption of the fuel flow and engine stalling.

6. After the air is purged and with the engine still running, *slowly* loosen the vent cap on the filter cover. The fuel level will start falling. When the level falls to the top of the retainer/deflector collar, tighten the vent cap securely *by hand.*
7. With the engine running, check for leaks.
8. Shut down the engine.

NOTE:
The see-thru filter cover will not fill completely during engine operation. It will gradually fill over time as the filter medium becomes clogged. The filter element does not require changing until the fuel level has risen to the top of the element, or after one year of service, whichever comes first.

NOTE:
The secondary fuel filter must be changed at regular hour intervals. Refer to section 13.13.14.

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2.11.3 Removal of See-Thru Water Filter Bowl and Collar Assembly

Removal of the see-thru water filter bowl and collar assembly at the bottom of the processor body may be required for occasional cleaning. To remove and clean the bowl and collar assembly, proceed as follows:

1. Close the fuel inlet and outlet valves and loosen the vent cap on the see-thru cover.
2. Place a suitable container under the see-thru bowl, and remove the drain valve plug. Open the drain valve, and drain the filter, processor, and bowl completely of fuel. Dispose of the fuel in an environmentally friendly manner, according to state and/or federal (EPA) recommendations.
3. Using the offset wrench supplied with the Sea Pro 152 fuel processor assembly, turn the retainer collar clockwise (as viewed from the top) until it separates from the processor body. Pull the collar and bowl assembly down and away from the processor body. Remove and retain the O-ring seal in the groove at the top of the bowl.
4. Clean the bowl and collar assembly in mild detergent and warm water and dry with a clean, soft cloth.

2.11.3.1 Inspection of See-Thru Water Filter Bowl and Collar Assembly

Inspect the see-thru water filter bowl and collar assembly as follows:

1. Inspect the top seal for damage. If reusable, reinstall. If damaged, replace.
2. Inspect the bowl for damage. If reusable, reinstall the assembly. If damaged, replace the bowl as follows:

   [a] Hold the bowl securely and disassemble the drain valve by turning counterclockwise.

   [b] Remove the drain valve and separate the bowl and collar from the deflector. Remove and discard the bowl and the O-ring seal between the deflector and the bowl.

   [c] Clean the deflector thoroughly in mild detergent and warm water to remove any residual seal material and dry with a soft cloth.

NOTICE:
Do not overtighten the drain valve, since this will damage the threads in the bowl, resulting in fuel leakage.

   [d] With the deflector facing up, place a new O-ring seal over the center opening. Position the collar-threaded side up on top of the deflector, then place the new bowl onto the O-ring seal. Screw the drain valve into the threads in the bowl, and tighten securely by hand.

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2.11.4 Installation of See-Thru Water Filter Bowl and Collar Assembly

Install the see-thru water filter bowl and collar assembly as follows:

1. With the O-ring seal in the top groove of the bowl, position the bowl and collar assembly onto the base of the processor body and thread the retainer collar onto the processor.
2. Using the offset wrench supplied with the fuel processor assembly, tighten the collar securely.

2.11.5 Priming Sea Pro 152

For efficient engine operation, the Sea Pro 152 processor system *must* be properly primed after the filter element is replaced and *before* the engine is started.

NOTICE:
Failure to prime the fuel system after filter replacement may result in aerated fuel reaching the injectors. This could cause hard starting, reduced engine performance, injector damage, or all three consequences.

Prime the Sea Pro 152 fuel processor system as follows:

1. Refer to section 2.11 of the *Series 60 Service Manual*, and replace the Sea Pro filter element.

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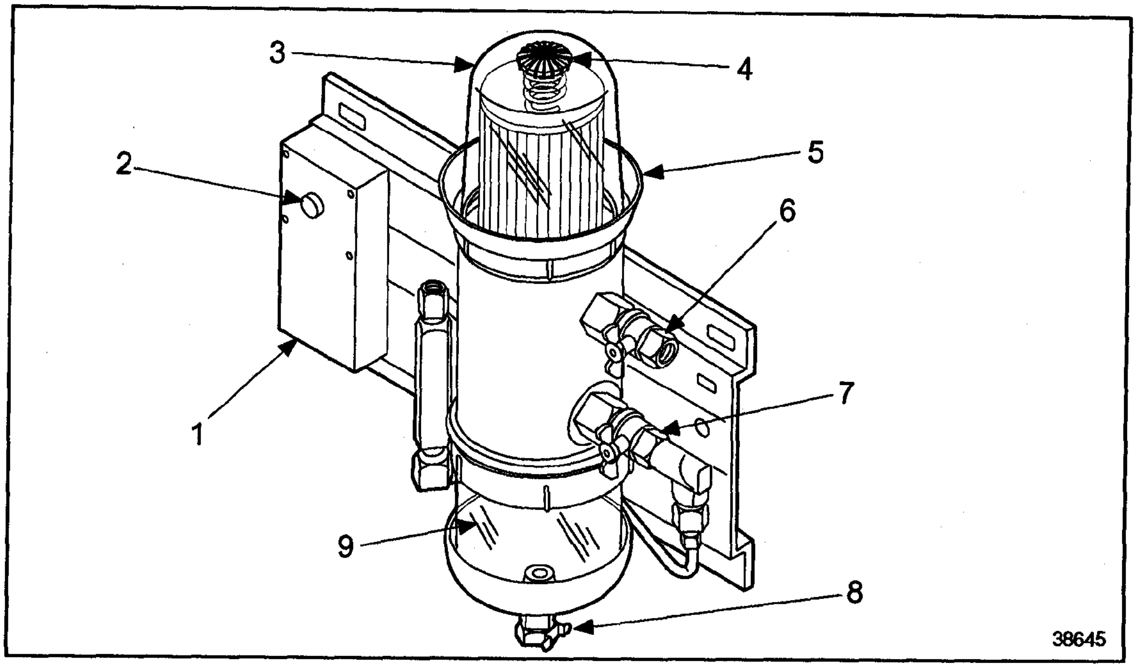
2. With the replacement element installed, make sure the outlet valve and drain valve on the processor assembly are closed. See Figure 2-66.



1. Priming Pump
2. Momentary Switch Button
3. See-Thru Cover
4. Vent Cap
5. Retainer Collar/Deflector
6. Fuel Outlet Valve
7. Fuel Inlet valve
8. Drain Valve
9. See-Thru Bowl

Figure 2-66 Sea Pro 152 Fuel Processor System

3. Open or remove the vent cap on the see-thru cover assembly by turning counter-clockwise. Then open the fuel inlet valve on the fuel processor. *Do not open the fuel outlet valve at this time.*
4. Press the momentary switch button on the electric priming pump until the see-thru filter cover is filled with enough fuel to cover the filter element.

NOTICE:
To avoid possible cover or vent cap damage, do not use tools to tighten the vent cap.

5. After ensuring the O-ring seal is installed on the vent cap, replace the vent cap on the see-thru filter cover, if previously removed. Tighten the vent cap *by hand* until secure.
6. Refer to section 2.11.2 for the exhaust caution before preceeding. Open the fuel outlet valve on the fuel processor, and start the engine.

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7. When the lubrication system reaches its normal operating pressure, increase engine speed to 1500 rpm for 2 or 3 minutes.

NOTICE:
Do not allow the fuel level in the see-thru cover to fall below the top of the retainer collar/deflector, since this may lead to interruption of the fuel flow and engine stalling.

8. After the air is purged and with the engine still running, *slowly* loosen the vent cap on the filter cover. The fuel level in the see-thru cover will start falling. When the level falls to the top of the retainer collar/deflector, tighten the vent cap quickly *by hand.*
9. With the engine running, check for leaks.
10. Shut down the engine.
11. If the drained fuel is to be reused, return it to the fuel tank. If the fuel is not to be reused, dispose of it in an environmentally friendly manner, according to state and/or federal (EPA) recommendations.

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2.12 FUEL FILTER TYPE FOR THE SERIES 60G ENGINE

The primary (High Pressure) natural gas filter and secondary natural gas filter must be a coalescing one-micron @ 98% efficiency fuel filter. Detroit Diesel recommended filters include the following:

- ☐ Racor - FFC-113

2.12.1 Replacement of Fuel Filter for the Series 60G Engine

Detroit Diesel does not service the fuel filter. Refer to OEM to replace as necessary.

2.12.2 Removal of Fuel Filter for the Series 60G Engine

Prior to removal or replacement of the fuel filter, the fuel system must be vented. Refer to section 2.40.1 and Refer to section 2.40.2.

CAUTION:

To avoid injury from the explosion of natural gas, the engine must be kept in a well-ventilated area away from open flames, sparks, and electrical resistance (heating) coils.

Refer to OEM for removal procedure for the fuel filter.

2.12.3 Installation of Fuel Filter for the Series 60G Engine

Refer to OEM for installation procedure.

The high pressure gas filter is mounted between the manual shutoff valve and the DDEC controlled shutoff valve. The low pressure 1 micron coalescing natural gas filter is mounted between the GFI regulator and the compuvalve.

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NOTICE:
The fuel filter is directional. Gas from the regulator must be plumbed to the fuel filter inlet port and from the fuel filter outlet port to the compuvalve. This provides proper filtration.

CAUTION:

To avoid injury from an explosion of natural gas, the following precautions must be taken:

- ☐ **Do not smoke when installing or servicing the engine or fuel system.**
- ☐ **Installation or servicing of natural-gas equipment must only be conducted in well-ventilated, natural gas compatible areas. Do not install or service equipment in an enclosed area where ignition sources are present without first ensuring that an undetected gas leak may be safely vented without being ignited.**
- ☐ **Bleed natural gas lines before installing or servicing any component connected to the fuel lines.**
- ☐ **Natural gas fuel systems are pressurized. Relieve pressure from any fuel system component prior to installation or service of that component.**
- ☐ **Use a combustible-gas detector. Liquefied natural gas (LNG) is odorless and cannot be detected by smell. Compressed Natural gas (CNG) may be odorless and may not be detected by smell.**
- ☐ **Equipment fuel systems are the responsibility of the Original Equipment Manufacturer (OEM). Equipment fuel system guidelines must be closely adhered to when installing or servicing equipment. Refer to OEM guidelines specifying which maintenance procedures require venting of fuel lines and fuel tanks.**
- ☐ **LNG systems are pressurized and contain extremely cold (-260°F [-162°C]) fluids. Contact the fuel supplier or OEM for LNG safety requirements. Contact with LNG may cause personal injury (freezing).**
- ☐ **Vent systems on the equipment should be ducted to a safe area whenever equipment is in an enclosed area.**

Natural gas is highly flammable and explosive and may be extremely cold (-260°F [-162°C]).

Refer to section 2.40.3 for leak checking procedure.

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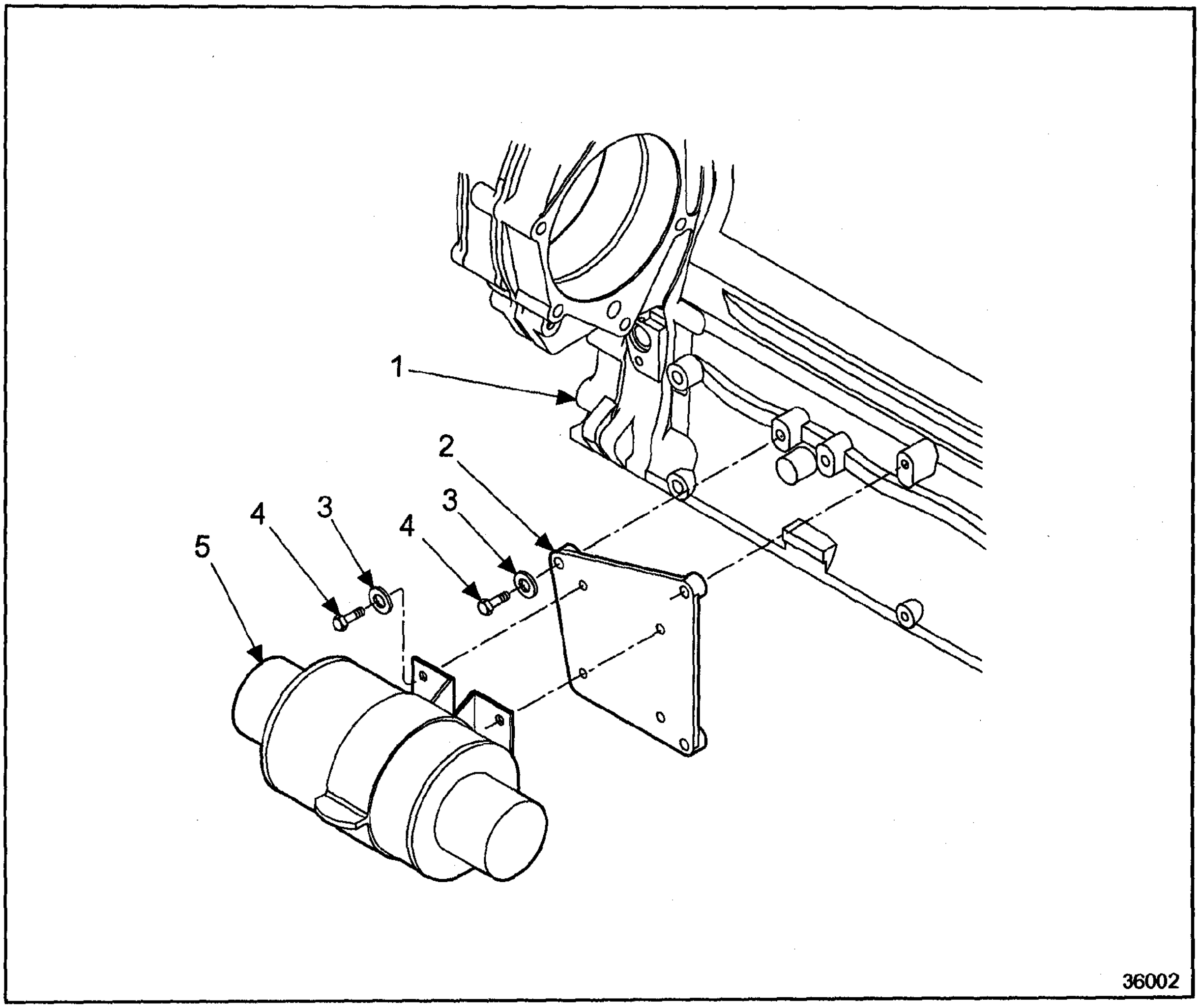
2.13 FUEL COOLER (HEAT EXCHANGER-COOLED MARINE ENGINE)

The Series 60 heat exchanger-cooled marine engine uses a tube-and-shell style fuel cooler mounted with connector hoses and clamps on the inlet side of the raw water pump. See Figure 2-67. The fuel cooler is a brazed assembly and cannot be disassembled. It should be removed and inspected for plugging and damage once a year and replaced every four years, regardless of apparent condition. Replace sooner if severe plugging or damage is indicated.



1. Engine Block
2. Mounting Plate
3. Washer
4. Bolt
5. Fuel Cooler

Figure 2-67 Fuel Cooler Location

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NOTICE:

Failure to inspect the fuel cooler for plugging or replace it when required may lead to restricted coolant flow and high fuel temperatures, which could result in loss of power and inefficient engine operation.

2.13.1 Removal of the Fuel Cooler

Remove the fuel cooler as follows:

1. With the engine at ambient temperature, place a suitable container under the heat exchanger and drain the raw water from the heat exchanger tank. Discard the raw water.
2. Close the shutoff valves located on the fuel inlet and outlet lines attached to the fuel cooler. Mark the lines for easy reinstallation.
3. With a suitable container placed under the fuel cooler to catch any dripping, carefully remove the lines from the fuel cooler fittings. Cap the lines to prevent any contamination of the fuel.
4. Loosen the hose clamps holding the fuel cooler to the raw water pump inlet elbow.
5. Loosen the hose clamps holding the fuel cooler to the raw water supply line.
6. With the cooler properly supported, remove the fuel cooler from the bracket holding it to the block, slide it off the connector hoses, and carefully pull it away from the engine.

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2.13.1.1 Inspection of the Fuel Cooler

Inspect the fuel cooler as follows:

1. Inspect the cooler shell for dents, fuel or water leaks, and fuel inlet or outlet fitting damage. A fuel cooler showing obvious signs of damage should not be reused.
2. If no obvious signs of damage, inspect the cooler tubes for plugging. If tubes are not plugged, proceed to step 3. If tubes are plugged, remove plugging as follows:

   [a] Circulate a cleaning solvent such as Powercool® 2001 On-Line Cleaner, or equivalent, through the tubes. Carefully rod out the tubes with a bore brush, and flush out any loosened material with clean, fresh water.

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

   [b] Drain all water from the fuel cooler and blow dry with compressed air.

3. Pressure check fuel cooler as follows:

   [a] Block water outlet with hose, end cap, and clamps.

   [b] Block water inlet with hose, end cap modified with pressure valve, and clamps.

   [c] Fill cooler tubes with clean fuel.

CAUTION:

To avoid injury from flying debris when using compressed air, wear adequate eye protection (face shield or safety goggles) and do not exceed 40 psi (276 kPa) air pressure.

   [d] Apply 207 kPa (30 $lb{\cdot}in^2$) air pressure to pressure valve on water inlet.

   [e] If pressure leak down or no bubbles in the fuel occur, replace fuel cooler.

   [f] If no pressure leakdown or no bubbles occur in the fuel, reuse fuel cooler.

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2.13.2 Installation of the Fuel Cooler

Install the fuel cooler as follows:

1. Attach the fuel cooler securely to the mounting bracket on the block, ensuring the cooler inlet and outlet openings are properly oriented.
2. Slide the connector hoses from the raw water pump inlet elbow and the raw water supply line onto the cooler openings and tighten the hose clamps.
3. Install fuel inlet and outlet lines to the cooler.

CAUTION:

Diesel engine exhaust and some of its constituents are known to the State of California to cause cancer, birth defects, and other reproductive harm.

- **Always start and operate an engine in a well ventilated area.**
- **If operating an engine in an enclosed area, vent the exhaust to the outside.**
- **Do not modify or tamper with the exhaust system or emission control system.**

4. Prime the raw water pump and prime the fuel system. Start the engine and check for raw water or fuel leaks.

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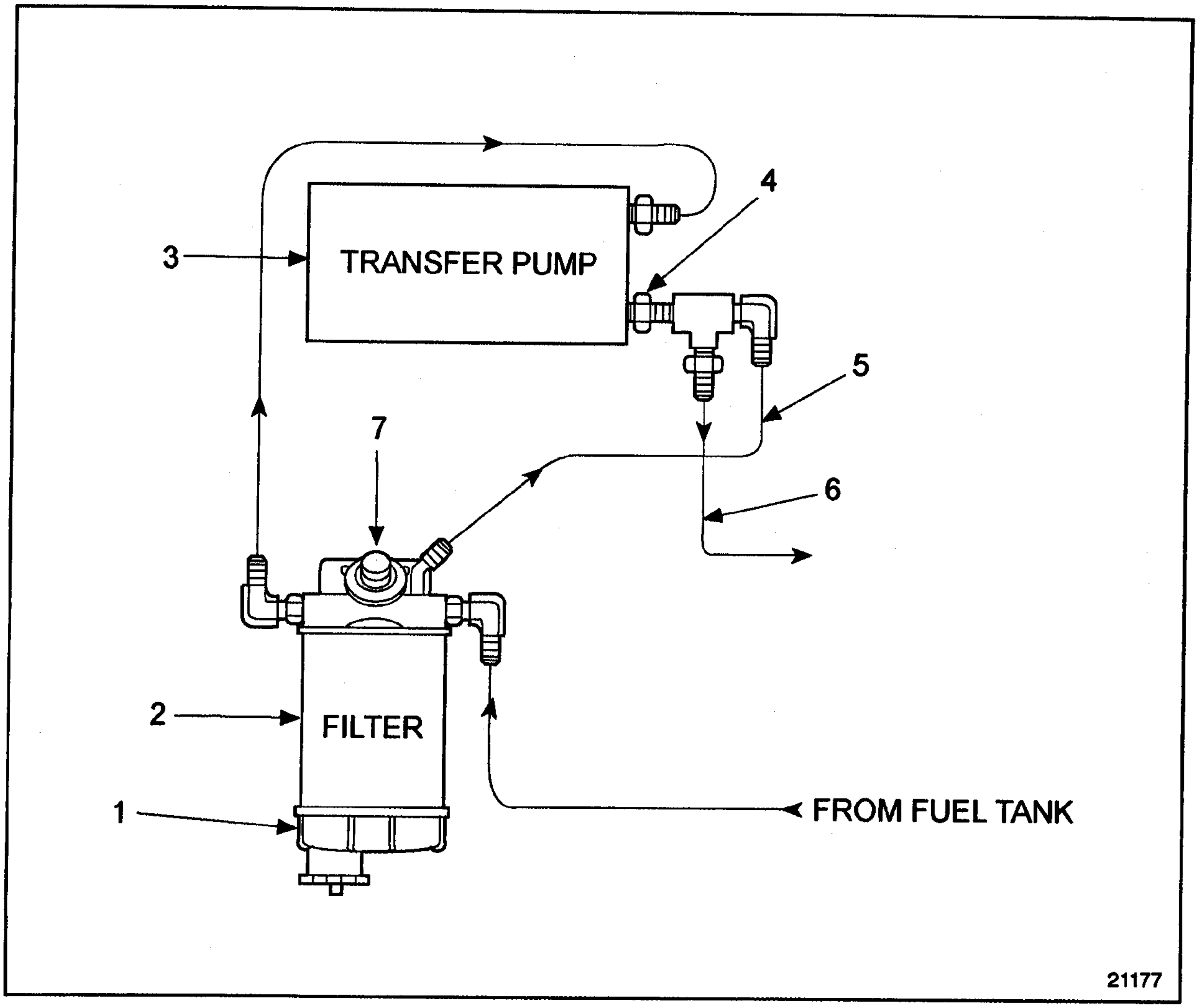
2.14 ASSEMBLY FUEL FILTER AND WATER SEPARATOR

The fuel filter and water separator assembly facilitates the settling of water in a collection bowl. See Figure 2-68.



1. Collection Bowl
2. Spin-on Element
3. Priming Pump
4. Reducer Bushing
5. Filter Head to Transfer Pump Hose
6. Hose to Secondary Fuel Filter

Figure 2-68 Typical Fuel Filter and Water Separator Installation

2.14.1 Replacement of Fuel and Water Separator Element

Use the following procedure:

1. Drain off some fuel by opening the drain valve on the collection bowl. Close the valve.
2. Remove the element and bowl together, then remove the bowl from the element. Clean the bowl and the O-ring gland.
3. Apply a coating of clean fuel or grease to the new O-ring and element seal. Spin the bowl onto the new element and them spin the assembly onto the filter head by hand until snug. Do not use tools to tighten.
4. To eliminate air from the filter, operate the primer pump until the fuel purges at the filter assembly.

CAUTION:

Diesel engine exhaust and some of its constituents are known to the State of California to cause cancer, birth defects, and other reproductive harm.

- **Always start and operate an engine in a well ventilated area.**
- **If operating an engine in an enclosed area, vent the exhaust to the outside.**
- **Do not modify or tamper with the exhaust system or emission control system.**

5. Start the engine and check for fuel leaks. Correct any leaks with the engine shut off.

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2.14.2 Fuel Return System Check Valve

The purpose of the check valve is to reduce the risk of fuel prime loss and fuel siphoning from the head when the fuel filter is removed. See Figure 2-69.

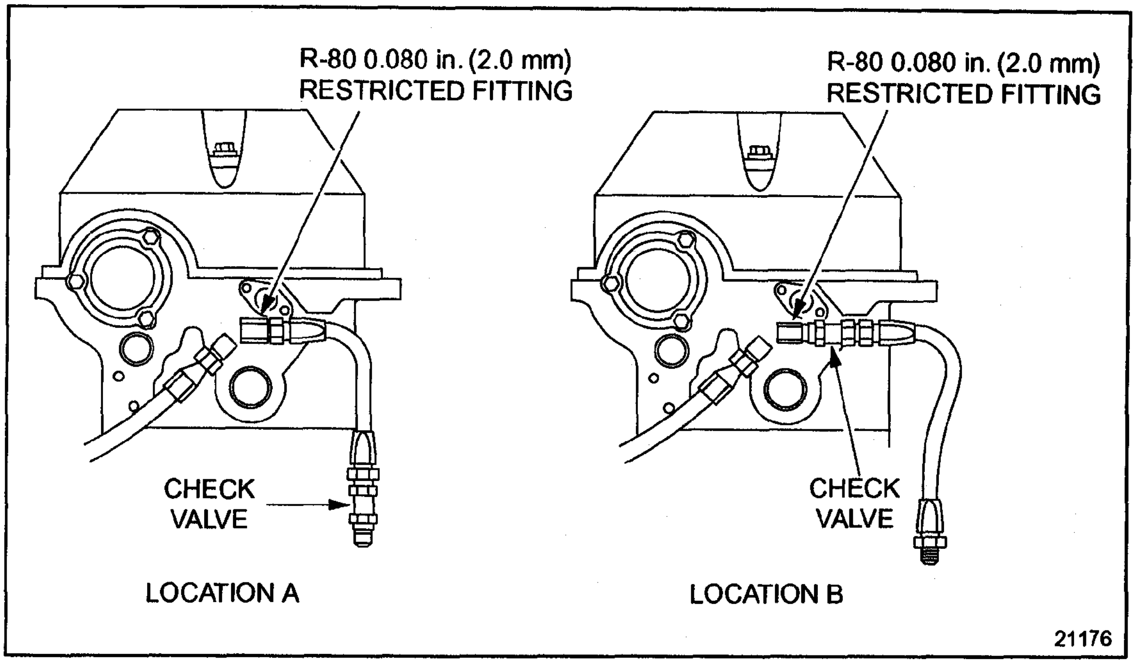

Figure 2-69 Typical Fuel Return Check Valve Locations

NOTICE:
The check valve must be included in the fuel system. If the check valve is removed for any reason or found to be defective, a new valve must be installed and the fuel system primed before start-up. The R-80 — 0.080 in. (2.0 mm) restricted fitting (elbow connector) which is ahead of the check valve must also be included in the fuel system.

NOTICE:
Do not increase the size of the orifice in restricted fittings. Increasing restricted fittling hole size can cause injector caviation, resulting in reduced durability of injectors and other engine components, and increased engine emissions.

A check valve is connected to a hose in the fuel return line coming from the rear of the cylinder head or at the cylinder head restricted fitting, depending on individual installation requirements. See Figure 2-69.

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2.14.3 Removal of PRO-CHEK Fuel System Check Valve

Remove the valve as follows:

NOTICE:
The PRO-CHEK fuel system check valve is installed after the secondary filter. Any dirt or debris entering the fuel system at this point may cause severe injector damage.

1. Clean the area around the PRO-CHEK® valve thoroughly to remove loose dirt or debris.
2. Disconnect the fuel supply and return lines from the bottom of the valve and cap the hoses immediately to prevent the entrance of dirt.
3. Disconnect the air purge line from the top elbow on the valve and cap the line to prevent the entrance of dirt.
4. Remove the valve and bracket assembly from the engine as follows:
   [a] If rear mounted, remove the two 12 mm bolts securing the valve to the rear lifter bracket.
   [b] If side mounted, remove the two 10 mm bolts and spacers holding the valve to the cylinder head.

2.14.3.1 Inspection of the PRO-CHEK Fuel System Check Valve

Inspect the PRO-CHEK fuel system check valve as follows:

1. Visually inspect exterior casing of the PRO-CHEK valve for cracks, leaks, or other signs of damage.
   [a] If the PRO-CHEK valve has no cracks, leaks, or other signs of damage, reuse the valve.
   [b] If the PRO-CHEK valve has cracks, leaks, or other signs of damage, replace the valve.

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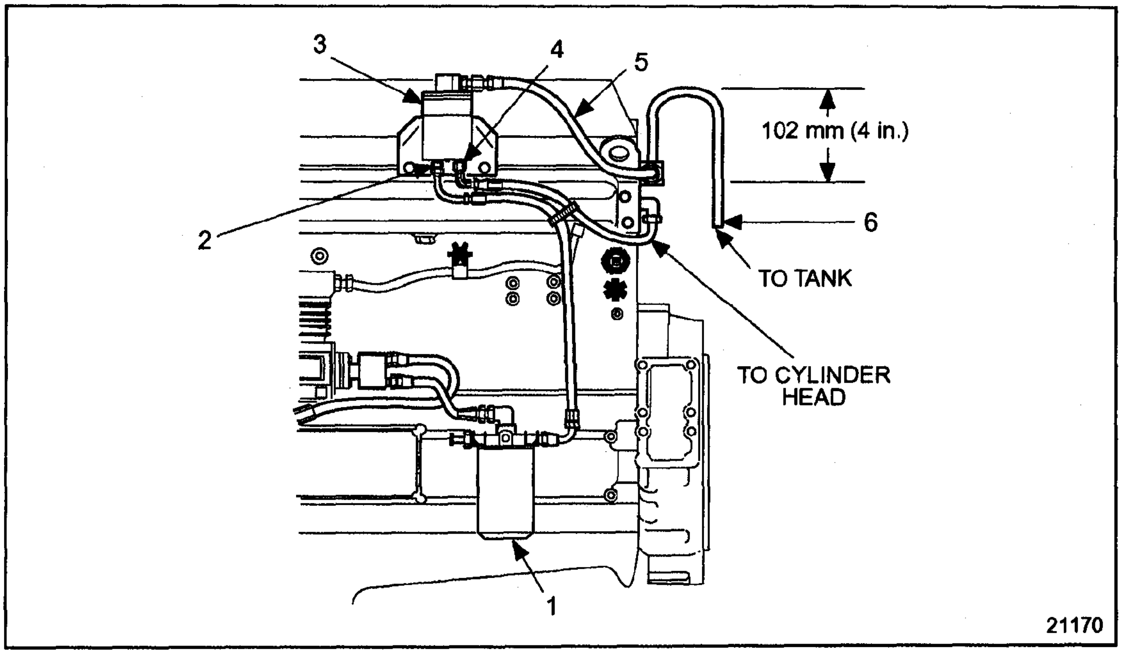
2.14.4 Installation of PRO-CHEK Fuel System Check Valve

The PRO-CHEK fuel system check valve is an optional item that, when properly installed, removes air from the fuel supply line between the secondary filter and the cylinder head. No priming is required even after filter change, since any air that may get into the lines is automatically removed when it reaches the PRO-CHEK valve.

Install the PRO-CHEK valve as follows:

1. Mount the PRO-CHEK valve on the side or rear of the Series 60 engine.
   [a] If side-mounted, install with two 10 mm bolts and spacers. The location may be ahead of or behind the location shown. See Figure 2-70.



1. Secondary Fuel Filter
2. Fuel Inlet
3. PRO-CHEK Valve
4. Air Purge Line
5. Fuel Outlet
6. Fuel Spill Line

Figure 2-70 Typical Side-mounted PRO-CHEK Installation

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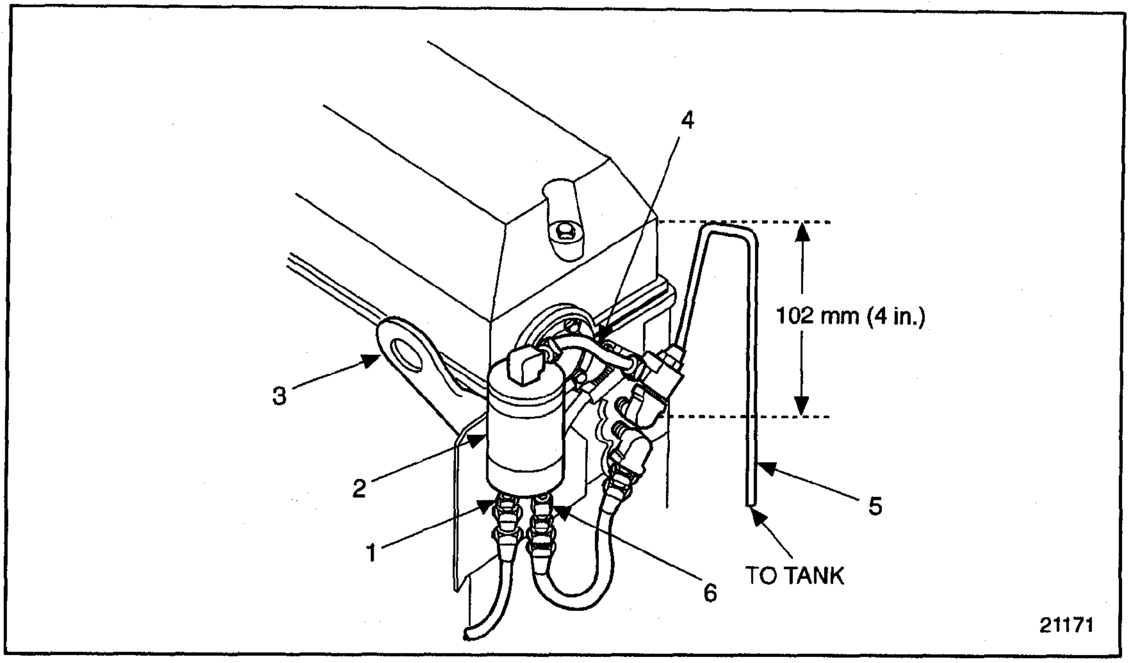
[b] If rear-mounted remove the two 12 mm bolts holding the rear lifter bracket and install the PRO-CHEK valve against the bracket with two 12 mm bolts that are 5 mm (approximately 0.20 in.) longer and two spacers. See Figure 2-71.



1. Fuel Inlet
2. PRO-CHEK Valve
3. Engine Lifter Bracket
4. Air Purge Line
5. Fuel Spill Line
6. Fuel Outlet

Figure 2-71 Typical Rear-mounted PRO-CHEK Installation

2. Disconnect the fuel supply hose assembly at the rear of the engine and reconnect it to the PRO-CHEK 3/8 in. SAE flared bottom fitting marked with the words *Fuel In.*
3. Connect a separate fuel hose assembly to the 1/4 in. 18 NPTF PRO-CHEK female bottom fitting marked with the words *Fuel Out.* Install the other end in the fuel manifold inlet port at the rear of the engine.
4. An R80 2.03 mm (.080 in.) restricted fitting is installed in the fuel spill (return) opening in the cylinder head. Install a tee-fitting after the R80 spill fitting. The spill hose from this tee-fitting must be routed at least 4 in. (101.6 mm) above the fuel gallery. See Figure 2-70 and see Figure 2-71. Connect a 1/4 in. diameter fuel hose assembly to the elbow in the top port of the PRO-CHEK. Route this air purge hose to the spill tee— fitting.
5. Tie-wrap the PRO-CHEK inlet and outlet fuel lines to prevent chafing and/or contact with metal parts.
6. Prime the fuel system.
7. Refer to section 2.14.1 for the exhaust caution before preceeding. Start the engine and check for leaks.

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The PRO-CHEK valve is fully assembled and ready to install when received. If the *Fuel In* or *Fuel Out* fittings are accidentally loosened or removed for any reason, they must be reinstalled in their proper locations as follows:

- ☐ The male fitting with the long, solid pipe is installed in the fuel in port. See Figure 2-72.
- ☐ The female fitting with the short, perforated pipe is installed in the fuel out port. See Figure 2-72.

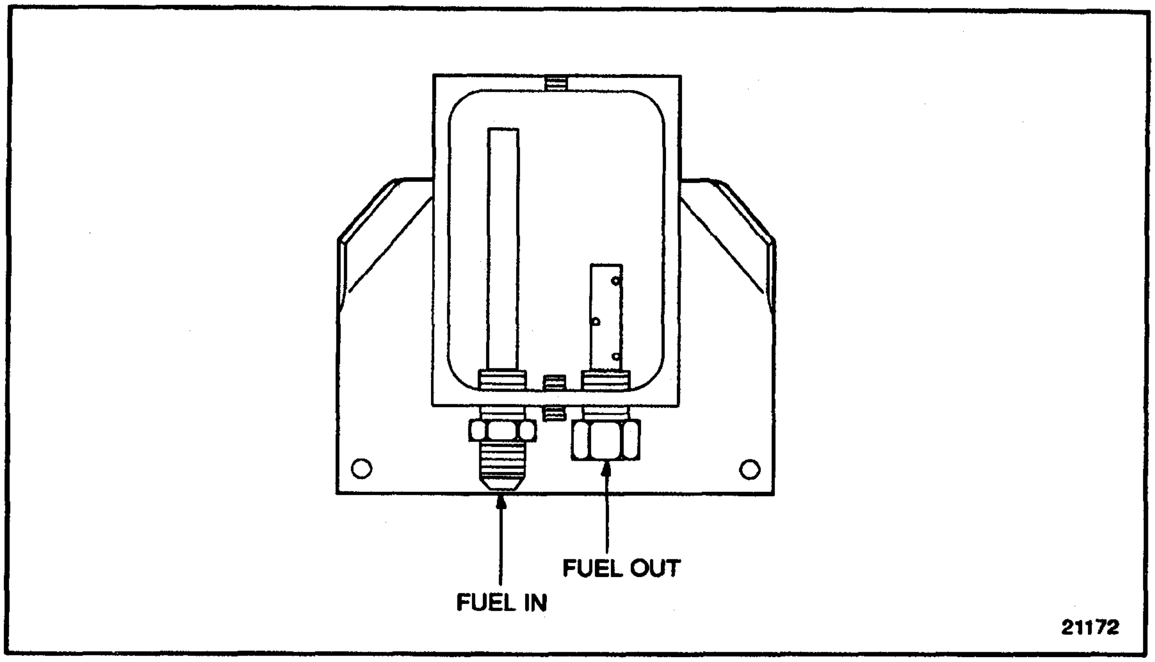

Figure 2-72 PRO-CHEK Valve Cutaway View

NOTICE:
Fittings must remain clean when installed, since anything that gets inside the PRO-CHEK valve will be carried into the fuel manifold and may damage the injectors.

NOTICE:
Do not overtighten the *Fuel In* or *Fuel Out* fittings or the top elbow, since this may damage the threads on the fittings or the PRO-CHEK body, resulting in fuel leaks. If fitting or body threads are damaged, the complete assembly *must* be replaced.

1. Thread the inspected, clean dry fittings into the valve body for a few turns.

NOTICE:
Do not use Teflon® pipe sealant tape on the male pipe fittings, since this may flake off into the fuel system and damage the injectors.

2. Apply a light coating of pipe sealant with Teflon to the visible male threads.
3. Torque the *Fuel In* fitting and top elbow to 14-19 N·m (10-14 lb·ft).
4. Torque the *Fuel Out* fitting to 19-24 N·m (14-18 lb·ft).

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2.15 ELECTRONIC ENGINE CONTROL

The Detroit Diesel Electronic Control System (DDEC) controls fuel injection timing and output by the electronic unit injectors (EUI) on the Series 60 Diesel engine. DDEC controls throttle, gas valve and the ignition system on the Series 60G engine. The system also monitors several engine functions using electrical sensors which send electrical signals to the Electronic Control Module (ECM). The ECM then computes the incoming data and determines the correct fuel output and timing for optimum power, fuel economy and emissions. The ECM also has the ability to display warnings or shut down the engine completely (depending on option selection) in the case of damaging engine conditions, such as low oil pressure, low coolant, or high oil temperature.

Early Series 60 engines have the DDEC system called DDEC I. Later Series 60 engines have the 2nd generation DDEC system called DDEC II. See Figure 2-73. The current engines have the third generation DDEC system, DDEC III/IV.

The replacement of DDEC components is based on indicated diagnostic codes leading to faulty components. Check the *Detroit Diesel Single ECM Troubleshooting Manual* (6SE497) for more complete information on diagnosis of components and system problems.

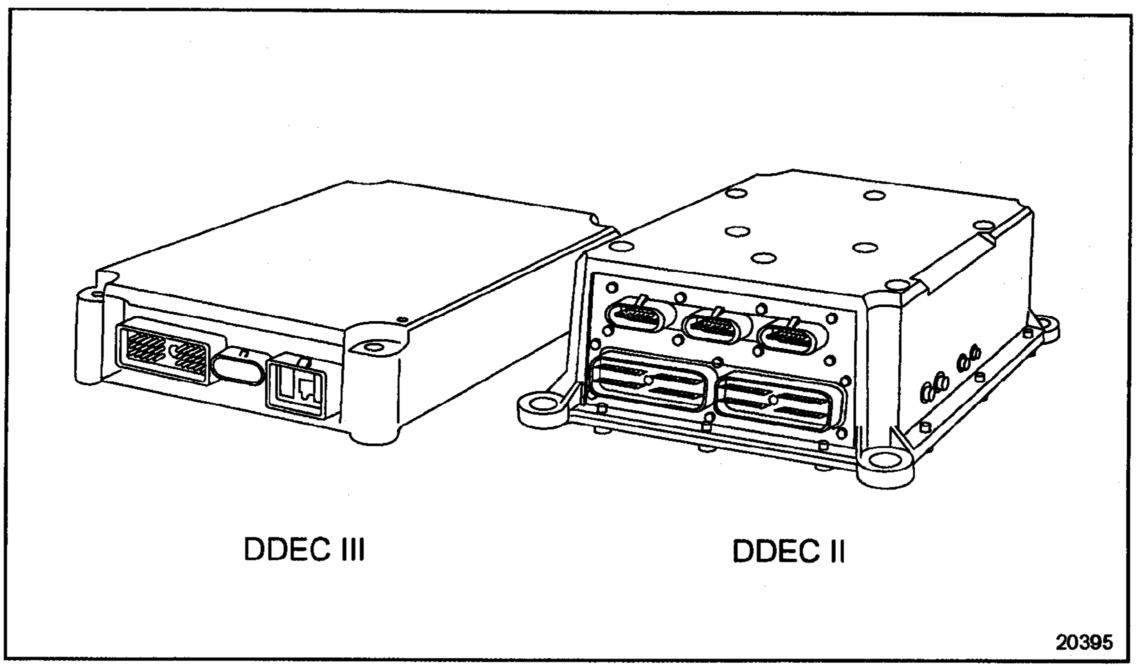

Figure 2-73 DDEC III/IV and DDEC II Electronic Control Module (ECM)

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2.16 DDEC III/IV ELECTRONIC CONTROL MODULE

DDEC III/IV provides an indication of engine and vehicle malfunctions. The ECM continually monitors the DDEC III/IV system. See Figure 2-74 and see Figure 2-75.

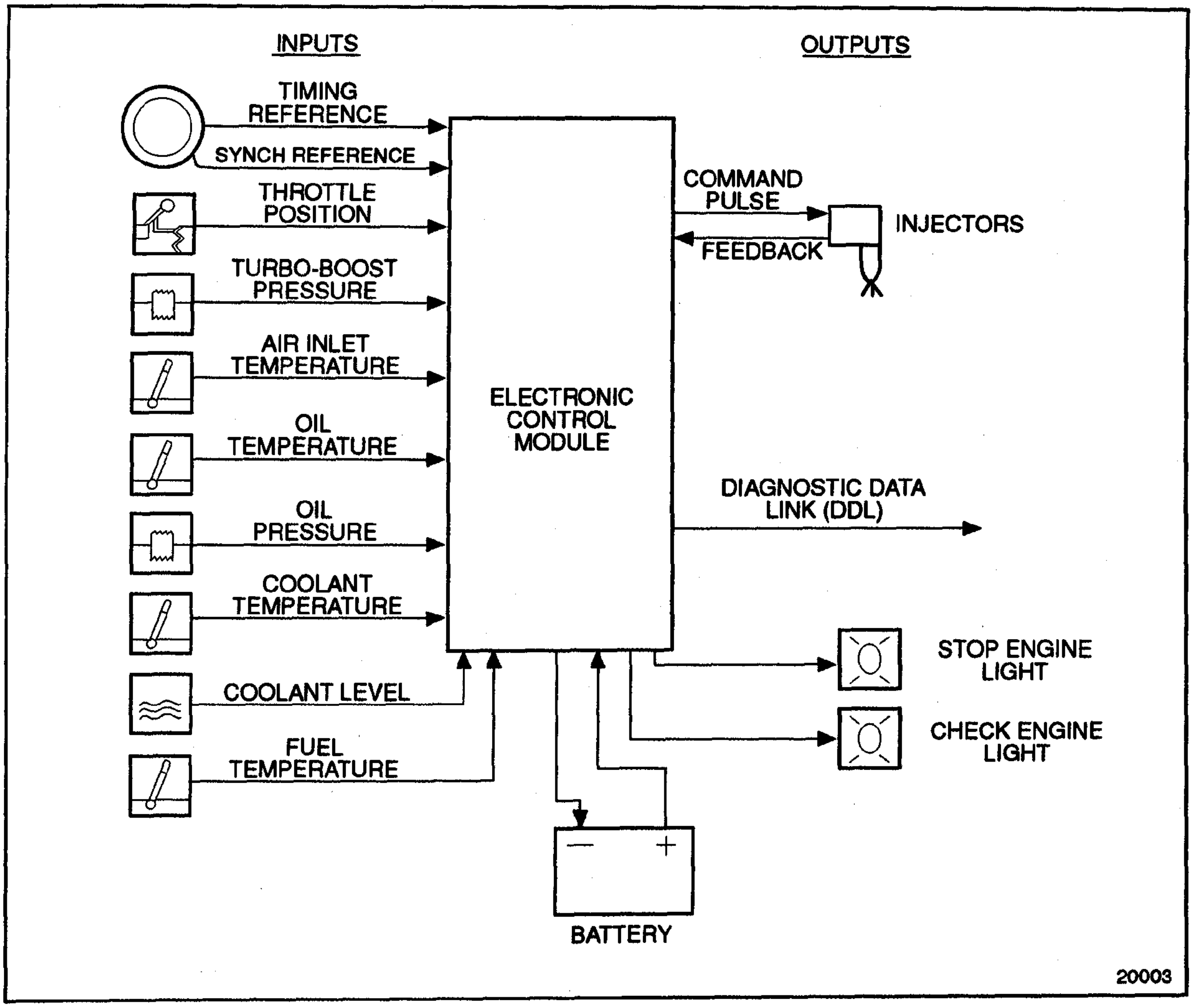

Figure 2-74 DDEC III/IV System Series 60 Diesel Engine

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Figure 2-75 DDEC III/IV System Series 60 Natural Gas Engine

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Any faults that occur are stored as codes in the ECM's memory. These codes can be accessed in any of three ways:

1. A DDR can be used to read the codes. See Figure 2-76.
2. A personal computer (PC) connected to the ECM through a translator device which converts J1708 to RS232 protocol can be used.
3. The Check Engine Light (CEL) or the Stop Engine Light (SEL) is illuminated.
   - The CEL (panel mounted yellow indicator light) illuminated diagnose condition as soon as convenient.
   - The SEL (panel mounted red indicator light) and CEL illuminated, a major fault occurred and immediate attention required to avoid engine damage.
   - Automatic engine shutdown or rampdown is available as an option. A shutdown override switch is required to allow the vehicle to be moved to a safe location during automatic shutdown or rampdown.

DDEC III/IV features programmable with a Diagnostic Data Reader (DDR) are:

- Password
- Droop
- Active hp braking
- Cruise control
- Engine brake
- Vehicle speed limiting
- Vehicle speed sensor
- Variable Speed Governor cruise switch
- Idle timer shutdown
- Idle timer between air temperatures
- Vehicle ID number (VIN)
- Idle adjustment
- Progressive shifting
- Engine protection

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The hand-held DDR is used on engines equipped with DDEC III/IV to display engine description, diagnostic data, fault codes, and to program the ECM calibration. A printout of the information displayed on the DDR, can be obtained by attaching a printer. The diagnostic data reader kit, J 38500-D, includes a reader, cable, carrying case, DDEC cartridge, manual, and a six-pin adaptor. See Figure 2-76.

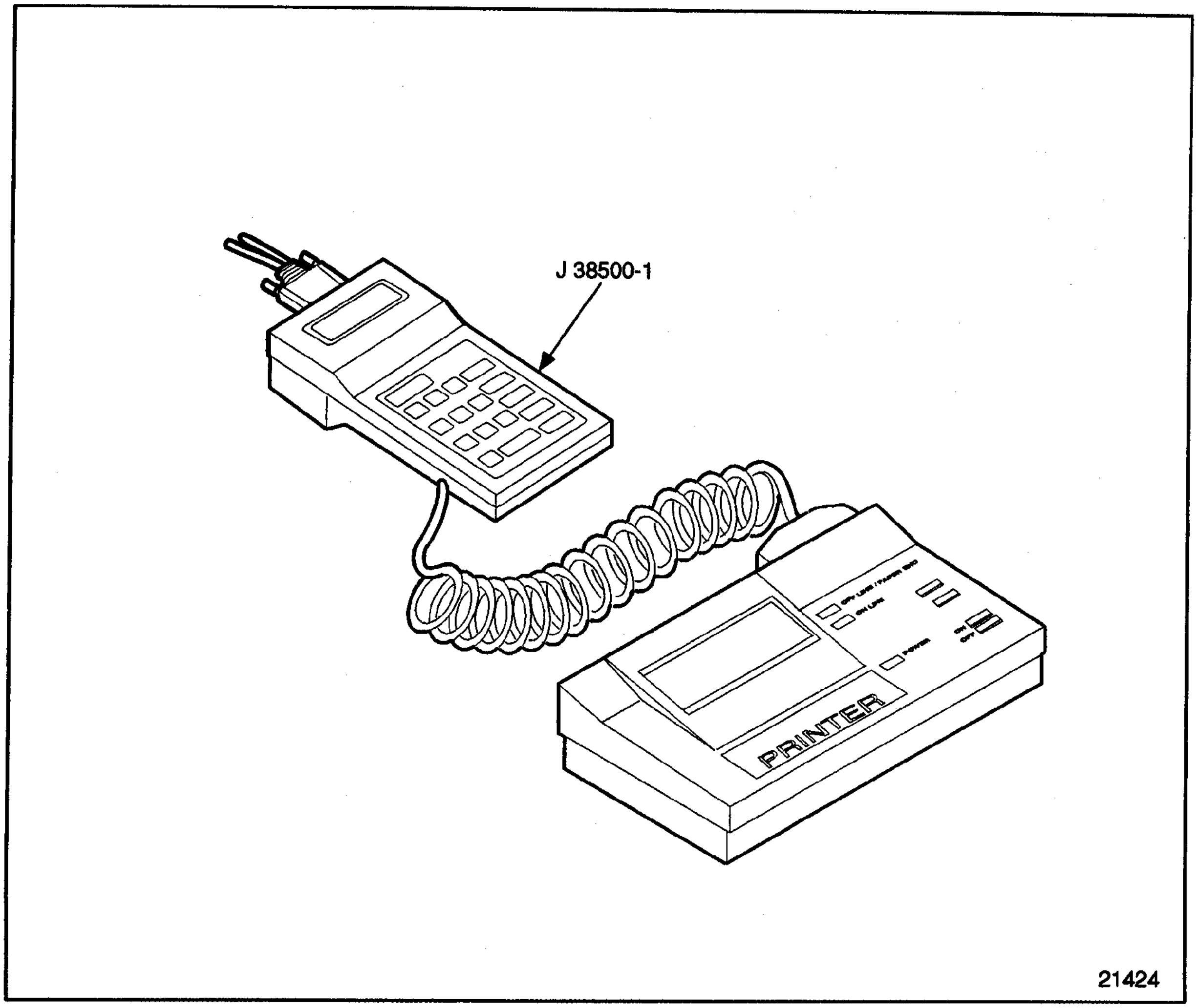

Figure 2-76 The DDR and Printer

The SAE Standard Communications of the DDEC III/IV system are listed in Table 2-5. The fan control inputs and outputs for DDEC III/IV are listed in Table 2-6. The engine brake control features of DDEC III/IV are listed in Table 2-7. DDEC III/IV can identify faulty components and other engine-related problems by providing the technician with a diagnostic code. A comparison of DDEC II and DDEC III/IV engine hardware is listed in Table 2-8. A comparison of DDEC II and DDEC III/IV standard sensors is listed in Table 2-9 and a comparison of optional sensors is listed in Table 2-10.

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SAE Standard Communication
SAE J1587 protocol on J1708 hardware
Diagnostics
Electronic dashes
Data Hub
SAE J1922 protocol on J1708 hardware
Traction control systems
Transmission controls
SAE J1939 high speed data link
Vehicle controls

Table 2-5 SAE Standard Communications for DDEC III/IV

Inputs	Outputs
Coolant temperature	Single on/off fan clutch
Oil temperature	Dual on/off fan clutch
Air temperatures	Two-speed single fan
Air conditioning	Modulated fan clutch

Table 2-6 Fan Controls for DDEC III/IV

Engine Brake Control
Eliminates OEM engine brake module
Compatible with cruise control
Engine brake will go on and off without disabling cruise control
Engine fan braking
Requires fan and engine brake control
Fan turns on when engine brake is on high
In cruise control, engine brake operates electronically
MPH activating speeds are set with DDR
Cruise control, engine brake operates manually

Table 2-7 Engine Brake Control with DDEC III/IV

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Engine Hardware	DDEC II	DDEC III/IV
Electronic Foot Pedal Assembly	Three Wires	Three or five wires
Coolant Level Sensor	Coolant Probe/Module	Coolant Probe Only
Diagnostic Request Stop Engine Override	Two Separate Switches	One Combined Switch
Communications	Vehicle Interface Harness SAE J1587/J1922	Vehicle Interface Harness SAE J1587 Communications Harness SAE J1922, SAE J1939
Power Harness	6-Pin Connector	5-Pin Square Connector
Wiring	16 gauge wire, 4 Power, 2 Ground	12 gauge wire (Eliminates Splicing), 2 Power, 2 Ground

Table 2-8 DDEC II vs DDEC III/IV

DDEC II	DDEC III/IV
Oil Temperature (Truck)	Oil Temperature
Oil Pressure	Oil Pressure
Coolant Level	Coolant Level
Turbo Boost	Turbo Boost
Throttle Position (OEM Supplied)	Throttle Position
Timing Reference	Timing Reference
Synchronous Reference	Synchronous Reference
Fuel Temperature	Fuel Temperature, Air Temperature

Table 2-9 Standard Sensors

DDEC II	DDEC III/IV
Fuel Pressure	Fuel Pressure
Pressure Governor (Firetruck)	Pressure Governor (Firetruck)

Table 2-10 Optional Sensors

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2.16.1 Repair or Replacement of the DDEC III/IV Electronic Control Module

The DDEC III/IV ECM is a sealed, nonserviceable unit. Tag defective ECM for recore.

2.16.2 Removal of the DDEC III/IV Electronic Control Module

Perform the following steps for ECM removal:

1. Carefully disengage the lock tab on the power harness and injector harness connectors when removing.
2. Remove the two (2) wire and three (3) wire harness connections at the ECM.
3. Remove the two 30-pin connectors.
4. Remove the through-bolts holding the ECM to the engine.
5. Remove the ECM and cold plate from the engine, if so equipped.
6. Remove the screws securing the cold plate to the ECM. Remove the cold plate from the ECM, if so equipped.

2.16.3 Installation of the DDEC III/IV Electronic Control Module

Perform the following steps for ECM installation:

1. Install the cold plate on the ECM, if so equipped. Tighten the screws securing the cold plate to the ECM. Use Loctite® 262, or equivalent, on the cold plate-to-ECM screws. Torque to 9.5-12 N·m (84-106 lb·in.).
2. Inspect the ECM isolators for damage and replace if required.
3. Mount the ECM and cold plate to the engine.
4. Secure the ECM to the engine with through-bolts. Torque the ECM-to-engine bolts to 23-27 N·m (17-20 lb·ft).

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5. Apply Teflon® tape to the threads of the engine-side of the jack screws only on the two 30–pin connectors. Install the connectors in the ECM and torque the jack screws to 2.49–3.16 N·m (21–26 lb·in). See Figure 2-77.

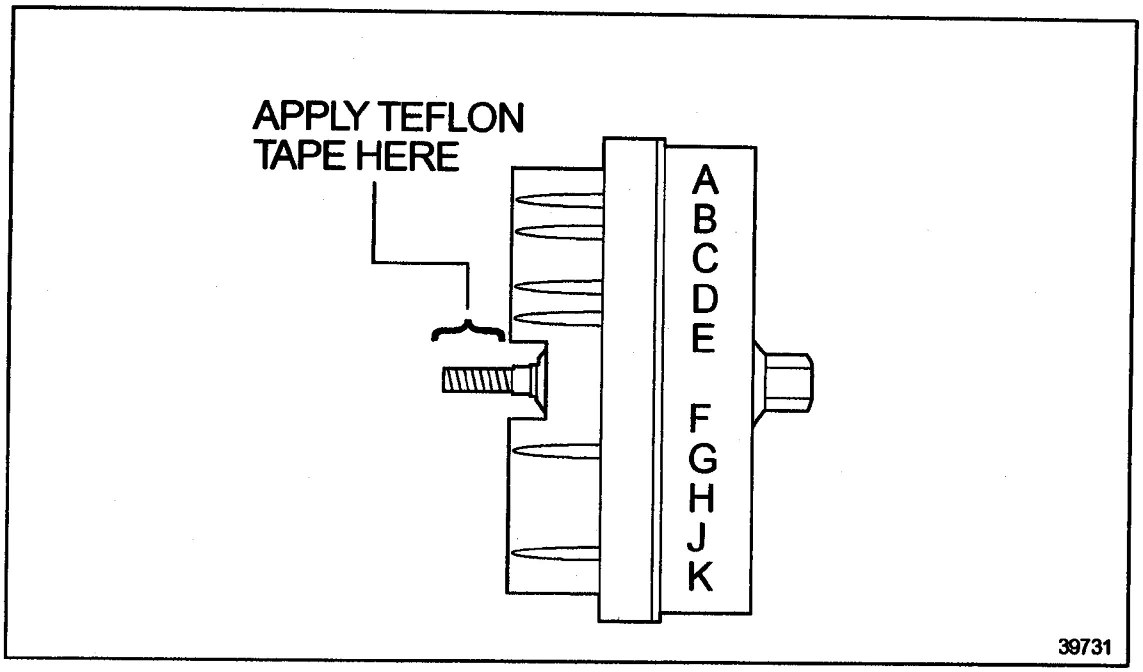

Figure 2-77 Application of Teflon Tape on Jack Screw

6. Engage the lock tab on the power harness and injector harness connectors.
7. Turn the ignition to the "ON" position. Observe the DDR for any diagnostic code(s). If any code(s) other than code 25 is logged, refer to the *Detroit Diesel DDEC III/IV Single ECM Troubleshooting Manual* (6SE497).

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CAUTION:

Diesel engine exhaust and some of its constituents are known to the State of California to cause cancer, birth defects, and other reproductive harm.

- **Always start and operate an engine in a well ventilated area.**
- **If operating an engine in an enclosed area, vent the exhaust to the outside.**
- **Do not modify or tamper with the exhaust system or emission control system.**

8. Start the engine, and check for leaks.

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2.17 DDEC II ELECTRONIC CONTROL MODULE

This system utilizes an engine-mounted ECM only with the EDU components of the DDEC I system contained in the ECM. The replaceable PROM is an EPROM in the DDEC II ECM. The ECM has isolator mounts for both vibration and electrical isolation. Depending upon application, some units have fuel cooling of the ECM. The engine-mounted system simplifies vehicle wiring for greater reliability.

The DDEC II ECM is a microprocessor. It is the control center of the DDEC II system. See Figure 2-78.

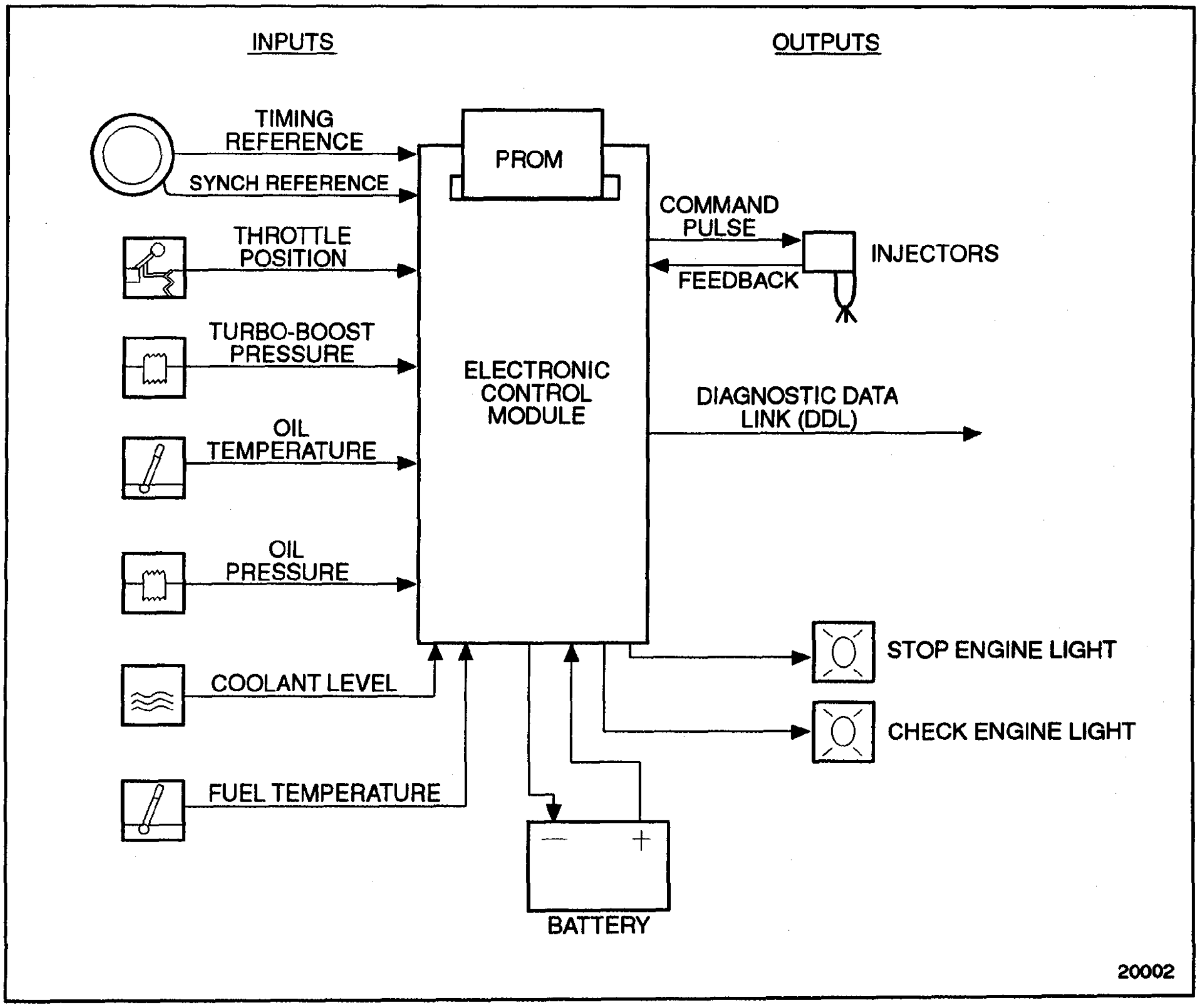

Figure 2-78 Schematic Diagram of DDEC II

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The DDEC II ECM is packaged in a die-cast aluminum housing with sealed connectors. See Figure 2-73. It is mounted on the left side of the engine block.

The DDEC II consists of the following:

- The DDEC II ECM
- A replaceable EPROM
- Connections to various engine sensors, operational displays, power and fuel injectors

2.17.1 Replacement of the DDEC II Electronic Control Module

The DDEC II ECM is a sealed, nonserviceable unit. Tag defective ECM for recore.

2.17.2 Diagnostic Procedures

Basic mechanical checks should be made beforehand to verify that the problem is definitely related to the electrical portion of the system. If the basic mechanical checks fail to locate the problem, refer the *Detroit Diesel Single ECM Troubleshooting Manual,* (6SE497). Start by reading the "Basic Knowledge Required" section before attempting to diagnosis electrical faults.

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There are two diagnostic Data Readers (DDR) that can be used for diagnosis of DDEC I and DDEC II engines. See Figure 2-79 and see Figure 2-80.

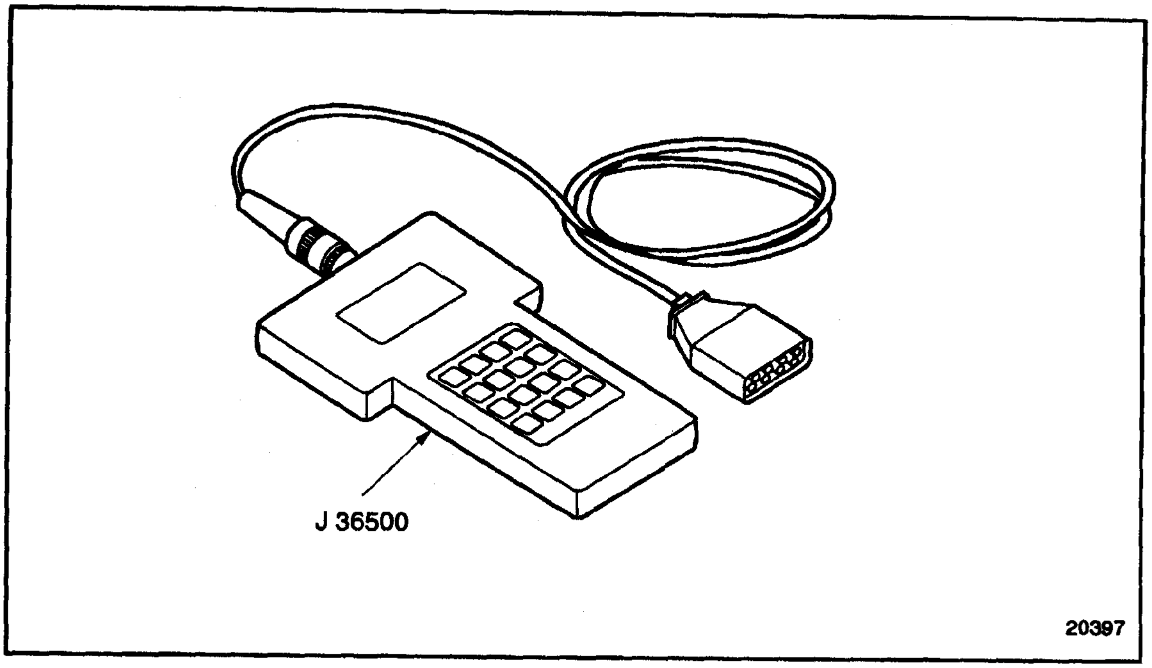

Figure 2-79 DDEC I & II Reader

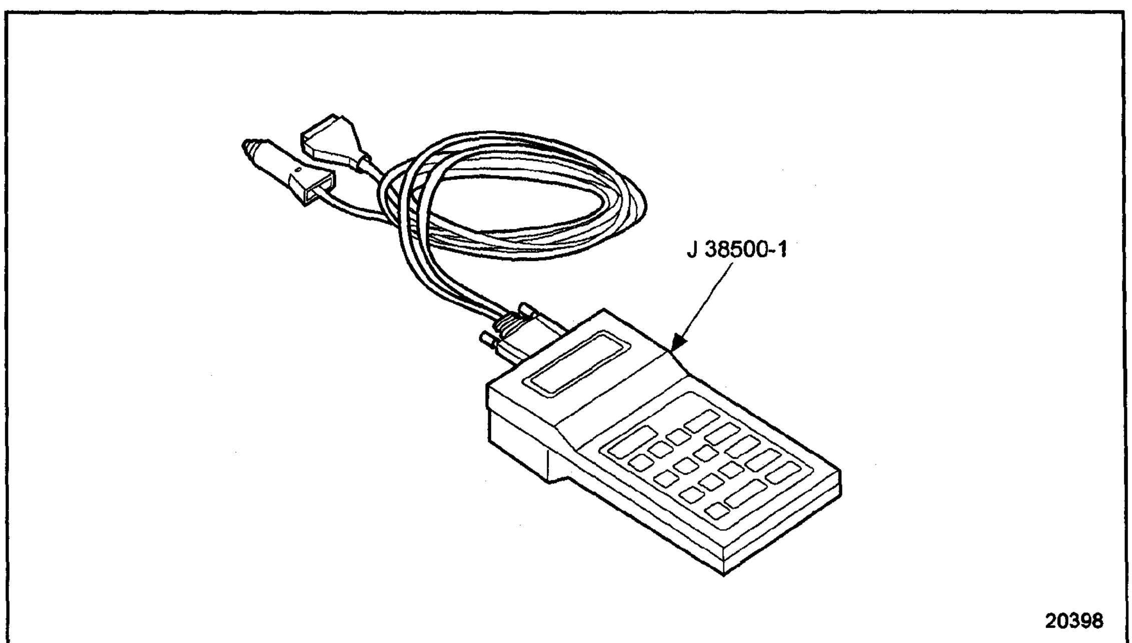

Figure 2-80 DDEC II & III/IV Reader

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2.17.3 Removal of DDEC II Electronic Control Module

Perform the following steps for ECM removal:

1. Carefully disengage the lock tab on the power harness and injector harness connectors.
2. Remove the five (5) wire harness connections at the ECM.
3. Remove the through-bolts holding the ECM to the engine.
4. Remove the ECM and cold plate from the engine, if so equipped.
5. Remove the screws securing the cold plate to the ECM. Remove the cold plate from the ECM, if so equipped.

2.17.4 Installation of DDEC II Electronic Control Module

Perform the following steps for ECM installation:

1. Install the cold plate on the ECM, if so equipped. Tighten the screws securing the cold plate to the ECM. Use Loctite® 262, or equivalent, on the cold plate-to-ECM screws. Torque to 9.5-12 N·m (84-106 lb·in.).
2. Inspect the ECM isolators for damage and replace if required.
3. Mount the ECM and cold plate to the engine.
4. Secure the ECM to the engine with through-bolts. Torque the ECM-to-engine bolts to 23-27 N·m (17-20 lb·ft). Torque the ECM connector hold-down screws to 2.4-3.0 N·m (21-26 lb·in.).
5. Connect the five (5) wire harness connections at the ECM.
6. Engage the lock tab on the power harness and injector harness connectors.
7. Turn the ignition to the "ON" position. Observe the DDR for any diagnostic code(s). If any code(s) other than code 25 is logged, refer to the *Detroit Diesel Single ECM Troubleshooting Manual* (6SE497).

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CAUTION:

Diesel engine exhaust and some of its constituents are known to the State of California to cause cancer, birth defects, and other reproductive harm.

- **Always start and operate an engine in a well ventilated area.**
- **If operating an engine in an enclosed area, vent the exhaust to the outside.**
- **Do not modify or tamper with the exhaust system or emission control system.**

8. Start the engine, and check for fuel leaks.

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Using "Check Engine" light, read the DDEC II Diagnostic codes. If the diagnostic reader is not available, the following procedure can be used to read the fault codes using the "Check Engine" light on the dashboard of the vehicle. See Figure 2-81.

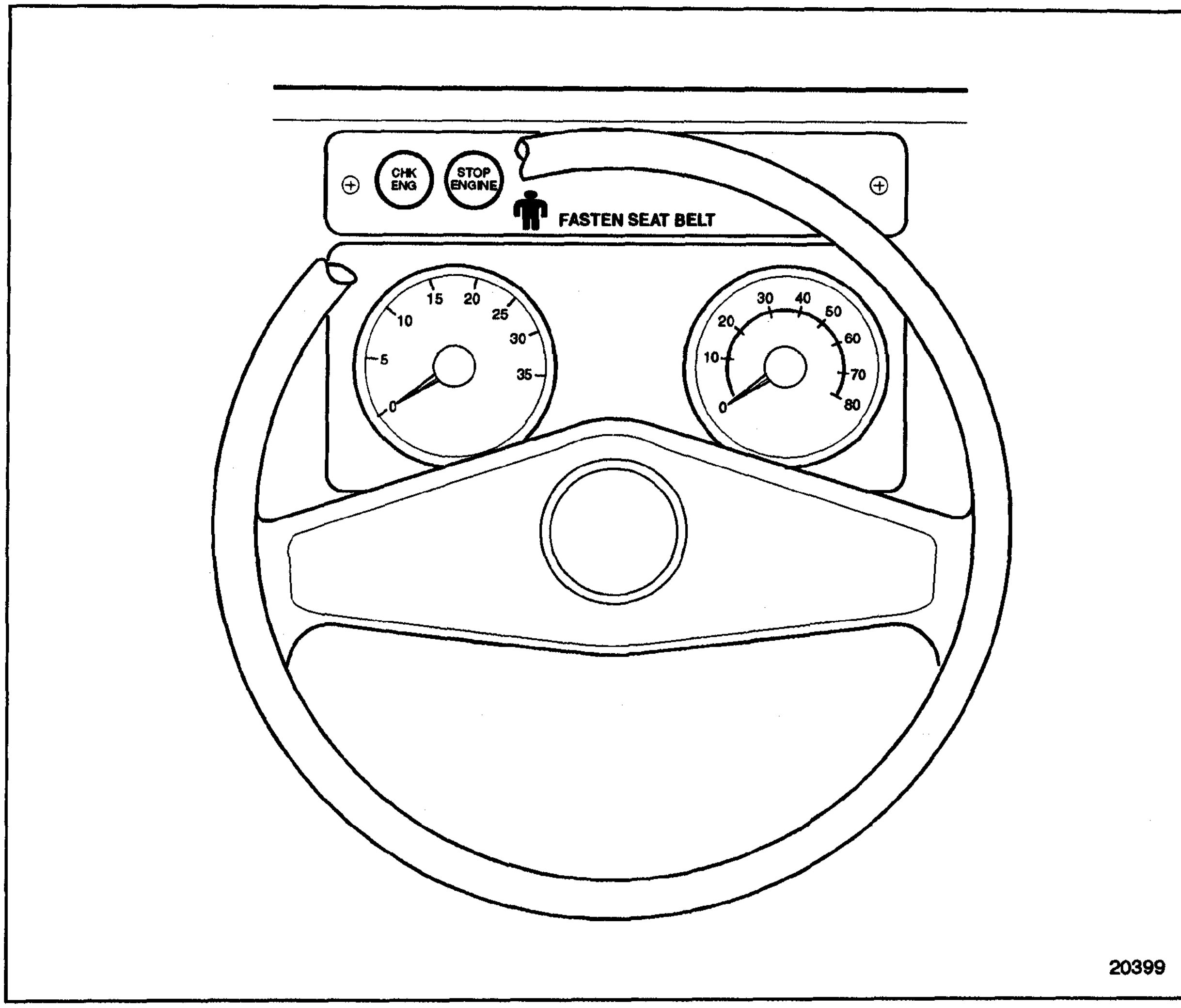

Figure 2-81 Dashboard Warning Lights

If the vehicle is equipped with an OEM supplied diagnostic switch, hold the switch in the "ON" position. This should be done with the ignition on and the engine not running.

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If there is no diagnostic switch, locate the 12-pin Diagnostic Data Link (DDL) connector (for DDEC I and II applications only) under the dash of the vehicle. See Figure 2-82.

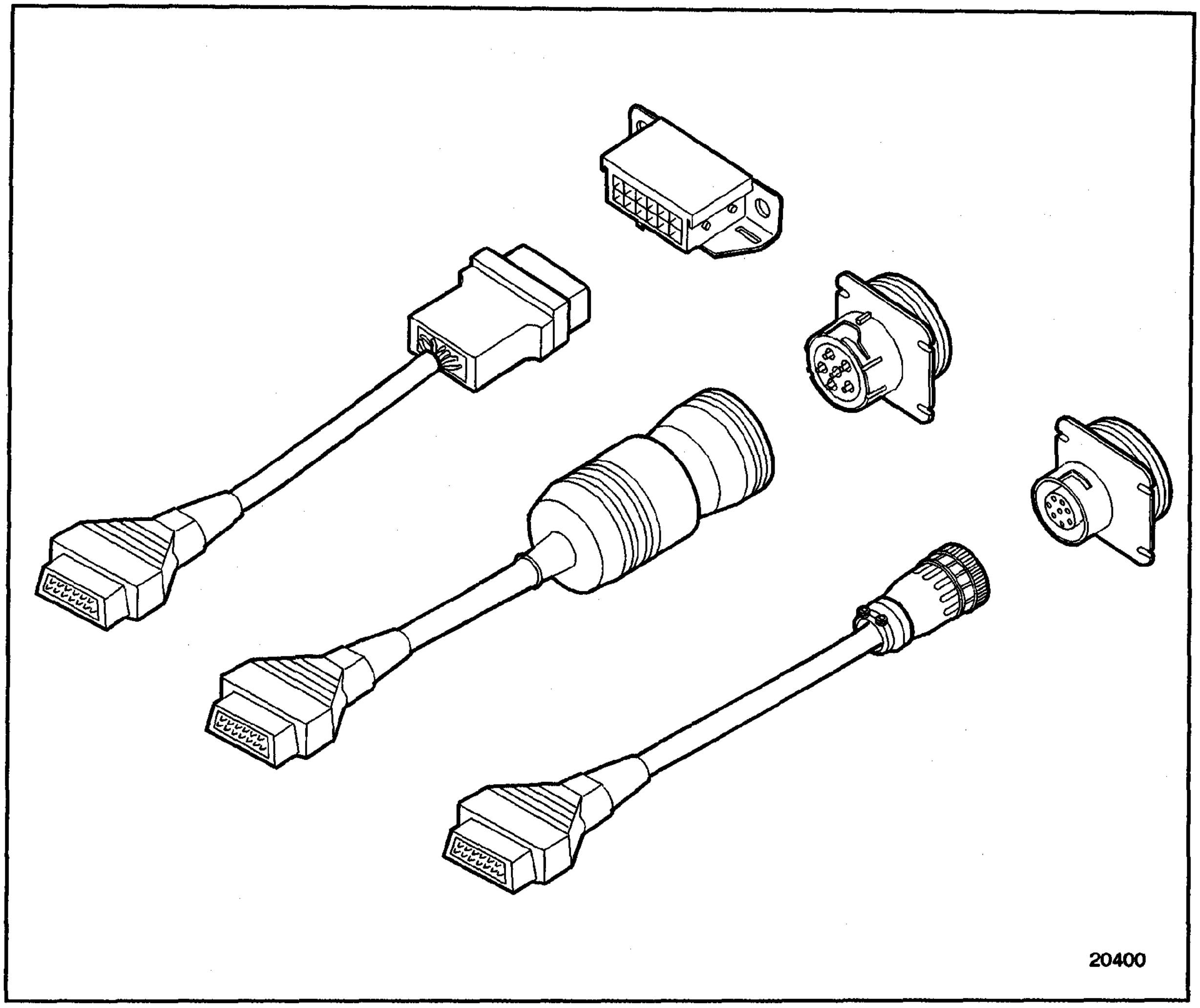

Figure 2-82 Examples of Diagnostic Data Link (DDL) Connector

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NOTICE:

If the vehicle is equipped with an OEM supplied diagnostic switch, the switch must NOT be switched on when operating the vehicle. If this is done, the diagnostic mode line will be grounded, and the throttle will be forced to the idle position, affecting vehicle operation. This condition will not occur when a diagnostic reader is used.

These methods will cause the Check Engine light to begin flashing a code when the ignition is turned to the ON position. Code 25, for example, would be two flashes followed by a pause, followed by five more flashes. This code would indicate no trouble codes logged since the last system check. This flashing code will be repeated until the diagnostic switch is turned OFF or the jumper wire is removed from pins A and M (on DDEC II engines only). If any code(s) other than code 25 is logged, refer to the *Detroit Diesel Single ECM Troubleshooting Manual* (6SE497).

Fault codes can be cleared from the DDEC II and III/IV systems only by using a diagnostic reader. Follow the instructions supplied with the reader to clear the fault codes.

NOTE:
Before beginning any repair procedures, the ignition switch must be in the OFF position.

2.17.5 Replacement of the DDEC II EPROM

The following tools are required to replace the former EPROM with the improved EPROM stabilizer kit:

- ☐ 1/4 in. Nut Driver
- ☐ Thin-head standard screwdriver
- ☐ Kent-Moore antistatic wrist strap BT-8639-B (for electrostatic discharge)

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To replace a DDEC II EPROM, see Figure 2-83.

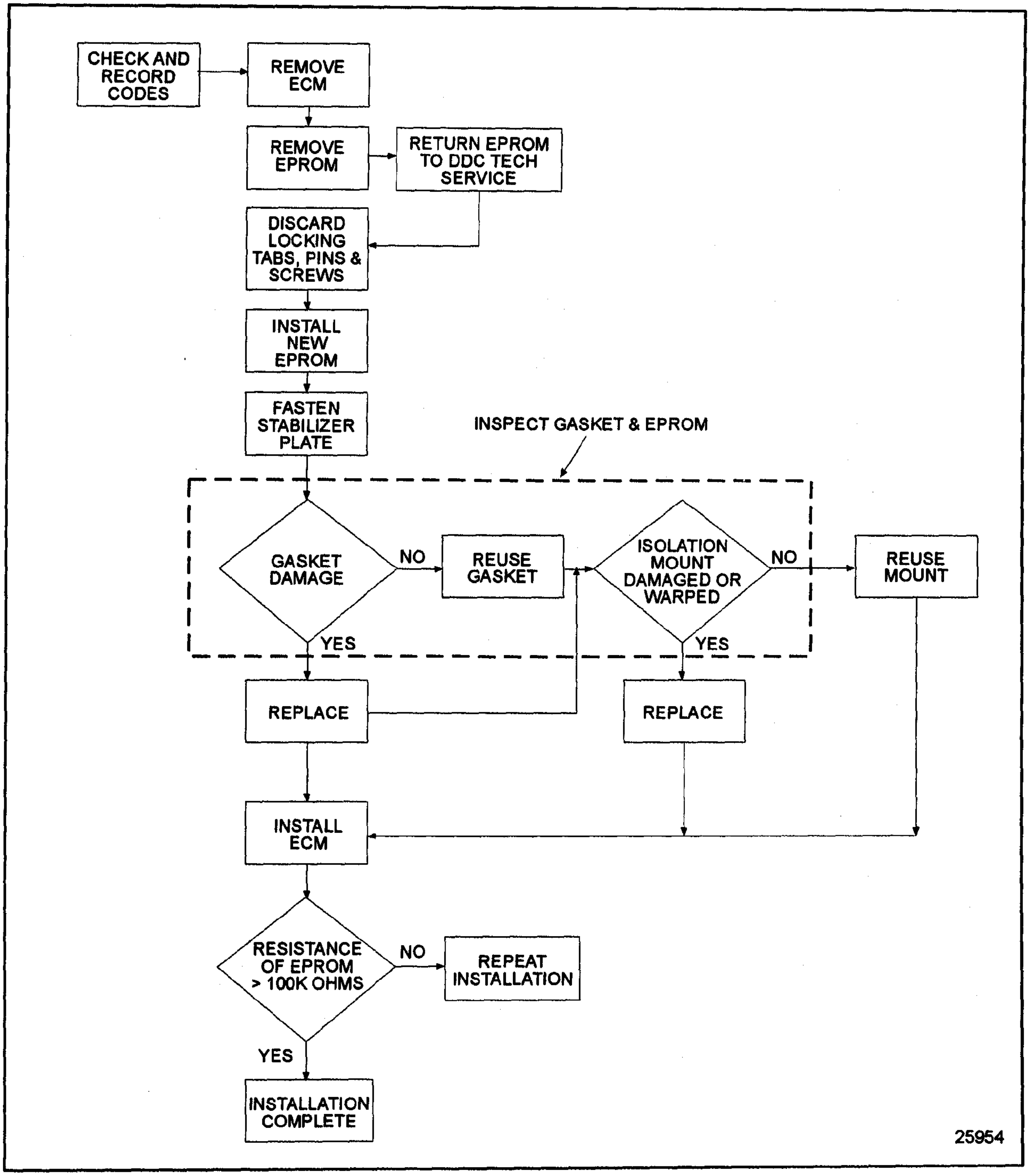

Figure 2-83 Replacement Flowchart for DDEC II EPROM

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2.17.6 Removal of the DDEC II EPROM

Perform the following steps to remove the former EPROM:

1. Using a Diagnostic Data Reader (DDR),J 38500-B, check for codes in the electronic control module (ECM). Note the codes. Erase the codes.
2. Remove the ECM from the engine and take to a clean environment.

NOTICE:
Failure to properly ground your hand while handling the ECM may result in damage to the EPROM, the ECM or both.

3. Fasten the wrist strap of tool BT-8639-B securely around your wrist and attach the test clip to a good ground.
4. Using the 1/4 in. nut driver, remove the 16 screws which fasten the ECM cover to the case.

NOTICE:
Use care to avoid damaging the cover gasket on the ECM. A damaged cover gasket could allow contaminants to enter the ECM, which may cause damage.

5. Using the thin head standard screwdriver, *carefully* pry the cover loose from the case.
6. Early EPROM assemblies may have been installed in a blue 28-pin socket at the end of the ECM and under the stabilizer plate. To remove the EPROM assembly from its socket, push down (unlatch) the blue and white locking tabs and move them to the side. Remove the EPROM. Then, using a suitable narrow diameter tool, remove the locking tabs by carefully pressing out the pins holding the tabs to the socket. Discard the tabs and pins.

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2.17.7 Installation of the DDEC II EPROM

Install the improved EPROM stabilizer kit as follows:

1. Using the 1/4 in. nut driver, remove the three mounting screws adjacent to the blue 28-pin socket. Discard the screws.
2. The EPROM assembly and socket are keyed, so the assembly can be installed only one way. Observe the keying and install the EPROM assembly by pushing it firmly down into the socket.
3. See Figure 2-84 and place the shorter spacer with two bands over the hole at location 1. Place the longer spacers over the holes at locations 2 and 3. Lay the stabilizer plate over the EPROM so that the bolt holes line up with the spacers and the holes in the circuit board. Fasten the stabilizer plate to the case with three #8-32 x 1 3/4 in. screws. Torque screws to 3.0-3.7 N·m (26.6-32.7 lb·in.).

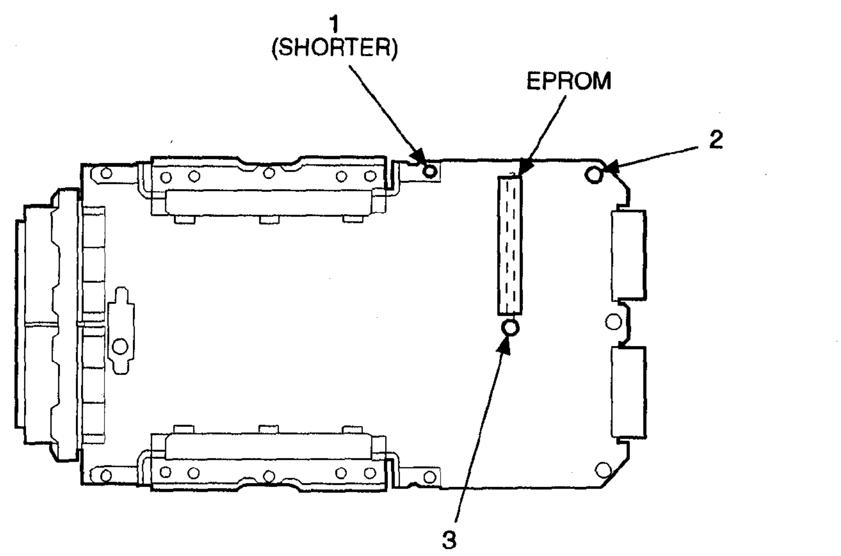

Figure 2-84 EPROM and Spacer Locations

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NOTICE:

Use care to avoid damaging the cover gasket on the ECM. A damaged cover gasket could allow contaminants to enter the ECM, which may cause damage.

4. Carefully inspect the cover gasket for any damage or areas where a dust leak could possibly occur.

NOTE:
If the gasket is damaged, it *must* be replaced with a new gasket.

5. Fasten the cover to the case with the 16 previously removed #8 - 32 x 1/2 in. screws. Torque screws to 2.0-2.2 N·m (17.7-19.5 lb·in.).
6. Remove the wrist strap and ground clip of tool BT-8639-B and store for next use.
7. Test the EPROM for proper installation. Refer to section 2.17.7.
8. Install the ECM on the engine. Refer to section 2.17.4.

2.17.7.1 Testing of the ECM

The resistance of the ECM to block must be checked after installation. Use the following procedure:

1. With the six-pin connector unplugged, connect the leads of an ohmmeter between the ECM case and the engine.
2. Return the removed EPROM assembly to an authorized Detroit Diesel distributor.

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2.18 DDEC I

This system utilizes an engine mounted EDU and a cab mounted ECM, which has a replaceable Programmable Read-Only Memory (PROM). The EDU functions as the high current switching unit for the actuation of the injector solenoids and is fuel-cooled.

The DDEC I ECM is a microprocessor. It is the control center of the DDEC I system. See Figure 2-85.

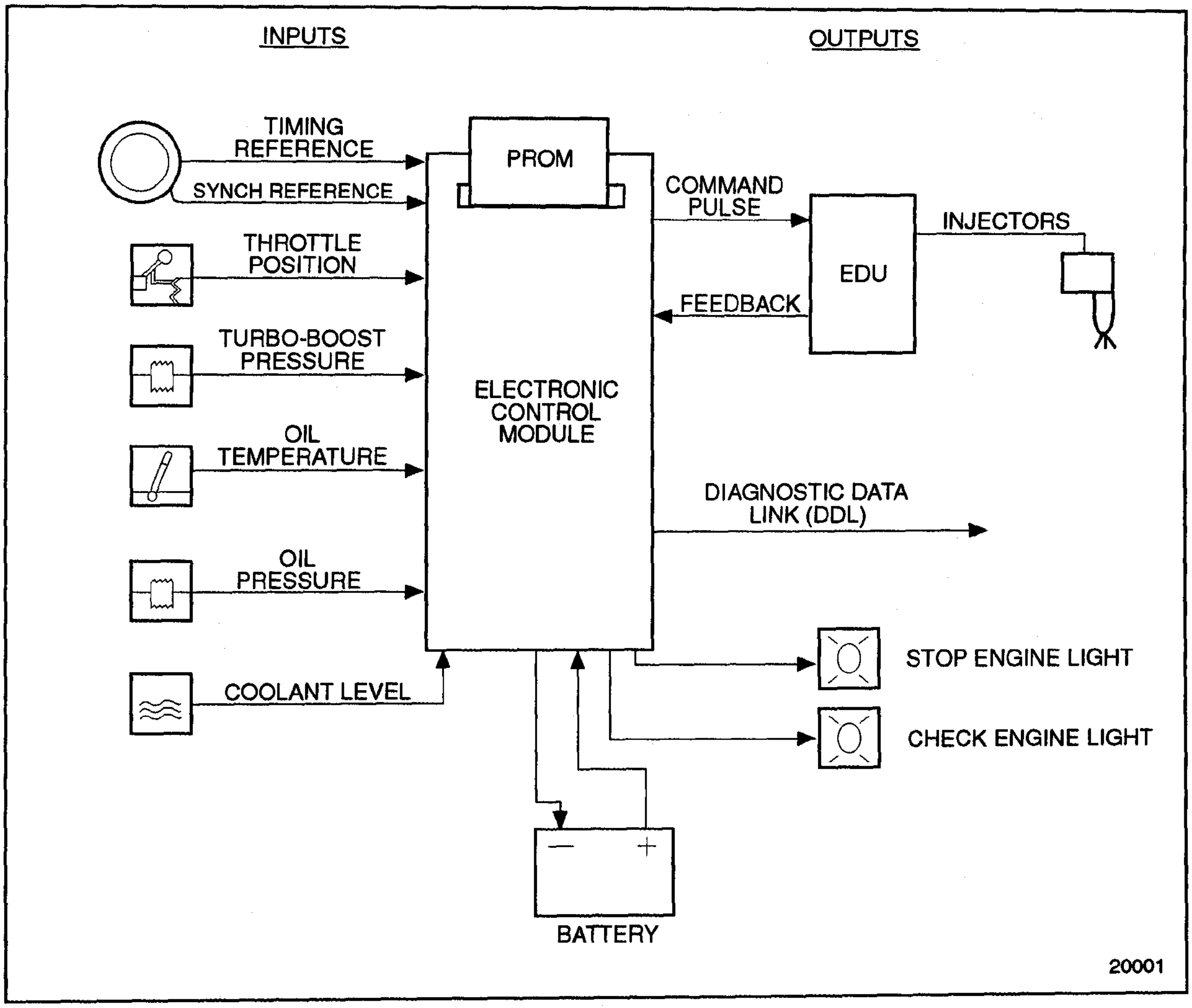

Figure 2-85 Schematic Diagram of DDEC I

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The DDEC I ECM is packaged in a die-cast aluminum housing with sealed connectors. See Figure 2-86.

The DDEC I system consists of the following:

- ☐ The DDEC I ECM
- ☐ A replaceable PROM
- ☐ Connections to various engine sensors, operational displays, power and fuel injectors

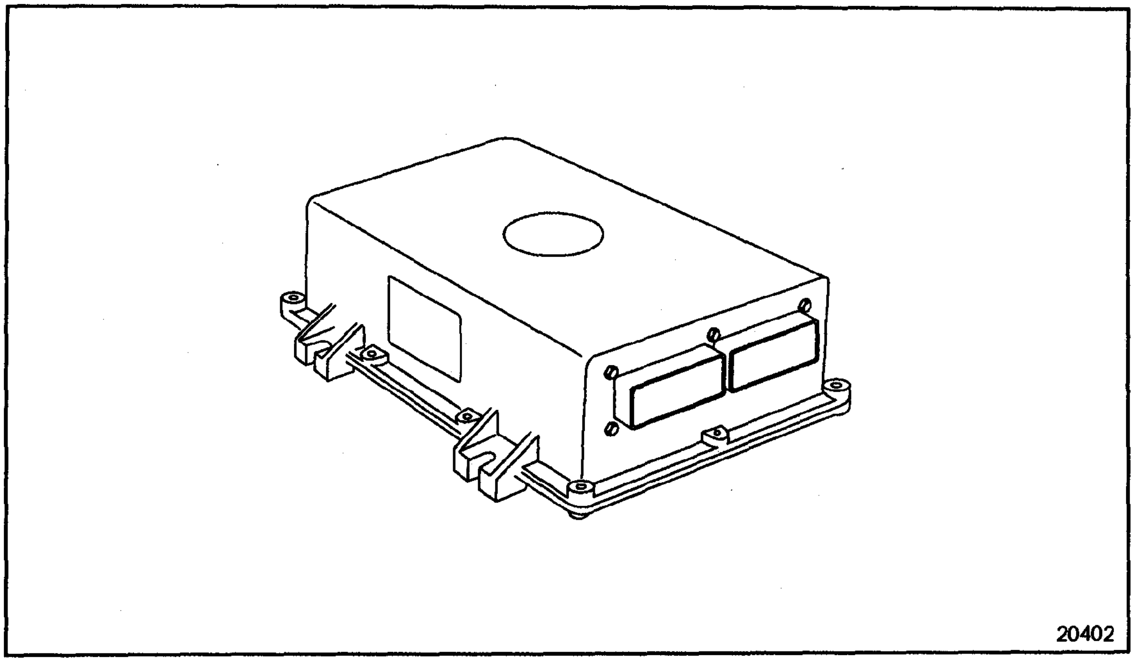

Figure 2-86 Electronic Control Module - DDEC I

It is usually mounted inside the passenger compartment of the vehicle.

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2.18.1 Replacement of the DDEC I Electronic Control Module

DDEC I ECM is a sealed nonserviceable unit.

Basic mechanical checks should be made beforehand to verify that the problem is definitely related to the electrical portion of the system. If the basic mechanical checks fail to locate the problem, refer to the *Detroit Diesel Single ECM Troubleshooting Manual* (6SE497). Start by reading the "Basic Knowledge Required" section before attempting to diagnosis electrical faults.

The DDL Reader can only be used on DDEC I engines. See Figure 2-87.

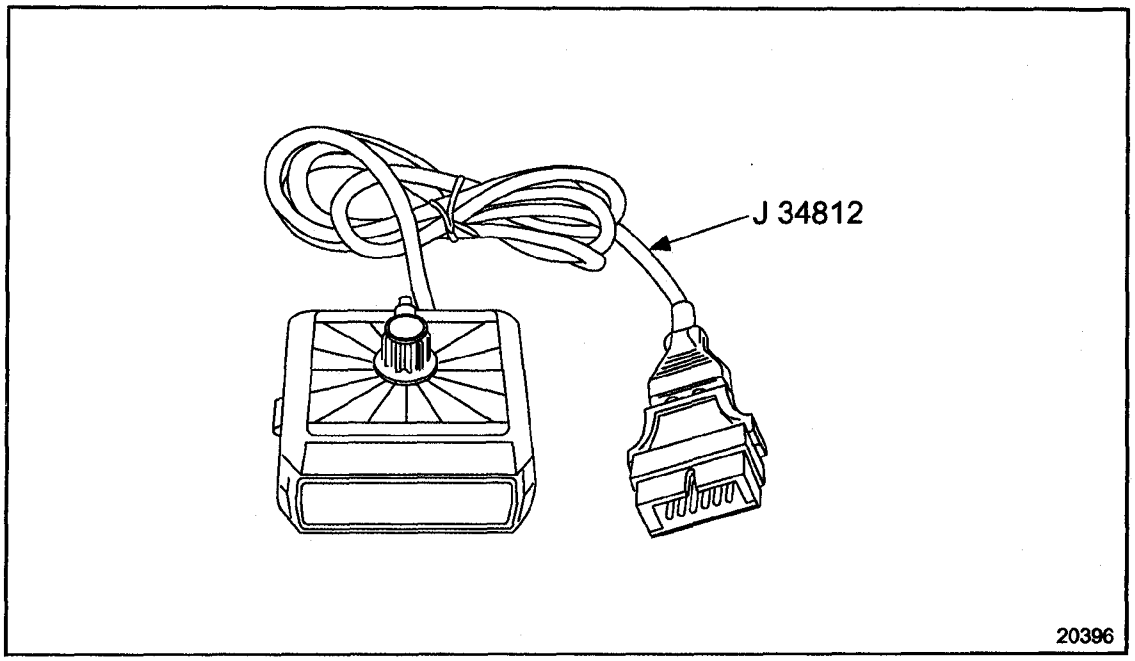

Figure 2-87 DDEC Reader

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If the diagnostic reader is not available, the following procedure can be used to read the fault codes using the Check Engine light on the dashboard of the vehicle.

If the vehicle is equipped with an OEM supplied diagnostic switch, hold the switch in the on position. This should be done with the ignition on and the engine not running. See Figure 2-81.

CAUTION:

To avoid injury from electrical shock, follow OEM furnished operating instructions prior to usage.

NOTICE:

If the vehicle is equipped with an OEM supplied diagnostic switch, the switch must NOT be switched on when operating the vehicle. If this is done, the diagnostic mode line will be grounded, and the throttle will be forced to the idle position, affecting vehicle operation. The throttle will also go to idle if pins A and M in the DDL connector are jumpered together. This condition will not occur when a diagnostic reader is used.

These methods will cause the Check Engine light to begin flashing a code when the ignition is turned to the ON position. Code 25, for example, would be two flashes followed by a pause, followed by five more flashes. This code would indicate no trouble codes logged since the last system check. This flashing code will be repeated until the diagnostic switch is turned OFF or the jumper wire is removed from pins A and M.

If any code(s) other than code 25 is logged, refer to the *Detroit Diesel Single ECM Troubleshooting Manual* (6SE497).

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Fault codes can be cleared from the DDEC I system by interrupting the power flow to the ECM. This can be accomplished by turning the ignition to the OFF position and removing the 5-amp ECM fuse for ten seconds or more. See Figure 2-88.

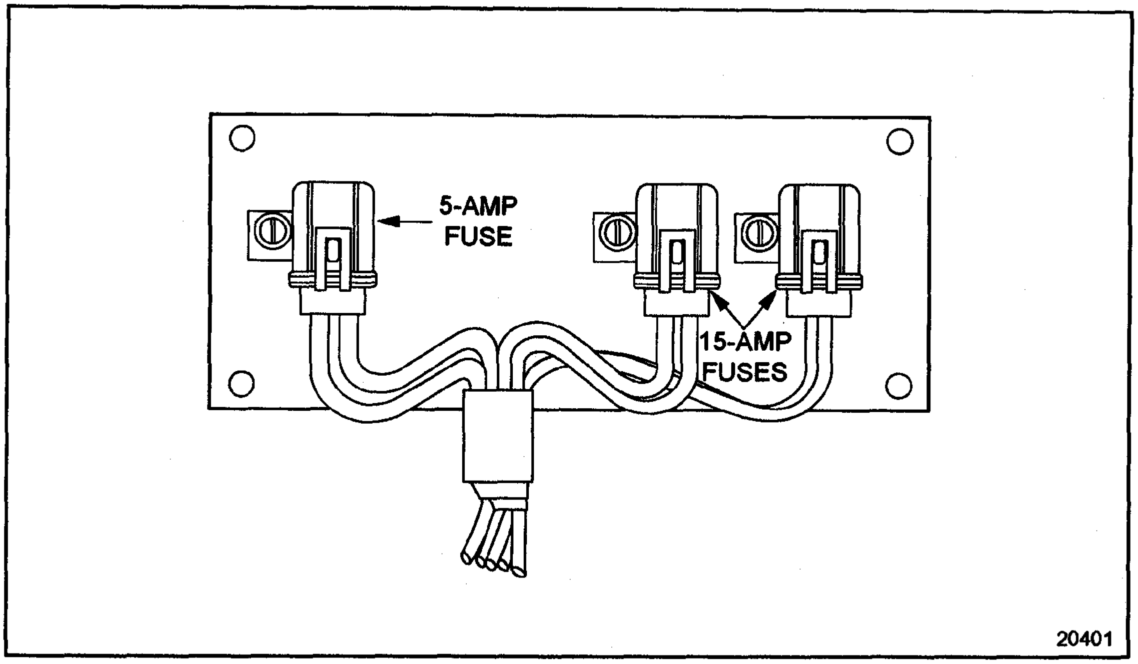

Figure 2-88 Typical Electronic Control Module Power Fuse Panel

NOTE:
Some OEMs will use circuit breakers. Follow the OEM schematic. Some OEMs will use a different fuse plate configuration than the one shown. See Figure 2-88.

NOTE:
Before beginning any repair procedures, the ignition switch must be in the OFF position.

The following section(s) are basic replacement procedures for the DDEC components. Components should NOT be replaced unless a defective unit has been concluded by the *Detroit Diesel Single ECM Troubleshooting Manual* (6SE497).

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2.18.2 Removal of DDEC I Electronic Control Module

Perform the following steps for ECM removal:

1. Loosen, but do not remove, the two hold-down screws attaching the wire harness connectors to the ECM.
2. Pull gently on the connectors and remove them from the ECM sockets.
3. Remove the three bolts securing the ECM to the vehicle.
4. Remove the ECM from the vehicle.
5. If the programmable read-only memory (PROM) is to be reused, remove it from the ECM using the PROM removal instructions; refer to section 2.19.2.

2.18.3 Installation of DDEC I Electronic Control Module

Perform the following steps for ECM installation:

1. Secure the ECM to the vehicle using three bolts. Torque the ECM connector hold-down screws to 2.4-3.0 N·m (21-26 lb·in.). The three bolts that secure the ECM to the vehicle should be torqued to 16 N·m (12 lb·ft).
2. Install connectors in ECM sockets.
3. Tighten the two hold-down screws attaching the wire harness connectors to the ECM.
4. Turn the ignition to the ON position. Observe the DDR for any diagnostic code(s). If any code(s) other than code 25 is logged, refer to the *Detroit Diesel Single ECM Troubleshooting Manual* (6SE497).

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2.19 PROGRAMMABLE READ-ONLY MEMORY (PROM) DDEC I

The PROM is an electronic component located in a compartment in the back of the ECM. See Figure 2-89.

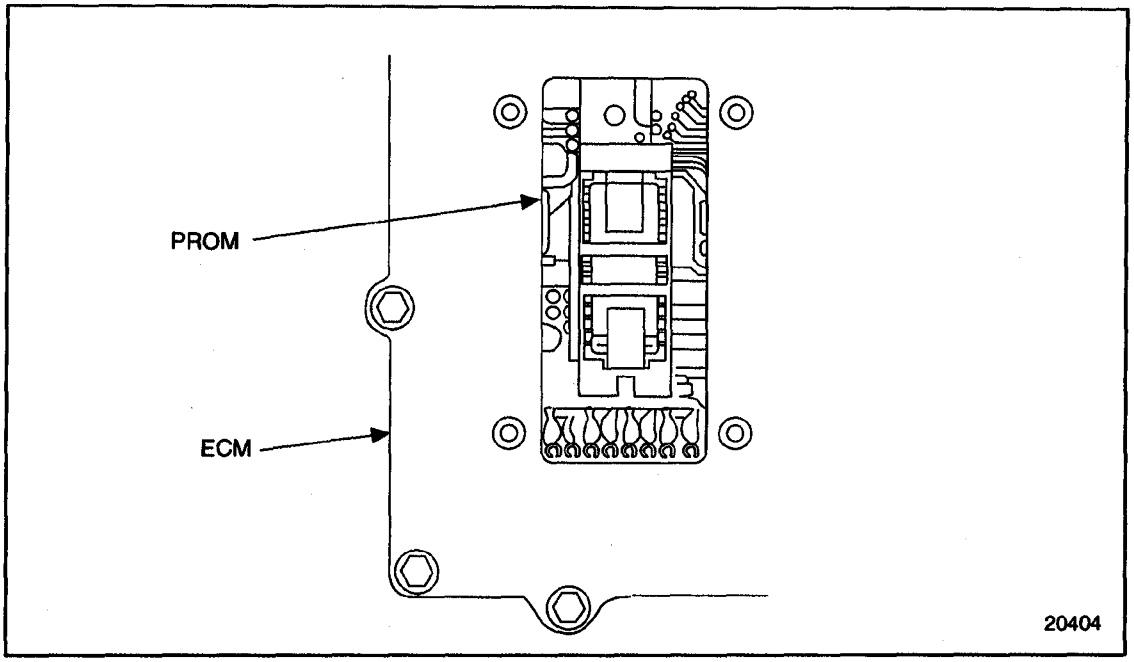

Figure 2-89 Programmable Read-Only Memory

When plugged in, it becomes part of the circuits of the ECM. The PROM is used to establish engine operating specifications. Each PROM has an individual part number.

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2.19.1 Replacement of the DDEC I PROM

The PROM is not repairable, it must be replaced.

2.19.2 Removal of PROM

Perform the following steps for PROM removal:

1. Remove the ECM. Refer to section 2.18.2.
2. Remove the four PROM access cover screws.
3. Using the rocker type PROM removal tool, J 35889-A, engage one end of the PROM carrier with the hook end of the tool. See Figure 2-90.

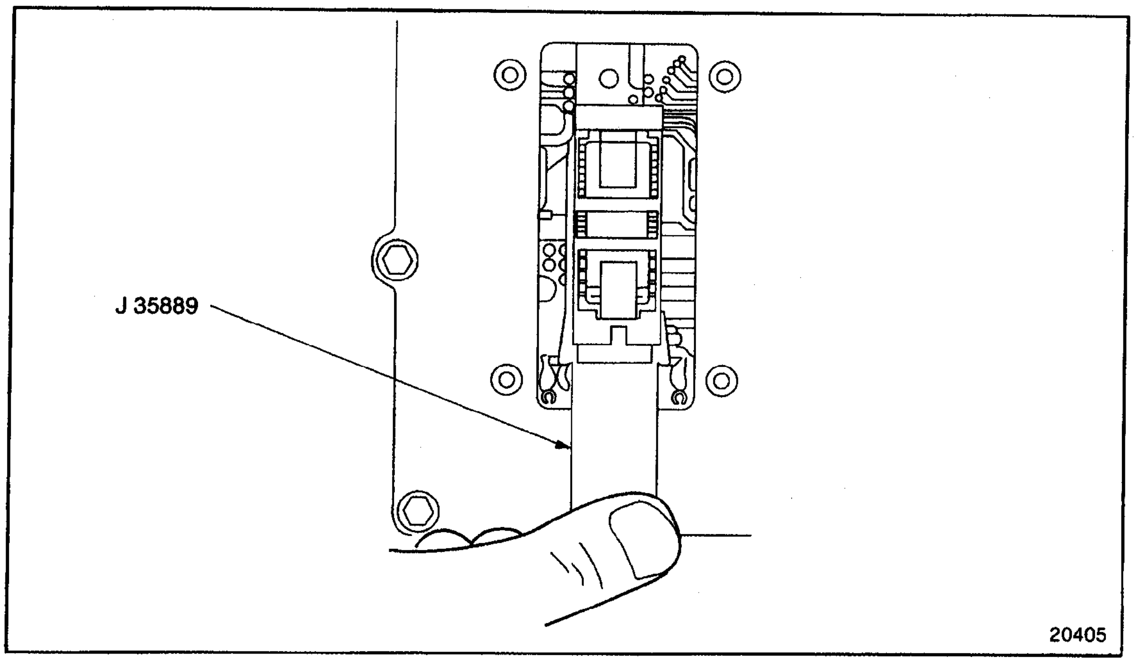

Figure 2-90 Removing PROM

4. Press on the vertical bar end of the tool and rock the engaged end of the PROM carrier up as far as possible.
5. Engage the opposite end of the PROM carrier in the same manner and rock this end up as far as possible. Repeat this process until the PROM carrier and PROM are free of the socket. When done correctly, the PROM and carrier should easily lift free of the socket.

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2.19.3 Installation of PROM

Perform the following steps for PROM installation:

NOTICE:
Any time a PROM is installed backwards, it will be destroyed upon applying power to the ECM.

1. Take the new PROM (already mounted in a carrier) out if its packaging, and check the part number, making sure it represents the PROM chosen to replace the one removed.
2. Position the new PROM and carrier squarely over the PROM socket with the small notched end of the carrier aligned with the narrow tab on the socket. The numeral one in a circle at the lower right corner of the PROM carrier should be installed in the same position as the numeral one located on the socket. See Figure 2-91.

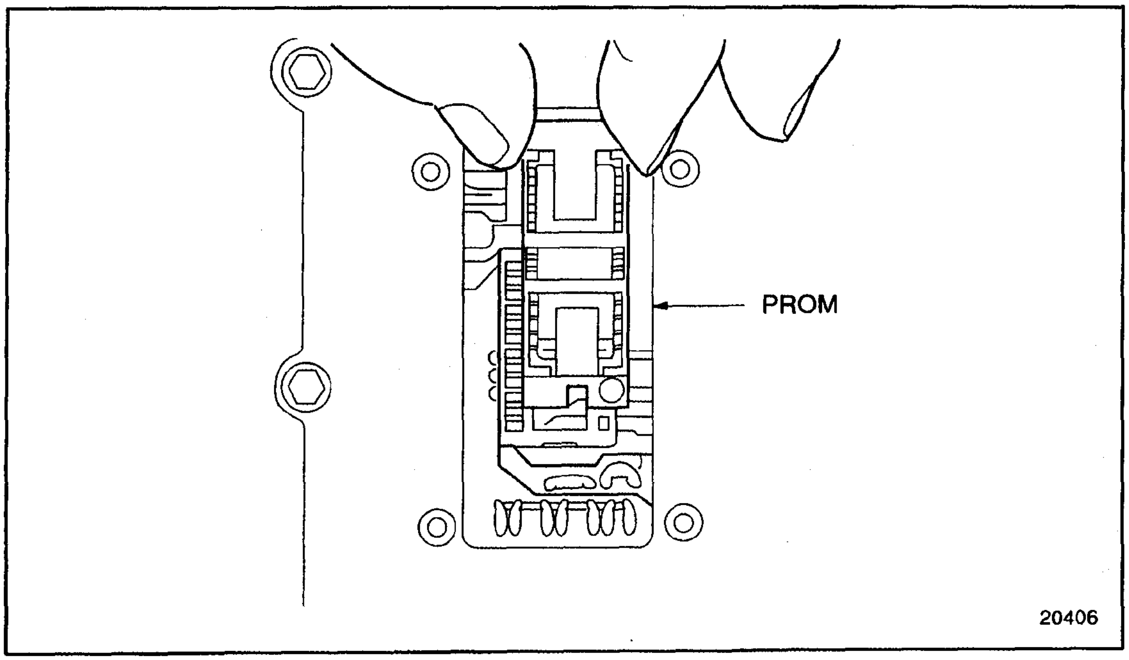

Figure 2-91 Indexing PROM for Installation

NOTICE:

Do NOT press on the PROM. To avoid damaging the PROM, press on the carrier.

3. Press on the PROM carrier until it is firmly seated in the socket. See Figure 2-92.

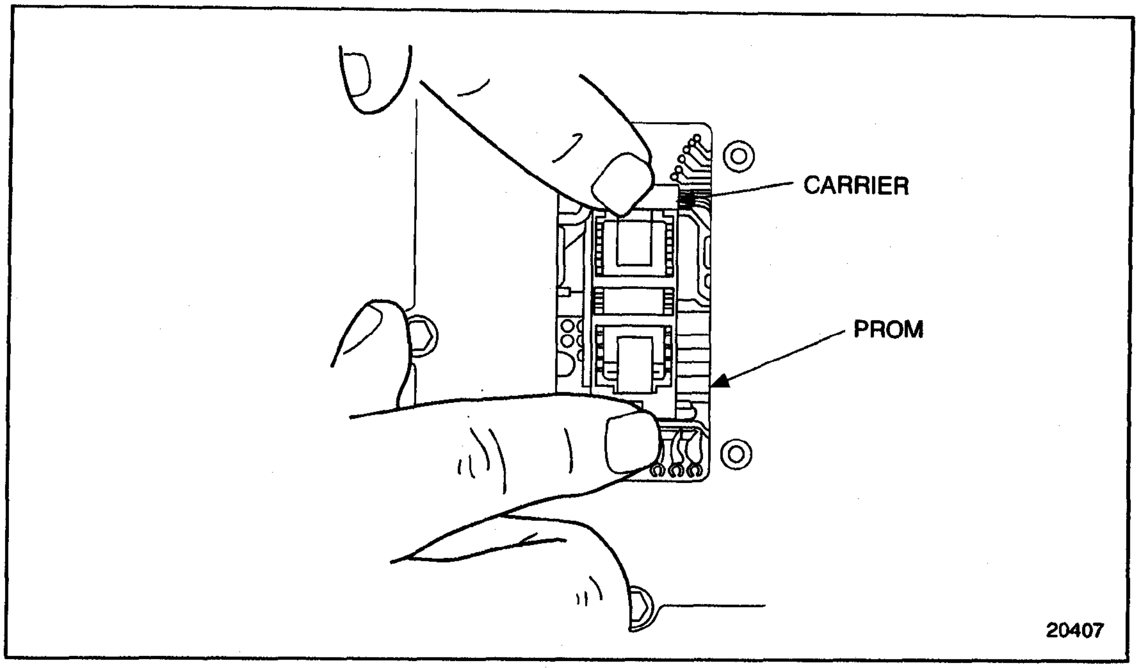

Figure 2-92 Installing PROM

4. Reinstall the access cover screws.
5. Place a security label over the access cover next to the original label.
6. Reinstall the ECM in the vehicle and plug in the connectors.
7. Tighten the connector hold-down screws.

NOTE:

In the event the PROM is defective, the DDL reader will not function. The check engine light must be used to read malfunction codes.

8. Turn the ignition to the ON position. Observe or read any diagnostic codes.
9. If code 51 occurs, check for the following conditions:
   - ☐ If it is necessary to check the PROM, follow removal instructions.
   - ☐ If not fully seated, press firmly on the carrier.
   - ☐ If pins are bent, remove the PROM, straighten pins, and reinstall the PROM.
   - ☐ If bent pins break or crack during straightening, discard the PROM and replace it.
   - ☐ If found defective, replace the PROM.
   - ☐ If the PROM is installed backwards, replace it.

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2.20 ELECTRONIC DISTRIBUTOR UNIT DDEC I

The Electronic Distributor Unit (EDU) is mounted in a die-cast aluminum housing with sealed electrical connectors. For a typical engine location, see Figure 2-93.

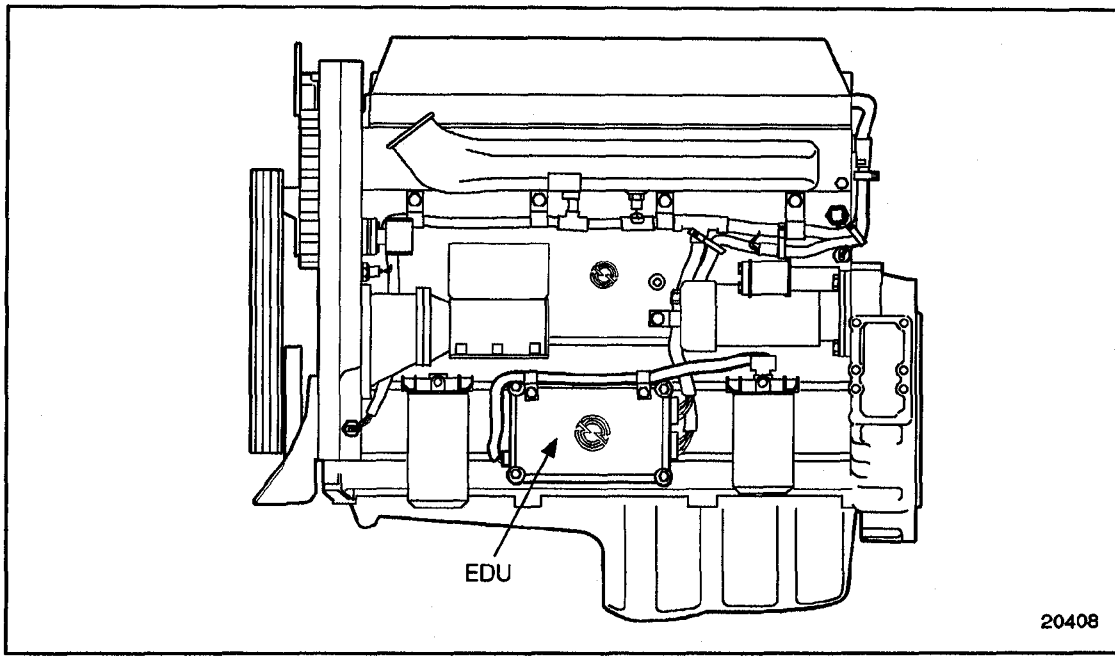

Figure 2-93 Electronic Distributor Unit and Related Parts

Heat generated by the EDU during engine operation is absorbed by a cold plate mounted between the EDU and the engine block. Fuel from the fuel pump circulates through the cold plate and the secondary filter to the engine where it is used by the injectors.

The main function of the EDU is to generate electrical signals to operate the injector solenoids. These electrical signals are controlled by the ECM.

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2.20.1 Replacement of the Electronic Distributor Unit

The EDU is a sealed unit that must be replaced.

2.20.2 Removal of Electronic Distributor Unit

Remove the EDU as follows:

1. Disconnect the fuel line (at the secondary fuel filter) that runs from the EDU cold plate. Position the line over a suitable container to collect any fuel coming from the system.
2. Disconnect the inlet and return lines from the EDU cold plate.
3. Loosen, but do not remove, the two wire harness connector hold-down screws. Pull gently on the connectors to disengage them from the EDU sockets.
4. Remove the through-bolts and washers holding the EDU to the engine.
5. Remove the EDU and cold plate from the engine.
6. Remove the screws securing the cold plate to the EDU. Remove the cold plate from the EDU.

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2.20.3 Installation of Electronic Distributor Unit

Install the EDU as follows:

1. Install the screws securing the cold plate to the EDU. Use Loctite® 262, or equivalent, on the cold plate-to-EDU screws. Torque to 9.5-12 N·m (84-106 lb·in.).
2. Install the cold plate to the EDU.
3. Install the EDU and cold plate to the engine.
4. Install the through-bolts and washers holding the EDU to the engine. Torque the EDU-to-engine bolts to 30-38 N·m (22-28 lb·ft). Torque the EDU connector hold down screws to 2.4-3.0 N·m (21-26 lb·in.).

NOTE:
Torque the harness connector to EDU screws to 2.4-3.0 N·m (21-26 lb·in.).

5. Connect the inlet and return lines to the EDU cold plate.
6. Connect the fuel line (at the secondary fuel filter) that runs from the EDU cold plate.
7. Turn the ignition to the ON position. Observe the DDR for any diagnostic code(s). If any code(s) other than code 25 is logged, refer to the *Detroit Diesel Single ECM Troubleshooting Manual* (6SE497).

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CAUTION:

To avoid injury before starting and running the engine, ensure the vehicle is parked on a level surface, parking brake is set, and the wheels are blocked.

CAUTION:

Diesel engine exhaust and some of its constituents are known to the State of California to cause cancer, birth defects, and other reproductive harm.

- **Always start and operate an engine in a well ventilated area.**
- **If operating an engine in an enclosed area, vent the exhaust to the outside.**
- **Do not modify or tamper with the exhaust system or emission control system.**

8. Start the engine and check for fuel leaks.
9. Shut down upon completion of test.

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2.21 ELECTRONIC FOOT PEDAL ASSEMBLY

The Electronic Foot Pedal Assembly (EFPA) connects the accelerator pedal to a Throttle Position Sensor (TPS). See Figure 2-94. The TPS is a device that sends an electrical signal to the ECM. The signal varies in voltage according to the pressure on the pedal. The system is installed in the space normally occupied by the mechanical foot pedal. The EFPA has maximum and minimum stops that are built into the unit during manufacture.

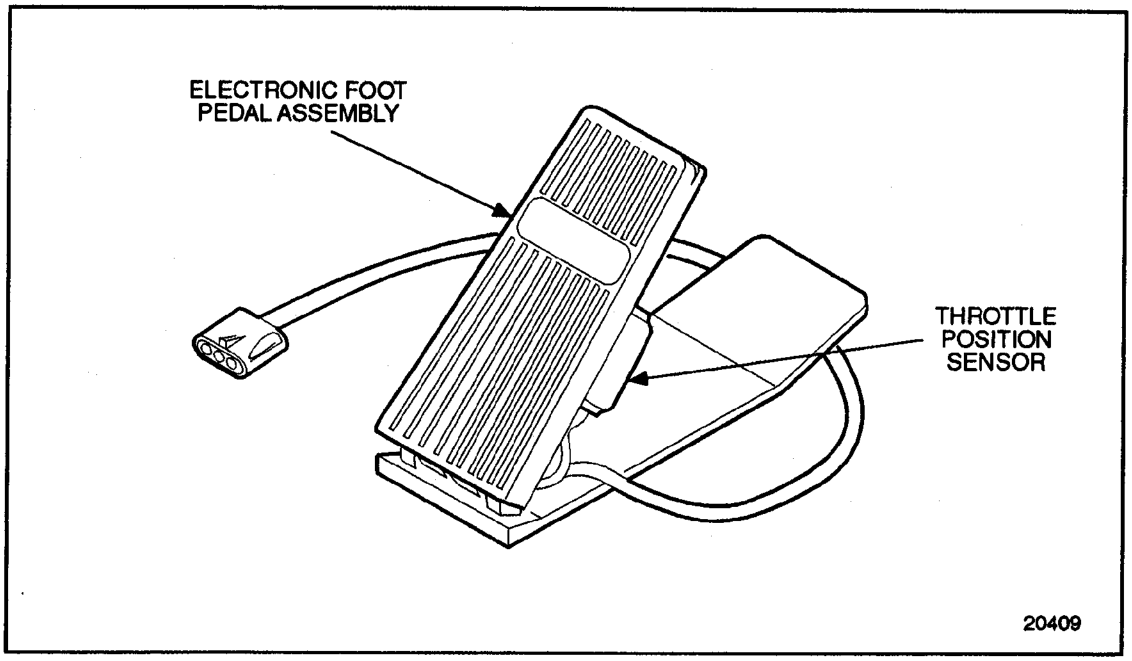

Figure 2-94 Electronic Foot Pedal Assembly

2.21.1 Replacement of Electronic Foot Pedal Assembly

The EFPA assembly is supplied by the vehicle manufacturer. Refer to the guidelines for service procedure.

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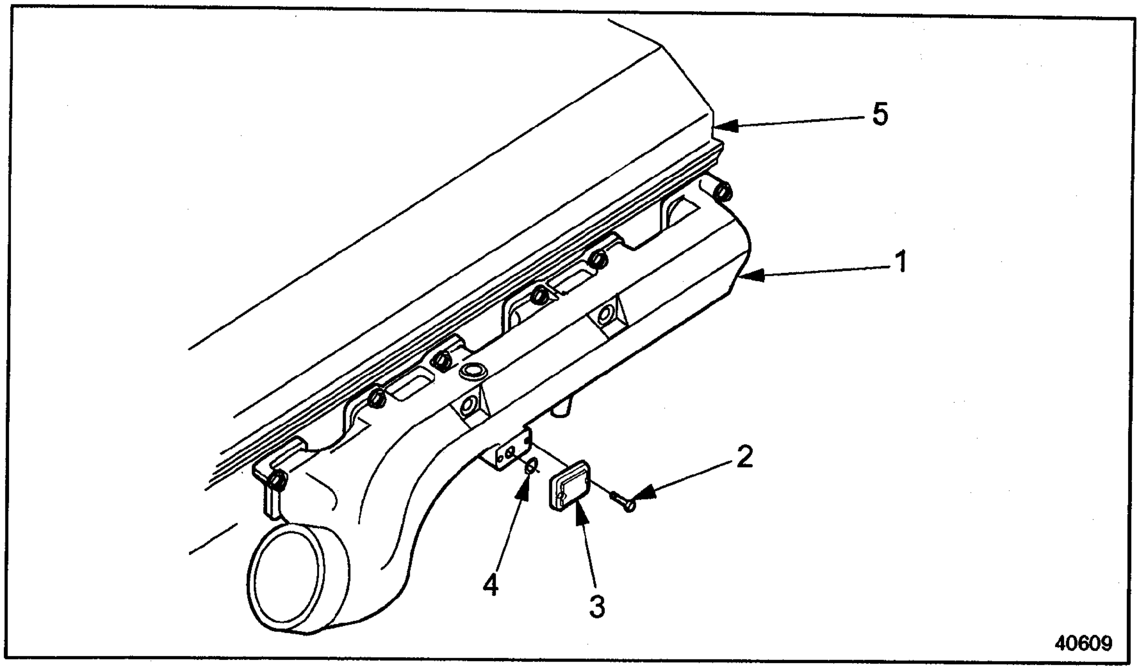
2.22 TURBO BOOST PRESSURE SENSOR

The Series 60 Diesel Turbo Boost Sensor (TBS) is mounted to the intake manifold with two bolts. A rubber O-ring is used to seal the sensor to the manifold. See Figure 2-95.



1. Intake Manifold
2. Turbo-Boost Pressure Sensor Bolt
3. Turbo-Boost Pressure Sensor
4. O-ring

Figure 2-95 Turbo Boost Pressure Sensor

NOTE:
The DDEC I and DDEC II Turbo Boost Sensors are not identical and must not be mixed up.

This device is a pressure sensor that sends an electrical signal to the ECM. The ECM uses this information to compute the amount of air entering the engine. Fuel supply is regulated by the TBS information to control engine smoke.

2.22.1 Replacement of Turbo Boost Sensor

The TBS is non-serviceable and must be replaced as an assembly. No adjustment is required.

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2.22.2 Removal of Turbo Boost Sensor

Remove the TBS as follows:

1. Disengage the locking tang on the TBS connector body. Grasp the terminal body and gently pull it from the sensor.
2. Remove the two bolts that secure the TBS to the intake manifold.

NOTE:
Be careful not to lose the O-ring.

3. Remove the TBS from the intake manifold.

2.22.3 Installation of Turbo Boost Sensor

Install the Series 60 diesel TBS as follows:

NOTE:
The TBS is an electronic device. Use care during installation.

1. Apply petroleum jelly to the O-ring.
2. Install O-ring to the TBS.

NOTICE:
Do not overtighten the bolts that mount the TBS to the intake manifold. Damage to the TBS may result. Torque the bolts to no more than 2.4 - 3.0 N·m (21 - 26 in·lb).

3. Install the TBS to the intake manifold.
4. Install the two bolts that secure the TBS to the intake manifold. Torque to 2.4-3.0 N·m (21-26 lb·in.).
5. Engage the locking tang on the TBS connector body. Grasp the terminal body and gently pull it towards the sensor.
6. Turn the ignition to the ON position. Observe the DDR for any diagnostic code(s). If any code(s) other than code 25 is logged, refer to the *Detroit Diesel Single ECM Troubleshooting Manual* (6SE497).

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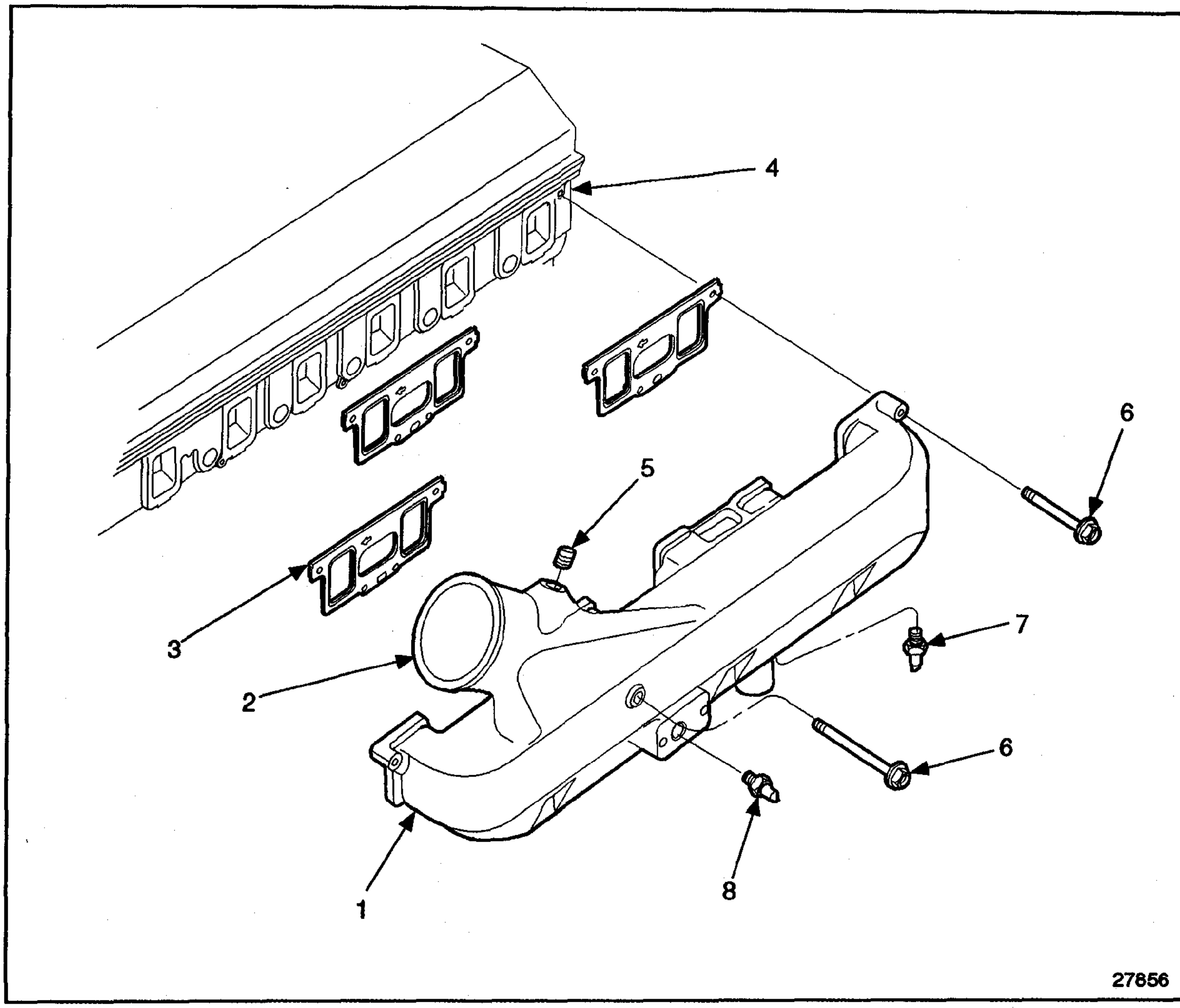
2.23 AIR INTAKE PRESSURE SENSOR

The Series 60G Air Intake Pressure (AIP) sensor is threaded into the intake manifold. See Figure 2-96. The Series 60G natural gas engines use a wide range sensor that allows pressure measurement under conditions of either manifold vacuum or boost.



1. Intake Manifold
2. Intake Manifold Inlet
3. Intake Manifold Gasket
4. Cylinder Head
5. Bolt
6. Bolt
7. Air Temperature Sensor (Different location on the High Pressure Fuel System)
8. Air Intake Pressure Sensor (AIP)

Figure 2-96 Air Intake Pressure Sensor Series 60G Engine

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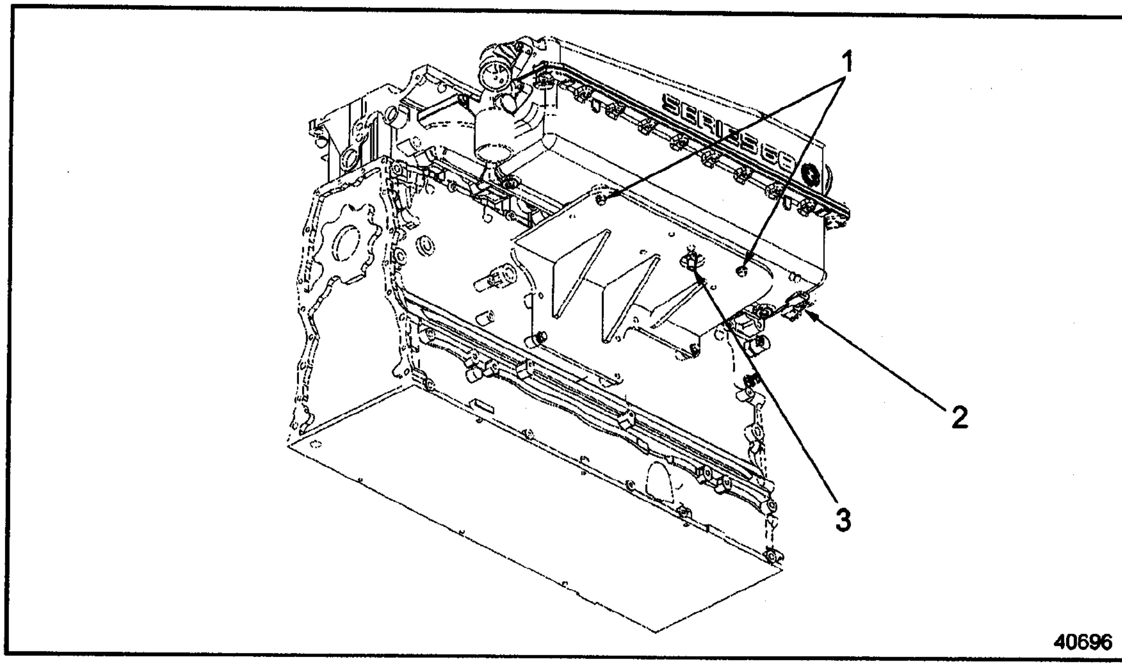
This device is a pressure sensor that sends an electrical signal to the ECM. The ECM uses this information to compute the amount of air entering the engine. Fuel supply is regulated by the AIP sensor information to control engine air fuel ratio. The AIP sensor information is also used to control ignition timing.

NOTE:
For the location of the AIP sensor on the heat exchanger-cooled pleasure craft marine engine, refer to section 4.4. See Figure 2-97.



1. Charge Air Cooler Condensate Drains
2. Turbo Boost Pressure Sensor
3. Charge Air Temperature Sensor

Figure 2-97 Locations of Turbo Boost Pressure Sensor and Charge Air Temperature Sensor

2.23.1 Replacement of Air Intake Pressure Sensor

The AIP sensor is non-serviceable and must be replaced as an assembly. No adjustment is required.

2.23.2 Removal of Air Intake Pressure Sensor

Remove the AIP sensor as follows:

1. Disengage the locking tang on the AIP sensor connector body. Grasp the terminal body and gently pull it from the sensor.
2. Remove the AIP sensor from the intake manifold.

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2.23.3 Installation of Air Intake Pressure Sensor

Install the AIP as follows:

NOTE:
The AIP sensor is an electronic device. Use care during installation.

1. Install the AIP sensor into intake sensor manifold. Torque to 2.4-3.0 N·m (21-26 lb·in.).
2. Engage the locking tang on the AIP connector body.
3. Turn the ignition to the ON position. Observe the DDR for any diagnostic code(s). If any code(s) other than code 25 is logged, refer to the *Detroit Diesel Single ECM Troubleshooting Manual* (6SE497).

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2.24 OIL PRESSURE SENSOR

The Oil Pressure Sensor (OPS) is installed into the main engine oil gallery. A typical location is the left rear corner of the cylinder block. See Figure 2-98.

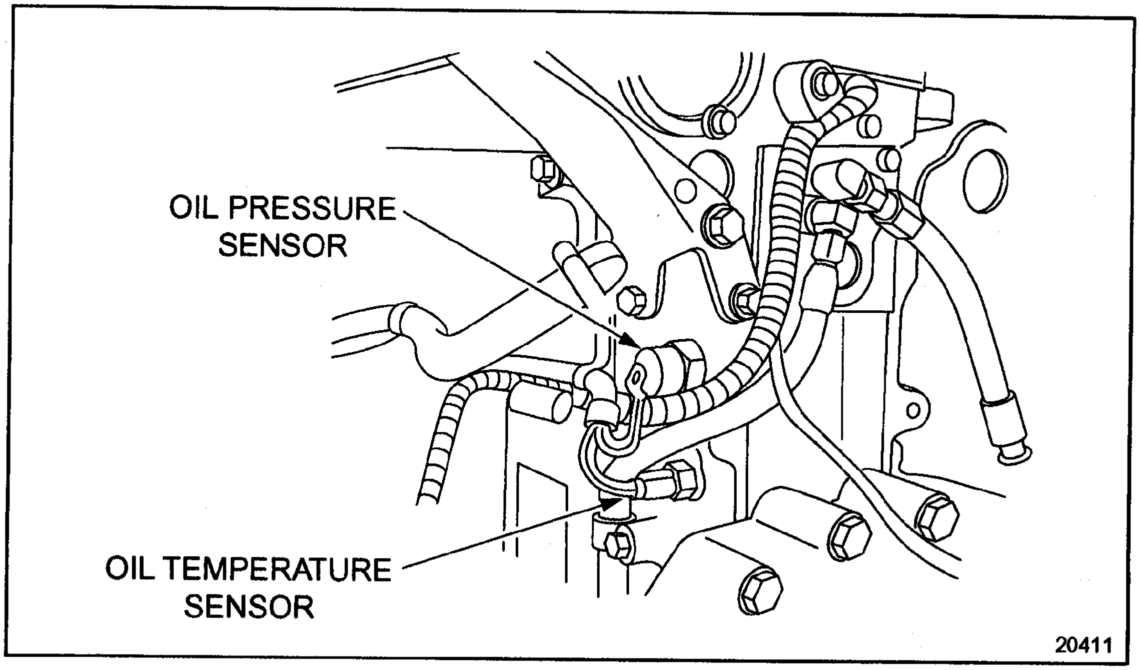

Figure 2-98 Engine Oil Pressure Sensor Location

The OPS sends an electrical signal to the ECM telling it what the engine oil pressure is at any given speed. A low oil pressure signal exceeding seven seconds is used by the ECM to begin the stop engine or warning function.

2.24.1 Replacement of the Oil Pressure Sensor

The OPS is non-serviceable and should be replaced as a unit. No adjustment is required.

2.24.2 Removal of Oil Pressure Sensor

Remove the OPS as follows:

1. Disengage the locking tang on the three-wire connector. Grasp the body of the connector and gently pull it free of the OPS.
2. Use the appropriate wrench on the hex end of the OPS to unscrew it from the engine.

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2.24.3 Installation of Oil Pressure Sensor

Install the OPS as follows:

NOTE:
The OPS is an electronic device. Use care on installation.

1. Place the sensor on the engine and using the appropriate wrench on the hex portion of the sensor tighten it.
2. Use Loctite® Pipe Sealer with Teflon, PT-7260, (or equivalent) on all but the first two threads of the OPS to prevent leaks.
3. Place the connector in the socket and engage the locking tang.
4. Turn the ignition to the ON position. Observe the DDR for any diagnostic code(s). If any code(s) other than code 25 is logged, refer to the *Detroit Diesel Single ECM Troubleshooting Manual* (6SE497).

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2.25 OIL TEMPERATURE SENSOR

The Oil Temperature Sensor (OTS) is installed into the main engine oil gallery. A typical location is the left rear corner of the cylinder block. See Figure 2-99. The OTS sends an electrical signal to the ECM indicating engine oil temperature. The ECM uses this information to modify engine speed for better cold weather starts and faster warm-ups. Oil temperatures exceeding specification for two seconds or more will begin the stop engine or warning function.

NOTE:
Series 60G automotive (high pressure fuel system) engines do not have an oil temperature sensor. All DDEC and OEM functions reference coolant temperature.

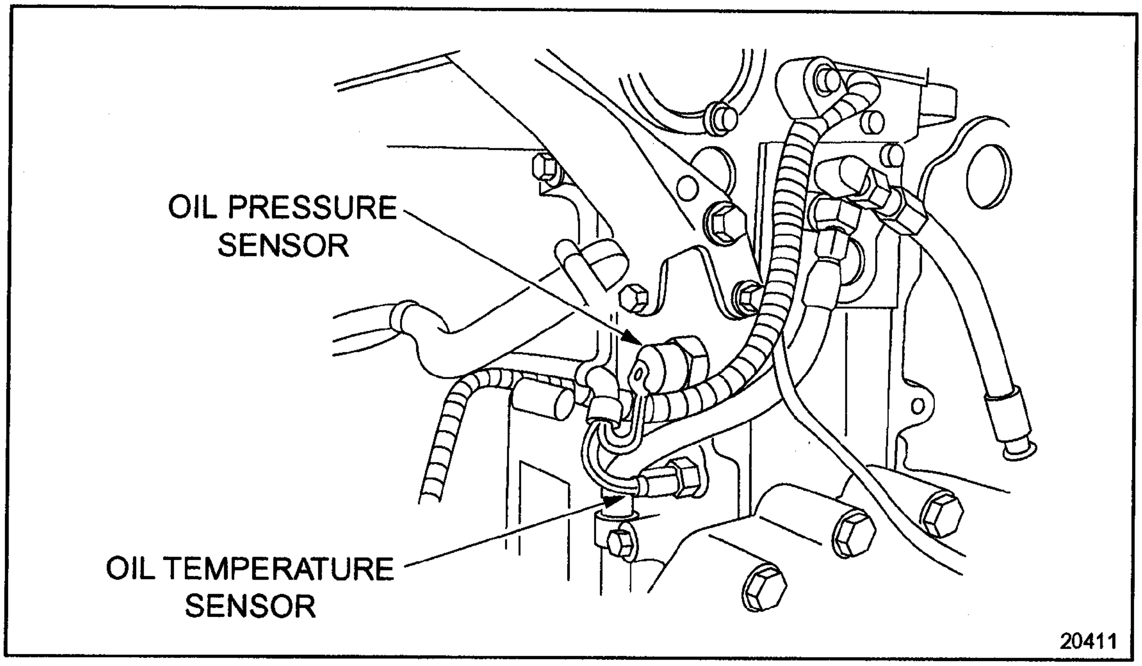

Figure 2-99 Engine Oil Temperature Sensor Location

2.25.1 Replacement of Oil Temperature Sensor

The OTS is non-serviceable, and is replaced as a unit. No adjustment is required.

2.25.2 Removal of Oil Temperature Sensor

Removal the OTS as follows:

1. Disengage the locking tang on the two-wire connector.
2. Grasp the body of the connector and gently pull it from the socket.
3. Use the appropriate wrench on the hex portion of the sensor and unscrew it.

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2.25.3 Installation of Oil Temperature Sensor

Install the OTS as follows:

NOTE:
The Oil Temperature Sensor is an electronic device. Use care in the installation process.

1. Place the sensor and using the appropriate wrench on the hex portion of the sensor tighten it.
2. Use Loctite® Pipe Sealer with Teflon, PT-7260 (or equivalent) on all but the first two threads of the OTS to prevent leaks.
3. Place the connector in the socket and engage the locking tang.
4. Turn the ignition to the ON position. Observe the DDR for any diagnostic code(s). If any code(s) other than code 25 is logged, refer to the *Detroit Diesel Single ECM Troubleshooting Manual* (6SE497).

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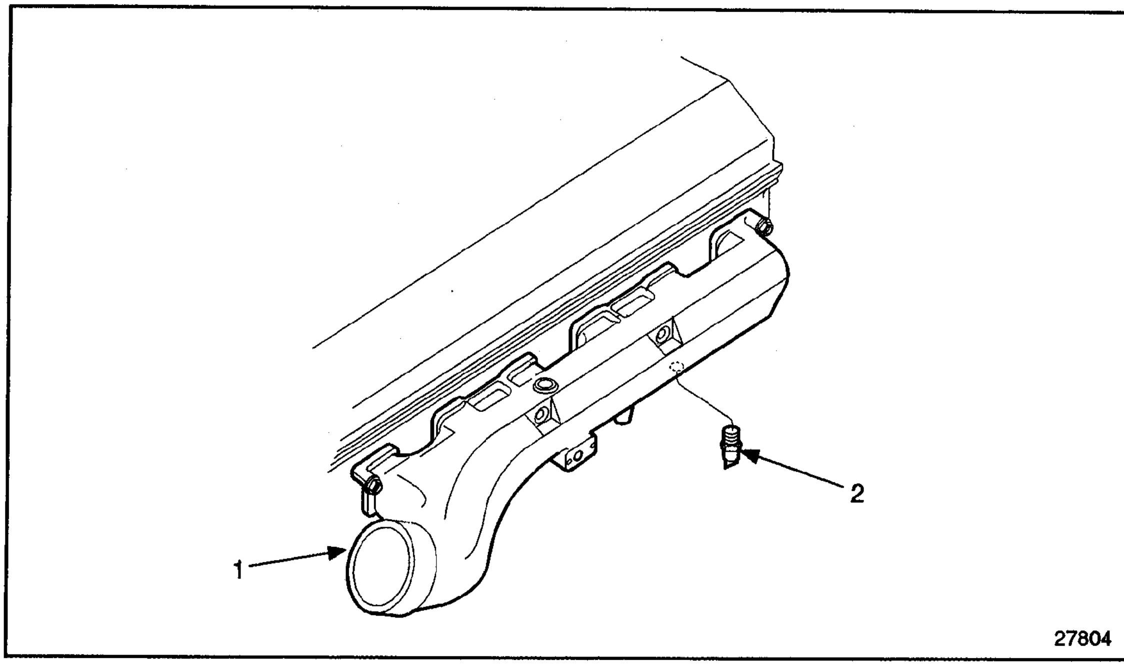
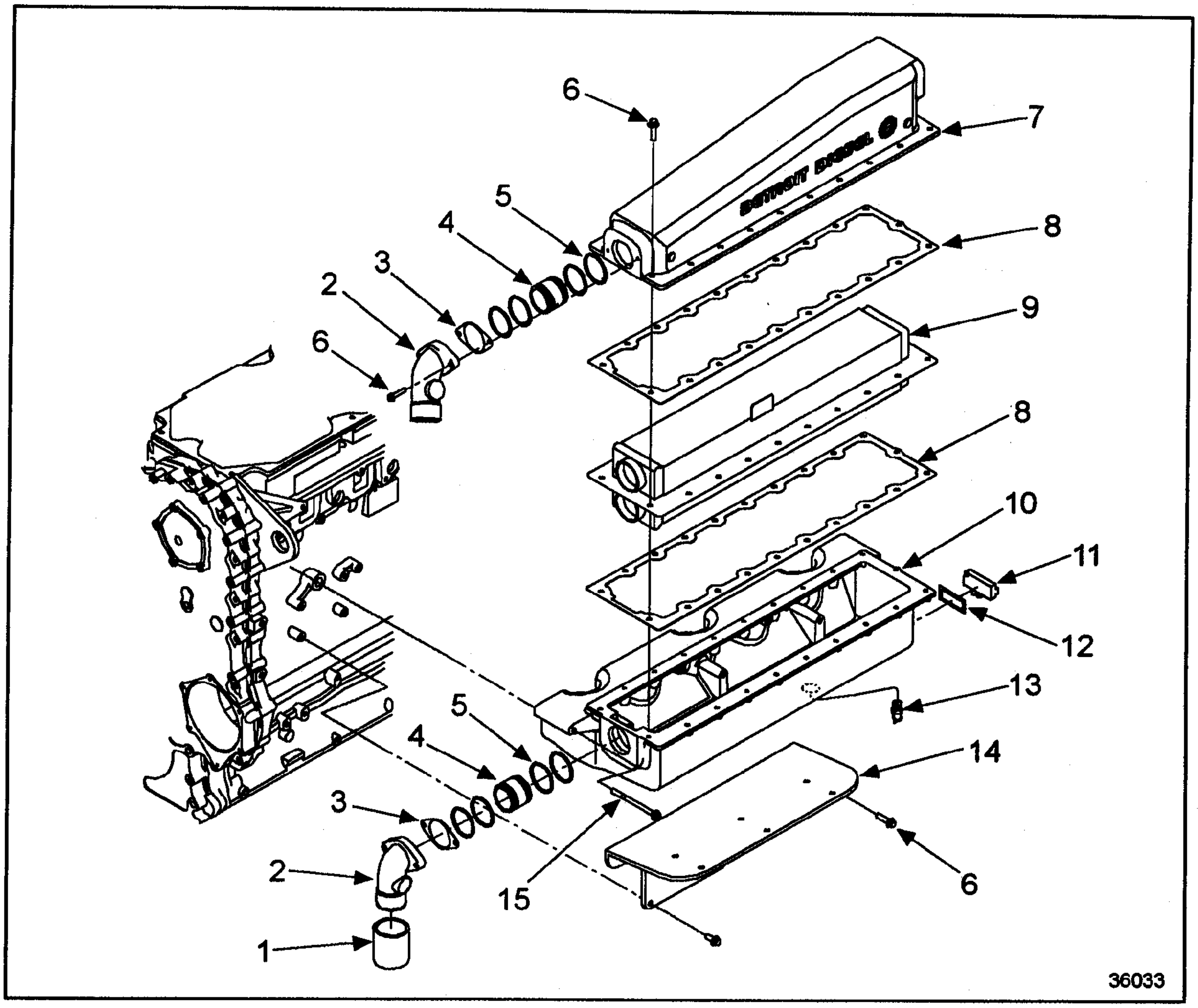
2.26 AIR TEMPERATURE SENSOR

On DDEC III/IV engines there is an Air Temperature Sensor (ATS) mounted to the bottom of the intake manifold. The ATS sends an electrical signal to the ECM indicating the inlet manifold temperature of the air entering the engine. The ECM uses this information to adjust gas flow, control air fuel ratio and in some cases fan control. The ATS provides necessary input to vary hot idle speed and injection timing resulting in improved cold starts and reduced white smoke. See Figure 2-100 and see Figure 2-101.



1. Intake Manifold
2. Air Intake Sensor

Figure 2-100 Air Temperature Sensor (All Diesel Except Heat Exchanger-Cooled Pleasure Craft Marine)



1. Hose
2. Elbow
3. Gasket
4. Sleeve
5. Seal Ring
6. Bolt
7. Housing Upper
8. Gasket
9. CAC Matrix
10. Housing Lower
11. Sensor
12. Seal Ring
13. Air Temperature Sensor
14. Bracket
15. Bolt

Figure 2-101 Air Temperature Sensor (Heat Exchanger-Cooled Pleasure Craft Marine)

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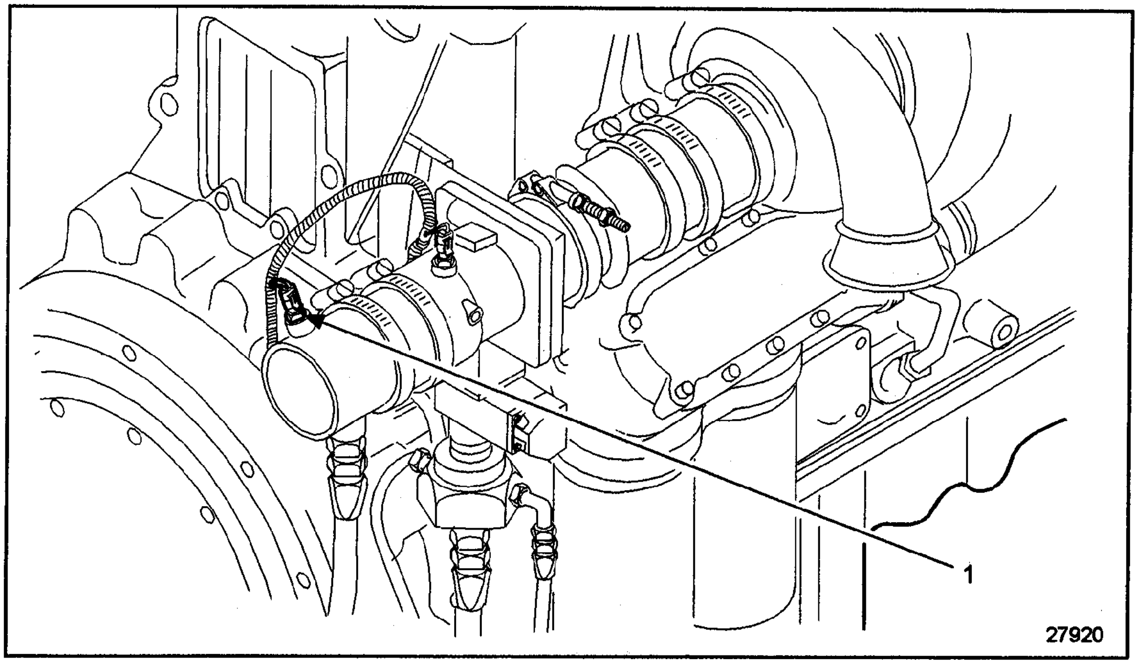
The Series 60G natural gas engine air temperature sensor (ATS) is installed into the air inlet tube. See Figure 2-102. The ATS sends an electrical signal to the ECM indicating air inlet temperature. The ECM uses this information to adjust gas flow and control air fuel ratio.



1. Air Temperature Sensor

Figure 2-102 Air Temperature Sensor

2.26.1 Repair or Replacement of Air Temperature Sensor

The ATS is non-serviceable, and is replaced as a unit. No adjustment is required.

2.26.2 Removal of Air Temperature Sensor

Remove the ATS as follows:

1. Disengage locking tang on two-wire connector.
2. Grasp body of the connector and gently pull it from the socket.
3. Use the appropriate wrench on the hex portion of the sensor and unscrew it from manifold.

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2.26.3 Installation of Air Temperature Sensor

Install the ATS as follows:

NOTICE:
Overtightening will distort and crack the sensor body, resulting in sensor malfunction. Damage may not be evident until sensor removal, when body may break apart.

1. If installing a new ATS, there is no need to use sealer as it is applied during manufacturing. When reinstalling a serviceable ATS, apply Loctite® pipe sealant with Teflon PT-7260 or equivalent on all but first two threads.
2. Install ATS to the intake manifold (diesel) or air inlet tube (natural gas).

NOTE:
Because of its plastic body, the ATS must be hand started and carefully tightened.

3. Torque to 11-16 N·m (8-12 lb·ft).
4. Carefully fasten connector onto sensor and engage locking tang.
5. Turn the ignition to the ON position. Observe the DDR for any diagnostic code(s). If any code(s) other than code 25 is logged, refer to the *Detroit Diesel Single ECM Troubleshooting Manual* (6SE497).

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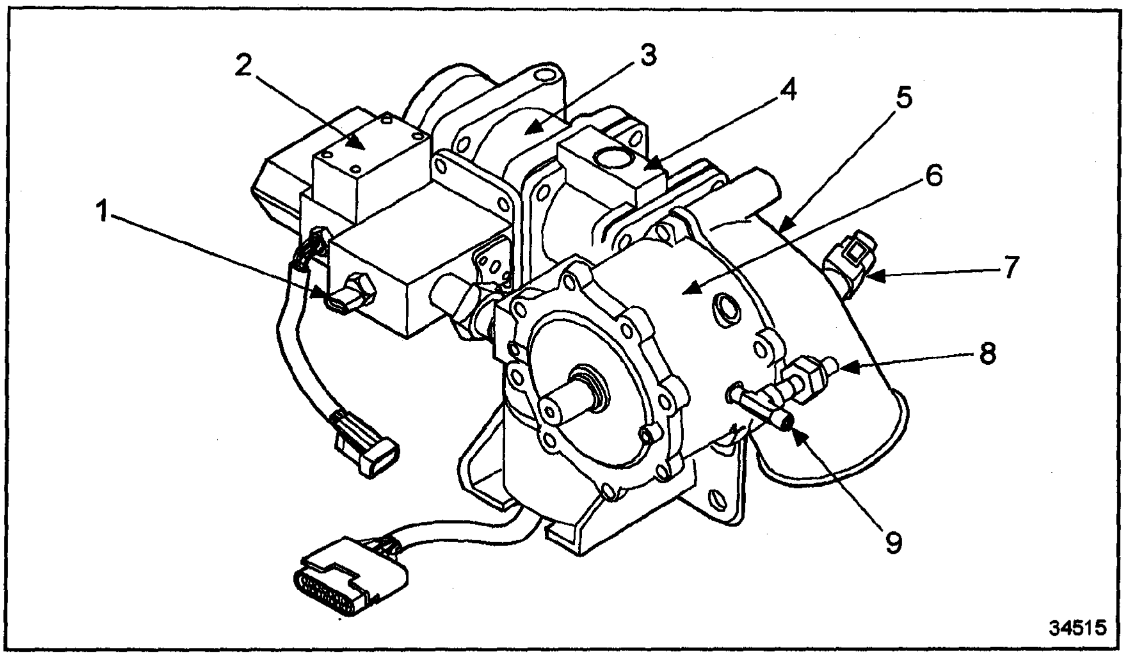
2.27 AIR TEMPERATURE SENSOR FOR HIGH PRESSURE FUEL SYSTEM

On DDEC III/IV engines there is an Air Temperature Sensor (ATS) mounted to the bottom of the inlet elbow. The ATS sends an electrical signal to the ECM indicating the inlet manifold temperature of the air entering the engine. The ECM uses this information to adjust gas flow, control air fuel ratio and in some cases fan control. The ATS provides necessary input to vary hot idle speed and injection timing resulting in improved cold starts and reduced white smoke. See Figure 2-100.



1. Fuel Temperature Sensor
2. PSV
3. Fuel Mixer
4. Throttle
5. Air Inlet Elbow
6. Low Pressure Regulator
7. Air Temperature Sensor
8. Fuel Pressure Sensor
9. Fuel Inlet Tee-Fitting

Figure 2-103 Fuel Temperature Sensor Series 60G Engine with High Pressure Fuel System

The Series 60 natural gas engine air temperature sensor (ATS) is installed into the air inlet tube. The ATS sends an electrical signal to the ECM indicating air inlet temperature. The ECM uses this information to adjust gas flow and control air fuel ratio.

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2.27.1 Repair or Replacement of Air Temperature Sensor for High Pressure Fuel System

The ATS is non-serviceable, and is replaced as a unit. No adjustment is required.

2.27.2 Removal of Air Temperature Sensor for High Pressure Fuel System

Remove the ATS as follows:

1. Disengage locking tang on two-wire connector.
2. Grasp body of the connector and gently pull it from the socket.
3. Use the appropriate wrench on the hex portion of the sensor and unscrew it from inlet elbow.

2.27.3 Installation of Air Temperature Sensor for High Pressure Fuel System

Install the ATS as follows:

NOTICE:
Overtightening will distort and crack the sensor body, resulting in sensor malfunction. Damage may not be evident until sensor removal, when body may break apart.

1. If installing a new ATS, there is no need to use sealer as it is applied during manufacturing. When reinstalling a serviceable ATS, apply Loctite® pipe sealant with Teflon PT-7260 (old number J 26558-92) or equivalent on all but first two threads.
2. Install ATS to the intake manifold (diesel) or air inlet tube (natural gas).

NOTE:
Because of its plastic body, the ATS must be hand started and carefully tightened.

3. Torque to 11-16 N·m (8-12 lb·ft).
4. Carefully fasten connector onto sensor and engage locking tang.
5. Turn the ignition to the ON position. Observe the DDR for any diagnostic code(s). If any code(s) other than code 25 is logged, refer to the *Detroit Diesel Single ECM Troubleshooting Manual* (6SE497).

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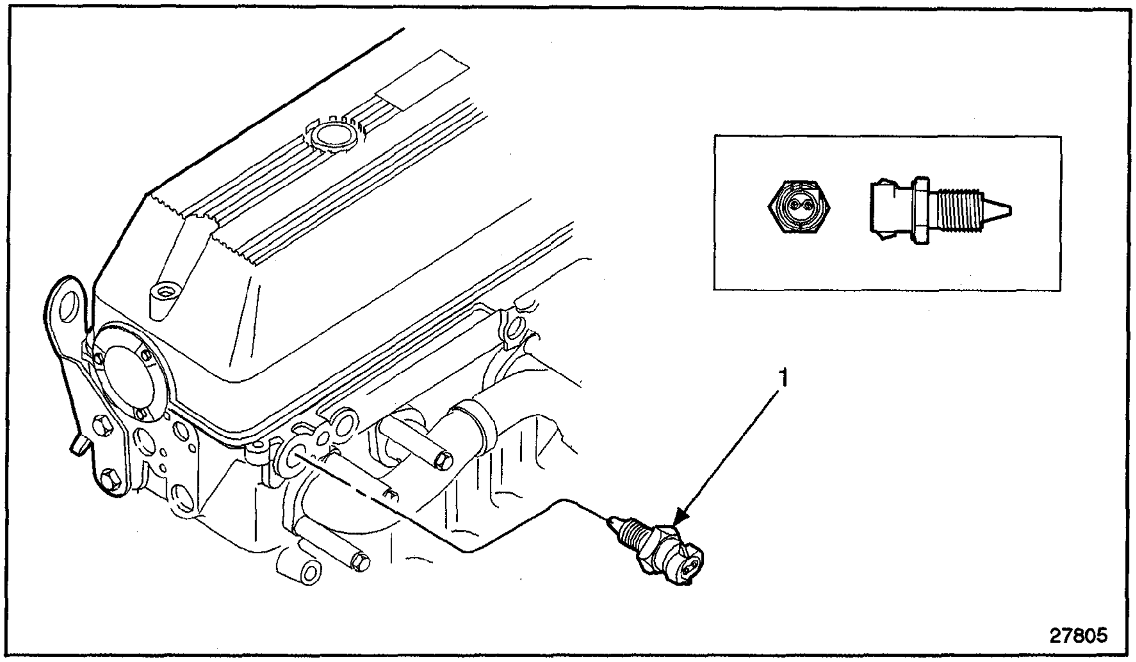
2.28 COOLANT TEMPERATURE SENSOR

The Coolant Temperature Sensor (CTS) is mounted on the right rear corner of the cylinder head, behind the turbocharger. The CTS sends an electrical signal to the ECM indicating the engine coolant temperature. The CTS activates engine protection if coolant temperature exceeds the specified limits. See Figure 2-104.



1. Air Intake Sensor

Figure 2-104 Coolant Temperature Sensor Location

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2.28.1 Repair or Replacement of Coolant Temperature Sensor

The CTS is non-serviceable, and is replaced as a unit. No adjustment is required.

2.28.2 Removal of Coolant Temperature Sensor

Remove the CTS as follows:

1. Disengage locking tang on two wire connector.
2. Grasp body of the connector and gently pull it from the socket.
3. Use the appropriate wrench on the hex portion of the sensor and unscrew it from the cylinder head.

2.28.3 Installation of Coolant Temperature Sensor

Install the CTS as follows:

1. Apply Loctite® pipe sealant with Teflon PT-7260 or equivalent on all but first two threads.
2. Install CTS to the cylinder head.
3. Torque to 102-127 N·m (75-94 lb·ft).
4. Carefully fasten two-wire connector onto sensor and engage locking tang.

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2.29 SYNCHRONOUS REFERENCE SENSOR

The Synchronous Reference Sensor (SRS) is an electronic component that is mounted to the rear of the gear case. See Figure 2-105.

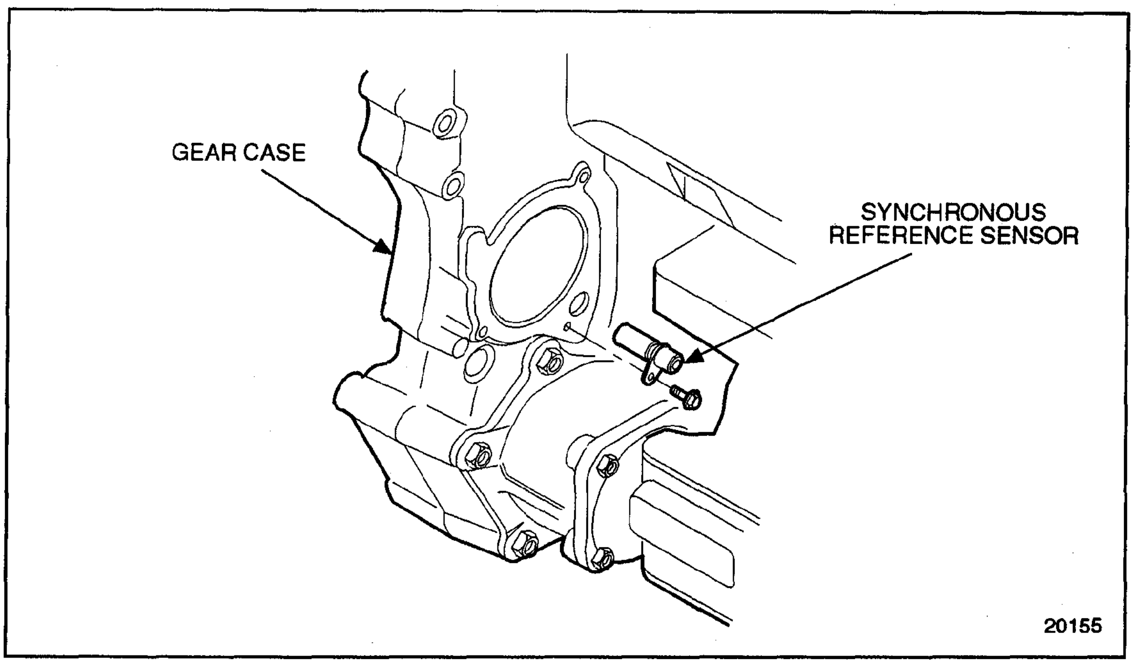

Figure 2-105 Synchronous Reference Sensor Location

NOTE:
The length of the SRS sensor element is 33.15-33.66 mm (1.305-1.325 in.).

The sensor portion of the SRS extends through a hole in the gear case, and is positioned very near the rear of the bull gear. A bolt, inserted through a hole in the SRS bracket, secures the SRS assembly to the gear case. The SRS connector is black in color.

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The SRS sends a signal to the ECM. This signal is generated by a raised metal pin on the rear of the bull gear. See Figure 2-106.

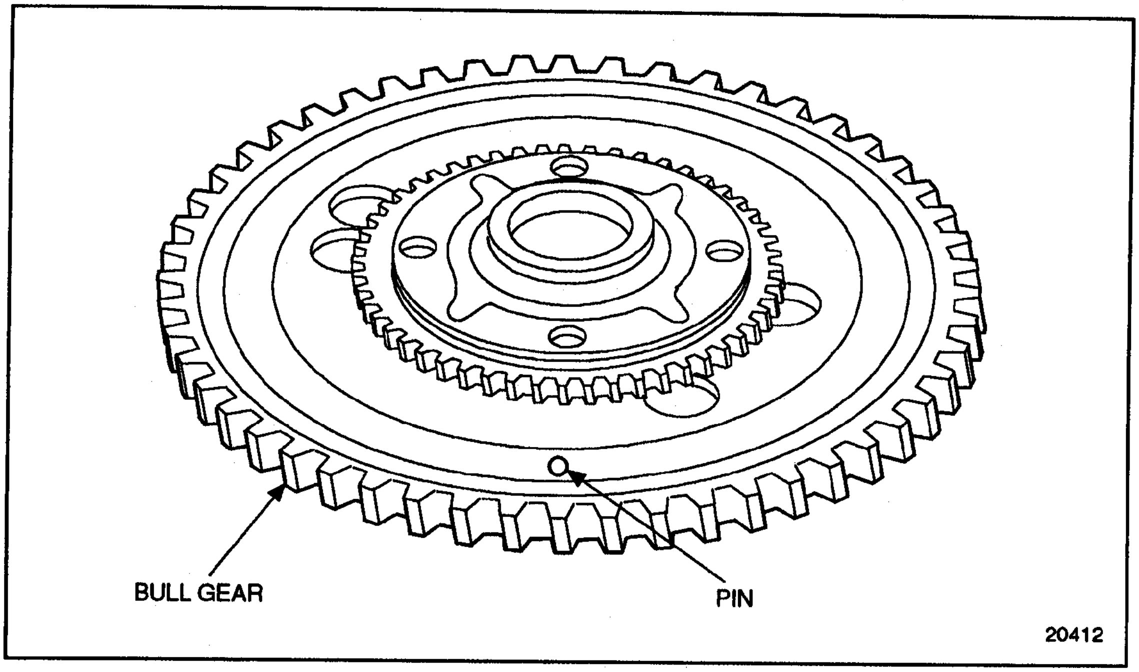

Figure 2-106 Bull Gear

The bull gear pin passes by the SRS as the number one piston reaches approximately 45 degrees before Top-Dead-Center (TDC). This information is used by the ECM to determine number one piston in the firing order.

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2.29.1 Replacement of Synchronous Reference Sensor

The SRS is a non-serviceable item and is replaced as a unit. No adjustment is required.

2.29.2 Removal of Synchronous Reference Sensor

Remove the SRS as follows:

1. Disengage the locking tang on the SRS connector. Grasp the connector bodies and gently pull them apart.
2. Using a socket and long extension, remove the SRS bolt.
3. Remove the SRS by pulling it straight out of the gear case.

2.29.3 Installation of Synchronous Reference Sensor

Install the SRS as follows:

NOTE:
The SRS is an electronic component. Use care upon installation.

1. The O-ring on the sensor may be coated with clean engine oil for ease of installation.
2. Insert the SRS into the gear case and index the hole in the bracket with the hole in the gear case.
3. Insert the SRS bolt and torque it to 30-38 N·m (22-28 lb·ft).
4. Plug the connectors together, making sure the locking tang clicks into place.
5. Turn the ignition to the ON position. Observe the DDR for any diagnostic code(s). If any code(s) other than code 25 is logged, refer to the *Detroit Diesel Single ECM Troubleshooting Manual* (6SE497).

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2.30 TIMING REFERENCE SENSOR

The Timing Reference Sensor (TRS) is an electronic component that is mounted to the left side of the gear case, near the crankshaft centerline. See Figure 2-107.

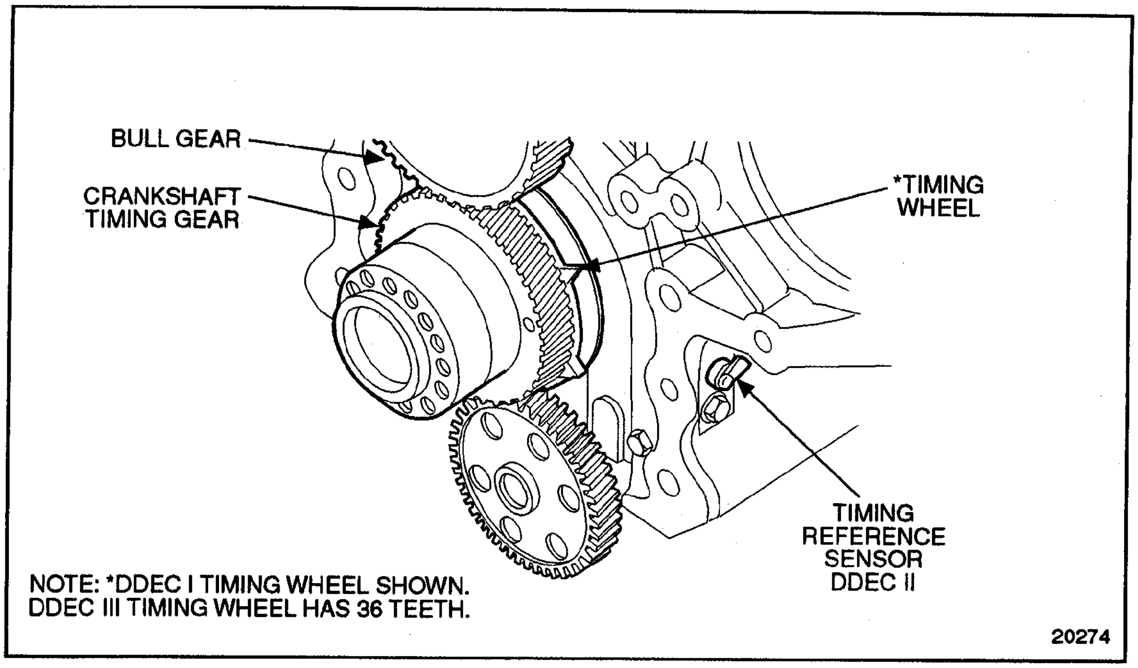

Figure 2-107 Timing Reference Sensor Location

NOTE:
The length of the TRS sensor element is 56.06-56.58 mm (2.207-2.227 in.).

The sensor portion of the TRS extends through an opening in the gear case, and is positioned near the teeth of the timing wheel. A bolt, inserted through a hole in the TRS bracket, secures the TRS assembly to the gear case. The TRS connector is gray in color.

The TRS sends a signal to the ECM. This signal is generated by a series of evenly spaced teeth on the timing wheel. As the timing wheel rotates with the crankshaft, a tooth passes by the TRS. These signals are used by the ECM to determine injector solenoid operation times and engine speed.

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2.30.1 Replacement of Timing Reference Sensor

The TRS is a non-serviceable component and is replaced as a unit. No adjustment is required.

2.30.2 Removal of Timing Reference Sensor

Remove the TRS as follows:

1. Disengage the locking tang on the TRS connector. Grasp the connector bodies and gently pull them apart.
2. Remove the bolt that secures the TRS to the gear case.
3. Remove the TRS by pulling it straight out of the gear case.

2.30.3 Installation of Timing Reference Sensor

Install the TRS as follows:

NOTE:
The TRS is an electronic component. Use care upon installation.

1. The O-ring on the sensor may be coated with clean engine oil for ease of installation.
2. Insert the TRS into the gear case and index the hole in the bracket with the hole in the gear case.
3. Insert the TRS bolt and torque it to 30-38 N·m (22-28 lb·ft).
4. Plug the connectors together, making sure the locking tang clicks into place.
5. Turn the ignition to the ON position. Observe or read any diagnostic code(s). If any code other than code 25 appears, refer to the required *DDEC Troubleshooting Manual:* 6SE477 (DDEC I), 6SE489 (DDEC II), or 6SE497 (DDEC III/IV).

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2.31 COOLANT LEVEL SENSOR

The Coolant Level Sensor (CLS) is a two-piece sensor for DDEC II, and a single sensor for DDEC III/IV. See Figure 2-108. The sensor probe (supplied by the vehicle, vessel or equipment manufacturer) is mounted in the top tank or overfill tank. For DDEC II the sensor module is mounted on the vehicle. The module sends an electrical signal to the ECM to indicate coolant level. Low coolant will activate the stop engine function or warning function.

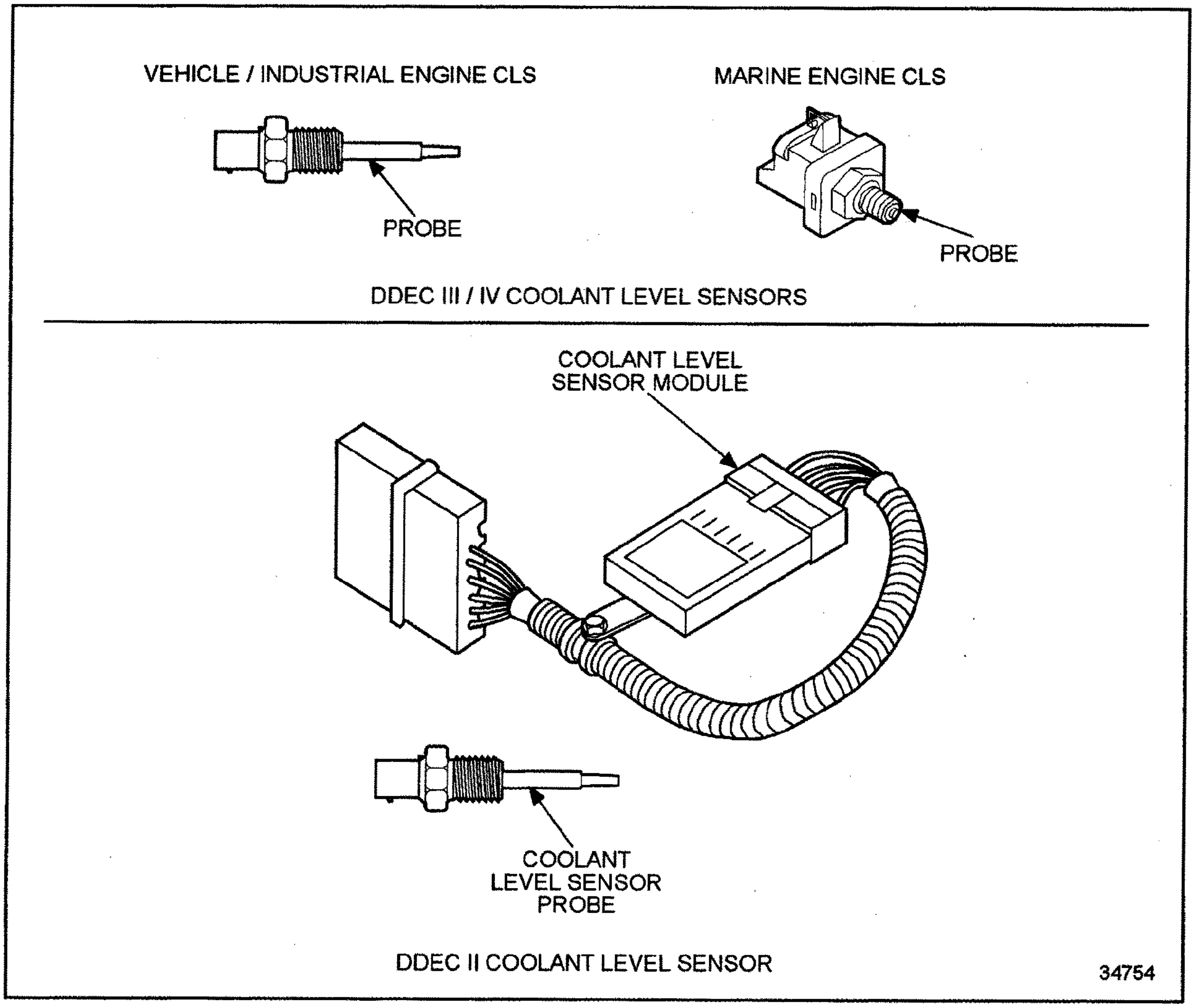

Figure 2-108 Coolant Level Sensors

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2.31.1 Replacement of Coolant Level Sensor

Both the CLS sensor probe and module are non-serviceable and should be replaced as necessary.

2.31.2 Removal of Coolant Level Sensor

Remove the CLS as follows:

1. Open the drain cock at the bottom of the radiator and drain the coolant into an appropriate container. Remove only as much coolant as is necessary to clear the CLS probe.
2. Remove ground wire screw and ground wire from side of probe.
3. Loosen and remove nut from sensor lead of probe.
4. Remove sensor lead, or unplug the two-pin connector.
5. Use the appropriate wrench on the hex portion of the sensor and unscrew it from the radiator.

2.31.3 Installation of Coolant Level Sensor Probe

Install the CLS Probe as follows:

1. Install CLS probe into the radiator or heat exchanger as follows:

NOTE:
New sensors are pre-coated with a thread sealer. If sensor is new, no additional sealant is required. If sensor is reused, apply Loctite® 567 pipe sealant with Teflon® or equivalent.

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Teflon® is a registered trademark of the E. I. DuPont de Nemours and Company, Inc.

[a] Install and torque vehicle or industrial engine CLS to 8–10 lb·ft (11–14 N·m).

[b] Install and torque marine engine CLS to 4–6 lb·ft (5–8 N·m).

2. Connect the two-pin connector.
3. Fill the cooling system. Refer to section 13.13.4.
4. Turn the ignition to the ON position. Observe or read any diagnostic code(s). If any code other than code 25 appears, refer to the *DDEC Troubleshooting Guide:* 6SE477 (DDEC I), 6SE489 (DDEC II), or 6SE497 (DDEC III/IV).

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CAUTION:

To avoid injury before starting and running the engine, ensure the vehicle is parked on a level surface, parking brake is set, and the wheels are blocked.

CAUTION:

Diesel engine exhaust and some of its constituents are known to the State of California to cause cancer, birth defects, and other reproductive harm.

- ☐ **Always start and operate an engine in a well ventilated area.**
- ☐ **If operating an engine in an enclosed area, vent the exhaust to the outside.**
- ☐ **Do not modify or tamper with the exhaust system or emission control system.**

5. Start the engine and check for leaks.
6. Shut down engine upon completion of test. Perform necessary repairs.

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2.31.4 Removal of Coolant Level Sensor Module

Remove the CLS module as follows:

1. Disengage the locking tang on the CLS module connector. Grasp the connector bodies and gently pull them apart.
2. Remove module from vehicle.

2.31.5 Installation of Coolant Level Sensor Module

Install the CLS Module as follows:

NOTICE:
Use care during the installation of the CLS module or damage may occur.

1. Insert the CLS module to the vehicle.
2. Grasp both connector bodies. Gently push them together and engage locking tang on the CLS module connector.

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2.32 FUEL PRESSURE SENSOR

The Fuel Pressure Sensor (FPS) is installed into the secondary fuel filter. The FPS is not used in all applications. The FPS sends an electrical signal to the ECM telling it what the engine fuel pressure is at any given speed. See Figure 2-109.

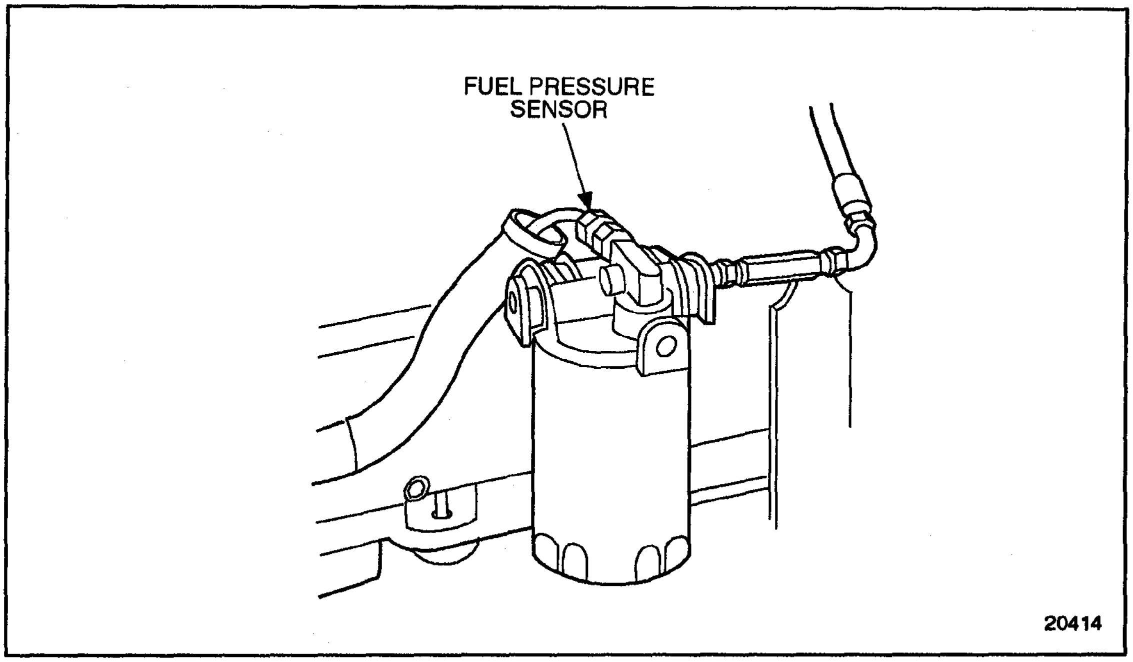

Figure 2-109 Fuel Pressure Sensor Location (Industrial Application Only)

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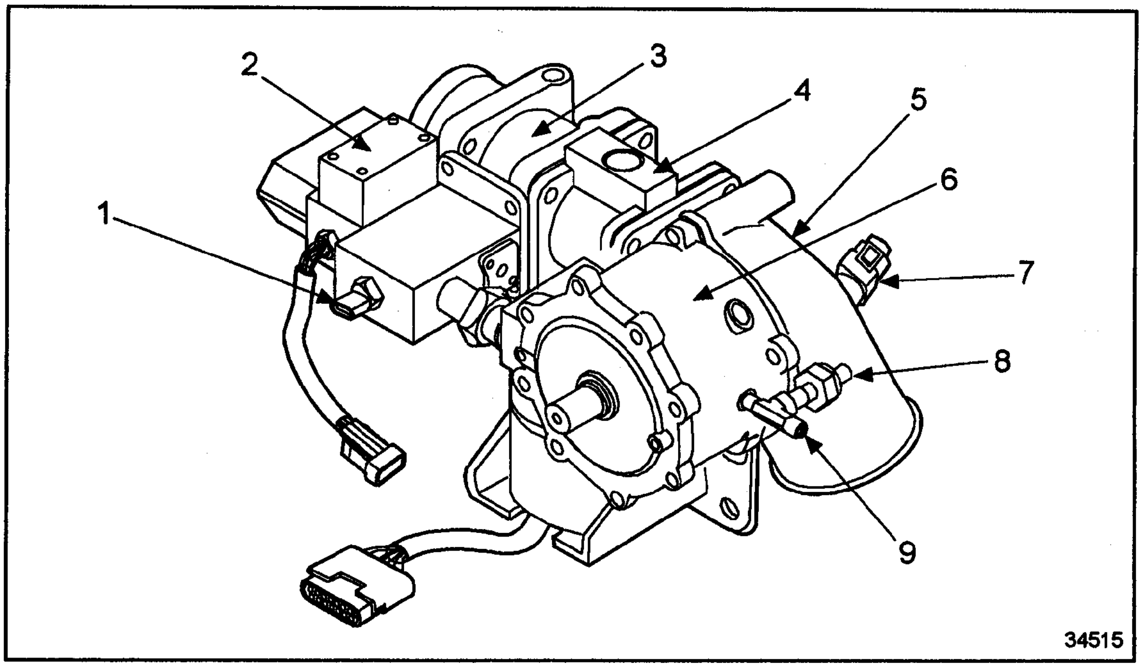
On Series 60G engines with the high pressure fuel system the fuel pressure sensor is installed in a tee at the inlet to the low pressure regulator. See Figure 2-110.



1. Fuel Temperature Sensor
2. PSV
3. Fuel Mixer
4. Throttle
5. Air Inlet Elbow
6. Low Pressure Regulator
7. Air Temperature Sensor
8. Fuel Pressure Sensor
9. Fuel Inlet Tee Fitting

Figure 2-110 Fuel Pressure Sensor for Series 60G

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2.32.1 Replacement of Fuel Pressure Sensor

The FPS is non-serviceable and should be replaced as a unit. No adjustment is required.

2.32.2 Removal of Fuel Pressure Sensor

Remove the FPS as follows:

1. Disengage the locking tang on the three-wire connector. Grasp the body of the connector and gently pull it free of the FPS.
2. Use the appropriate wrench on the hex end of the FPS to unscrew it from the filter.

2.32.3 Installation of Fuel Pressure Sensor

Install the FPS as follows:

NOTICE:
The FPS is an electrical device. Use care on installation or damage may occur.

1. Use Loctite® Pipe Sealant with Teflon, PT-7260 (or equivalent) on all but the first two threads of the FPS to prevent leaks.
2. Screw FPS into the filter.
3. Engage locking tang.
4. Turn the ignition to the ON position. Observe the DDR for any diagnostic code(s). If any code(s) other than code 25 is logged, refer to the *Detroit Diesel Single ECM Troubleshooting Manual* (6SE497).

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2.33 FUEL TEMPERATURE SENSOR

The Series 60 diesel engine Fuel Temperature Sensor (FTS) is installed into the secondary fuel filter. See Figure 2-111. The FTS sends an electrical signal to the ECM indicating fuel inlet temperature. The ECM uses this information to calculate fuel consumption.

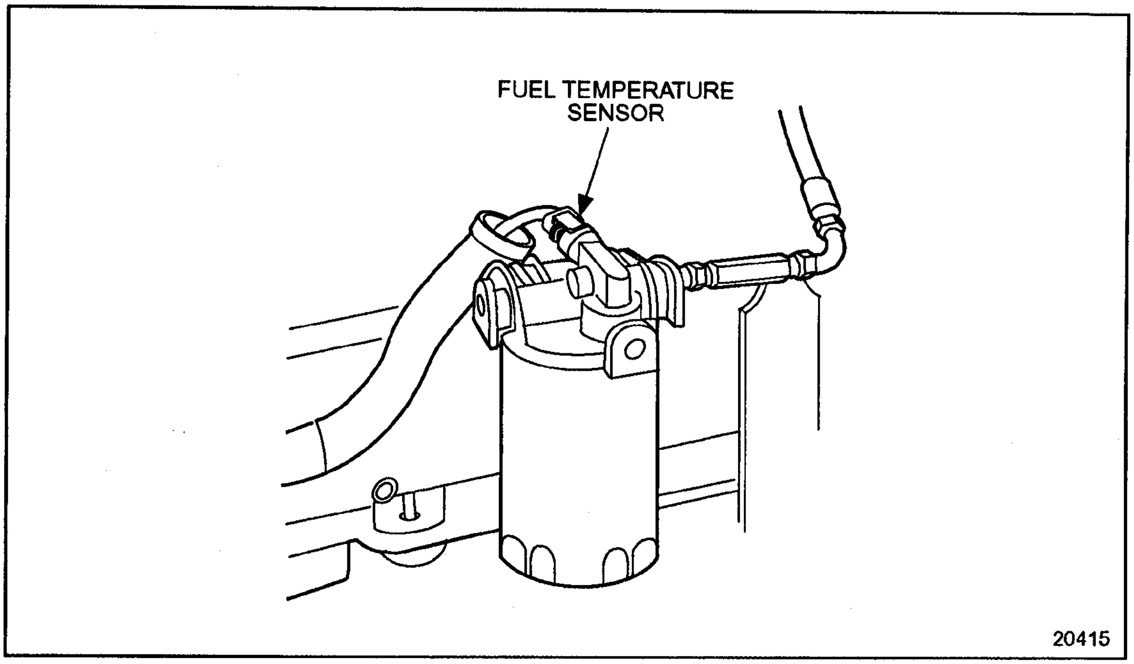

Figure 2-111 Fuel Temperature Sensor Location (Series 60 Diesel Engine)

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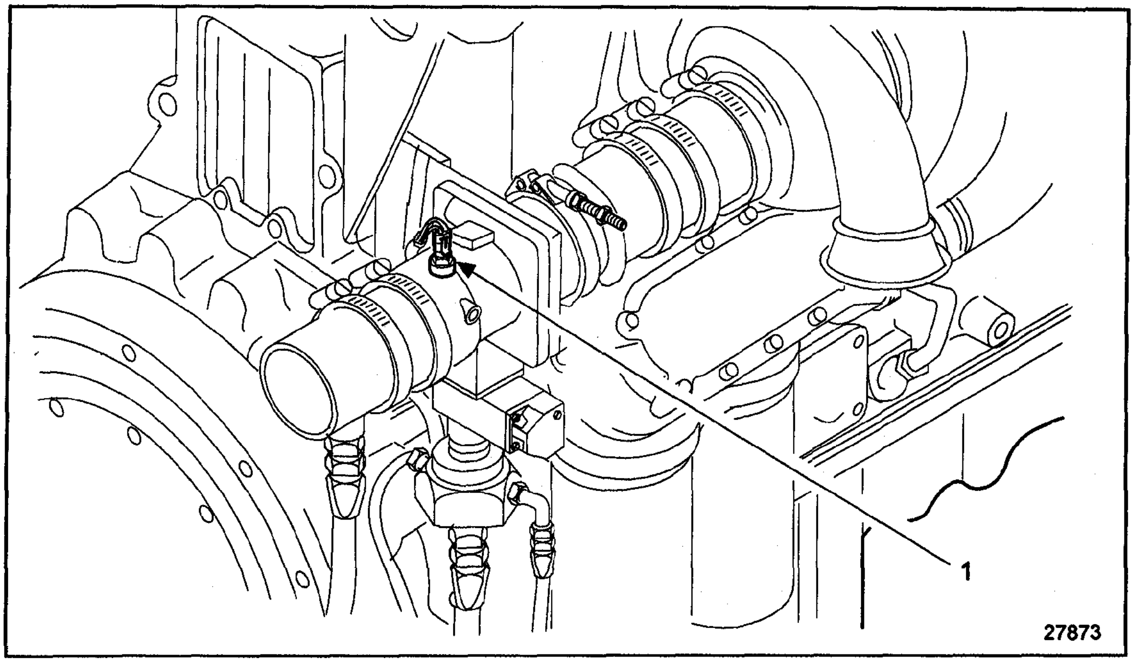
The Series 60 genset natural gas engine Fuel Temperature Sensor (FTS) is installed into the gas mixer housing. See Figure 2-112. The FTS sends an electrical signal to the ECM indicating fuel inlet temperature. The ECM uses this information to adjust gas flow and control air fuel ratio.



1. Fuel Temperature Sensor

Figure 2-112 Fuel Temperature Sensor Location (Series 60G Genset Application)

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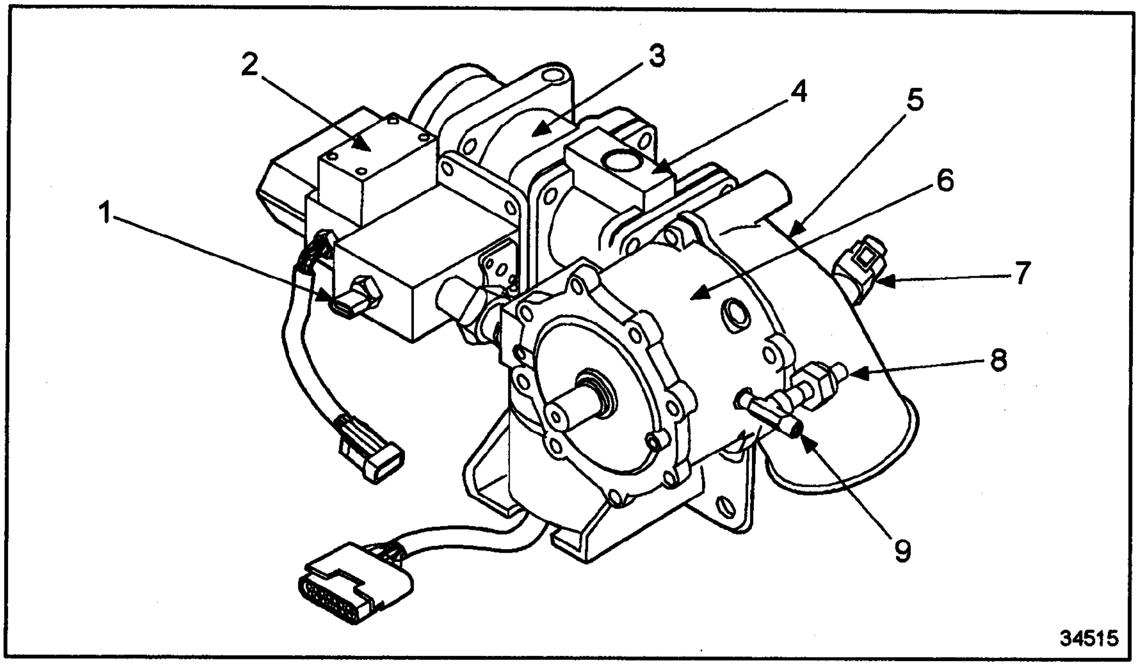
On Series 60G engines with the high pressure fuel system the fuel temperature sensor is located in the PSV. See Figure 2-113.



1. Fuel Temperature Sensor
2. PSV
3. Fuel Mixer
4. Throttle
5. Air Inlet Elbow
6. Low Pressure Regulator
7. Air Temperature Sensor
8. Fuel Pressure Sensor
9. Fuel Inlet Tee Fitting

Figure 2-113 Fuel Temperature Sensor Series 60G Engine with High Pressure Fuel System

2.33.1 Replacement of Fuel Temperature Sensor

The FTS is non-serviceable and should be replaced as a unit. No adjustment is required.

2.33.2 Removal of Fuel Temperature Sensor

Remove the FTS as follows:

1. Disengage the locking tang on the two-wire connector. Grasp the body of the connector and gently pull it from the socket.
2. Use the appropriate wrench on the hex portion of the sensor and unscrew it from the fitting.

2.33.3 Installation of Fuel Temperature Sensor

Install the FTS as follows:

NOTICE:
The Fuel Temperature Sensor is an electrical device. Use care in the installation process or damage may occur.

1. Use Loctite® Pipe sealer with Teflon PT-7260 (or equivalent) on all but the first two threads of the FTS to prevent leaks.
2. Screw the FTS into the fitting or housing.
3. Engage locking tang.
4. Turn the ignition to the ON position. Observe the DDR for any diagnostic code(s). If any code(s) other than code 25 is logged, refer to the *Detroit Diesel Single ECM Troubleshooting Manual* (6SE497).

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2.34 EXHAUST GAS OXYGEN SENSOR FOR SERIES 60G ENGINES

The Exhaust Gas Oxygen Sensor is mounted in the vehicle exhaust pipe within 12 inches of the turbocharger exhaust outlet in the top half of the pipe. The sensor is threaded into an M18 boss welded to the exhaust pipe. The sensor works in conjunction with an oxygen sensor interface module that is mounted to a sensor bracket located at the rear of the cylinder block above the flywheel housing. See Figure 2-114 and see Figure 2-115.

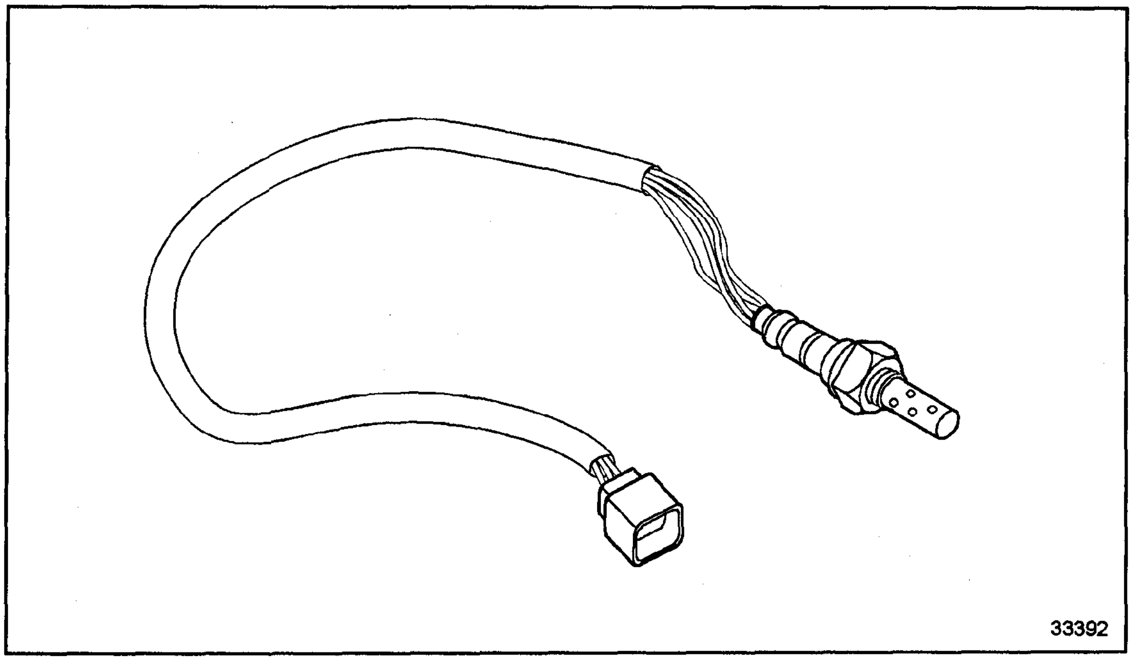

Figure 2-114 Exhaust Gas Oxygen Sensor

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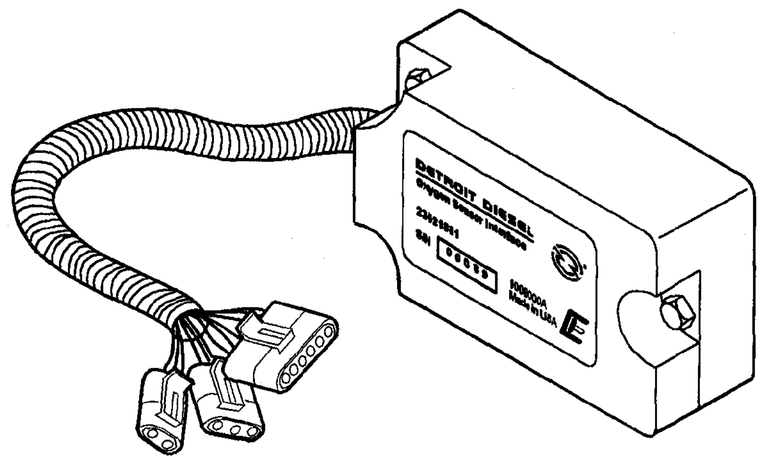

Figure 2-115 Oxygen Sensor Interface Module

The oxygen sensor and interface module provide a signal to DDEC which is proportional to the concentration of oxygen in the exhaust gas. DDEC calculates the air-fuel ratio from this signal and uses the data in controlling fuel delivery to the engine. The exhaust gas oxygen sensor is electrically connected to the interface module through the oxygen sensor wiring harness. The oxygen sensor interface module is electrically connected to DDEC and to battery power through the engine sensor harness. The oxygen sensor is a heated sensor. This allows the sensor to function at the optimum temperature range for accuracy. The interface module is a microprocessor that provides heater control, signal processing and diagnostic capabilities. The output from the oxygen sensor and interface module can be monitored using the Diagnostic Data Reader (DDR). The output is displayed as air fuel ratio in Lambda units. Lambda is the ratio of actual air fuel ratio to the stoichometric air-fuel ratio.

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NOTICE:

Exposure to solvents or excessives amounts of oil or water can cause exhaust gas oxygen sensor failure. Exercise care when cleaning or performing repairs on air system, cylinder kit, valve train, turbocharger and exhaust system components. It may be necessary to replace the oxygen sensor with a plug and run engine without the sensor briefly to prevent exposure.

2.34.1 Replacement of the Exhaust Gas Oxygen Sensor and the Oxygen Sensor Interface Module

The exhaust gas oxygen sensor and the oxygen sensor interface module are not serviceable and must be replaced as an assembly. No adjustments are required.

2.34.2 Removal of the Exhaust gas Oxygen Sensor and the Oxygen Sensor Interface Module

Remove the exhaust gas oxygen sensor as follows:

1. Disengage the connector between the oxygen sensor wire harness and oxygen sensor wire pigtail.
2. Loosen and remove the oxygen sensor from the exhaust pipe.

Remove the oxygen sensor interface module as follows:

1. Disconnect oxygen sensor harness six–pin connector at interface module.
2. Disconnect three–pin engine sensor wire harness connector at interface module.
3. Disconnect two–pin engine sensor wire harness connector at interface module.
4. Remove three M6 bolts that attach the module to the sensor bracket.
5. Remove module from bracket.

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2.34.3 Installation of the Exhaust Gas Oxygen Sensor and the Oxygen Sensor Interface Module

Install the exhaust gas oxygen sensor as follows:

NOTICE:
Use of excessive amount of anti-seize compound or direct sensing element contact with compound can cause sensor poisoning and erroneous sensor readings or failure.

1. New sensors have antiseize compound pre-applied to the threads of the sensor. If reinstalling a used sensor, lightly apply antiseize compound to threads of sensor.
2. Install sensor in boss and torque to 40–50 N·m (29.5–36.9 lb·ft).
3. Connect oxygen sensor harness to sensor.
4. Turn on ignition and, with the Diagnostic Data Reader, clear the AFR (air fuel ratio) learn table.
5. Start engine and check for check engine or stop engine light.

Install the oxygen sensor interface module as follows:

1. Position module on sensor bracket and install three M6 attaching bolts.
2. Connect to three-pin and two-pin connectors in engine sensor wire harness.
3. Connect to six-pin connector in oxygen sensor wire harness.
4. Turn on ignition and, with the Diagnostic Data Reader, clear the AFR (air fuel ratio) learn table.
5. Start engine and check for check engine or stop engine light or read any diagnostic codes. If any code other than 25 is obtained, refer to the *Detroit Diesel Single ECM Troubleshooting Manual* (6SE497).

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2.35 EXHAUST TEMPERATURE SENSOR FOR THE SERIES 60G ENGINES

The Exhaust Gas Temperature Sensor is threaded into the exhaust pipe within 12 inches of the turbocharger turbine outlet. The device is a temperature sensor that provides an electrical signal to the ECM. The sensor is electrically connected to the ECM through the engine sensor wiring harness. Temperature data from the sensor is used for engine protection and diagnostics.

2.35.1 Replacement of the Exhaust Gas Temperature Sensor

The Exhaust Gas Temperature Sensor is non-serviceable and must be replaced as an assembly. No adjustment is required.

2.35.2 Removal of the Exhaust Gas Temperature Sensor

Remove the exhaust gas temperature sensor as follows:

1. Disengage the connector from the engine sensor harness.
2. Loosen the nut and remove sensor from the exhaust pipe.

2.35.3 Installation of the Exhaust Gas Temperature Sensor

Install the exhaust gas temperature sensor as follows:

1. Insert in fitting in the exhaust pipe.
2. Tighten nut.
3. Connect sensor to engine sensor wire harness.
4. Turn the ignition to the ON position. Observe or read any diagnostic codes. If any codes other than 25 appears, refer to the *DDEC II/IV Troubleshooting Guide,* 6SE497.

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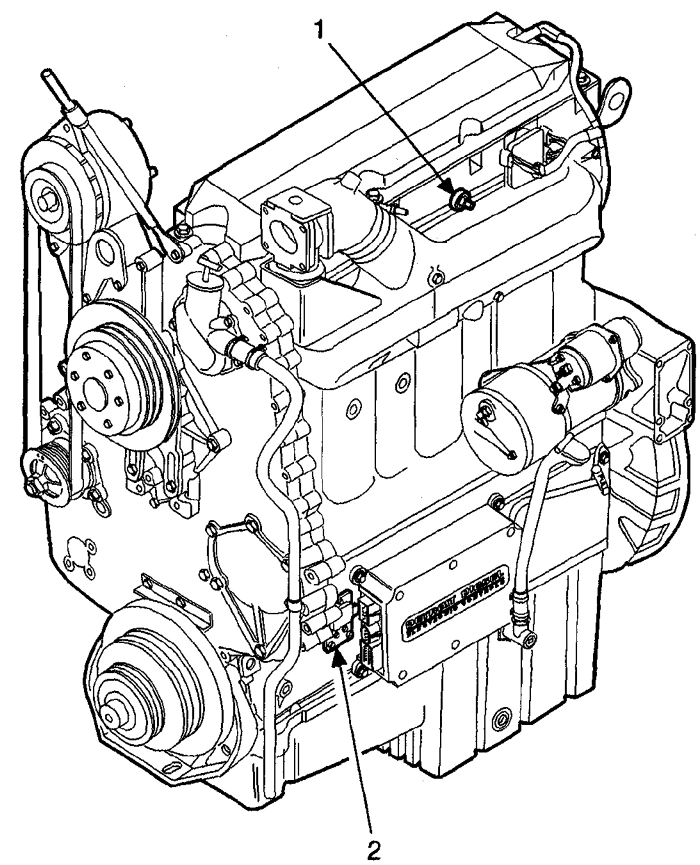
2.36 KNOCK SENSOR AND SIGNAL NOISE ENHANCEMENT FILTER MODULE

For knock protection, the Series 60 natural gas engines are equipped with a Knock Sensor and Signal Noise Enhancement Filter (SNEF) module. The knock sensor is located at the left rear of the cylinder head. The SNEF module is mounted on the left side of the cylinder block. The SNEF module receives electrical signals from the knock sensor and sends electrical signals to the ECM indicating knock level. The ECM uses this information to determine if the engine is knocking and adjusts ignition timing, air fuel ratio and throttle plate to protect the engine from excessive knock. See Figure 2-116.



1. Knock Sensor
2. SNEF Module

Figure 2-116 Location of Knock Sensor and Signal Noise Enhancement Filter Module

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Listed in Table 2-11are the knock sensor and knock interface module diagnostic codes:

Description	Voltage	SID	FMI	Information
Knock Control	HIGH	S76	3	Indicates that the knock sensor input to the ECM has exceeded 95% (normally >4.75 volts) of the sensor supply voltage. This diagnostic is typically detected when there is an open sensor return circuit or the sensor signal circuit is shorted to the sensor +5 volt supply.
Knock Control	LOW	S76	4	Indicates that the knock sensor input to the ECM has dropped below 5% (normal < 0.25 volts) of the sensor supply voltage. This diagnostic is typically detected when there is:- An open sensor signal circuit- An open sensor +5 volt supply circuit- The sensor signal is shorted to the sensor return circuit or to ground- The sensor +5 volt supply is shorted to sensor return circuit or to ground.
Knock Control	HIGH	S76	0	Indicates that the knock interface module has detected that the engine knock level has exceeded the first level of the recommended engine operational range.
Knock Control	MECHANICAL FAULT	S76	7	Indicates that the knock interface module has detected that the engine knock level has exceeded the second level of the recommended engine operational range.

Table 2-11 Knock Sensor Diagnostic Codes for the Series 60G Engine

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2.36.1 Replacement of Knock Sensor and Signal Noise Enhancement Filter Module

The knock sensor and SNEF module are non-serviceable and each should be replaced as a unit. No adjustment is required.

2.36.2 Removal of Knock Sensor and Signal Noise Enhancement Filter Module

Remove the knock sensor as follows:

1. Disengage the locking tang on the single wire connector. Grasp the body of the connector and gently pull it from the socket.
2. Use the appropriate wrench on the hex portion of the sensor and unscrew it from the fitting.

Remove the SNEF module as follows:

1. Disengage the locking tang on the wire connector. Grasp the body of the connector and gently pull it from the socket.
2. Remove the two bolts attaching the SNEF module to its mounting bracket.

2.36.3 Installation of Knock Sensor and Signal Noise Enhancement Filter Module

Install the knock sensor as follows:

1. Screw the sensor into the cylinder head. Torque to 16-22 N·m (12-16 lb·ft).
2. Engage locking tang.

Install the SNEF module as follows:

1. Install the SNEF module to its mounting bracket and attach with two mounting bolts.
2. Engage locking tang.

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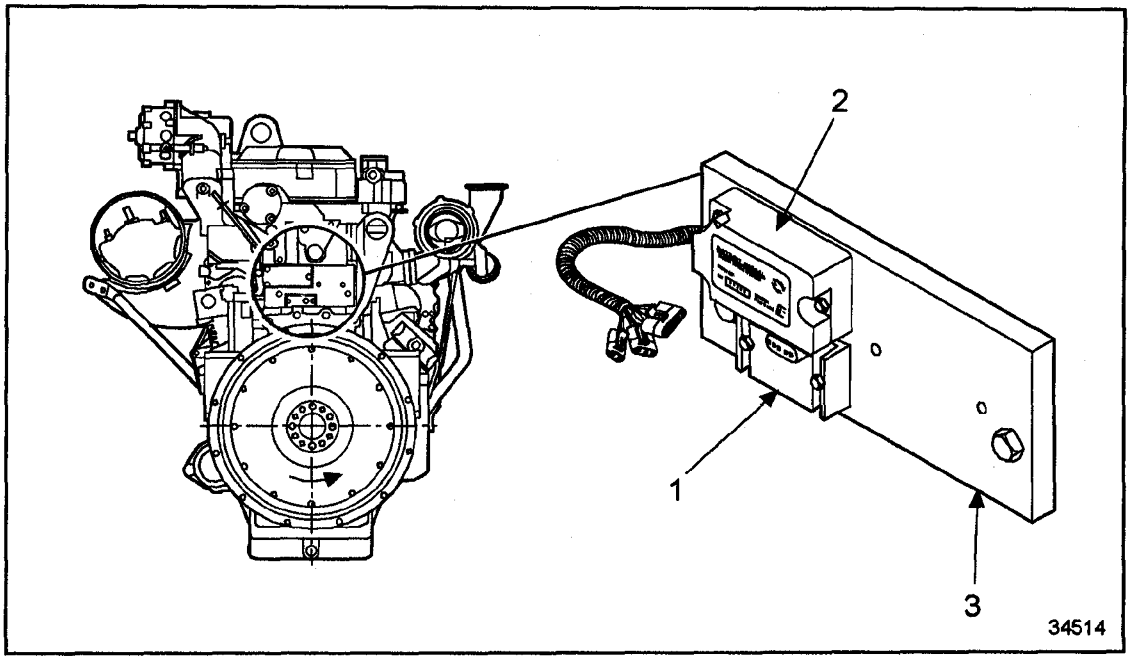
2.37 BAROMETRIC PRESSURE SENSOR FOR THE SERIES 60G ENGINE WITH HIGH PRESSURE FUEL SYSTEM

The Barometric Pressure Sensor (BARO sensor) is mounted to the sensor bracket at the rear of the cylinder block just above the flywheel housing. The sensor sends an electrical signal to the ECM indicating barometric pressure. It is electrically connected to the ECM through the engine sensor wire harness. A hose is attached to the inlet of the sensor to protect it form dirt and prevent plugging. The ECM uses the data in controlling fuel delivery to the engine. See Figure 2-117.



1. Barometric Pressure Sensor
2. Oxygen Sensor Interface Module
3. Sensor Bracket

Figure 2-117 Barometric Pressure Sensor for Series 60G Engines

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2.37.1 Replacement of the Barometric Pressure Sensor

The barometric pressure sensor is non-serviceable and must be replaced as an assembly.

2.37.2 Removal of the Barometric Pressure Sensor

Remove the Barometric Pressure Sensor as follows:

1. Disengage the locking tang on the BARO sensor.
2. Disconnect the hose from the inlet of the sensor.
3. Loosen two attaching bolts and remove sensor from bracket.

2.37.3 Installation of the Barometric Pressure Sensor

Install the BARO sensor as follows:

NOTICE:
Use care tightening sensor attaching bolts. Overtightening the bolts will damage the sensor.

1. Install the sensor on the bracket. Torque bolts to 2.7 N·m (24 lb·in.).
2. Connect the inlet hose.
3. Engage it to the sensor wire harness connector.
4. Turn ignition on and, with Diagnostic Data Reader, clear the AFR (air fuel ratio) learn table.
5. Turn ignition to the "ON" position. Observe or read any diagnostic codes. If any codes other than 25 appears, refer to the *DDEC II/IV Troubleshooting Guide,* 6SE497.

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2.38 OVERVIEW OF HIGH PRESSURE FUEL SYSTEM FOR SERIES 60G ENGINES

For a schematic diagram of a typical CNG fuel system, see Figure 2-118.

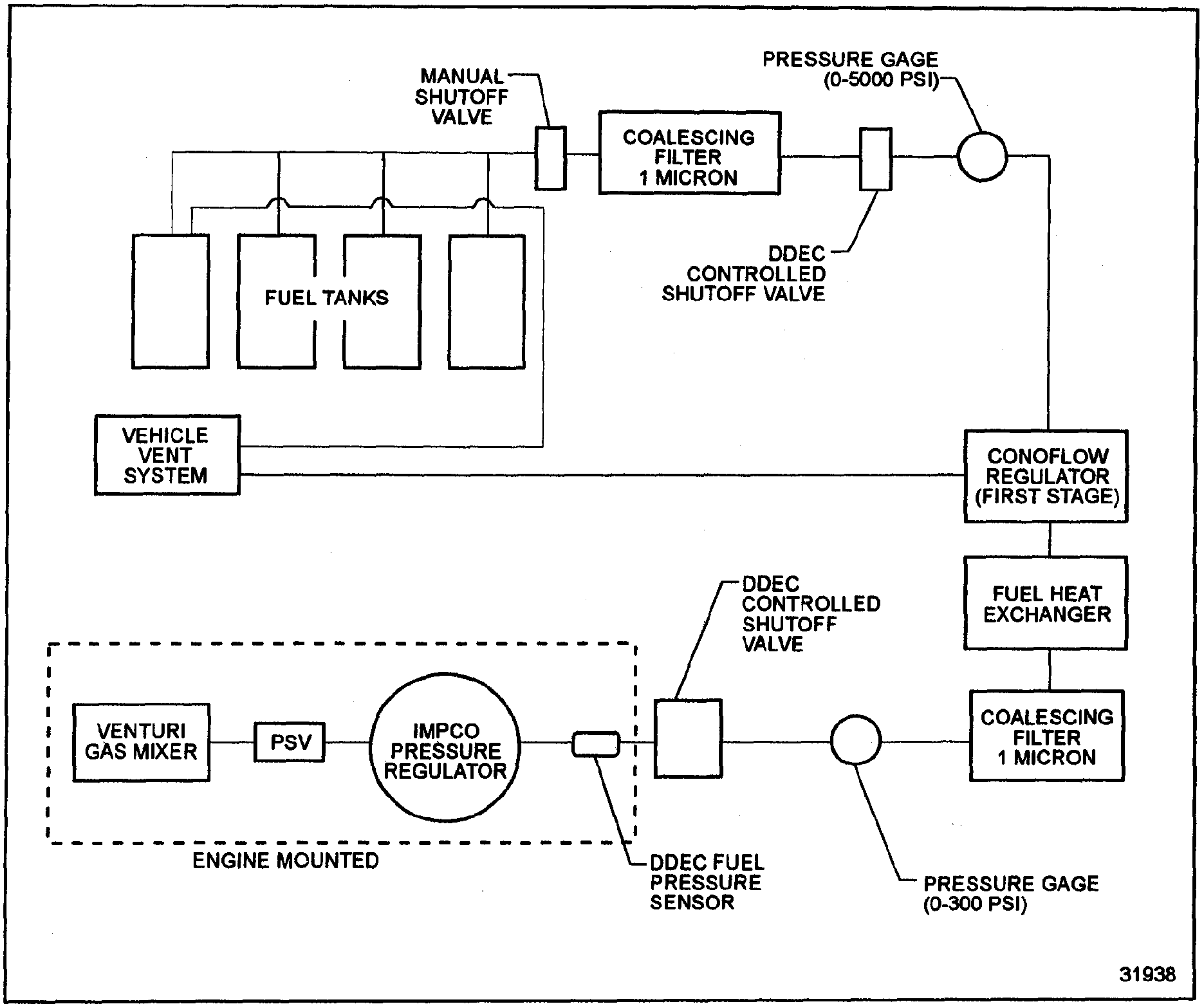

Figure 2-118 Schematic Diagram of Typical CNG Fuel System for 1998 and Later Series 60G Engines

NOTE:
The maximum distance between the second DDEC solenoid and the IMPCO regulator is 18 inches.

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The fuel system includes the following components:

DDC supplied:

- ☐ Venturi Type Gas Mixer
- ☐ PSV (Pulse width modulated Stepper motor Valve)
- ☐ IMPCO Low Pressure Regulator
- ☐ ITT Conoflow High Pressure Regulator
- ☐ Low Pressure DDEC Controlled Gas Shutoff Valve

OEM supplied:

- ☐ Fuel Tanks
- ☐ Fuel Lines
- ☐ Manual Shutoff Valves
- ☐ Coalesing Fuel Filters
- ☐ High Pressure DDEC Controlled Gas Shutoff Valve
- ☐ Pressure Gages
- ☐ Fuel Heat Exchanger

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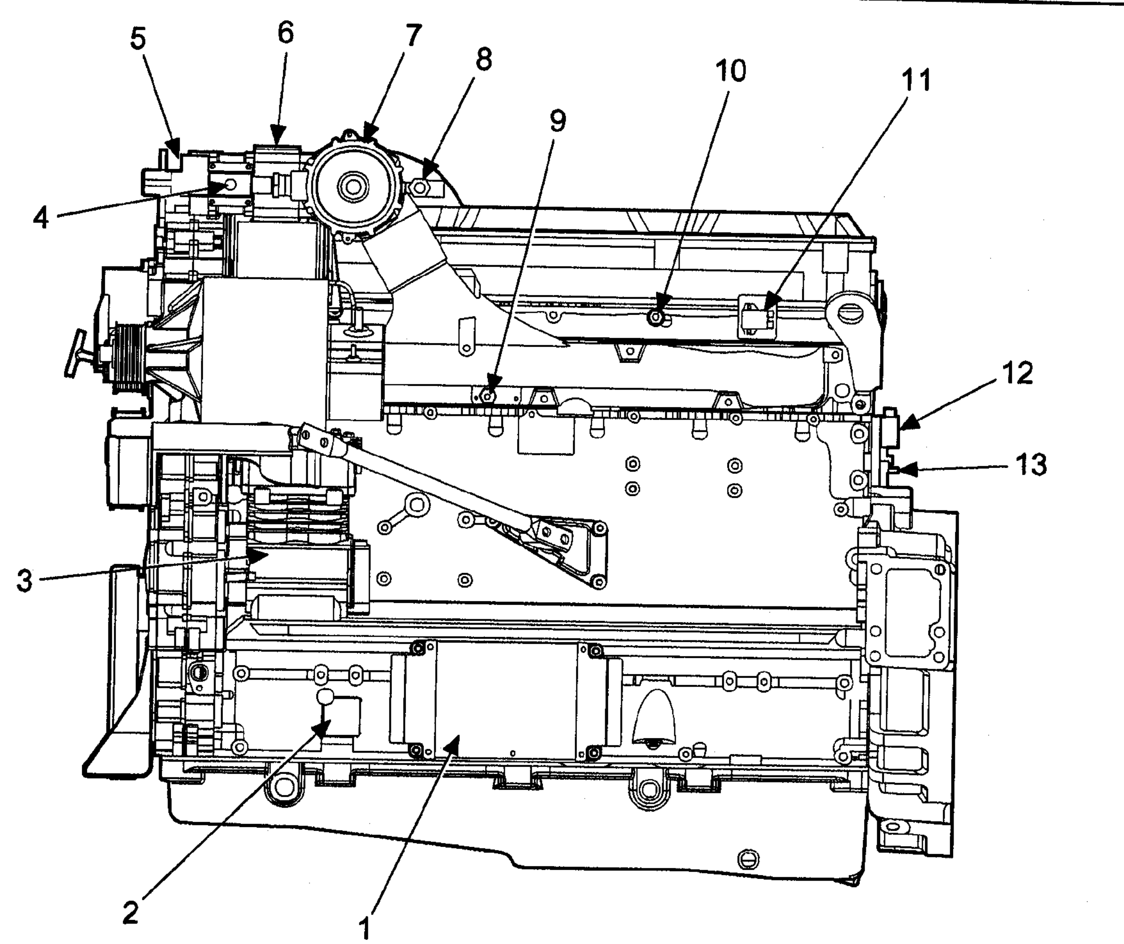
See Figure 2-119 for a component overview of the High Pressure fuel system.

The fuel system is designed to accurately deliver clean fuel at the correct air fuel mixture to the combustion chamber at any engine operating condition.



1. Electronic Control Module
2. SNEF Module
3. Air Compressor
4. Fuel Temperature Sensor
5. PSV
6. Throttle Actuator
7. IMPCO Regulator
8. Fuel Pressure Sensor, Fuel Inlet
9. Manifold Air Pressure Sensor
10. Knock Sensor and Stud
11. Ignitor Module
12. Oxygen Sensor Interface Module
13. Barometric Air Pressure Sensor

Figure 2-119 Series 60G Engine Component Location

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CAUTION:

To avoid injury from an explosion of natural gas, the following precautions must be taken:

- ☐ **Do not smoke when installing or servicing the engine or fuel system.**
- ☐ **Installation or servicing of natural-gas equipment must only be conducted in well-ventilated, natural gas compatible areas. Do not install or service equipment in an enclosed area where ignition sources are present without first ensuring that an undetected gas leak may be safely vented without being ignited.**
- ☐ **Bleed natural gas lines before installing or servicing any component connected to the fuel lines.**
- ☐ **Natural gas fuel systems are pressurized. Relieve pressure from any fuel system component prior to installation or service of that component.**
- ☐ **Use a combustible-gas detector. Liquefied natural gas (LNG) is odorless and cannot be detected by smell. Compressed Natural gas (CNG) may be odorless and may not be detected by smell.**
- ☐ **Equipment fuel systems are the responsibility of the Original Equipment Manufacturer (OEM). Equipment fuel system guidelines must be closely adhered to when installing or servicing equipment. Refer to OEM guidelines specifying which maintenance procedures require venting of fuel lines and fuel tanks.**
- ☐ **LNG systems are pressurized and contain extremely cold (-260°F [-162°C]) fluids. Contact the fuel supplier or OEM for LNG safety requirements. Contact with LNG may cause personal injury (freezing).**
- ☐ **Vent systems on the equipment should be ducted to a safe area whenever equipment is in an enclosed area.**

Natural gas is highly flammable and explosive and may be extremely cold (-260°F [-162°C]).

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CAUTION:

To avoid injury from the explosion of natural gas, the engine must be kept in a well-ventilated area away from open flames, sparks, and electrical resistance (heating) coils.

Fuel is stored in the fuel tanks at a pressure as high as 3600 PSI. The fuel passes through high pressure fuel shutoff valves, typically controlled by both DDEC and OEM systems, through primary fuel filters to the high pressure regulator. The pressure is reduced by the high pressure regulator to approximately 110 PSI. Flow continues through the secondary fuel filter, through the DDEC controlled low pressure fuel shutoff valve on to the low pressure regulator. The low pressure regulator is balanced to the air system at the inlet to the fuel mixer assembly. It maintains outlet fuel pressure slightly higher than turbo boost pressure at the mixer inlet. Fuel from the regulator passes through the PSV, enters the venturi mixer and is mixed with incoming air.

Air flow through the venturi creates a pressure drop at the throat of the venturi that increases and decreases in proportion to air flow. This pressure differential is used to draw fuel through the venturi insert, the PSV and low pressure regulator. The system is sometimes referred to as a demand system. Increases in pressure drop across the venturi increase the demand for fuel flow required to maintain the fuel outlet pressure at the low pressure regulator.

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Fine control of fuel flow is achieved by positioning of the gas valve. Changes in gas valve position change the flow restriction between the venturi and low pressure regulator. For a given set of engine speed and load conditions, reducing the valve opening increases restriction resulting in reduced fuel flow and a leaner air fuel mixture. Likewise, increasing the valve opening reduces restriction resulting in increased fuel flow and a richer air fuel mixture.

In part, fuel flow is controlled by calibration and matching of the key fuel system components, the venturi mixer, the PSV (gas valve position) and the low pressure regulator. Electronics are used to further refine control. Electric control is provided by DDEC. The DDEC output which allows control of fuel delivery is the gas valve position. Input to DDEC for fuel delivery control is provided by engine speed, inlet manifold pressure, inlet manifold temperature, fuel temperature, coolant temperature, throttle position and exhaust gas oxygen sensors.

In addition exhaust gas temperature, fuel pressure and knock sensors provide engine protection and diagnostics capabilities unique to the Series 60 natural gas engine. The system is a closed loop system. This refers to the fact that input or feedback from the exhaust gas oxygen sensor is used to make adjustments in fuel delivery. The system is constantly making use of this feedback to adjust air fuel ratio to the desired value.

Electronic control of the fuel system provides the capability to adjust and correct for changes in operating condition, environmental condition, changes in fuel quality, and differences in components and component changes that occur over time. For fuel quality specifications refer to section 5.1. Refer to section 2.16 for details on the DDEC system for Series 60 Natural Gas engines.

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2.39 FUEL PRESSURE GAGES FOR THE SERIES 60G ENGINE WITH A HIGH PRESSURE FUEL SYSTEM

Fuel pressure gages should be installed on both high and low pressure sides of fuel system. The high pressure gage should have a range of 0 - 4000 PSI mounted between the tank and 1st stage regulator. The low pressure gage should have a range of 0 - 200 PSI.

2.39.1 Replacement of Fuel Pressure Gages for the Series 60G Engine

Detroit Diesel does not service the fuel pressure gages. Refer to OEM to replace as necessary.

2.39.2 Removal of Fuel Pressure Gages for the Series 60G Engine

Prior to removal or replacement of fuel system pressure gages, the fuel system must be vented. Refer to section 2.40.1 and refer to section 2.40.2.

CAUTION:

To avoid injury from the explosion of natural gas, the engine must be kept in a well-ventilated area away from open flames, sparks, and electrical resistance (heating) coils.

Refer to OEM for removal procedure for the fuel pressure gages.

2.39.2.1 Inspection of Fuel Pressure Gages for the Series 60G Engine

Refer to OEM for inspection procedure for the fuel pressure gages.

2.39.3 Installation of Fuel Pressure Gages for the Series 60G Engine

Refer to OEM for installation procedure for the fuel pressure gages.

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CAUTION:

To avoid injury from an explosion of natural gas, the following precautions must be taken:

- ☐ **Do not smoke when installing or servicing the engine or fuel system.**
- ☐ **Installation or servicing of natural-gas equipment must only be conducted in well-ventilated, natural gas compatible areas. Do not install or service equipment in an enclosed area where ignition sources are present without first ensuring that an undetected gas leak may be safely vented without being ignited.**
- ☐ **Bleed natural gas lines before installing or servicing any component connected to the fuel lines.**
- ☐ **Natural gas fuel systems are pressurized. Relieve pressure from any fuel system component prior to installation or service of that component.**
- ☐ **Use a combustible-gas detector. Liquefied natural gas (LNG) is odorless and cannot be detected by smell. Compressed Natural gas (CNG) may be odorless and may not be detected by smell.**
- ☐ **Equipment fuel systems are the responsibility of the Original Equipment Manufacturer (OEM). Equipment fuel system guidelines must be closely adhered to when installing or servicing equipment. Refer to OEM guidelines specifying which maintenance procedures require venting of fuel lines and fuel tanks.**
- ☐ **LNG systems are pressurized and contain extremely cold (-260°F [-162°C]) fluids. Contact the fuel supplier or OEM for LNG safety requirements. Contact with LNG may cause personal injury (freezing).**
- ☐ **Vent systems on the equipment should be ducted to a safe area whenever equipment is in an enclosed area.**

Natural gas is highly flammable and explosive and may be extremely cold (-260°F [-162°C]).

Refer to section 2.40.3 for leak checking procedure.

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2.40 VENTING AND LEAK CHECKING PROCEDURES FOR A NATURAL GAS ENGINE (HIGH PRESSURE SYSTEM)

To vent and leak check an operable engine, refer to section 2.40.1.

2.40.1 Venting an Operable Engine to Relieve Natural Gas Pressure

Vent an operable engine as follows:

CAUTION:

To avoid injury from the explosion of natural gas, the engine must be kept in a well-ventilated area away from open flames, sparks, and electrical resistance (heating) coils.

1. Shut off manual valves on natural gas supply tanks and main shutoff valve on natural gas fuel supply line.
2. Start engine and run until it stalls due to fuel starvation.
3. Check to ensure gage pressure at point on the natural gas fuel line to be vented has been reduced to zero. If not, repeat step 1. Then repeat step 2.
4. Disconnect the vehicle batteries using switch(s) in the battery compartment or by disconnecting battery ground cable.
5. Slightly loosen the CNG fuel line fitting to be serviced in a well-ventilated area to allow any remaining gas to vent.
6. Completely open the fitting that was slightly opened and allow to vent in a well-ventilated area.

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2.40.2 Venting an Inoperable Engine to Relieve Natural Gas Pressure

If the engine *cannot run*, use the following venting procedure to relieve the natural gas pressure downstream of the shutoff valve:

CAUTION:
To avoid injury from the explosion of natural gas, the engine must be kept in a well-ventilated area away from open flames, sparks, and electrical resistance (heating) coils.

1. Shut off manual valves on natural gas supply tanks and main shutoff valve on natural gas fuel supply line.
2. Disconnect the vehicle batteries using switch(s) in the battery compartment or by disconnecting the battery ground cable.
3. Open a fitting to assure all pressure has been relieved in the natural gas vehicle fuel line.
4. Check all connections that were loosened for leaks after installation, service and troubleshooting are complete.

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2.40.3 Leak Checking the Natural Gas Fuel System

Use the following steps to check for leaks:

CAUTION:

To avoid injury from an explosion of natural gas, the following precautions must be taken:

- ☐ **Do not smoke when installing or servicing the engine or fuel system.**
- ☐ **Installation or servicing of natural-gas equipment must only be conducted in well-ventilated, natural gas compatible areas. Do not install or service equipment in an enclosed area where ignition sources are present without first ensuring that an undetected gas leak may be safely vented without being ignited.**
- ☐ **Bleed natural gas lines before installing or servicing any component connected to the fuel lines.**
- ☐ **Natural gas fuel systems are pressurized. Relieve pressure from any fuel system component prior to installation or service of that component.**
- ☐ **Use a combustible-gas detector. Liquefied natural gas (LNG) is odorless and cannot be detected by smell. Compressed Natural gas (CNG) may be odorless and may not be detected by smell.**
- ☐ **Equipment fuel systems are the responsibility of the Original Equipment Manufacturer (OEM). Equipment fuel system guidelines must be closely adhered to when installing or servicing equipment. Refer to OEM guidelines specifying which maintenance procedures require venting of fuel lines and fuel tanks.**
- ☐ **LNG systems are pressurized and contain extremely cold (-260°F [-162°C]) fluids. Contact the fuel supplier or OEM for LNG safety requirements. Contact with LNG may cause personal injury (freezing).**
- ☐ **Vent systems on the equipment should be ducted to a safe area whenever equipment is in an enclosed area.**

Natural gas is highly flammable and explosive and may be extremely cold (-260°F [-162°C]).

1. Spray soapy water or commercially available leak checking solutions on connections which are pressurized to working pressure. Bubbles will form if there is a leak.

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2. Repair any leak by:

   [a] Tightening connection using the fitting technique of the manufacturer.

NOTE:
Bleed the fuel lines before replacing leaking components using the procedure in this section. This will prevent a discharge of gas.

   [b] Replacing leaking component.

   [c] Replace the pipe threaded connector with a new one if the leak is a pipe thread connection. Use anaerobic sealant with Teflon (such as SWAK®) applied to the threads. *SWAK® is a registered trademark of The Cajon Company.*

3. Re-check connection with procedure in step 1.
4. Use a combustible gas detector to check for presence of natural gas. If natural gas is detected, continue looking for leaks until the locations of all the leaks are determined.
5. Repair the leak using the procedure in step 2.

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2.41 HIGH PRESSURE FUEL REGULATOR FOR THE SERIES 60G ENGINE

The Conoflow high pressure fuel regulator is typically mounted in the engine compartment of the vehicle. The function of the regulator is to supply fuel flow based on engine demand at a reduced pressure. The regulator reduced the pressure from the tank pressure, which can be as high as 3600 PSI, to approximately 110 PSI. The regulator is heated with coolant supplied from the cylinder head and returned to the water pump inlet. The regulator includes a pressure relief device to protect downstream components. The pressure relief valve is set to open at approximately 300 PSI. The pressure relief is connected to the vehicle gas vent system. The gas inlet connection to the regulator is a female SAE No. 6 O-ring connection. The gas outlet is a female SAE No. 8 O-ring connection. The pressure relief is a male 1/4 NTPF connection. Coolant supply and return connections are 1/4 inch NPTF female pipe thread holes. See Figure 2-120.

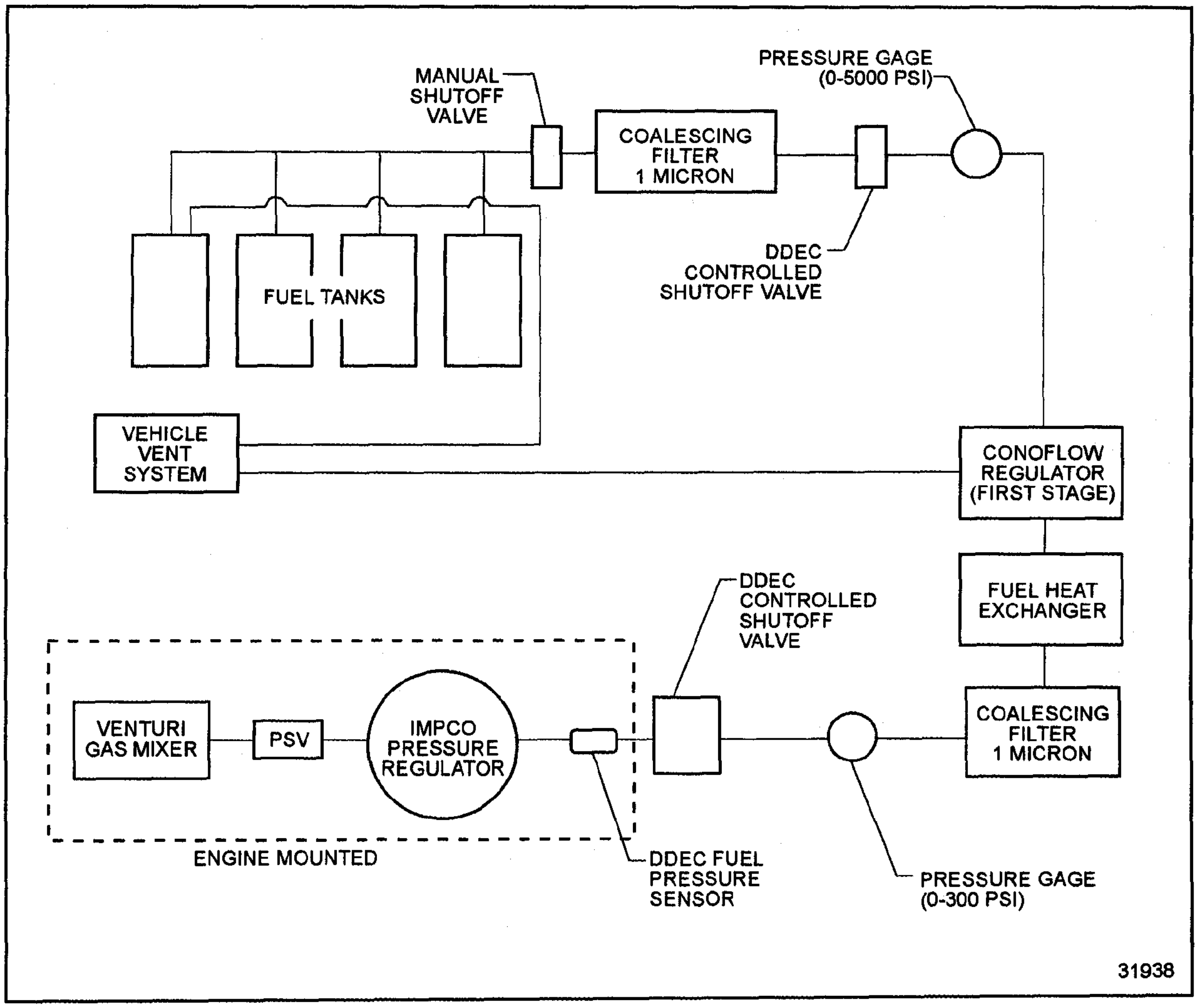

Figure 2-120 High Pressure Fuel Regulator for Series 60G Engines

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2.41.1 Replacement of the High Pressure Regulator for the Series 60G Engine

The high pressure fuel regulator is not serviceable and should be replaced as a unit. No adjustment is required.

2.41.2 Removal of the High Pressure Regulator for the Series 60G Engine

Remove the high pressure fuel regulator as follows:

1. Vent fuel system, refer to section 2.49.
2. Disconnect fuel supply pipe at regulator inlet.
3. Disconnect fuel pipe from regulator outlet.
4. Drain coolant.
5. Disconnect coolant supply and return hoses at regulator.
6. Disconnect vent pipe at regulator.
7. Remove two M8 bolts attaching the regulator to its mounting bracket.
8. Remove regulator from bracket and remove fittings for reuse.

2.41.3 Installation of the High Pressure Regulator for the Series 60G Engine

Install the high pressure fuel regulator as follows:

1. Install gas inlet and outlet O-ring fittings.
2. Position regulator on mounting bracket.
3. Install two M8 mounting bolts.
4. Connect fuel outlet pipe.
5. Connect fuel supply pipe.
6. Connect coolant supply and return hoses.
7. Refill with coolant.
8. Connect vent pipe.
9. Open fuel shutoff valves and crank engine to supply fuel to regulator.
10. Check for leaks, refer to section 2.48.

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2.42 PULSE WIDTH MODULATED STEPPER MOTOR VALVE (PSV) FOR SERIES 60G AUTOMOTIVE ENGINES

A pulse width modulated stepper motor valve (PSV) is used to bias gas flow to the venturi mixer as a means of air fuel ratio control. The PSV is connected to the low pressure regulator through a special connector tube with two O-rings that seal against the inside diameter of the gas inlet port in the PSV. It is mounted to the mixer housing with four attaching bolts and uses an O-ring to seal the mounting flange. Gas flows through the PSV housing.

The gas outlet passage in the PSV is intersected by a bore in which a piston operates. Gas flow is controlled by precise positioning of the piston and the amount that the piston protrudes into the gas outlet passage. Greater protrusion into the gas passage increases restriction and results in reduced gas flow and a leaner air fuel ratio. Similarly, less protrusion reduces restriction resulting in higher gas flow and a richer are fuel mixture.

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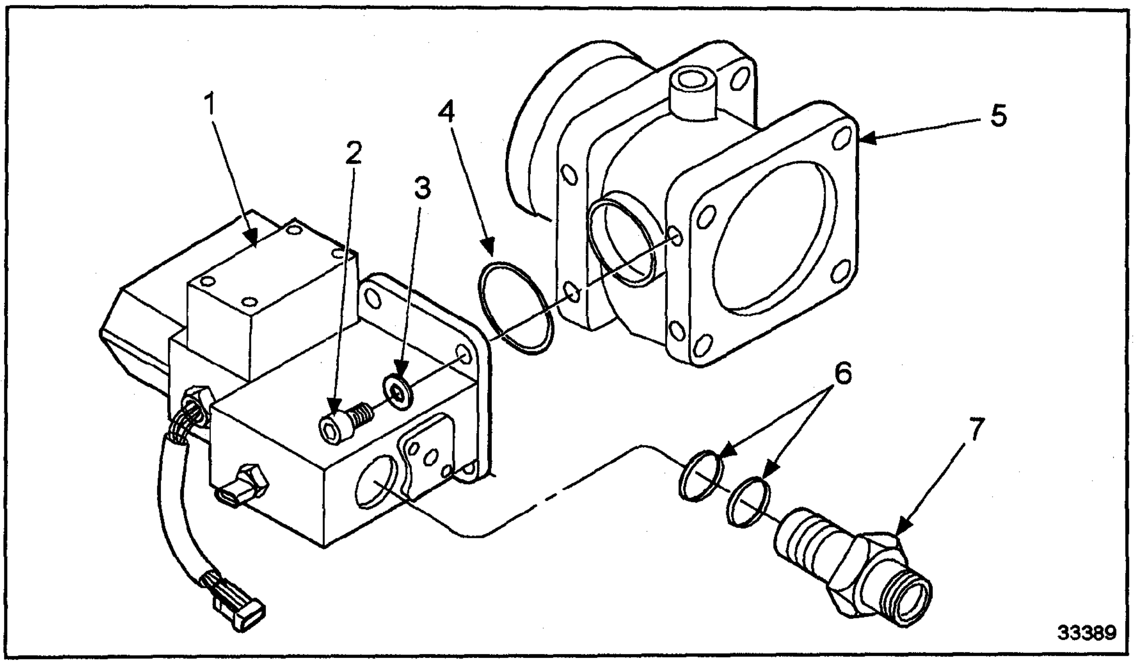
The piston is driven by a stepper motor which positions the piston based on a (PWM) position command signal from DDEC. The PSV is electrically connected to the ECM and 12–volt battery power through a seven—pin connector that mates to the engine sensor harness. The PSV supplies a "gas valve position" analog signal to DDEC which can be monitored using the diagnostic data reader (DDR). The signal indicates valve opening position and is scaled from 0 to 100 percent. A diagnostic signal is supplied to DDEC for loss of command signal, piston obstruction or valve electronics failure. See Figure 2-121.



1. PSV
2. Bolt
3. Washer
4. PSV O-ring
5. Mixer
6. Connector O-rings
7. Connector Tube

Figure 2-121 Series 60G Automotive PSV 1998 and Later Engines

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2.42.1 Replacement of Pulse Width Modulated Stepper Motor Valve for the Series 60G Engine

The PSV is non-serviceable and should be replaced as a unit. No adjustment is required.

2.42.2 Removal of Pulse Width Modulated Stepper Motor Valve for the Series 60G Engine

Remove the PSV as follows:

CAUTION:

To avoid injury from the explosion of natural gas, the engine must be kept in a well-ventilated area away from open flames, sparks, and electrical resistance (heating) coils.

1. Vent fuel system; refer to section 2.49.
2. Disconnect the seven-wire connector from the engine sensor wiring harness.
3. Remove the four bolts connecting the PSV to the fuel mixer.
4. Slide the PSV forward to separate from the connecting tube.

2.42.3 Installation of Pulse Width Modulated Stepper Motor Valve for the Series 60G Engine

Install the PSV as follows:

1. Lubricate connector O-rings and PSV O-ring.
2. Loosen bolts attaching fuel mixer to throttle.

NOTE:
The bolt holes in the throttle are slotted to allow adjustment to align the PSV with the connector tube in the low pressure regulator.

3. Position PSV against the mixer with O-ring in place and align gas inlet port with connector. Slide rearward to engage connector until bolts holes are aligned.
4. Secure PSV to the fuel mixer with four bolts and torque to 20 N·m (15 lb·ft).
5. Tighten fuel mixer to throttle attaching bolts.

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CAUTION:

To avoid injury from an explosion of natural gas, the following precautions must be taken:

- **Do not smoke when installing or servicing the engine or fuel system.**
- **Installation or servicing of natural-gas equipment must only be conducted in well-ventilated, natural gas compatible areas. Do not install or service equipment in an enclosed area where ignition sources are present without first ensuring that an undetected gas leak may be safely vented without being ignited.**
- **Bleed natural gas lines before installing or servicing any component connected to the fuel lines.**
- **Natural gas fuel systems are pressurized. Relieve pressure from any fuel system component prior to installation or service of that component.**
- **Use a combustible-gas detector. Liquefied natural gas (LNG) is odorless and cannot be detected by smell. Compressed Natural gas (CNG) may be odorless and may not be detected by smell.**
- **Equipment fuel systems are the responsibility of the Original Equipment Manufacturer (OEM). Equipment fuel system guidelines must be closely adhered to when installing or servicing equipment. Refer to OEM guidelines specifying which maintenance procedures require venting of fuel lines and fuel tanks.**
- **LNG systems are pressurized and contain extremely cold (-260°F [-162°C]) fluids. Contact the fuel supplier or OEM for LNG safety requirements. Contact with LNG may cause personal injury (freezing).**
- **Vent systems on the equipment should be ducted to a safe area whenever equipment is in an enclosed area.**

Natural gas is highly flammable and explosive and may be extremely cold (-260°F [-162°C]).

6. Clear AFR learn table using the Diagnostic Data Reader (DDR).
7. Check for diagnostic codes using DDR.
8. Check for leaks, refer to section 2.49.

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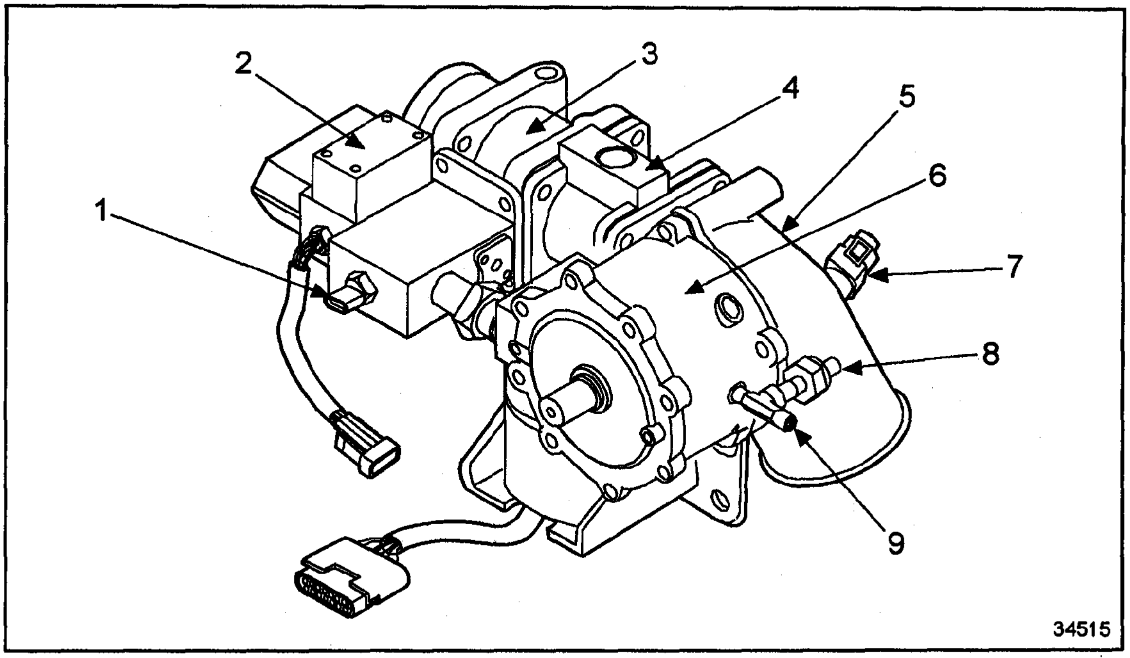
2.43 FUEL MIXER FOR THE SERIES 60G HIGH PRESSURE FUEL SYSTEM

The venturi fuel mixer assembly consists of a die cast aluminum body with a spun aluminum venturi permanently inserted into it. The unit has no moving parts. The mixer assembly is attached to the throttle located at the left front of the engine. See Figure 2-122.



1. Fuel Temperature Sensor
2. PSV
3. Fuel Mixer
4. Throttle
5. Air Inlet Elbow
6. Low Pressure Regulator
7. Air Temperature Sensor
8. Fuel Pressure Sensor
9. Fuel Inlet Tee-Fitting

Figure 2-122 Fuel Mixer for the Series 60G Engine

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2.43.1 Replacement of Fuel Mixer for the Series 60G Engine High Pressure Fuel System

The fuel mixer is non-serviceable and should be replaced as a unit. No adjustment is required.

2.43.2 Removal of Fuel Mixer for the Series 60G Engine High Pressure Fuel System

Remove the fuel mixer as follows:

CAUTION:

To avoid injury from the explosion of natural gas, the engine must be kept in a well-ventilated area away from open flames, sparks, and electrical resistance (heating) coils.

1. Vent fuel system; refer to section 2.49.1and refer to section 2.49.2.
2. Disconnect hose between mixer and charge cooler outlet tube.
3. Disconnect and remove the PSV from the fuel mixer, refer to section 2.42.2.
4. Disconnect air balance hose at mixer.
5. Remove four fuel mixer mounting bolts.
6. Separate and remove the fuel mixer from the throttle.

2.43.3 Installation of Fuel Mixer for the Series 60G Engine High Pressure Fuel System

Install the fuel mixer as follows:

1. Clean gasket surface and install a new gasket.
2. Secure the fuel mixer to the throttle with four bolts finger-tight.
3. Install the PSV to the fuel mixer, refer to section 2.42.3.
4. Connect air balance hose to PSV and mixer.
5. Torque mixer bolts to 20 N·m (15 lb·ft).
6. Connect hose between mixer and charge cooler outlet tube.

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CAUTION:

To avoid injury from an explosion of natural gas, the following precautions must be taken:

- **Do not smoke when installing or servicing the engine or fuel system.**
- **Installation or servicing of natural-gas equipment must only be conducted in well-ventilated, natural gas compatible areas. Do not install or service equipment in an enclosed area where ignition sources are present without first ensuring that an undetected gas leak may be safely vented without being ignited.**
- **Bleed natural gas lines before installing or servicing any component connected to the fuel lines.**
- **Natural gas fuel systems are pressurized. Relieve pressure from any fuel system component prior to installation or service of that component.**
- **Use a combustible-gas detector. Liquefied natural gas (LNG) is odorless and cannot be detected by smell. Compressed Natural gas (CNG) may be odorless and may not be detected by smell.**
- **Equipment fuel systems are the responsibility of the Original Equipment Manufacturer (OEM). Equipment fuel system guidelines must be closely adhered to when installing or servicing equipment. Refer to OEM guidelines specifying which maintenance procedures require venting of fuel lines and fuel tanks.**
- **LNG systems are pressurized and contain extremely cold (-260°F [-162°C]) fluids. Contact the fuel supplier or OEM for LNG safety requirements. Contact with LNG may cause personal injury (freezing).**
- **Vent systems on the equipment should be ducted to a safe area whenever equipment is in an enclosed area.**

Natural gas is highly flammable and explosive and may be extremely cold (-260°F [-162°C]).

7. Perform a leak check procedure. Refer to section 2.49.3.

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2.44 FUEL SHUTOFF VALVE FOR SERIES 60G ENGINE WITH HIGH PRESSURE FUEL SYSTEM

The fuel shutoff valve is typically mounted in the engine compartment close to the low pressure fuel regulator. The function of the valve is to shutoff fuel at the inlet to the regulator. The valve is powered by an electric solenoid. The valve is normally closed and is available with either 12–volt or 24–volt solenoids.

Electrical power to the solenoid is controlled by both DDEC and vehicle electrical systems. The DDEC ECM supplies a signal to open the valve when ignition is on and engine speed is above 60 rpm. The valve is closed when ignition is switched off, or when engine speed falls below 60 rpm or when an engine protection shutdown occurs. Vehicle systems typically tie power to the valve with the ignition switch and other safety systems such as fire suppression or methane (gas leakage) detection systems. The solenoid power is supplied through the vehicle wire harness. The gas inlet and outlet are female 1/2–inch NPTF connections. The shutoff valve comes with a mounting bracket attached. See Figure 2-123.

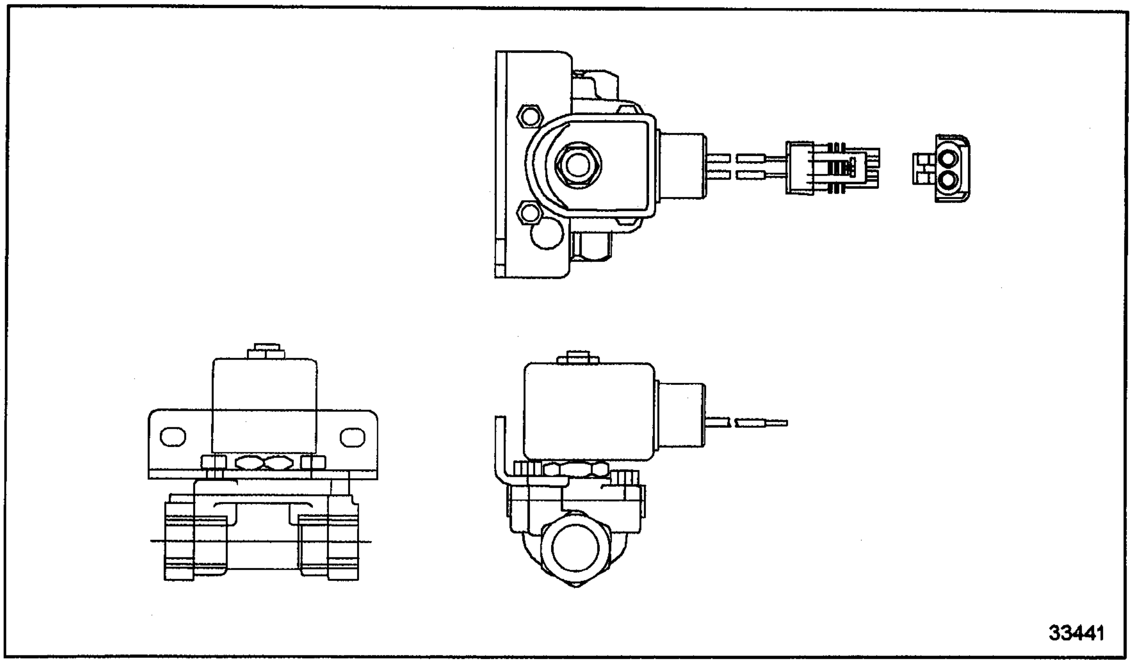

Figure 2-123 Fuel Shutoff Valve for Series 60G Engine

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2.44.1 Replacement of the Fuel Shutoff Valve for the Series 60G Engine

The fuel shutoff valve is not serviceable and should be replaced as a unit. No adjustment is required.

2.44.2 Removal of the Fuel Shutoff Valve for the Series 60G Engine

Remove the fuel shutoff valve as follows:

1. Vent fuel system, refer to section 2.49.
2. Disconnect fuel supply pipe at shutoff inlet.
3. Disconnect fuel pipe from shutoff outlet.
4. Disconnect electrical connector.
5. Remove two bolts attaching the shutoff valve bracket to its mounting bracket and remove shutoff valve and bracket assembly.

2.44.3 Installation of the Fuel Shutoff Valve for the Series 60G Engine

Install the fuel shutoff valve as follows:

1. Install gas inlet and outlet fittings.
2. Position shutoff valve on mounting bracket.
3. Install mounting bolts.
4. Connect fuel outlet hose to outlet fitting.
5. Connect fuel supply pipe to inlet fitting.
6. Connect solenoid electrical connector to connector in vehicle wire harness.
7. Open manual fuel shutoff valves and crank engine to supply fuel.
8. Check for leaks, refer to section 2.49.3.

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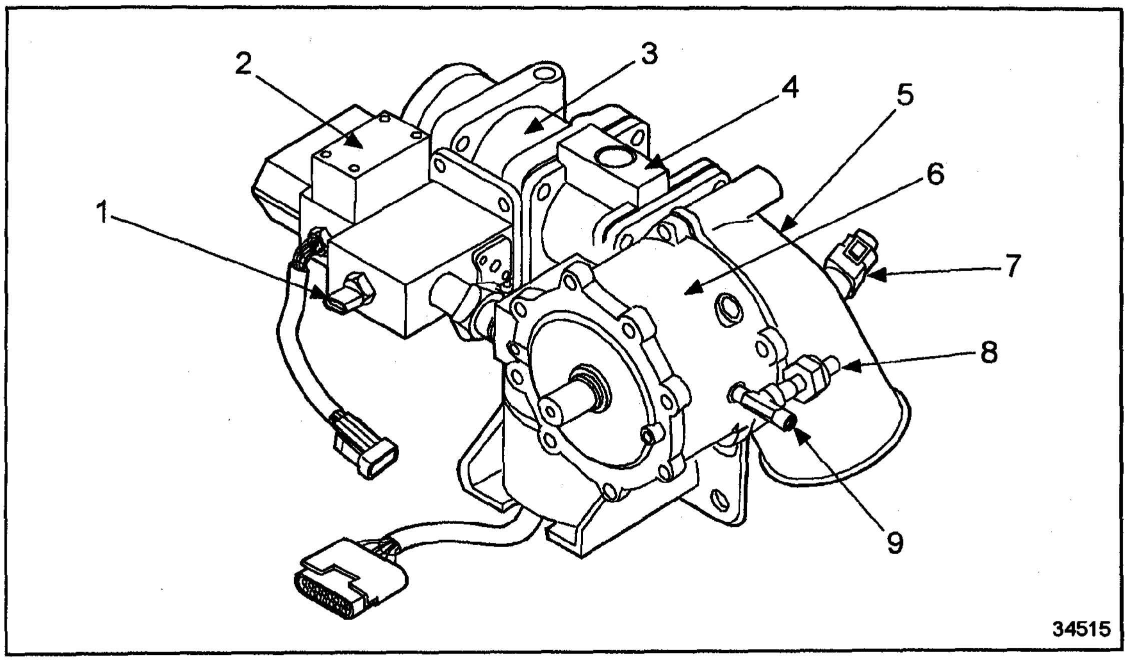
2.45 IMPCO LOW PRESSURE FUEL REGULATOR FOR THE SERIES 60G ENGINE HIGH PRESSURE FUEL SYSTEM

The IMPCO® low pressure regulator is mounted to the air inlet elbow at the front left side of the engine. The gas inlet connection is a 1/4–in. NPTF pipe thread and is connected through a special natural gas compatible No. 8 hose to the low pressure DDEC controlled fuel shutoff valve. The gas outlet connection is a one—inch NPTF pipe thread and is mated to the inlet of the PSV through a special tube connector. The regulator is heated by engine coolant. The regulator outlet fuel pressure is balanced to turbo boost pressure at the mixer inlet. This pressure is communicated to the regulator through a No. 8 hose that connects to a 1/8–in. NPTF pipe thread hole in the regulator cover and to a 1/4–in. pipe thread connection in the top of the mixer housing.

IMPCO® is a registered trademark of IMPCO Technologies, Inc.

The purpose of the regulator is to provide a controlled flow of natural gas to maintain regulator outlet fuel pressure at a pressure nearly equal to air pressure (turbo boost) at the inlet to the mixer. Gas enters the regulator at a pressure of approximately 110 PSI. See Figure 2-124.



1. Fuel Temperature Sensor
2. PSV
3. Fuel Mixer
4. Throttle
5. Air Inlet Elbow
6. Low Pressure Regulator
7. Air Temperature Sensor
8. Fuel Pressure Sensor
9. Fuel Inlet Tee-Fitting

Figure 2-124 60G Throttle with Integrated Actuator

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2.45.1 Replacement of the Low Pressure Regulator for the Series 60G Engine

The low pressure fuel regulator is not serviceable and should be replaced as a unit. No adjustment is required.

2.45.2 Removal of the Low Pressure Regulator for the Series 60G Engine

Remove the low pressure fuel regulator as follows:

CAUTION:
To avoid injury from the explosion of natural gas, the engine must be kept in a well-ventilated area away from open flames, sparks, and electrical resistance (heating) coils.

1. Vent fuel system, refer to section 2.49.
2. Disconnect fuel supply hose at the regulator.
3. Disconnect fuel pressure sensor from engine sensor wiring harness.
4. Drain coolant.
5. Disconnect coolant supply and return hoses at regulator.
6. Disconnect air balance hose at regulator cover.
7. Remove two M6 regulator to air inlet elbow mounting bolts. Support regulator to avoid cocking the connector tube in the PSV and possibly damaging the PSV gas inlet bore.
8. Slide regulator rearward to disengage outlet connector tube from the PSV.
9. Remove gas inlet tee, fuel pressure sensor, coolant inlet fittings, coolant outlet fittings, balance hose fitting, outlet connector tube and O-rings for reuse.

2.45.3 Installation of the Low Pressure Regulator for the Series 60G Engine

Install the low pressure fuel regulator as follows:

NOTICE:
Use caution when installing hoses to avoid twisting or kinking the hose. This could result in increased flow restriction and affect engine performance.

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CAUTION:

To avoid injury from an explosion of natural gas, the following precautions must be taken:

- **Do not smoke when installing or servicing the engine or fuel system.**
- **Installation or servicing of natural-gas equipment must only be conducted in well-ventilated, natural gas compatible areas. Do not install or service equipment in an enclosed area where ignition sources are present without first ensuring that an undetected gas leak may be safely vented without being ignited.**
- **Bleed natural gas lines before installing or servicing any component connected to the fuel lines.**
- **Natural gas fuel systems are pressurized. Relieve pressure from any fuel system component prior to installation or service of that component.**
- **Use a combustible-gas detector. Liquefied natural gas (LNG) is odorless and cannot be detected by smell. Compressed Natural gas (CNG) may be odorless and may not be detected by smell.**
- **Equipment fuel systems are the responsibility of the Original Equipment Manufacturer (OEM). Equipment fuel system guidelines must be closely adhered to when installing or servicing equipment. Refer to OEM guidelines specifying which maintenance procedures require venting of fuel lines and fuel tanks.**
- **LNG systems are pressurized and contain extremely cold (-260°F [-162°C]) fluids. Contact the fuel supplier or OEM for LNG safety requirements. Contact with LNG may cause personal injury (freezing).**
- **Vent systems on the equipment should be ducted to a safe area whenever equipment is in an enclosed area.**

Natural gas is highly flammable and explosive and may be extremely cold (-260°F [-162°C]).

1. Install gas inlet tee, fuel pressure sensor, coolant inlet fittings, coolant outlet fittings, balance hose fitting, outlet connector tube and O-rings.
2. Lubricate connector O-rings.

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3. Position regulator on air inlet elbow with outlet connector aligned with bore in PSV. Slide regulator forward engaging outlet tube in PSV until regulator mounting bolt holes are aligned.
4. Install two M6 mounting bolts.
5. Connect fuel supply hose.
6. Connect coolant supply and return hoses.
7. Refill with coolant.
8. Connect air balance hose.
9. Connect fuel pressure sensor to engine sensor wiring harness.
10. Clear AFR learn table using DDR.
11. Start engine and check hoses and fitting for leaks. Refer to section 2.37.3.

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2.46 OVERVIEW OF THE LOW PRESSURE NATURAL GAS FUEL SYSTEM

The purpose of the fuel system is to store the fuel, keep it clean and free from air, water, or other impurities and to deliver it to the combustion chamber at the correct pressure, temperature, air and fuel mixture. The Series 60G engine requires an adequate fuel supply for proper performance and to develop full-rated power. This section describes the Detroit Diesel Series 60G compressed natural gas fuel system.

The following are DDC supplied parts:

- ☐ Pulse width modulated stepper motor valve (PSV)
- ☐ Low pressure regulator
- ☐ Venturi fuel mixer
- ☐ Regulator hoses
- ☐ Air inlet tube

The following are OEM supplied parts:

- ☐ Gas inlet pipe
- ☐ Genset controlled gas shutoff valve

The fuel system uses computer calculations for both fuel flow and air flow, while maintaining a lean air - fuel mixture for low emissions and good fuel economy. Calculations are based on knowing the temperature of the air and fuel along with the temperature and pressure of the fuel and air mixture in the inlet manifold. The air temperature sensor is located in the air intake tube located in front of the gas mixer. The fuel temperature sensor is located in the gas mixer. An intake manifold pressure sensor is located in the intake manifold. See Figure 2-125.

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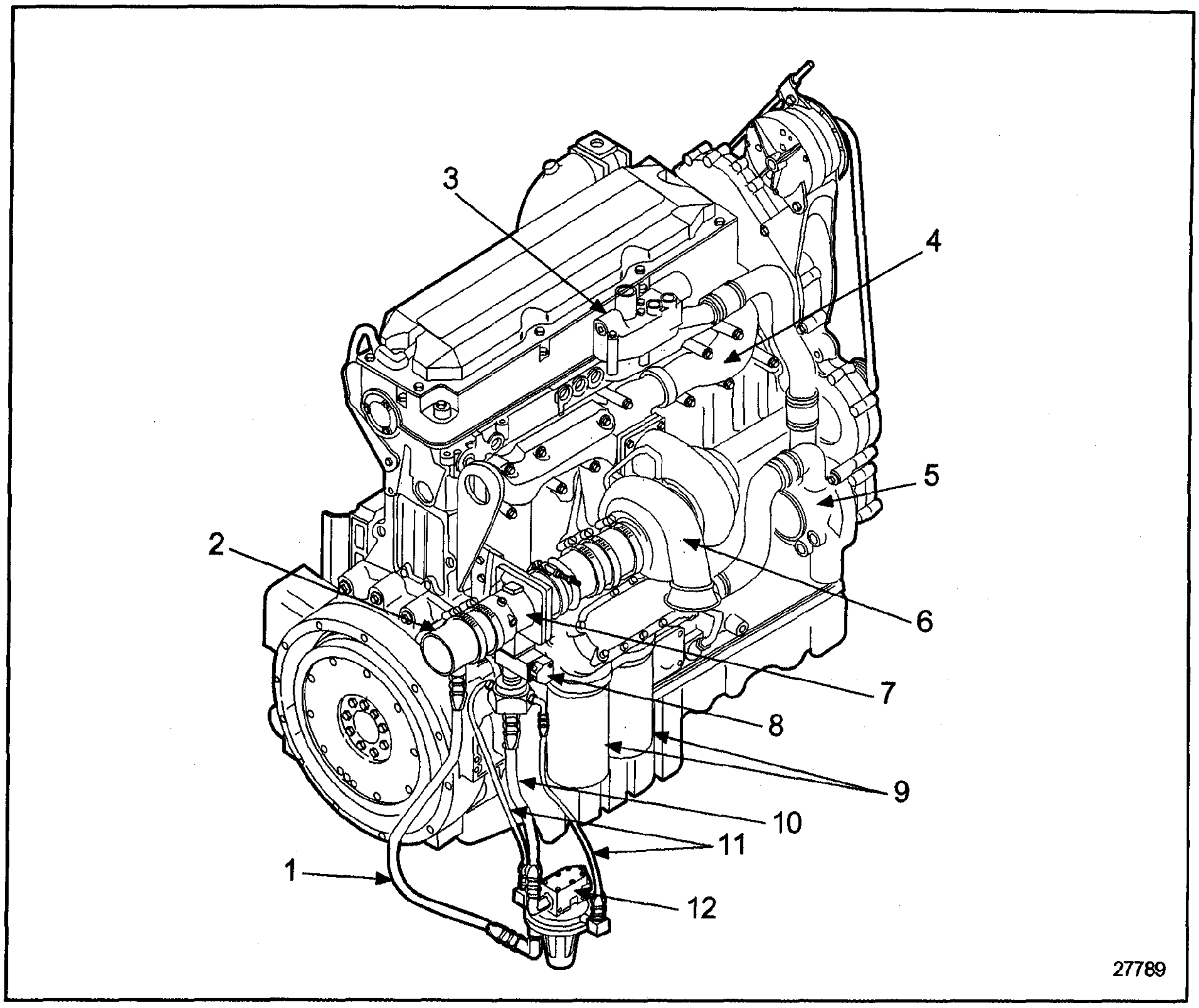

1. Air Balance Hose
2. Air Inlet Tube
3. Thermostat Housing
4. Exhaust Manifold
5. Fresh Water Pump
6. Turbocharger
7. Fuel Mixer Assembly
8. Pulse Width Modulated Stepper Motor Valve (PSV)
9. Lube Oil Filters
10. Fuel Supply Hose
11. Fuel Balance Hoses
12. Low Pressure Regulator

Figure 2-125 Low Pressure Fuel System (Series 60G Engine)

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CAUTION:

To avoid injury from an explosion of natural gas, the following precautions must be taken:

- ☐ **Do not smoke when installing or servicing the engine or fuel system.**
- ☐ **Installation or servicing of natural-gas equipment must only be conducted in well-ventilated, natural gas compatible areas. Do not install or service equipment in an enclosed area where ignition sources are present without first ensuring that an undetected gas leak may be safely vented without being ignited.**
- ☐ **Bleed natural gas lines before installing or servicing any component connected to the fuel lines.**
- ☐ **Natural gas fuel systems are pressurized. Relieve pressure from any fuel system component prior to installation or service of that component.**
- ☐ **Use a combustible-gas detector. Liquefied natural gas (LNG) is odorless and cannot be detected by smell. Compressed Natural gas (CNG) may be odorless and may not be detected by smell.**
- ☐ **Equipment fuel systems are the responsibility of the Original Equipment Manufacturer (OEM). Equipment fuel system guidelines must be closely adhered to when installing or servicing equipment. Refer to OEM guidelines specifying which maintenance procedures require venting of fuel lines and fuel tanks.**
- ☐ **LNG systems are pressurized and contain extremely cold (-260°F [-162°C]) fluids. Contact the fuel supplier or OEM for LNG safety requirements. Contact with LNG may cause personal injury (freezing).**
- ☐ **Vent systems on the equipment should be ducted to a safe area whenever equipment is in an enclosed area.**

Natural gas is highly flammable and explosive and may be extremely cold (-260°F [-162°C]).

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CAUTION:

To avoid injury from the explosion of natural gas, the engine must be kept in a well-ventilated area away from open flames, sparks, and electrical resistance (heating) coils.

The Series 60 natural gas engine low pressure fuel system consists of a venturi type fuel mixer, Pulsewidth Modulated Stepper Motor Valve (PSV), and low pressure regulator. It is referred to as a "demand" system in that the venturi mixer generates a suction at the regulator outlet. The regulator adjusts its outlet pressure in response to the demand (suction) of the venturi resulting in an increase of fuel flow. The opposite is true for conditions requiring a decrease in fuel flow. See Figure 2-126.

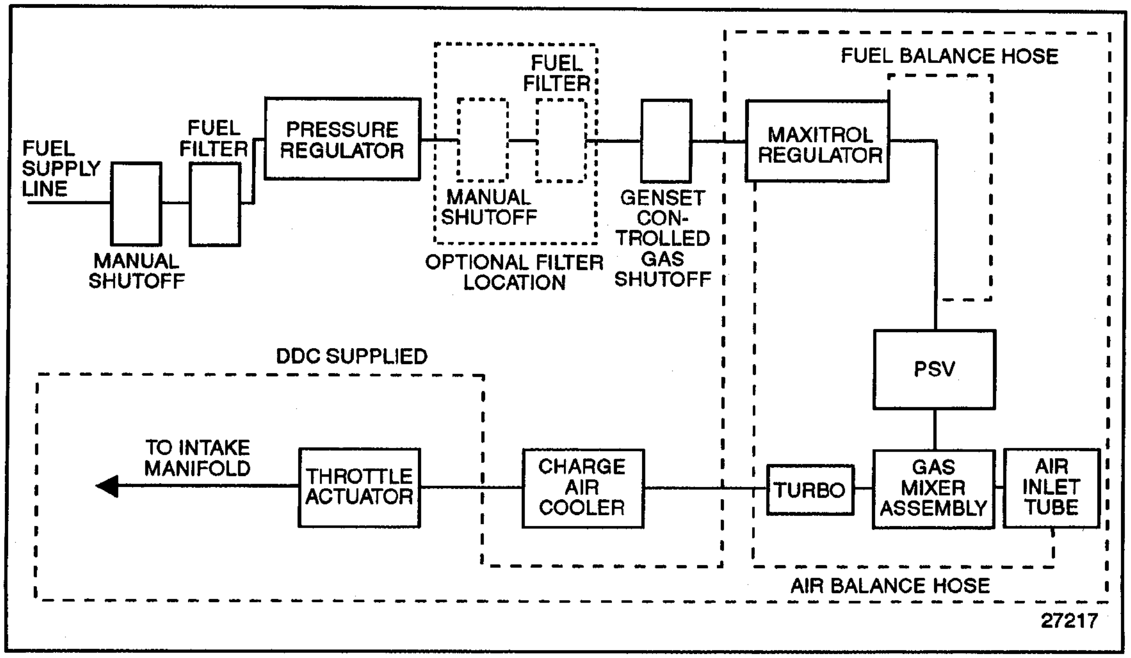

Figure 2-126 Low Pressure Natural Gas Fuel System (Series 60G Engine)

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Fuel supply is routed to the inlet side of the low pressure regulator at a pressure of 1-5 kPa (5-20 in. H_2O). The low pressure regulator is a balanced regulator and as such, reduces this pressure to a level approximately equal to air inlet pressure.

Regulated fuel is routed from the low pressure regulator to the PSV. The PSV is fully controlled by DDEC III/IV and is used to bias fuel flow, rich or lean, based on a predetermined engine calibration.

Fuel from the PSV enters the venturi mixer where it is drawn into and mixed with the airstream ahead of the turbocharger compressor inlet, charge air cooler, throttle and intake manifold.

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2.47 LOW PRESSURE FUEL REGULATOR FOR THE SERIES 60G ENGINE

The low pressure fuel regulator is mounted on the generator base on the right side of the engine. This location minimizes the distance between the regulator outlet and the inlet of the PSV. There are four hoses connecting the regulator to the engine; the fuel supply, one air balance and two fuel balance hoses. See Figure 2-125.

2.47.1 Reuse or Replacement of the Low Pressure Fuel Regulator for the Series 60G Engine

The low pressure fuel regulator is not serviceable and should be replaced as a unit. No adjustment is required.

2.47.2 Removal of the Low Pressure Fuel Regulator for the Series 60G Engine

Remove the low pressure fuel regulator as follows:

CAUTION:
To avoid injury from the explosion of natural gas, the engine must be kept in a well-ventilated area away from open flames, sparks, and electrical resistance (heating) coils.

1. Vent fuel system; refer to section 2.49.1and refer to section 2.49.2.
2. Disconnect and remove 1 in. air balance hose.
3. Disconnect and remove the two 3/8 in. fuel balance lines.
4. Disconnect and remove the 1 1/4 in. fuel supply line.
5. Remove the low pressure fuel regulator and fuel inlet pipe from the mounting bracket.
6. Remove fuel inlet pipe from regulator.

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2.47.3 Disassembly of the Low Pressure Fuel Regulator for the Series 60G Engine

Disassembly of the low pressure fuel regulator is not required.

2.47.4 Cleaning of the Low Pressure Fuel Regulator for the Series 60G Engine

Cleaning of the low pressure fuel regulator is not required.

2.47.4.1 Inspection of the Low Pressure Fuel Regulator for the Series 60G Engine

Inspection of the low pressure fuel regulator is not required.

2.47.4.2 Test of the Low Pressure Fuel Regulator for the Series 60G Engine

Test of the low pressure fuel regulator is not required.

2.47.5 Installation of the Low Pressure Fuel Regulator for the Series 60G Engine

Install the low pressure fuel regulator as follows:

1. Install fuel inlet pipe into the regulator.
2. Secure the low pressure fuel regulator and inlet pipe to the mounting bracket.
3. Connect the 1 1/4 in. fuel supply line.

NOTICE:
Use caution when installing hoses to avoid twisting or kinking the hose. This could result in increased flow restriction and affect engine performance.

4. Connect the two 3/8 in. fuel pressure balance lines.
5. Connect the 1 in. air balance line.

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CAUTION:

To avoid injury from an explosion of natural gas, the following precautions must be taken:

- **Do not smoke when installing or servicing the engine or fuel system.**
- **Installation or servicing of natural-gas equipment must only be conducted in well-ventilated, natural gas compatible areas. Do not install or service equipment in an enclosed area where ignition sources are present without first ensuring that an undetected gas leak may be safely vented without being ignited.**
- **Bleed natural gas lines before installing or servicing any component connected to the fuel lines.**
- **Natural gas fuel systems are pressurized. Relieve pressure from any fuel system component prior to installation or service of that component.**
- **Use a combustible-gas detector. Liquefied natural gas (LNG) is odorless and cannot be detected by smell. Compressed Natural gas (CNG) may be odorless and may not be detected by smell.**
- **Equipment fuel systems are the responsibility of the Original Equipment Manufacturer (OEM). Equipment fuel system guidelines must be closely adhered to when installing or servicing equipment. Refer to OEM guidelines specifying which maintenance procedures require venting of fuel lines and fuel tanks.**
- **LNG systems are pressurized and contain extremely cold (-260°F [-162°C]) fluids. Contact the fuel supplier or OEM for LNG safety requirements. Contact with LNG may cause personal injury (freezing).**
- **Vent systems on the equipment should be ducted to a safe area whenever equipment is in an enclosed area.**

Natural gas is highly flammable and explosive and may be extremely cold (-260°F [-162°C]).

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NOTICE:
When installing the low pressure fuel regulator components which supply the natural gas, apply an aerobic pipe sealant containing Teflon such as SWAK®to the component threads. Never apply sealant to the compression fittings.

NOTICE:
After installation of the low pressure fuel regulator, always check for leaks with a soapy water solution or equivalent.

6. Check hoses and fittings for leaks; refer to section 2.49.3.

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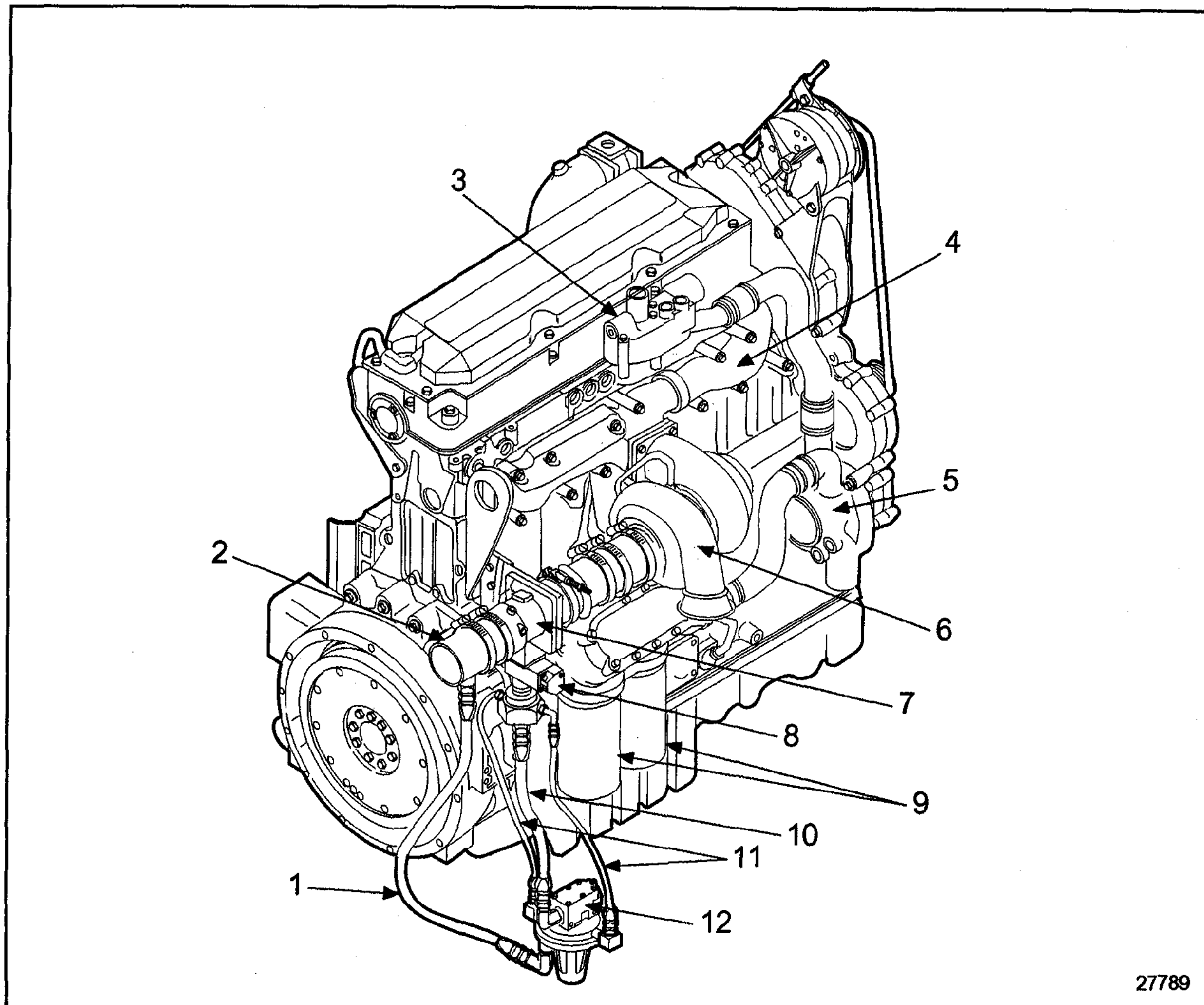
2.48 FUEL MIXER FOR THE SERIES 60G LOW PRESSURE SYSTEM

The venturi fuel mixer assembly consists of a die cast aluminum body with a spun aluminum venturi permanently inserted into it. The unit has no moving parts. The mixer assembly is attached to support brackets and located at the right rear of the engine. See Figure 2-127.



1. Air Balance Hose
2. Air Inlet Tube
3. Thermostat Housing
4. Exhaust Manifold
5. Fresh Water Pump
6. Turbocharger
7. Fuel Mixer Assembly
8. Pulse Width Modulated Stepper Motor Valve (PSV)
9. Lube Oil Filters
10. Fuel Supply Hose
11. Fuel Balance Hoses
12. Low Pressure Regulator

Figure 2-127 Low Pressure Fuel System (Series 60G Engine)

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2.48.1 Replacement of Fuel Mixer for the Series 60G (Low Pressure System)

The fuel mixer is non-serviceable and should be replaced as a unit. No adjustment is required.

2.48.2 Removal of Fuel Mixer for the Series 60G (Low Pressure System)

Remove the fuel mixer as follows:

CAUTION:
To avoid injury from the explosion of natural gas, the engine must be kept in a well-ventilated area away from open flames, sparks, and electrical resistance (heating) coils.

1. Vent fuel system; refer to section 2.49.1and refer to section 2.49.2.
2. Disconnect and remove the PSV from the fuel mixer, refer to section 2.42.2.
3. Remove four fuel mixer mounting bolts.
4. Separate and remove the fuel mixer from the mounting bracket.

2.48.3 Disassembly of Fuel Mixer for the Series 60G (Low Pressure System)

Disassembly of the fuel mixer is not required.

2.48.4 Cleaning of Fuel Mixer for the Series 60G (Low Pressure System)

Cleaning of the fuel mixer is not required.

2.48.4.1 Inspection of Fuel Mixer for the Series 60G (Low Pressure System)

Inspection of the fuel mixer is not required.

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2.48.4.2 Test of Fuel Mixer for the Series 60G (Low Pressure System)

Test of the fuel mixer is not required.

2.48.5 Installation of Fuel Mixer for the Series 60G (Low Pressure System)

Install the fuel mixer as follows:

1. Clean gasket surface and install a new gasket.
2. Secure the fuel mixer to the mounting bracket with four bolts. Torque to 20 N·m (15 lb·ft).
3. Install the PSV to the fuel mixer, refer to section 2.42.3.
4. Install air inlet hose and secure with V-band clamp. This hose must be of the current design that has a black interior surface. All former hoses have a blue interior surface and must be replaced. Also, the part number is printed on the exterior surface of the hose.
5. Perform a leak check procedure. Refer to section 2.49.3.

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2.49 VENTING AND LEAK CHECKING PROCEDURES FOR NATURAL GAS ENGINE (LOW PRESSURE SYSTEM)

Refer to section 2.49.1 for venting and checking of an operable engine and refer to section 2.49.2 for venting and checking of an inoperable engine.

2.49.1 Venting an Operable Engine to Relieve Natural Gas Pressure

If the engine *can run*, use the following venting procedure to relieve the natural gas pressure downstream of the shutoff valve:

CAUTION:

To avoid injury from the explosion of natural gas, the engine must be kept in a well-ventilated area away from open flames, sparks, and electrical resistance (heating) coils.

1. Turn off manual shutoff valve on natural gas fuel supply line.
2. Start engine and run until it stalls due to fuel starvation.
3. Disconnect the batteries using switch(s) in the battery compartment or by disconnecting the battery ground cable.
4. Slightly loosen the NG fuel line fitting to be serviced in a well-ventilated area to allow any remaining gas to vent.
5. Completely open the fitting that was slightly opened and allow to vent in a well-ventilated area.

2.49.2 Venting an Inoperable Engine to Relieve Natural Gas Pressure

If the engine *cannot run*, use the following venting procedure to relieve the natural gas pressure downstream of the shutoff valve:

CAUTION:

To avoid injury from the explosion of natural gas, the engine must be kept in a well-ventilated area away from open flames, sparks, and electrical resistance (heating) coils.

1. Turn off manual shutoff valve on natural gas fuel supply line.
2. Disconnect the batteries using switch(s) in the battery compartment or by disconnecting the battery ground cable.

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3. Open fitting (before and after genset shutoff valve) to assure all pressure has been relieved in the natural gas fuel line.
4. Check all connections that were loosened for leaks after installation, service and troubleshooting are complete.

2.49.3 Leak Checking the Natural Gas Fuel System

Use the following steps to check for leaks:

1. Open manual shutoff valve.
2. Start engine and run with no electrical load on generator.
3. Spray soapy water or commercially available leak checking solutions on connections. Bubbles will form if there is a leak.
4. Repair any leak by:
   - [a] Shut down the engine and close the manual shut off valve.
   - [b] Tighten connection using the fitting technique of the manufacturer.

NOTE:
Vent fuel lines before replacing leaking components; refer to section 2.49.1 and refer to section 2.49.2. This will prevent a discharge of gas.

   - [c] Replace leaking component.
   - [d] Replace the pipe-threaded connector with a new one if the leak is a pipe thread connection. Use anaerobic sealant with Teflon (such as SWAK®) applied to the threads.
5. Re-check connection with procedure in step 1thru step 3.
6. Use a combustible gas detector to check for presence of natural gas. If natural gas is detected, continue looking for leaks until the locations of all the leaks are determined.
7. Repair the leak using the procedure in step 4.

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2.A ADDITIONAL INFORMATION

Description **Page**

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SHOP NOTES

The following shop notes describe flexible fuel lines and their installation.

Fuel Lines

Flexible fuel lines are used to facilitate connection of lines leading to and from the fuel tank, and to minimize the effects of any vibration in the installation.

An 0.080 in. restricted orifice is incorporated in the fuel return fitting (upper fitting) at the rear of the cylinder head to maintain fuel pressure in the cylinder head. Do not use restricted fittings anywhere else in the fuel system, and do not substitute a standard fitting for the restricted fitting.

The 0.080 in. restricted orifice is designed to provide the proper fuel system pressure under all conditions. Do not alter or substitute another size since this may alter engine performance and emissions.

When installing fuel lines, it is recommended that connections be tightened only sufficiently to prevent leakage of fuel; thus flared ends of the fuel lines will not become twisted or fractured because of excessive tightening. After all fuel lines are installed, run the engine long enough to determine if all the connections are sufficiently tight. If any leaks occur, tighten the connections only enough to stop the leak. Also check that the fuel filters are tight against the filter adaptors. Do not overtighten filters.

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SPECIFICATIONS

Specifications are listed in the General Information section at the beginning of the manual. Exceptions are listed below:

Exceptions to Standard Fastener Torque Specifications

Exceptions to Standard Fastener Torque Specifications supporting the Series 60 Engine are listed in Table 2-12 and also listed in Table 2-13.

Fastener	Size	Torque, N·m	Torque, lb·ft
Bolt, Injector Clamp	M10 x 1.5	55-66	43-49

Table 2-12 Exceptions to Standard Fastener Specifications

Fastener	Size	Torque, N·m	Torque, in.·lb
Bolt, Turbo Boost Sensor-to-inlet	M5 x 0.8	2.4-3.0	21-26
Screw, Harness Connector-to-EDU	No.10-24	2.4-3.0	21-26
Screw, Harness Connector-to-ECM	No.10-24	2.4-3.0	21-26
Screw, Injector Wire Connector	M3 x 0.5	1.4-2.0	12-18

Table 2-13 Exceptions to Standard Fastener Torque Specifications

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The following format must be used if submitting an electronic 2028. The subject line must be exactly the same and all fields must be included; however, only the following fields are mandatory: 1, 3, 4, 5, 6, 7, 8, 9, 10, 13, 15, 16, 17 and 27.

From: "Whomever" whomever@avma27.army.mil
To: whomever@avma27.army.mil
To: TACOM-TECH-PUBS@ria.army.mil

Subject:DA Form 2028

1. ***From:*** Joe Smith
2. ***Unit:*** home
3. ***Address:*** 4300 Park
4. ***City:*** Hometown
5. ***St:*** MO
6. ***Zip:*** 77777
7. ***Date Sent:*** 19-OCT-93
8. ***Pub no:*** 55-1915-200-10
9. ***Pub Title:*** TM
10. ***Publication Date:*** 11-APR-88
11. ***Change Number:*** 12
12. ***Submitter Rank:*** MSG
13. ***Submitter Fname:*** Joe
14. ***Submitter Mname:*** T
15. ***Submitter Lname:*** Smith
16. ***Submitter Phone:*** 123-123-1234
17. ***Problem:*** 1
18. ***Page:*** 1
19. ***Paragraph:*** 3
20. ***Line:*** 4
21. ***NSN:*** 5
22. ***Reference:*** 6
23. ***Figure:*** 7
24. ***Table:*** 8
25. ***Item:*** 9
26. ***Total:*** 123
27. ***Text:***

This is the text for the problem below line 27.

RECOMMENDED CHANGES TO PUBLICATIONS AND BLANK FORMS

For use of this form, see AR 310-1; the proponent agency is the US Army Adjutant General Center.

Use Part II *(reverse)* for Repair Parts and Special Tool Lists (RPSTL) and Supply Catalogs/Supply Manuals (SC/SM).

DATE: Date form is filled out.

TO: *(Forward to proponent of publication or form) (Include ZIP Code)*

Mailing address found on title block page.

FROM: *(Activity and location) (Include ZIP Code)*

Your mailing address.

PART I - ALL PUBLICATIONS (EXCEPT RPSTL AND SC/SM) AND BLANK FORMS

PUBLICATION/FORM NUMBER:	DATE:	TITLE:
TM X-XXXX-XXX-XXX	Date of the TM.	Title of TM.

ITEM NO.	PAGE NO.	PARA-GRAPH	LINE NO.	FIGURE NO.	TABLE NO.	RECOMMENDED CHANGES AND REASON (Exact wording of recommended change must be given)
	0019 00 1	3	1	1		Step No. 2 says to secure doors open with locking bar or hooks from where to what? The bars or hooks are not identified.
	0019 00 4	4	1	1		Step No. 19 states to remove locking bars, pins or hooks from where to what? The bars, pins or hooks are not identified. Where are they stored?

SAMPLE

* Reference to line numbers within the paragraph or subparagraph.

TYPED NAME, GRADE OR TITLE	TELEPHONE EXCHANGE/AUTOVON, PLUS EXTENSION	SIGNATURE
Doe, John, CPL	755-1313	*CPL John Doe*

TO: *(Forward to proponent of publication or form) (Include ZIP Code)*	**FROM:** *(Activity and location) (Include ZIP Code)*	**DATE:**

PART II- REPAIR PARTS AND SPECIAL TOOL LISTS AND SUPPLY CATALOGS/SUPPLY MANUALS

PUBLICATION/FORM NUMBER:	**DATE:**	**TITLE:**
TM X-XXXX-XXX-XXX	Date of the TM.	Title of TM.

PAGE NO.	**COLM NO.**	**LINE NO.**	**FEDERAL STOCK NUMBER**	**REFERENCE NO.**	**FIGURE NO.**	**ITEM NO.**	**TOTAL NO. OF MAJOR ITEMS SUPPORTED**	**RECOMMENDED ACTION**

SAMPLE

PART III - REMARKS *(Any general remarks or recommendations, or suggestions for improvement of publications and* blank forms. Additional blank sheets may be used if more space is needed.)

* Reference to line numbers within the paragraph or subparagraph.

TYPED NAME, GRADE OR TITLE	TELEPHONE EXCHANGE/AUTOVON, PLUS EXTENSION	SIGNATURE
Doe, John, CPL	755-1313	*CPL John Doe*

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RECOMMENDED CHANGES TO PUBLICATIONS AND BLANK FORMS For use of this form, see AR 310-1; the proponent agency is the US Army Adjutant General Center.	Use Part II *(reverse)* for Repair Parts and Special Tool Lists (RPSTL) and Supply Catalogs/Supply Manuals (SC/SM).	DATE:
TO: AMSTA-LC-CI / TECH PUBS, TACOM-RI, 1 Rock Island Arsenal, Rock Island, IL 61299-7630	FROM: *(Activity and location) (Include ZIP Code)*	

PART I - ALL PUBLICATIONS (EXCEPT RPSTL AND SC/SM) AND BLANK FORMS

PUBLICATION/FORM NUMBER:	DATE:	TITLE:
TM 55-1945-222-14&P-1	15 MAY 2004	Technical Manual Operator, Unit, Direct Support and General Support Maintenance Manual

ITEM NO.	PAGE NO.	PARA-GRAPH	LINE NO.	FIGURE NO.	TABLE NO.	RECOMMENDED CHANGES AND REASON (Exact wording of recommended change must be given)

* Reference to line numbers within the paragraph or subparagraph.

TYPED NAME, GRADE OR TITLE	TELEPHONE EXCHANGE/AUTOVON, PLUS EXTENSION	SIGNATURE

TO: *(Forward to proponent of publication or form) (Include ZIP Code)*

FROM: *(Activity and location) (Include ZIP Code)*

DATE:

PART II- REPAIR PARTS AND SPECIAL TOOL LISTS AND SUPPLY CATALOGS/SUPPLY MANUALS

PUBLICATION/FORM NUMBER:

DATE:

TITLE:

PAGE NO.	COLM NO.	LINE NO.	FEDERAL STOCK NUMBER	REFERENCE NO.	FIGURE NO.	ITEM NO.	TOTAL NO. OF MAJOR ITEMS SUPPORTED	RECOMMENDED ACTION

PART III - REMARKS *(Any general remarks or recommendations, or suggestions for improvement of publications and* blank forms. Additional blank sheets may be used if more space is needed.)

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TELEPHONE EXCHANGE/AUTOVON, PLUS EXTENSION

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By Order of the Secretary of the Army:

PETER J. SCHOOMAKER
General, United States Army
Chief of Staff

Official:

JOEL B. HUDSON
Administrative Assistant to the
Secretary of the Army
0410305

DISTRIBUTION: To be distributed in accordance with the initial distribution requirements for IDN: 256832, requirements for TM 55-1945-222-14&P-1.

The Metric System and Equivalents

Linear Measure

1 centimeter = 10 millimeters = .39 inch
1 decimeter = 10 centimeters = 3.94 inches
1 meter = 10 decimeters = 39.37 inches
1 dekameter = 10 meters = 32.8 feet
1 hectometer = 10 dekameters = 328.08 feet
1 kilometer = 10 hectometers = 3,280.8 feet

Weights

1 centigram = 10 milligrams = .15 grain
1 decigram = 10 centigrams = 1.54 grains
1 gram = 10 decigram = .035 ounce
1 dekagram = 10 grams = .35 ounce
1 hectogram = 10 dekagrams = 3.52 ounces
1 kilogram = 10 hectograms = 2.2 pounds
1 quintal = 100 kilograms = 220.46 pounds
1 metric ton = 10 quintals = 1.1 short tons

Liquid Measure

1 centiliter = 10 milliters = .34 fl. ounce
1 deciliter = 10 centiliters = 3.38 fl. ounces
1 liter = 10 deciliters = 33.81 fl. ounces
1 dekaliter = 10 liters = 2.64 gallons
1 hectoliter = 10 dekaliters = 26.42 gallons
1 kiloliter = 10 hectoliters = 264.18 gallons

Square Measure

1 sq. centimeter = 100 sq. millimeters = .155 sq. inch
1 sq. decimeter = 100 sq. centimeters = 15.5 sq. inches
1 sq. meter (centare) = 100 sq. decimeters = 10.76 sq. feet
1 sq. dekameter (are) = 100 sq. meters = 1,076.4 sq. feet
1 sq. hectometer (hectare) = 100 sq. dekameters = 2.47 acres
1 sq. kilometer = 100 sq. hectometers = .386 sq. mile

Cubic Measure

1 cu. centimeter = 1000 cu. millimeters = .06 cu. inch
1 cu. decimeter = 1000 cu. centimeters = 61.02 cu. inches
1 cu. meter = 1000 cu. decimeters = 35.31 cu. feet

Approximate Conversion Factors

To change	*To*	*Multiply by*
inches	centimeters	2.540
feet	meters	.305
yards	meters	.914
miles	kilometers	1.609
square inches	square centimeters	6.451
square feet	square meters	.093
square yards	square meters	.836
square miles	square kilometers	2.590
acres	square hectometers	.405
cubic feet	cubic meters	.028
cubic yards	cubic meters	.765
fluid ounces	milliliters	29,573
pints	liters	.473
quarts	liters	.946
gallons	liters	3.785
ounces	grams	28.349
pounds	kilograms	.454
short tons	metric tons	.907
pound-feet	newton-meters	1.356
pound-inches	newton-meters	.11296

To change	*To*	*Multiply by*
ounce-inches	newton-meters	.007062
centimeters	inches	.394
meters	feet	3.280
meters	yards	1.094
kilometers	miles	.621
square centimeters	square inches	.155
square meters	square feet	10.764
square meters	square yards	1.196
square kilometers	square miles	.386
square hectometers	acres	2.471
cubic meters	cubic feet	35.315
cubic meters	cubic yards	1.308
milliliters	fluid ounces	.034
liters	pints	2.113
liters	quarts	1.057
liters	gallons	.264
grams	ounces	.035
kilograms	pounds	2.205
metric tons	short tons	1.102

Temperature (Exact)

°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

PIN: 081397-000