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Real Property Operations and Maintenance

MAINTENANCE AND OPERATION OF ELECTRIC POWER GENERATOR SYSTEMS

This pamphlet gives technical information and guidance to help power production supervisors and technicians maintain, repair, and operate electric power generating plants and systems. It emphasizes safe operational methods and repair procedures related to reliable and efficient operation. It applies to all Air Force civil engineering organizations and members, including the US Air Force Reserve (USAFR). It does not apply to the Air National Guard. Send suggestions for improvement through channels to HQ AFESC/DEMM, Tyndall AFB FL 32403-6001.

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Chapter 1

GENERAL INFORMATION

1-1. Engineering Fundamentals. This chapter explains principles of engineering fundamentals associated with power plant operation. Force, length, and time are the basis for measuring all systems. Specific explanations are as follows:

a. Time. The second (sec) is the fundamental unit of time.

b. Length. The foot is the fundamental unit of length equal to 1/3 of a standard yard (yd). You may also express the length in inches (in).

c. Area. You express the measurement of an area of a surface in square feet (ft^2) or square inches (in^2). The area of a round surface is equal to the square of the diameter (D^2) times pi/4, or D x D x pi/4. The constant pi = 3.1416 and pi/4 = 0.7854.

d. Volume. The volume (V) of a body, such as a cylinder, is equal to the area of the circular end times the length (L). For example, if the diameter (D) of an engine cylinder is 8 inches and the stroke L is 10 inches, the volume displaced by each stroke of the piston is equal to piston areas times the length of stroke or D x D x pi/4 x L, or (8" x 8" x 3.1416 x 10") ÷ 4 or 502.66 cubic inches (in^3).

e. Rotary Motion. The movement of the crankpin around the center of the main bearing is an example of rotary motion. You measure its movement from an original position by the angle of rotation expressed in degrees. One complete revolution is equal to 360 degrees (°).

f. Velocity. If an object is moving at a constant rate of speed, it has a uniform or constant velocity. Velocity (v) is the distance traveled per unit of time and is equal to distance divided by time [miles per hour (mph) or feet per second (ft/sec)].

g. Acceleration. If the velocity of a body is not uniform, it will be accelerating when velocity is increasing, or decelerating when velocity is decreasing. Acceleration (a) is the rate of change of velocity, as feet-per-second change of velocity in one second; generally expressed as ft/sec/sec or ft/sec^2.

h. Force (F). The standard unit for the measurement of force (F) is the pound (lb).

i. Mass (m). The unit mass (m) of a body is the mass that can accelerate at a rate of a = 32.2 ft/sec^2 by a force of 1 lb. This is a very fundamental relationship expressed as F = ma.

j. Weight. You measure the weight (w) of a body in pounds (lbs). For example, 1 ft^3 of water weighs 62.4 lbs and 1 ft^3 of air at atmospheric pressure weighs about 0.075 lbs.

k. Pressure (p). You measure a force acting on a unit area of a surface in terms of pressure per unit area. You express it in pounds per square inch (lb/in^2):

Unit Pressure (lb/in^2) = force/area

or Total force (F) = Unit pressure (lbs/in^2) times the area (in^2). For example if the diameter of a piston is 10 inches, the piston area = pi/4 D^2 = 3.1416 x 10 x 10/4 = 78.54 in^2. Assume the gas pressure in the cylinder is 800 lbs/in2. The total force (F) exerted on the piston is equal to the unit pressure times the area, or 800 x 78.54 = 62,832 lbs.

l. Low Pressure Measurement. Pressures of air to an engine and exhaust gases from an engine in their respective manifolds are very low in comparison to the cylinder pressure. For greater accuracy, measure air and gas pressures in these manifolds by a U-tube or manometer (see figure 1-1). You can use the difference in heights of the two liquid columns in the manometer to calculate the pressure in (lbs/in^2). Use either water or mercury as a liquid in the manometer. To determine the pressure in lbs/in^2, multiply the difference in liquid-level height by the liquid constant. Liquid constant for mercury is 0.491; for water it is 0.0361. For example, if the liquid in the manometer illustrated in figure 1-1 is mercury, the pressure in the manifold will be p = (20 inches) times 0.491 or equal to 9.82 lbs/in^2. If the liquid in the manometer is water, then the pressure in the manifold will be p = (20 inches) times 0.0361 or 0.722 lbs/in^2. Atmospheric or barometric pressure is a measure of the weight of the air layer surrounding the earth's surface and under standard conditions at sea level. It exerts a pressure on the earth's surface of 14.7 lbs/in^2, equivalent to 29.92 inches of mercury. The barometric pressure varies slightly from day to day, and decreases with altitude above sea level. Absolute pressure, or total pressure, (lbs/in^2area) is equal to the sum of barometric pressure plus the pressure measured by conventional gauges.

m. Temperature. Temperature (t) of a body is a measure of hotness or coldness. You call the measuring instruments thermometers. In engi-

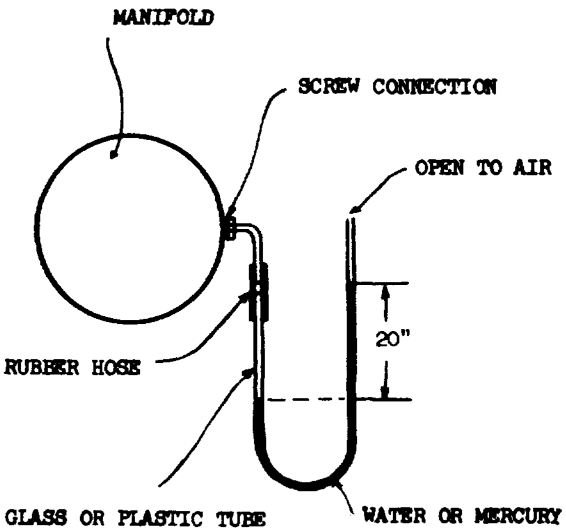


Figure 1-1. Method of Low Pressure Measurement.

neering work, use the fahrenheit (F) temperature scale. Reference temperatures are:

(1) The temperature of a mixture of ice and water at standard sea level atmospheric pressure equals 32°F.

(2) The boiling point of water at the same pressure is 212°F.

n. Specific Gravity. A material's specific gravity is the ratio of its density to that of water. The term "density" refers to the weight of material per ft^3. For water this is 62.4 lb/ft^3 or 8.34 lbs/gal. For example, if the specific gravity of a fuel oil is 0.86, the weight of 1 gallon will be 8.34 (lbs/gal of water) x 0.86 = 7.17 lbs.

o. Work (W). If force exerts against a body and the body moves through a certain distance, work is done. You measure it by the product of the force applied and how far it moves the body. For example, if you apply a force of 50 lbs to a hand truck and the truck moves 10 ft, the work done is 500 ft·lbs (W = 50 lbs x 10 ft = 500 ft·lbs). Work necessary to lift a 200-lb weight through a distance of 12 ft requires the work of 200 x 12 = 2400 ft·lb.

p. Power. Power is a measure of the unit of work (ft·lb) which can be done in a unit of time, or the "time rate" of doing work. You express power in terms of ft·lb of work/minute. In engineering work, the term horsepower (hp) is the most common measurement of power, one horsepower being equivalent to 33,000 ft·lb per min, or 550 ft·lb per sec. For example, if the work in lifting the 200 lb weight through 12 ft was performed in 2 seconds, the power required was:

$$\text{Power} = \frac{\text{Work}}{2\text{ sec}} = \frac{2400\text{ ft·lb}}{2\text{ sec}} =$$

1200 ft·lb per sec.

$$\text{Or horsepower} = \frac{1200\text{ ft·lb per sec}}{550\text{ ft·lb per sec}} = 2.18\text{ hp.}$$

If this work was done in 2 minutes, the

$$\text{Power} = \frac{2400\text{ ft·lb}}{2\text{ min}} = 1200\text{ ft·lb per min}$$

and the

$$\text{Horsepower} = \frac{1200\text{ ft·lb per min}}{33{,}000\text{ ft·lb per min}} = 0.0364\text{ hp}$$

Thus, if work is done at a slower rate, it requires a corresponding lower horsepower to do the same amount of work. The unit for measurement of power in electrical machinery is in kilowatts (kw) and is convertible to horsepower in the ratio of 1 hp = 0.746 kw or 1 kw = 1.341 hp. For example, if an electrical generator produces 1000 kw, the engine which drives the generator would theoretically have to produce 1000 x 1.341 = 1,341 hp. However, in practice, the engine not only has to produce 1000 kw electrical power but it also has to overcome the losses of the alternator. Alternator efficiencies range from 0.92 for small generators to 0.96 for large generators. So, the engine in the above example has to produce 1.341 hp divided by the alternator efficiency. Assuming, for example, an alternator efficiency of 0.94, the engine would have to produce 1.341 ÷ 0.94 = 1421 hp to produce electrical output of 1000 kw.

q. Torque. When you apply force perpendicularly (at right angles) to a crank, it creates a torque (T) or turning force. The twisting force in the shaft is equal to the force (F) times the crank radius (r). The units of torque are pound-foot (lb/ft), or pound-inch (lb/in) and T = F x r. For example, if you apply a force of 500 lbs to a 6-inch crank, the torque in the crankshaft is 500 x 6 = 3000 lb/in. The torque increases by increasing either the force or length of the crank.

r. Energy. The energy possessed by a body is a measure of its ability to do work. This energy may be due to position, to motion, or to conditions such as pressure and temperature.

s. Units of Energy Measurement. You already know the foot pound (ft·lb) is the unit of mechanical energy or work. (A ft·lb being equivalent to the energy of a force of 1 lb acting through a distance of 1 ft.) The British thermal unit (Btu) is the unit for measuring thermal en-

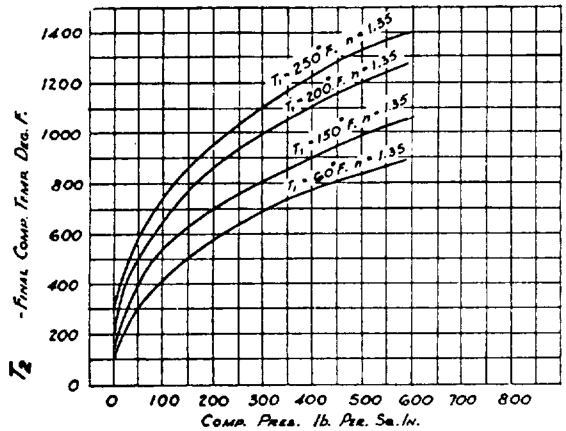


Figure 1-2. Temperature-Pressure Relationship During Compression.

ergy. It is the energy required to raise the temperature of 1 lb of water 1 degrees Fahrenheit. You can convert these units of energy based on work (ft·lb) and on thermal energy (Btu) from one to the other. To do this, apply the mechanical equivalent of heat as 1 Btu 778 ft·lb. The horsepower hour (hp hr) is the measure of one horsepower for 1 hour. The 1 horsepower hour = 2545 Btu and 1 kilowatt-hour (kw hr) is equal to 3413 Btu. In other words, 2545 Btu is the heat equivalent of 1 hp delivered for 1 hour and 3413 Btu is equivalent to 1 kw hr. This conversion relationship will be very helpful to you later when calculating engine performance and efficiency.

t. Specific Heat. The quantity of heat energy required to produce a given temperature rise in a unit weight of a material varies from one material to another. The term "specific heat" means the quantity of heat (Btu) required to raise the temperature of 1 pound of material 1°F. Lets suppose 1 Btu will raise the temperature of 1 lb of water 1°F. The specific heat of any other material may be called the ratio of the heat required to raise 1 lb of the material 1°F to that required for water or 1. Gases have two specific heats--the specific heat at constant pressure (cp) and the specific heat at constant volume (cv). For air at normal atmospheric conditions, cp = 0.240 Btu per lb per 1°F and cv = 0.171 Btu per lb per 1°F.

u. Engine Compression. Figure 1-2 shows you how to determine approximate compression temperature according to compression pressure and for various initial air temperatures (t) in the cylinders. For example, the compression pressure in an engine cylinder measures 500 lbs/in^2 and the temperature of air entering the cylinder is 150°F. Locate the 500 lbs/in ^{2} point along the bottom of figure 1-2 and then follow the vertical line to the curve marked T1 = 150 °F. From this point of intersection, go to the left and read the final compression temperature (t2) of about 980 °F. If the air cools from 150 to 60 °F before entering the cylinders, the intersection of the 500 lbs/in ^{2} line with curve marked T1 = 60 °F indicates a final compression temperature of 840 °F. Thus, for a 90 °F drop of the air to the cylinder, the final compression temperature drops 140 °F. This explains why it may be difficult to start an engine during extremely cold weather. (The air temperature to the engine may be so low that final compression temperature becomes too low to ignite the fuel charge.) The cooling of combustion air reduces the engine operating temperature making it possible to carry more load at comparable exhaust temperatures.

v. Compression Ratio. When associating compression ratio with diesel engines, in reality, it's the cylinder volume ratio, not the pressure ratio. It refers to the ratio of maximum volume (cubic inches) in the engine cylinder, with the piston at bottom dead center (BDC) (piston displacement volume plus volume of combustion space), to the minimum volume (cubic inches) in the cylinder (combustion space volume) when the piston is at top dead center (TDC). Compression ratios vary from engine-to-engine and range from 12 in large diesel engines to 17 or more for small high speed engines. Figure 1-3 gives approximate compression temperature for any given compression ratio, and for various initial air temperatures (T_1) to the cylinders. For example, the curves show that if the engine's compression ratio is 13. The air to the cylinder before compression is 100°F. The final compression temperature will be about 925°F. This is more than enough to ignite the fuel charge. With 60°F air to the cylinders and 13 compression ratio, the final compression temperature, according to figure 1-3 is 800°F. Note the decrease of 40°F in initial air temperature causes a drop of 125°F in the compression temperature, based on an equal compression ratio.

w. Engine Displacement. For you to estimate the volume of air the engine requires, you should know the engine displacement per minute. This is expressed as the volume of air passing through an engine in cubic feet per minute (ft^3/min). You can calculate this volume as number of cylinders "N" x areas of piston "A"

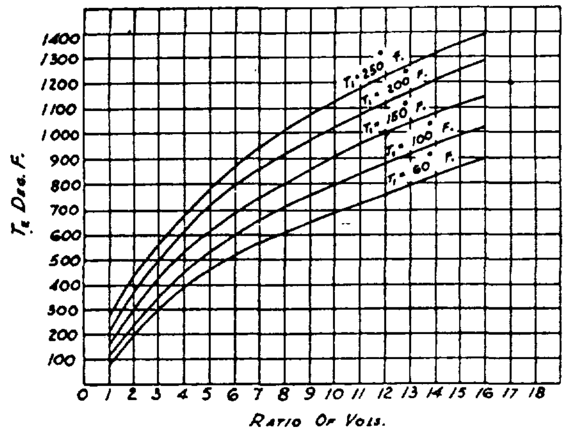


Figure 1-3. Temperature-Volume Relationship During Compression.

(ft^2) x stroke "S" (ft) x number of cycles per cylinder per minute "m," or

Engine displacement per minute
= N x A x S x M = (ft^3/min) where,
M = rpm, for two-cycle engines
M = rpm/2, for four-cycle engines

For example, the displacement of an eight cylinder, four-cycle engine having a bore of 15 in (1.25 ft), a stroke of 18 in (1.5 ft) and operating at 360 rpm, is equal to 8 x pi/4 x 1.252 x 1.5 x 360/2 or 8 x 0.7854 x 1.5625 x 1.5 x 180 = 2650 ft^3/min free air. This represents the approximate air volume per minute at atmospheric pressure required by the above four-cycle engine when naturally aspirated. If turbocharged, the air volume at full load would increase about 1.3 to 1.6 times that amount. Two-cycle engines require a volume about 1.3 to 1.6 times the engine displacement to allow for scavenging.

x. Brake Horsepower (BHP). This is the actual or net power output, at the end of the crankshaft, for doing useful work. It is so called because it is determined on the test floor by a brake or a dynamometer.

y. Friction Horsepower (FHP). The portion of power which an engine has to produce to overcome its internal friction.

z. Indicated Horsepower (IHP). The power developed inside the engine cylinders, as determined from the pressure indicator card. It is the sum of BHP plus FHP.

aa. Mechanical Efficiency (e_m). The engine's e_m is the ratio of the actual engine-shaft output (bhp) to the total work done in the cylinders (ihp). Mechanical efficiencies vary with different types of engines. On the average they range from 80 to 85 percent. For example, an engine generating 80 bhp at the shaft and having a mechanical efficiency of 80 percent, the friction horsepower (fhp) would be 20. The indicated horsepower (ihp) of the engine would be the sum of both (80 + 20 = 100).

ab. Thermal Efficiency (e_{th}). This is the ratio of the heat equivalent of work (hp) done by an engine to the total heat in the fuel supplied to the engine. It gives the operator an indication of how efficiently the engine converts the fuel into mechanical energy. You can calculate the thermal efficiency of an engine as follows:

$$e_{th} = \frac{\text{Net kw hrs generated} \times 3413 \times 10}{\text{Btu/gal of fuel} \times \text{number of gallons consumed during same time}} = \%$$

Thermal efficiencies of diesel and gas engines, without heat recovery, range from 33 percent to 37 percent. This means that 33 to 37 percent of the energy in fuel consumed by the engine converts to net electrical energy. The rest is lost in the exhaust, cooling fluid, internal friction, and radiation. The heat content of fuels in diesel operation ranges from 135,000 to 145,000 Btu/gal, averaging about 142,000 Btu/gal for grade DF-2.

ac. Brake Mean-Effective Pressures (BMEP). An engine's BMEP is a hypothetical value indicating the average or "mean" pressure in a cylinder during the power stroke, to produce a given torque at the shaft. This value generally is for evaluating the thermal and mechanical loading of a engine. It has no direct relationship to peak firing pressures. You can calculate the BMEP with an average generator efficiency of 93 percent as follows:

(1) For two-cycle engines:

$$BMEP = \frac{kw \times 730{,}000}{L \times D \times D \times n \times rpm}$$

(2) For four-cycle engines,

$$BMEP = \frac{kw \times 1{,}460{,}000}{L \times D \times D \times n \times rpm}$$

Where BMEP = Brake mean effective pressure in lb/in^2.

kw = Generator output in kilowatt.
L = Length of engine stroke in inches.
D = Diameter of engine cylinder bore in inches.
n = Number of cylinders.
rpm = Revolution per minute.

ad. Average Piston Speed of an Engine. Calculate this speed as:

Average piston speed (ft/min) =

$$\frac{2 \times L \times rpm}{12}$$

For example, if an engine has a piston stroke of 12" and operates at 720 rpm:

Average piston speed would be = $\frac{2 \times 12 \times 720}{12}$

or 1440 ft/min.

ae. Fuel Consumption. You usually express an engine's fuel economy as the brake specific fuel consumption (BSFC). For liquid fuels, it is pounds of fuel the engine consumes per brake horsepower it produces for 1 hour (lb per bhp-hr). For gaseous fuels, the BSFC is the heating value of the gas (Btu/ft^3) times the cubic feet of gas consumed divided by the brake horsepower produced, for 1 hour (Btu/ bhp-hr). For power plant operation, fuel consumption is often expressed by the ratio of net kilowatt hours (kwh) produced, to gallons of fuel used. The average is from 11 to 13 kwh per gallon.

af. Plant Utilization Factor (PUF). Depending on fluctuations of power demand, it is preferable to operate engines in the range from 75 percent to 100 percent of rated load. You can calculate the plant utilization factor, in percent, as follows:

PUF = TOT kw hrs produced by plant x 100 = %
TOT of (hrs each unit operated x corresponding kw rating)

You should calculate and plot this factor for each weekly operating period. The plot will show, at a glance, how well the plant operation used engine capacity over an extended period.

1-2. Common Power Language Terms. The terms listed in attachment 1 will help establish a common power language among plant operating personnel. Personnel are urged to become familiar with them.

1-3. Engine Classification. A generator will have several KW ratings depending on the application. These ratings are essentially tradeoffs for maximum engine KW, expected operating hours, required maintenance and expected engine life (or time to overhaul). Industry application classes for rating generator sets differ from the class ratings of power plants given in attachment 1. Load characteristics (varying or nonvarying/continuous) and the type of operation (continuous or limited time/standby) determines industrial classifications. The International Organization for Standardization (ISO) Standard 8528 defines three applications classes. You should specify generator ratings in terms of this ISO classification. You should continue to specify power plants as Class A, B, or C. The ISO classes are as follows:

a. Continuous Power. Power which a generator is capable of delivering continuously for an unlimited number of hours per year between the manufacturer's stated maintenance intervals. This is a continuous operation with continuous or nonvarying load rating. Normally, a generator will have the capability of operating at 110 percent of this rating for a limited period. Typically, this is 1 hour, with or without interruption, within a 12-hour period of operation. But, not all generators will have this overload capability and you should specify it if required.

b. Prime Power. The maximum power available during a variable power sequence, which may be run for an unlimited number of hours per year between stated maintenance intervals. The permissible average power output during a 24-hour period must not exceed some percentage of the prime power rating. The manufacturer specifies this percentage which is typically 80 to 90 percent. Prime power is a continuous operation with variable load rating. In the absence of specific information, the continuous power rating would be a conservative estimate of the permissible average power output. As in the the case of the continuous power rating, some generators also have a 10 percent overload capability which should be specified if required.

c. Limited Time Running Power. The maximum power that a generator is capable of delivering for up to 300 hours per year, between stated maintenance intervals. This is a limited time operation with no overload capability. It uses the standby rating of the generator and should not exceed it. The generator can operate at this rating for more than 300 hours per year if you follow the manufacturer's maintenance recommendations. But, engine wear will increase and the time (number of operating hours) to overhaul or "engine life" will decrease. There also may be limitations on continuous operating hours or run time.

Chapter 2

DIESEL AND GASOLINE ENGINE GENERATING PLANTS

2-1. Basic Power Plant Construction:

a. Arranging Generators. Engine generators are generally arranged side-by-side on centers equal to twice the overall width of the engine. The No. 1 engine is parallel to the end wall of the building. This allows an aisle between the engine and the wall equal to the overall width of the engine. In a small plant having only one engine, initially, there is enough room for a second engine. Figure 2-1 shows a typical standby generator installation. Forced air ventilation of prime power engine rooms is usually necessary because the internal combustion engines generate considerable heat. A 15- to 20-degree (F) temperature rise (T) is a reasonable target for engine rooms. A rule of thumb for airflow required to maintain this temperature rise is as follows:

$AF = \frac{500 \times P}{T}$ Where AF = Airflow required in CFM

P = Rated engine power in HP

T = Engine room temperature rise above ambient in °F

b. Constructing Foundations:

(1) The lack of supervision during the forming, pouring, and grouting process causes most concrete foundation problems. The engine builder may assume the responsibilities for de signing the foundation, to be sure of proper installation. Always follow the manufacturer's recommendations.

(2) Grout is a plastic compound used to fill voids between a generator and its foundation. The two principle types of grout are cementitious (cement-based) and epoxy based. Not all

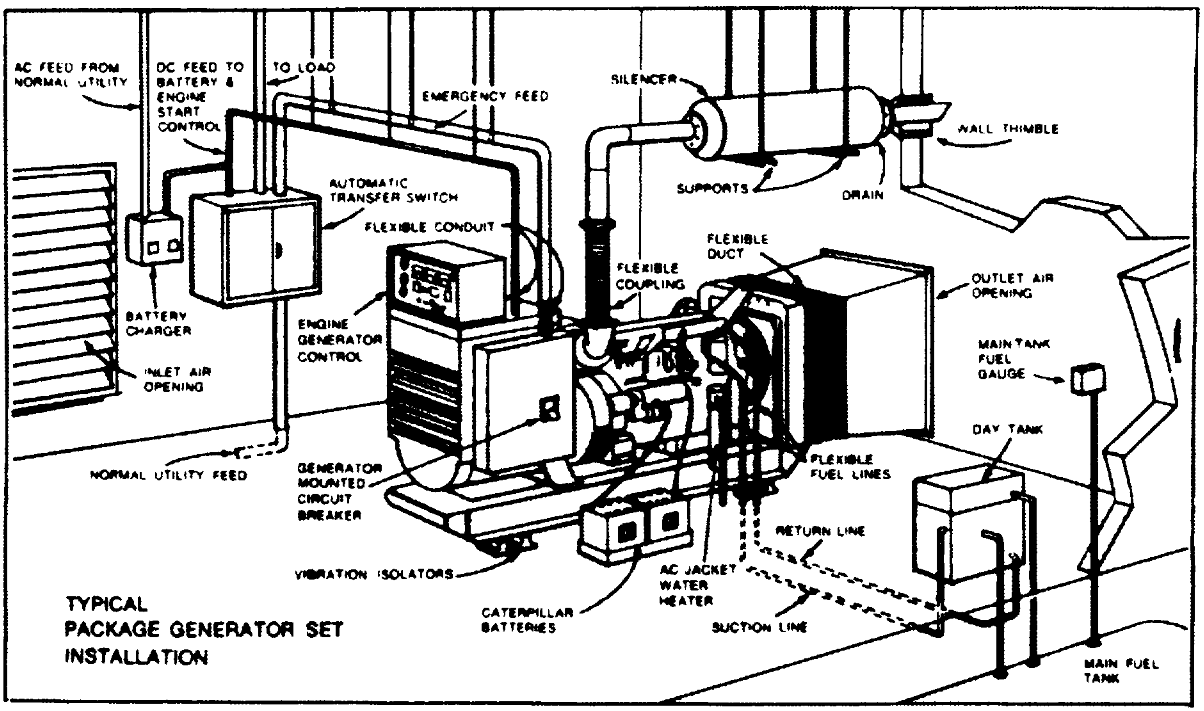


Figure 2-1. Typical Standby Generator Installation. (Courtesy Caterpillar, Inc)

engine manufacturers recommend grouting. When it is recommended, the grouting process can be one of the most important steps (assuming a good foundation) toward a long trouble-free generator installation. The generator support plates, or rails, are mounted on spacer blocks to allow some clearance to the concrete beneath. This space is then filled with grout. The grout forms a high strength support fully contacting both the foundation below and the steel work above. Generator weight is distributed evenly over the entire support surface. Such full support prevents sagging of steel works during long service. Grout also serves as a stiffener for controlling resonances in steel baseplates. The following are some basic rules for using grout:

(a) Use nonshrinking material.

(b) Apply to clean surfaces.

(c) Make sure surfaces are dry for epoxies and moist (for at least 24 hours) for cementitious.

(d) Quickly pour grout.

(e) Avoid temperature extremes.

(f) Fill voids completely; avoid entrapment of air.

(g) Allow adequate curing time.

(h) Don't add too much water to cementitious grout as reduced strength will result.

(i) Make sure grout placement is rapid, continuous, and directional (from one direction only).

c. Isolating Vibrations. A layer of cork or other resilient material under and around the foundation isolates structure from vibration in some installations. Also, the engine may have spring vibration dampers which rest on the foundation. Supporting an engine on springs or other resilient material, creates a set natural frequency (up and down motion per minute). The reciprocating and rotating parts of the engine create periodic impulses. These impulses may have the same frequency as the natural frequency of vibration of the spring-mounted engine, or an even multiple thereof. If this happens, the vibration of the system may become very violent (resonance). The natural frequency of a spring-mounted weight (engine) relates to the static deflection of the springs supporting the weight. This relationship is shown in figure 2-2. Let's say an engine is set on springs and their deflection, due to the weight, is 1 inch. The natural frequency of the system is approximately 200 vibrations per minute. With a softer set of springs to support the same weight the spring deflection would be 2 inches. The natural frequency of the system would reduce to approximately 140 vibrations per minute. With stiffer springs (less deflection) the natural frequency would increase. Vibration, if left uncorrected, will cause damage to the bearings and crankshaft of nearby engines which are at rest and not protected by vibration dampers.

d. Spring System Design. The most severe vibration-supporting forces are synchronous with the rotative speed of the engine (rpm). The spring system design should allow the static deflection of the springs so the natural frequency (vibration per minute) of the whole system remains considerably below the rpm figure. For example, say a 720 rpm engine will have spring support. The springs should statically deflect about 3/8 inches under the weight of the engine. According to figure 2-2, the natural frequency of the entire assembly is about 300 vibrations per minute. No resonance with the rotative speed forces of the engine is possible.

2-2. Types of Engines:

a. General Information. Internal combustion engines are generally classified according to the kind of fuel they burn and/or according to the number of piston strokes (up and down) required for each power cycle.

b. Two- or Four-Stroke Cycle Engines. A two-stroke cycle (two-cycle) engine imparts one power impulse per cylinder to the crankshaft for every two strokes of the piston. That is, one power impulse per cylinder for each revolution of the crankshaft. Conversely, a four-stroke (four-cycle) engine imparts one power impulse per cylinder to the crankshaft for every four strokes of the piston. That is, one power impulse per cylinder for each two revolutions of the crankshaft. Accordingly, in a multicylinder four-stroke engine, all cylinders complete their cycle in two revolutions of the crankshaft. But, no two cylinders fire at the same time. This is because the crankshaft is built so that the cylinders fire at regular intervals during two revolutions. If the engine had six cylinders, the spacing between power strokes would be 1/3 revolution of the crankshaft.

c. Engine Modifications. There are modifications to the standard two- and four-stroke engines, such as the opposed piston engine and turbocharged standard two- and four-cycle en-

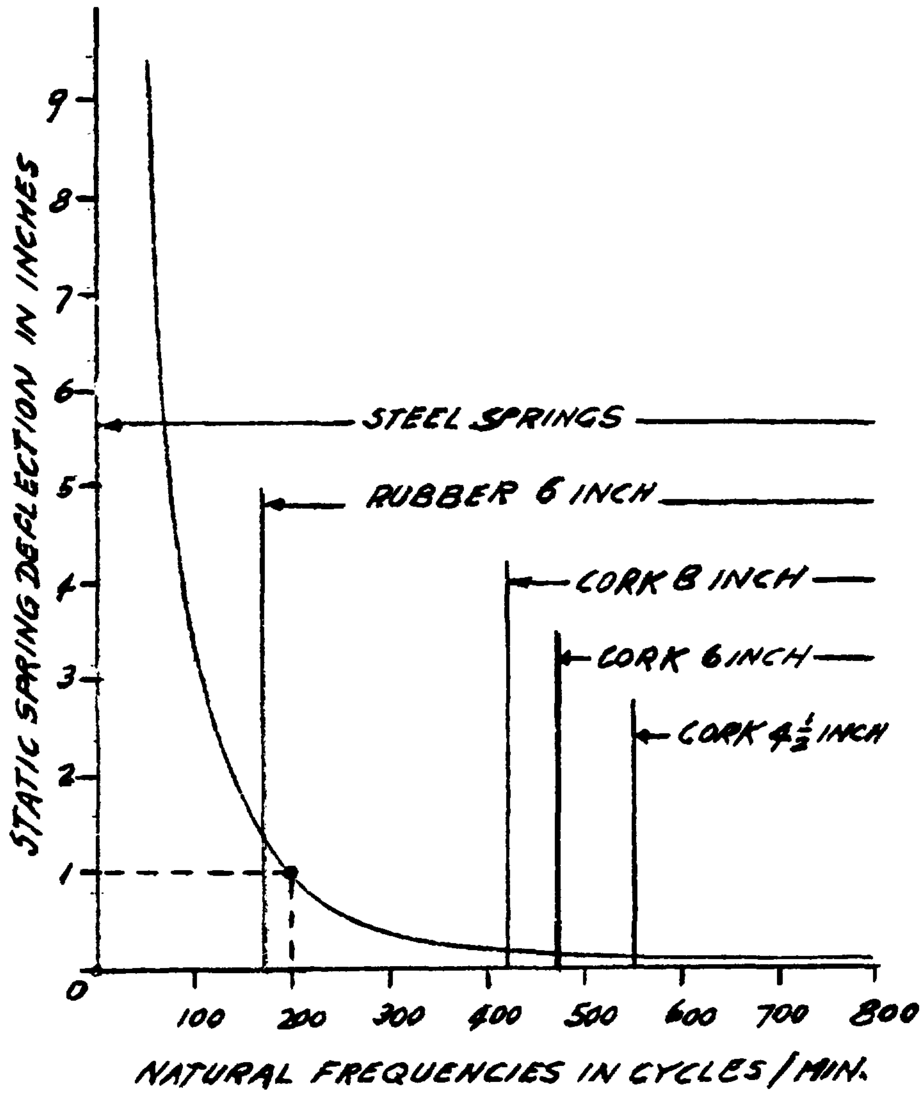


Figure 2-2. Natural Frequencies for Spring Mounted Generators.

gines. Turbocharged engines include a turbocharger usually driven by exhaust gases, for precompressing the combustion air before it enters the engine cylinders. The majority of engines manufactured today are multi-cylinder V-type, high speed design.

d. Natural Gas Engines. Where natural gas is plentiful, engines equipped to burn this gas fuel can produce power more economically than liquid fuel. Modern high compression gas engines operate with compression ratios approaching those of the diesel. The engines may employ spark ignition or pilot fuel ignition. They may be of the naturally aspirated or turbocharged types, operating on either the two-stroke or four-stroke cycle principle. The cylinders are charged with a mixture of gas and air. It is better to keep this mixture on the lean side of a perfect mixture. This aids in preventing ignition during compression without a pilot-oil injection or an electric spark. The combustion air sometimes throttles progressively as the engine load decreases to maintain the best air-gas mixture.

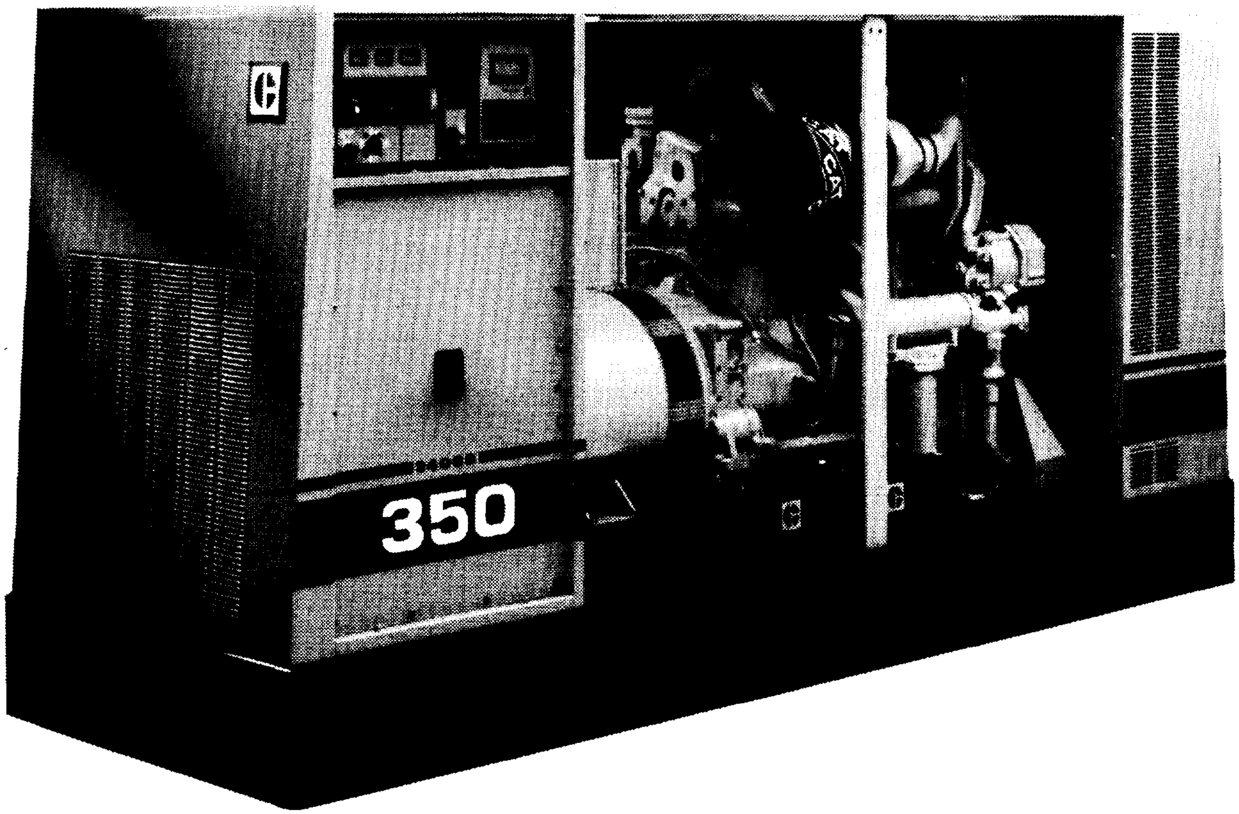


Figure 2-3. Typical Small Packaged Diesel. (Courtesy Caterpillar, Inc)

2-3. Description of Diesel Engines:

a. General Engine Information. The most important feature that makes the diesel engine different from gasoline and some gas engines, is that air only, rather than a mixture of air and fuel, is compressed during the compression stroke. This allows a diesel's compression pressure to rise considerably above compression pressures employed in mixture-aspirated internal-combustion engines, because no preignition of fuel can possibly take place. Fuel under high pressure is injected into the cylinder at the end of the compression stroke as the piston approaches top-dead-center (TDC). During the injection process, the fuel is finely atomized as it enters the cylinder and is mixed intimately with the air to form a combustible mixture. The surrounding air then heats the fuel particles to their ignition temperature. The mixture and heating must be completed in a fraction of a second. As the fuel burns, it raises the pressure in the cylinder to the maximum firing pressure, which then drives the piston downward to produce work on the crankshaft. Consequently, the diesel engine requires no carburetor for the preparation of the combustible mixture, nor does it require spark plugs or other devices to aid the initial ignition of the fuel. Figures 2-6, 2-7 illustrate cutaways of typical heavy-duty diesel engines for power production.

b. Principles of Operation. It is necessary to know some of the basic principles of two- and four-cycle engines to properly understand their operation and to sensibly perform maintenance. Recommend all power production technicians obtain the book, "Diesel and High Compression Gas Engines," by Edgar J. Kates and William E. Luck, (NSN 7610-00-836-9205).

c. Two-Cycle Engines (Figure 2-8). The series of events that takes place in a two-cycle diesel engine are air compression, combustion, expansion, exhaust, and scavenging. Two strokes of the piston (one complete revolution of the crankshaft) are necessary to complete the cycle.

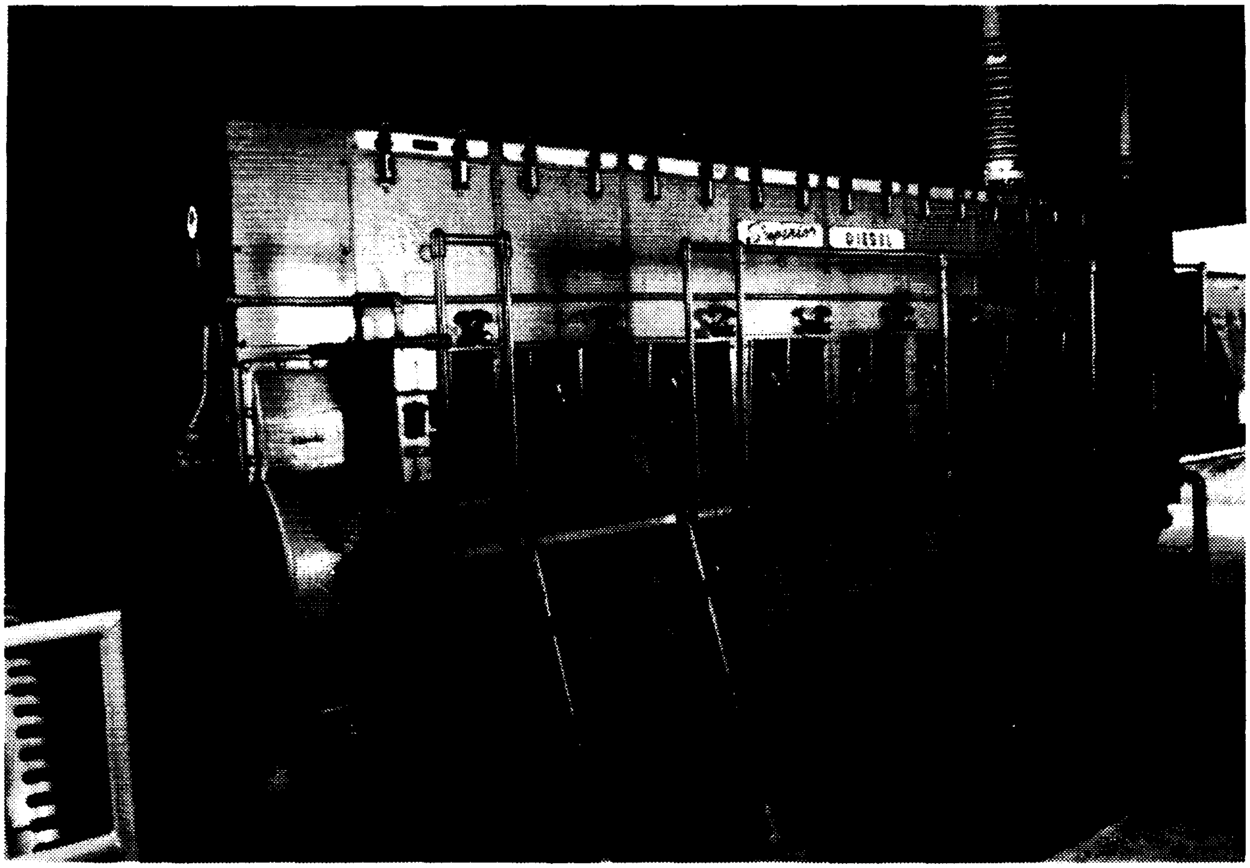


Figure 2-4. Typical Older Style Diesel.

The cycle begins with the upward movement of the piston from its bottom-dead-center (BDC) position. After the piston has covered the scavenging air and the exhaust ports in the cylinder walls or after the exhaust valves are closed, where such valves take the place of ports, the air in the cylinder is compressed. Compression causes the air temperature to rise. As the piston nears the top-dead-center (TDC) position, a metered amount of fuel oil is injected into the combustion space. The fuel oil, under high pressure enters the combustion space as a finely divided spray, forming a mixture that is easily ignited by the high temperature of the air in the cylinder. Combustion takes place, and the hot gases expand until the piston nears the end of the power stroke. When the piston has traveled from 80 to 85 percent of its expansion or power stroke, the piston uncovers the exhaust ports or in some engines the exhaust valves are opened to release the gases, remaining in the cylinder, to the atmosphere. The piston continues to move downward, uncovering the scavenging air ports. Air, precompressed in a scavenging pump or centrifugal blower to 3 to 5 lbs/in^2, enters the cylinder through the scavenging ports. The scavenging air has two distinct tasks, namely, to purge the cylinder of the remaining burned gases and to provide a fresh, clean charge of air for subsequent compression. The process of scavenging is a feature peculiar to the two-cycle engine.

d. Four-Cycle Engines (Figure 2-9). In a four-cycle engine, a series of events takes place: intake stroke, compression stroke, combustion, expansion or power stroke and exhaust stroke. Four strokes (two complete revolutions of the crankshaft) are necessary to complete the cycle. As the piston starts its downward travel (intake stroke), a charge of fresh air is drawn into the cylinder through the open inlet valve or valves. When the piston reaches bottom-dead-center (BDC), the cylinder is filled with fresh air at approximately atmospheric pressure. As the pis-

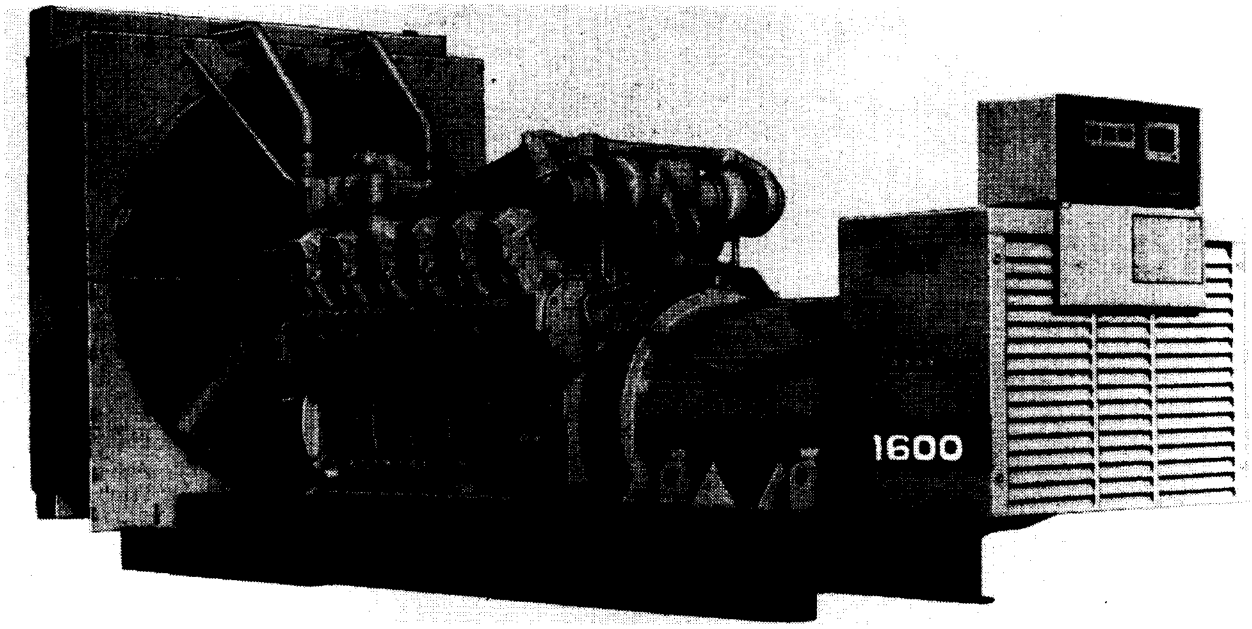


Figure 2-5. Large Packaged Diesel. (Courtesy Caterpillar, Inc)

ton starts moving upward (compression stroke), all valves are closed so the air in the cylinder is compressed to a small volume. The decrease in air volume increases the pressure and, correspondingly, the temperature. At the end of the compression stroke, fuel is injected into the combustion chamber at high pressure. The temperature of the compressed air in the combustion chamber is sufficiently high to ignite the fuel on coming into contact with the air. Combustion commences, pushing the piston downward on its power stroke. Near the end of the power stroke, the exhaust valves are opened and, as the piston again reverses its direction, the gases remaining in the cylinder are expelled during the exhaust stroke. The four-stroke cycle is completed.

e. Dual-Fuel Engines. Engines designed and equipped for burning either gas or liquid fuel or a combination of the two are commonly called dual-fuel engines. They may be of the two or four-cycle types and may be either naturally aspirated or turbocharged. They operate with conventional diesel compression ratios. In dual-fuel engines, the gas charge is admitted to the cylinder before or during the early part of the compression stroke, and combustion is initiated by a charge of pilot fuel injected near the end of the compression stroke. Aside from initiating combustion, the pilot-fuel injection also serves as the ignition timer. In a gas-supply failure or a gas shortage, the engine automatically adjusts itself to operate on any ratio of gas and oil up to 100 percent fuel oil.

f. Tri-Fuel Engines. These are dual-fuel engines additionally provided with a spark-ignition system.

g. Supercharged Engines:

(1) In a nonsupercharged engine, air is drawn into the cylinders by the downward movement of the pistons. As a result, the air pressure in the cylinder prior to compression is slightly below atmospheric. In contrast, when supercharging is employed, the cylinders are charged with air equivalent to the charging pressure which may be as high as 15 lbs/in^2. This is the reason that supercharging can re store the nonsupercharged rating of an engine when installed at higher altitudes. At moderate altitudes, the supercharged engine can develop 50 to 100 percent more horsepower than can be developed by a nonsupercharged engine of the same size. The fuel consumption of a supercharged engine is always lower than that of comparable size nonsupercharged unit.

(2) For supercharging engines, the most common method is the use of a turbocharger driven by exhaust gas from the engine (figure 2-10). The method is commonly called turbocharging. The energy in the exhaust gas, oth-

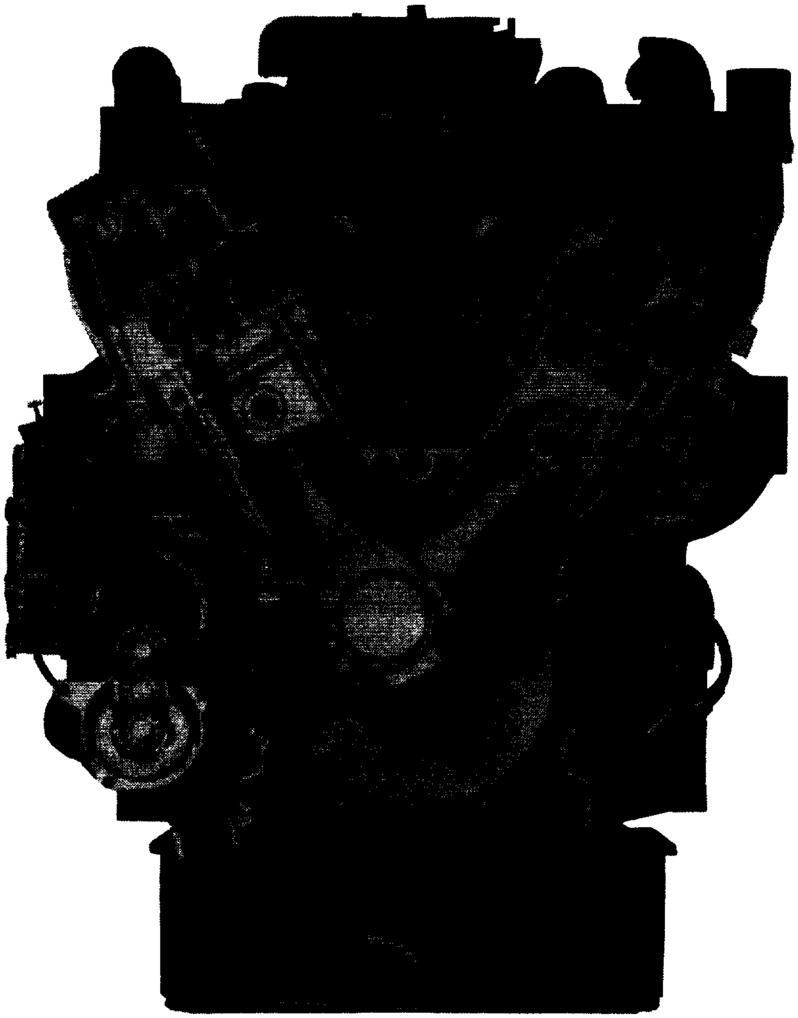


Figure 2-6. End View Cutaway of Modern Diesel. (Courtesy Caterpillar, Inc)

erwise lost through the exhaust system, is used to drive a single-stage turbine. The turbine is connected directly to a centrifugal blower which precompresses the combustion air. The precompressed air is then delivered to the individual cylinders by way of the conventional intake manifold. Turbocharging has the following advantages:

(a) A greater charge air density is available in the cylinder for combustion.

(b) The combustion space is scavenged of residual gases (valve overlap).

(c) All portions of the combustion chamber are effectively cooled by the precompressed air passing through the cylinder during the valve overlap period.

(d) The air charging pressure adapts itself automatically to all engine loads - that is, the speed of the turbo and consequently the volume of air delivered by the turbocharger increases or decreases in ratio to engine load.

(e) The engine can usually be operated at a reduced load as a nonsupercharged engine if the turbocharger fails.

(f) An engine must be designed for operation as a turbocharged unit. Engines already in service sometimes can be altered to permit turbocharging. However, the manufacturer should be contacted concerning the feasibility of turbocharging an existing engine.

(3) To get still more power from a conventional supercharged engine, an intercooler is

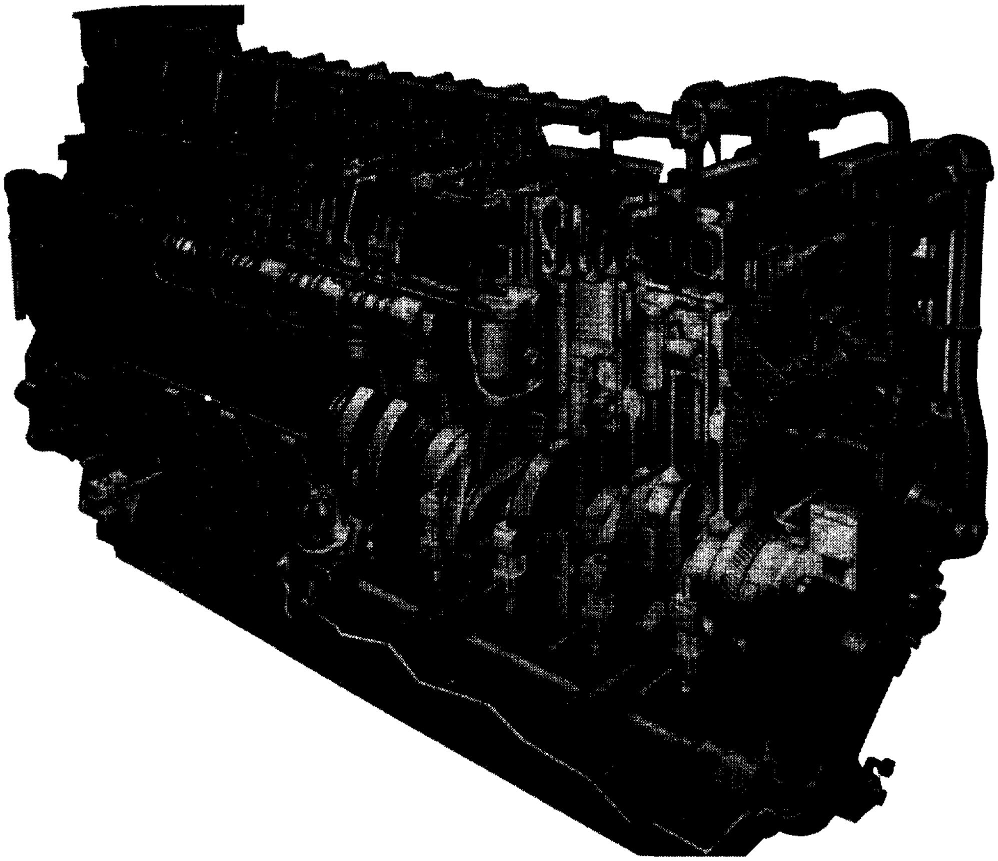


Figure 2-7. Cutaway of Typical Diesel. (Courtesy Caterpillar, Inc)

sometimes added to cool the air discharged from the turbocharger before it enters the engine. Cooling increases the density of air delivered to the cylinders and thus enables the engine to burn more fuel. For example: On the basis of equal exhaust temperatures, a reduction of 10 °F air temperature to an engine increases its load-carrying capacity by about 4 percent.

2-4. General Operating Instruction for Diesel Engines:

a. Engine Speed. The manufacturer determines the engine speed rating. For the purposes of this pamphlet, engine classification by speed, are:

(1) Slow Speed: Below 350 rpm.

(2) Medium Speed: 350 to 1200 rpm.

(3) High Speed: Above 1200 rpm.

b. Engine Load. Gradual assumption of the load by the generator is preferable. This is not always possible due to automatic transfer switch or other conditions. Full load can be assumed almost immediately without damage if the engine is kept warm. The amount of load should be within the manufacturer's recommendations. An overload can be harmful and may be indicated by excessive alternator temperature, overheating of the prime mover, black smoke from the exhaust, excessive firing pressure, or engine knocking. Low load conditions should also be avoided. With internal combustion engines, torsional vibrations of varying severity occur in the crankshaft system at certain engine

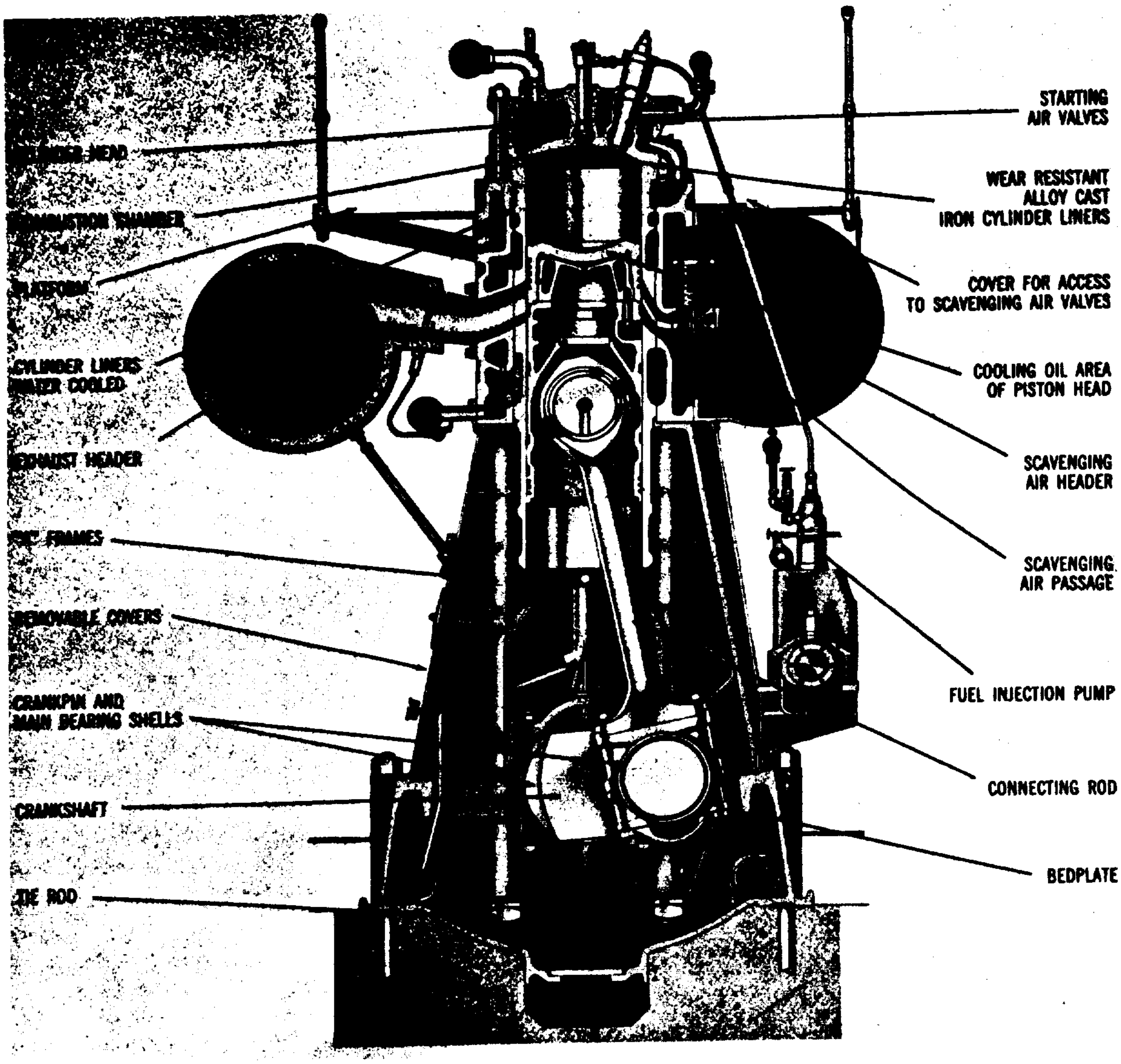


Figure 2-8. Cross Section of Heavy Duty Two-Cycle Diesel Engine.

speeds between zero and normal operating speed. Therefore, it is advisable, when starting and stopping an engine, to bring it up to speed or reduce it to zero as quickly as possible. This may prevent damage to the crankshaft and bearings.

c. Turbocharger Operation. To ensure the proper operation of turbochargers, carefully follow manufacturer's instructions. Do not attempt to make repairs without careful study of the instructions. Make sure only clean air enters the air inlet, because an accumulation of foreign matter on the impeller throws the rotor out of balance and causes damaging vibration. Use the proper grade of lube oil, as recommended by the engine manufacturer. Make sure no more than 12 seconds elapse between the start of rotation of the turbocharger and oil pressure indication. Many modern engines now have priority valves which provide immediate lube oil to the turbo bearings. These modern turbos also have oil reservoirs above the turbo bearings to assure lube oil availability before startup. Any significant increase in the coolant temperature

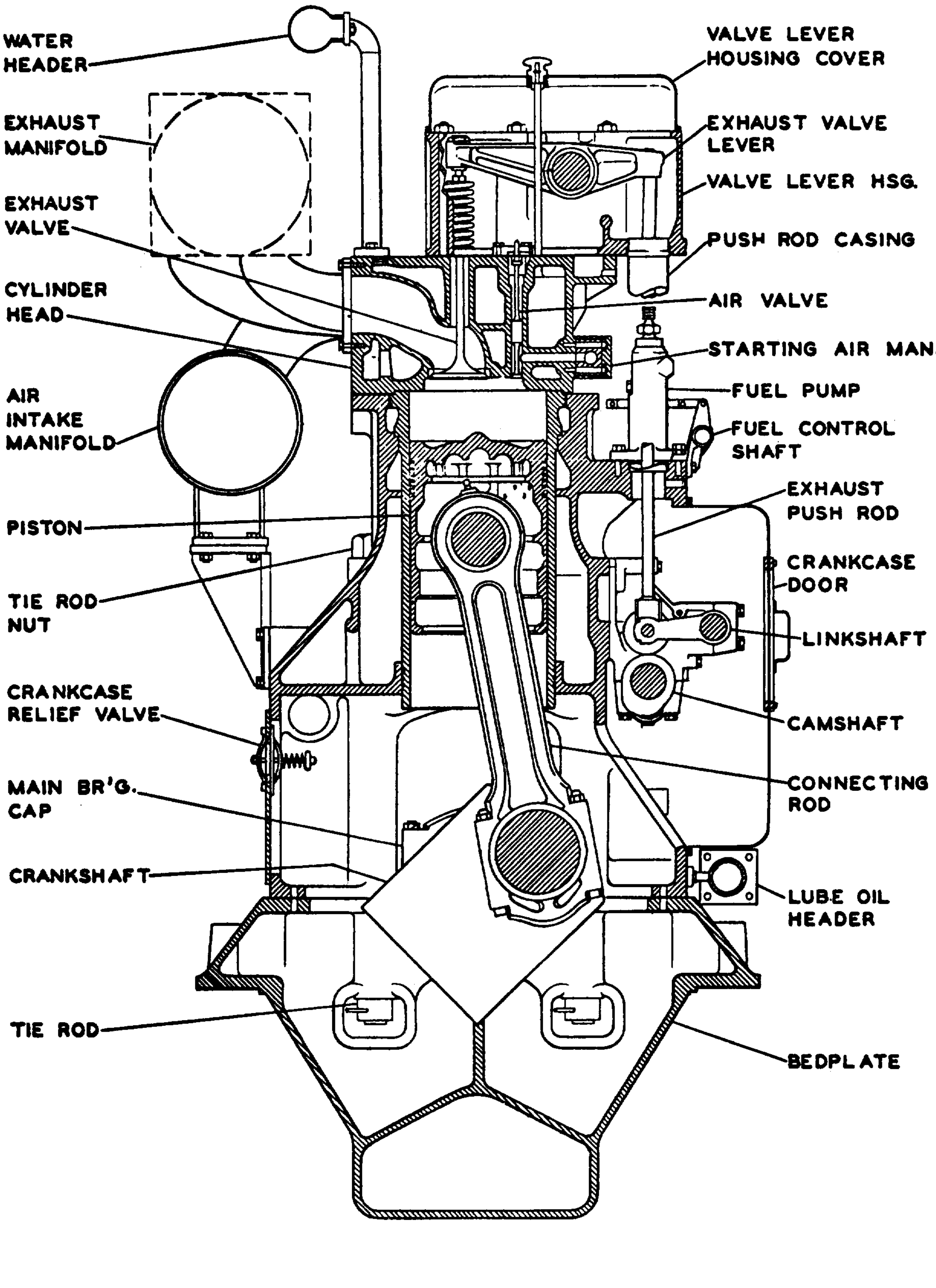


Figure 2-9. Four Cycle Engine Cross Section.

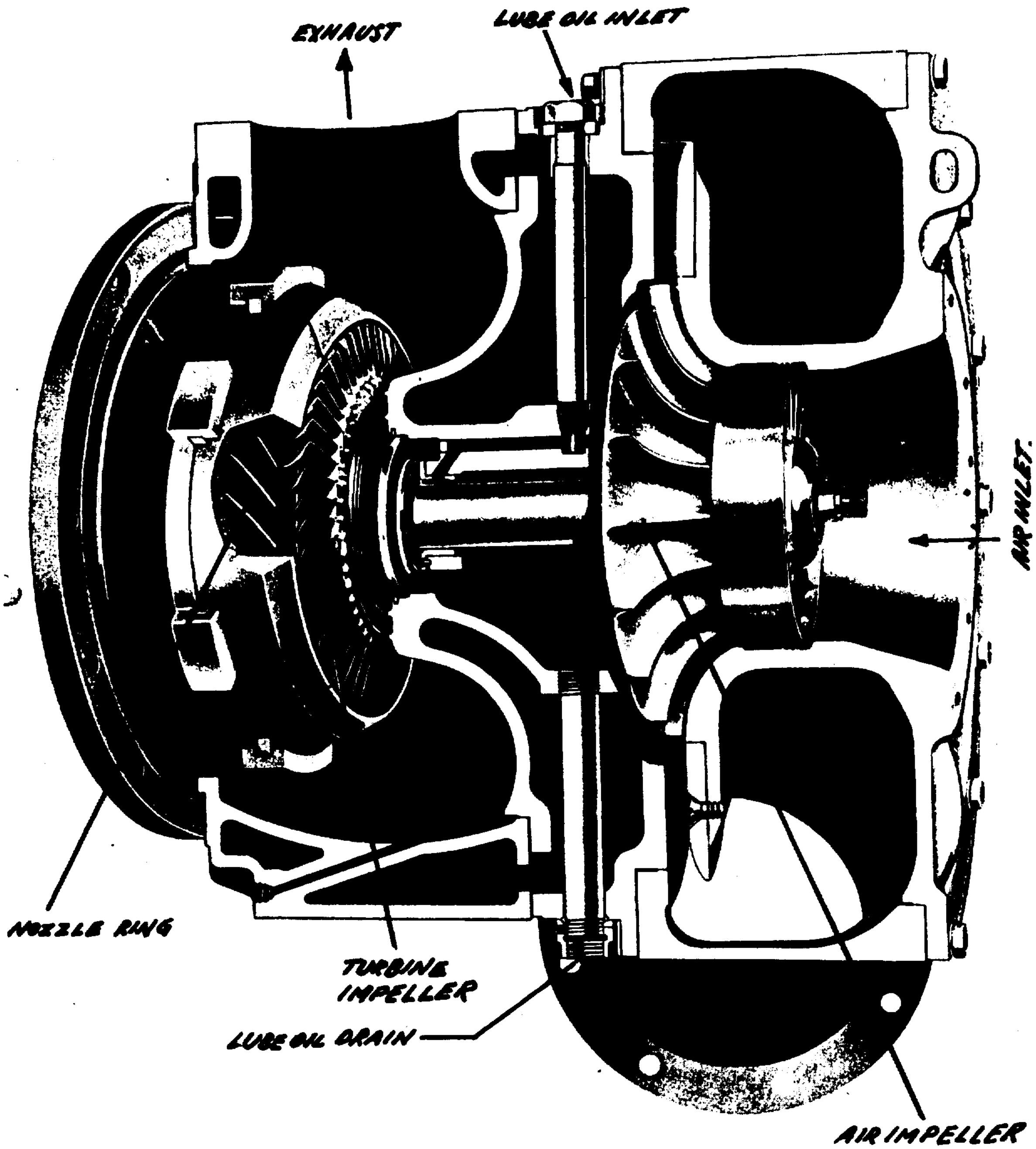


Figure 2-10. Exhaust Driven Turbocharger.

across the turbocharger could indicate scale buildup or a plugged coolant passage. In this event, see the manufacturer's maintenance manual for the necessary corrective action.

2–5. Carburetion Characteristics of Gasoline Engines. Most gasoline engines are of the four-cycle type. Carbureted engines of the two-cycle type are uneconomical because some of the fuel mixture is carried away and lost during cylinder scavenging. In a gasoline engine, a combustible mixture of gasoline vapor and air is drawn into the cylinder during the intake stroke. After the mixture compresses, an electric spark initiates combustion. All loads must maintain a fairly definite relationship of fuel

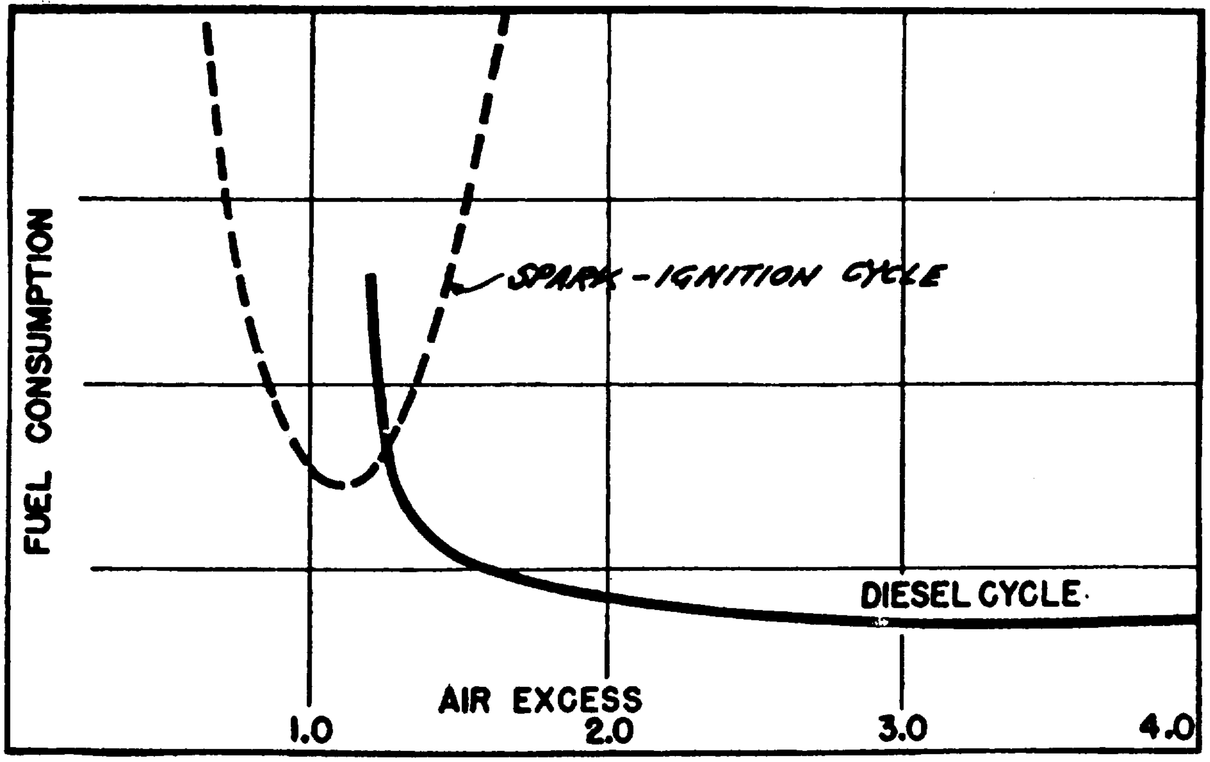


Figure 2-11. Effect of Excess Air on Fuel Consumption Spark Ignition Cycle Vs Diesel Cycle.

and air. The loads must be held within rather narrow limits, or excessive fuel consumption will result. Figure 2-11 illustrates this by the curve marked "spark ignition cycle." It shows that for best economy, a small air excess is desirable (slightly lean mixture). Operation on either side of optimum air-fuel ratio (leaner-richer) causes the fuel consumption to rise rapidly. To maintain this favorable air-fuel ratio for all loads, a throttle, controlled by a governor, adjusts the mixture entering the cylinders. Thus, the throttle position varies in proportion to the load. Also note in figure 2-11 that the air-fuel ratio is not critical with diesel operation. Diesels operate very economically with air excess of 1.2 and larger, as shown by curve marked "diesel cycle."

2-6. Diesel Engine Fuel Injection Systems. Figure 2-12 shows a typical fuel system (with other auxiliary systems) for a diesel engine. Typical components of diesel engine fuel systems include bulk fuel storage tank, fuel oil transfer pump, reservoir on day tank, flow meter (quantity), filters and strainers, hand priming pump, injection pumps, and injectors (valves/nozzles). The function of a fuel system is to deliver an exactly metered amount of fuel to the engine cylinder to develop sufficient power to overcome the load demand. Subparagraphs a through f below describe specific types of systems:

a. Pressure Time (PT) Fuel System. This system (also called the common rail system), works on the pressure time principle. It consists of a single high pressure fuel pump that supplies fuel to a common header or rail at a pressure of about 250 lbs/in^2. Individual fuel lines carry the fuel from the header to the injectors. The quantity of fuel injected is controlled by varying the length of time the injector valve is open and the amount of pressure on the fuel. The pump throttle position determines the pressure.

b. Individual Cylinder Fuel Injection System. The individual cylinder fuel injection system consists of 4 major parts; they are the transfer pump, fuel pump, injection pump (also called a jerk pump), and injectors. Each cylinder has its own injection pump. The transfer pump (figure 2-13) supplies fuel to the injection pump

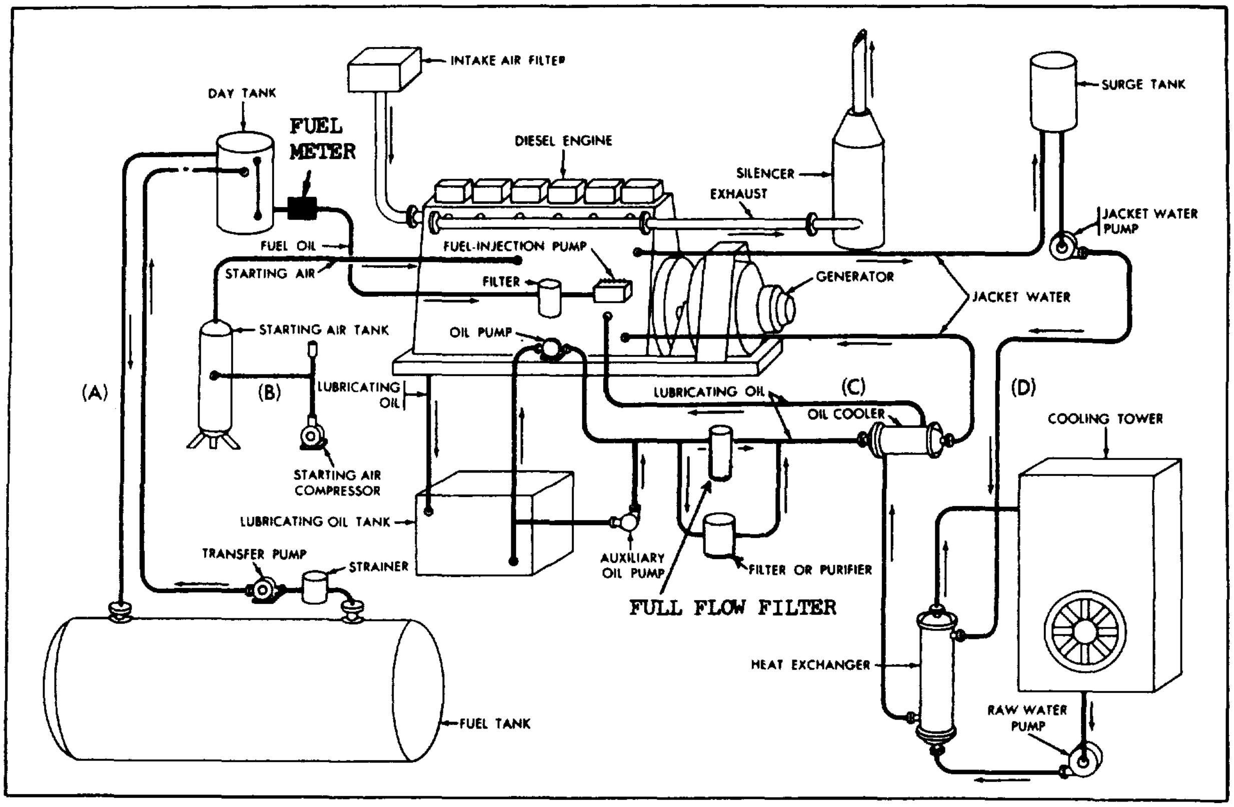


Figure 2-12. Fuel and Other Auxiliary Systems of a Diesel Engine Installation.

via the fuel header (manifold). The injection pump is actuated by the engine camshaft. This type system generally is used on larger engines since the spacing of the pumps along the engine, near each cylinder, permits the use of short, high-pressure injection lines of equal length.

c. Unit Injection Fuel System. The unit injection fuel system operates on the same principle as the individual cylinder injection system. But, the pump and injector are combined in one unit hence the term "unit injection" (figure 2-14). This system consists of the pump/injector combination, fuel header, and transfer pump. It has the advantage of eliminating the high pressure lines from the injection pump to injection nozzle. Also, the individual unit injectors can be replaced independently.

d. Multi-Plunger Injection System. This system operates on the same principle as the individual cylinder and unit injector systems. But, several fuel pumps are assembled into one housing (figure 2-15). This housing contains a common control rack and an engine-driven camshaft to activate the pumps. This system utilizes hydraulically controlled injectors.

e. Distributor Type Fuel System. This type system is presently used on many light- and medium-sized diesel engines. It is popular because of its quick response, lower cost, light weight, compactness, and its adaptability to small high-speed diesel engines. The system consists of a hand-priming pump, transfer pump, distributor injection pump, and hydraulic injectors. The injection pump consists of at least one plunger and a single-delivery valve doing the work of several such valves (see figure 2-16).

f. Fuel System Maintenance. The fuel system is the single most important component of an engine with respect to performance. Maintain it strictly according to the manufacturer's instructions. Routine servicing will minimize major problems and promote efficient operation. Technicians performing fuel system maintenance must become thoroughly familiar with

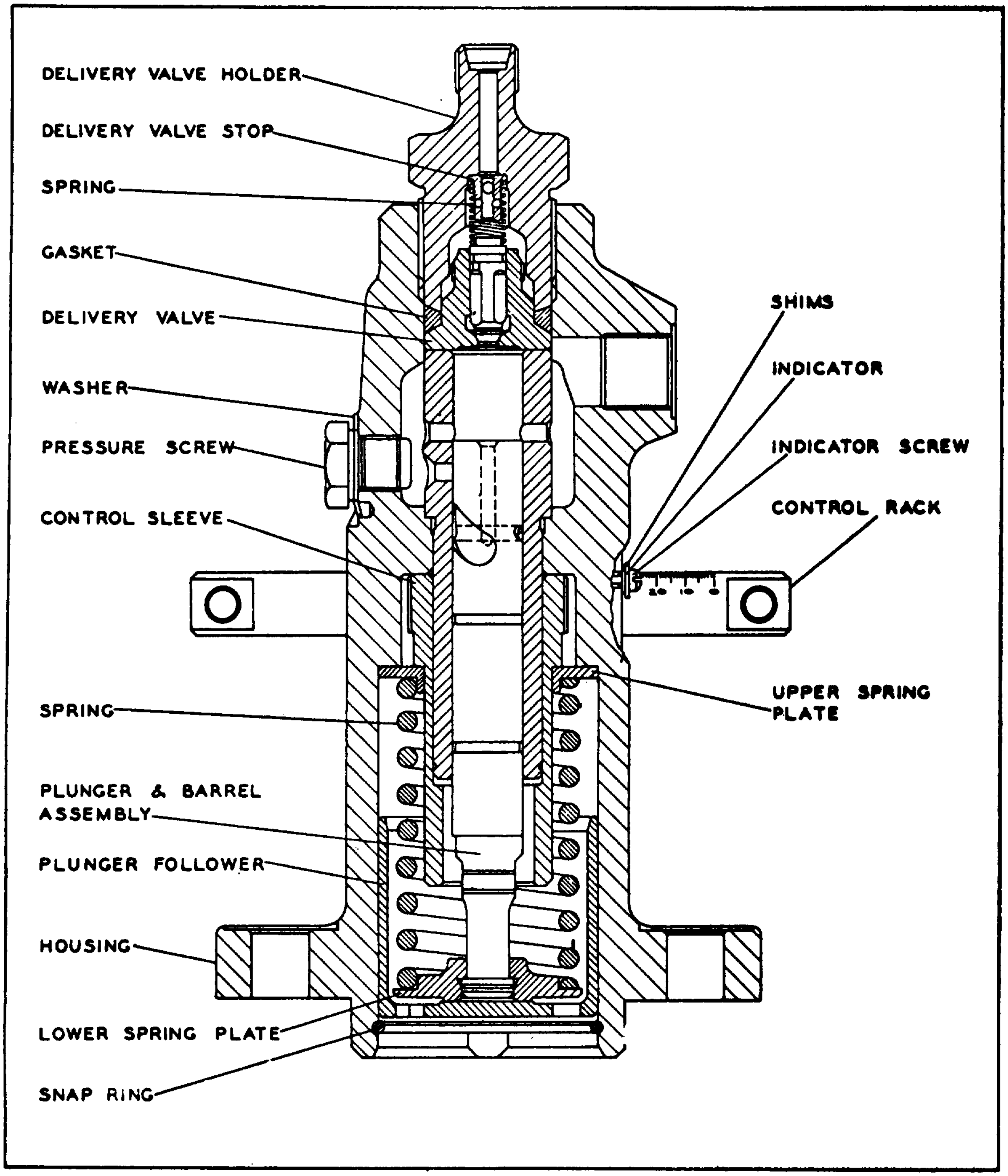


Figure 2-13. Individual Fuel Injection Pump.

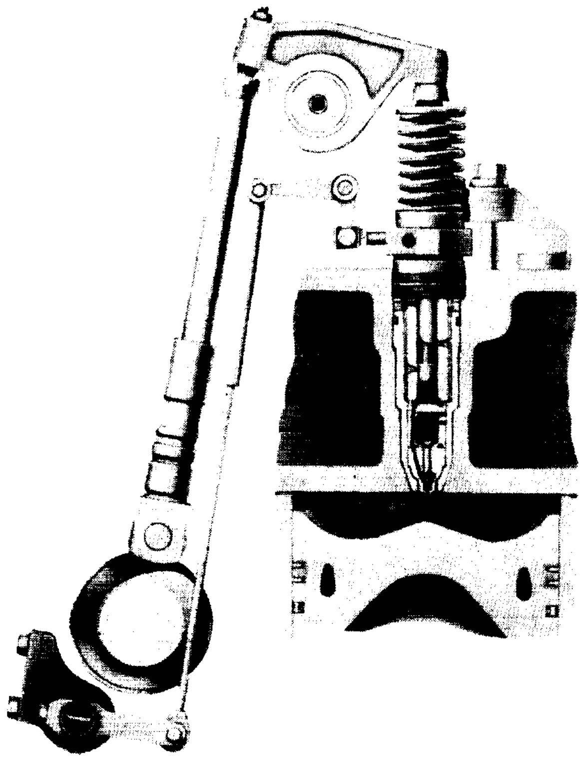


Figure 2-14. Unit Injector. (Courtesy Caterpillar, Inc)

the entire system. Technicians should not attempt fuel injection pump repair unless the proper calibration equipment is available and the technician is thoroughly familiar with the prescribed procedures for operations and adjustments. When symptoms point to the malfunction of a pump, it is usually advantageous to replace it with a spare pump and disassemble, inspect, and clean the components of the removed pump. Before dismantling a pump, consult the manufacturer's instructions. Plunger and barrel, delivery valve and valve body are fitted together carefully at the factory. You should never interchange them. Use light fuel oils as cleaning agents if more effective cleaners are not available. Fuel oil will readily remove grease and dirt provided a brush is used. It will not dissolve lacquers formed on the parts. Never use sharp tools, abrasive cloth, or any other abrasive to clean the critical parts. After washing, lay the parts on a clean surface, preferably paper, and examine all parts carefully. Replace any worn or scored parts and check for hairline cracks. Fuel pump racks (on engines not using unit or multiplunger injectors) are connected to the engine governor so that action is positive for increasing the fuel delivery, but is under spring tension when fuel is decreased. This type connection is needed so that if one or two racks of a multicylinder engine become stuck, (fuel pump seizure), the governor can still return the remaining racks into the "no fuel" position. But if, for example, two racks of a six- or eight-cylinder engine are stuck in the full load position, the engine will take off without control, as soon as the load is removed from it. So, frequently check the fuel pump racks, fuel control shaft bearings, and control linkage for freeness, preferably when the engine is at rest. Apply a few drops of oil occasionally to the racks, and move each back and forth a few times.

g. Fuel-Injection Valves (Nozzles (Figure 2-17)):

(1) The fuel nozzle injects the fuel delivered by the pump into the combustion chamber in a finely atomized form. Most fuel-injection valves are hydraulically operated and are usually of the spring-loaded, differential, needle-valve type. The spring keeps the needle from lifting until the pump has delivered oil at a pressure that, when exerted on the differential area of the needle valve, is greater than the spring loading. As soon as the pressure lifts the needle, fuel enters the combustion chamber through an orifice or a number of spray orifices. The spring tension can be adjusted by a screw or adding or removing shims to the desired nozzle opening pressure. The preferred opening pressure is specified in the manufacturer's manual. Nozzle-valve body and the needle valve are fitted together carefully at the factory and should never be interchanged.

(2) If operational symptoms indicate that an injector is not functioning properly, it is usually advantageous to replace it with a spare injector. This procedure will reduce unit downtime and allow operating personnel to inspect and check the removed nozzle as time permits. Most injection trouble is caused by dirt, water, or excessive heat. Dust in the fuel, consisting of minute abrasive particles, damages the valve seats and valve stems. Dirt in the fuel also erodes or clogs the nozzle orifices and causes the valve to stick in its guide. Water in fuel causes corrosion, which results in enlarged nozzle orifices and sticking of needle valves. Frequent attention to the fuel filter ensures that only clean fuel gets to the nozzles. Poor cooling of the nozzle results in deposits of carbon at the tip and formation of varnish on the parts in contact with the fuel.

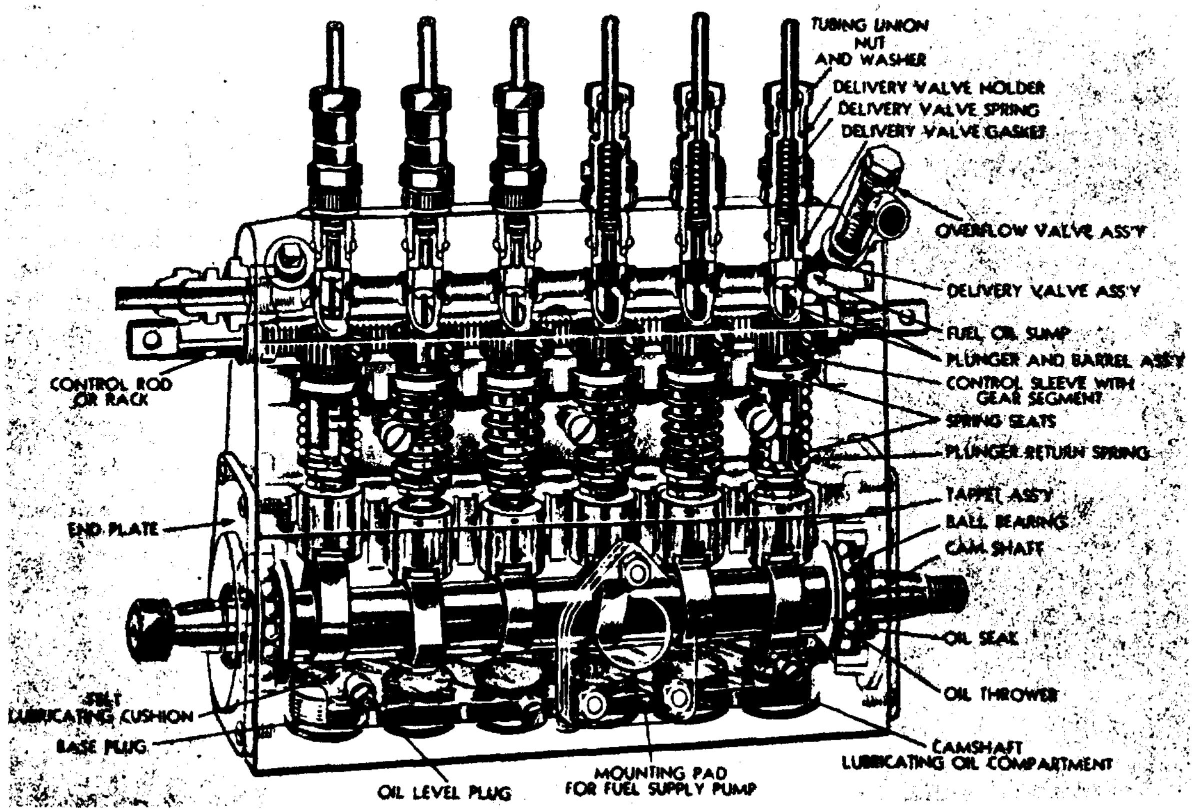


Figure 2-15. Multiplunger Fuel Injection Pump.

(a) Before cleaning injectors, clean the workbench and cover it with paper. Have sev eral clean containers available for solvent and kerosene or light fuel oil. Do the following to clean and inspect the injectors parts:

1. Soak the nozzle tip for several hours in solvent.

2. Clean spray tip holes using a piece of piano wire clamped in a pin vice. The wire should be one size smaller than the spray hole diameter. Rotate the wire while gently inserting it into the orifice.

3. Carefully wash each part in solvent until all traces of deposits have disappeared, be careful not to nick or scratch any of the lapped surfaces.

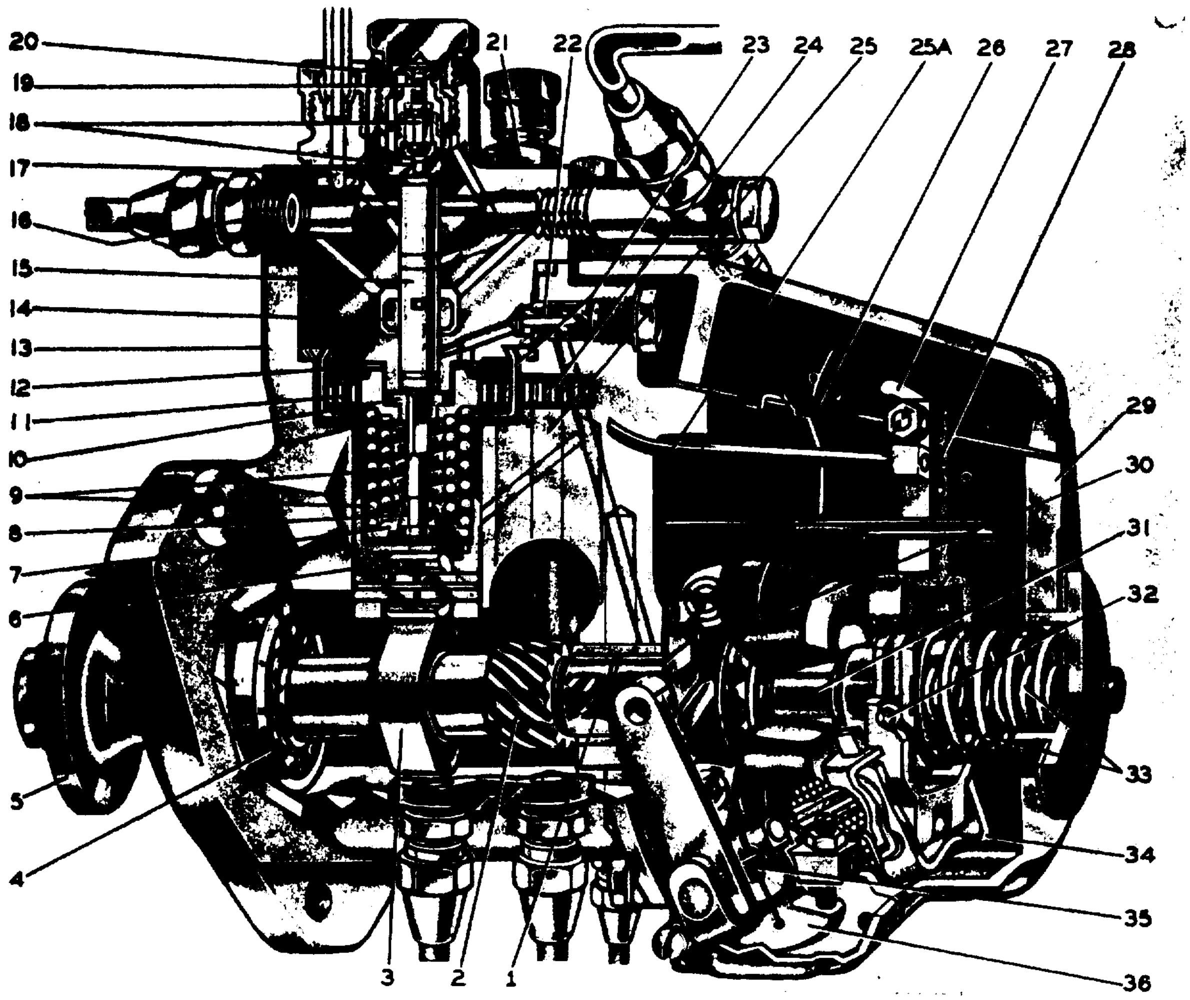
4. Examine all parts for nicks and scratches. Wear is usually minute. If, after cleaning, the needle valve does not slide freely in the valve body, replace it. With only fuel oil as a lubricant, the needle valve should slide slowly downward under its own weight. If the valve sticks in any position, the parts should be removed and rerinsed until properly free. Lapping the needle valve with jeweler's rouge is an emergency measure only. If a valve is lapped, replace the assembly as soon as replacement parts are available.

(b) Before installing the injector into the engine, test it in a nozzle tester as follows:

1. Connect the fuel injector to the test pump. **WARNING:**Fuel discharged from an injector has sufficient velocity to penetrate flesh. Fuel oil in the blood stream may cause blood poisoning. Wear gloves and goggles when testing nozzles.

2. Operate the pump several strokes to check for leaks and to expel air from the system.

3. Then apply pressure slowly until the valve opens and note the reading on the pressure gauge. The valve should open with a distinct popping sound. If the opening pressure is different from that recommended by the manufacturer, reset the adjusting screw or remove or add shims until the valve opens at the correct



1. Sleeve bearing
2. Spiral gear
3. Cam and cam shaft
4. Ball bearing
5. Drive hub
6. Tappet assembly
9. Plunger return spring
14. Control sleeve
15. Plunger
18. Delivery valve assembly
24. Plunger drive gear
30. Governor fly weights
33. Speed control spring

Figure 16. Cross Sectional View of Distributor Type Fuel Injection Pump.

pressure. If nozzle dribbling occurs, it is an indication of a worn needle valve or seat, improper mating of the lapped surfaces of the nozzle and spacer assemblies, or improper torque of the nozzle cap nut to the holder body.

h. Fuel Filters and Strainers:

(1) Proper filtration of fuel is one of the most effective means of preventing difficulties. Fuel, as it leaves the refinery is clean but sand, scale, dirt, and water will get into the fuel during transit and storage. Such matter, if allowed to enter the engine fuel system, is sure to clog the nozzles, and accelerate wear of the fuel pumps, injection valves, and engine cylinders. To prevent this, filters capable of removing fine particles are placed in the piping between day tank and engine, between engine transfer pump

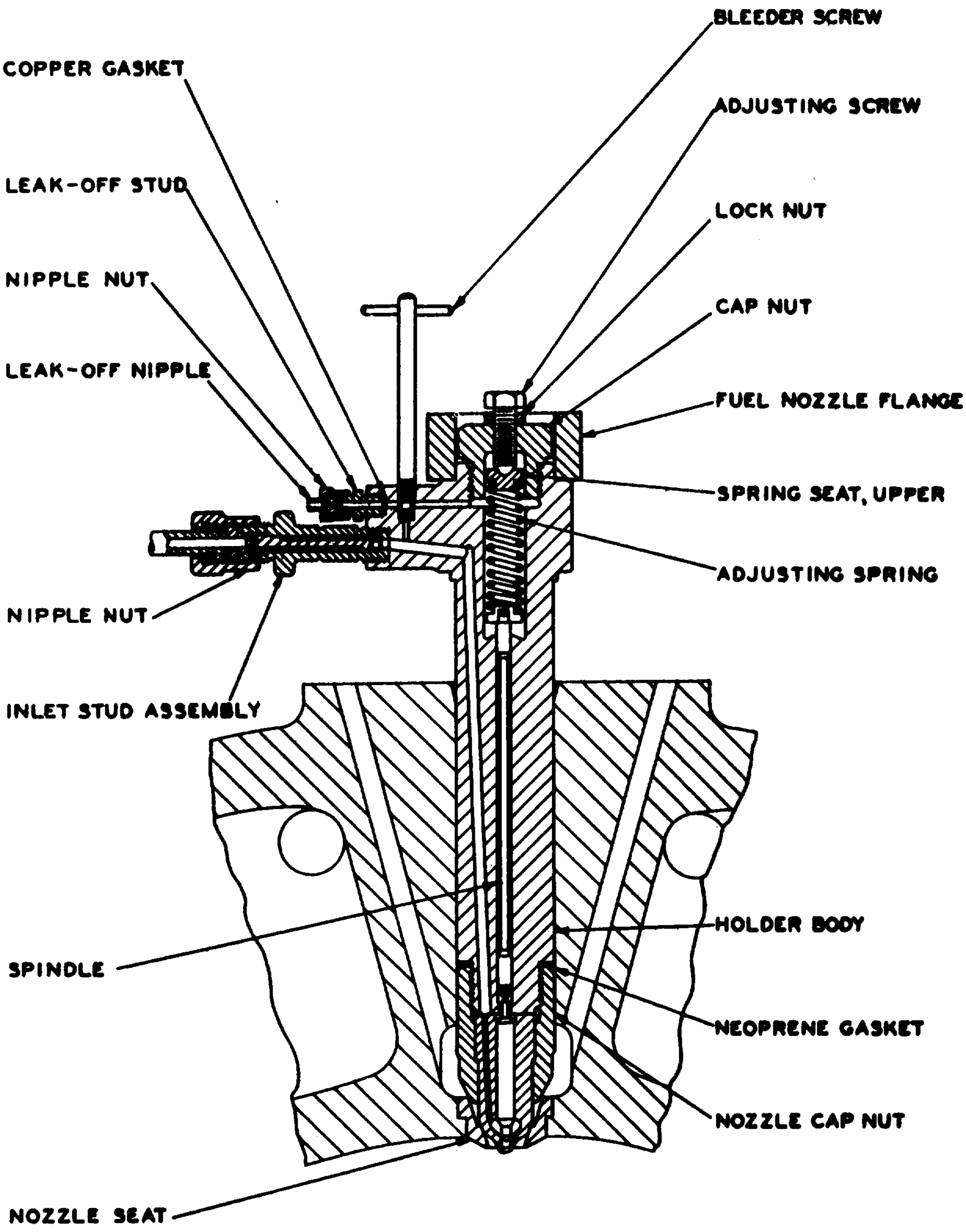


Figure 2-17. Typical Fuel Injection Nozzle.

and injection pumps or, in some cases, at both places. Place a fine-screen strainer in the main storage tank fill line. This prevents the accumulation of foreign matter in the storage tank and protects the transfer pumps. Also, place a filter or strainer ahead of each fuel meter. Filters and strainers should preferably be of the duplex type so that filtration can be switched from one side to the other while the engine is operating. When one filter side is cleaned or replaced, make sure that the replacement cartridge is fully saturated with fuel and that the filter case is completely full of fuel. If air trapped in the filter is not fully vented, an interruption in fuel supply may result. Place filters and strainer where they are easily accessible for cleaning and replacing cartridges, and provide space under edge or disk-type filters for a receptacle to catch dirt and oil drained from the bottom of the filter during cleaning.

(2) Filter flow capacity is generally specified in gallons per hour at a certain pressure drop across the filter. The capacity at a given pressure drop is influenced by the viscosity of the fuel. For example, a certain filter may filter 50 gallons per hour of fuel having a viscosity of 39 centistokes or 180 saybolt universal seconds (SUS). But, with the same pressure drop across the filter it may only handle 30 gallons per hour for fuel having a viscosity of 108 centistokes (500 SUS). Viscosity is explained in paragraph 2-17a(1). If the same filter must handle 50 gallons per hour of 108 centistokes fuel, the pressure drop across the filter will increase materially from what it was for the fuel with 39 centistokes viscosity. So, in selecting a filter, consider:

(a) The maximum fuel flow rate through the filter.

(b) The maximum viscosity of the fuel (minimum temperature) at which it will pass through the filter.

(c) The maximum allowable pressure drop across the filter.

(d) Filter efficiency.

(e) Retention capability. For example, a filter with 90 percent efficiency and a retention capability of 3 microns means that no more than 10 percent of the particles larger than 3 microns (about 0.0001 inch) are expected to pass through the filter in one pass. From this, one can see that the more liberally the filter is sized the less frequently it will have to be cleaned. A good rule is to procure a high-efficiency filter having the lowest pressure drop for the maximum flow at operating temperature. Preferably, the pressure drop across a filter should not exceed 2 to 4 lbs/in^2 when new (based on the delivery rate and average fuel temperature). The pressure drop will increase gradually with length of service and may reach as much as 15 lbs/in^2. Inasmuch as the pressure drop is an indication of the loading of the filter, use it as a guide for determining the need of filter change. As long as the minimum required fuel pressure to the engine is maintained and as long as the permissible pressure drop across the filter does not exceed that recommended by the manufacturer, there is normally no need for changing or cleaning filter elements. To know the condition of the filter elements at all times, it is good operating practice to plot pressure drop (lb/in^2) through the filter at regular time intervals such as days, weeks, or months. By this means, the operator is aware at all times of the filter condition, and can schedule cleaning or replacement far in advance.

(3) Fuel Systems for Gasoline Engine:

(a) The combustible mixture of fuel and air for a gasoline engine is prepared before it is inducted into the cylinders. Proportion the mixture properly so that it will liberate the greatest amount of energy. Make sure the fuel atomizes completely because the finer the particles of fuel the better and the more explosive the mixture. This is a function of the carburetor. In a constant-speed engine, a governor and a throttle control the amount of fuel mixture admitted to the cylinders. The load demands on the engine are met by varying the amount of combustible mixture admitted to the cylinders.

(b) The components of the fuel system are gasoline storage tank, fuel pump, gravity priming tank, strainers and filters, carburetors (one or more), and governor.

(c) The fuel system can have more than one carburetor, depending on the size of the engine. A well-designed carburetor is simple, efficient, of ample capacity, and affected little by climatic and temperature differences. It is provided with backfire traps and performs its function of mixing the correct proportion of fuel and air to meet all load conditions of the engine. Properly adjust the carburetor while the engine is hot. Too lean a mixture causes the engine to spit or backfire when the load changes suddenly. Too rich a mixture causes the engine to run unevenly or labor and show black smoke at the exhaust. Disassemble and clean the carburetor at regular intervals. The cleaning frequency depends on the number of engine operating hours, amount of dust in the air, and grade of fuel. Follow the manufacturer's instructions for disassembling and cleaning.

2-7. Engine Governing Systems:

a. Speed Governors. A speed governor automatically varies the flow of fuel to the engine so the power developed just equals that required at the desired engine speed. Below are some common expressions you will hear when discussing governor characteristics:

(1) Speed Droop. This is the change in engine speed from that at no load to that at full load. This change is usually expressed in percent:

$$\text{Speed droop } (\%) = \frac{No - Nr \times 100}{Nr}$$

Where Nr = speed at full load (rpm)
No = speed at no load (rpm)

For example, if full-load speed (Nr) of an engine is 500 rpm, and the no-load speed (No) is 520 rpm, the speed droop is 4 percent.

(2) Isochronous. This is the maintenance of constant engine speed independent of the load being carried (zero droop). An isochronous governor will maintain, or can be adjusted to maintain, constant engine speed.

(3) Stability. This is a governor's ability to maintain the desired engine speed without speed fluctuations.

(a) A governor's lack of stability results in "hunting" or oscillations due to over-correction.

(b) A governor's stability is indicated by the number of corrective movements it makes and by the time it takes to correct the fuel flow for a given load change.

(4) Response. A governor's speed response is expressed as the time in seconds required to move the fuel control for a change in load.

(5) Speed Changer. A device for adjusting the speed governing system to change the engine speed or power-output relationship with other engine-generator units when in parallel operation.

(6) Speed Regulation Changer. A device for adjusting the steady-state speed regulation (speed droop) while the engine is in operation.

(7) Load Limit Changer. An adjusting device for limiting the maximum fuel flow to the engine, thus limiting the engine's output to any desired maximum value.

b. Governor Basics. An engine governor is basically a speed sensitive device that automatically controls the speed of an engine. It does this by limiting the amount of fuel to the cylinders. Governors first measure the engine speed with an accurate speed measuring device. This speed indication then transfers to a movement of the governor terminal or output shaft. This shaft connects to the control rod of the fuel injection system, thus regulating the amount of fuel injected into the cylinders. Therefore, all governors consist basically of a speed measuring device and an actuator.

(1) Speed Sensing. Currently there are basically two types of speed measurement devices in governors. They are the mechanical and electronic sensors.

(a) In the usual mechanical speed sensor shown in figure 2-18, a pair of fly weights are located on opposite sides of a shaft rotated by the engine through gears. The rotating weights produce a centrifugal force which is opposed and balanced by a spring. This spring is generally called a speeder spring. If the speed increases, the centrifugal force on the fly weights increases. This moves the weights out from the axis of rotation. The outward movement of the weights lifts the ball-arm toes and the speeder rod. This continues until the force of the spring is balanced and an equilibrium point is reached.

(b) One type of electronic speed sensing device measures the speed of the engine by measuring the speed of the flywheel. A magnetic pickup device is positioned so as to detect the passing of the flywheel teeth. This is used to generate a signal proportional to engine speed. Another type of electric speed sensor measures the engine speed by measuring the frequency of the electric current produced by the alternator. Usually, the electric signals developed by electric or electronic speed sensors operate a solenoid type actuator.

(2) Actuator Types. There are basically 3 types of actuators; hydraulic, electromechanical and mechanical:

(a) In a hydraulic actuator, the power to move the throttle comes from a hydraulic power piston or servomotor. This is a piston acted upon by a fluid, usually oil, under the pressure of a pump as shown in figure 2-19. The speed measuring device is attached to a small cylindrical valve, called a pilot valve (or spool valve), by the speeder rod. The pilot valve slides up and down in a bushing which contains parts that control

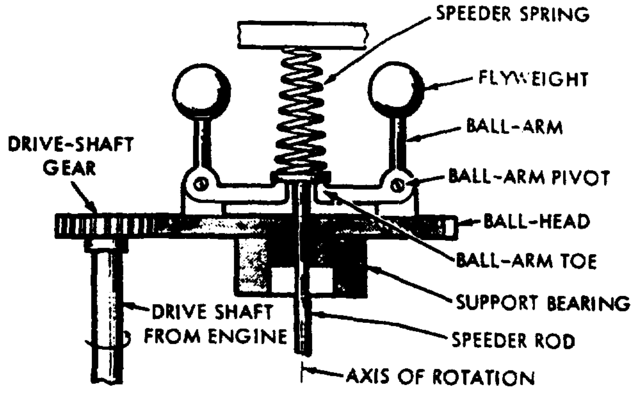


Figure 2-18. Centrifugal Ball-Head Mechanical Sensor.

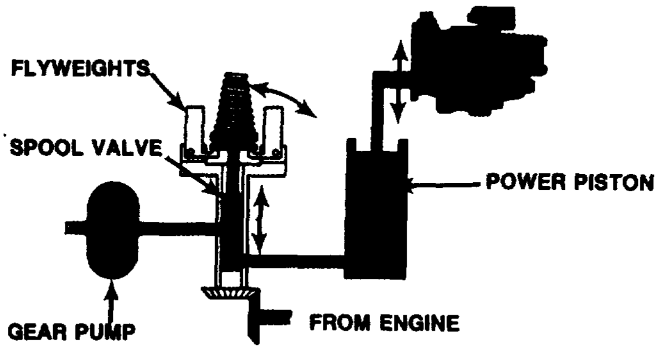


Figure 2-19. Hydraulic Actuator With Mechanical Sensor. (Courtesy Cummins, Inc)

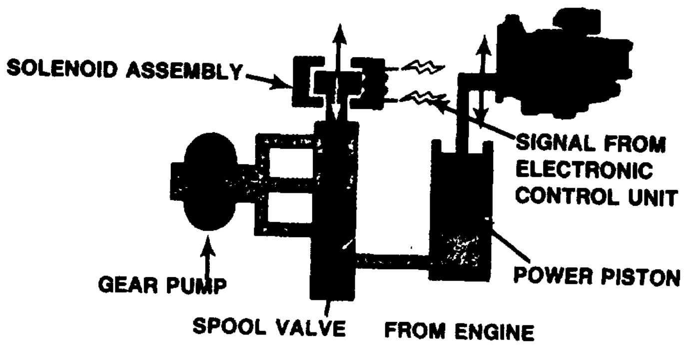


Figure 2-20. Electromechanical Actuator. (Courtesy Cummins, Inc)

the oil flow to and from the servomotor. The force needed to slide the pilot valve is exceedingly small compared to the force developed by the servomotor throttle.

(b) Electromechanical actuators (Figure 20) utilize an electromechanical plunger (solenoid) to control the pilot valve which controls the flow of pressurized fluid to a power piston. This power piston moves the throttle. Another type electromechanical actuator consists of a solenoid valve which when energized, causes an actuator shaft to turn. As the shaft rotates, the alignment between the fuel port in the shaft and the fuel pump cavity is changed. This changes the amount of fuel to the engine.

(c) In a governor having a mechanical actuator the force to move engine throttle comes directly from the speed measuring device by way of a speeder rod. Mechanical actuators have several disadvantages which limit their use. They will not be discussed further.

c. Parallel Operation. When two or more diesel generators are to be paralleled, the following items must be remembered:

(1) Inasmuch as the electrical frequency (Hertz) depends directly on the rotative speed of the engines, adjustment to a desired frequency can only be accomplished through a change in engine speed (rpm).

(2) Most governors are provided with a speed droop adjustment with which engine speed may be maintained either constant throughout the entire load range (zero droop) or engine speed may be decreased from no-load to full-load (droop operation).

d. Speed-Droop Operation. Speed droop can be represented graphically as shown in figures 2-21 and 2-22. For example, consider first the speed-load line of engine A. It shows that engine speed at "no load" was set at 520 rpm. With the setting of a certain speed droop at the governor, the engine speed, in this example, decreases as the load it carries increases and reaches 500 rpm at full engine load. Speed droop, in the above case, is 4 percent. By assuming now that two engines operating in parallel have identical speed droop settings (line A) and the total station load is 100 kW (rated capacity of each unit is 100 kW), we see that each engine will carry 50 kW (point 1) at equal speeds of 510 rpm (load equally divided). If, now the speed setting of engine B is increased (speed changer at governor), but both droop settings are left untouched, the speed load line of engine B assumes a position as illustrated in figure 2-21. With the new speed setting, the division of the 100 kW station load between the two engines operating in parallel can only occur at a point where both engines operate at the same speed. In the above case, this speed, common to both engines, is 515 rpm (horizontal line 2-3), at which engine A carries 25 kw and engine B carries 75 kw. But, with the new load division, the electrical system frequency has increased in the ratio of the change in engine speed or 515 divided by 510. If now the station load increases to 150 kW (with both governor settings untouched), the load is divided 50 kW to unit A and 100 kW to unit B (horizontal line 1-4). With both engines operating at speed and droop setting for engines A and B left as shown in figure 2-21, the effective capacity of the plant would thus be only 150 kW instead of 200 kW (total capacity of both units). The foregoing example shows how the load can be shifted from one unit to the other by a change in one unit's speed in relation to that of the other. Operation of a generator or generators with droop is common where they are parallel with a commercial or nonisolated bus.

e. Combination Isochronous and Speed-Droop Operation. In most AC electric power systems, constant-cycle operation is more desirable than to have the electrical frequency reduced with heavy station load and increased with light station loads as occurs with speed-droop governing of all units. For this reason, it is customary to have one unit operate with isochronous governing (constant engine speed from zero to full load) and the remaining units operate with speed droop. This condition is illustrated in figure 2-22. Horizontal line C represents speed vs load for the isochronous unit, line D represents the relationship for the speed-droop unit. By assuming again that each unit has a rated capacity of 100 kW, we can see that each unit will carry 50 kW (point 5) at a speed of 510 rpm. If, with this governor setting the station load increases to 150 kw, the droop unit D will still carry 50 kW, but the isochronous unit C will be fully loaded-with both engines remaining at a speed of 510 rpm (line 5-6). A further increase in station load would overload unit C while unit D would continue carrying only 50 kW, until the maximum overloading of unit C (set by the load limit changer) is reached. If the station load were increased still further, engine speed and system frequency would decrease and allow the droop unit to pick up additional load.

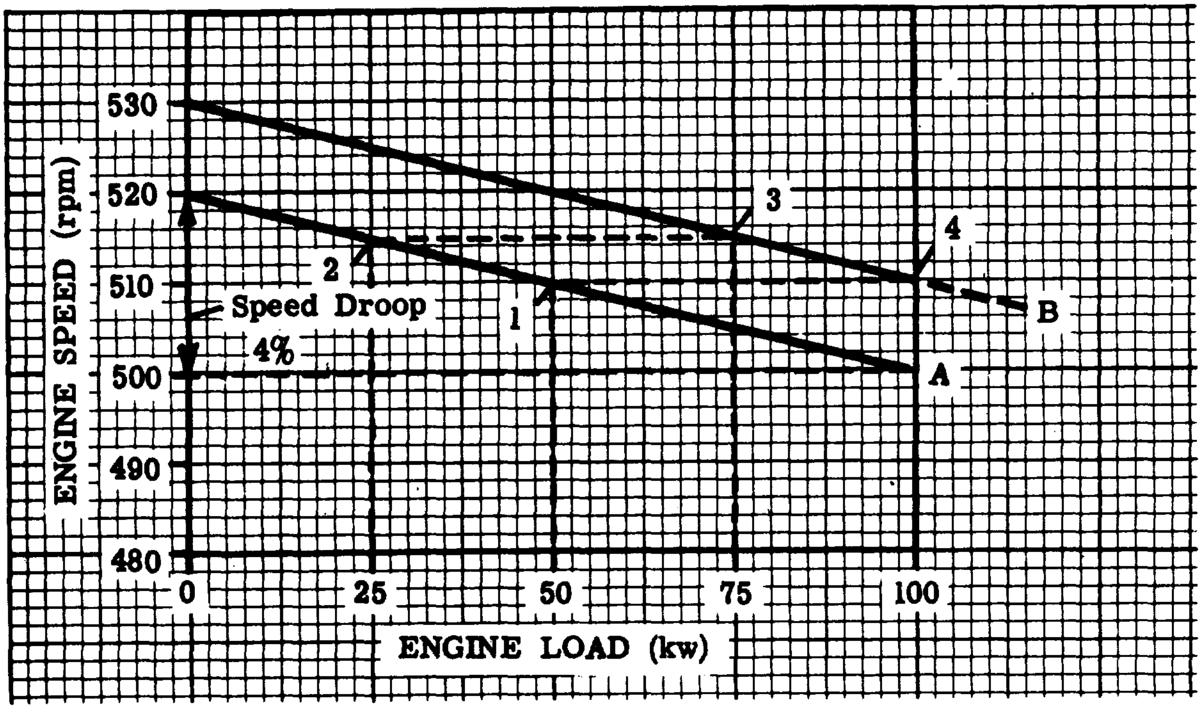


Figure 2-21. Speed Droop Operation.

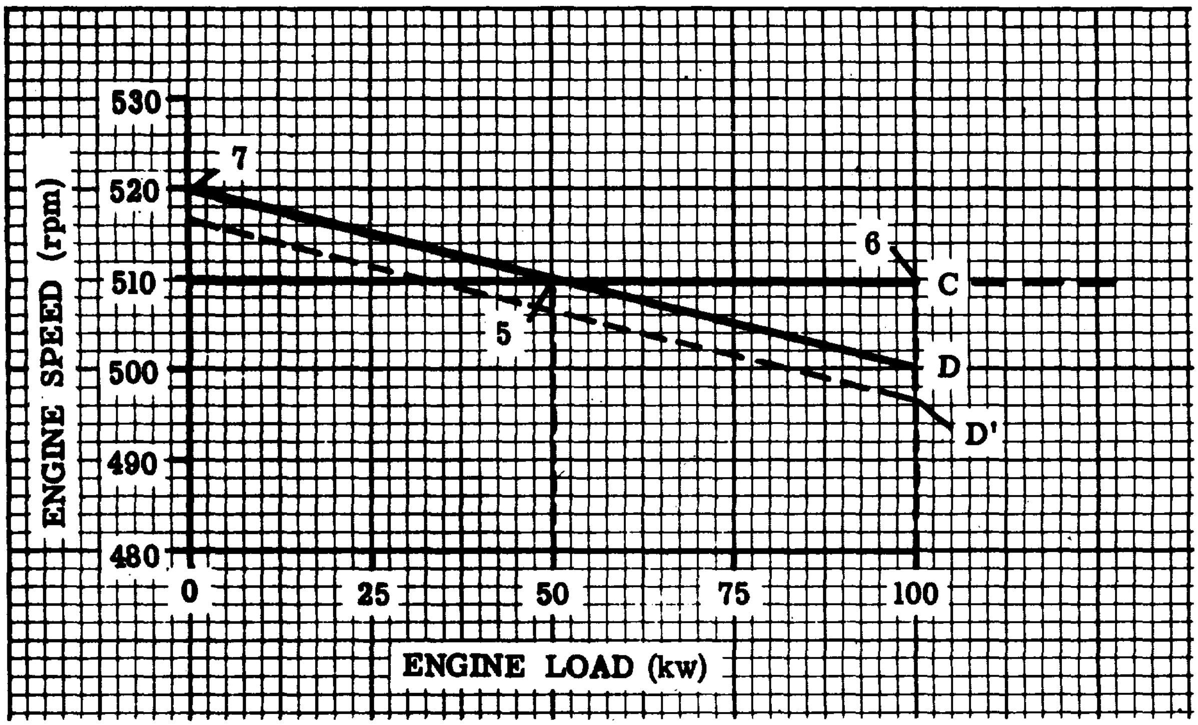


Figure 2-22. Isochronous Operation.

Conversely, if the station load were reduced to 50 kW total, it would all be carried by the droop unit D. A further decrease of the station load would result in an increase in engine speed and system frequency along line 5-7. As a result, the isochronous unit C would be motored by the droop unit D at a speed above its setting. In practice, the advantage of isochronous governing is the maintenance of constant system frequency. The extreme conditions described above can be avoided by readjusting the speed setting of the droop unit to, for example, line D, so as to keep the isochronous (lead) unit loaded at nearly half load. In other words, in operating a multi-engine plant, a constant load is usually applied to the unit with the droop setting and variations in power demand are absorbed by the isochronous or lead unit. Since the advent of electronic governors, this type of plant operation is rare.

f. Isochronous Load-Sharing Operation. Isochronous load-sharing is a method of operation in which all generators connected to a bus run in the isochronous mode. This is accomplished by adding a load sensing module to the electronic isochronous governors installed on each generator. These load sensors are interconnected by what are called paralleling lines. Any load imbalance between units will cause a change to the regulating circuit in each governor. Depending on how sophisticated the controls are, the load will split between the generator sets in any percentage while they continue to run isochronously. Import/export (I/E) devices can also be used with this type governor. I/E devices are normally used when generators and commercial power operate into a common bus. The I/E device determines how much power is drawn from or fed into the commercial system because it controls the generator's output.

g. Governor Maintenance. The governor is a sensitive, precision device, and should be treated accordingly. For hydraulic governors the two chief requirements for dependable operation are a vibration-free drive and a supply of clean oil of a recommended grade. Dirt is a major cause of governor trouble. There are many minor maintenance procedures which can be accomplished to prevent or correct most problems. The manufacturer's manual usually contains step-by-step instructions to keep the governor operating efficiently. Electronic governors require little maintenance compared to other types. A spare governor assembly should be kept in a prime power plant. If a malfunction occurs, the unit can be replaced with the spare, and the failed assembly either repaired on site (if minor), or sent to either an established repair facility or the factory.

h. Governor Linkage and Adjustments. If the linkage is set to give the fuel control racks full travel with 1/4 of governor-lever travel, the governor can do only 1/4 of its maximum work; so, the speed droop will also be only 1/4 of the maximum obtainable. When the manufacturer's manual gives no specific procedure for linkage adjustment, a good rule of thumb is the 2/3 rule. The 2/3 travel of the governor linkage for full travel of the engine fuel control rack or the throttle between fuel and maximum fuel. Governor linkage and connections to the fuel pump racks should be lubricated and checked frequently for excessive play in the pivot bearings. Also, fuel pump racks frequently should be moved in and out a few times, to make sure they are free.

2-8. Alarm and Shutdown Systems. The temperature and pressure of coolant and lube oil are important indicators of engine performance. Coolant level alarms are also advisable where possible. Most engines are equipped with basic engine protective circuitry and monitoring devices. The most common are the the low lube oil pressure, high coolant temperature, and overspeed. Some are equipped with alarms that sound before a shutdown occurs. This alerts the operator that there is a problem that needs immediate attention. The following are some brief discussions on typical control systems.

a. Temperature Sensing Devices. Thermal switches are used to monitor the temperature of the coolant. They are normally mounted at the highest point in the system. This is usually the hottest point during operation. The sensing bulb and the capillary tube, if remote, contain a liquid or gas whose pressure will vary with temperature changes and actuate the switch. This type switch is preadjusted for the maximum safe operating temperature. If actuated, it operates an alarm or a shutdown device. These switches, along with the associated protective circuitry, are extremely important to safe engine operation. They must therefore, be periodically tested and calibrated according to the manufacturer's specifications.

b. Pressure Sensing Devices. Pressure sensitive devices monitor the engine lubricating oil pressure. They are normally mounted in a part of the engine block which connects directly to the lube oil galley, or header. If oil pressure drops below the minimum safe level, pressure sensing devices usually energize (or deenergize) and electrical circuit, or hydraulically operate a piston, valve, or latch. This secondary device will, in turn, interrupt the fuel or airflow to shut the engine down. To prevent shutdown for low oil pressure during engine startup, a normally closed (N.C.) fuel pressure switch is sometimes used as a time delay for the low lube oil alarm/shutdown. When electrically used in series with a normally open (N.O.) low oil pressure contact, the fuel pressure switch will close only when sufficient fuel pressure is built up. This is normally enough time to allow the oil to come to operating pressure. Pressure sensing devices and circuitry are very important to safe engine operation. They must be periodically tested and calibrated according to the manufacturer's recommendations.

c. Overspeed Device. The main engine governor normally will limit maximum engine speed. Engines also have a speed sensing device that shuts the engine down if the main governor, governor drive or the fuel control mechanism fails. Such overspeed devices frequently consist of a separately driven centrifugal switch in which a flyweight's movement actuates a shutdown device. This usually occurs when the engine speed exceeds 10 percent rated speed. There are also electronic speed switches which operate on a signal from a magnetic pickup. If the overspeed device actuates during normal engine operation, the cause should be determined before the engine is started again.

d. Testing Alarms and Shutdown Devices. In a properly maintained installation, safety and shutdown devices seldom operate. Therefore, they should be periodically tested to be sure they will function when needed. Below are generic test procedures to use in the absence of specific instructions from the manufacturer:

(1) For temperature sensing devices, remove the temperature switch and immerse it in a container of water that is heated and agitated. Operation of the switch is noted with a continuity checker and an accurate thermometer. After the temperature of the water reaches 190 °F, it should be increased slowly to obtain an accurate reading. The switch should operate at the temperature shown in the manufacturer's manual. Some modern engine generator sets utilize cooling systems designed to operate at temperatures above 212 °F. The safety switches in these systems may have trip points of 220 to 230 °F and cannot be checked by immersing in boiling water. In this case, a 50-50 mixture of antifreeze and water can be used. Also, some control panels allow testing switch operation at temperatures lower than normal shutdown levels.

(2) Pressure sensing devices should be tested periodically to see if the set point is accurate. With the switch removed from the engine, use a calibrated pressure gage and a continuity meter. A gage calibration kit listed in Table of Allowance 489 can be used to accomplish this test. Reinstall the switch carefully since overtightening may alter the setting.

(3) The overspeed sensing device (overspeed device) can be tested on a engine which is scheduled to shut down. First disconnect the load, then raise the engine speed to slightly higher than the setting of the overspeed speed switch. The switch should operate and cause the engine to be shut down. If it does not, it should be repaired or replaced prior to placing the unit back into service. Some overspeed switches can be adjusted to allow shutdown at speeds lower than rated speed.

2-9. Engine Lubricating Systems (Figure 2-23):

a. Full-pressure System. The bearings and moving parts of all modern diesel engines receive lubrication from a full-pressure system. The essential elements of the system are:

(1) The storage space to hold the oil in the system.

(2) A pump to supply pressure for forcing oil through the bearings and the engine oil passages.

(3) An oil cooler to remove heat picked up by the oil in passing through the engine.

(4) Filters or treating equipment to remove dirt and sludge.

(5) In some cases a centrifuge.

(6) Pipes, valves, and instruments (gauges, thermometers).

b. Wet and Dry Sumps. All engines provide for some kind of oil storage. When engine oil enters this storage, it settles before recirculating through the engine. Makeup oil is also supplied at this time. The reservoir is called a sump. Many engines have what is commonly called a wet sump. In a wet sump, the oil storage is in the crankcase. Some engines, however, have the sump outside the crankcase. This avoids excessive lubrication of the cylinder walls by oil fog.

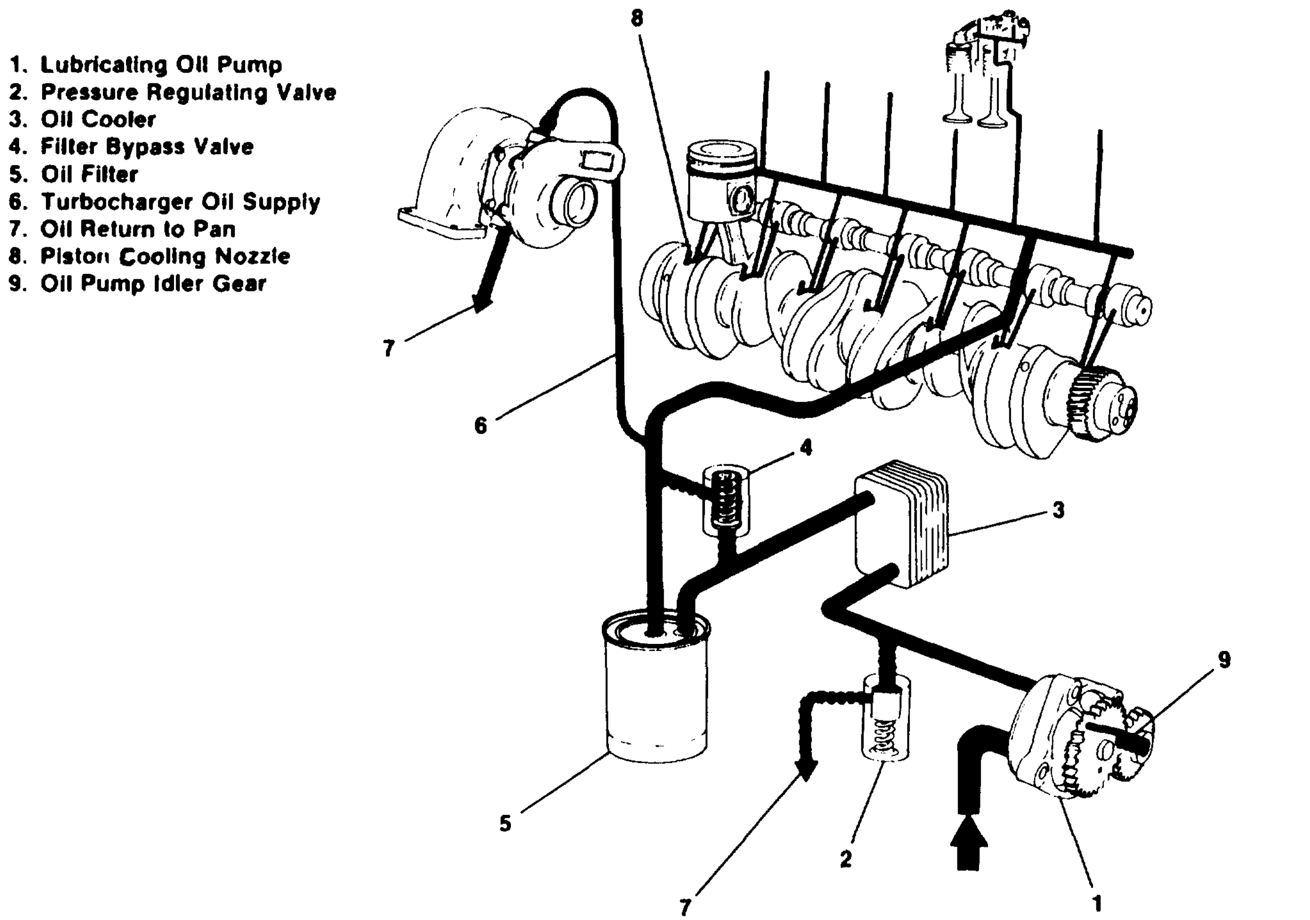


Figure 2-23. Schematic of Typical Lubricating System. (Courtesy Cummins, Inc)

This oil fog is caused by air currents created by the rapid motion of the crankshaft and piston rods. Having the sump outside the engine removes most oil from this turbulence.

c. Lube Oil Flow. The lubricating oil pump draws oil from the sump tank and feeds it in succession through the strainers, the oil filters, and the cooler to a header located at the engine with branches leading to the various parts to be lubricated. Leads extend from the header directly to each main bearing. From here the oil passes through drilled passages in the crank webs to the connecting rod bearing. From there it goes to the wrist pin bearing. From here the oil is either used to cool the piston or, in the case of uncooled pistons,the oil drains down to the engine crankcase and back to the pump. Other branches from the header supply lubricating oil to gear trains, camshaft bearings, rocker arms, and push rods. The cylinder walls and pistons normally obtain their lubrication by oil discharging from the main and connecting rod bearings (splash). Some engines, particularly large two-cycle units, require additional lubrication at the upper portion of the cylinder wall above the ports. A mechanical lubricator usually supplies this lubrication. Lube oil systems may vary in some details for different makes of engines, but the fundamental principle is the same for all. Figure 2-24 is a cross section of a diesel engine showing the lube oil flow.

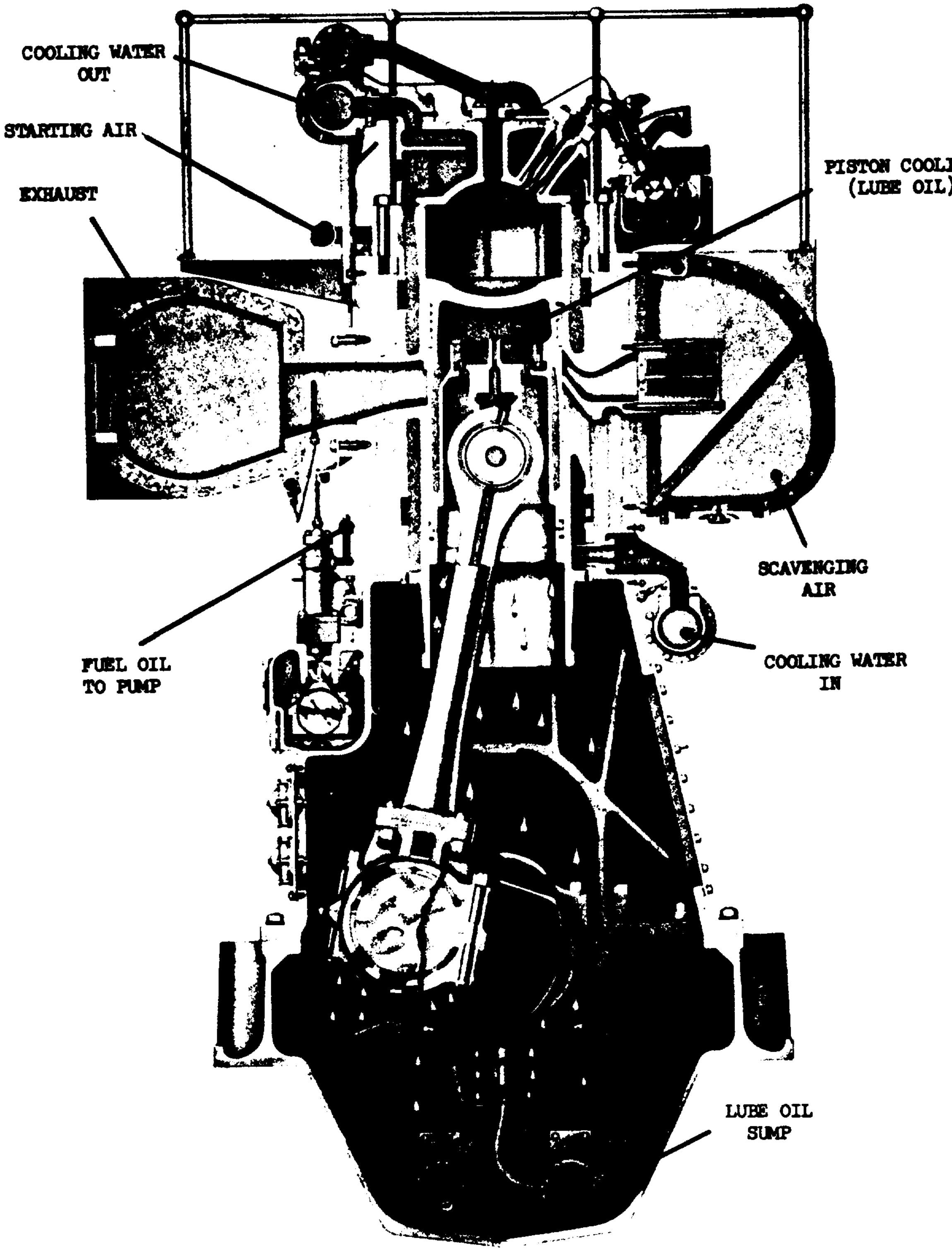


Figure 2-24. Cross Section of Diesel Engine Showing Lube Oil Flow.

d. Piston Cooling. The need for piston cooling depends on the size of the piston and rated BMEP of the engine. Practically all two-cycle and all medium and large four-cycle engines require some type of piston cooling. The three gen eral methods of cooling pistons are the shaker, circulating and spray cooling:

(1) The shaker method is common in cast iron pistons in which oil passes through the con necting rod to a compartment in the piston head.The oil is shaken around by the motion of the piston and can escape to the crankcase through holes or pipes.

(2) The circulating method used with some aluminum pistons where oil circulates through a series of grooves cut into the piston over which a steel ring sleeve (provided with piston ring grooves) is shrunk. Another type of circulation cooling consists of coils of tubing cast into an aluminum piston head through which oil circulates.

(3) The spray cooling method is usually applied to cast-iron and aluminum pistons. A jet of oil from the wrist pin end of the connecting rod is directed against the under side of the piston crown (see figure 2-25).

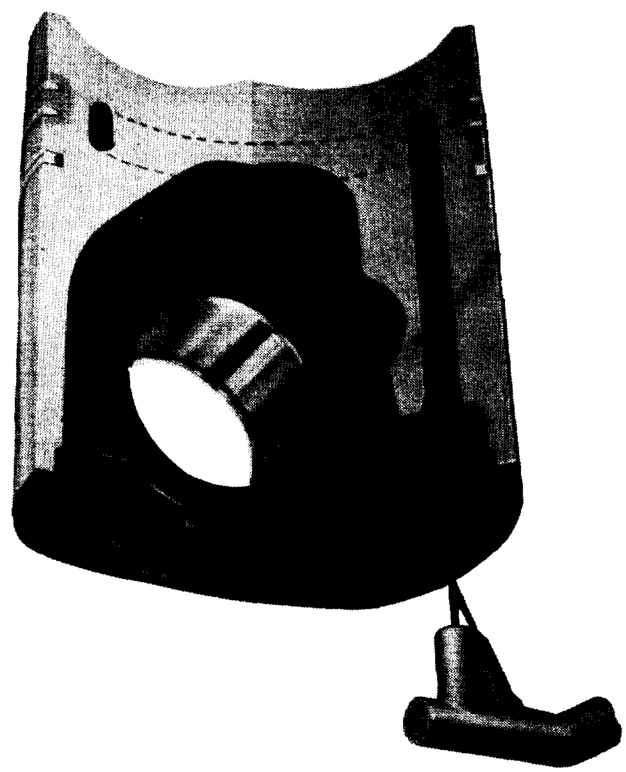


Figure 2-25. Spray Cooling of Piston. (Courtesy Caterpillar, Inc)

e. Lube Oil Pumps. In most installations, an engine-driven gear pump supplies the pressure needed to circulate oil through the engine lubrication system. Lube oil pump capacities vary with different engine makes and range between 2 and 5 gallons per kW rated output per hour. Lubricating oil pressure may vary from 20 to 75 lbs/in^2, depending on the type of engine. The manufacturer usually specifies the acceptable engine oil pressure range. In connection with oil pressures, remember the pressure measured at the pump is higher than that at the engine header. The amount depends on the pressure lost in the full flow filter and the oil cooler. This pressure at the pump is sometimes fixed by the pressure relief valve. As the pressure drop across the filter increases (dirty), the pressure at the engine header will decrease correspondingly. Additionally, as the engine bearing clearances increase (normal wear), the pressure at the engine header will drop further. Accordingly, the gradual change of oil pressure at the engine header may be used as an indicator of the wear on the engine bearings in the following manner: After the engine is started up with clean filters, the pressure relief valve at the oil pump is adjusted (note that some manufactures do not allow adjustment) so as to obtain the maximum recommended pressure at the engine - for example, 70 lbs/in^2. If the pressure drop through the filter is measured at 41bs/in^2, then the pressure before filter - that is, at the pump - will be about 74 lbs/in^2. If later the pressure drop across the filter increases to 15 lbs/in^2, the pressure at the engine header theoretically should show 59 lbs/in^2 (if there are no bearing wear or leaks). If, however, this pressure is recorded as only 50, indications are that the bearings have worn. So, after properly adjusting the pressure relief valve at the lube oil pump, leave it alone for evaluation of bearing wear. Naturally this does not apply if for some reason, the oil pressure at the engine header falls below the manufacturer's recommendations. Thus, differences of oil pressures at the engine, with known allowance for the pressure drop across the full-flow oil filter and oil cooler, can be an indicator for bearing wear or internal oil leaks.

f. Lube-Oil Pump Location. In practically every case, lubricating oil pumps are built into and driven by the engine. In high-speed engines, the oil pump frequently is placed in the crankcase sump and is driven by the crankshaft through a vertical shaft. In larger engines, the pump is usually gear or chain driven by the crankshaft and mounted at the end of the engine, either inside or outside the crankcase. Larger diesel engines are frequently provided with an auxiliary motor-driven lubricating oil pump with which oil may be circulated through the bearings before the engine is started. As soon as the engine is up to speed, the motor-driven pump cuts off automatically. Finally, the auxiliary pump is used to circulate the lube oil for a time after the engine is shut down, to gradually cool the bearings, journals, and pistons (if connected to a control designed for this function). When an auxiliary pump is used, a check valve should be placed in the discharge line of the auxiliary pump to prevent lube oil from flowing back through it when the engine comes up to speed and the auxiliary pump shuts down.

g. Lube Oil Coolers . Circulating lubricating oil absorbs heat from the engine. Frictional heat is absorbed from the bearings, and the oil film on the cylinder walls absorbs heat from the combustion gas before dripping down into the crankcase. This heat must be dissipated either by radiation or by an oil cooler if the oil temperature is to be kept at or below certain prescribed limits. A cooler is particularly necessary for engines having oil cooled pistons. The majority of lube oil coolers are of the shell-and-tube construction, and generally are designed for water to flow across the tubes. They usually have a thermostatically controlled bypass which allows oil to flow around the cooler when cooling is not desired (during startup).

h. Oil Cooler Location. On most modern engines, the oil cooler is an internal component of the unit. But, they are also sometimes mounted on the side of the engine or on the floor alongside the engine base. Cooling water passes through the cooler unit before it enters the engine jackets.

i. Lube Oil Purification. All modern diesel installations within the Air Force are being equipped with full-flow lube oil filters by which all oil delivered by the pump passes through the filter before reaching the engine. With such a filter arrangement, the pump discharge pressure must be equal to the minimum required at the engine plus the maximum allowable pressure drop across the filter. Since the engine must have oil at all times, some full-flow filters are equipped with bypass check valves which open when the pressure drop across the filter element becomes excessive. When this happens, only a portion of the oil to the engine is filtered. Therefore, to prevent oil from bypassing around the filter, the pressure drop across the filter should be watched at all times and the filter cleaned or elements replaced before the pressure drop reaches a level at which the bypass will open.

2-10. Engine Cooling Systems. Successful operation of any engine depends upon the removal of excess heat from the cylinders, pistons, valves, etc., to keep the temperature of these parts within allowable limits. Most diesel and gas engines are water cooled, although a few of the smaller, higher speed engines are air cooled.

a. Cooling of Cylinders, Cylinder Heads, and Pistons. Cylinders, cylinder heads, and pistons are the parts of the engine that are exposed to the intense heat of combustion. The heat carried away from these parts by the cooling fluid is generated by the gas energy released within the engine cylinder and represents a direct loss of energy. Depending on the type of engine, about 18 to 21 percent of the fuel's energy is lost in the cooling fluid. Cooling systems also may include cooled exhaust manifolds and air intercoolers or aftercoolers for cooling the air from the supercharger. Some engines have oil-cooled pistons whereas others, operating under similar conditions, depend on the cylinder liners to cool the pistons. Engine valves, except for very large sizes, generally are cooled by being in contact with parts of the cylinder head.

b. Flow of Cooling Water (See figure 2-12). Usually, cooling water is circulated through the engine by a centrifugal pump. The pump is normally driven directly by the engine, on small and medium-size engines. An independently (motor driven) pump is used for circulating the cooling fluid on larger installations. Such pumps require little maintenance, except for occasional tightening of the packing glands. Slight leakage should be permitted at the gland since the packing is cooled and lubricated by the cooling liquid being pumped. Usually, the water from the pump first passes through the oil cooler. From the oil cooler, it enters the lower portion of the engine cylinders and then flows upward through the cylinder head. In some engines, a cooled exhaust header is employed and the water from the cylinder heads further passes to the exhaust header and from there to the heat exchanger.

c. Control of Engine Temperature. Engine temperature may be controlled by varying the amount of cooling water passing through the engine and radiator. General practice, however, is to maintain the temperature of the water discharging from an engine within the range of 160 to 190°F, depending on the engine make and size, and to limit the temperature rise of the jacket water through the engine to 10 to 15°F. This will prevent extreme expansion and contraction of critical engine parts. After discharge from the engine, the cooling fluid is passed through a radiator or heat exchanger where it is cooled before being returned to the engine. Often, radiators are provided with thermostats so a part or all of the cooling fluid may pass around the radiator when the engine operates at part or no load. The advantage of this arrangement is that the rate of flow through the system remains constant for all engine loads. If the rate of cooling fluid is variable, local overheating (hot spots) are possible at low flow velocity. Consult the engine manufacturer's instructions for recommended operating temperatures.

d. Rate of Flow of Cooling Water. The rate of flow of cooling water through an engine depends mainly on the design of the cooling system. On the basis of 15°F temperature rise through the engine, the flow of cooling fluid ranges from 0.4 to 0.6 gal/min/rated kW. The more rapid the rate of flow, the less danger there is of the formation of scale deposits and "hot spots." The high water velocity has a scouring effect on the metal surfaces of the jackets, and the heat is conducted away more quickly.

e. Cooling of Fuel Injection Valves. In most engines, the fuel-injection valves must be cooled because the amount of fuel passing through the valves is not sufficient to keep them cool. Cooling is normally done by circulating the cooling fluid around the lower portion of the injection valve assembly. Overheated valves lead to carbon buildup around the nozzle tips.

f. Type of Cooling Systems. Two general types of cooling systems are known: The "closed system" and the "open system," with many variations of each. The two types may be described as follows:

(1) Closed-Type Cooling System. A closed liquid cooling system is like a automotive-type cooling system. The components of a simple closed liquid cooling system consist of the engine water jacket, a circulating water pump, a radiator and radiator shutters and controls, and a temperature-regulating valve. A cooling fan is either driven by the engine or remotely driven by an electric motor. On large installations, a conventional heat exchanger is used and the engine coolant circulating through the heat exchanger is cooled by water from a cooling tower (figure 2-12-D). The most common method of cooling water in a closed system is by an air-cooled radiator. When the heat of the engine jacket is directly transferred to the air by the radiator, the process is sometimes referred to as dry cooling in comparison to wet cooling with a conventional heat exchanger. Most portable and semiportable, and some large newer stationary power units have radiators. A remotely mounted radiator is shown in figure 2-26. A closed system with cooling tower is shown in figure 2-27. All heat carried away from the engine is eventually conveyed to the atmosphere. A closed-type cooling system is most desirable from the standpoint of using antifreeze and treated coolant.

(2) Open Cooling System. In this system water is circulated under pressure through the engine jackets. A bypass may recirculate part of the water back to the jackets, but most of the water is either wasted through evaporation or is recirculated through a cooling pond or an open tower. Constant addition of makeup water increases the concentration of both the hardness and impurities in the water and result in scale-formed deposits in the engine water passages. The open cooling system is generally not recommended unless an ample supply of chemically inert water is available. Note that this system is not recommended for some modern diesels (a closed system is required).

g. Ebullient Cooling Systems. This type of cooling system (also called vapor-phase cooling), differs from other cooling systems primarily in the temperature level. Conventional cooling systems operate with temperatures as high as 160 to 190 °F, but vapor-phase operates at 212 °F or higher, thus necessitating a pressurized system. Such a system is shown in figure 2-28. No circulation or cooling of the jacket water takes place until the water reaches the system's design temperature. The temperature of the cooling fluid then stays approximately constant, regardless of heat input, by action of the water flashing into steam in a flash tank or vapor phase unit. Due to the latent heat of vaporization phenomenon, heat required for changing water to steam is taken from the water and thus maintains the water at an even temperature in accordance with the system

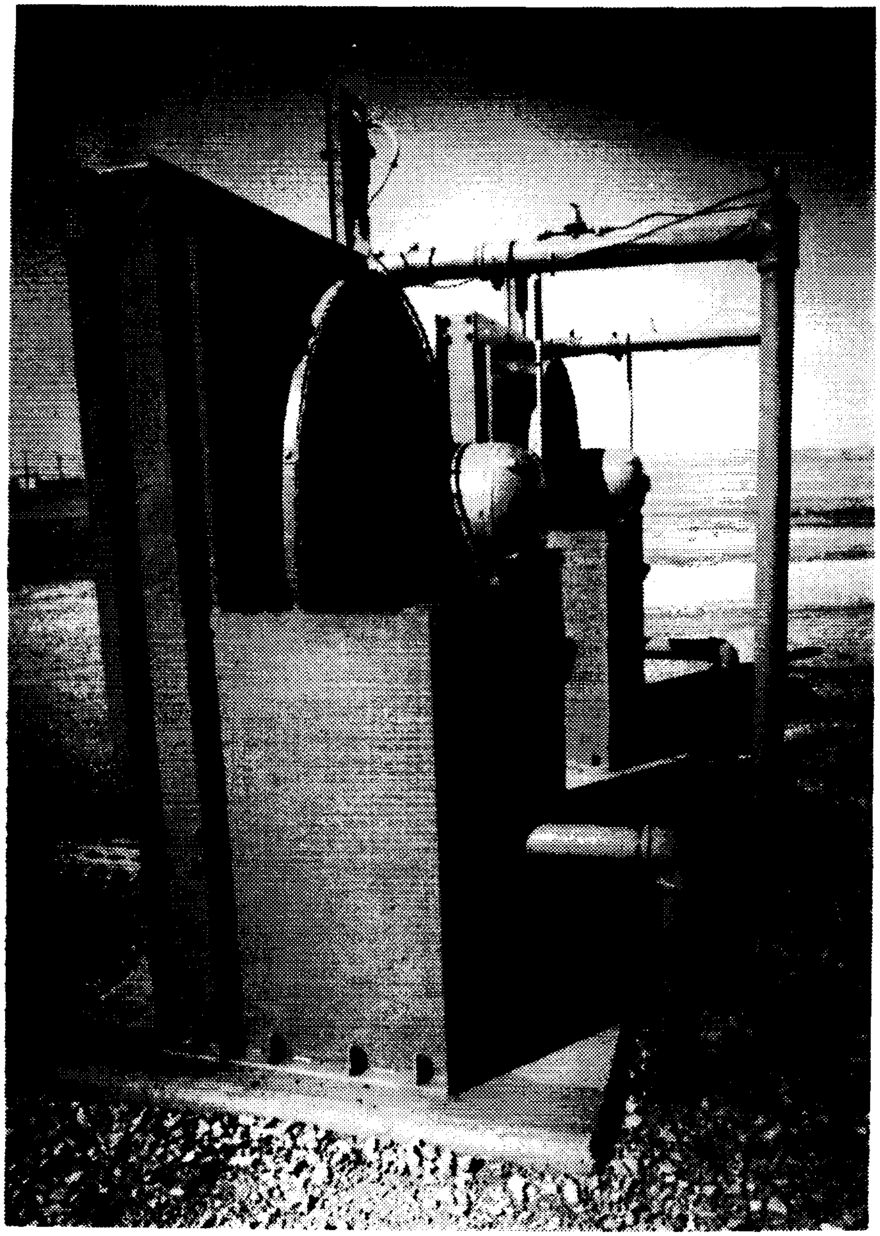


Figure 2-26. Remotely Mounted Radiator.

pressure. For example, water at 3 lbs/in^2 pressure boils after it reaches a temperature of 219°F. At 15 lbs/in^2 pressure, it comes to a boil 248°F. The vapor phase unit is located at a sufficient distance above the engine, so as to be at the top of the thermosyphon system used for circu lating the water through the engine without the aid of a pump. Steam thus produced may be used for heating or process work (waste heat recovery) or may be condensed immediately in a steam condenser and returned to the jacket water supply. In the arrangement according to fig ure 2-28, air across a coil is used to condense the steam but any other convenient method for condensation could be used. Heat absorbed by the water in cooling the engine is exactly balanced by heat removed by flashing it into steam. This principle can be demonstrated with a pan of wa-

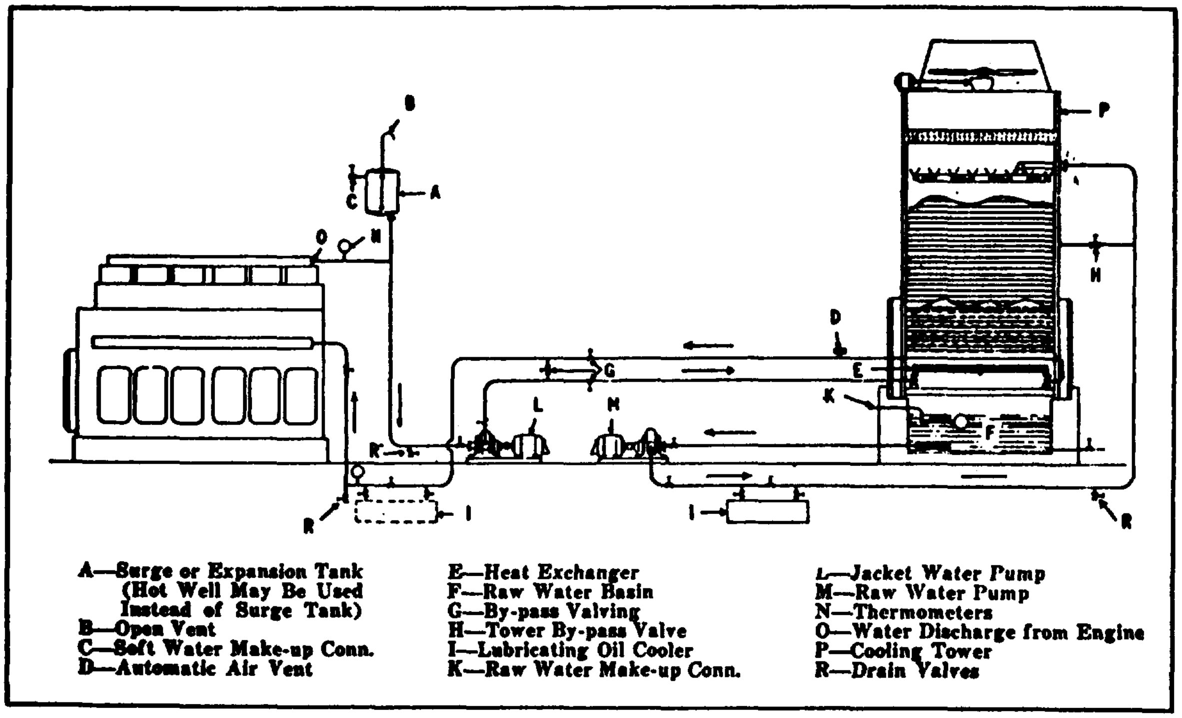


Figure 2-27. Closed System With Cooling Tower.

ter and a thermometer. If the water is brought to a boil at standard atmospheric pressure and temperature, the water temperature will remain at 212 °F regardless of the amount of heat supplied to it. If the rate of heat supplied to the water is increased, the rate of steam increases which removes more heat. But, the temperature of the water will remain constant. For example, the heat removed by converting 1 lb of water to steam is 970 Btu/lb. In contrast, the heat removed from cooling water by reducing the temperature (conventional cooling) from 180 to 165 °F is only 15 Btu/lb. Several benefits are claimed for the high temperatures method of cooling. With the water temperature practically constant throughout the system, liner and engine block temperatures are uniform from top to bottom. Temperatures within the cylinder are maintained above the dew point of water vapor. Thus water vapor formed during combustion leaves the engine as steam with the exhaust, and does not condense and mix with other byproducts of combustion to form acidic material. It is claimed that corrosive wear and also sludging is reduced. In addition, auxiliary power is reduced since no power is normally taken from the engine for circulating the jacket water (thermo-syphon).

h. Mode of Operation. As water passes through the engine jackets and picks up heat from the engine parts, a small percentage of steam is formed. The water and steam mixture enters the vapor-phase unit (separator) where the water and any solid contaminants are centrifugally separated from the steam and the water is returned to the engine jackets. The steam from the separator then passes to the steam condenser and the condensate is also returned to the separator.

i. Jacket Water Waste Heat Recovery. According to AFM 88-15, bases must use waste heat from jacket water and exhaust gas when economically feasible. Steam from the vapor phase unit may be used for heating purposes. Usually part of the steam is transferred to the building or process steam heating systems and the remainder of the steam goes to the condenser. If the steam pressure exceeds the desired operating pressure, the proportion of steam to the condenser is increased by a pressure control

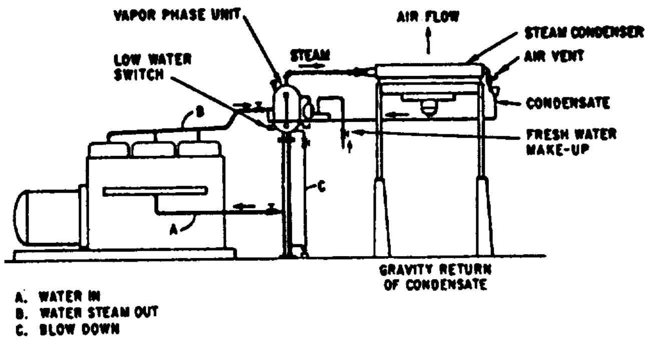


Figure 2-28. Ebullient Cooling System.

valve in the system. The condensed steam from the condenser and heating systems returns to a condensate receiver where it is pumped (under pressure) back to the separator.

j. Exhaust Waste Heat Recovery. For each pound of fuel burned in a diesel engine, approximately one-third of its energy goes to develop power at the shaft, a small amount goes to overcome internal friction, about one-third is still in the exhaust gas when it leaves the cylinders, and the remainder is normally lost in the jacket water. If an exhaust waste heat boiler is installed, only a portion of the heat can be saved. To obtain heat transfer from the exhaust gas to another medium such as steam, hot water, or air, considerable temperature difference must exist between the two mediums. Conversely, exhaust gases contain superheated steam and if the gases are cooled to the temperature at which the steam condenses into water, corrosion in the exhaust boiler (gasside) will set in. Present exhaust waste heat boilers can be classified in the same general manner as conventional boilers-namely, fire-tube types and water-tube types. Of late, combination waste heat boilers-silencers (mufflers) are available and can operate either wet or dry, and simultaneously act as exhaust silencers.

k. Combination Jacket Water and Exhaust Waste-Heat Recovery. Where great quantities of steam are used, the jacket water heat plus the exhaust heat is recovered as steam. In this case, part of the water condensed in the steam separator or vapor-phase unit returns to the engine inlet header and the remainder flows to the exhaust heat recovery unit (exhaust boiler or combination exhaust boiler-silencer).

l. Cooling Water Treatment. All diesel engines should be checked regularly for fresh water conditions, and corrective action should be taken when required. This is because all water contains impurities that can be more or less harmful to an engine and its cooling system. Proper treatment of the jacket cooling water is necessary to hold scale deposits to a minimum. Scale deposits from untreated fresh water cause uneven heat transfer. Excessive heat concentration causes stresses in the affected members and may crack liners, heads, or other parts. Ideally, jacket water should be soft, clean, and free from deposits and scale-forming materials. It also should be slightly alkaline and inhibited against rust and corrosive action. Non-alkaline (acidic) water causes corrosion and cavitation. Cooling water should therefore be maintained at a pH between 7.5 and 8.5. For closed systems requiring non makeup water, inhibited antifreeze (ethylene glycol) is usually all that is required for water treatment. If necessary, the sodium-nitrate-borax treatment listed below can be added to the antifreeze for additional corrosion control (Check with the engine manufacturer first). Inhibited antifreeze is available under NSNs 6850-00-181-7929 (1 gal can); 685-00-181-7933 (5 gal can); and 6850-00-181-7940 (55 gal drum). Use the information in m through n below if the manufacturer's recommendations are not available:

m. Removal of Scale. The inhibited antifreeze identified above contains corrosion inhibitors to prevent scaling. Inhibited sulfamic acid conforming to military specifications MIL-B-224144 (scale removing compound), will remove scale already formed. (Check with the engine manufactures before using.) The compound contains a material which changes color when the acid is spent. After the system has been cleaned, it should be flushed thoroughly with fresh water before it is put in service. A final rinsing with water containing about one ounce of soda ash per gallon is desirable. Dispose of used solvent in an approved manner.

n. Corrosion/Cavitation Control. Acidic water, or water having high chloride or sulfate contents, and even pure distilled-type water can cause pits, cracks, and tubercles in liner heads and other engine parts. Corrosion control inhibitors are available to prevent this. This includes a nitrite-borax mixture. This is a mixture of three parts sodium nitrite to one part of borax. This inhibitor mix, if permitted by the engine manufacturer, has proven to be effective in controlling cavitation-corrosion of diesel engine cylinder liners. For this purpose, recommend concentration of 2000-3000 parts per million of nitrite be in the coolant. Maintain the pH of the solution between 7.5 and 8.5. Preparation of the engine coolant is accomplished by adding about four pounds of sodium nitrite-borax per one hundred gallons of cooling system capacity. Sodium nitrite-borax is compatible with antifreeze solutions. A thirty-pound can of sodium-nitrite/borax inhibitor is available under NSN 6850-01-185-1187. Commercially it is available as "Corrosion Inhibitor CS, " from the Calgon Corporation. It is also available in 50 pound bags under the trade name "Dearborn No. 527", from the Dearborn Chemical Division of the Chemed Corporation. (See AFP 91-41 for more information on this inhibitor.)

2-11. Engine Starting System. This system brings the diesel engine up to enough speed to raise the air-fuel mixture in the cylinder to combustion temperature. The following systems or types are in use:

a. Air Starting. This system is used for all large engines with compressed air usually applied to all cylinders. The most frequently used system of supplying compressed air to the cylinders is the one in which air from a storage tank is admitted to the starting air manifold (figures 2-12-B and 2-29) and, in turn, to the starting air valves in each cylinder head (figure 2-30). Except during startup, the starting air

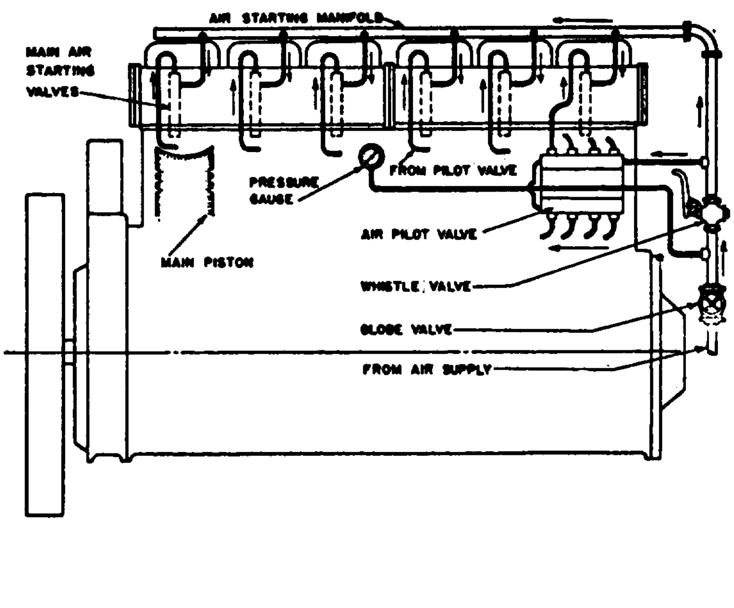


Figure 2-29. Typical Diagram, Air Starting System; Air-Operated Starting Valves.

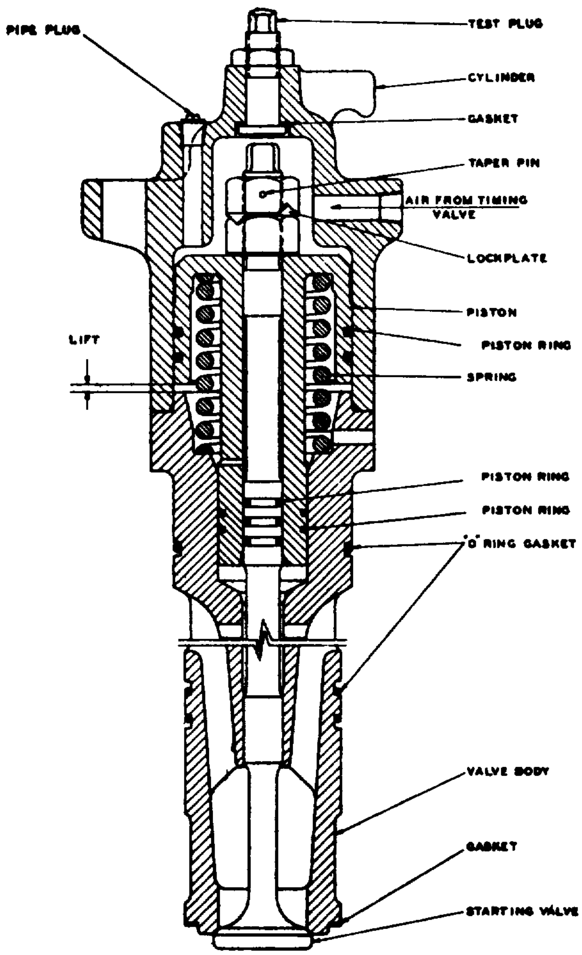


Figure 2-30. Air Starting Valve.

valves remain in a closed position. During starting, pilot air is supplied through air pilot valves or a pilot air distributor to each starting air valve which pneumatically opens the starting air valves in firing order sequence and keeps them open during a certain period of the power stroke. This allows compressed air to be admitted to the cylinders during timed intervals. The pilot valves or distributors are normally actuated from the engine camshaft and may consist of a series of cam-operated poppet valves or a ported distributor disk. Pilot air is supplied to the pilot valves or distributor from the air starting manifold and from there it is lead through small individual tubes to each starting air valve. Starting air is normally supplied by a separately driven compressor and is stored in tanks at 250 to 200 lbs/in^2 (figure 2-31). Starting with air, as described, is fast and positive.

b. Electric Motor Starting. This method of starting is used for smaller diesel engines and is of the same general construction as the used commonly on automobile engines except that the system is more powerful. The starting motors are operated at 12 to 24 volts or higher from storage batteries. Overheating can damage starting motors if operated continuously for more than one minute. Recommend a continuous cranking period of no more than 30 seconds. Usually equal cranking and rest periods of about 10 seconds up to a minute of cranking cycle is used.

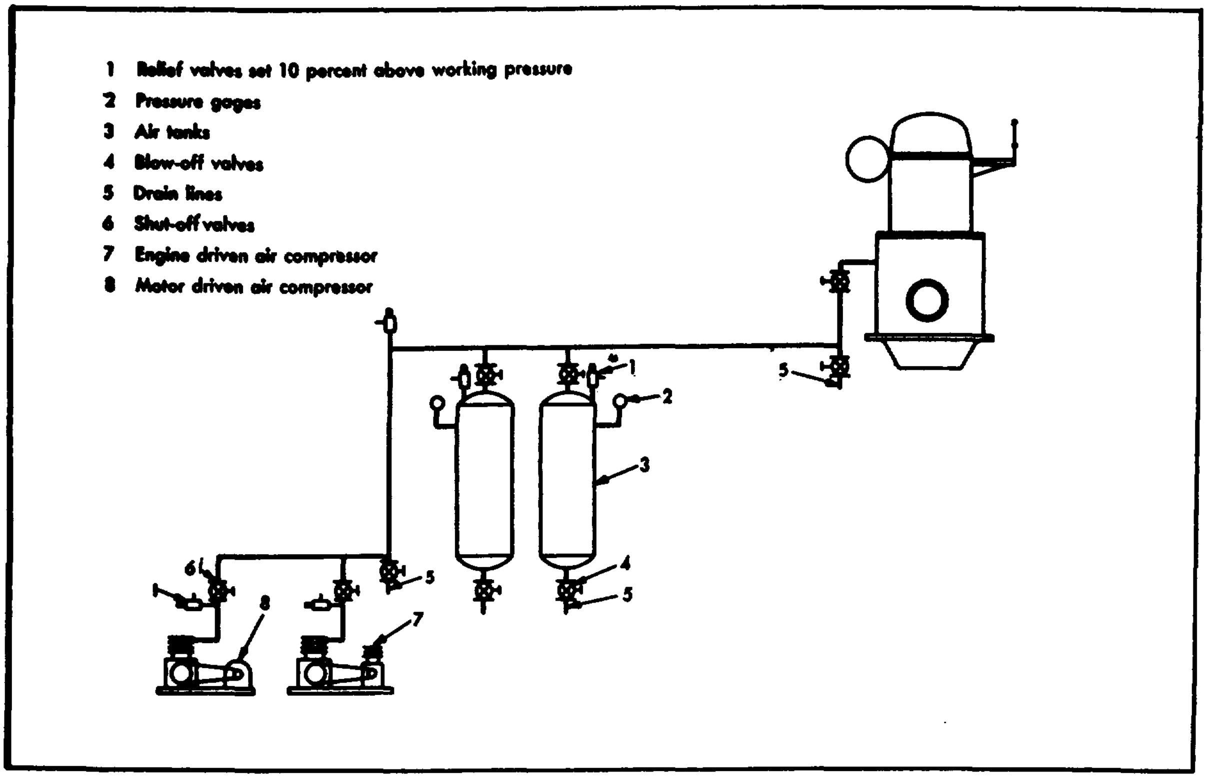


Figure 2-31. Diagram of Typical Air Starting System.

c. Storage Batteries. The lead-calcium type is the most commonly used storage battery for engine starting service. The alkaline-type, nickel-cadmium battery is also used. It is somewhat heavier and higher in price but has advantages over the lead-acid type battery such as high internal strength, no loss of active material, and no gasing, which permits it to be sealed. The capability of countless charge-discharge cycles combine to give it very long life. A storage battery is a chemical device in which energy is released by chemical reaction, and the chemical reactions are slowed down at low temperatures. For example, a lead-calcium battery at 0 °F has only about 47 percent of its normal temperature performance capacity and only about 78 percent of its normal 5-second sustained voltage. The standard most commonly used to specify batteries is the cold-cranking ampere rating. This standard is defined as the load in amperes which a fully charged battery at 0 °F (-18 °C) can deliver while maintaining a voltage of 1.2 volts per cell or higher. Note the ampere hour rating is now obsolete. Marine duty batteries should be specified for generator starting systems.

d. Air Starting Motor. The two common types of air motors used as engine starters are the turbine and vane. Air motors are normally operated on air at pressures from 75 to 150 lbs/in^2. This starting system has the advantage over electrical starting systems in that it is safer in a hazardous atmosphere, and is not subject to as great a loss of starting torque at low temperatures as is an electrical starting system.

e. Hydraulic Starting Motors. High-pressure oil (1000 to 3000 lbs/in^2) is used to operate the hydraulic cranking motor. The system normally includes a piston-type accumulator, an engine driven pump for charging the accumulator during engine operation, a hand pump, and an oil reservoir.

f. Cold Weather Starting. Since the operation of a diesel engine depends upon high air temperature for the ignition of the fuel, cold weather starting may require the addition of heat to both the air charge and the engine. This heat may be obtained in many different ways. For example, electric resistance heaters can be installed in the intake manifold to heat the intake air; or the engine may be preheated by heating either the engine coolant fluid or lube oil. Engine preheating by heating the lube oil is desirable because it results in higher cranking speeds which, in turn, increases the compression temperature during start up. The coolant may be preheated by either of the following:

(1) Installing an externally mounted tube type resistance heater with or without a circulating pump.

(2) Installing electric resistance immersion heaters in the coolant systems.

(3) Interconnecting the coolant systems of multiple-engine plants in such a way that hot water from an operating engine circulates through the nonoperating engine system.

2–12. Air Intake and Exhaust Systems:

a. Air Intake System (Figures 2-32 and 2-33):

(1) The air intake system is an essential part of the engine. Some functions of an air intake system are:

(a) Silencing air noises.

(b) Cleaning or filtering the air.

(c) Furnishing an adequate supply of air required for scavenging and combustion.

(d) Cooling the air after it leaves the supercharger (aftercooler or intercooler). This increases the charge air density so that more can enter the combustion chamber to burn the fuel more completely.

(2) The air system consists of several, if not all, of the following items.

(a) Silencer.

(b) Filter.

(c) Scavenging blower or supercharger.

(d) Aftercooler or intercooler (supercharged engines).

b. Air Requirement. The average engine air requirement (expressed in cubic feet per minute per kw full load output at 80 degrees Fahrenheit and at nominal atmospheric pressure) are as follows:

(1) Naturally aspirated four-cycle: 3.3 to 4.2 ft^3/min/KW.

(2) Turbocharged four-cycle: 4.0 to 5.0 ft^3/min/kW.

(3) Two-Cycle (blower scavenged): 5.0 to 6.0 ft^3/min/kW.

c. Air Filters. Air filters are an essential part of the air intake system. A rule of thumb is that one teaspoon of sand will destroy the rings and valve guides of one cylinder in 50 hours of operation. Many types of filters are available. They may be classified as dry, oil-bath, and impingement filters.

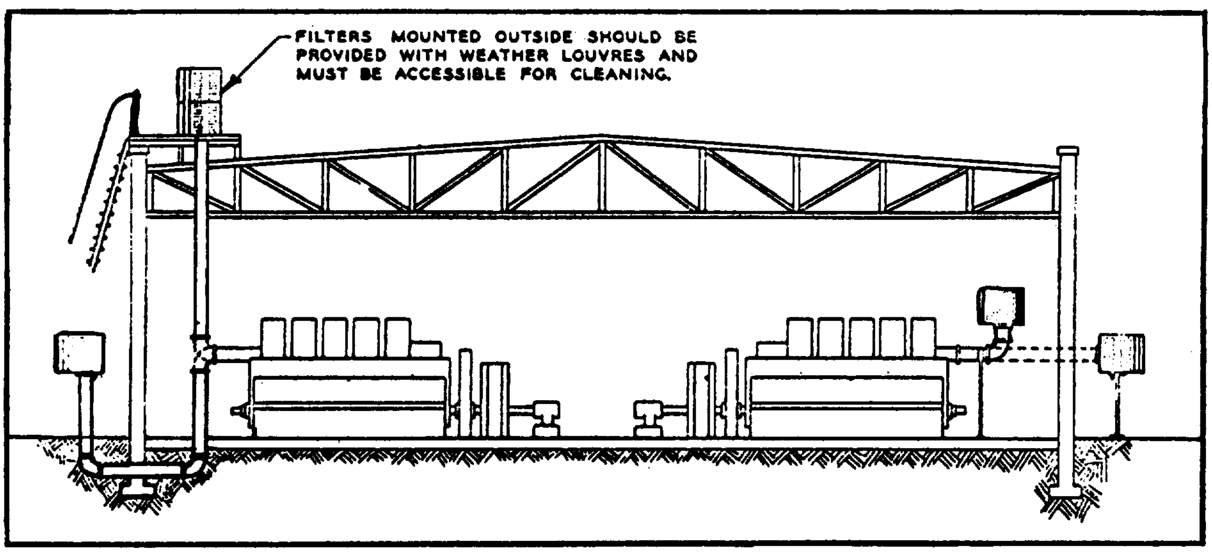


Figure 2-32. Air Intake System Arrangement.

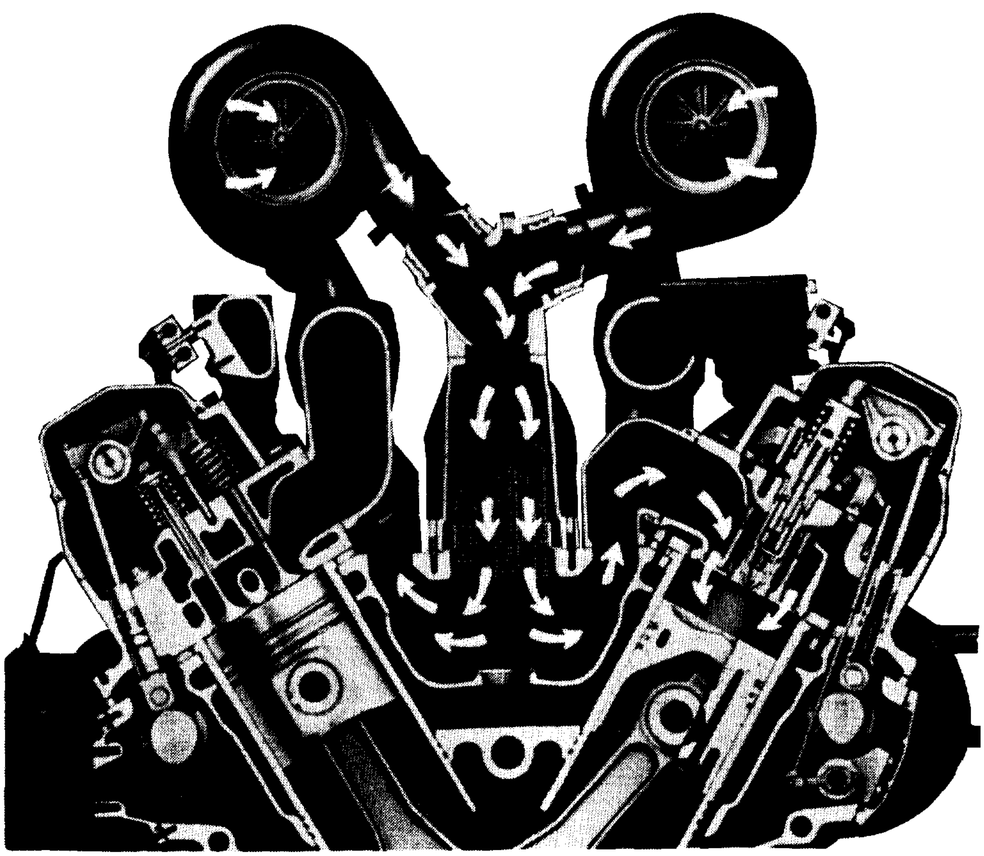


Figure 2-33. Air Induction System. (Courtesy Caterpillar, Inc)

(1) Dry-filter elements retain varying proportions of the total dirt content in the air. They include screens, mesh, crimped metal, fiber, felt, spun glass, cloth, or paper. It is a characteristic of this type of filter that efficiency improves as dirt collects. But resistance to air flow also increases.

(2) Oil-bath filters are widely used on some types of small diesel and gas engines. Normally, the air (before entering the engine) passes through an oil bath and, in so doing, it picks up some oil and carries it into the filter element. The oily dirt particles and the oil are deposited on the filter element, and the cleaned air passes out of the filter. The oil and dirt then tends to drain down to the sump. These filters have a high cleaning efficiency and a relatively low pressure drop. If oil-bath filters are properly sized, cleaning efficiency is good over the whole range of the engine's air flow. On the other hand, too low an air velocity through the filter (oversized filter) can impair cleaning efficiency. High velocity flow (because of too small a filter) may result in pullover of oil into the intake manifold.

(3) Oil-bath filters for large engines permit entering air to be deflected toward the oil sump and, as it changes direction to flow upward, large dirt particles are trapped in the oil. Thus, turbulence caused by the air flow through the oil scrubs the oil and removes the bulk of particles. Oil is constantly carried to the outer diffuser screen, the inner filter element, and the remaining particles of dirt impinge on these wetted surfaces. Thus, new oil is continually supplied to the screen and filter elements and results in a washing action that keeps diffuser and filter clean while carrying trapped dirt to the sump.

(4) Impingement filters depend upon a tacky coating on the various filtering media to catch dirt particles as the air passes through the filter. They are built in unit panels and several such panels can be mounted in an enclosure. Each panel consists of crimped metal, metal screening, special metallic wools, or spun glass. Pressure drop through this type of filter is very low. Openings in the filtering media are relatively large but the material is arranged in depth so that the air cannot go through in a straight line. Thus, dirt in the air will impinge on the tacky surface and be held. Air velocity through the filter affects the filtering efficiency. If too low, fine dirt particles will tend to change direction with the air as it passes through the filter and will not be caught. Very high velocities will tend to force dirt, even dirt already trapped, through the openings. Effectiveness of these filters is almost wholly dependent on the coatings used. Used dry, they will only strain out the largest particles. Special coatings or tacky additives are available from the various oil companies for reconditioning the filtering surfaces. A good coating should have excellent wetability so that trapped dirt will be quickly saturated. Its viscosity should be fairly stable over the normal operating range, so it will not thin out and run off the filter panel as temperatures rise.

(5) The self-cleaning filter, traveling panel, or screen self-cleaning filter, is a special type of impingement filter. Panels are carried on two chains up the front, over sprockets and down the back. Filtering material in the panels is cleaned and recharged with viscous oil at least once in 24 hours when the panels pass through the tank at the bottom. This type of filter is generally not used with pulsating flow encountered with reciprocating pump-scavenged two-cycle engines.

(6) Another type of self cleaning filter is the cyclone dust-ejector type. This is a two stage heavy duty filter with a precleaner turbine driven by the engine exhaust. The precleaner turbine spins and ejects dust which would otherwise be trapped by the paper filter. This type of filter is designed for use in severe dust environments.

d. Maintenance of Air Filters. There is no common rule for servicing air cleaners. The type of service depends on the air cleaner, air conditions, and the application. Some engines utilize restriction indicators to indicate that servicing of the filter is required. A filter operating in severe dust conditions will obviously need servicing more often than one operating in a clean environment. Inspect the filters often to determine the best service schedule. As always, check the manufacturer's manual. The following are some suggestions for servicing the various air cleaners:

(1) To service a dry-type cleaner:

(a) Wipe out the housing with a clean cloth.

(b) Replace paper elements instead of cleaning them. To determine if a paper element is still usable, hold a bright light on one side. Partial light should show through but should be uniform. Bright spots may indicate a rupture. Another method is to use a low pressure air (30-40 lbs/in^2 maximum). Direct the air against the inside of the filter to see how much passes through the filter.

(c) Inspect the gasket inside the housing.

(2) To service an oil-bath type air cleaner:

(a) Remove oil canister from the air cleaner and separate the removable element or screen from the canister. Empty oil from canister and clean out sludge with fuel oil.

(b) Clean the separator screen or removable element by washing in a solvent and dry with compressed air. An even pattern of light should be visible through the screen when held to the light. Replace if necessary.

(c) Clean the air cleaner inlet tube by running a solvent-soaked rag through it.

(d) Reassemble and fill with clean oil (same grade as engine) to the required level. Do not overfill. To much oil may cause some to be pulled through the air cleaner and into the engine, carrying dirt with it.

(e) Make sure all gaskets and joint are tight.

(f) When there is a contamination buildup or plugging, remove the entire air cleaner from the engine and clean the fixed-element. Do not remove the fixed-element from the cleaner body. Submerge in solvent and agitate until clean. If element cannot be cleaned, replace it.

e. Turbocharger and Blower Inspection:

(1) Below are some recommendations for inspecting and servicing a turbocharger. The performance of turbochargers should be observed at regular intervals:

(a) Lubricating oil pressure should be at the manufacturer's recommended level at full load. Be sure the pressure relief valve and pressure gage are operating at each startup. Keep the turbocharger oil clean by changing the filter element when required.

(b) Be sure the oil temperature supplied to the turbocharger and at the drain are within the manufacturer's recommendations. Any sudden increase should be investigated since the cause may be obstructions in the internal oil passages.

(c) Check the water temperature periodically to be sure the temperature rise across the turbocharger does not exceed the manufacturer's limits. An excessive rise indicates stoppage of the circulating passages.

(d) Observe the engine frequently to detect any noticeable vibration. If a vibration is present, the unit should be shut down and the cause determined. Vibration may be caused by damage to the impeller, shaft or turbine wheel, or by worn or loose bearings. Any uneven deposit of foreign matter or dirt on the impeller can also be a cause of vibration.

(e) Light loading (30-50 percent) of engine may cause the turbocharger to weep oil. This oil may foul the intake manifold over a period of time. So check the manifold periodically if engine is lightly loaded.
(NOTE: The air pressure from a turbocharger will also be low at 30-50 percent load.)

(f) Periodically check the rotor end play and the radial clearance between the turbine blade O.D. and either the inlet casing or nozzle ring (cold). Repair if not within manufacturer's tolerances.

(2) The following are some recommendations for inspecting and servicing a blower. In most cases it is not necessary to remove the blower for inspection:

(a) Check rotors for abrasions. Dirt drawn through the blower will cause deep scratches in the rotors and housing and throw up burrs and abrasions. If burrs cause interference between rotors or between rotor and housing, remove blower from engine and dress parts to eliminate it. If too badly scored, the rotors should be replaced.

(b) Check the inlet screen. Inspect for an accumulation of dirt which will affect air flow. Remove and wash in fuel oil. Clean with a stiff brush and reinstall.

(c) Inspect oil seals. Oil radiating away from the oil seals usually means a worn seal.

(d) Inspect the rotor shaft and bearings. Check loose rotor shaft and damaged bearings by observing the crowns of the rotor lobes and mating rotor roots and between the rotors and end plates. A loose shaft usually causes rubbing between the rotors and end plates. Worn or damaged bearing will cause rubbing at some point between the mating rotor lobes or allow the rotors to rub the housing.

(e) Check the timing gear. Excessive backlash between blower the timing gear usually results in rotor lobes rubbing their entire length.

f. Exhaust System (Figure 2-34):

(1) The engines' exhaust system essentially consists of an exhaust manifold, exhaust pipe leading from the engine or turbocharger to a silencer which damps the exhaust pressure pulses and exhaust noise, and a tail pipe or stack. The silencer is sometimes called a muffler.

(2) Many designs of exhaust silencers are in use. All tend to smooth out pressure waves or pulsations to quiet exhaust noise. Exhaust silencers essentially consist of a series of expansion chambers interconnected by passages arranged to provide the desired acoustic properties at low resistance to the gas flow, without imposing undue back pressure on the engine. Most silencers are equipped with a moisture drain point. This point should be kept clean to prevent moisture accumulation. Even though a rain cap may be installed on the stack, condensation may accumulate and find its way to the engine. This can lead to severe damage.

(3) Sometimes exhaust manifolds are water cooled. This is done when the temperature of the engine room rises above acceptable limits.

(4) Periodically clean pyrometers and thermocouples to be sure of proper operation.

2-13. Operating Procedures. Operating procedures should be developed which are specific to each plant or standby engine. As previously emphasized, always follow the manufacturer's recommendations. The following are some generic recommendations:

a. Preoperational Inspection. Make sure any automatic switching equipment is in the correct position. Check all fluid levels. Visually inspect for loose connections or cracked hoses.

b. Inspection During Operation. Record all temperature and pressure readings hourly. Watch for any abnormalities such as leaks, unusual noises, vibrations, etc.

c. Securing the Engine After Shutdown. After load has been removed, continue to run the engine for a short period to allow temperatures to stabilize. Top-off the fuel tank if possi-

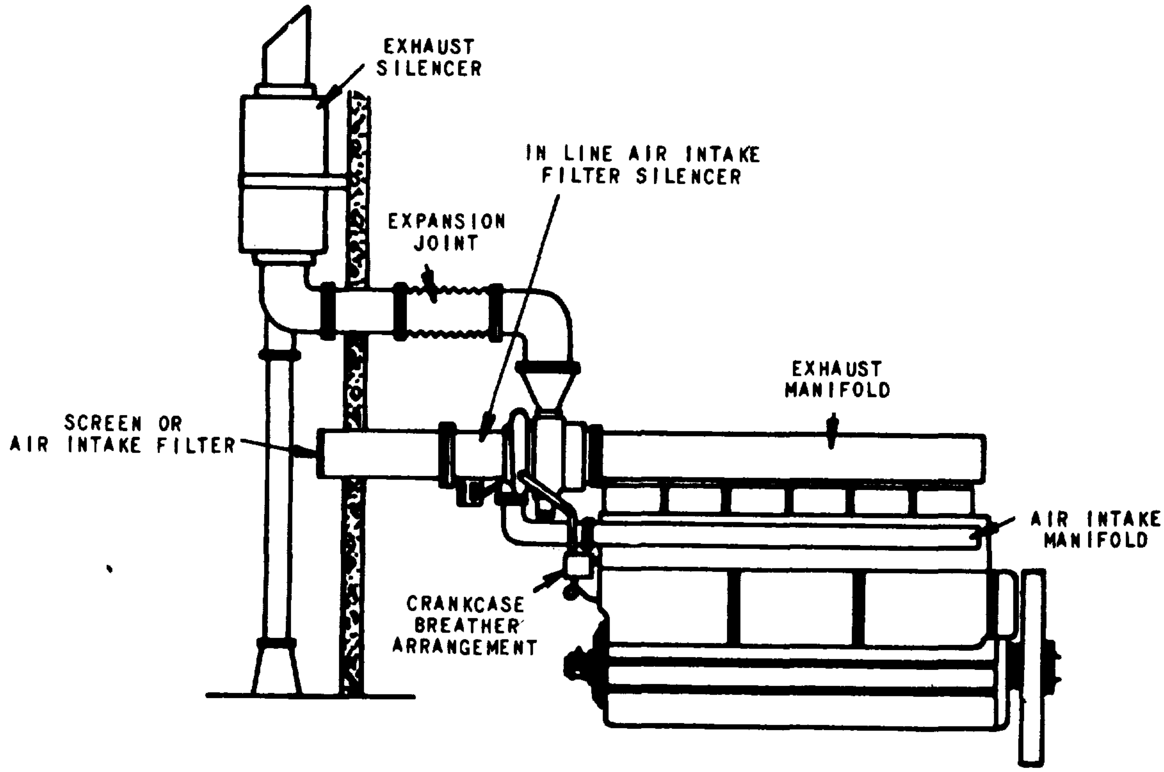


Figure 2-34. Typical Air Intake and Exhaust Systems.

ble. Wipe the engine down. If batteries are present, check to see if they are at the correct voltage or are charging properly. Make sure the engine is ready for the startup.

2–14. Engine Starting: The engine may be started when preparations for starting, listed in previous paragraphs, have been completed. If the engine speed is controlled by the governor, see that the overspeed trip latch is in the "RESET" position and that the governor speed control knob is set at about the normal speed position. Move the starting gear to the "START" position to admit starting air. After the engine has made several revolutions, move the starting gear to the "RUN" or "FUEL" position. When ignition occurs, the engine will pick up speed on fuel. Operating personnel should be alert to observe the instant at which the engine has attained sufficient speed on starting air. It is important to transfer the engine from air to fuel as quickly as possible to conserve starting air. As soon as the engine runs on fuel and the speed has been brought under control, the operator should read all pressure gages such as lube oil, fuel oil and jacket water to make sure that normal pressures are being maintained. Listen for unusual noises. Shut the engine down if any unusual condition is noted.

a. Observing Engine While Operating. After the engine reaches normal operating temperature, be constantly alert to detect and bring under control slight irregularities. Otherwise they may develop into malfunctions that require stopping the engine. Observe pressures, temperatures, and other data as required and record them in the operating log. Also watch other important gages, thermometers and pryometers carefully at all times. High exhaust temperature, smoky exhaust, and overheating may indicate a malfunction of injection components.

b. Operating Instructions. Each engine or plan should have a standard operating procedure (SOP) specifically for the site and equipment. The SOP should be a by-by-step list of the actions necessary to start, run, and troubleshoot the specific equipment. Illustrations and diagrams will be helpful. Also include site and mission requirements.

2–15. General Operating Rules and Procedures. You should check the manufacturer's manual for normal operating parameters (temperature, pressure, etc.). When an engine begins to operate other than the normal range of any of these parameters, it indicates a need for maintenance. Make sure these parameters are properly recorded and reviewed, they are important when programming maintenance. For example, a gradual drop in lube oil pressure usually means the filters are becoming clogged and must be changed at the earliest opportunity. You should investigate sudden and dramatic changes at once.

a. Engine Temperatures. Proper temperatures are necessary for efficient operation and to prevent engine damage. For example, continuously operating an engine with a low water temperature is harmful. The low water temperature tends to cool the cylinder walls to below the dew point of the steam formed in the cylinder during combustion, and oil sludging will result. Water temperatures 190 to 200 oF or higher are generally acceptable for the more modern engines, especially in medium and small size units. Excessively high lube oil temperatures can be harmful because they lead to oil sludging and varnish formation on the lubricated parts. Oil temperature normally averages slightly higher than the inlet water temperature. This is because the condition of the oil cooler and temperature regulating valves control it. You can't correct high oil temperature through operation. Only maintenance will correct it.

(1) If you notice overheating, remove the load from the engine as soon as possible. Idle the engine while investigating the cause of overheating. Check the radiator fan and drive, cooling fluid pressure to engine and water level in surge tank. If cooling fluid level is low, add cooling fluid gradually. If the cause of over-heating cannot be corrected by the above means, shut the engine down and let it cool before removing any crankcase covers.

(2) Avoid the sudden addition of large amounts of cold water to a hot engine. If you must add coolant, add it slowly to the engine while running. Sudden cooling of the internal components can cause cracks in the liners and heads or piston seizure.

b. Monitoring Pressures. Keep close check on pressure differential through oil and an fuel filters.

c. Oil Level Checks. Check the oil level in the sump regularly, and check for water and contamination in the sump tank.

d. Stopping Engine. When an engine is ready for shut down, reduce the load gradually to allow the engine to cool gradually. Except in an emergency, allow at least 5 minutes for this process.

2–16. Diesel Fuel Storage and Characteristics. Fuels meeting basic specifications will result in optimum engine performance and durability. Diesel fuel for Air Force diesels should meet Federal Specification VV-F-800 or NATO Code F-54 requirements. Overseas sites may use JP-8 fuel. Engine suppliers need to know if JP-8 will be burned. (JP-8 is very similar to DF-A).

a. Handling and Storage. Cleanliness is the most important quality of diesel fuel. Keep all dirt, dust, water, and sediment out of the fuel to prevent damage to the fuel injection equipment. For long, economical service, use the specified grade of clean distillate. You can prevent contamination by reducing, as much as possible, the number of times the fuel is handled. Fuel delivery to a storage tank and pumping it directly to the engine day tank minimizes handling. Also, you should not mix different grades of fuel. Diesel fuel tends to form sludge during extended periods in storage. This sludge is formed in the presence of bacteria and water and can clog fuel filters and cause injector trouble. The best way to preserve fuel in storage is to frequently drain the water from the bottom of tank, and to keep it full. Other types of contamination have caused many engine failures. The following are some ways of detecting fuel contaminations:

(1) You can usually detect rust, scale, or sediment in diesel fuel by carefully inspecting the fuel filters.

(2) You can detect water in diesel fuel by either settlement in a glass jar, or the white, cloudy appearance of the fuel.

(3) Only a laboratory test will detect oil-soluble soaps. The usual cause of this type of contamination is the storage of fuel in galvanized tanks or containers.

(4) During cold weather keep fuel tanks as full as possible to prevent condensation inside the tank.

b. Fuel Characteristics. The major fuel properties which affect engine operation are as follows:

(1) Ignition Quality. The ability of a diesel fuel to ignite by itself under the conditions existing within an engine cylinder is referred to as ignition quality. The lower the temperature at which the fuel will self-ignite, the higher the ignition quality. Ignition quality is commonly expressed as "cetane."

(2) Heating Value. The heating value of fuel oil indicates how much energy is supplied to the engine. It is closely related to the gravity of the fuel. Light fuel oils generally produce higher heat values. Conversely, heavy fuel oils produce lower heat values. The heating value of the fuel oil used will directly affect the cost of operation.

(3) Volatility. The volatility of diesel fuel refers to the readiness with which it changes to a vapor. It is determined by testing what temperature 90 percent of a given sample will have vaporized at. The lower the temperature of vaporization, the higher the volatility. High volatility is desirable for diesel engines to obtain low fuel consumption, low exhaust temperatures and minimum smoke.

(4) Flash Point. The flash point of fuel oil is the lowest temperature at which it will produce flammable vapors that will ignite when brought in contact with a flame. Minimum flash points are controlled by law and are pertinent to safety in handling only. The flash point has no relationship with ignition quality. (Ref ASTM D-93)

(5) Pour Point. The pour point is the temperature at which an oil solidifies or congeals. The minimum pour point used should should be at least 10 oF lower than the coldest temperature encountered at the installation site.

(6) Carbon Residue. Carbon residue is that portion of the fuel that remains when all volatile matter in a given sample has evaporated. This substance forms coke or carbon on engine parts. (Ref ASTM D-524 or D-189)

(7) Viscosity. The viscosity of a fluid is the measure of its internal friction or resistance to flow. Viscosity for oil is normally expressed in saybolt universal seconds, but, the most common method of expressing the viscosity of diesel fuel is in centistokes. (ASTM D2161 contains the ASTM method for conversion of kinematic viscosity expression to saybolt universal seconds.) Both expressions relate directly to the amount of time required for a given amount of fuel to flow from an orfice at a precise temperature. The longer time required, the higher the viscosity. With regard to diesel engines, viscosity indicates the ability to flow in the system, lubricate the pump and injectors, and atomize upon injection. Too low a viscosity would not properly lubricate, too high a viscosity would not properly atomize and would affect performance. (Ref ASTM D-445)

(8) Sulfur. Sulfur in the fuel burns along with the rest of the fuel and forms gases which become corrosive liquids when they react with water. The corrosive affects are most apparent in engines operated at low load or low temperature. These conditions allow the moisture in the engine to condense and mix with the gases, rapidly deteriorating the valves, pistons, rings, liners, lubricating oil, and the exhaust system. (Ref ASTM D-129 or D-1552)

(9) Ash. A fuel's ash content is determined by burning a known quantity of the oil and weighing the noncombustable material that remains. Ash normally is made up of sand, rust or other impurities that are extremely abrasive, and will destroy fuel system components. (Ref ASTM D-482)

(10) Specific Gravity. The specific gravity of a liquid is the weight of that liquid compared to the weight of an equal volume of water. The specific gravity is considered to be a rough indicator of the fuel grade. Heavy fuel oils, or those with high specific gravity, tend to have lower heat values and light fuel oils, or those with low specific gravity, tend to have high heat values. Specific gravity is commonly expressed in degrees in a formula calculated by the American Petroleum Institute (API). That is:

$$\text{Gravity API deg} = \frac{14.15}{\text{Specific gravity} - 131.5}$$

A fuel oil of high specific gravity does not necessarily have a high viscosity, nor does a fuel oil of low specific gravity necessarily possess a high ignition quality. These properties can differ widely and should not be confused with the relationship between heat value and specific gravity. Viscosity and ignition quality are the most important properties of diesel fuel. (Ref ASTM D-287)

(11) Water and Sediment. Water and sediment most often enter the fuel in storage and handling. Rust and scale become dislodged from tanks and pipes, and condensation will form within tanks and pipes that are not kept full. These and other impurities may be detected that are natural compounds which were not removed during the refining process. They include paraffin, salt, sand, and clay. Impurities will cause corrosion and wear of the fuel system components and excessive amounts of water

will result in irregular combustion. (Ref ASTM D-1796)

(12) Cloud Point. The temperature at which wax crystals begin to form. These wax crystals tend to plug fuel filters and shout down the engine.

c. Quality Control of Fuels. Engine malfunctions and particularly failures of injection equipment have been traced to improper type or contaminated fuel received from the supplier. In an effort to detect such deficiencies before serious damage is done to the engines, the following procedure is recommended:

(1) Visual Check. Collect a sample from every delivery of diesel fuel to storage in a clear glass bottle properly dated including supplier identification and cap it tightly. Allow sample to settle for at least 12 hours and compare it with previous sample as to appearance (color), water and sediment. Cloudy appearance suggest that fine droplets of water are entrained in the fuel which, in time, will settle to the bottom of the sample. If fuel is contaminated with gasoline or kerosene (lighter fractions), it will float and collect at the top of the bottle. Contaminants such as pipe scale, paint or other solids will settle and collect at the bottom of the sample.

(2) If the quality or identity of the fuel is in doubt, send a sample to an approved laboratory for analyzing.

2-17. Lubricating Oils. Engine oil performs several basic functions besides providing lubrication. It helps keep the engine free of rust and corrosion. It also acts as a coolant and sealant. Lubricating oils for diesel engines should meet military specifications MIL-L-2104 and MIL-L-46167 (artic) Follow the recommendations of the engine manufacturer on the specific type and grade of oil for the best engine performance.

a. Oil Characteristics. A knowledge of the physical characteristics of the oil is necessary to understand how it will perform in service. The ideal lubricant should be sufficiently viscous to prevent metal-to-metal contact between bearing surfaces. It should remain stable under changing temperature conditions, keep lubricated parts clean, and prevent corrosion of metallic surfaces. An oil that does not do a good job can ruin an engine. Conversely, an engine in poor operating condition can break down oil. There are two things to watch in the performance of the oil, namely, sludge and varnish formations. Sludge is a black substance with the consistency of mayonnaise that collects in strainers, filters, crankcase, cam boxes, tops of cylinder heads, and around the valve springs. In the majority of cases, sludge cannot be blamed on the oil, but is caused by faulty operation such as improper operating temperatures or water leaks. If these operating conditions are not corrected, sludge will plug up the oil passages. This reduces the supply of lubrication to the bearings and also causes ring sticking. Ring sticking eventually leads to excessive ring and liner wear, and loss of compression. Varnish (or lacquer) formation is more difficult to solve. The bright appearance of the crankcase and lubricated surfaces make it difficult to detect. However varnish and lacquer will lead to trouble faster than sludge deposits do. Varnish will build up on piston pins, piston skirts, and liners. It usually forms on lubricated parts that have been hot at one time. Sometimes lacquer and varnish also form on bearing surfaces. This is serious because dirt is caught in the layers of the varnish or lacquer, and will act as a lapping compound. The principle characteristics of an engine oil as measured by laboratory tests are:

(1) Viscosity. The viscosity of a lubricating oil indicates its body, or relative fluidity. Viscosity is generally considered to be the most important property of a lubricating oil since friction, wear, and oil consumption depends more or less on viscosity. Viscosity is usually expressed as the number of seconds required for approximately two ounces of oil to flow through an orifice of about 1/16" diameter at temperatures of either 100, 130, or 210 °F. It is measured in the Saybolt Universal Viscometer (figure 2-35) generally used in the US and is expressed in Saybolt Universal Seconds (SUS). It should be remembered that the viscosity of an oil changes with its temperature. The heavier the oil the higher its viscosity. All oil companies have adopted the Society of Automotive Engineers (SAE) viscosity number system which classifies oil that falls within a certain range of SUS. For example, if the viscosity of oil at 210 °F lies between the limits of about 70 and 60 SUS, it is considered an SAE 30 oil. Oils with lower SAE numbers are lighter and flow more readily than oils with higher numbers. The SAE number refers to no other characteristic or property. The use of an oil that is to low in viscosity may result in metal-to-metal contact and wear, because the oil is too thin to carry the prevailing loads. The use of an oil that is to heavy may cause sluggishness and power loss, or it may cause poor distri-

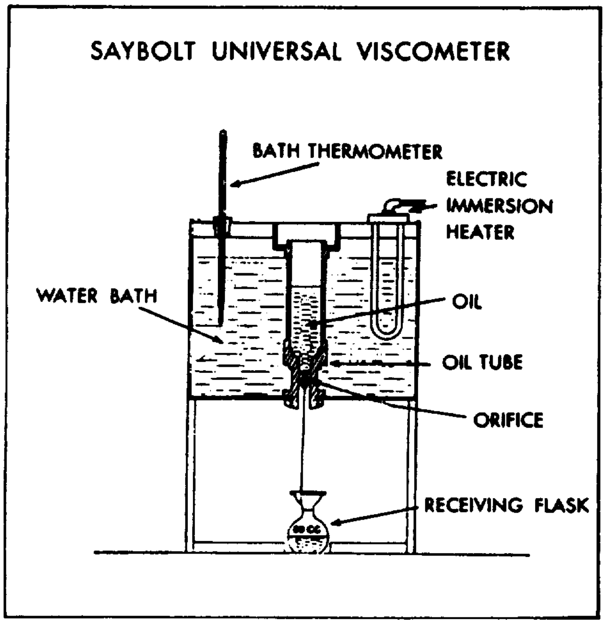


Figure 2-35. Saybolt Universal Viscometer.

bution of the oil film which result in engine wear or failure. Also, a change in oil viscosity during operation is one of the best indicators for determining oil contamination or fuel dilution.

(2) Carbon Residue. Carbon residue, or the amount of carbon the oil leaves when it is burned, is determined by burning a specified amount of oil under standard conditions. The carbon formed during the test is carefully weighed and its percentage is an indication of the oil's carbon-forming tendency.

(3) Pour Point. The pour point of an oil is the lowest temperature, reached under prescribed laboratory conditions, at which the oil will still flow. Pour point is an important consideration if an oil is exposed to cold weather or low temperatures. If an oil becomes to sluggish when cooled, it may be prevented from proper circulation to the parts requiring lubrication.

(4) Flash Point. The flash point is the temperature to which an oil must be heated before its vapors will flash or ignite when a small flame is applied above it. It determines the relative danger of a crankcase explosion. The flash point test is also used to determine the the type of contamination in the oil. For example, a decrease in the flash point from the original value indicates fuel or fuel soot contamination.

(5) Fire Point. The fire point of an oil may be considered as a continuation of the flash point. It is the temperature to which an oil must be heated not only to flash, but also to burn steadily on application of the test flame.

(6) Presence of Water. Good quality lubricating oil must be free of water and sediment. Water usually can be detected by the cloudy appearance of the oil or by taking a sample and letting it stand and settle in a glass tube or bottle. Water will settle to the bottom of the tube.

(7) Fuel in the Oil (fuel dilution). When fuel is allowed to get into the lubricating oil, the oil's viscosity may be decreased to such a degree that it will destroy the lubricating qualities and result in wear and eventual seizure of parts. An excepted rule of thumb is that 5 percent dilution with fuel will reduce an SAE 30 oil to SAE 20. Therefore, an engine operating with fuel-diluted lube oil is bound to run into bearing and piston ring difficulties. To avoid an uncontrolled mixing of fuel with lube oil, the operator should watch at all times for traces of fuel in the oil. Fuel contamination will decrease an oil's viscosity and flash point. It is considered dangerous if the viscosity drops 10 percent from the original value or the flash point drops below 390 °F.

(a) The preparation and test of the following mixtures is a recommended procedure for determining fuel dilution:

1. 5 percent (95 cc new lube oil, 5 cc fuel).

2. 3 percent (97 cc new lube oil, 3 cc fuel).

3. 1 percent fuel (99 cc new lube oil, 1 cc fuel).

(b) Test the three mixtures for flash point and compare with the flash point of oil used in the engine. This will establish a reliable base for determining the extent of dilution for the oil used. When fuel is discovered in the lube oil, the cause must be found and corrected. See troubleshooting section for possible causes.

(8) Neutralization Number. The neutralization number is a measure of an oil sample acid content. It is determined by finding how much of a known alkaline (base material) is needed to neutralize acid in oil. Operation oxidizes oil and produces organic acids. Some of these acids are corrosive to certain bearing metals. Neutralization number is also called a Total Base Number.

b. Oil Additives. Lubricating oil begins with a base of mineral oil which provides the lubricating properties. But, this mineral oil will deteriorate rapidly in an engine without additives. Below are some common additives and their purpose:

(1) Detergents. Detergents help keep engines clean by chemically reacting with oxidation products to stop the formation and deposit of insoluble compounds.

(2) Oxidation Inhibitors. These inhibitors help prevent viscosity from increasing, and the development of organic acids and carbon related matter.

(3) Dispersants. Dispersants help prevent sludge formation by dispersing contaminants and keeping them in suspension.

(4) Alkalinity Agents. These agents help neutralize acids.

(5) Pour Point Dispersants. These keep the oil fluid at low temperatures by preventing the growth of wax crystals.

(6) Antiwear Agents. These agents reduce friction by forming a film on metal surfaces.

(7) Viscosity Improvers. Viscosity improvers help prevent the oil from becoming too thin at high temperatures.

c. Oil Tests. Oil contaminants include fuel soot, sludge, oxidized materials, dirt, and wear particles. Several tests are available to determine this type of contamination.

(1) Blotter Test. A reliable test after a norm and color comparison have been established is a drop of oil on a white blotter. Progressive fuel soot contaminants produces progressively blacker spots. Other solid contaminants leave a residue on top of the blotter, the amount indicates the extent of contamination. For this test, several commercial concerns market blotters with comparison charts. The reliability of this test depends on the ability of the person performing it.

(2) ASTM D91-52 Test. A given quantity of naptha is mixed in an oil sample, which is then centrifuged for a specified period in a cone-shaped bottled. Percentage readings are taken directly from the bottle tip through graduated markings. This test only reports percentage total contaminants but is usually possible to detect metal present at the extreme tip of the cone shaped bottle. One percent normally is the maximum allowable contamination when using this method. It has good reliability but, again, depends to a large extent, on the tester's analytical ability.

(3) ASTM 893-52 Without Flocculent Test. Given quantities of oil and pentane are mixed in one bottle; given quantities of oil and benzene in another. Both are centrifuged. The resultant deposits are then heated in an oven under stipulated conditions. The weighed results indicate dirt, sand, and metal in one bottle, plus oxidized oil in the other. The difference between the two is oxidized material. This method is the most accurate test, as it requires the weighing of centrifuged contaminants.

(4) Dispersion (or Detergency) Test. These two words are normally used interchangeably. Two very simple methods are available to evaluate this properly:

(a) The first method requires visual observation with accurate records of crankcase deposits. Some deposits will normally occur at the bottom of the crankcase, but none will normally be noted on sidewalls, handhole covers, and so forth, until the oil reaches saturation level.

(b) The second method involves the use of a blotter. Oil with a high dispersion value will carry the fuel soot and contaminants evenly to the edge of the spot. Oil without this feature will drop the contaminants rapidly in a fairly small circle. Sample comparison charts are available to establish limits. These test will indicate relative oil's ability to hold contaminating particles suspended rather than to deposit them within the engine passage.

(5) Acidity Test. The acidity of oil is indicated by its neutralization number or total base number (TBN). A quick and easy test kit for determining TBN is available as part number SLM 4484042 (Mobil TBN Test Kit). The part is available from Anderson, Dunstan and Helene, Inc., 114 Mayfield Avenue, CN 3053, Edison, NJ 08818-3027.

(6) Viscosity Test. Oil Viscosity should be periodically checked by using a device under the trademark "Visgage." It is listed in TA 489 as NSN 6630-00-255-8057.

d. Mixing of Oils. Different refineries may use a different type of additive in detergent oils, and to mix different oils may alter the detergent characteristics. To obtain maximum benefit from additive oils, they should not be mixed with straight mineral oils as the additive concentration will be reduced.

e. Oil Changes. How often should you change the lubricating oil? That depends on the make of engine, its load condition (constant versus variable), atmospheric conditions, and operating temperature level. The quality of fuel, especially sulfur content, also affects oil changes. The best policy is to follow the manufacturer's recommendations. If these are not available, recommend the following:

(1) Operate engine for 300 hours on new oil

(2) Replace with new oil and have the used oil analyzed.

(3) If the used oil is found to be satisfactory, increase the time of operation to 500 hours with the second batch.

(4) Replace the new oil and have the second batch analyzed.

(5) If found to be satisfactory, increase the time of operation to 700 hours with a third batch.

(6) Repeat process until oil is found to be unsatisfactory for further use. After such an oil change period has been established for an engine type, subsequent oil changes can be scheduled far in advance with certainty. Continue to watch the oil between oil changes for possible contamination with fuel or water due to leaks. Remember that oil changes will be required more often if an engine operates at high oil temperatures. Drain oil while warm, preferably immediately after shut down. This is because most of the sediment will then be in suspension, and will drain readily.

f. Selection of Viscosity. Although the selection of the right viscosity oil is largely a matter of experience, there are guiding principles:

(1) The higher the cylinder wall temperature, the higher the viscosity needed.

(2) A poorly cooled engine requires a more viscous lubricant (higher SAE number) than a well cooled engine.

(3) An engine running on part load a great percentage of time can use a lighter lubricant than one running constantly at full load.

(4) An old engine with large clearances and with rings and cylinder walls in poor condition will require a heavier oil than new engines.

g. Oxidizing Influences. Oxidation takes place at all times, regardless of the base of crude oil from which the lubricating oils are made. The rate of oxidation increases rapidly as the oil heats, especially if air and moisture is present. Some oils that will not burn completely at prevailing cylinder wall and ring temperatures may vaporize and partially oxidize to materials. It then appears as piston lacquer and sticky ring groove deposits. A continued buildup of such deposits (combined with fuel residue, dust, and dirt) causes ring sticking. The sticking most often starts with the top compression ring. This permits the blow-by of hot combustion gases which interferes with the proper transfer of piston and ring heat to the cylinder walls. The result is rapid progressive sticking of the remaining rings. Continuous exposure of lube oil to high temperatures may also cause a deterioration called "hot sludge." Its appearance is similar to coffee grounds. "Cold sludge," on the other hand, generally occurs in crankcase areas as a pasty emulsion. It consists principally of water, oil and combustion residue resulting from blow-by.

h. Effect of Temperature and Pressure on Wear. Under high-pressure and high-temperature conditions, the lubricant must be able to spread rapidly on cylinder walls and replenish its own lubricating film. It must have film strength even when exposed to high combustion temperatures and piston ring pressures, and it must maintain a complete piston seal under all conditions. Cylinder liner wear is generally greatest at the combustion end of cylinders where maximum temperatures and pressures exist. Wear successively decreases along the cylinder walls in proportion to the lower temperatures and pressures encountered during the power stroke.

i. Overlubrication of Cylinders. Excessive lubrication of cylinders is detrimental to good operation. In small high-speed engines where the cylinders receive lubrication from oil thrown from the crankshaft bearings, operators have no control over the rate of feed. Overlubrication leads to abnormal carbon deposits in the cylinders, valves, passages, port areas, and the exhaust system.

j. Mechanical Lubricators. Mechanical lubrication may be required to furnish additional lubricating oil to the cylinder walls primarily for large, slow speed, two-cycle engines. Copper tubing and compression fitting usually connects the mechanical lubricator to various points in the cylinder liners with a check valve in each line. All mechanical lubricators have individual adjustments to control the amount of oil delivered to each cylinder. Also, most of them have sight glasses which give positive indication of oil delivery.

k. Spectrometric Analysis of Oil. Spectrometric analysis of oil is not an analysis of the oil itself. It is an analysis of microscopic bits of engine wear metal in the oil. These microscopic metal particles are produced by the friction of the engine's moving parts. These particles enter the oil stream and are uniformly suspended throughout the oil. Spectrometric analysis identifies these wear metal elements and aids in determining where they came from. By periodically analyzing engine oil, abnormal wear can be detected. The worn parts can be repaired or replaced before major damage occurs.

(1) Spectrometric Analysis Principles. Usually an atomic absorption spectrophotometer is used. This device emits and detects light of the wavelength of the element being tested. For diesel engines this is usually copper, chromium, aluminum, iron and silicon. You can see the significance of these elements below. The detection of excessive amounts of these elements indicate impending failure of specific engine components:

(a) Iron generally indicates oil pump wear, shaft wear, and liner wear.

(b) Chromium signals wear of piston rings, bearings and sometimes valve stems.

(c) Copper signals water entry from coolers and thrust bearing wear.

(d) Aluminum indicates piston or bearing wear.

(e) Silicon measures dirt contamination.

(2) Trend Analysis. Most engine manufacturers have data on the allowable amounts of these elements. If you can get this information use it to evaluate the spectrometric analysis results of the test sample. Note that some manufacturers won't release this information. In this case, you can use the spectrometric analysis as a trend analysis. This is simply the comparison of the present analyses to the previous analyses. Look into excessive deviations from the established trend. It usually takes about 3 or 4 analyses to form an initial baseline of engine operating and wear characteristics.

(3) Sampling Procedures. Oil sampling procedures for spectrometric analysis are contained in TO 33-1-37, section III. Sampling Kit NSN 6695-01-045-9820 can also available. The kit comes complete with a DD Form 2026, Used Oil Analysis Request. The unit of issue is a carton which contains 144 kits. For engines 100 kW and larger, recommend you take oil samples and analyze them before every oil change. Send samples to the nearest joint oil analysis program (JOAP) laboratory. The JOAP is a triservice program set up primarily to analyze oil from aircraft and has laboratories around the world. They will analyze oil samples from diesel free of charge. Contact the nearest aircraft maintenance squadron to determine the nearest JOAP laboratory.

2-18. Maintenance of Storage Systems. Dirt, lint, and other foreign matter are more easily kept out of fuel and lube oil than removed after it gets into it. Keep supply tanks clean. Strain fuel and lube oil before putting into the supply tanks. Tanks should be well covered. Most dirt is abrasive and will cause excessive wear to engine parts if allowed to enter. Rules for handling fuel and lube oil are as follows:

a. Use covered containers as specified in AFOSH 127 series safety regulations.

b. Do not use waste or linty rags around fuel or lube oil containers, fuel injection equipment or carburetors.

c. Clean all storage tanks at regular intervals.

d. When emptying a drum of fuel or lube oil, agitate the liquid as little as possible and always leave about an inch of it in the bottom of the drum.

e. Keep all fuel and lube oil handling equipment such as measures, funnels, and containers very clean and covered when not in use.

2-19. Plotting Performance Curves:

a. Performance Curves. While the AF Form 1167 serves as a means for evaluating on-the-spot engine performance, it is the gradual change in an engines performance that makes the operator aware of engine deterioration. For this reason it is most beneficial to graphically plot essential performance data. The graph will reveal performance trends over a time. The most important data for evaluating the engine's operating condition are compression pressure, cylinder firing pressure, exhaust temperature, crankcase pressure (vacuum), lube oil consumption, and fuel consumption. These data are preferably plotted as illustrated in figure 2-36. Such a graph shows operating trends and signs of distress at a glance. When plotting the curves be sure the measurements are made at essentially the same load each time. For example, 75 percent of rated load. In this manner the curves become meaningful.

b. Compression Pressure Curve. The compression pressure curve (figure 2-36) is prepared from data recorded on AF Form 1167. The horizontal portion of the graph represents operating hours, the vertical, may represent the average of the compression pressures of all cylinders. If the compression pressure readings indicate that the cylinders deviate excessively from each other, it is advisable to plot the compression pressure for each cylinder separately.

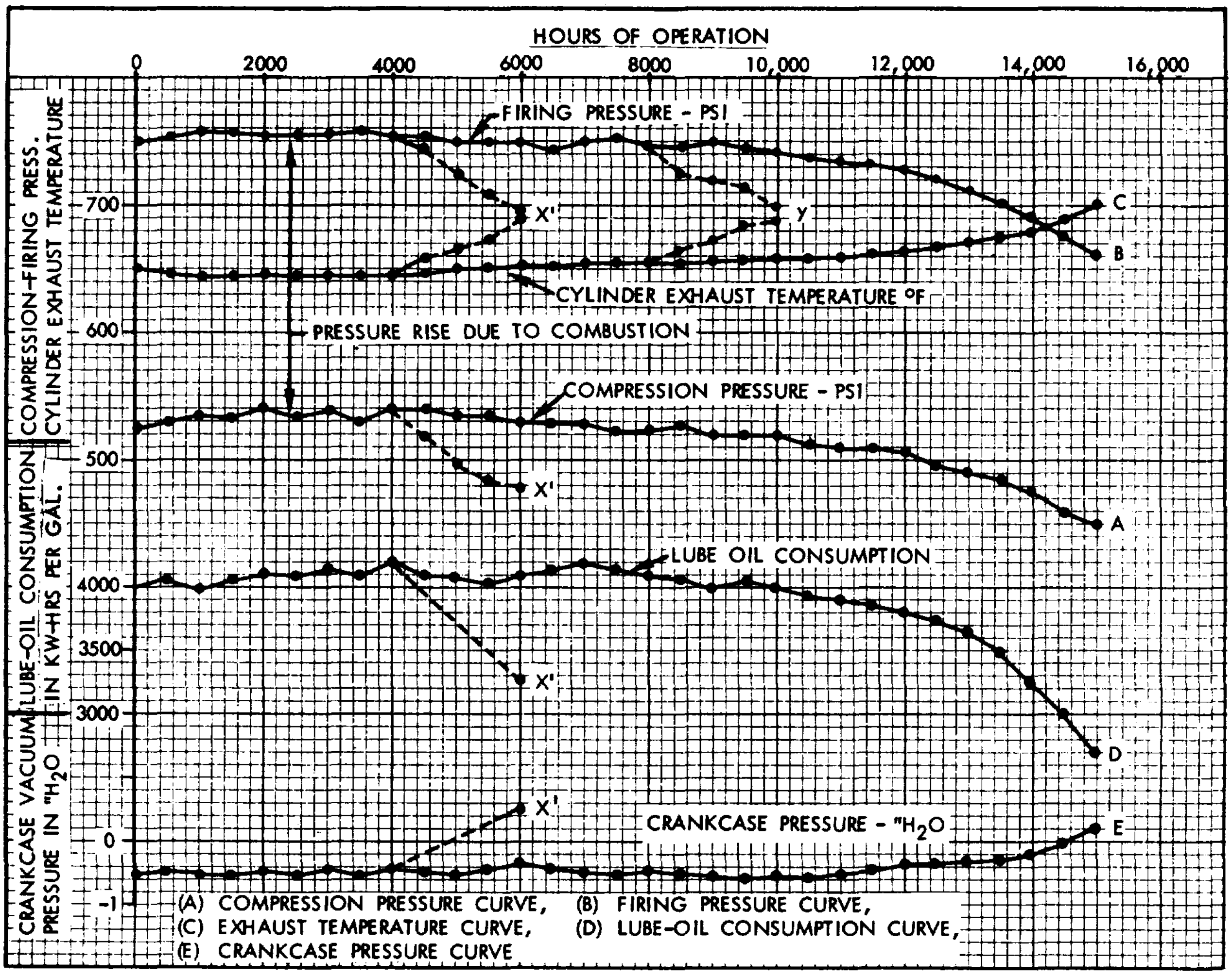


Figure 2-36. Compression, Firing and Crankcase Pressure; Exhaust Temperature; and Lube Oil Consumption Curves.

From these curves, the condition of the piston rings and valves can be judged. As long as curves remain approximately flat, it can assumed be that the rings and valves are in good con dition. A gradual drop in a curve would indicate that either the piston rings are wearing, or the valves are sticking or beginning to leak. A more rapid drop in the curve as indicated, for example, at "X" after only 4000 operating hours will indicate trouble such as broken or stuck rings or badly leaking valves. It may be noted from figure 2-36 that, after 8000 hours of operation, the curve starts to drop and continues its downward trend beyond 14,000 hours. This drop indicates that the piston rings or valves will soon need attention. If individual curves for each cylinder shows a similar trend, then all cylinders need attention. If only one of the cylinders shows a downward trend, only it needs attention. However, before corrective action is taken, a study of the other curves, (as described in c below) should be made to more accurately pinpoint the trouble as in either the rings or valves.

c. Lube Oil Consumption Curve (Figure 2-36). Kilowatt hours generated per gallon of lube oil used are determined from data recorded on AF Form 1167 and plotted at arbitrary intervals ranging from 250 to 500 hours. As in the case of the compression pressure curve, the lube oil consumption curve will be flat as the rings are seating properly, and no oil is lost due to leaks. A gradual drop in the curve indicates worn or weakened compression and oil scraper rings or other trouble. A sudden drop in the lube oil consumption curve as indicated, for example "X" indicates either trouble in the cylinders or a leak in the lube oil system. If, on the other hand, the lube oil consumption remains at a constant level, while compression drops, it can be reasonably assumed that:

(1) The compression rings are not the reason for the loss of compression, but

(2) The inlet and exhaust valves are leaking, or

(3) In the case of two-cycle engines, the scavenging valves are not functioning properly.

d. Crankcase Pressure Curves. The crankcase pressure or vacuum curve (figure 2-36) is plotted from data recorded on AF Form 1167. This curve is another indicator of the condition of the piston rings. As long as the curve is approximately flat there is little or no ring blow-by and this indicates that the rings are in good condition. However, a gradual rise of this curve would indicate excessive gas leakage past the rings. A sudden rise, as at point "X" in curve E, occurring simultaneously with the drop at point "X" in curve D is a confirmation that the sudden drop at point "X" in the compression curve A is caused by failing piston rings. The majority of today's engines, particularly turbocharged engines, operate with a slight vacuum in the crankcase. A vacuum in the crankcase equivalent to a column of 1/4- to 1/2-inch water is normal. The vacuum in the crankcase is usually produced by a pipe between the crankcase and blower intake or turbocharger. In some cases a separately driven fan is provided to maintain a vacuum in the crankcase. As ring blow-by increases, the vacuum in the crankcase will decrease from the original value.

e. Cylinder Firing Pressure and Exhaust Temperature Curves. Cylinder firing pressure and exhaust temperature curves (figure 2-36) are also prepared from data recorded on AF Form 1167. Both curves are helpful in evaluating the quality of combustion. As in the case of the compression pressures, the average value of all cylinders may be plotted or individual curves for each cylinder may be prepared. Preferably the firing pressure curve is plotted directly above the compression pressure curve, as illustrated. The distance between the two represents the pressure rise in the cylinder during combustion. This figure is very important to watch. If this pressure rise is approximately the same for all cylinders regardless of the actual level of compression and firing pressure, it can be reasonably assumed that each cylinder receives the same amount of fuel and that combustion and thermal loading of each cylinder is correct and uniform. Under these circumstances, the exhaust temperature also should be approximately the same for each cylinder. If, on the other hand, the pressure rise for one or a number of cylinders is considerably lower than the rest (in excess of about 60 lbs/in2), either the combustion in the respective cylinder is faulty, or the cylinders receive less fuel than the rest.

f. Fuel Oil Consumption. The fuel oil consumption curve (figure 2-37) is plotted from data on AF Form 1167 as kW hrs generated per gallon of fuel used. This curve is another indicator from which the general engine condition may be judged. A drop in this curve means that either:

(1) Combustion is faulty - that is, not all of the fuel injected is burned completely;

(2) Excessive blow-by past the piston and rings exist;

(3) Internal friction has increased (bearing and ring friction);

(4) Inlet and exhaust valves are leaking;

(5) With two-cycle engines, the scavenging valves are malfunctioning (plugged); or

(6) The air inlet and exhaust passages are excessively restricted by carbon accumulation.

g. Lube Oil Filter-Pressure-Drop Curve. This curve (figure 2-31) is plotted from the data recorded on AF Form 1167. The curve supplies valuable information, but is applicable only to filter installations that are the full flow type - that is, those in which all of the lube oil passing through the engine first passes through the filter at all times. When the filter elements are new or have been cleaned thoroughly, the pressure drop across the filter (pressure before minus pressure after filter) will be the minimum. As time lapses and sediment accumulates, however, the pressure drop will increase until a point is reached at which the filter element must be cleaned or changed. The filter manufacturer usually prescribes a maximum allowable pressure drop through the filter. Pressure drop across the filter always should be compared on the basis of approximately equal oil temperatures. No type of filter element can remove contaminants from oil efficiently, unless the oil is hot. Ideally the viscosity should not exceed 120 SUS. Approximate temperatures required for various oils to provide this viscosity are 165 °F

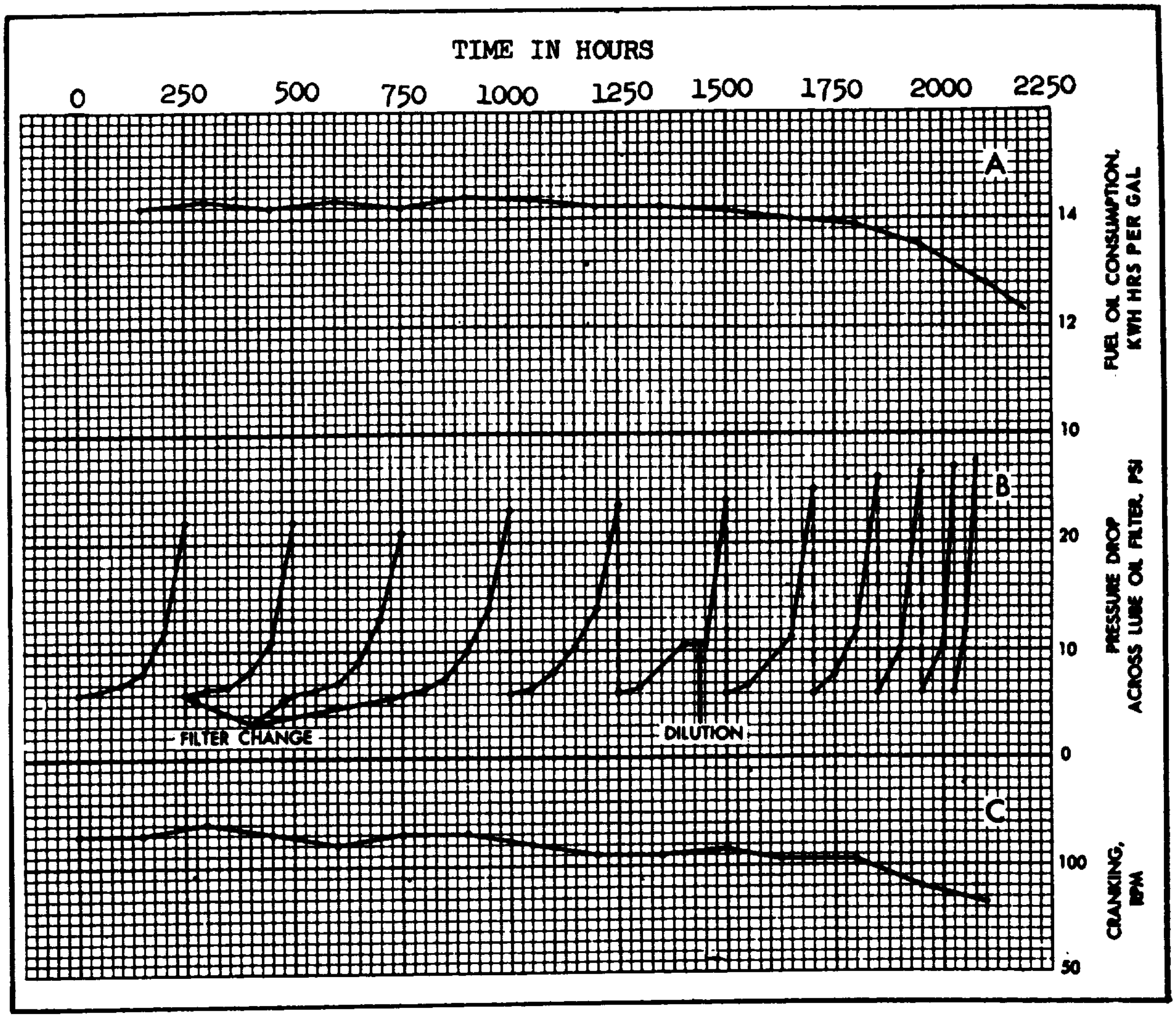


Figure 2-37. Fuel Consumption; Lube Oil Filter Pressure Drop and Cranking RPM Curves.

for SAE 20; 175 °F for SAE 30; 185 °F for SAE 40. Accordingly, oil always should be filtered before it passes through the oil cooler. The curves also indicate any dilution of the oil. For example, if the curve does not follow the usual trend, but remains level for a time, it could indicate dilution due to change in the oil's viscosity, which permits the diluted oil to pass through the filter with less effort even though filter contamination has increased. These curves also indicate the engine's general condition. As time lapses and the period for changing the filter element become progressively shorter, as shown in the curves, and other conditions being equal, the chances are that the engine is approaching the time for overhaul.

h. Cranking RPM Curve (Figure 2-37). The readings for this curve must be taken each time with the air tank charged to the same pressure or the battery charged to the same strength, and with the engine warm. A drop in rpm may indicate several possible troubles, such as sluggish starting valve, dirt, or excessive moisture in the starting system, deposits or lacquer on pistons or bearings, scoring of the cylinder liner and rings or misalignment of the engine crankshaft. If the curve remains approximately flat, it indicates that the engine is in good mechanical condition. Another method for determining the freeness of an engine is to have the engine idling for about 5 minutes after the load is removed. Then shut the engine down and determine the time in seconds it takes for the engine to come to a complete stop from the instant the starting lever is moved to the stop position. The runout time can be plotted as a function of operating hours similar to that for cranking RPM. Shorter runout time could indicate misalignment of crankshaft or excessive friction in bearings, piston and other moving parts. Still another indicator from which the degree of freeness of an engine can be determined is to observe the behavior of the engine crankshaft system as it come to a stop; rocking back and forth is a good indication that the moving parts are free.

2-20. General Overhaul and Repair:

a. Common Practices. There are a number of good practices you should follow when overhauling and repairing any engine. These are mostly common sense items but are worth reviewing:

(1) Don't mix or confuse engine parts. Mark for position on disassembly. Identify parts reground to special sizes by careful and secure tagging reground. Tag assemblies from different engines.

(2) Don't mix cap screws, bolts, and washers. These items are of a size, material, and heat treatment suited for their purpose and place. Many times a cap screw too long or too short has caused a leakage or interference with internal parts. Washers of various materials and types are selected according to application. Standard soft steel washers have caused engine failures when used to retain idler shafts. Hardened washers are used at that particular point.

(3) Inspect engine parts during disassembly. Once engine parts have been disassembled and cleaned, many valuable indications of engine condition are lost. Material found in oil, or on burned or carboned surfaces at disassembly, often suggest abnormal conditions.

(4) Protect delicate parts and surfaces. Don't pile engine parts, injector equipment and so on indiscriminately. Apply oil to surfaces subject to rust. Plug off passages likely to accumulate dust, machining chips, etc.

(5) Clean the engine thoroughly. No engine is completely overhauled if it is not cleaned internally and externally to new "new part" condition. It's difficult to inspect dirty parts, and they won't fit properly. They don't conduct heat efficiently either. Once clean, keep it clean.

(6) Work accurately. Use precision gages where needed. Follow tables of limits and tightening torque values for best performance.

(7) Always inspect thoroughly.

(8) Take positive steps to prevent unintentional starts when the engine is being worked on. The throttle should be blocked or locked, and a safe clearance tag (AF Form 982), Do Not Start, attached to the starting control. Disconnect the starting batteries or close the starter air supply before beginning repairs.

(9) Follow the manufacturer's recommendations, e.g., shop manual.

b. Crankcase Alignment Inspection. It is very important that all crankshaft main journals be in good alignment. The alignment should be checked during the original installation and during major inspection periods, or more often if bearing trouble is encountered. Deviations from the correct alignment are usually due to wear and distortion or excessive wear of one bearing or wear of the associated journal or crankcase distortion from uneven mounting surface. For example, it can create excessive clearance. Wear and distortion can also cause the shaft to deflect downward and bend under the force of combustion. A good indicator for detecting crankshaft misalignment (binding) is to observe the unit as it comes to a stop after exercises. A back and forth rocking motion indicates that the shaft system is free. Bending is taken up in the crank webs, and if not corrected, causes early failure of the shaft. On larger engines, improper alignment can be determined by using a dial deflection gauge. The cranks of all cylinders should be checked in sequence. Extreme care must be taken to be sure successive readings are taken at exactly the same spot on the webs. For this purpose, the manufacturer usually puts small prick-punch marks into the side of the webs for locating the ends of the distortion gauge. Deflections are determined by inserting the dial distortion gauge between the sides of two webs as illustrated on AF Form 731, Crankshaft Deflection Record. Deflection readings are taken in the following manner:

(1) With piston in bottom dead center position (BDC), insert dial strain gage between two webs as near to the connecting rod as possible by using the existing punch marks (position 1). The dial indicator should be set to zero and the gage actually spun until the points have worn in and the reading remains at zero. If the prick-punch marks are used, the instrument will be in the same location each time. This is essential be-

cause if the distortion gauge is not level or parallel with the shaft, erroneous readings will be taken. Too much tension should not be put on the instrument. If no prick-punch marks are available, the strain gauge should be placed as far away as possible from the outer diameter of the crankpin.

(2) Rotate the crankshaft in its normal direction of rotation with the dial distortion gauge in place. Readings should be taken at each quarter revolution (position 2, 3, 4, and 5), and plus or minus readings recorded in the spaces provided. Crankshaft deflections should be maintained as close as possible to zero. Deviations from the zero reading are frequently largest at the crank adjacent to the flywheel. Crank deflections can be corrected (equalizing plus and minus from zero) by moving the out board bearing (paragraph 2-20i) up or down (adding or removing shims) or sidewise as necessary. The maximum permissible deflection for an engine is usually given in the manufacturer's instruction manual. **CAUTION:** When deflection readings are taken, all pistons must be installed and the engine turning gear must be disengaged or relaxed. Keep permanent records of deflection readings so that any gradual change of deflection may be detected.

c. Bedplate Inspection. Where bedplates are involved, the distortion of bearing saddles is generally due to irregular support or cracking. Leveling wedges may have shifted, foundation bolts may be loose, or in the case of skid mounts, structural members may have deflected. Steps should be taken to correct whatever condition is found. With the bedplate releveled, a crankshaft deflection check should again be made to ensure accuracy of the work. In smaller engines where the crankshaft is often supported in the upper crankcase or block, misalignment is usually due to distortion of the supporting member. The alignment of the bearing saddles is usually checked with the crankshaft and bearing shells removed but with the bearing caps torqued in place. When the alignment of the crankshaft is difficult to maintain, check the bedplate or crankshaft carefully for possible cracks.

d. Checking of Crankshaft Thrust Clearance. Thrust clearance should be maintained at values and limits recommended in the manufacturer's instruction manual. To check the clearance, a pitch bar should be used to force the shaft tight against one face of the thrust bearing. A dial indicator should then be set up to zero indicating on the end of the crankshaft. Next pry the crankshaft in the opposite direction and read the dial indicator. Note that the shaft must stay in position after the pitch bar is removed.

e. Crankcase Inspection. After placing an engine in service, make a crankcase inspection every 24 hours for the first 3 or 4 days. Continue the inspection when the engine is taken off the line. The inspection should include the following:

(1) Check for loose bolts, nuts, cotter pins and broken lock wire. Also check condition of the camshaft drive gear train.

(2) Check all main and connecting rod bearings for signs of bearing metal squeezing out the sides, and for metal discoloration.

(3) Operate the motor-driven lube-oil pump or hand-priming pump, and check for oil leaks and excessive flow around the crankshaft journals. Too much flow or metal particles found in the crankcase indicates excessive wear of the bearings.

(4) Check for water leaks, especially around the outside of the liners. If motor-driven water-circulating pumps are included, have them operating during the water check.

(5) Check the crankcase for general cleanliness. Make sure that no foreign matter (dust or sand) enters the crankcase during the time the covers are off.

(6) If crankcase vapor is escaping around the crankshaft oil seal during operation, check the seal and replace if necessary. The escape of vapor may also indicate excessive piston ring blow-by.

f. Inspection of Cylinder Liners. Measure liners for wear and check for dry spots, overheating, and scoring when removing cylinder heads. Record measurements of liner wear on AF Form 734, Cylinder Liner and Ring Wear Record, and retain as a permanent record. Remove all lacquer and varnish deposits on liners. If a liner is scored slightly, polish it with a fine convex oil stone. Take measurements in the direction parallel to the axis of the crankshaft and also at 45° , 90° and 135° to the axis approximately at the following distances from the top of the liner at position:

(1) In the area where the top compression ring stops when the position is in top dead center.

(2) About 1/10 of piston stroke below position (A).

(3) About 1/5 of piston stroke below position (A).

(4) About 1/2 of piston stroke below position (A).

(5) About one piston stroke below position (A).

To make sure the measurements are taken at the same distance from the top each time, make a sheet metal gage similar to the one illustrated in figure 2-38 for each size engine. If cylinder liner wear and out-of-roundness is found to be within the limits recommended in the manufacturer's manual and the cylinders are otherwise is good condition, do not replace the liners. Liner wear normally occurs most rapidly at right angles to the axis of the crankshaft. For this reason, liner life often can be increased by rotating the liner 90 o within the block. When new liners are installed, (Figure 2-39) use the manufacturer's recommendation for break-in. If their recommendations are not available, break the liners in as follows:

(a) Idle engine for about 10 to 15 minutes at operating speed.

(b) Increase load to about 1/3 of rated and operate for about 1 hour.

(c) Increase load to about 1/2 of rated and operate for 2 hours.

(d) Increase load to 3/4 of rated and operate for 5 hours.

(e) Take compression pressure at the end of 3/4 load run. The engine should be ready to assume full continuous load.

g. Inspection of Pistons and Piston Rings (Figure 2-40). Do not remove piston rings from the piston for cleaning or inspection unless good evidence exists that they are excessively worn or the piston has to be worked on. If removal is necessary, use ring skids of sheet metal strips, as illustrated in figure 2-41. Measure gap clearance (which gives an indication of ring wear) with a feeler gage by inserting the rings in the bottom end of a spare liner (figure 2-42). Record gap clearance measurement of new rings before installation, and keep measurement records of used rings, including hours of operation as provided for on AF Form 734. The measurements serve for establishing ring wear and wear rates. If the gap is about 3 to 4 times larger than the original gap, do not return to service and, if one or two rings per piston have worn beyond acceptable limits, replace all rings of the respective piston. After replacing rings apply the same run-in procedure as described in f above.

h. Inspection of Oil Control or Scraper Rings. The scraping edge of oil rings is usually made very sharp and, as the land on the scraping edge becomes wider, the rings lose their effectiveness. The scraping edge of the rings should be inspected very closely. This may be done without removing the rings from the piston. If the land width of the used ring is found to be about twice as wide as the land of a new ring or if nicks or burrs are noted, the ring should be replaced. Moreover, a scraper ring will not scrape oil from the cylinder walls efficiently if the drain holes in the ring grooves of the piston are clogged with carbon or sludge.

i. Bearing Inspection. Methods used for checking bearing clearance vary widely with engine size. For small high speed engines, bearing clearance commonly is checked by using strips of "pastigage." This method of checking clearance can be used equally well on either main bearings or connecting-rod bearings. Connecting-rod bearings clearance is frequently checked by the indicator method. In this method, a dial indicator is firmly clamped to any part of the connecting rod with the stem of the dial indicator contacting the circular portion of the crank web. The connecting rod is then pried up and down with a long bar or timber. The difference in the dial indicator reading is the bearing clearance. An advantage of this method is that the bearing does not have to be dismantled or disturbed. In some cases, where the bearing metal peels off due to fatigue and builds up in one spot, the apparent clearance registered by the dial indicator might be zero or a very low figure. This will indicate to the operator that the bearing is in distress. Clearance above normal should be checked against the manufacturer's recommended limits. When determining the condition of the main bearings without dismantling, you should remember that the main bearings are much less loaded than the connecting rod bearings and, therefore, their life is usually longer. However, if the lube oil pressure to the engine has fallen off constantly to a value much lower than when the engine was new, without a change in lube oil pump relief valve setting, you can assume that bearing clearances have increased. Foreign material and bearing material found the lube oil filters or crankcase definitely indicate bearings in distress. Cranking speed changes are another means of determining bearing condition. Crankshaft web deflection measurements are also a good means of determining bearing conditions. Measuring the main bearing clearance is a little more difficult than for connecting rod bearings. One method is to check the clearance at the bearing crown with

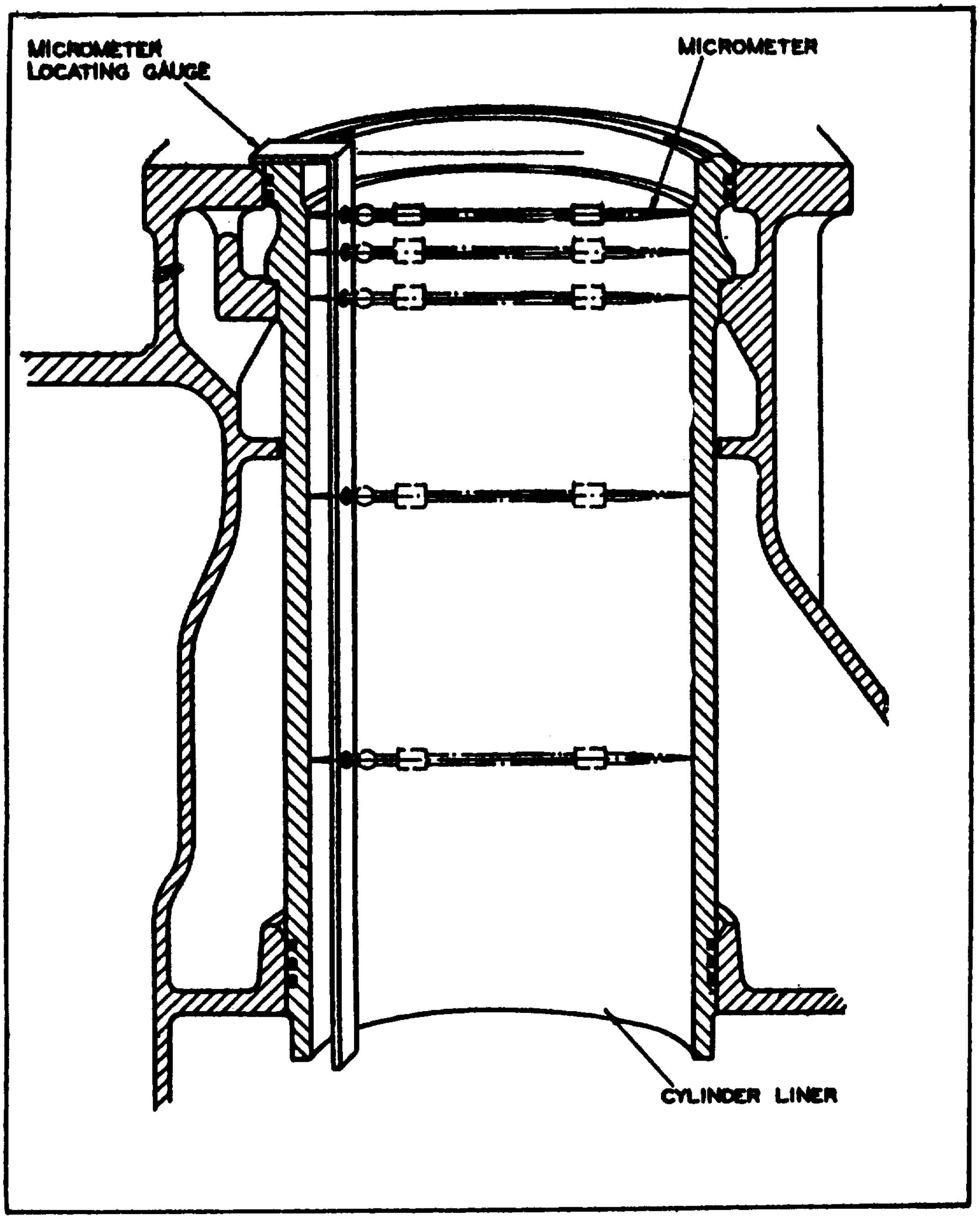


Figure 2-38. Location of Cylinder Liner Measurements.

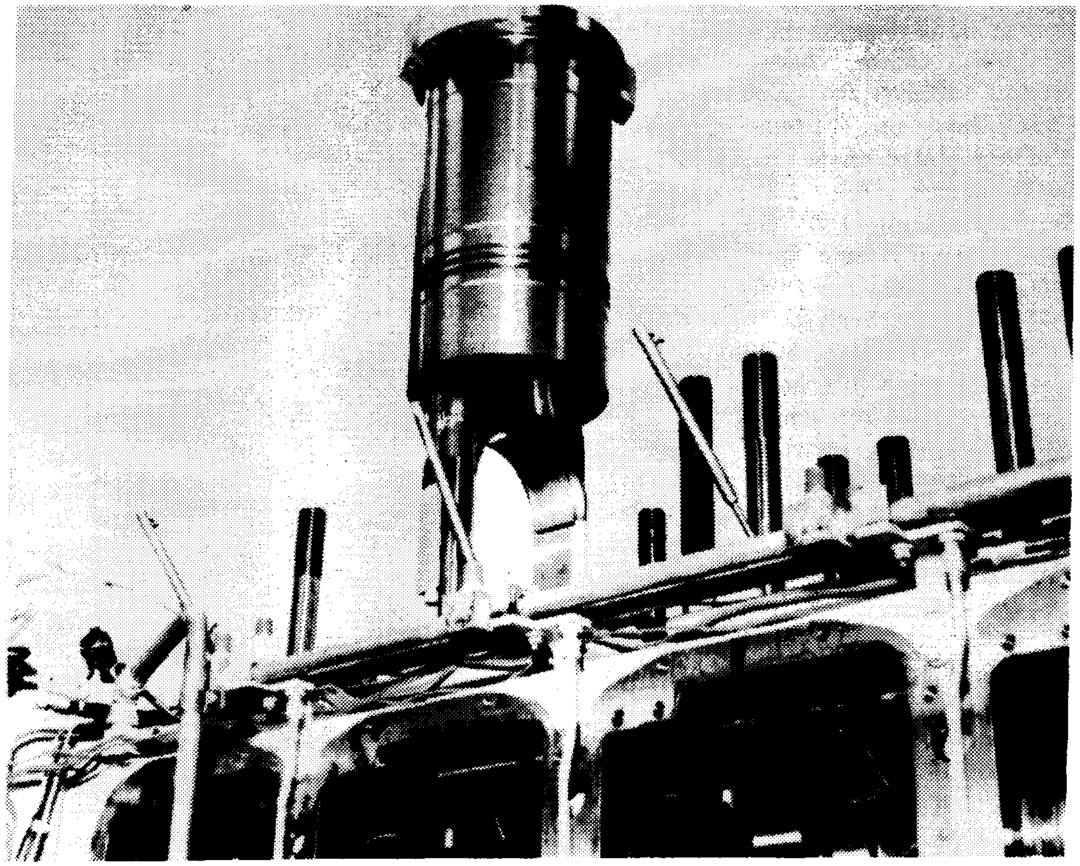


Figure 2-39. Installing New Cylinder Liner. (Courtesy Caterpillar, Inc)

feeler gages. Several thin feeler gages should be used, rather than one heavy gage. The lead wire method should not be used since the wire may damage the bearing surface. If only one new bearing is installed, it should be broken in gently by idling the engine for about 1 hour and is checking for overheating. If the temperature about the same as the two adjacent bearings, the engine is ready for continuous service. If all bearings are replaced, they should be broken in gradually on several short runs at light load with an inspection of temperature (hand touch) after each run. After any bearing change, crankshaft deflection readings should be taken.

j. Crankshaft Size. Allowable limits on wear and out-of-roundness of crankshaft pins and journals are usually given in the manufacturer's manual. In many cases, connecting rod bearings have given satisfactory service even though the pins were out-of-round beyond the manufacturer's recommended limits. In other cases, bearing failures increased as out-of-roundness increased. Out-of-roundness or flat spots on the crank pin or journal can be caused by insufficient lubrication or dirt in the lube oil. Out of roundness can also be caused by vibrations from reciprocating equipment in or near the engine room. These vibration are transmitted to the crankshaft at rest when the generator is not equipped with vibration isolators. Bearing surfaces should be calibrated as described in above if bearing trouble is being encountered. These measurements should be carefully recorded. Where crankshaft pins and journals have been scored or grooved due to failure of the bearings, the operator, before installing new bearings, should use a fine hand stone (never a file) to smooth the surfaces after being convinced that wear and out-of-roundness have not progressed beyond the manufacturer's recommended limits. However, if they have and the bearing surfaces are badly scored, a new shaft should be procured and the damaged shaft of an engine of 250 kW and over, be sent to the factory for metalizing (chromium plating). Chromium-plated shafts have been very successful and actually are better in many respects than conventional-carbon steel shafts, because the chromium bearing surfaces are much harder than carbon steel. Moreover, the bearing pins and journals of the plated shaft are brought back to their original size. (There is no requirement for undersized bearings.) The chromium-plated shaft can then serve as a spare for the plant. If connecting rod bearing failures are frequent, it is good practice to check the respective connecting rods for straightness and bearing-bore out-of-roundness, especially if there is evidence of discoloration due to overheating.

k. Generator Alignment. Improper alignment of the engine crankshaft with the rotor shaft of the generator will result in excessive vibration, short life of compound bearings, and coupling clutch parts and a need for frequent realignment. Good alignment practices include proper shimming, correct torque on hold-down bolts, accurate dial indicator usage, allowances for bearing clearances, thermal growth and other characteristics of the specific engine. Types of misalignment are shown in figures 2-43 and 2-44:

(1) Inaccurate Flanges. Inaccurate flanges can cause apparent misalignment and make accurate alignment impossible. Face runout refers to distance the face of the hub is out of perpendicular to the shaft line (see figure 2-45). Bore runout refers to the distance the driving bore of a hub is out of parallel with the shaft centerline (see figure 2-46). The face and bore runouts of the flywheel, clutch or coupling, driven members, and hubs must be checked when inconsistent alignment results occur. Face or bore errors must be corrected. The bore-to-pilot diameter runout error should not be more than approximately .002 inch (.05mm) on the flywheel and .005 inch (.13mm) on adapters (if any), bolted to the flywheel. The flange runout should not be more than .002 inch (.05mm). Consult the manufacturer's catalog for specific tolerances.

(2) Single Bearing Generators. These generators are supported by a bearing in the generator frame. The front of the rotor is then supported by the rear crankshaft bearing. This allows you to use modest couplings and simple alignment procedures. The generator mounting (bell housing) flange bolts to the engine flywheel housing. Such close coupled housings are piloted to determine alignment. When two

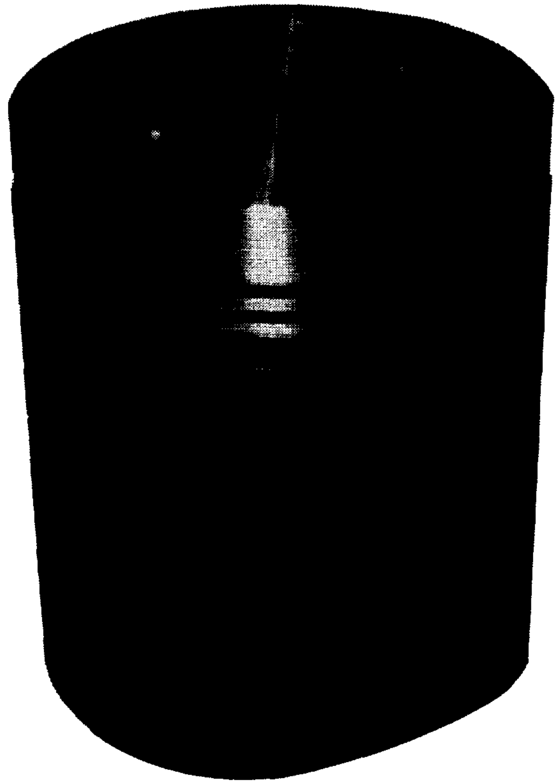


Figure 2-40. Typical Piston. (Courtesy Caterpillar, Inc)

piloted housings join together in a parallel manner, they are aligned. But, outside stresses can be introduced by poor mounting practices and allow the flywheel housing to flex. To check for outside stresses, loosen the mounting bolts between the generator and the engine flywheel housing. There should be no contact between the flywheel housing and the generator bell housing to assure that neither is stressed. The clearance between the two separated faces should be parallel within about .005inch (.013mm). Check with dial indicator mounted to generator shaft, reading on the fly wheel face. An out-of-tolerance condition indicates the rear main bearing of the generator is not centered in relation to the engine, and is subject to the generator manufacturer's accepted tolerances, flywheel housing nominal runout, and flywheel droop. Misalignment is corrected by shimming under generator supports. For more information on specific procedures and tolerances, consult the manufacturer's manuals.

(3) Two-Bearing Generators. The two-bearing generator frame totally supports the rotor with bearings at either end. Alignment is, however, critical and more difficult than one-

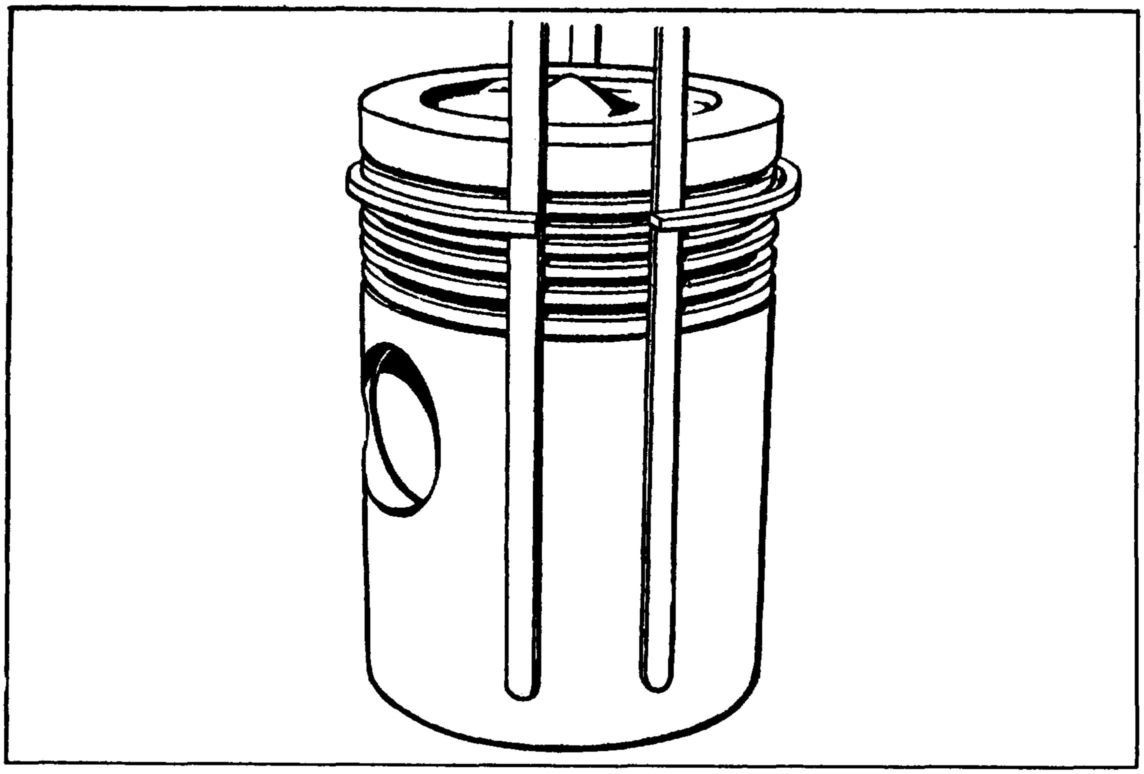


Figure 2-41. Removing Piston Rings.

bearing machines. Recommend you use cold alignment procedures. All components must be at ambient temperature. Under static conditions, the rotor shaft of remote mounted two-bearing generators is always mounted higher than the engine crankshaft. This compensates for vertical growth, flywheel sag, and main bearing oil film lift on the crankshaft (when running). Thermal growth, or expansion, occurs as engine and generator reach operating temperatures. Engine heat causes the expansion of metal in the engine and generator. This expansion causes a change in the locations of the centerlines of the crankshaft and rotor shaft. However, the thermal expansion of the engine is greater than the remote mounted generator. This causes the change in location of the horizontal centerline of the crankshaft to be greater than the change in the centerline of the rotor shaft. Heat also causes vertical growth to occur at each component's mounting feet. All these factors cause the relative positions of the crankshaft and rotor shaft to shift between static and running conditions (see figure 2-47). Thermal growth figures are generally available from the manufacturers.

(4) Alignment Tests. As pointed out in (3) above, follow the manufacturer's instructions for aligning generator and engine. In the absence of manufacturer's procedures for checking alignment, use the following:

(a) To check for parallel shaft (runout) misalignment (see figure 2-48), bolt the indicator to one of the coupling halves and scribe the position of the dial button on the opposite coupling half. Rotate both shafts simultaneously, keeping the finger or bottom of the indicator at the reference mark on the coupling hub. Note the reading on the indicator dial of each one-quarter revolution. A variation of readings at different positions will indicate how the machine should be adjusted to obtain misalignment of .002 inches. Place or remove slotted shims from under prime mover or generator mounting pads until properly aligned.

(b) To check for angular misalignment (see figure 2-48), fasten the dial indicator to one-half of the coupling hub and a reference surface fastened to the other coupling half. Scribe the

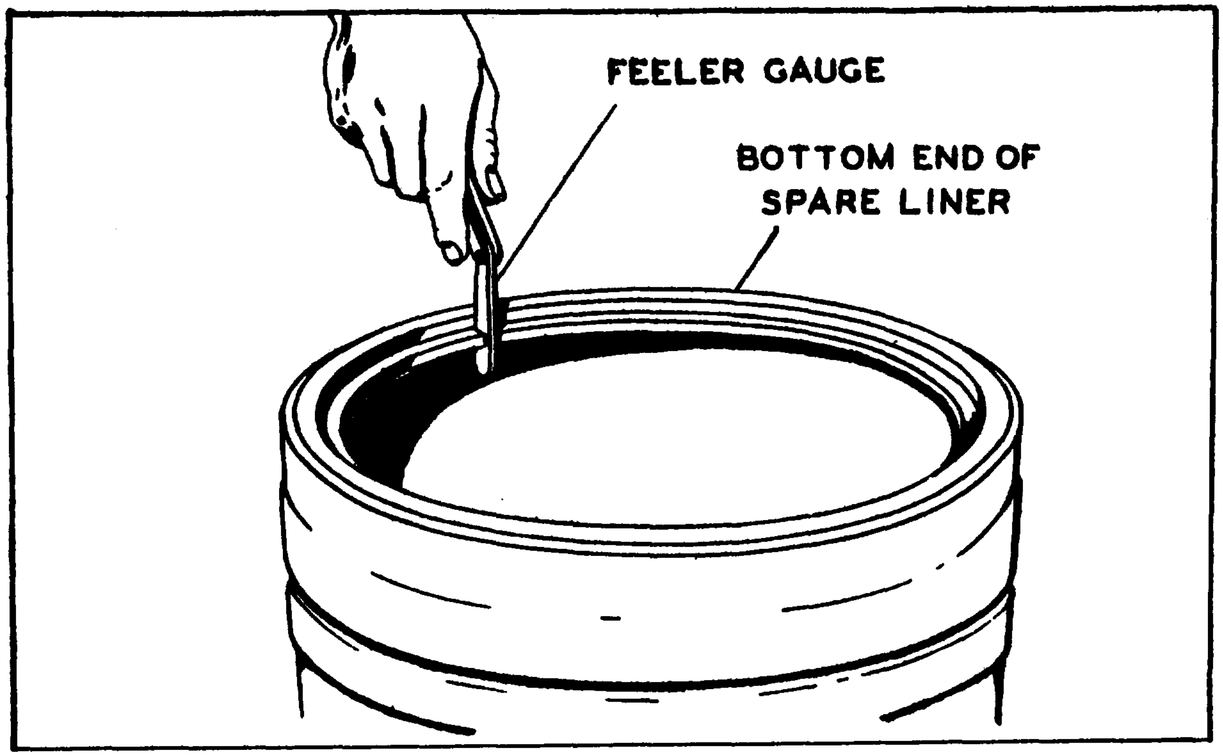


Figure 2-42. Measuring Piston Ring Gap.

location of the dial button on the reference surface and take all readings with the indicators at this position. Rotate both shafts simultaneously, note the readings at each quarter revolution. Angular misalignment of the shaft must not exceed .001 inch for each inch of radius of the coupling hub, total indicator reading. (see manufacturer's specifications).

(c) Tighten the mounting bolts to specified torque and recheck alignment. If alignment is within the above tolerance, check the coupling manufacturer's recommendation for lubrication and bolting information.

2-21. Startup After Overhaul. Use the manufacturer's instructions to start an engine after a overhaul involving replacement, if available. This also includes replacing major components such as cylinder liners, pistons and rings, main and connecting rod bearings. But if manufacturer instructions aren't available, the following procedures work well for both startup and break-in:

a. Preparing for Startup:

(1) Inspect any parts of engine system that have been worked on to make sure the work is complete. See that covers are in place. Be sure it's safe to operate any equipment which has been tagged out.

(2) Check all pipe connections to see if they are tight and the systems have been connected properly.

(3) Make a thorough check of the lubricating system. Check sump level and fill if necessary. If the engine has a separate oil pump, prime it. Remove inspection plates. Make a visual check to see if oil is present at all points of the system and at each main bearing. Examine pipes and fittings for leaks. If the engine has lubricators, make sure they are full.

(4) If installed, inspect air receiver, filter and blower's discharge passages for cleanliness and remove any oil accumulations.

(5) Inspect oil level on hydraulic governors.

(6) Examine all moving engine parts to see that they are clear for running. Check the intake exhaust, and air starting valve assemblies for freedom of movement.

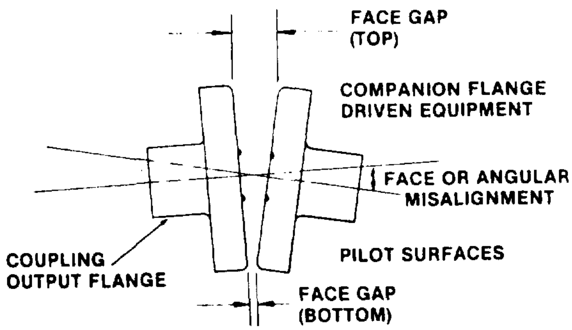


Figure 2-43. Angular or Face Misalignment of Generator Coupling. (Courtesy Caterpillar, Inc)

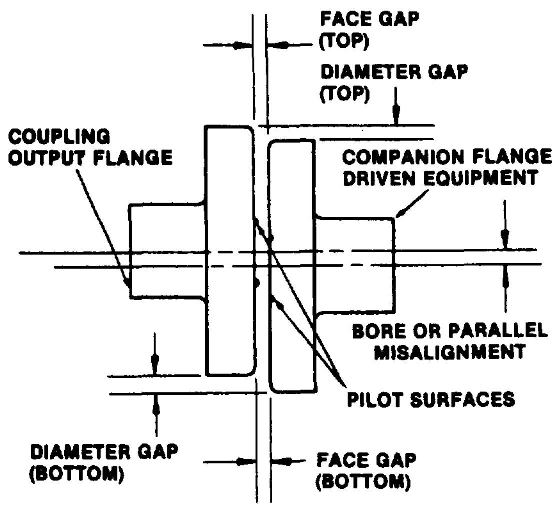


Figure 2-44. Parallel or Bore Misalignment of Generator Coupling. (Courtesy Caterpillar, Inc)

(7) Check fuel injector timing.

(8) Inspect the fuel oil service tank for water or sediment. Vent all air from fuel system by using vent cocks. Examine fuel lines and piping for leaks, especially inside the engine. Be sure fuel oil strainers have been cleaned or new filters have been installed.

(9) If engine has an air starting system, open the lines on the system and blow them out. Reconnect and pressurize the starting-air tanks.

(10) Check coolant levels, vent air from cooling system.

(11) Dry run test oil pressure and water temperature safeties and others if applicable.

(12) Check overspeed shut down hardware. Be certain injection pump rack can fully close and that butterfly valves (on gas engines) fully close.

b. Cranking the Engine:

(1) Set band override speed controls to control speed in case governor is misadjusted or malfunctioning.

(2) Make one final check and start the engine. Slowly open hand control until governor takes over, readjust governor if necessary. Check oil pressure immediately.

(3) Idle the engine (no load) for 10 to 15 minutes. Check and record all temperature and pressure readings every few minutes. Listen for any erratic engine noise. Shut engine down and inspect for oil, fuel or water leaks. Check oil for fuel dilution. Tighten all external bolts.

(4) Restart the engine and gradually bring to one-third load. Operate for 1 hour, recording all temperature and pressure readings every 15 minutes. Listen for erratic engine noises and perform visual check for leaks.

(5) Increase gradually to one-half load, and operate for 2 hours. Record all temperature and pressure readings every 30 minutes. Listen for erratic engine noises.

(6) Increase gradually to three-fourths load and operate for 2 hours. Record readings as in (4) above.

(7) Increase to full load and operate for 5 hours. Record readings as in (4) above.

(8) Operate at 110 percent load for 1 hour. Record readings as in (4) above.

(9) Check oil for fuel or water dilution and change the oil. The engine is now ready for normal operation.

2-22. Crankcase Explosions. The ignition of highly volatile oil or fuel vapor in the crankcase by an overheated piston or hot bearings causes crankshaft explosions. Piston rings that are too tight in the ring grooves or poor lubrication (causing scoring) lead to overheating pistons. Large engines usually have crankcase explosion relief valves. If, during operation, slight explosions are heard in the crankcase, or popping of the relief valves is noticed, shut the engine down immediately. Do not remove any cover plates until the engine has cooled off. During the cooling off period, open the indicator cocks

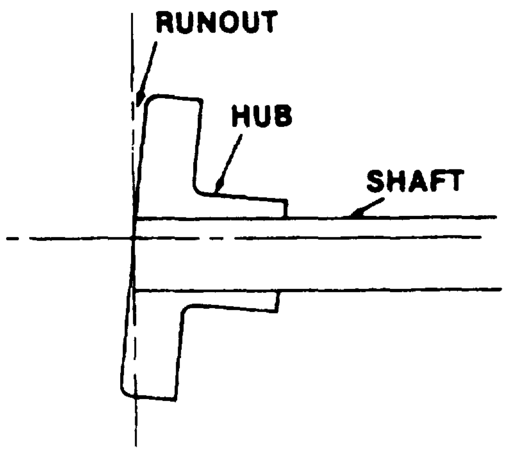


Figure 2-45. Face Runout of Generator Coupling. (Courtesy Caterpillar, Inc)

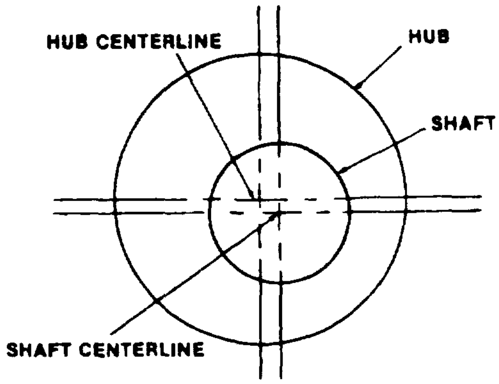


Figure 2-46. Bore Runout of Generator Coupling. (Courtesy Caterpillar, Inc)

and bar the engine over slowly, to prevent seizure.

2–23. Troubleshooting Procedures. Troubleshooting is an organized study of a problem, and a planned method for investigating and correcting it. In most cases, the solution is very simple. Most problems require only a knowledge of the construction of the generator and the principles of its operation. Below are

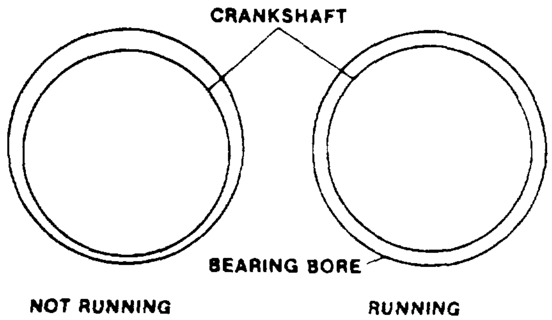


Figure 2-47. Running and Static Positions of Crankshaft. (Courtesy Caterpillar, Inc)

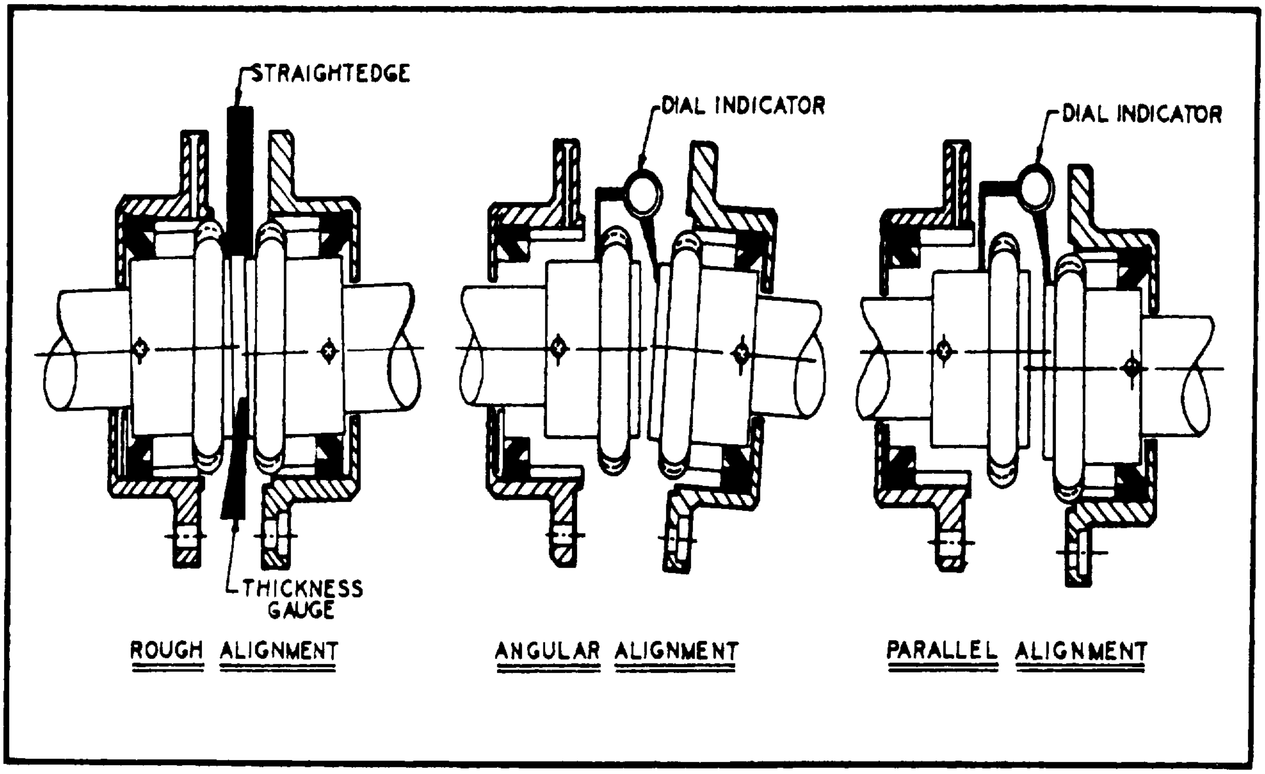
some suggestions to help your troubleshooting be more effective. Also, table 2-1 contains a list of diesel engine problems (some cases gasoline), and possible causes. Table 2-2 covers problems common to gasoline engines:

a. Studying the Problem. Study the problem by looking for and examining warning signs. Determine what previous repair and maintenance work has been done and if similar trouble occurred before.

b. Searching for the Problem. Look for the most obvious problems first. Most problems are simple and easy to fix. For example, low power may be caused by loose throttle linkage or dirty filter. Or, leaking gaskets or connections may cause excessive oil consumption.

c. Doublechecking Suspected Problems. Doublecheck for visible or external problems before beginning the time-consumming task of disassembling the engine. The source of most engine troubles can be traced to not one part but the relationship of one part with another. Hasty disassembly often destroys all evidence. Check again to be sure an easy solution has not been overlooked.

d. Correcting the Problem. After you find the problem, correct it. Also try to correct any conditions suspected of causing the problem or failed part. This is the best defense against a recurrence.



Courtesy Kato Engineering Inc.

Figure 2-48. Testing Coupling Alignment. (Courtesy Kato Engineering, Inc)

Table 2-1. Diesel Engine Problems and Possible Causes.

Problem	Possible Cause	Comments
1. Overheating	1. Overloaded engine.	
	2. Inoperative water pump.	
	3. Clogged Cooling System.	
	4. Inadequate lubrication.	
	5. Low coolant level	
2. Loss of Power	1. Overloaded engine.	
	2. Clogged fuel filter or lines.	
	3. Air in fuel.	
	4. Improper timing.	
	5. Carbon buildup.	
	6. Governor load limit set too low.	
	7. Fuel injection pump rack stuck or blocked.	
	8. Dirty air filter	
3. Starting Difficulties	1. Clogged fuel filter or lines.	
	2. No fuel in tank.	

Problem	Possible Cause	Comments
	3. Air in fuel.	
	4. Improper timing.	
	5. Water in fuel.	
	6. Safety stop not reset.	
	7. Internal seizure.	
	8. Low battery voltage.	Battery start only
	9. Low air starting.	Air start only
	10. Governor malfunction.	
	11. Interconnect control linkage adjustment.	
	12. Governor load limit improperly adjusted.	When incorporated.
	13. Low compression pressure	Check for leaky intake/exhaust valves, worn piston rings, improper seated piston rings.
	14. Starting valves stuck or leaking.	
	15. Inoperative intake/ exhaust valves.	
4. Sudden Stopping	1. Clogged fuel filter or lines.	
	2. No fuel in tank.	
	3. Air in fuel.	
	4. Water in fuel.	
5. Misfiring	1. Water in fuel.	
6. Low Oil Pressure	1. Clogged oil filter or lines.	
	2. High oil temperature.	
	3. Worn bearing.	
	4. Defective oil pump.	
	5. Faulty gage.	
	6. Low oil level	
7. High Exhaust Temperature in one Cylinder	1. Bad injector nozzle.	
	2. Exhaust valves not seated properly.	
	3. Individual adjustment in pump control lever improperly set.	Applies to jerk pumps, unit injectors, and gang pumps.
8. Low Exhaust Temperature in one Cylinder	1. Loose connections of high-pressure fuel line.	
	2. Nozzle in poor condition.	
	3. Fuel pump plunger worn.	
	4. Individual adjustment in pump control lever improperly set.	Applies to jerk pumps, unit injectors and gang pumps.
9. Excessive Noise in Front or Rear End	1. Loose chain drive.	If equipped.
	2. Improper gear backlash.	If equipped

Problem	Possible Cause	Comments
	3. Loose gears.	with gear drive.
10. Excessive Noise at one or more Cylinders	1. Worn crankpins. 2. Worn bearings.	
11. Engine Knock or Ping	1. Overload.	
	2. Injection pump malfunction.	Overfueling.
	3. Improper fuel pump timing.	Too early.
	4. Water in fuel lines. 5. Loose connecting rod bearing. 6. Loose piston pin. 7. Loose flywheel.	
	8. Excessive piston slap.	Check for worn pistons or liners.
	9. Improperly adjusted inlet and exhaust valve clearance.	
	10. Poor grade of fuel.	Low cetane.
12. Black or Gray exhaust (incomplete combustion)	1. Incompletely burned fuel.	Check for high exhaust back- pressure or restricted air intake.
	2. Excessive fuel or irregular distribution.	Check for improperly timed injectors or improperly positioned injector rack control levers.
	3. Restricted air intake dirty air filter	
13. Blue Exhaust (Excessive Lubri cation)	1. Lubricating oil in cylinder not burned.	Applies to two-stroke engines.
	2. Excessive oil in combustion chamber.	Check for worn or broken lube oil control rings, leaks from cracked piston, oil entering engine from turbo- charger.
14. White Exhaust	1. Cooling system leaks. 2. Clogged silencer or exhaust drain points. 3. Water in the intake air filter. 4. Leaks in the heat re covery system (if used).	White exhaust indicates excessive moisture in exhaust gas.
15. Fuel in Lube Oil	1. Unburned or partly burned fuel getting past piston rings into crankcase.	

Problem	Possible Cause	Comments
	2. Fuel leaks in the fuel pumps and the high-pressure line between nozzle and pump.	
	3. Leaky fuel injector valves.	Fuel drips into cylinder while at rest.
	4. Fuel seeping past lapped fits in nozzle or pump of plugged fuel leak-off lines.	Leaks difficult to find.

Table 2-2. Gasoline Engine Problems and Possible Causes.

Problem	Possible Cause	Comments
1. Loss of Power	1. Late ignition timing.	
	2. Burned or maladjusted points.	
	3. Defective ignition coil or condenser.	
	4. Fouled or improperly set spark plugs.	
	5. Ignition current leaks.	
	6. Defective Carburetion.	
	7. Clogged fuel filter or lines.	
	8. Ruptured fuel pump diaphragm or leak in manifold system.	
	9. Low compression.	
	10. Valves too tight.	
2. Smoky Exhaust	1. Oil too thin or level in sump too high.	Blue smoke.
	2. Fuel mixture too rich.	Gray smoke.
	3. Piston rings worn or stuck.	Blue smoke.
	4. Piston or cylinder sleeves worn.	Blue smoke.
	5. Cylinder misfiring	Puffs.

Chapter 3

SUPPLY AND REPAIR PARTS

3-1. What This Chapter Covers. This chapter gives guidance for establishing and maintaining an adequate supply of repair parts, materials and equipment to support the mission. The type and quantity of materials required in stock is dependent on a number of factors. Each organization must establish and reevaluate each factor. The methods and procedures for procuring, handling, storing, and accounting for supplies and equipment are in AFR 67-23 and AFM 67-1. This chapter also covers some of the management tools necessary to establish an adequate stock of expendable and repairable items, tools and test equipment. It will help you identify the proper repair parts, and how to document requisitions. The success of each shop to perform maintenance in a timely manner is greatly dependent upon their ability to use the supply system.

3-2. Establishing a Bench Stock. A bench stock is a group of items used regularly by a maintenance activity. These items are usually in close proximity to the maintenance area. These items are brought from the supply warehouse to minimize communications and transportation. Responsibilities of the using activity and the bench stock support unit, as well as criteria for establishing a bench stock and complete procedures for management of these items are in AFM 67-1, volume II, part two. Most shops will require a bench stock to enhance maintenance capabilities. It should be comprised of those items required to perform routine, recurring work and items required for the most frequently encountered emergencies. (NOTE: Also see paragraph 3-6, which covers Civil Engineering Material Acquisition System (CEMAS)).

3-3. Adjusted Stock Levels. You may need to maintain a stock of infrequently used items for emergency standby equipment. You can establish this requirement by submitting AF Form 1996, Adjusted Stock Level, to the Standard Base Supply System. AFM 67-1 tells how to do it. Requests for special levels of bench stock items don't require submission of the AF Form 1996. Also, a request for numerous items may not require submission of individual AF Forms 1996. (See AFM 67-1 for details.) Base Supply keeps most of these items in stock, but you have to justify them periodically. By maintaining a special stock level, you know the item is there when you need it.

3-4. Supply Point. A supply point item is one which Base Supply owns and controls. But the item has been identified as an item specifically related to the needs of the using organization. The using organization has established the need for the items to be near the activity they support. You can maintain any supply item, except equipment items, on supply point. Users must adequately justify low usage, expendable items. Normally, the user's operations support officer has to approve them. AFM 67-1 shows you how to establish and maintain a supply point operation.

3-5. Identification and Requisition Documentation:

a. Identifying Parts. To identify and order replacement parts, you must have the proper publications. You'll need the technical order (TO) or the manufacturer's parts manuals applicable to the specific equipment's make, model, and serial number. As with TOs, you must read and become familiar with the manufacturer's parts manuals. Some manufacturers will list several applications of a particular piece of equipment in the same manual. They differentiate only by a group, type, or option selected at the time of purchase. Others require the serial number of the equipment, and generic part number to identify the manufacturer's specific equipment or component drawing. The physical characteristics of these components may vary slightly due to improvements in design or the manufacturing process. When you get the correct part number, review the Master Cross Reference List (MCRL-1) of the Federal Supply Catalog Microfiche to see if it has a national stock number (NSN). You will need to know the appropriate Federal Supply Code for Manufacturers (FSCM), or Commercial and Government Entity Code (CAGEC) for the part or reference number. This is because several manufacturers may have identified one of their products using the same series of letters or digits. You can find the proper manufacturer's code by using the H4/H8 Section A (Name of Code), of the Federal Supply

Catalog microfiche. See AFP 72-5 for other information you can obtain from the Federal Supply Catalog. Information about the above references and those below are available through your material control section. Some of the tools that will aid in research are:

(1) MCRL-1, Master Cross Reference List, contains part or reference number to NSN. (Federal Supply Catalog C1, volume IV)

(2) MCRL-2, Master Cross Reference List, contains NSN to part or reference number.

(3) MCRL-3, Master Cross Reference List, contains the same information as the MCRL-1, but is in sequence by the Federal Stock Code for manufacturers.

(4) ML-C, is the Consolidated Management Data List which contains the information necessary to determine validity of the NSN, source of supply, the prime user of the item, repair code, cost, and other pertinent management data. (Federal Supply Catalog C1, volume II)

(5) H4/H8 Section A contains the commercial and government entity code (CAGEC) formerly referred to as the Federal Supply Code for Manufacturers (FSCM), listed by the manufacturers or suppliers name, geographical location, former name, and status, in alphabetical sequence. (Federal Supply Catalog C1, volume II)

(6) H4/H8 Section B provides the same information as Section A, but is listed in CAGEC sequence.

(7) H5 provides information of corporate complex structure of parent companies and affiliates which have a commercial and government entity code. (Federal Supply Catalog C1, volume XII)

b. Requisition Documentation. Proper documentation of material requirements is an important step in the procurement process. A mistake as minor as the misprint of a single digit of a NSN may result in hundreds of dollars difference in cost, unwanted quantities and receipt of the wrong part or material. It is imperative that the information provided to Material Control be accurate, concise and neat. Different organizations may use numerous means of requisition documentation. But, the forms most widely used are as follows:

(1) AF Form 1445, Materials and Equipment List, is used to requisition all materials except base service store items, individual equipment and tool issue items, EAID items and bench stock replenishment. The exception to this is found at bases which have implemented the CEMAS. The AF Form 1445 provides the BCE with a consolidated bill of materials and material control with data for entry onto AF Form 2005. AFR 67-23 gives issue procedures and explanation of data fields on the AF Form 1445.

(2) AF Form 2005, Issue/Turn In Request, is used primarily by Material Control to request or turn in expendable items to Base Supply. (Also see AFR 67-23 and AFM 67-1).

(3) DD Form 1348-6, DOD Single Line Item Requisition System Document, is used in conjunction with AF Forms 1445 or 2005 to submit requests for items that don't have a NSN. It's very important that you fill out this form accurately. AFR 67-23 has instructions for filling it out.

3-6. CEMAS Operation Concept. CEMAS is an automated stock management system to identify and obtain materials for civil engineering functions. It expedites and streamlines the supply functions within the civil engineering complex. This is done through automation of requisition documentation, itemization of material lists, stock inventory and financial accounting. The system incorporates the Contractor Operated Civil Engineering Supply Store (COCESS), and supplements the Standard Base Supply System. Since CEMAS is a subsystem of the Work Information Management System (WIMS), any organization having WIMS may implement it. The Air Force Engineering and Services Center's Implementation and Conversion (I/C) Plan, and AFM 171-202, volume XI contain implementation and conversion procedures for CEMAS. AFM 67-1, volume II, contains operating procedures for interaction with Base Supply.

3-7. Type and Quantity of Stocked Materials. As previously stated, the type and quantity of tools and materials required to be maintained in stock will vary dependent upon may factors. When programming inputs for bench stock, supply point, special levels and equipment accounts, the following factors should be carefully considered:

a. Plant or system classification.

b. Number of identical systems or components to be maintained.

c. Level of maintenance capability (e.g., depot, intermediate).

d. Materials required to perform routine, recurring work as opposed to lead time required for the procurement process (e.g., monthly, semiannual and annual preventative maintenance inspections, etc).

e. Material requirements for frequently encountered minor emergencies, (e.g., blown fuses, leaking gaskets).

f. Low failure rate, long lead items that can incapacitate the system and cannot be bypassed or substituted in an emergency situation, (e.g., governor controls or actuators, special protective relays).

g. Geographical separation of organization from supplier (e.g., overseas units).

3-8. Special Tools and Equipment:

a. Authorization and General Information. To properly maintain an electrical power system, a wide variety of special tools and test equipment will be needed. Some of these items will be identified by the supply system as equipment assets (Equipment Authorization Inventory Data (EAID), or non-EAID), and will require special management and accountability. EAID equipment is identified and authorized by a specific TA within TA 001, the Master Equipment Management Index (MEMI). The specific TA for civil engineering generator sets and maintenance equipment for diesel engines, generators and arresting barriers is TA 489. TAs are recorded on microfiche and maintained on file in the equipment management section of Base Supply. When reviewing the TA, special attention should be directed to the preface. This section contains information concerning the Basis of Issue (BOI), and other important data.

b. Ordering Equipment Items. Requisition equipment items on AF Form 2005, except EAID items which are not authorized on the applicable TA, or when approval is required at higher than base level. In cases when an item is required to perform or support the mission, the equipment custodian may request a change to the TA or assignment of an allowance source code (ASC) for a special allowance on AF Form 601. (See AFR 67-23 and AFM 67-1 for instructions on preparing and processing equipment requests, special allowances, management and accountability procedures, and custodian responsibilities.) You should request changes to the TA when allowances are inadequate, excessive or the equipment is unsuitable to support the mission requirement.

Chapter 4

ELECTRIC GENERATORS AND AUXILIARIES

4-1. Alternator Components. Major components of alternating current generators include a stationary armature referred to as the stator and a rotating field member referred to as the rotor (see figure 4-1). Small, low voltage generators may be designed with the armature rotating within a stationary field structure.

4-2. Frequency (Hertz) Relationship. When any given armature coil has passed a pair of poles, the voltage or current has gone through 360 electrical degrees or one cycle. The frequency depends upon the number of poles and the rotor speed. Engine-driven generators normally run at relatively slow speed and require more poles to produce 60 Hz frequency than does a steam or gas turbine-driven generator. Generators are usually designed with two, four, six, or more poles. The relationship between frequency, number of poles, and rotative speed is expressed by the following equation:

$$f = \frac{P \times (rpm)}{2(60)} \quad \text{or} \quad rpm = \frac{120 \times f}{P}$$

NOTE: Where (f) is the frequency in hertz, (P) is the number of poles, and (rpm) is the revolutions per minute.

4-3. General Description of AC Generator Rotors. Damper windings are usually on the rotor to stabilize the speed of the AC generator and reduce hunting under changing loads. These damper windings are copper bars located in the faces of the rotor pole pieces. The two basic types of rotors found in AC generators are salient-pole rotors and cylindrical rotors:

a. Salient-Pole Rotors. This rotor is constructed by attaching laminated steel plates to the rotor core which are wound under the field conductor. These wound steel plates are called poles pieces. This type rotor is normally for low- and medium-speed applications.

b. Cylindrical Rotor. This rotor is constructed by machining slots in the rotor core to accept the windings. This type rotor is used in medium- to high-speed machines because it is less susceptible to failure from centrifugal forces.

4-4. Alternator Ventilation. Salient-pole type alternators are air cooled by vent fans mounted on the drive shaft around their field coils and armature winding. Cylindrical type units of large capacity require forced ventilation or some type of cooling system.

4-5. Generator Grounding. Generators are wound as either "delta" or "wye." Most units are "wye" wound because of the lower insulation level required. Additionally, a "wye" wound generator can be effectively grounded at the neutral point (0). During unbalanced loading of the phases or when a fault occurs in one of the phases, a current will flow through the grounded neutral. When appropriate relays and instruments (such as alarms) are installed in the grounding circuit, the current so sensed can be used to detect phase imbalance, line faults, and deficiencies. When a fault or short circuit occurs on the system, the current from the generator reaches a very high value. If a fault persists for more than a few seconds, the alternator may be seriously damaged. For this reason, either a resistance or a reactance device should be included in the neutral grounding circuit. The determination of the proper impedance value requires engineering calculation. See the NEC for rules concerning grounding of low voltage windings. Also see IEEE/ANSI STD 442, Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications. This publication contains an excellent chapter on how to ground emergency generators (fixed and mobile), to ensure proper operation of protective equipment.

4-6. Surge Protection. All rotating apparatus (motors or generators) connected to lines subjected to lightning may be seriously damaged without proper protection. When lightning strikes a line, a voltage impulse wave is suddenly impressed upon the system and surges along the line until it is either dispersed in a grounding connection or divides into multiple circuits. If it terminates at an ungrounded generator neutral, it will be reflected back into the windings with a magnitude that may exceed the incoming value. Surges result in high voltages of short duration. The first incoming winding turns are most vulnerable to these high voltages. Several schemes may be considered for protecting alternators against such incidents, depending upon the system characteristics.

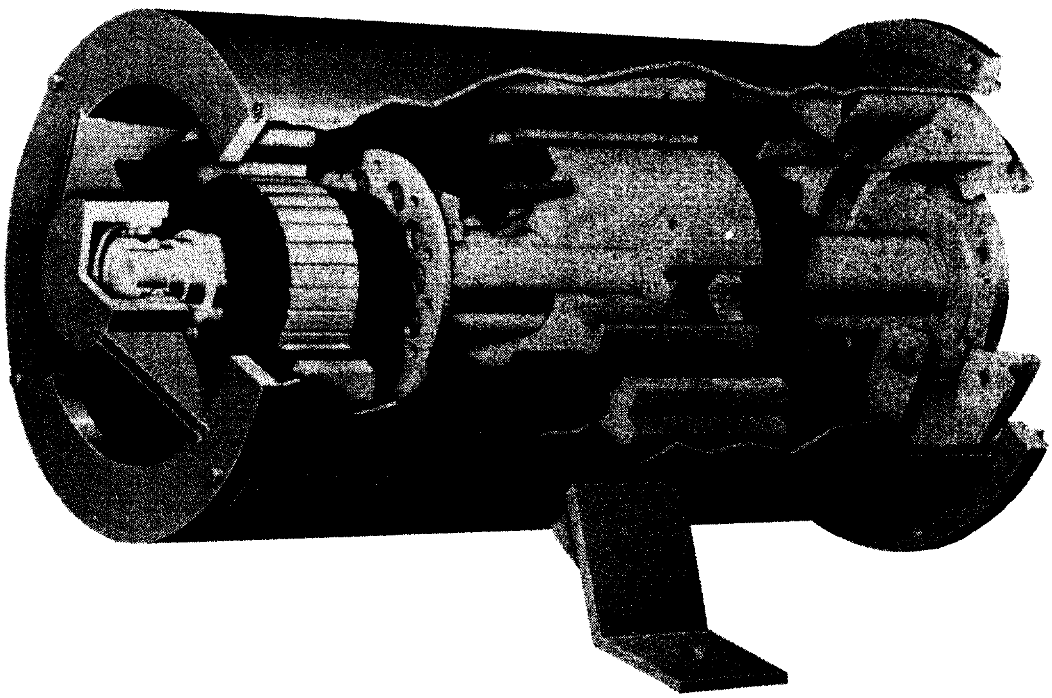


Figure 4-1. Typical Alternator. (Courtesy Caterpillar, Inc)

4-7. Description and Maintenance of Exciters:

a. Purpose and Types of Exciters. The exciter provides a source of field current for producing a suitable magnetic field in the generator. When the intensity of the magnetic field increases, so does the output voltage of the generator. An exciter failure results in the immediate loss of generation. Exciters must also provide enough field excitation under fault conditions to maintain short circuit current level so as to selectively trip branch breakers. (Some types of exiters allow the field to collapse and the fault current to decrease below full load level.) The most common types of exciters are the brush-type, brushless-type, static-type, and permanent magnet generator (PMG):

(1) The brush-type exciter can be mounted on the same shaft as the AC generator armature or can be housed separately from, but adjacent to, the generator. When it is in separate housing, the AC generator rotates the exciter (usually a DC generator), through a drive belt.

(a) The distinguishing feature of the brush-type generator is that stationary brushes are used to transfer the DC exciting current to the rotating generator field. Current transfer is made via rotating slip rings (collector rings) that are in contact with the brushes.

(b) Each collector ring is a hardened-steel forging mounted on the exciter shaft. There are two collector rings on each exciter. Each ring is fully insulated from the shaft and each other. The inner ring is usually wired for negative polarity, the outer ring for positive polarity.

(2) In brushless exciters, the brushes and sliprings are replaced with a rotating, solid state rectifier assembly. The exciter armature, generator mainfield rotating assembly, and rectifier assembly are mounted on a common shaft. The rectifier assembly rotates with, but is insulated from, the generator shaft as well as from each winding. The rectifier leads to the field coils pass thru the shaft, which is hollow. Self excited generators use a voltage regulator which supplies a regulated DC current to the exciter field by rectifying a small amount of AC output from the generator. While this type of machine is self protecting, it will not selectively trip branch circuit breakers because its field voltage collapses. One

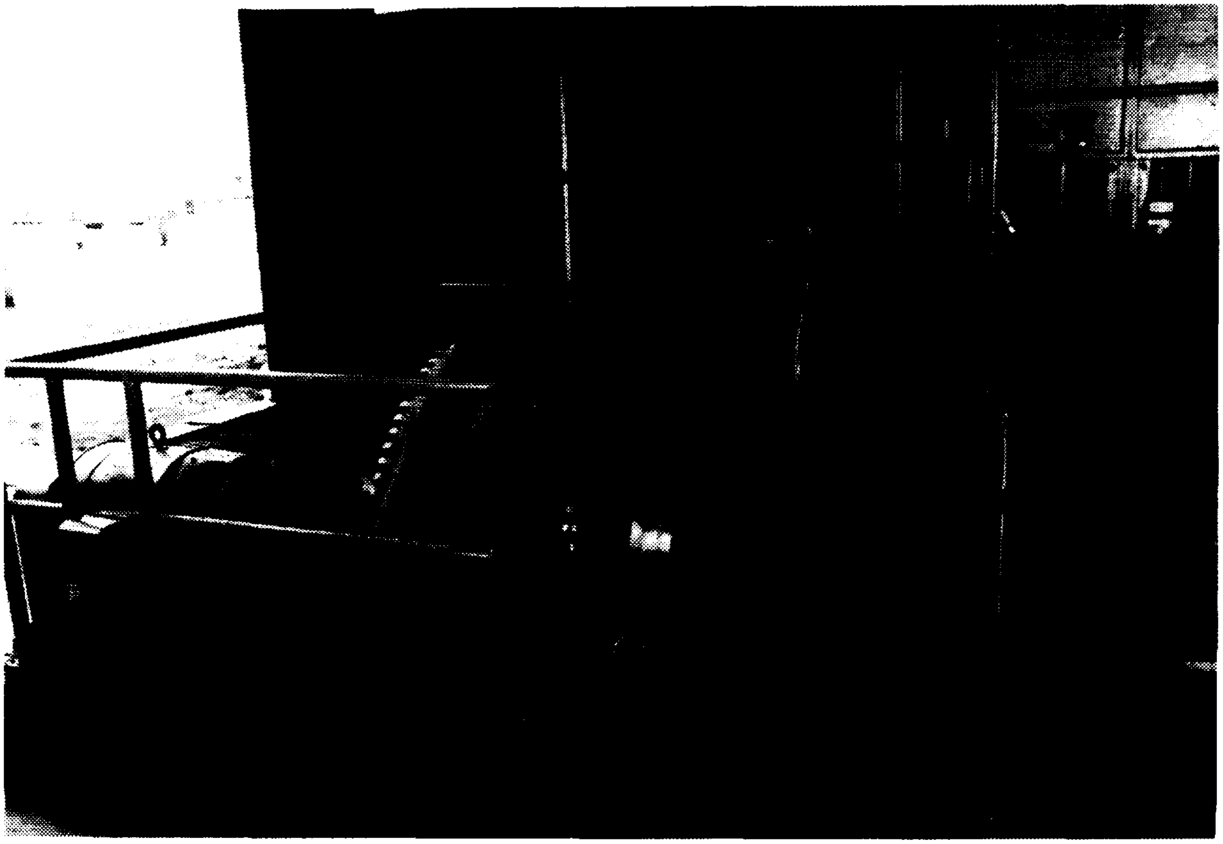


Figure 4-2. Typical Alternator With Separate DC Exciter.

way of sustaining short circuit current is with a series boost system. A series boost system rectifies current (short circuit current in the absence of generator voltage under fault condition) to supply the main field excitation.

(3) The static-type exciter system rectifies AC power from the output of the generator and sends a controlled DC current to the rotating field through collector rings. This exciter might be of the magnetic amplifier type but is usually an SCR bridge controlled by a solid state regulator circuit. Under short circuit conditions, this exciter allows the field voltage to collapse which decreases the short circuit current. The other disadvantages are that the system has two collector rings with brushes and that the SCR type has a spike in the generator output. This spike is caused by the instantaneous short circuit which occurs when the SCR bridge commutates.

(4) The permanent magnet generator (PMG) pilot exciter is actually a type of brushless exciter (see figure 4-3). But it's important enough to point out separately. The PMG pilot exciter is basically a revolving field single phase AC generator (figure 4-4). As in a conventional AC generator, voltage is induced in a stator coil when a magnetic field (produced by permanent magnets in this case) is rotated. The output of this PMG stator winding is fed to a solid state voltage regulator. The output of the voltage regulator is modified by feedback from the main generator output and is fed to a stationary exciter field winding. This exciter field winding induces a voltage on the exciter rotor winding. The current induced in the exciter rotor winding is then rectified by a rectifier bridge mounted on the rotor and fed to field windings on the main generator. Some of the advantages of a PMG pilot exciter are that it supports full excitation under fault conditions and maintenance is minimal, since it has no bearings, brushes or slip rings.

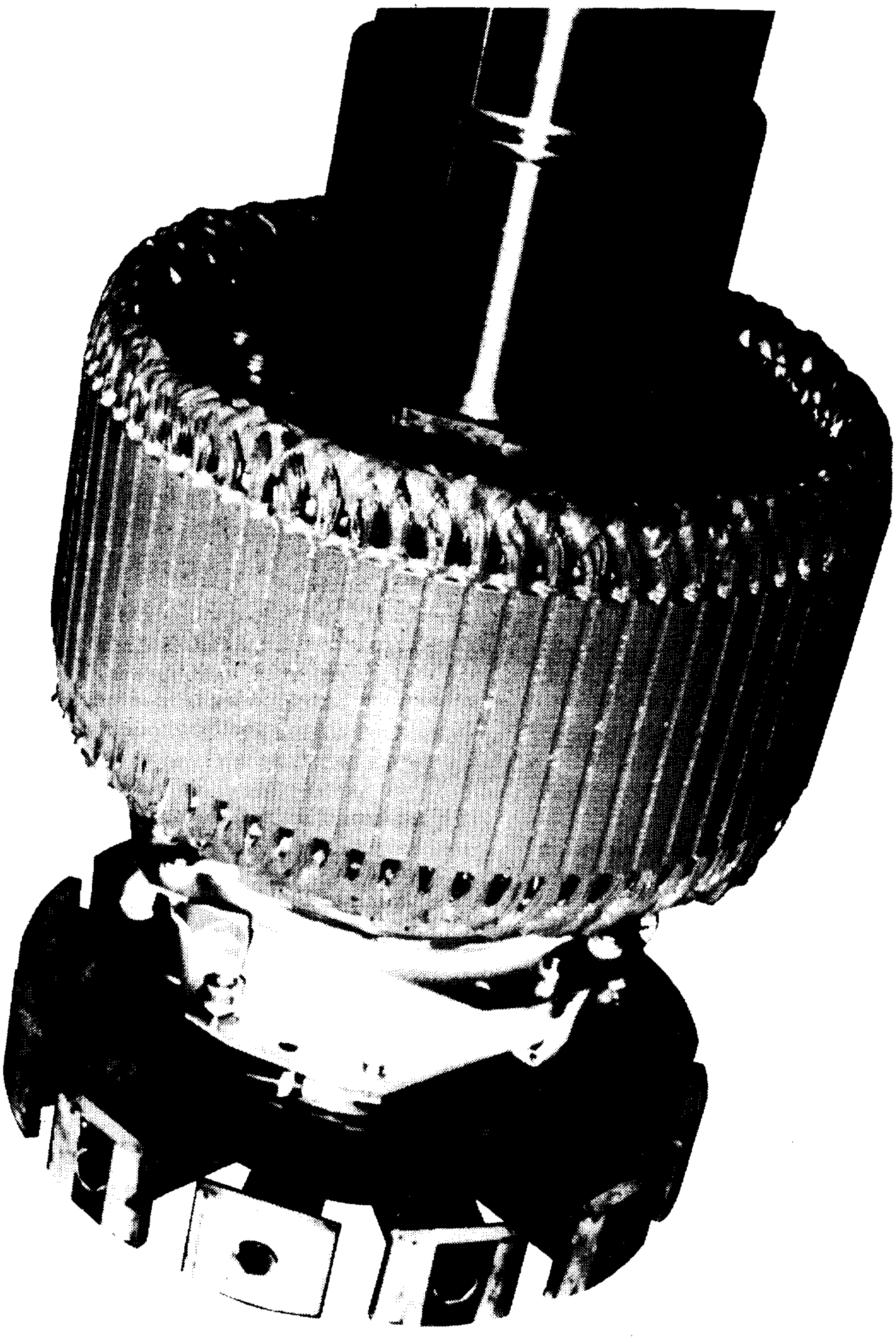


Figure 4-3. Alternator Rotor With PMG Rotor. (Courtesy Kato Engineering, Inc)

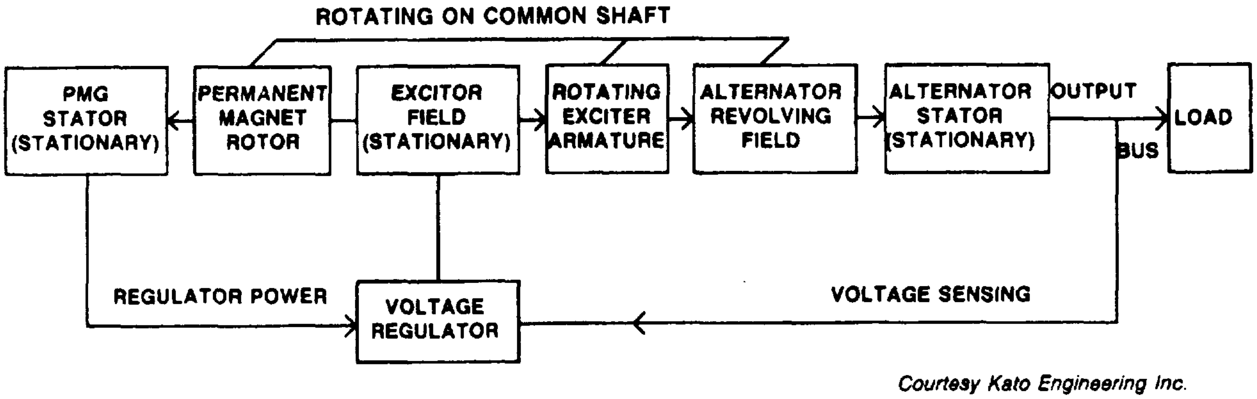


Figure 4-4. Block Diagram of PMG Pilot Excitor.(Courtesy Kato Engineering, Inc)

b. Maintenance of Brush Type Exciters. Accumulated carbon, dust, and dirt should be blown out at frequent intervals with compressed air. Particular care should be taken to blow out the area behind commutator necks. Air pressure should not exceed 50 psi. You should expel any water accumulated in the air piping before applying air. Frequently check and maintain, where applicable, the following items:

(1) Condition and tightness of drive belts.

(2) Axial position of brushes on commutator.

(3) Bearing lubricant, as prescribed in manufacturer's manual.

(4) Brush replacement should be done when they have worn to about half their original length. When new brushes as installed, adjust tension from 2-1/2 to 3-1/2 lbs/in2 of brush riding surface.

(5) Check for excessive arcing and chattering.

(6) Check commutator for roughness, hard spots, and out of round condition.

(7) Check all electrical connections.

4-8. Synchronizing and Load Division Between Paralleled Units:

a. Synchronizing. To operate one generator in parallel with another or in parallel with a utility system, a number of conditions must first be fulfilled. This paragraph explains the process of "synchronizing"--that is, getting a machine in rhythm with the remainder of the system, and the proper methods of dividing the "vars" and watts between several units.

(1) Before paralleling a generator with an electrical system, its terminal voltage, frequency, and phase relationships must be the same as that of the bus.

(2) Synchronizing lights may be used in place of the synchroscope to determine whether a unit is in phase with the bus. If the speed of the unit to be paralleled is adjusted to a point where the synchronizing lights remain dark, then an in phase condition has been attained.

b. Circulating currents. When the second alternator has been synchronized with the first unit, it "floats" on the line if the torque supplied to its shaft equals the mechanical and electrical losses of engine and generator. If additional torque is applied to this second alternator, it will pick up a part of the total load, thus relieving the first alternator of some of the load. If the two units are in parallel and the voltage of one unit is raised until its "var" output is greater than system requirement, the excess "var" output will feed back into the second unit. This condition causes a circulating current to flow between the two units. These currents can cause alternators to become very unstable and may ultimately lose synchronism with possible damage to the system and its components.

4-9. Generator Operating Procedures. The shop supervisor should prepare a complete set of standard operating procedures (SOP). Use hints in the manufacturer's instruction manual and from operating experience to make them more complete. Include single line diagrams of the electrical system showing normal and emergency switches. Positively identify circuit breaker positions. Also include notes, legends, and cautions in the diagram as they apply to special equipment. Promptly post completed SOPs in a convenient place for the technicians.

a. Pre-Starting Inspection. Before starting an alternator, make certain that no loose parts and material are in or on the rotor, or in the air-gap spaces. Pickup all small tools or other objects near the units. They could be magnetically drawn into the air-gap spaces and cause serious damage. (Good housekeeping is essential.) Also check the generator and auxiliaries for loose nuts and bolts.

b. Tasks to Perform After Startup. After the generator has been brought up to speed, do the following:

(1) Select and adjust the automatic voltage regulator.

(2) Adjust the governor speed control on the prime mover until the frequency approximates the bus frequency. Close the appropriate synchronizing switch to activate the synchroscope or synchronizing lights.

(3) In-phase condition is indicated by a vertical synchroscope hand or dark lights. Regulate the speed of the incoming machine to produce a frequency slightly above the bus frequency. This condition is indicated by a slowly moving synchroscope pointer in the clockwise direction or the synchronizing lights alternately changing from bright to dark.

(4) Just before the pointer passes through the synchronizing point (12 o'clock), or just before the lights reach the synchronizing point (dark), close the main circuit breaker. Practice is necessary to obtain smooth paralleling operation. If the circuit breaker is closed with the units too far apart (out of phase) a serious "jolt" will occur with possible damage to the alternator.

c. Stabilizing the Generator. After the unit is paralleled with the bus, observe the division of alternator "var" output and, if necessary, adjust the voltage regulator droop control to equalize the "var" output of all generators connected to the bus.

NOTE: Generators are most stable at their rated power factor. The system load controls the total "var" output but, for stable system operation, the generator should carry at least its share of the "vars" for a power factor below 0.9. The following table shows the relationship between "var" output and power factor, and the conversion from one to the other. Table 4-1. Generator Stabilizing Factors.

d. Calculating Power Factors. The factors in table 4-1 are based on a generator output of 100 kVA. For generator outputs other than 100 kVA, multiply the factors by the applicable kva generator output and divide by 100. For example, kW and kvar output of a 500 kVA generator operating at 85% power factor may be calculated as follows:

$$\frac{(500\,\text{kVA})\,X\,(85.0\%)}{100} = 425.0\,\text{kW and}$$

$$\frac{(500\,\text{kVA})\,X\,(52.6\,\text{var})}{100} = 263.0\,\text{kvar}$$

4-10. Alternator Maintenance. A technician should perform a routine inspection frequently to spot-check the principal components of a prime power unit. The supervisor should prepare a complete inspection list on the basis of instructions in the manufacturer's manual, and from past operating experience. If possible, use a suitable stroboscopic instrument to inspect the condition of the rotating parts, while the alternator is operating. This enables the technician to detect and correct any abnormal condition before serious harm occurs. Check for loose stator iron, and the condition of the rotor wedges and bolts. Inspect Pole bolts to be sure they are tight.

4-11. Cleaning Alternator Windings. There are several methods of cleaning alternators and exciters. Below are the most common and preferred methods:

a. Cleaning With Compressed Air. This is the most convenient method of removing accumulated dirt. The airline must be free from moisture and the airstream directed, so that dirt is blown out without compacting the insulation and windings. A pressure of approximately 25 to 50 lbs/in^2 should give good results.**CAUTION:**Wear safety glasses or approved face shield and an approved respirator when using compressed air for this purpose. Exercise caution to avoid direct personal contact with the compressed air blast.

b. Cleaning With Solvents. Use solvents to remove dirt, grease, and oil. The purpose is to clean and restore the equipment to as near its original condition as possible. There are various means of cleaning, depending on the type and ratings of the insulation. Most cleaning solvents are toxic and, in some cases, flammable. Refer to AFOSH 127-66 for information on the safe handling of solvents and to AFOSH 161-1 for threshold limit values of airborne contaminants. Also, consult the manufacturer's manual for compatibility with the generator insulation. The cleaning room should be well-ventilated. Technicians must follow fire safety regulations and precautions while using the solvent. After cleaning, dry the parts. Then, if possible, revarnish them with an approved insulating varnish.

4-12. Outboard Bearings. On some diesel-driven alternators, an engine bearing supports the shaft-flywheel-rotor assembly on one end. An outboard bearing (one-bearing generator) supports the other end. This arrangement makes it easier to align to the crankshaft, through raising or lowering the level of the outboard bearing. The outboard bearing should be isolated from the base plate to prevent circulating (shaft) currents (electrolysis). These currents will cause bearing failure. The temperature of the outboard bearing and the oil level in the bearing should be checked every hour (hand touch). Outboard bearings are usually of the sleeve type, and the oil should be changed after about every 6 months operation.

4-13. Insulation Testing. The failure of an insulation system is the most common cause of problems in electrical equipment. Insulation is subject to many efforts which can cause it to fail, such as, mechanical damage, vibration, excessive heat or cold, dirt, oil, corrosive vapors, moisture from processes, or just the humidity on a muggy day. As pin holes or cracks develop, moisture and foreign matter penetrate the surfaces of the insulation, providing a low resistance path for leakage current. Sometimes the drop in insulation resistance is sudden, as when equipment is flooded. But it most often drops gradually, giving plenty of warning, if checked periodically. Such checks permit planned reconditioning before service failure. The electrical insulation resistance test is most often conducted to determine the quality of armature and alternator field winding insulation. It is a simple, quick, convenient and nondestructive test. It will indicate the contamination of insulation by moisture, dirt or carbon. There are other tests available to determine the quality of insulation. But they are generally too complex or destructive. You should do an insulation resistance test immediately following generator shutdown when the windings are still hot and dry. Recommend you use a megohmmeter for the test:

a. Preparing for Insulation Testing. Before testing the insulation, do the following:

(1) Take the equipment you're testing out of service. This involves deenergizing the equipment and disconnecting it from other equipment and circuits.

(2) If for some reason you can't disconnect the equipment from the circuit, inspect the installation to determine what equipment is connected and will be included in the test. Pay particular attention to conductors that lead away from the installation. This is very important because the more equipment that is included in the test, the lower the reading will be, and the true insulation resistance of the apparatus in question may be masked by that of the associated equipment. It is always possible, of course, that the insulation resistance of the complete installation will be satisfactory, especially for a spot check. Or, it may be higher than the range of the megohmmeter, in which case nothing would be gained by separating the components because the insulation resistance of each part would be still higher.

Table 4-1. Generator Stabilizing Factors.

KW	KVAR	POWER FACTOR	KVA
100	0	1.0	100
97.5	22.2	0.975	100
95	31.1	0.95	100
92.5	38.0	0.925	100
90.0	43.7	0.90	100
87.5	48.6	0.875	100
85	52.6	0.85	100
82.5	56.5	0.825	100
80.0	60.0	0.80	100

(3) Test for foreign or induced voltages with a volt-ohm-milliammeter. Pay particular attention once again to conductors that lead away from the circuit being tested and make sure they have been properly disconnected from any source of voltage.

(4) Large electrical equipment and cables usually have sufficient capacitance to store a dangerous amount of energy from the test current. So, discharge capacitance both before and after any testing by short circuiting or grounding the equipment under test.

(5) Apply safety grounds.

(6) Generally, there is no fire hazard in the normal use of a megohmmeter. But there is a hazard when testing equipment in inflammable or explosive atmospheres. There may be slight sparking when attaching test leads to equipment in which the capacitance has not been completely discharged. It also can occur when discharging capacitance following a test. For this reason you should not use a megohmmeter in an explosive atmosphere. But if you must conduct a test in an explosive atmosphere, don't disconnect test leads for at least 30 to 60 seconds following a test. This allows time for capacitance discharge.

(7) Do not use a megohmmeter whose terminal operating voltage exceeds that which is safe to apply to the equipment under test. A megohmmeter of not over 500V is adequate for insulation testing. The formula below is an accepted standard for measuring the insulation resistance of stator windings. The resistance after one minute should not be less than:

$$\text{Resistance in megohms} = \frac{\text{Rated voltage of machine} + 1000}{1000}$$

b. Spot Reading Method. To take a spot insulation reading, connect the meoghmmeter across the insulation to be tested and operate it for a short, specific timed period (60 seconds usually is recommended). Bear in mind also that temperature and humidity, as well as condition of your insulation affect your reading. Your first spot reading on equipment with no prior test, can be only a rough guide as to how "good" or "bad" the insulation is. By taking readings periodically and recording them, you have a better basis for judging the actual insulation condition. Any persistent downward trend is usually fair warning of trouble ahead, even though the readings may be higher than the suggested minimum safe values. Equally true, as long as your periodic readings are consistent, they may be OK, even though lower than the recommended minimum values. You should make these periodic tests in the same way each time, with the same test connections and with the same test voltage applied for the same length of time. Table 4-2 includes some general observations about how you can interpret periodic insulation resistance tests and what you should do with the results.

c. Time Resistance Method. Another insulation test method is the time resistance method. It is fairly independent of temperature and often can give you conclusive information without records of past tests. You simply take successive readings at specific times and note the differences in readings. Tests by this method are sometimes referred to as absorption tests. Test voltages applied are the same as those for the spot reading test. Note that good insulation shows a continual increase in resistance over a period of time. If the insulation contains much moisture or contaminants, the absorption effect is masked by a high leakage current which stays at a fairly constant value, keeping the resistance reading low. The time resistance test is of value also because it is independent of equipment size. The increase in resistance for clean and dry insulation occurs in the same manner whether a generator is large or small. You can, therefore, compare several generators and establish standards for new ones, regardless of their kW ratings. The ratio of two-time-resistance readings is called a Dielectric Absorption Ratio. It is useful in recording information about insulation. If the ratio is a 10-minute reading divided by a 1-minute reading, the value is called the Polarization Index. Table 4-3 gives values of the ratios and corresponding relative conditions of the insulation that they indicate.

d. Insulation Inspection Considerations. Because of the variety of materials used for insulation and the complex paths measured in apparatus insulation- resistance tests (insulation, varnish, jacket materials, air, iron, and perhaps oil) the insulation resistance measurements may vary for identical apparatus under identical ambient conditions. For a reasonably long insulation life, exposed insulation should be inspected periodically and kept clean and dry.

e. Keeping Windings Serviceable. To be sure the windings are in good condition, the generators should be operated under load at least once each month. If the relative humidity is high, the units should be operated more frequently. If this cannot be done, heating lamps or heating resistances should be placed near the windings to ensure that they are kept dry.

4-14. Collector Rings and Brushes. Sparking is the principal indication of improper brush and alternator-collector performance. It is caused by imperfect contact between the brushes and collector rings, and may be the result of any one or a combination of the following conditions:

a. Brush Overhang. The alignment of brushes on the ring should be checked periodically to make sure that a brush does not overhang the edge of the ring. An over-hanging part of a brush develops a thin edge that breaks off, and causes uneven wear of the collector rings.

b. Dirt Buildup. Keep collector rings, brushes, and brush holders clean and free from carbon, dust, and oil. See that all brushes move freely in their holders. Remove sticking brushes and rub their sides with fine sandpaper. Thoroughly clean brush holders and collectors. Use a flat stick wrapped with a piece of canvas dipped in grease solvent, to clean the brush rigging and collector parts. Dirt that has accumulated between brush and holder may conduct sufficient current to bond the brush to the holder. Frequent cleaning of the brush rigging will prevent this condition.

c. Incorrect Brushes. Sparking and poor service may occur if other than specified types of brushes are used. If a brush is too large, it will stick in the holder; if too small, it is likely to bind at an angle.

d. Vibration of brush rigging. This vibration causes poor contact. Tighten any loose parts of the brush rigging.

Table 4-2. Interpreting Insulation Resistance Test Results.

Condition	What To Do
1. Fair to high values and well-maintained.	No cause for concern.
2. Fair to high values, but showing a constant tendency towards lower values.	Locate and remedy the cause and check the downward trend.
3. Low but well-maintained.	Condition is probably all right, but cause of low values should be checked.
4. So low as to be unsafe.	Clean, dry out or otherwise raise the values before placing equipment in service. (Test wet equipment while drying out.)
5. Fair to high values, previously well-maintained but showing sudden lowering.	Make tests at frequent intervals until the cause of low values is located and remedied; or until the values have become steady at a lower level but safe for operation; or until values become so low that it is unsafe to keep the equipment in operation.

Table 4-3. Conditon of Insulation Indicated by Dielectric Absorption Ratios.

Insulation Condition	60/30-Second Ratio	10/1-Minute Ratio Polarization Index
Dangerous		Less than 1
Questionable	1.0 to 1.25	1.0 to 2
Good	1.4 to 1.6	2 to 4
Excellent	Above 1.6	Above 4

* These values must be considered tentative and relative - subject to experience with the time resistance method over a period of time.

e. Improper Spring Tension. The spring tension should be sufficient to maintain contact between the brush and the ring, but the pressure should not be so great as to cause excessive mechanical wear. A brush pressure of approximately 2 1/2 lbs/in2 brush area gives the best brush performance, for most generators. As brushes shorten from wear, tighten the springs to maintain proper brush pressure. Replace brushes before they reach the limit of their life. Unequal distribution of current between the brushes on the same ring may cause sparking. When this occurs, temporarily relieve the spring tension on the sparking brush. The spring tension of the other brushes on the same ring may then need adjustment so each will carry its proper share of the current.

f. Rough or Marked Rings. Remove black spots on the surface of the collector rings by carefully polishing the surface lightly with fine sandpaper, and crocus (a special abrasive) cloth. (Light mottling may be tolerated.) If rings should become particularly rough, repolish them with the unit running at idle speed.

g. Eccentricity of Rings. A slight imbalance in the rotor or eccentricity of the collector rings can cause the brushes to lift off the ring, and draw an arc once every revolution. Repeated arcing at the same place on the ring eventually burns an imprint of the brush into the ring. The trueness of rings can be checked with a dial indicator on the back of a brush while the unit is running at low speed. When eccentricity is noticed, the rings should be ground and polished. Replaced collector rings may be slightly eccentric after assembly on the shaft, and should be checked and trued if necessary.

h. Brush Chatter. This results from a long period of operation with an unusually low value of field current, such as when a generator is running at "no load" for extended periods.

i. Uneven Hardness of Rings. If a ring is not uniformly hard it wears unevenly and sparking may develop. Such rings should be replaced with rings obtained from the original manufacturer if possible.

j. Electrolytic Action. There is always some electrolytic action at ring surfaces. Performance and life is improved by occasionally reversing the polarity of rings.

4–15. Generator Troubleshooting. If a problem develops, you should perform general troubleshooting to determine the cause. Use table 4-4 as a troubleshooting guide in the absence of a manufacturer's troubleshooting chart. After you diagnose the problem, see the manufacturer's manuals for repair information, if available.

Table 4-4. Generator Troubleshooting Guide.

Problem	Possible Cause	Comments
1. Vibration	a. Misalignment of generator and prime mover.	Align generator set; check coupling
	b. Generator not properly mounted.	
	c. Generator airgap not uniform.	Center rotor by replacing or shimming bearings.
	d. Generator rotor out of balance.	Balance rotor
2. Overheating	a. Clogged ventilating screens and air passages.	
	b. Dry or defective bearings.	Replace if defective.
	c. Coupling misaligned; or on belt-driven sets, belt too tight.	
	d. Generator field coils shorted or grounded.	Test field coils for shorts.
	e. Electrical load unbalanced.	Balance load.
	f. Open line fuse.	Replace fuse.
	g. Stator windings shorted, open or grounded.	
3. No output voltage.	a. Open circuit breaker or fuse.	
	b. Overvoltage/undervoltage devices tripped (Devices with protective circuit).	Check for cause of abnormal conditions. Correct deficiences and reset devices.
	c. Open circuit in exciter field.	Check continuity of shunt field and leads to voltage control.
	d. Open circuit in stator windings.	Check continuity.
	e. Open circuit in manual voltage adjust circuit.	Check potentiometer for continuity.
	f. Malfunction of automatic voltage regulator.	See regulator manual for troubleshooting.
	g. Short circuited generator output leads.	Clear short circuit.
	h. Open in rotating rectifier (when used).	Check rotating rectifiers on exciter rotor and replace if necessary.
	i. Open in alternator field.	Check for continuity in rotor windings.
	j. Shorted surge protector (if used).	Check for shorts.
	k. Shorted rotating rectifier.	Check for shorts in exciter rotor rectifier.
	l. Shorted exciter armature.	Check for short.
	m. Shorted leads between exciter armature and generator field.	Test and repair.
	n. Shorted slip rings (if used).	Repair as directed by manufacturer.

Problem	Possible Cause	Comments
	o. Internal moisture.	Megohmmeter, if low reading, dry windings.
	p. Voltmeter defective.	Replace.
	q. Ammeter shunt open.	Replace ammeter and shunt.
4. Low voltage.	a. Defective voltage regulator (when used).	Check regulator, adjust or replace if defective.
	b. Improper adjustment of voltage rheostat.	Adjust rheostat.
	c. Excessive load.	Reduce load, balance if necessary.
	d. Line loss.	Increase size of line wire.
	e. High resistance connection to load.	Connections will be hot or warm, make proper connections.
	f. Shorted field.	Check resistance of coils with ohmmeter of resistance bridge.
	g. Low power factor.	Reduce inductive (motor) load. Do not use motor larger than necessary to carry load.
	h. Weak field due to warm ambient temperature.	Improve ventilation of generator. Increase field current not to exceed temperature rating on name-plate.
	i. Improper speed of engine-driven generator set due to defective governor, ignition system or carburetor.	Check and correct deficiencies.
5. Fluctuating voltage.	a. Voltage regulator not operating properly (if used).	Check regulator, repair or replace as necessary.
	b. Prime mover speed fluctuating.	Check engine governor.
	c. Loose internal or load connections.	Check and correct.
	d. Generator overloaded.	Reduce load to rated value.
	e. DC exciter voltage fluctuating.	Trace DC excitation circuit and correct deficiences.
	f. Paralleled generator cross-current compensation inoperative or incorrectly connected.	Check polarity of connections to cross-current transformer. Refer to regulator manual.
	g. Poor commutation (if used).	Clean slip rings and reseat brushes.
	h. Fluctuating load.	Adjust voltage regulator and governor speed.
6. High voltage.	a. Overspeed.	Correct speed of prime mover.

Problem	Possible Cause	Comments
	b. Improper adjustment of voltage adjust rheostat on voltage regulator (over-excited).	Adjust to proper setting.
	c. One leg of delta-connected stator open.	Replace or repair defective coils.
7. Frequency incorrect or fluctuating.	a. Speed incorrect or fluctuating.	Adjust speed governoring device.
	b. DC excitation voltage fluctuating.	Adjust belt tension of exciter generator (if used).
8. Voltage hunting.	a. External field resistance (if used) in out position.	Adjust resistance.
	b. Voltage regulator contacts (if used) dirty.	Clean and reseat contacts.
9. Stator overheats in spots.	a. Open phase windings.	
	b. Rotor not centered.	Realign and replace bearings if necessary.
	c. Unbalanced circuits.	Balance circuits.
	d. Loose connections or wrong polarity coil	Tighten or correct polarity.
	e. Shorted coil.	
10. Field over-heating.	a. Shorted field coil.	Replace or repair.
	b. Improper ventilation.	Remove obstructions, clean air ducts.
11. Alternator produces shock when touched.	a. Reversed field coil.	Check polarity, change leads as necessary.
	b. Static charge.	High speed belts build up static charge, connect alternator frame to a ground strip.

Chapter 5

MAINTAINING SWITCHGEAR

5–1. Electrical Switchgear Components and Missions:

a. Switchgear Components and Circuits. Switchgear is a general term covering switching and interrupting devices that control, meter and protect the flow of electric power. The component parts include circuit breakers, instrument transformers, transfer switches, voltage regulators, instruments, and protective relays and devices. Switchgear includes associated interconnections and supporting or enclosing structures. The various configurations range in size from a single panel to an assembly of panels and enclosures (see figures 5-1 and 5-2). Figure 5-3 contains a diagram of typical switchgear circuitry. Two generators (GEN 1 and GEN 2), related voltage regulators, and the main power bus are shown. Refer to the legend that accompanies the diagram for identification of the other component parts. Generator prime movers are not shown in the diagram.

b. Switchgear Subdivisions and Missions. Switchgear subdivides large blocks of electric power and perform the following missions:

(1) Distributes incoming power between technical and nontechnical loads.

(2) Isolates the various loads.

(3) Controls auxiliary power sources.

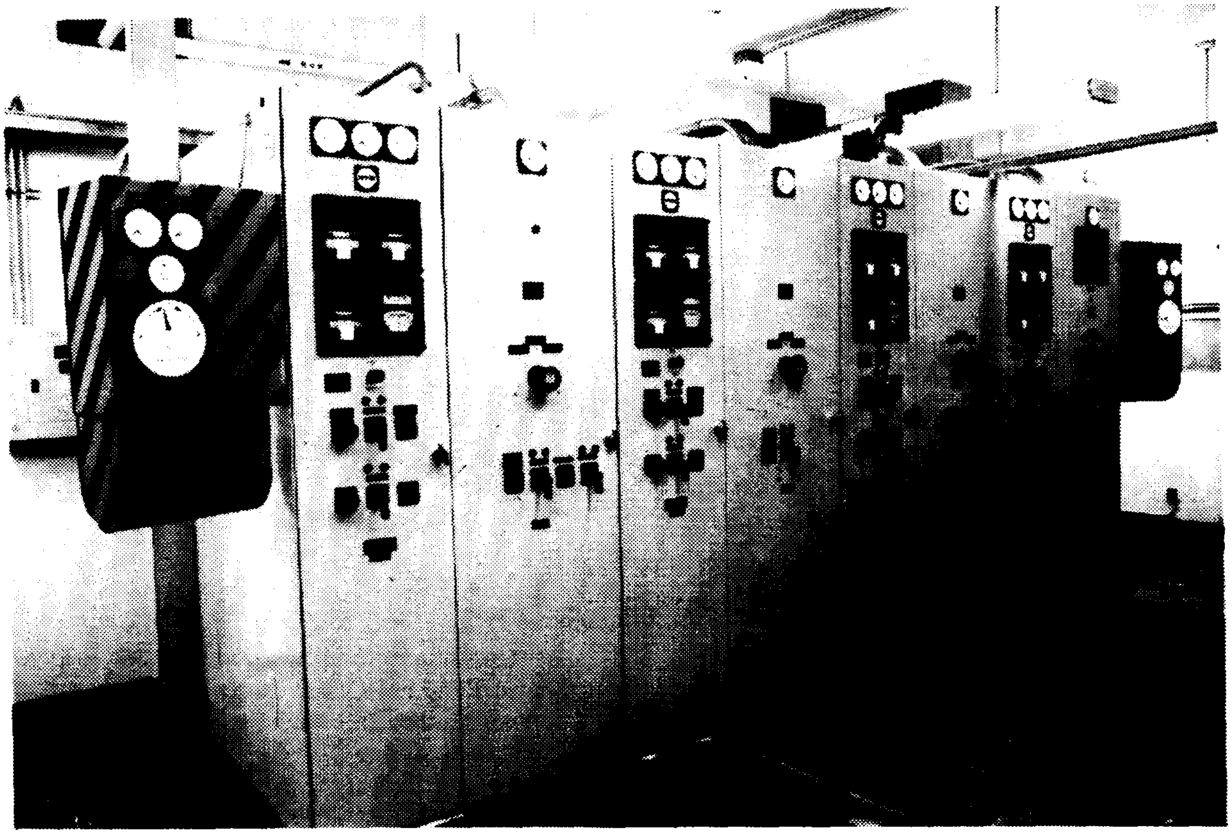


Figure 5-1. Typical Metal-Enclosed Switchgear.

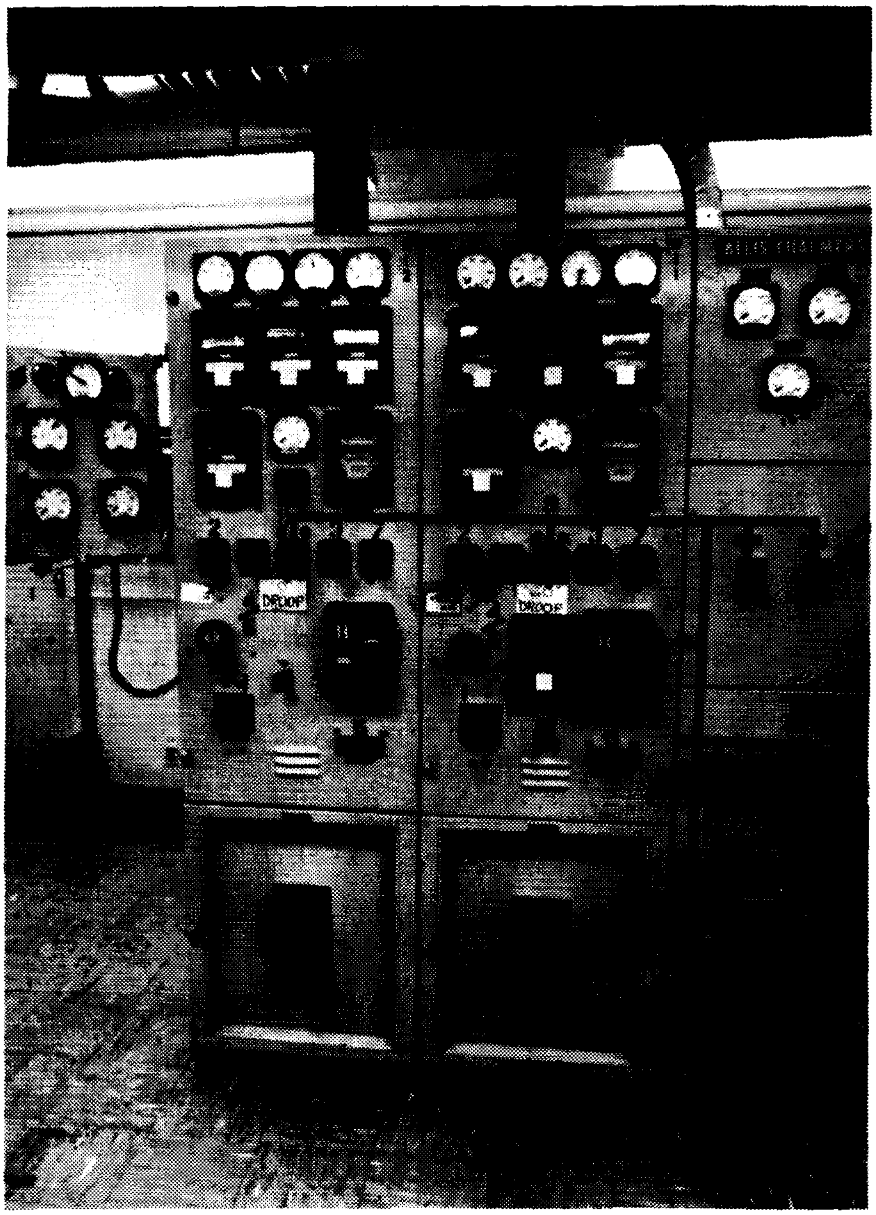


Figure 5-2. Typical Switchgear Showing Relays.

(4) Provides the means to determine the quality and status of electric power.

(5) Protects the generation and distribution equipment and personnel from abnormal electric system conditions.

5-2. Types of Switchgear. Auxiliary power generation systems use low voltage and medium voltage switchgear equipment. Switchgear at military installations is usually in a grounded, metal enclosure. The Institute of Electrical and Electronics Engineers (IEEE), rates equipment up to 1,000 volts AC as low voltage. They rate equipment equal to or greater than 1,000 volts, but less than 15,000 volts AC as medium voltage:

a. Low Voltage Switchgear. Major elements of low voltage switchgear are circuit breakers, potential transformers, current transformers, and control circuits and protective relaying. Related elements of the switchgear include the service entrance conductor, main box, switches, indicator lights, and instruments. The service entrance conductor and main bus (sized as re-

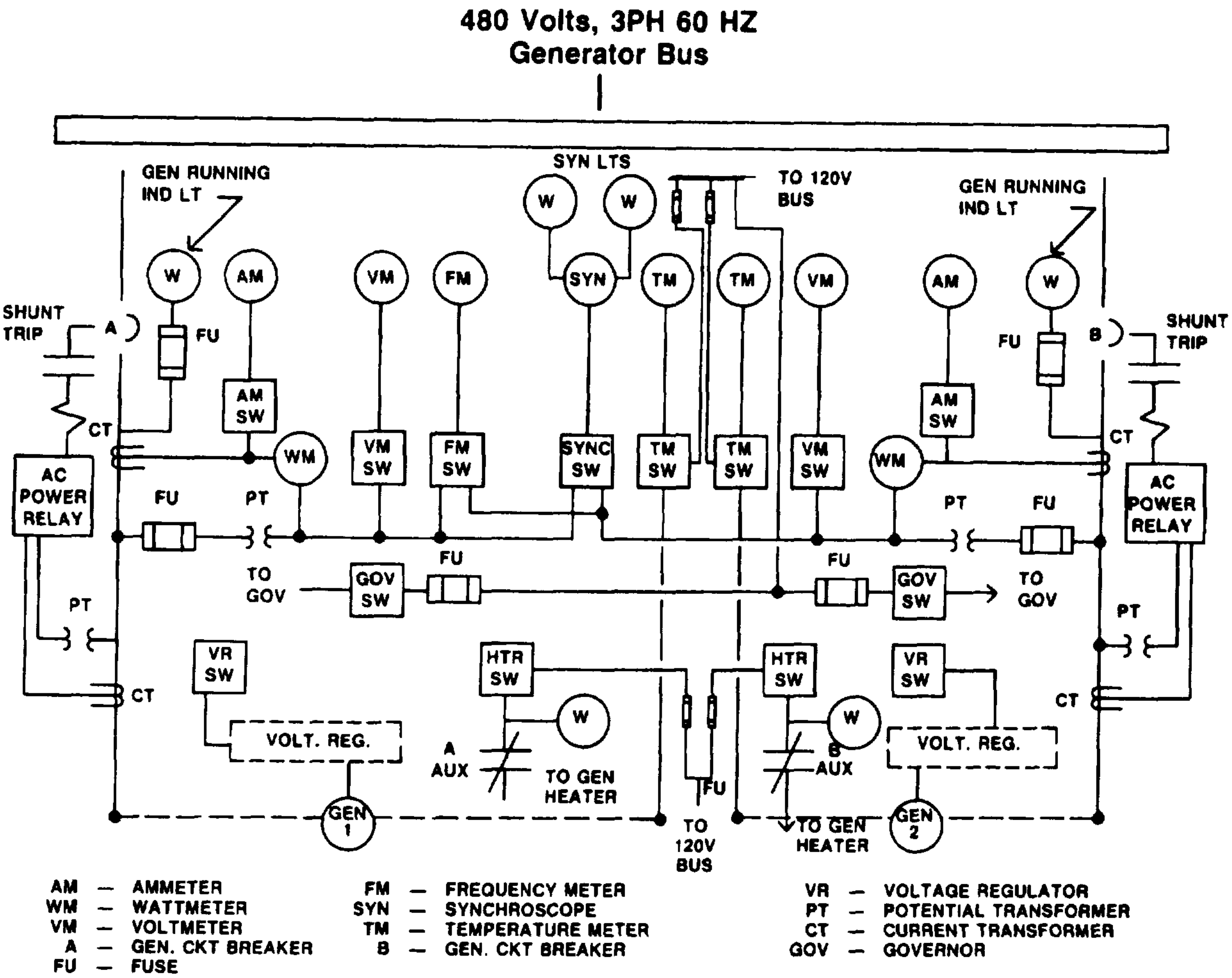


Figure 5-3. Typical Switchgear Circuitry One-Line.

quired) are typical heavy duty conductors that carry heavy current loads.

b. Medium Voltage Switchgear. Medium voltage switchgear consists of major and related elements as in low voltage switchgear. (See paragraph 5-4 for details.) Construction of circuit breakers employed in the two types of switchgear and the methods to accomplish breaker tripping are the primary differences. The service entrance conductors and main bus are typical heavy-duty conductors rated for use between 601 volts AC and 15,000 volts AC, as required.

0–3. Low Voltage Equipment:

a. Circuit Breakers. Low voltage equipment uses either molded-case or air circuit breakers. Usually the air circuit breakers have draw-out construction. This feature permits removal of an individual breaker from the switchgear enclosure for inspection or maintenance without deenergizing the main bus.

(1) Air circuit breakers usually are for heavy-duty, low voltage applications. Heavy-duty circuit breakers can handle higher power loads than molded-case units and have higher current-interrupting capacity. Air circuit breakers release stored energy, either electrically or manually, to actuate the main contacts. Accordingly, this power positions the mechanism where it can release the stored energy to close or open the contacts very quickly. The closing or tripping action can be done manually (by hand or foot power), or electrically (where a sole-

noid provides mechanical force). The mechanical force may be applied magnetically. Air circuit breakers contain power sensor overcurrent trip devices that detect an overcurrent to the load and initiate tripping or opening of the circuit breaker.

(a) Manual circuit breakers have spring-operated, stored-energy mechanisms for operation. Release of the energy results in quick operation of the mechanism to open or close the contacts. Operating speed is not dependent on the speed or force the operator uses to store the energy.

(b) Fast and positive action prevents undesirable arcing between the movable and stationary contacts. This results in longer contact and breaker life.

(c) Manual stored-energy circuit breakers have springs which you charge by operating the insulated handle. This charging action compresses or extends the springs prior to closing or opening action. This is to make sure the circuit breaker has enough energy stored for quick and positive operation. Part of the stored energy, which is released during closing, can also charge the opening springs.

NOTE: Some manual circuit breakers have a charged capacitor to initiate (electrically) the opening of a stored-energy type of mechanism.

(d) Some manual breakers require several up-down strokes to fully charge. The springs are released on the final downward stroke. In either of the manual units, there is no motion of the contacts until the springs are released.

(e) Electrical quick-make/quick-break breakers are operated by a motor or solenoid. In smaller units, a solenoid is used to conserve space. In large sizes, an AC/DC motor is used to keep control-power requirements low (4 amps at 230 volts).

(f) When the solenoid is energized, the solenoid charges the closing springs and drives the mechanism past the center/neutral point in one continuous motion. Motor-operated mechanisms automatically charge the closing springs to a predetermined level. When a signal to close is delivered, the springs are released and the breaker contacts are closed. The motor solenoid does not aid in the closing stroke; the springs supply all the closing power. There is sufficient stored-energy to close the contacts under short-circuit conditions. Energy for opening the contacts is stored during the closing action.

(g) A second set of springs opens the contacts when the breaker receives a trip impulse or signal. The breaker can be operated manually for maintenance by a detachable handle.

NOTE: Circuit breakers usually have 2 or 3 sets of contacts (main, arcing and intermediate). Arcing and intermediate contacts are adjusted to open after the main contacts open to reduce burning or pitting of the main contacts.

(h) A typical power sensor for an air circuit breaker precisely controls the breaker opening time in response to a specified level of fault current. Most units function as overcurrent trip devices and consist of a solenoid tripper and solid-state components (part of the power sensor) which provide precise and sensitive trip signals.

(2) Low current and low energy power circuits are usually controlled by molded-case circuit breakers. The trip elements act directly to release the breaker latch when the current exceeds the calibrated current magnitude.

(a) Thermal-magnetic circuit breakers have a thermal bi-metallic element for an inverse time-current relationship to protect against sustained overloads. This type also has an instantaneous magnetic trip element for short-circuit protection.

(b) Magnetic trip-only circuit breakers have no thermal elements. This type has a magnetic tripping arrangement to trip instantaneously (no purposely introduced time delay) at currents equal to, or above, the trip setting. These are only for short-circuit protection of motor branch circuits where other elements provide motor overload or running protection.

(c) Nonautomatic circuit interrupters have no automatic overload or short-circuit trip elements. These are for manual switching and isolation. Other devices must be provided for short-circuit and overload protection.

b. Instrument Transformers (Figure 5-4). Instrument transformers permit the use of standard low voltage and current meters for all high voltage or high current AC circuits. Also, these devices protect operating personnel from exposure to the high voltage circuits. There are two types of instrument transformers, potential and current:

(1) A potential transformer is similar to a constant-potential step-down power transformer that is used to measure switchgear voltage (see figure 5-4). The primary winding of a potential transformer is connected in parallel with the circuit in which the voltage is to be monitored.

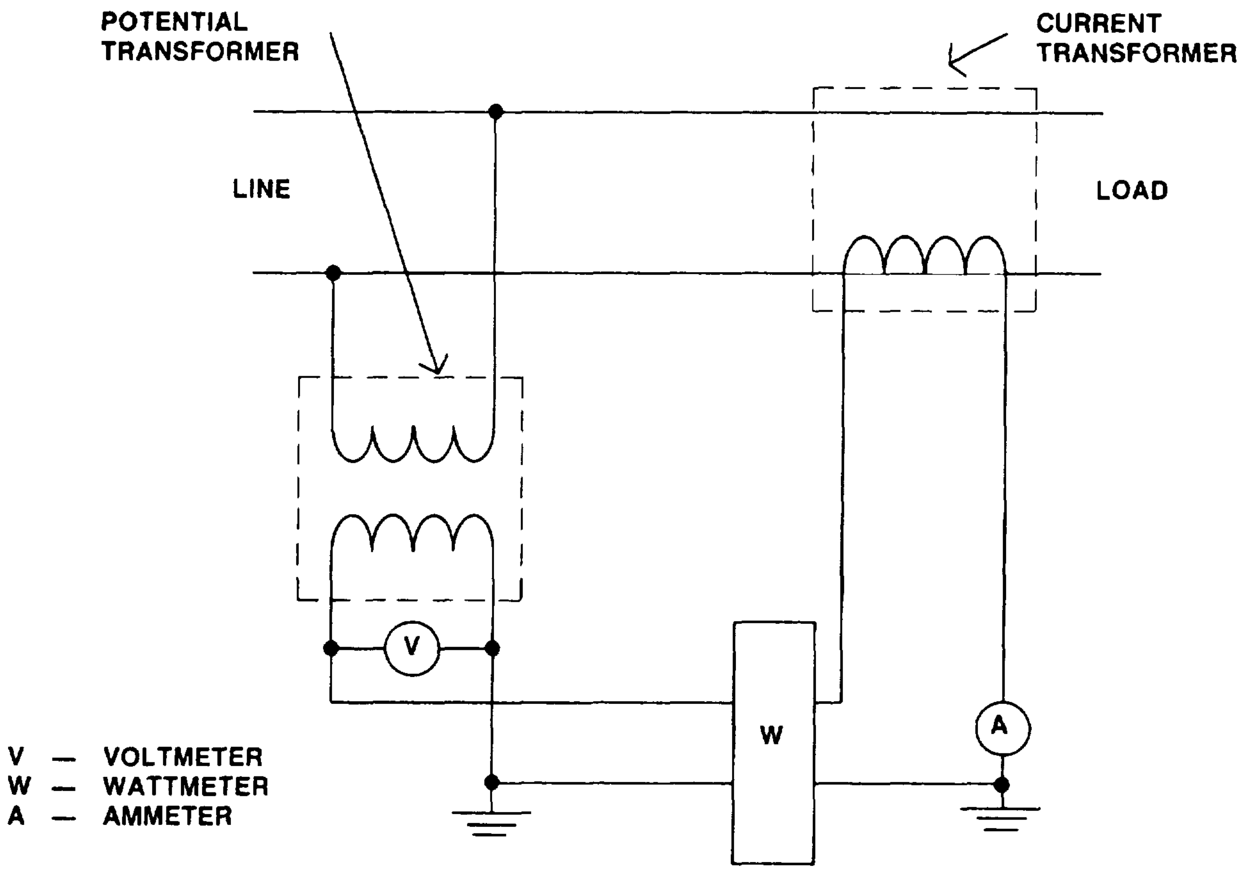


Figure 5-4. Typical Application of Instrument Transformers.

Potential transformers are usually rated at 120 volts in the secondary. The primary of potential transformers is connected either line-to-line or line-to-neutral, and the current that flows through this winding produces a flux in the core. Since the core links the primary and secondary windings, a voltage is induced in the secondary circuit (see figure 5-4). The ratio of primary to secondary voltage is in proportion to the number of turns in the primary and secondary windings. This proportion produces 120 volts at the secondary terminals when rated voltage is applied to the primary.

(2) A current transformer is used to measure current. The primary winding of the current transformer is connected in series with the circuit whose current is to be monitored. Current transformers are usually rated at 5 amps in the secondary circuit. This transformer differs from the potential transformer in that the primary winding is connected in series with the line. The ratio of primary to secondary current is inversely proportional to the ratio of primary to secondary turns. It produces 5 amps in the secondary when rated current is flowing in the primary. WARNING: Never open the secondary of a current transformer while the primary is energized. Life endangering high voltage is present in the secondary. The secondary must be shorted (or grounded) before opening to avoid injury to personnel or damage to equipment.

c. Control Circuits. Switchgear control circuits provide control power for the starting circuit of the prime movers and the closing and tripping of the switchgear circuit breakers. Additionally, the control circuits provide control power to operate the various relays and indicating lights associated with the control circuitry. The control circuits are classified as either AC or DC:

(1) The AC control circuits usually derive their power from the source side of the circuit breaker being controlled. This procedure applies to main incoming line circuit breakers, generator circuit breakers, and feeder circuit breakers (see figure 5-5). Depending on the system voltage, the control power can be taken directly from the main bus or it can be connected through a control power transformer. In systems using a tie breaker, the control power for the tie breaker and the feeder breakers is supplied through a throw-over scheme so control power is available if either side of the tie breaker is energized (see figure 5-6). In applications that require synchronizing circuitry, the running and incoming control buses are usually supplied via the potential transformers. The transformer primaries are connected to both the line side and the load side of the circuit breakers that are used for synchronizing. The transformer secondaries are connected to the proper control bus through contacts on the synchronizing switch, or through contacts on certain auxiliary relays. The synchronizing switch would be used for manual operation and the auxiliary relay would be used when automatic synchronizing is provided.

(2) The DC control circuits derive their power from a battery source consisting of a bank of batteries and a charger that maintains the batteries at the proper charge. The battery bank can be rated at various levels ranging between 24 volts and 125 volts DC. Those circuits that require a source of control power completely independent of the power system are connected to the DC control bus. Examples of these are the prime mover staring circuits and, in some cases, the trip circuits for the circuit breakers when devices, other than the direct-acting overcurrent trip devices, are used. Also, the closing circuits for the circuit breakers are sometimes connected to the DC control bus.

d. Service Practices. Service practices for low voltage switchgear consist of a complete maintenance program that is built around equipment and system records and visual inspections. The program is described in the manufacturer's literature furnished with the components. If a problem develops, the user should perform general troubleshooting procedures. The program includes appropriate analysis of the records.

e. Record Keeping. Equipment and system log sheets are important and necessary functions of record keeping. Log sheet should be specifically developed to suit individual application (e.g., auxiliary use).

f. Operation and Maintenance. Maintenance personnel should refer to the records cited in (1) above for interpretation and comparison of performance data (i.e., log sheets), if abnormal operation is observed. Comparisons of operation should be made under equal or closely similar conditions of load and ambient temperature. Below are some general operation and maintenance hints. (Also, see paragraph 5-8 for troubleshooting data):

(1) Use recognized industrial practices as the general guide for servicing (refer to manufacturer's literature).

(2) Refer to manufacturer's literature for specific information on individual circuit breakers.

(3) For circuit breakers, note the following safety requirements:

(a) Do not work on an energized breaker.

(b) Do not work on any part of a breaker with test couplers engaged. (Test couplers connect the breaker to the control circuit during testing.)

(c) Have only personnel experienced in releasing the spring load in a controlled manner service spring-charged breaker mechanisms.

(d) Make operational tests and checks on a breaker after maintenance, before returning it to service.

(e) Do not work on a spring-charged circuit breaker when it is in the charged position.

(4) Note that switchgear needs exercise. If the circuit breaker remains idle, either open or closed, for 6 months or more, it should be opened and closed several times during the period, preferably under load. If the breaker is operated by a relay or a switch, they also should be operated at this time.

(5) Remember, service for molded-case circuit breakers consists of the following procedures:

(a) Inspect connections for signs of arcing or overheating. Replace faulty connectors and tighten all connections. Clean the connecting surfaces.

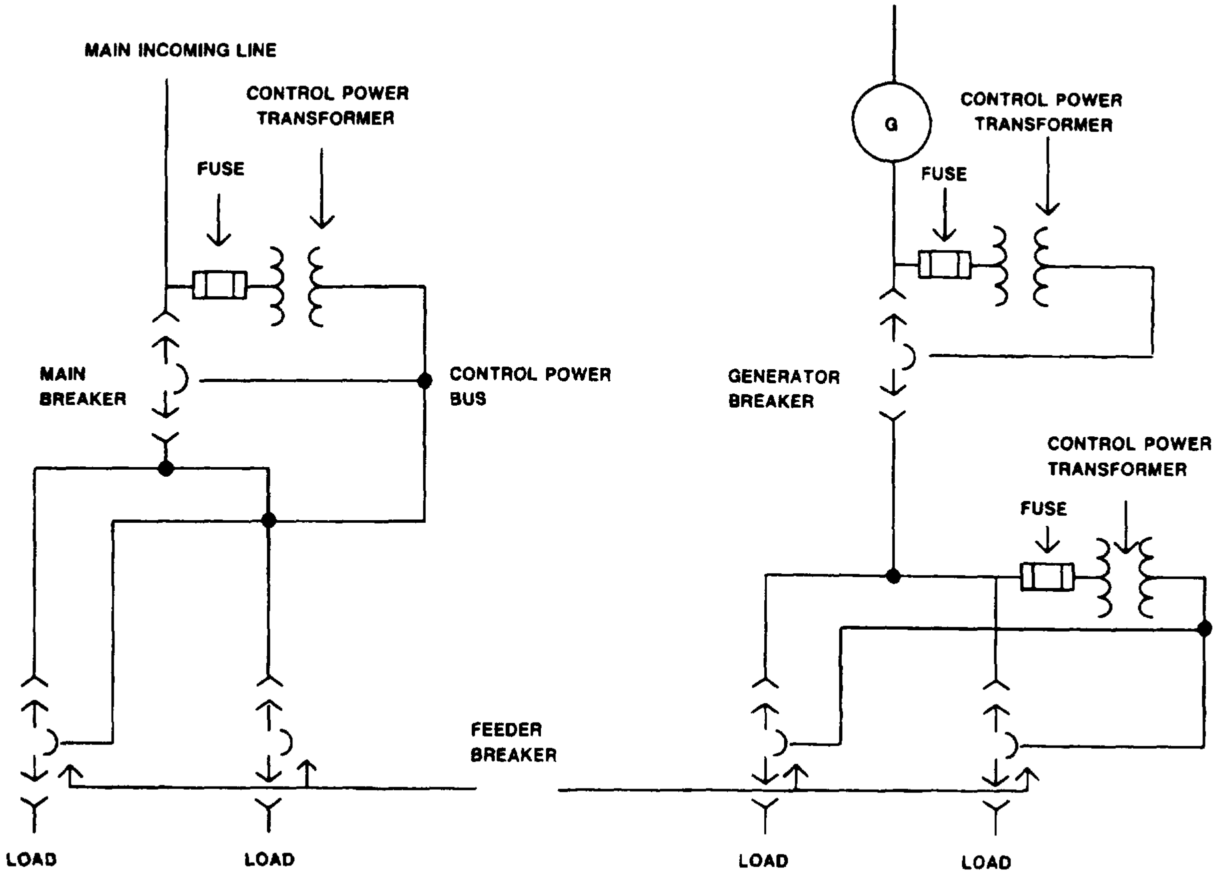


Figure 5-5. AC Control Circuit.

(b) Perform overload tripping tests. Verify automatic opening of breaker. Verify that the magnetic tripping feature is operating. NOTE: Perform circuit breaker overload tripping tests. Proper action of the breaker-tripping components is verified by selecting a percentage of breaker current rating (such as 300%) for testing. This overload is applied separately to each pole of the breaker to determine how it will affect automatic opening of the breaker. Refer to manufacturer's test information.

(c) Turn the breaker on and off several times to verify satisfactory mechanical operation.

(6) Remember, service for air circuit breakers consists of the following procedure (see figure 5-7):

(a) Install the safety pin to restrain the closing spring force. With the pin in place, the contacts will close slowly when the breaker is manually operated.

(b) Inspect connections for signs of arcing or overheating. Replace faulty connectors and tighten all connections. Clean the connecting surfaces.

NOTE: An infrared (IR) survey by in-house technicians is a recommended inspection procedure. The IR survey should be performed when the circuit breaker is under load (and closed) to detect overheating of connections.

(c) Perform general troubleshooting of the breaker if a problem develops. If the trouble cannot be corrected, refer to the manufacturer's literature for specific information on individual breakers. Instrument transformers require no care other than keeping them dry and clean. Refer to manufacturer's literature if specific information is required.

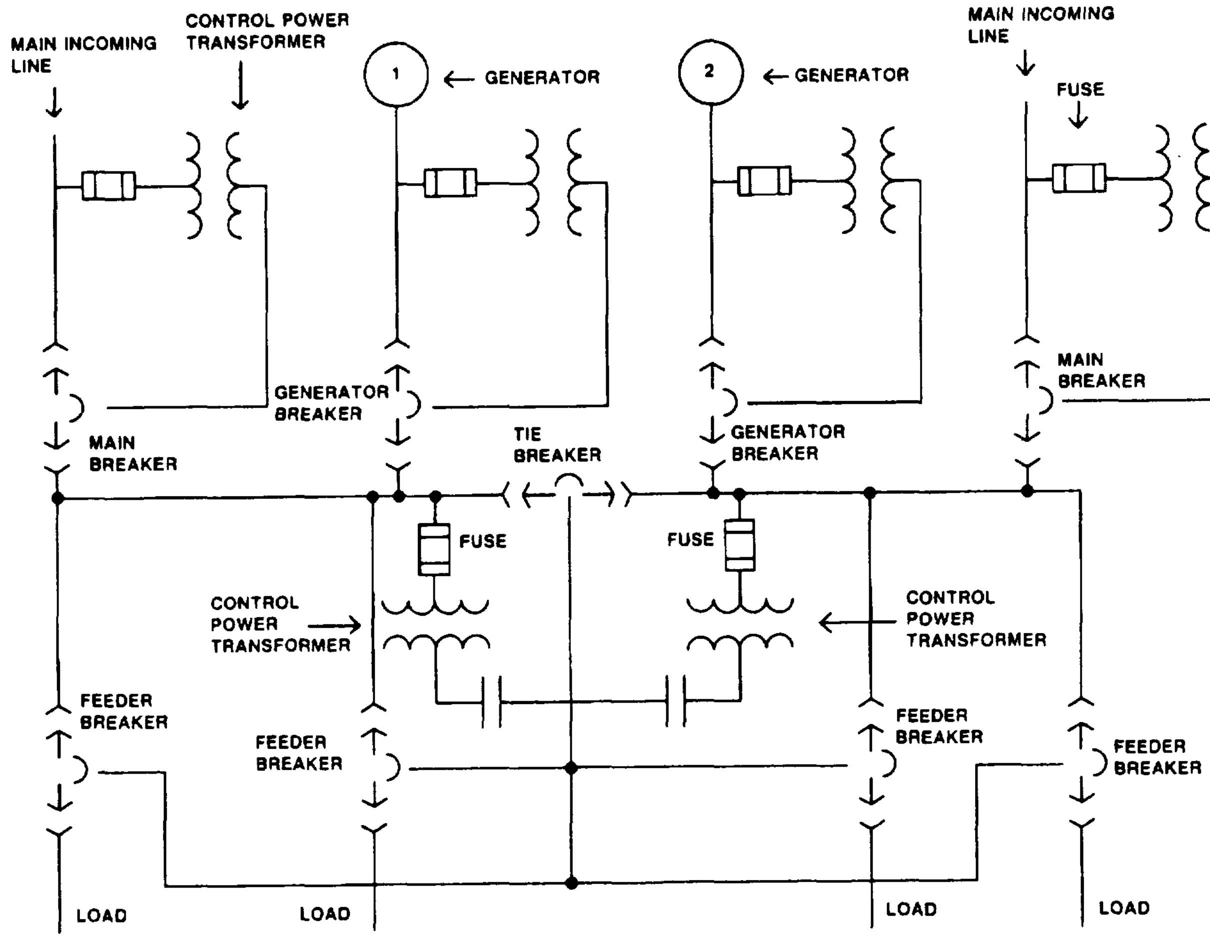


Figure 5-6. AC Control Circuit With Tie Breaker.

5-4. Medium Voltage Equipment:

a. Circuit Breakers. Medium voltage switchgear uses oil, air-blast, or vacuum circuit breakers. Usually, the circuit breakers have draw-out construction to permit removal of an individual breaker from the enclosure for inspection or maintenance without deenergizing the main bus. All of these circuit breakers can quickly interrupt and extinguish the electric arc that occurs between breaker contacts when the contacts are separated:

(1) When the contacts are separated in oil rather than air, the interrupted voltage and current can be greater as compared to separation in air at room temperature:

(a) Arc interruption is better in oil than air because the dielectric strength of oil is much greater than air. Also, the arc generates hydrogen gas from the oil. Hydrogen is superior to air as a cooling medium.

(b) Usually the contacts and the arc are enclosed in a fiber arcing chamber, with exhaust ports on one side, to increase the capacity.

(2) Arc extinction by high pressure air blast is another method of quickly interrupting and extinguishing electric arc. Cross-blast type air circuit breakers are usually used in medium voltage switchgear:

(a) A cross-blast breaker uses an arc chute with one splitter (insulating fin) that functions as an arc barrier.

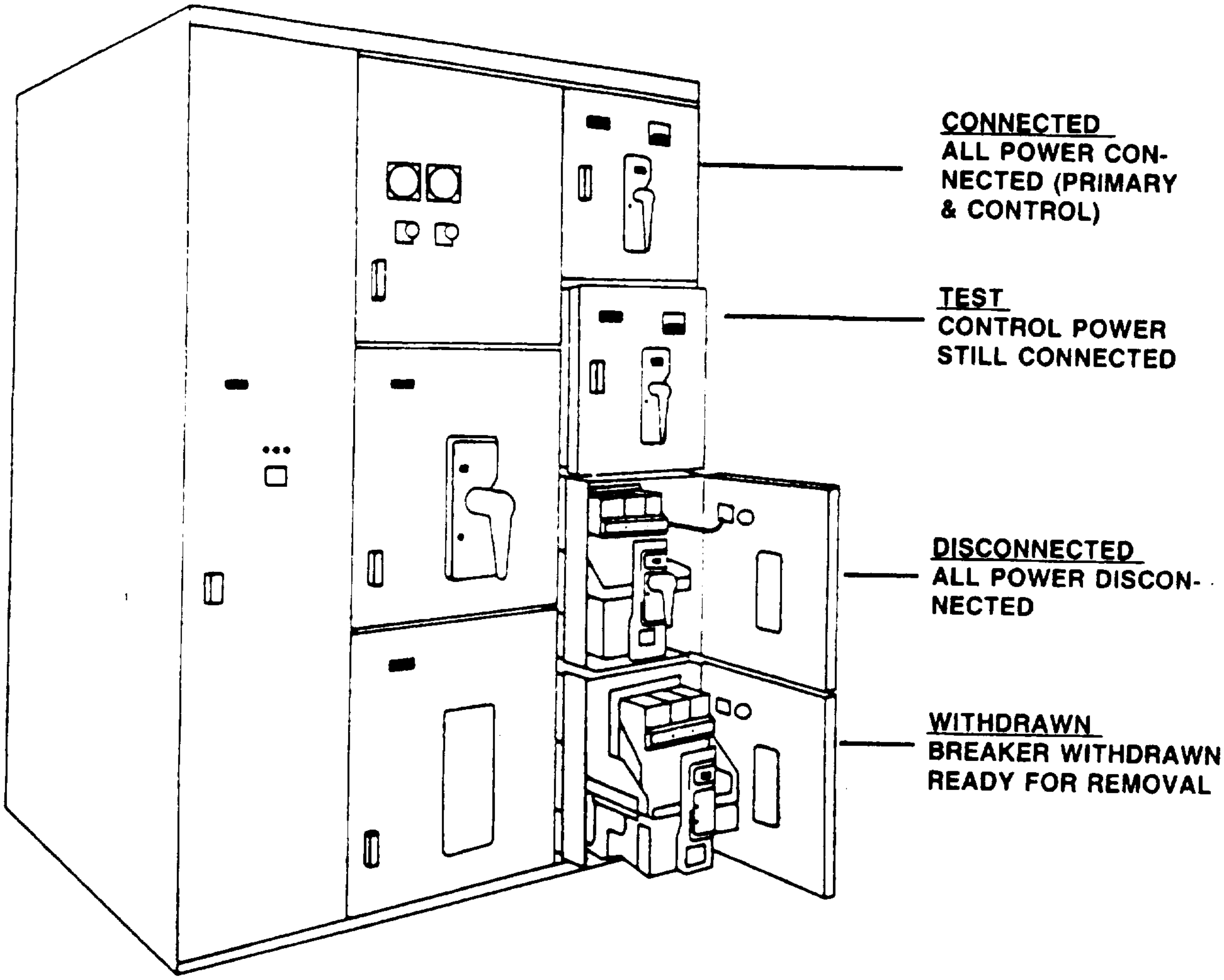


Figure 5-7. Maintenance For Typical Low Voltage Switchgear With Air Circuit Breakers.

(b) The arc is drawn between the upper and lower electrodes. During interruption, a blast of high-pressure air is directed across the arc pushing the arc against the splitter. The arc is broken at current zero.

(3) Vacuum arc circuit breakers are the newest and quickest method of extinguishing an electric arc. This type breaker is oil-less, fireproof and nearly maintenance free. Service life is very long. Arc interruption is very rapid, usually in the first current zero. High dielectric strength of a small vacuum gap contributes to the rapid interruption of the arc. Short contact travel permits the mechanism to part the contacts much faster than for oil breakers. Vacuum breakers are smaller than other breakers and therefore have a stacking advantage.

b. Instrument Transformers. (See paragraph 5-3b.)

c. Control Circuits. Switchgear control circuits for medium voltage systems are functionally similar to those used for low voltage systems. The control circuits are similarly classified as either AC or DC.

d. Service Practices. Service practices for medium voltage switchgear consist of a complete maintenance program that is built around equipment, system records, and visual inspections. The program is described in the manufacturer's literature furnished with the components. If a problem develops, the user should perform general troubleshooting procedures. The program includes appropriate analysis of the records. Equipment and system log sheets are important and necessary functions of record keeping. The log sheets should be specifically developed to suit individual applications (e.g., auxiliary use). Maintenance personnel should then refer to the above records for interpretation and comparison of performance data (e.g., log sheets) if abnormal operation is noted. Comparisons of operation should be made under equal or closely similar conditions of load and ambient temperature. Below are some general operation and maintenance suggestions. See paragraph 5-8 for troubleshooting recommendations:

(1) Use recognized industrial practices as the general guide for servicing (see manufacturer's literature).

(2) Refer to manufacturer's literature for specific information on individual circuit breakers.

(3) Note that general service information for circuit breakers includes the following safety requirements:

(a) Do not work on an energized breaker.

(b) Do not work on any part of a breaker with the test couplers engaged. (Test couplers connect the breaker to the control circuit during testing).

(c) Remember, maintenance closing devices for switchgear are not suitable for closing in on a live system. Speed in closing is as important as speed for opening. A wrench or other maintenance tool is not fast enough.

(d) Before working on the switchgear enclosure, remove all draw-out devices, such as circuit breakers and instrument transformers.

(e) Do not lay tools down on the equipment while working on it. It is too easy to forget a tool when closing an enclosure.

(4) Note that switchgear needs exercise. Exercise switchgear per paragraph 5-3F(4).

(5) For service circuit breakers using insulating liquid, elevate the breaker on an inspection rack and untank it to expose the contacts. (NOTE: The insulating liquid usually used in circuit breakers is mineral oil. Equipment using liquids containing polychlorinated bipheynls (PCB) may still be in use. Since PCBs are carcinogenic and not biodegradable, their continued use is prohibited. Silicone insulating liquid can be used as substitute for PCBs when authorized by the Base Civil Engineer.) **WARNING:** Special handling is required if PCBs are used in any equipment. Refer to 40-CFR-761 for PCB details. PCBs are powerful solvents. Handling and disposal information and special gloves are required:

(a) Check condition, alignment, and adjustment of contacts. Verify that contact surfaces bear with firm, even pressure.

(b) Wipe clean all parts normally immersed in liquid, remove traces of carbon that remain after the liquid has drained. Inspect insulating parts for cracks, or other damage requiring replacement.

(c) Test the dielectric strength of the liquid, using a 0.1-inch gap with 1.1-inch diameter disk terminals. If strength is less than 22 kV, remove and filter or replace with new liquid having a dielectric strength of at least 26 kV. Filter the liquid when inspection shows excessive carbon, even if its dielectric strength is satisfactory, because the carbon will deposit on insulating surfaces decreasing the insulation strength. (NOTE: Liquid samples should be taken in a large-mouthed glass bottle that has been cleaned and dried with benzene. Use a cork stopper with this bottle. Draw test samples from the bottom of the tank after the liquid has settled. The samples should be from the tank proper and not from the valve or drain pipe.)

(d) Periodically remove the liquid from the the tank and wipe the inside of the tank, the tank linings, and the barriers to remove carbon.

(e) Inspect breaker and operating mechanisms for loose hardware and missing or broken cotter pins, retaining rings, etc.

(f) Check adjustments and readjust when necessary (see the manufacturer's instruction book).

(g) Clean operating mechanism and lubricate as for air-magnetic-type breaders (see manufacturer's instruction book).

(h) Before replacing the tank, operate breaker slowly with maintenance closing device to verify there is no friction or binding to prevent or slow down its operation; then, check the electrical operation.

(NOTE: Avoid operating the breaker any more than is necessary when testing it without liquid in the tank. It is designed to operate in liquid and mechanical damage can result from excessive operation without it.)

(i) When replacing the tank, fill to the correct level with fluid, be sure the gaskets are undamaged and the tank nuts and flange nuts on gauges and valves are tightened properly to prevent leakage.

(6) Service air-blast-type circuit breakers. Circuit breakers should be serviced (tested, exercised, and calibrated) at intervals not to exceed 2 years. Withdraw the breaker from its housing for maintenance.

(a) Wipe insulating parts, including bushings and the inside of box barriers, clean off smoke and dust. Repair moderate damage to bushing insulation by sanding smooth and refinishing with a clear insulating varnish.

(b) Inspect alignment and condition of movable and stationary contacts. Check their adjustment as described in the manufacturer's instruction book.

(NOTE: To check alignment, close the breaker with pieces of tissue and carbon paper between the contacts and examine the impression. Do not file butt-type contacts. Contacts which have been roughened in service may carry current as well as smooth contacts. Remove large projections or "bubbles", caused by unusual arcing, by filing. When filing to touch up, keep contacts in their original design - that is, if the contact is a line type, keep the area of contact linear, and if ball or point-type, keep the ball or points shaped out.)

(c) Check arc chutes for damage, replace damaged parts. When arc chutes are removed, blow out dust and loose particles.

(d) Clean silver-plated breaker primary disconnecting devices with alcohol or silver polish (see manufacturer's instruction book). Lubricate devices by applying a thin film of approved grease.

(e) Inspect breaker operating mechanism for loose hardware and missing or broken cotter pins, retaining rings, etc. Examine cam, latch and roller surfaces for damage or excessive wear.

(f) Clean and relubricate operating mechanism (see manufacturer's instruction book). Lubricate pins and bearings not disassembled. Lubricate the ground or polished surfaces of cams, rollers, latches and props, and of pins and bearings that are removed for cleaning.

(g) Check breaker operating mechanism adjustments and readjust as described in the manufacturer's instruction book. If adjustments cannot be made within specified tolerances, excessive wear and need for a complete overhaul is indicated.

(h) Check control device for freedom of operation. Replace contacts when badly worn or burned.

(i) Inspect breaker control wiring for tightness of connections.

(j) After the breaker has been serviced, operate it slowly with closing device to check absence of binding or friction and check that contacts move to the fully-opened and fully-closed positions. Check electrical operation using either the test cabinet or test couplers.

(7) Service vacuum circuit breakers. This breaker has primary contacts enclosed in vacuum containers (bottles), and direct inspection or replacement is not possible. The operating mechanism is similar to that used in other medium voltage circuit breakers, and the general outlines are the same for maintenance work. The enclosures are similar. The stationary contact is solidly-mounted; the moving contact is mounted in the enclosure with a bellows seal:

(a) Contact erosion is measured by the change in external shaft positions after a period of use. Consult the manufacturer's instruction book. WARNING: High voltage applied during testing may produce X-ray emission.

(b) Condition of the vacuum is checked by a hi-pot test applied every maintenance period. Consult manufacturer's instruction book for test procedures. The contacts in a vacuum circuit breaker cannot be cleaned, repaired or adjusted. The vacuum bottle is usually replaced if the test indicates a fault.

5-5. Transfer Switches:

a. General Operating Description. During actual or threatened power failure, transfer switches are actuated to transfer critical electrical load circuits from the normal source of power to the auxiliary (emergency) power source. When normal power is restored, the transfer switches either automatically retransfer their load circuits to the normal supply or must be transferred manually. Voltage and frequency-sensing relays are provided to monitor each phase of the normal supply. The relays initiate load transfer when there is a change in voltage or frequency in any phase outside of predetermined limits. Additionally, the relays initiate retransfer of the load to the normal source as soon as voltage is restored in all the phases beyond the predetermined pickup value of the relay. A transfer switch obtains its operating current from the source to which the load is being transferred.

b. Types of Transfer Switches. Transfer switches can either electrically operated or manually operated:

(1) An electrically operated switch obtains its operating current from the source to which the load is being transferred. But some systems use a separate voltage supply. Electrically operated switches consists of three functional elements. First are the main contacts to connect and disconnect the load to and from the source of power. Second are the sensing circuits to constantly monitor the condition of the power source and provide the information necessary for switch and related circuit operation. Then there is the transfer mechanism to make the transfer from source to source.

(a) Circuit breaker transfer switches are mechanically held devices using two circuit breakers. Usually the breaker handles are operated by a transfer mechanism which provides double-throw switching action (connecting one circuit terminal to either of two others). The transfer mechanism is operated electrically by a unidirectional gear motor (motor and integral speed-reducing gearbox) or by dual motor operators with all parts in positive contact at all times. These switches can also be operated manually and have provisions for disengaging the generator when necessary. Some transfer switches have a neutral position. But, the switch is mechanically and electrically interlocked so that a neutral position is not possible during electrical operation. Also, load circuits cannot be connected by the switch to normal and emergency sources simultaneously (whether the switch is operated electrically or manually).

(b) Contactor-type transfer switches have mechanically or electrically held contractors with a common load bus. The switches are mechanically and electrically interlocked so that a neutral position is not possible under normal electrical operation. Additionally, the load circuits cannot be connected to normal and emergency sources simultaneously.

(2) Manually operated transfer switches are mechanically held devices using two circuit breakers operated by a handle. All parts are in positive contact at all times. The switch is mechanically interlocked; it it impossible for the load circuits to be connected to normal and emergency sources simultaneously. Manually operated transfer switches are available with single or dual operating handles. A common operating mechanism across the two breakers mechanically connects and operates the breakers.

c. Transfer Switch Operating Modes. Transfer switches have two operating modes, automatic and manual:

(1) Automatic Transfer Switches. Automatic transfer switches have voltage-sensing relays for each phase. The sensing relays are connected to the normal power bus behind the protecting devices. The transfer switch is connected to the normal power source under normal conditions. When the sensing relays detect a sustained drop in the voltage of the normal power source, the relays will automatically start the auxiliary generator.
(NOTE: The transfer switch operates upon a sustained drop in voltage in any phase of the normal source (approximately a 30-percent drop and a delay of about 2 seconds) to start the auxiliary generator.) When voltage and frequency of the auxiliary generator are at rated values, and the normal power source is still below normal, the automatic control will transfer the load to the emergency source. Upon return to normal power to within 10 percent of rated voltage on all phases (and after a preset time delay), the switch automatically transfers the load to the normal source. Usually the auxiliary generator will run unloaded for about 5 minutes after the transfer, before it shuts down. The controls automatically reset for the next emergency start. Usually, the controls of a power transfer system have a test switch. This permits simulation of failure of the normal power source and test of transfer switch operation. Power transfer indicators are provided in most automatic transfer systems to indicate the currently used power source. Usually, an amber light (marked EMERGENCY POWER) shows that the system is on emergency power when illuminated. A white light (marked NORMAL POWER) shows that the system is receiving power from its normal source when illuminated. Automatic transfer panels may contain all or some of the following:

(a) Utility Power Monitor. This is normally a set of relays (usually one for each phase), mechanical or solid state, that remain energized while the utility power is applied. This keeps the contacts open so the generator will not start. If any one phase of utility power fails, the relay for that phase deenergizes allowing the contacts to close which starts the generator.

(b) Under-Over Voltage Sensing - Utility. Some ATP's have under- or over-voltage relays, or both. These relays constantly monitor the utility power and will cause the generator to start and assume the load if the utility power should drop below or rise above the preset limits.

(c) Under-Over Voltage Sensing - Generator. Like the under-over voltage relays for utility power, some ATP's also have a similar set of switches to monitor the generator output power. They will cause the load to be switched back to utility power if the generator malfunctions for some reason and the generator voltage drops below or rises above the preset limits.

(d) Circuit Breaker or Main Contacts. For the ATP to transfer power, circuit breakers or a set of main contacts are employed to connect and disconnect utility and generator power. Some of the larger (higher amperage) ATP's will have a set of arcing contacts. These arcing contacts close first and open last receiving the brunt of the arcing caused when an energized circuit is opened or closed. This saves wear and tear on the main contacts and lengthens their life.

(e) Purpose of Timers. Most ATPs have timers to signal when to transfer back to utility power and shut down the generator. The transfer timer should be set to maintain the generator on line until utility power has stabilized (about 5 to 10 minutes). If another utility power outage occurs during timeout of the timer, the timer will be reset to be ready to start timing again. The generator remains connected to the load until the timer times out completely. Once the timer times out completely, a signal is sent to a relay which energizes a motor or solenoid to change the position of the circuit breakers or main contacts. This reconnects the load to the utility power and disconnects the load from generator power. Once the load has been removed from the generator, the shutdown timer starts timing out. The timer should be set at 5 to 10 minutes to allow the generator to cool down prior to shut down. When this timer times out, it shuts the generator down and the ATP returns to normal monitoring mode.

(f) Battery Charger. Some ATPs have a battery charging circuit built in to maintain a trickle charge on the generator starting batteries.

(2) Manual Transfer Switches. In non-automatic operation, an operator is needed to manually transfer to or from the emergency power source. The operator can usually make the transfer without opening an enclosure. The transfer is usually based on instrument indications and is made by placing the transfer switch in the required emergency or normal position.

(a) Power transfer indicators are provided for the operator. An amber light (EMERGENCY POWER) shows that the system is on emergency power when illuminated. A White light (NORMAL POWER) shows that the system is receiving power from its normal source when illuminated.

(b) The operator is usually provided with an override switch which bypasses the automatic transfer controls. This feature permits indefinite connection of the emergency power source regardless of the condition of the normal power source.

d. Service Practices. Service practices for transfer switches consist of a complete maintenance program that is built around records and visual inspections. The program includes approximate analysis of these records. You should perform inspections and maintenance according to the manufacturer's instructions or technical orders. Use AF Form 3510 to record maintenance of automatic transfer switches. Perform general troubleshooting if a problem develops. Refer to the manufacturer's literature for specific information. Usually, all control elements are repairable or replaceable from the front of the switch without removing it from its enclosure or removing the main power cables. The ATPs should have a bypass switch to prevent a power interruption to the load while performing maintenance.

5-6. Description of Voltage Regulators:

a. General Purpose. A voltage regulator maintains the terminal voltage of an alternator or generator at a predetermined value. Voltage of the generated current is controlled by regulating the strength of the electromagnetic field produced in the alternator exciter. A voltage regulator overcomes voltage drop within the alternator by changing field excitation automatically as it varies with the load. There are 3 basic types of voltage regulators, electromechanical, static voltage, and static exciter:

(1) Electromechanical voltage regulators usually have a servo-control system with three principal elements:

(a) A voltage-sensing device with a voltage regulating relay. The device monitors the output voltage and sends a signal to the control circuits.

(b) An amplifying section (with or without time delay) which transmits the signal.

(c) A motor drive which responds to the signal by moving a tap changer or induction regulator in a direction to correct the voltage.

(2) A static voltage regulator usually has a static voltage sensor instead of a voltage-regulating relay:

(a) The voltage sensor output is applied to a solid-state or magnetic amplifier and a discriminator circuit. Signals are thereby provided for changing alternator output to raise or lower the voltage as required.

(b) The voltage zone between initiation of raising or lowering control action is called the voltage band. The band must be more than the minimum correction obtainable through the regulator or regulator hunting will occur.

(c) These regulators have accessories which include either thermal delay relays or a resistance-capacitance network to provide time delay for load trend correction. Time delay retards the signal until accumulated time outside the voltage limit, less accumulated time inside the voltage limit, exceeds the time delay setting.

(3) A static exciter regulator supplies the alternator field with DC voltage obtained from a three-phase, full wave bridge rectifier:

(a) A small part of the alternator's output goes to the regulator which meters the rectified DC voltage back to the exciter's field windings. The rectified DC voltage produces a 360 cycle ripple. If the ripple gets into the field windings, an electrical discharge from windings to shaft can occur. The discharge is caused because copper in the field windings and the metal shaft act like the plates in a capacitor. This action may result in shaft and bearing pitting and eventual bearing failure. A filter can be used to reduce ripple. A static exciter is a manufactured subassembly (assembled and wired at the manufacturer's plant), usually using one or more silicon rectifiers to convert AC voltage to DC. The subassembly usually includes a regulator and a filter. Refer to the manufacturer's literature for test and adjustment details.

(b) Accessories include either thermal delay relays or a resistance-capacitance network to provide time delay for load trend correction (see a(2)(c) above). A suppressor circuit (or ripple filter) is usually provided to bypass ripple to ground before it gets to the generator field.

b. Service Practice. Service practice for voltage regulators consists of a complete maintenance program that is built around records and visual inspections. The program includes appropriate analysis of these records. Equipment and system log sheets are important and necessary functions of record keeping. The log sheets should be specifically developed to suit auxiliary use. Use recognized industrial practices as the general guide for servicing. Refer to manufacturer's literature for specific information on individual voltage regulators. Troubleshooting procedures include the following:

(1) Check voltage for compliance with manufacturer's recommendations.

(2) Check for loose or insecure electrical connections.

(3) Check for correct setting, refer to manufacturer's literature.

(4) Check for unregulated voltage, refer to manufacturer's literature.

(5) Check the enclosure (should be weather tight).

(6) Check motor for proper operation and loose connections. Clean and lubricate as required. Refer to manufacturer's literature for details.

(7) Perform the procedure in the troubleshooting table.

5–7. Automatic Control Relays:

a. Purpose and Description. Relays are used with the automatic controls for auxiliary power generating systems. A relay responds to electrical or other operating parameters and causes an abrupt change in the control circuits when the measured values change. A relay consists of a sensing element and a control element with contacts. Relays used in switchgear include general purpose and protective types:

(1) General purpose relays function as part of regulation and verification devices throughout the system, including the prime mover:

(a) On industrial general purpose relays, portions of electrical systems are energized or deenergized (under normal or abnormal conditions) by relays. Since the relays are usually used with subsystem or equipment circuit breakers, the overall operating plan must be electrically coordinated. Coordination is usually accomplished by designing the system circuitry to selectively initiate the opening or closing of the relays. Relays constantly monitor the power system.

(b) Overload relays provide overload protection for the auxiliary motors. When an overload condition occurs in any of the three phases in which heaters are inserted, it will cause the relay to trip.

(c) If the system includes relays for time delay purposes, they will most likely be the solid-state type. Some pneumatic relays may still be in use.

(d) Pneumatic relays utilize a bellows-type arrangement to provide the time delay. They can be adjusted for time periods of less than a second to several minutes.

(e) Solid-state relays derive their time delay from a combination of several electronic components. They are also adjustable between fractions of a second to several minutes.

(f) Voltage-sensitive relays are used to sense an increase or a decrease in a specific voltage. It provides an output signal when the voltages pass the preset level.

(2) Protective relays detect or indicate abnormal electrical conditions. The operation of circuit breakers (or other protective devices) is initiated by these relays. In this sense, breakers are the brawn and relays are the brains of an electrical system. Some of the electrical hazards protected against are short circuit overcurrent, over or under voltage, and phase or frequency irregularities. To be successful, power production technicians must understand the functions, operating principles and basic testing procedures of protective relays. AFR 91-12 lists the National Electrical Manufacturer's Association (NEMA) relay device numbers and their definition and functions. Protective relays include the following basic types:

(a) Overcurrent. Overcurrent relays function when current flow exceeds the normal or desired value. Induction disk relays (with time delay) and cup-type relays (without time delay) are usually used.

(b) Overvoltage. Overvoltage relays function when voltage exceeds the normal or desired value. Induction disk relays (with time delay) and cup-type relays (without time delay) are usually used.

(c) Undervoltage. Undervoltage relays function when voltage is less than normal or desired value. Induction disk relays (with time delay) may be used in a balanced position between minimum and maximum voltages.

(d) Reverse Power. Reverse power relays function when power flows in the reverse direction from normal or desired. Reverse power relays can signal a breaker to isolate a generator from the distribution system and protect the engine from motoring damage.

(e) Underfrequency. Underfrequency relays function whenever the desired frequency becomes less than normal value. This condition is usually the result of reduced prime mover speed and may be caused by the prime mover governor or excessive electrical load.

(f) Differential. Differential relays function due to the difference between 2 quantities of the same kind (such as, 2 currents or 2 voltages). Differential relays, usually used to detect generator stator winding electrical failures, respond to percentage differences in current on each side of a generator. Current or voltage transformers used in differential network should be in matched sets.

(g) Current Balance. A current balance relay circuit monitors 2 or more current circuits and provides an output if the difference between any 2 exceeds the setting of the relay. The relay senses the difference between the current and one generator and the current of another generator (or the average of all other generators). Relay output may be used to trip bus tie contractors and split a parallel system to remove an unbalance.

(h) Ground Protection. Ground fault protection is usually provided by a ground sensor relay which measures the sum of currents in the lines to the load (in a three-phase system). Another relay is sometimes added to the transformer neutral-to-ground connection for backup.

(i) Directional overcurrent. These relays are sometimes used to protect against feeding fault current into the commercial system when parallel with the utility. Reverse power relays are not fast enough to prevent this.

b. Generator Protection. Generators are subject to a number of failures or abnormal conditions. These are listed below. Figures 5-8 through 5-11 show minimum and recommended relaying schemes for generator protection:

(1) Faults in windings.
(2) Ground faults.
(3) Overloads.
(4) Overspeed.
(5) Loss of excitation.
(6) Generator motoring.
(7) Single phasing.
(8) Out of synchronism (out of step).

c. Relay Testing. Periodic testing of relays is considered preventive maintenance. The preventive maintenance program is built around records and visual inspections, and includes analysis of the records. When testing relays, record the ambient operating temperature. Relays should be tested every 2 years. Most relays have draw-out construction so they can easily be separated from their enclosure. Therefore, disconnection for test or repair is usually not required. Follow the general procedures listed be-

PHASE CT'S SHOULD BE RATED APPROXIMATELY 150% OF FULL LOAD.

NEUTRAL CT SHOULD BE RATED APPROXIMATELY ONE HALF OF THE MAXIMUM GROUND FAULT CURRENT.

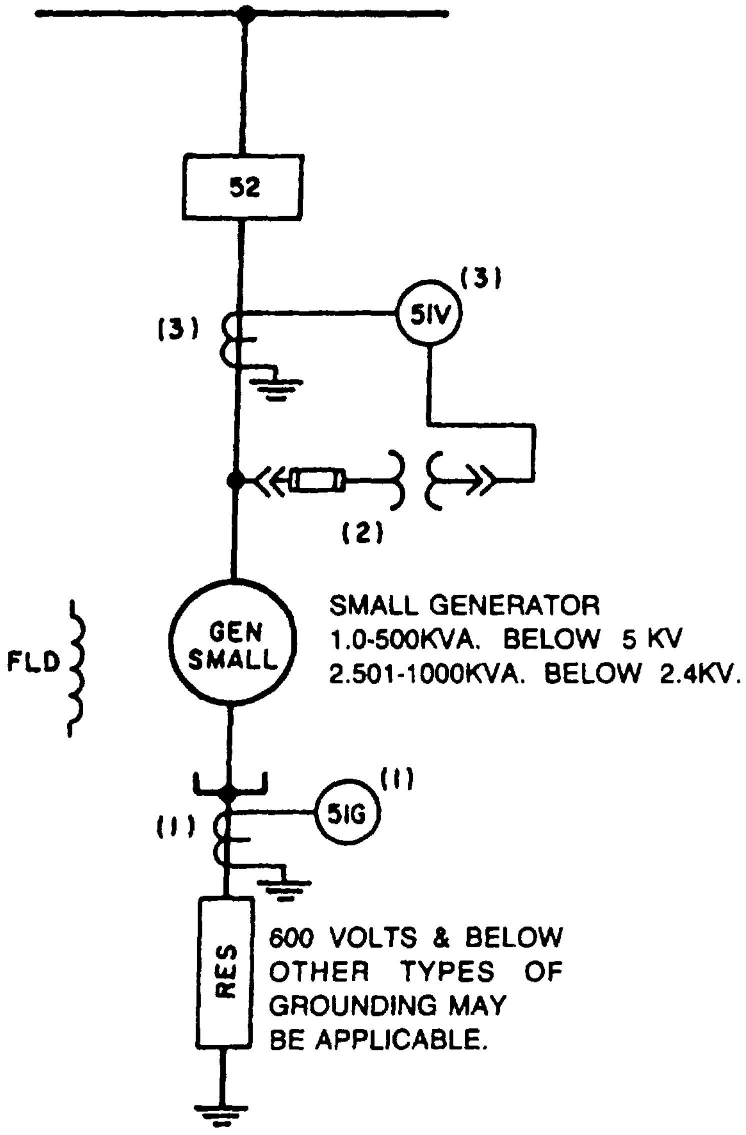


Figure 5-8. Minimum Protection for Small Generators.

low. Troubleshooting hints are listed in paragraph 5-8:

(1) Inspect the relay cover before testing. Remove dust and other foreign matter to prevent it from entering the relay. Record the inspection results.

(2) Check relay for "flag" indication. Also, check cover glass for fogging. If fogging is excessive, investigate the cause.

(3) Check all connections for proper tightness. If necessary, tighten to proper torque value.

(4) Check armature and connect gaps, compare with previous measurements. Adjust gaps if necessary (refer to manufacturer's instructions).

(5) Check contacts for burned or eroded condition. Burnish if necessary (refer to manufacturer's instructions).

(6) Verify proper contact operation. Open or close contacts to observe proper trip or reclose action (refer to manufacturer's instructions).

(7) Apply current or voltage to verify that pickup is within manufacturer's tolerances.

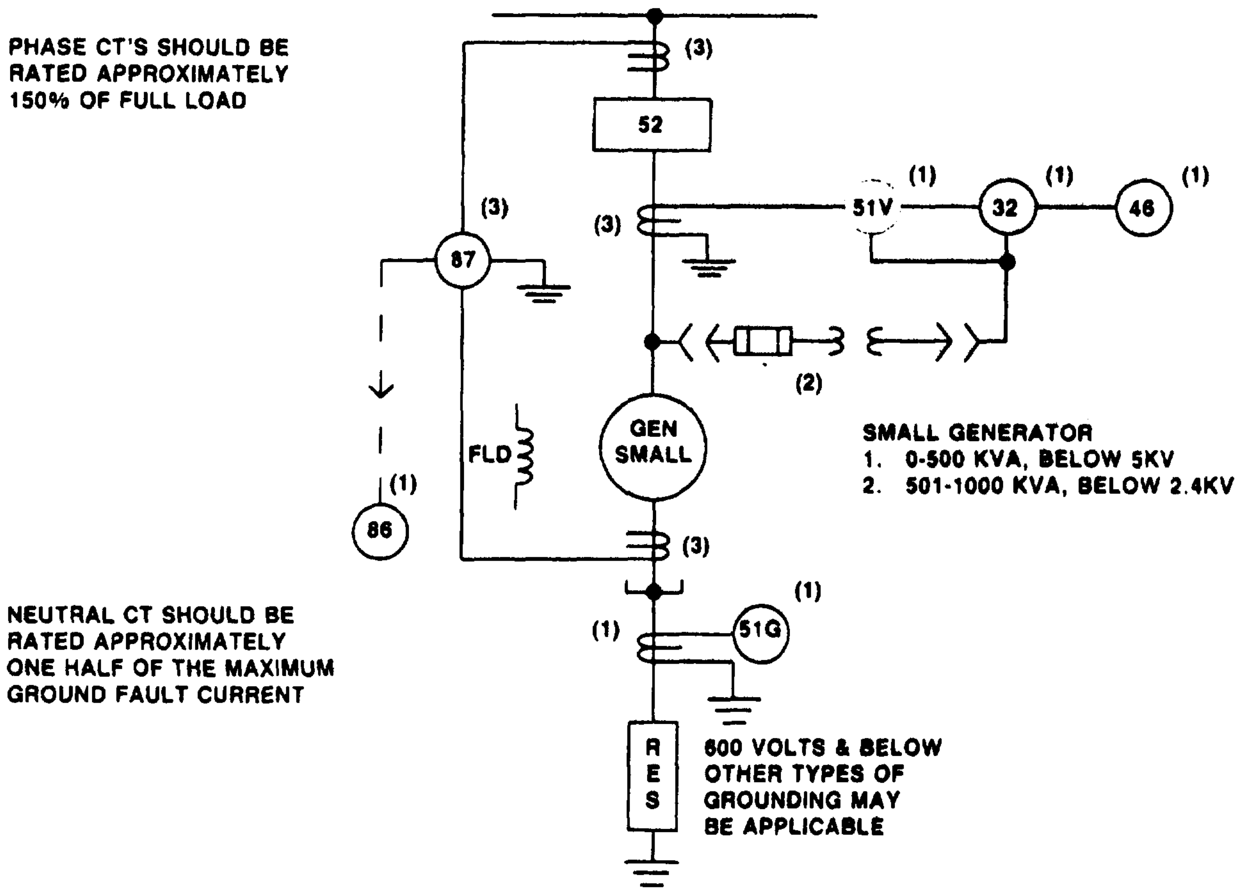


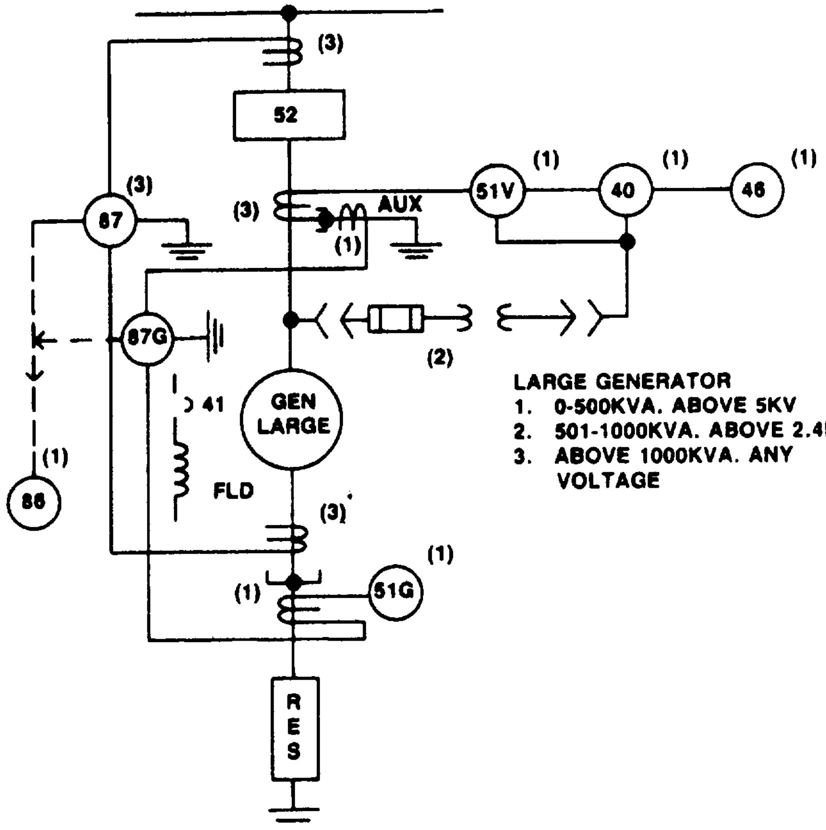
Figure 5-9. Recommended Protection for Small Generators.

(8) Reduce the current until the relay drops out or fully resets, verify that there is no binding during operation (refer to manufacturers's instructions).

(9) Verify that related devices (such as capacitors) are functioning properly (refer to manufacturer's instructions).

(10) Note that differential relays are usually very sensitive devices that use polarized sensing circuitry. Repeat the pickup test. Use the second test for comparison with previous and future test data (refer to manufacturer's instructions).

5-8. Troubleshooting Guidance. Tables 5-1 through 5-3 provide guidance to locating and repairing various defective equipment components. But when available, you should always refer to the manufacturer's literature for specific information on a particular piece of equipment. Supervisors should make every effort to obtain this literature.



LARGE GENERATOR
1. 0-500KVA. ABOVE 5KV
2. 501-1000KVA. ABOVE 2.4KV
3. ABOVE 1000KVA. ANY VOLTAGE

NOTES:
1. NEUTRAL CT'S SHOULD BE RATED APPROXIMATELY ONE HALF OF THE MAXIMUM GROUND FAULT CURRENT.
2. PHASE CT'S SHOULD BE RATED APPROXIMATELY 150% OF FULL LOAD.
3. DEVICE 40 MAY BE OMITTED IF THERE IS NO OTHER SOURCE.

Figure 5-10. Minimum Protection for Large Generators.

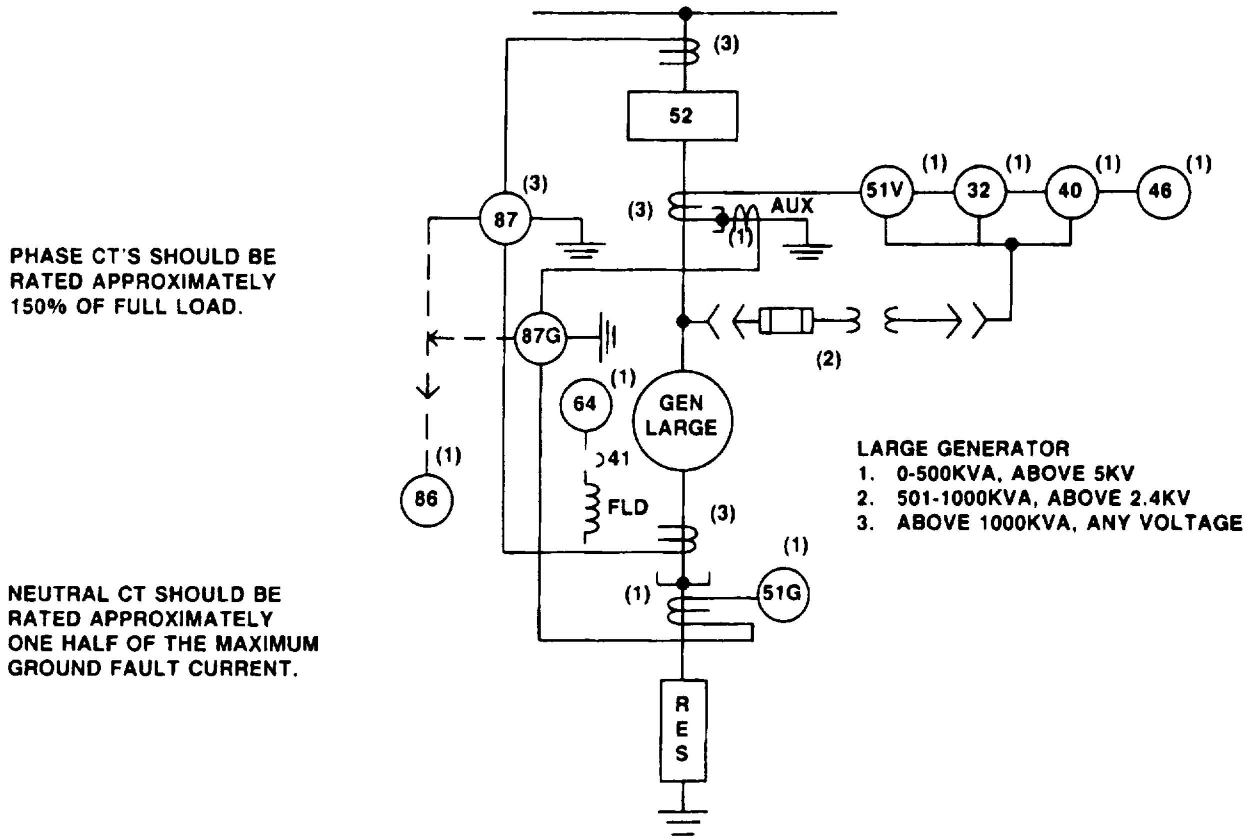


Figure 5-11. Recommended Protection for Large Generators.

Table 5-1. Low Voltage Circuit Breaker Troubleshooting Guide.

Problem	Possible Cause	Remedy
1. Overheating.	a. Contacts not aligned.	Adjust contacts.
	b. Contacts dirty, greasy or coated with dark film.	Clean contacts.
	c. Contacts badly burned or pitted.	Replace contacts.
	d. Current-carrying surfaces dirty.	Clean surfaces of current-carrying parts.
	e. Corrosive atmosphere.	Relocate or provide adequate enclosure.
	f. Insufficient bus or cable capacity.	Increase capacity of bus or cable.

Problem	Possible Cause	Remedy
	g. Bolts and nuts at terminal connections not tight.	Tighten, but do not exceed elastic limit of bolts or fittings.
	h. Current in excess of breaker rating.	Check breaker applications or modify circuit by decreasing load.
	i. Inductive heating.	Correct bus or cable arrangement.
2. Failure to trip.	a. Travel of tripping device does not provide release of tripping latch.	Adjust or replace tripping device.
	b. Worn or damaged trip unit parts.	Replace trip unit.
	c. Mechanical binding in overcurrent trip device.	Correct binding condition or replace overcurrent trip device.
	d. Electrical connectors for power sensor loose or open.	Tighten, correct, or replace electrical connectors.
	e. Loose or broken power sensor coil tap connections.	Tighten or reconnect tap connections.
3. False tripping.	a. Overcurrent pick-up too low.	Check application of overcurrent trip device.
	b. Overcurrent time setting too short.	Check application of overcurrent trip device.
	c. Mechancial binding in overcurrent trip device.	Correct binding condition or replace overcurrent trip device.
	d. Captive thumbscrew on power sensor loose. Fail safe circuitry reverts characteristics to minimum setting and maximum delay.	Adjust power sensor. Tighten thumbscrew on desired setting.
	e. Ground sensor coil improperly connected.	Check polarity of connections to coil. Check continuity of shield and conductors connecting the external ground sensor coil.
4. Failure to Close and Latch.	a. Binding in attachments preventing resetting of latch.	Realign and adjust attachments.
	b. Latch out of adjustment.	Adjust latch.
	c. Latch return spring too weak or broken.	Replace spring.

Problem	Possible Cause	Remedy
	d. Hardened or gummy lubricant.	Clean bearing and latch surfaces.
	e. Safety pin left in push rod.	Remove safety pin.
	f. Motor burned out.	Replace motor.
	g. Faulty control circuit component.	Replace or adjust faulty device.
5. Burned Main Contacts.	a. Improper contact sequence (main contacts not sufficiently parted when arcing contacts part).	Increase arcing contact wipe. Adjust contact opening sequence. See manufacturer's literature for contact maintenance and adjustment information. Also see 5-3a(1)(g).
	b. Short-circuit current level above interrupt-rating of breaker.	Requires system study and possible replacement with breaker having adequate interrupting capacity.
	c. Loss of contact wipe or pressure.	Replace stationary contact springs and dress up or replace contacts.

Table 5-2. Switchgear Equipment Troubleshooting Guide.

Problem	Possible Cause	Remedy
1. Watthour Meter Inaccurate.	a. Meter may be dirty or damaged.	Install new meter. Return faulty meter to repair deport for repair and calibration.
	b. Faulty wiring or connections.	Inspect and repair as necessary.
2. Watthour Meter Fails to Register.	a. Blown potential transformer fuse, broken wires or other fault in connections.	Renew blown fuses. Check wiring and repair as required.
	b. Wedge or block accidentally left at time of test or inspection.	Remove wedge or block. Verify that meter is in good operating condition.
3. Damaged Control, Instrument Transfer Switch, or Test Blocks.	a. Burned or pitted contacts.	Dress or clean burned contacts or replace with new contacts if necessary.
4. Relays Failing to trip Breakers.	a. Improper setting.	Adjust setting to correspond with circuit conditions. See manufacturer's instructions.

Problem	Possible Cause	Remedy
	b. Dirty, corroded or tarnished contacts.	Clean contacts with appropriate contact cleaning tool. Don't use emery cloth or sandpaper.
	c. Contacts improperly adjusted.	Adjust contacts. Verify proper wipe action.
	d. Open or short circuit in relay connections.	Check to verify that voltage is applied and that current is passing through relay in question.
	e. Improper application of target and holding coil.	Verify proper tripping action of target and holding coils.
	f. Faulty or improperly adjusted timing devices.	If timing device is of bellows or oil-film type, clean and adjust. If induction- disk type, check for mechanical interference. See manufacturer's literature.
5. Noises Due to Vibrating Parts.	a. Loose bolts or nuts permitting excessive vibration.	Tighten to proper torque value.
	b. Loose laminations in cores or transformers, reactors, etc.	Tighten loose nuts or core clamps to proper torque value.
6. Connections Overheating.	a. Increase of current due to overload conditions.	Increase the carrying capacity (increase the number or size of conductors). Remove excess current from circuit.
	b. Connecting bolts and nuts not tight.	Tighten all bolts and nuts to proper torque value.
7. Failure in Function of all Instruments and Devices Having Potential Windings.	a. Loose nuts, binding screws or broken wire at terminals.	Tighten all loose connections to proper torque value or repair broken wire circuits.
	b. Blown fuse in potential transformer circuit.	Renew blown fuses.
	c. Open circuit in potential transformer primary or secondary circuits.	Repair open circuit and check entire circuit for continuity and good condition.

Problem	Possible Cause	Remedy
8. Breaker Fails to Trip.	a. Mechanism binding or sticking caused by lack of lubrication.	Lubricate breaker mechanism, see manufacturer's instructions.
	b. Mechanism out of adjustment	Adjust all mechanical devices, (toggles, stops, buffers, opening springs, etc.) according to manufacturer's instructions.
	c. Failure of latching device.	Examine surface of latch. Replace latch if worn or corroded. Check latch wipe, adjust according to manufacturer's instructions.
	d. Damaged trip coil.	Replace damaged coil.
	e. Blown fuse in control circuit (where trip coils are potential type).	Replace blown fuse.
	f. Faulty connections (loose or broken wire) in trip circuit.	Repair faulty wiring. Tighten all binding screws to proper torque value.
9. Oil Contaminated.	a. Carbonization from too many operations.	Drain oil and filter, clean or replace. Add fresh oil. Clean inside of tank and all internal parts of breaker; see manufacturer's instructions.
	b. Condensation due to atmosphere conditions.	Same procedure as above.
	c. Overheating.	Eliminate cause of overheating.

Table 5-3. Relay Troubleshooting Guide.

Problem	Possible Cause	Remedy
(MAGNET-OPERATED INSTANTANEOUS TYPE)		
1. High Trip Action.	a. Faulty Coil.	Install coil with correct rating.
2. Low Trip Action.	a. Shorted turns (on high trip).	Test coil and replace with new coil if found defective.
	b. Mechanical binding, dirt, corrosion.	Clean parts.
	c. Assembled incorrectly.	See manufacturer's instructions.

Problem	Possible Cause	Remedy
(MAGNET-OPERATED INVERSE-TIME TYPE)		
1. Slow Trip Action.	a. Fluid too heavy, vent too small, or temperature too low.	Change fluid and open vent slightly, or regulate temperature.
	b. Worn parts.	Replace and adjust.
2. Fast Trip Action.	a. Worn, broken parts.	Replace and adjust.
	b. Fluid too light, vent too large or temperature too high.	Change fluid to proper grade. Close vent slightly or regulate temperature. Clean dashpots and refill with fresh fluid of proper grade.
(THERMAL TYPE)		
1. Fails to Trip Causing Motor Burnout.	a. Wrong size heater.	Check rating with recommendations on instruction sheet.
	b. Mechanical binding, dirt and corrosion.	Clean and adjust.
	c. Relay damaged by short circuit.	Replace relay.
	d. Motor and relay in different ambient temperature.	Install motor and control near each other or make temperature uniform for both.
2. Trips at Too Low Temperature.	a. Wrong heater.	Check rating with manufacturer's instruction sheet.
	b. Assembled wrong.	See manufacturer's instructions.
	c. Relay in high ambient temperature.	Install controls closer to each other or make temperature uniform.
3. Fails to Reset.	a. Broken mechanism, worn parts, corrosion, dirt.	Replace broken parts, clean and adjust. Install new relay.

BY ORDER OF THE SECRETARY OF THE AIR FORCE

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COMMON POWER LANGUAGE TERMS

1. **Auxiliary Power.** Power serving as backup for the primary power at the station main bus or prescribed sub-bus.

2. **Bus.** A conductor that serves as a common connection for a related group of power sources or loads.

3. **Circuit Breaker.** A device for interrupting an electrical circuit when the current becomes excessive. Circuit breakers may be oil, vacuum or air type.

4. **Class A Power Plants.** This type power plant generates power on a continuous basis. They serve as the sole or primary source of power. Class A plants most often have 100 percent generated power plus one standby and one maintenance reserve.

5. **Class B Power Plants.** The plants provide power on a standby basis for a significant number of hours each year. They are usually at locations that anticipate months of continuous operation (normally between 1000 and 4000 hours annually). Class B plants most often have 100 percent generated power for technical and selected essential nontechnical loads with a standby reserve.

6. **Class C Emergency Power Plants.** These plants usually have a quick start unit to cover short term outages of prime power. They usually run less than 1000 hours annually. Attendance is part-time. They may be of the manual or automatic start type.

7. **Class D Auxiliary Power.** An uninterruptible (no-break) power unit(s) using stored energy to provide continuous power within specified voltage and frequency tolerances.

8. **Control and Protective Devices.** The methods and means of governing the performance and prevention of destruction of any electric apparatus, machine or system.

9. **Demand Factor.** The ratio between the maximum demand on a system and its total connected load. (The maximum demand is usually the integrated maximum kilowatt demand over a 15 or 30 minute interval, rather than the instantaneous or peak demand.)

10. **Disconnecting Switch.** A device for closing, opening, or changing the connections in a circuit or system or for isolating purposes. It has no interrupting rating. It operates after another mechanism causes the circuit to open.

11. **Distribution Substation.** A substation that modifies electric energy or service to utilization equipment.

12. **Distribution Switchboard.** A power switchboard for distributing electric energy at the voltages common for such distribution within a building. Voltages seldom exceed 600 volts.

13. **Distribution voltage Drop.** The voltage drop between any two defined points of interest.

14. **Diversity Factor.** The ratio between the sum of the individual maximum demands of the various parts of a system and the maximum demand on the whole system. The diversity factor is always greater than unity.

15. **Fuse.** A protective device containing a piece of metal that melts under heat produced by excess current in a circuit. When the metal melts, it breaks the circuit.

16. **Fuse-Disconnecting Switch.** A disconnecting switch in which a fuse unit forms a part of the blade.

17. **Horn Gap Switch (Air Break Switch).** A switch with arcing horns, that ordinarily disconnects and breaks the charging current of overhead transmission and distribution lines.

18. **Load Factor.** The ratio between the average load over a designated time and the peak load occurring during that time.

19. **Low-voltage Enclosed Air Circuit Breaker Switchgear.** A dead-front switchgear assembly for service up to 600 volts alternating current. It contains air circuit breakers, buses, and connections, with an enclosure on both ends, back and top. The air circuit breakers

are in individual compartments. They operate by remote control from the front panels.

20. Metal-Clad Switchgear. An indoor or outdoor metal structure containing switching equipment and other associated equipment such as instrument transformers, buses, and connections. The transformers, buses, and connections are insulated and placed in separate grounded metal compartments. The circuit breaker has self-coupling disconnecting devices. It has a position-changing mechanism for physically moving it. It can move vertically or horizontally from the connection to the test or to a disconnected position. The technician can then remove it from the stationary structure. They have interlocks to be sure of proper sequence and safe operation during the insertion or withdrawal of the removable element.

21. Molded-Case Circuit Breaker. An integral unit in a supporting and enclosing housing of insulating material. Molded-Case breakers are for systems of under 600 volts.

22. Primary Power. A reliable source of power normally serving the station main bus. The source may be a Government-owned generating plant or a utility system.

23. Primary Substation. Equipment that switches or modifies voltage, frequency or other characteristics of primary power.

24. Power Circuit Breaker. A breaker for use on alternating current circuits exceeding 600 volts.

25. Reliability. The ratio in percent of the time power of acceptable quality is available to the time required, normally, continuously.

26. Solid State Uninterruptible Power Systems (SSUPS). This is a fully automatic, constantly-operating, uninterruptible power system that provides filtered, reliable AC power to critical loads.

27. Steadystate Variation. The bands within which the voltage and frequency remain under fixed load conditions from no load to full load over the operating range. It is expressed as percentage deviation from the nominal design value at the point measured.

28. Synchronizing Point. The location of devices for synchronizing two power sources.

29. Threshold. The values for setting sensing devices above or below at which activation of auxiliary power will occur.

30. Variation Monitors. The devices that sense voltage, current, frequency or time deviations capable of initiating transfer to other power sources when they exceed programmed limits. It is expressed as:

Nominal Voltage + %
Nominal Voltage - %
Nominal Current + %
Nominal Current - %
Nominal Frequency + %
Nominal Frequency - %
Millisecond Duration

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