# STANDARD OVERHAUL PRACTICES MANUAL

# MACHINING OF TITANIUM

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# STANDARD OVERHAUL PRACTICES MANUAL

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# STANDARD OVERHAUL PRACTICES MANUAL

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# INTRODUCTION

## 1. General

A. The instructions in this manual tell how to do standard shop procedures during maintenance functions from simple checks and replacement to complete shop-type repair.

B. This manual is divided into separate sections:

(1) Title Page

(2) Transmittal Letter

(3) Highlights

(4) Effective Pages

(5) Contents

(6) Revision Record

(7) Record of Temporary Revisions

(8) Introduction

(9) Procedures

C. Refer to SOPM 20-00-00 for a definition of standard industry practices, vendor names and addresses, and an explanation of the True Position Dimensioning symbols used.

D. The data is general. It is not about all situations or specific installations. Use it as a guide to help you write minimum standards.

E. If the component overhaul instructions are different from the data in this subject, use the component overhaul instructions.

## MACHINING OF TITANIUM

1. **INTRODUCTION**

   A. The data in this subject comes from Boeing Process Specification BAC5492, and Boeing Operators Handbook 6M59-553, "Machining Titanium".

   B. The data is general. It is not about all situations or specifications. Use this data as a guide to help you write minimum standards.

   C. Refer to SOPM 20-00-00 for a list of all the vendor names and addresses.

2. **MATERIALS**

   A. Cutting Fluids

      (1) Water soluble – Refer to BAC5008

      (2) DuPont TB-1, V18873

      (3) Freon - Cetyl Alcohol

      (4) Boelube 100A or 100F, V18554

      (5) Microcut 26, V0FCP2

3. **GENERAL**

   A. Some titanium alloys are easier to machine than others. Also, the recommended cutting speeds are different with each alloy and heat-treat condition. Table 1 gives relative index numbers for typical alloys and conditions. Annealed alloy 6Al-4V, a frequently-used titanium alloy, has an index of 100 to let you use this as a reference standard. If you know good cutting speeds for annealed alloy 6Al-4V, you can compare others. For example, an index of 90 for annealed alloy 6Al-6V-2Sn tells you to decrease the speed on this alloy to 90% of the value you use on annealed alloy 6Al-4V for the same type of cut.

**Table 1:** Relative Index Numbers for Machining Titanium Alloys

| | **Titanium Alloy** | | | |
|---|---|---|---|---|
| Heat-Treat Condition | 6Al-4V | Commercially Pure | 10V-2Fe-3Al | 6Al-6V-2Sn |
| I (Annealed) | 100 | 300 | 90 | 90 |
| III (Aged) | 70 | — | 60 | 60 |
| IV (Overaged) | 80 | — | — | — |
| V (Duplex annealed) | 100 | — | — | — |

   B. The data in this subject is for base material that has no surface contamination. But titanium alloy can have "alpha case," an embrittled surface layer that is usually thin, but can be as hard as Rockwell C 55. Tool failure can occur quickly on such a surface. Alpha case is frequently found on the surface of rolled plate, forging, extrusions, and thermally cut edges. It can also be caused by heat treatment and stress relief operations. The alpha case layer is usually removed as the part is made, but it could occur on parts in for overhaul. Then slower-than usual tool speeds must be used, and tool life will be shorter.

C. Lead, tin, cadmium and zinc must not touch the surface of titanium. These metals cause contamination and are not easy to remove. The contamination can cause the titanium part to crack on the airplane or during repair. Thus, do not use tools, permanent or temporary fasteners, or bushings of, or plated by, these metals on titanium parts.

D. Titanium can be made brittle by methyl alcohol, anhydrous ethyl alcohol, and BMS 3-11 hydraulic fluid (above 270°F).

E. Keep liquid oxygen away from titanium. Liquid oxygen on a bare titanium surface can start a violent reaction.

F. Water-based cutting fluids can be used on titanium if the parts are wiped or blown dry after the operation. Do not use Freon-based fluids if the part will be in temperatures above 600°F during repair or on the airplane. Cutting fluids are optional with hand-held drill motors. See Table 2 for recommended cutting fluids.

**Table 2:**

| PROCEDURE | CUTTING FLUIDS | HOW TO APPLY |
|---|---|---|
| ABRASIVE SAWING | WATER-BASE COOLANT | FLOOD |
| GRINDING | WATER-BASE COOLANT | FLOOD |
| BANDSAWING | WATER-BASE COOLANT | SPRAY |
| PLANING | WATER-BASE COOLANT | SPRAY |
| MILLING WITH HSS | WATER-BASE COOLANT | FLOOD |
| FACE MILLING, CARBIDE | WATER-BASE COOLANT | FLOOD |
| END MILLING, CARBIDE | WATER-BASE COOLANT | FLOOD |
| PERIPHERAL MILLING, CARBIDE | WATER-BASE COOLANT | FLOOD |
| HAND FINISHING | WATER | FLOOD |
| DRILLING AND REAMING | BOELUBE 100A OR 100F OR MICROCUT 26 OR FREON TB-1 *[1] | SPRAY |
| TAPPING | PURE MINERAL OIL | FLOOD |

*[1] DO NOT USE FREON TB-1 ON PARTS WHICH WILL BE IN 600°F OR HIGHER DURING OVERHAUL OR ON THE AIRPLANE

G. Fire Safety

(1) In most forms, titanium is not flammable. But very finely divided titanium, such as very thin machining chips or dust from grinders, can be ignited and will burn.

(2) Titanium chips do not ignite as easily or burn as violently as magnesium. But in some conditions they will ignite and burn, and quickly become a hot, glowing mass.

(3) Emergency Procedure for Titanium Fires

(a) Tell the fire unit.

(b) Extinguish fires of titanium chips with fully dry talc, calcium carbonate, sand, graphite, or water. Do not use carbon dioxide, carbon tetrachloride or the usual dry chemical fire extinguishers.

(c) If talc or equivalent powered agent is used, apply the powder in a continuous layer 1/2 inch deep or more, but do not scatter the burning metal. If the burning metal is on a surface that could burn, apply a 2-inch layer of powder on this surface and shovel the burning metal onto the powder. Carefully apply more powder if smoke continues in some areas.

(d) Water pump type fire extinguishers are recommended on fires in small piles of titanium chips. Apply the water at the base of the fire.

(e) If possible without risk of injury, confine the fire and scrape off the titanium metal that is not on fire.

(f) Do not let the burning metal get on concrete floors.

(g) For fires in large piles of titanium chips, give protection to surfaces and items that can burn.

(h) Wear safety approved dark goggles or other eye protection when you fight titanium fires.

(4) Fire prevention

(a) Keep a good flow of a water-base coolant on the part and the chips. Water-base coolants extinguish titanium fires, and wet chips do not ignite as easily.

(b) Replace the cutters at the first sign they are dull. A dull cutter makes hot chips that could ignite.

(c) Cut at a decreased speed if the surface of titanium has contamination. Contamination can cause a spark that can start a fire.

(d) Keep the feed rate high. Thick chips do not ignite as easily as thin chips.

(e) Do not let a large number of chips collect. The fewer the chips, the smaller the fire that could occur. Remove the chips from the machine frequently, and store them in approved and correctly identified containers.

## 4. TURNING AND BORING

A. Use carbide tools if possible. Indexable disposable insert types are recommended.

(1) Use sub-micro-grain carbide inserts when possible, as an alternative to the older grades C-1, C-2, and C-3.

(2) If sub-micro-grain carbide is not available, use carbide grade C-1 or C-2 for heavy roughing cuts and when impact loading is moderately high.

(3) If sub-micro-grain carbide is not available, use carbide grade C-3 for light, continuous cuts because it has a better abrasion resistance.

(4) If disposable insert tools are used, a positive rake angle is recommended unless impact loads are very high.

B. If carbide is not used, use high speed steel to make grooves, to cut pieces off, to make interrupted cuts, and for operations with form tools. Use PM high speed steels when possible.

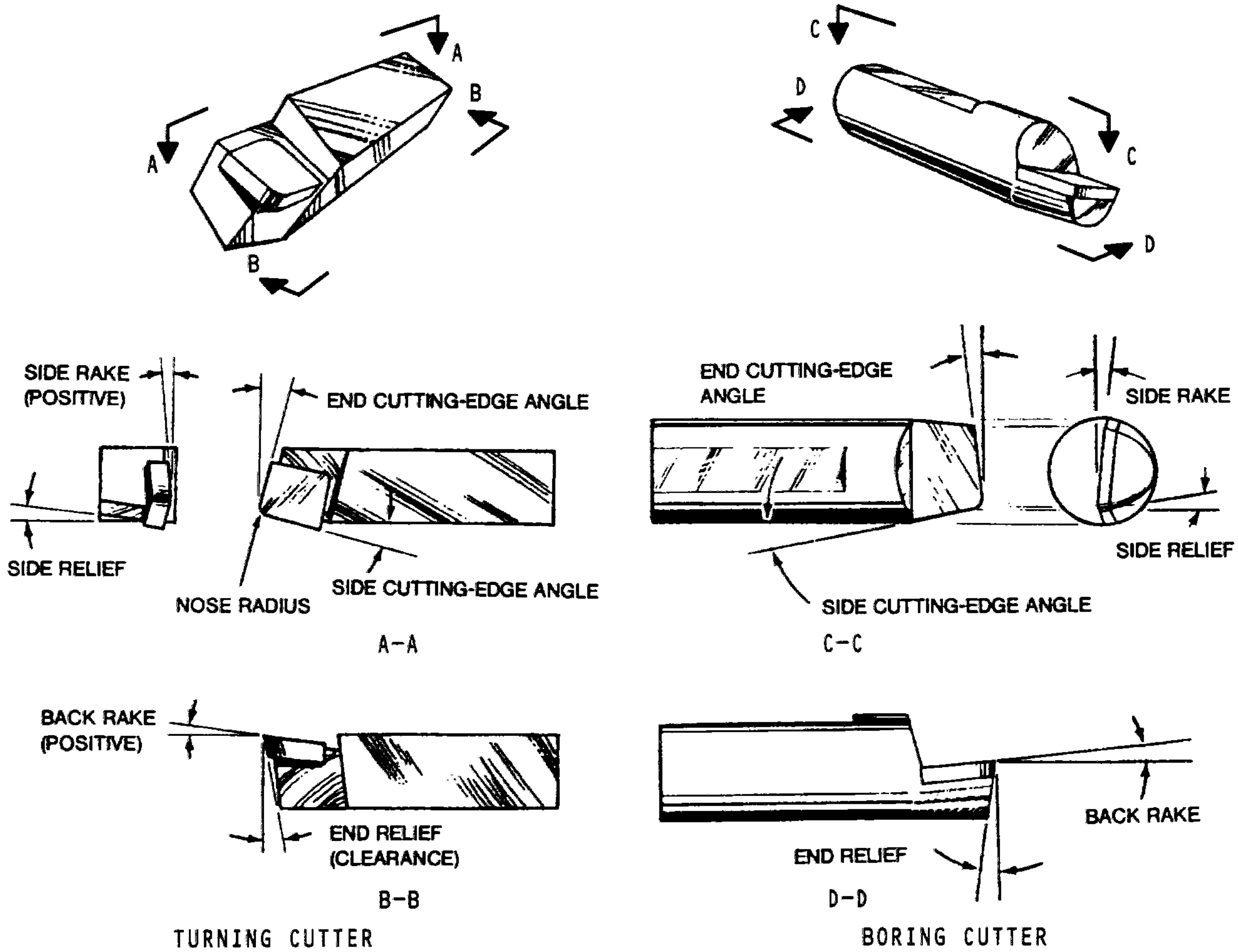
C. If possible, use a cutting tool with side-cutting edge angle (lead angle) of 15 degrees or more. To avoid smearing on the flank of the tool, use a relief angle of 10 degrees for facing and a minimum of 5 degrees for all other operations.

D. When you bore, decrease the cutting loads if the boring bar is not rigid.

E. See Figure 1 for recommended data.

| CUTTER | GEOMETRY | | | | |
|---|---|---|---|---|---|
| | BACK RACK | SIDE RAKE | END RELIEF | SIDE RELIEF | END CUTTING-EDGE ANGLE |
| CARBIDE BRAZED TOOL, GRADE C-2 | 0° | 6° | 5° | 5° | 5° |
| CARBIDE INDEXABLE INSERT, GRADE C-2 | 0° | 6° | 5° | 5° | 5° |
| HIGH SPEED STEEL | 0° | 5° | 5° | 5° | 15° |

| TITANIUM ALLOY | DEPTH OF CUT (INCHES) | CUTTING SPEED (SFM) | | FEED (IN. PER REV.) |
|---|---|---|---|---|
| | | CARBIDE | HSS | |
| 8AL-1MO-1V | 0.150 | 130 | 50 | 0.015 |
| | 0.025 | 155 | 60 | 0.007 |
| 6AL-4V, CONDITIONS I AND V | 0.150 | 130 | 50 | 0.015 |
| | 0.025 | 155 | 60 | 0.007 |
| 6AL-4V, CONDITIONS III AND IV | 0.150 | 100 | 40 | 0.010 |
| | 0.025 | 120 | 50 | 0.005 |




Turning and Boring Data
Figure 1

5. **GRINDING**

A. Rough grinding (by hand or machine) can be used for all surfaces, but then a minimum of 0.020 inch of metal must be removed by a finishing operation. Finish grinding is not permitted on important surfaces, such as those identified by BAC5492 class 1 or 2.

B. Use a good flow of cutting fluid per BAC5008 during the grind.

C. See Table 3 for recommended values.

**Table 3:** Surface Grinding Controls

| | Roughing | Finishing |
|---|---|---|
| Grinding Wheel | | |
| Aluminum oxide | | |
| Grit size | 46 | 60-80 |
| Hardness | J | L-M |
| Bond | Vitrified | Vitrified |
| Structure | 5-8 | 5-8 |
| Speed (surface feet per minute) | 1500-2500 | 1500-2500 |
| Silcon Carbide | | |
| Grit size | 46 | Norton C60 |
| Hardness | J | H |
| Bond | Vitrified | Vitrified |
| Structure | 7-8 | 8 |
| Speed (surface feet per minute) | 5000-6000 | 5000-6000 |
| Work speed (surface feet per minute) | 30-40 | 30-40 |
| Crossfeed, inch per pass | 0.060 | 0.050 |
| Downfeed, inch per pass | 0.0010 max | 0.0005 max |

6. **MILLING**

A. General

(1) Carbide cutters are recommended unless easily-broken cutters (such as small endmills or slitting saws) must be used. Sub-micro-grain carbide is recommended first, then carbide grade C-2, and then grade C-3. Inserts can be brazed, clamped mechanically, or held in place with a screw.

(2) If high speed steel cutters must be used, a PM type is better than standard grades. PM lets you use a higher cutting speed or has a longer tool life.

(3) In some operations, a titanium aluminum nitride coating on the cutter can help.

(4) Use a mill cutter with as many teeth as possible, but which has necessary strength and chip clearance. The greater the number of teeth, the higher the feed rate you can use.

(5) If possible, for longer tool life, mill with the edge of the cutter (end mill or slab mill) and not the end of cutter (face mill or end of an end mill).

B. Conventional and climb milling

(1) In conventional milling, the cutter turns in a direction opposite to the feed as seen at the point of contact. The thinnest part of the wedge-shaped chip is made first. Conventional milling is best used only to remove when alpha case or scale from the surface of a part with a high-speed steel cutter. In all other situations, climb milling is recommended.

(2) In climb milling, the cutter turns in the same direction as the feed as seen at the point of contact. The thickest part of the wedge-shaped chip is made first. Much less chip welding occurs and a better surface finish is made. But climb milling machines must have antibacklash devices.

C. Face Milling (Figure 2, Figure 3, Table 4, Table 5)

(1) Carbide face mills can be used. Cutters with indexable inserts or ground-in-place inserts are recommended. Some indexable insert face mills have special finishing (wiper) teeth that can make a finish of 32 microinches or smoother and thus can be used for finishing cuts.

(2) As the titanium chips are cut from the work material, they can weld to the face of cutter teeth. The risk of this is greater as the chip thickness increases at the exit point. Chip welding is a special problem during face milling. It decreases tool life and could cause sudden tool failure. When you face mill titanium, to decrease chip welding and increase tool life:

(a) Use a cutting fluid.

(b) Decrease the feed rate per tooth to 0.002-0.003 inch when you start a cut or machine over holes or irregular surfaces.

(c) Climb mill, and always align the exit side of the cutter with the edge of the part or the cut.

(3) Use the general cutter (Figure 3) unless you cut an internal corner at a shoulder. Use the other cutter shown in Figure 3, when it is necessary to cut an internal corner radius.

**Table 4:** Finish Face Mill Cutter Geometry

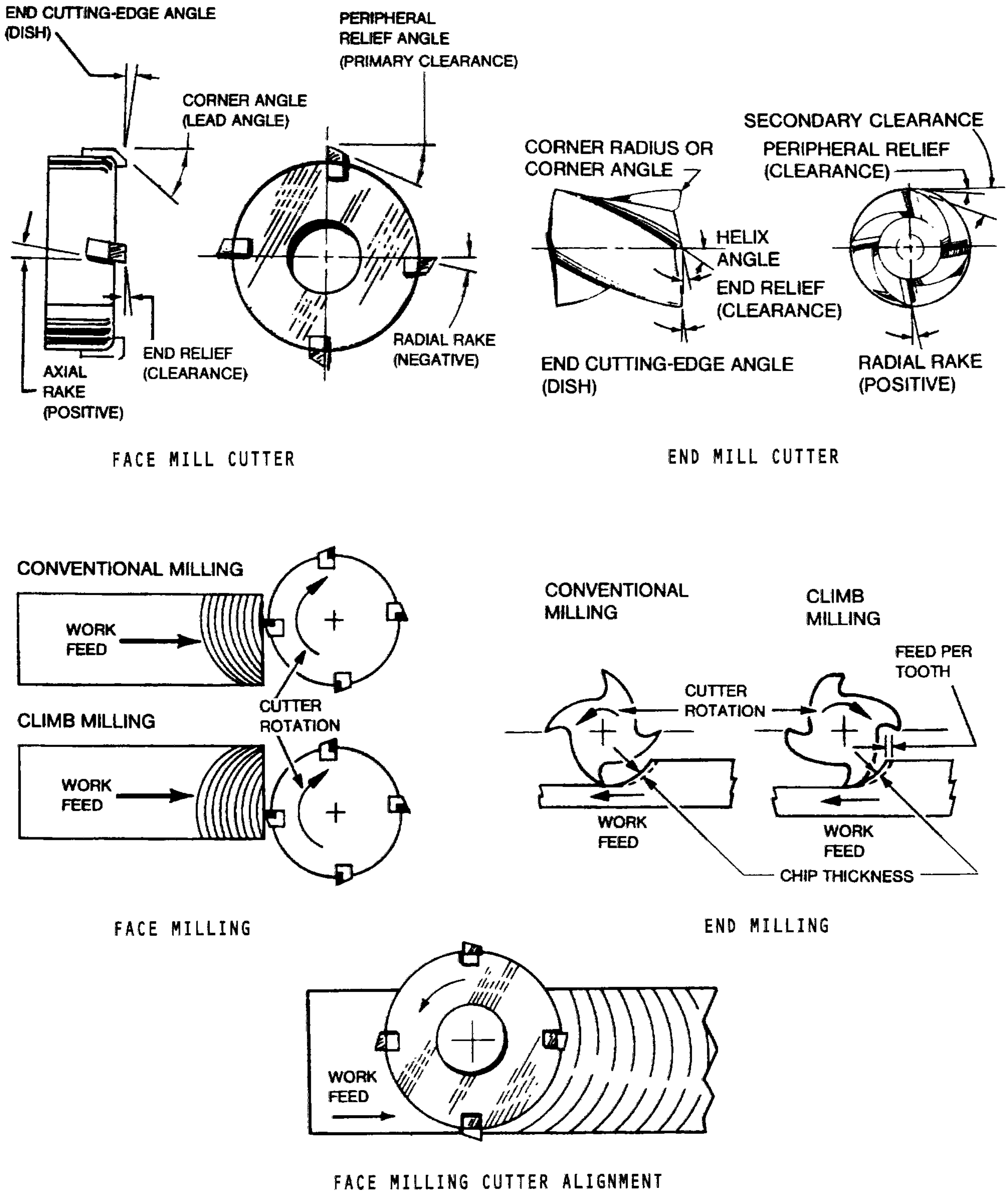
| CUTTER | CORNER ANGLE (LEAD ANGLE) | AXIAL RAKE | RADIAL RAKE | RELIEF ANGLE (PRIMARY CLEARANCE) |
|---|---|---|---|---|
| GROUND-IN-PLACE INSERTED TOOTH, SUB-MICRO-GRAIN AND CARBIDE GRADE C-2 | 45° | 5° | 0° | 10° |
| GROUND-IN-PLACE INSERTED TOOTH, HSS PM | 45° | 10-15° | 10-15° | 10° |

**Table 5:** Face Milling Machining Data

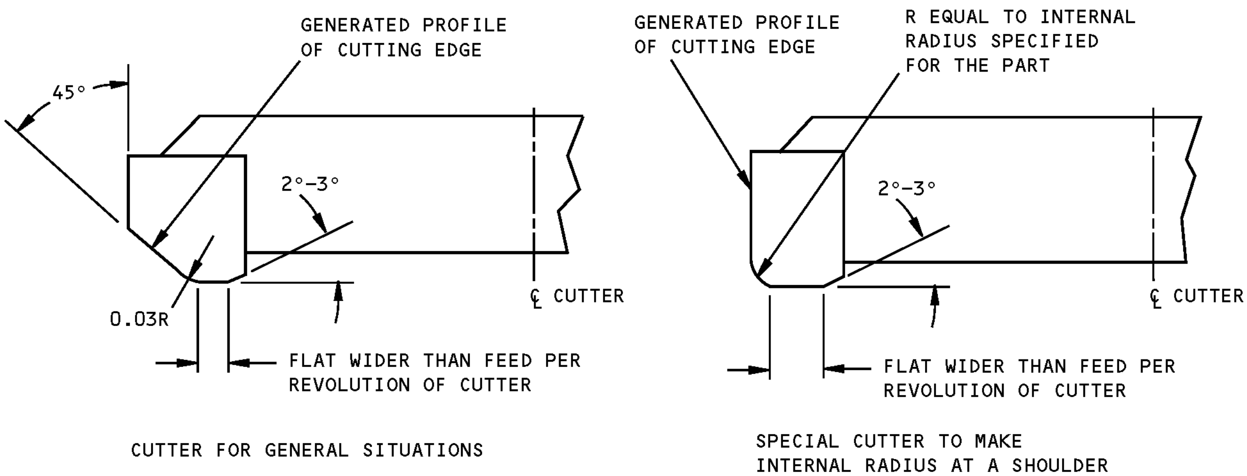
| CUTTER | FEED PER TOOTH, INCH | CUTTING FLUID | CUTTING SPEED (SFM) | | |
|---|---|---|---|---|---|
| | | | 8AL-1M0-1V | 6AL-4V COND. I & V | 6AL-4V COND. III & IV |
| GROUND-IN-PLACE INSERTED TOOTH, SUB-MICRO-GRAIN AND CARBIDE GRADE C-2 | 0.010 MAX | WATER-BASE COOLANT, FLOOD OR SPRAY | 120 | 100 | 90 |

**Table 5:** Face Milling Machining Data (Continued)

| CUTTER | FEED PER TOOTH, INCH | CUTTING FLUID | CUTTING SPEED (SFM) | | |
|---|---|---|---|---|---|
| | | | 8AL-1M0-1V | 6AL-4V COND. I & V | 6AL-4V COND. III & IV |
| GROUND-IN-PLACE INSERTED TOOTH, HSS PM | 0.010 MAX | WATER-BASE COOLANT, FLOOD OR SPRAY | 50 | 45 | 35 |




Milling Cutter Data
Figure 2




Face Mill Insert Cutters
Figure 3

## 7. DRILLING

A. Use a jobber-length drill with a ST10-907A or B point (135-degree split point and reduced rake) on an ST10-907J drill body. If a short-flute drill is not available, or if a longer flute length is necessary, use the ST10-907K drill with the ST10-907B point. For maximum drill life, use as short a drill length as possible. See Figure 4 for recommended speeds and feeds.

B. If the drill diameter is less than 1 inch, use cobalt high-speed steel. If the drill diameter is more than 1 inch, use standard high-speed steel.

C. Use a good flow of cutting fluid as specified in Table 2.

D. Dull drills usually break suddenly. A drill could be dull if one or more of these signs occur. If you are not sure, replace the drill.

(1) A change in chip shape or quality, such as smearing, rough edges, different colors, or local hot spots.

(2) A change in the sound of the drill, such as squeaks or chatters.

(3) A change in hole quality, such as of surface finish or diameter.

(4) An increased amount of burrs.

(5) A change in power is necessary. (Monitor the load meter if available.)

E. Always use solid clamping and backup devices to prevent vibration and burrs.

| TITANIUM ALLOY | 6AL-4V | | | 6AL-6V-2SN | | | A-40 OR A-70 | | |
|---|---|---|---|---|---|---|---|---|---|
| DRILL TYPE | ST10-907-K OR ST10-0001-D | | | ST10-907-K OR ST10-0001-D | | | ST10-907-K | | |
| DRILL POINT | ST10-907-B | | | ST10-907-A | | | ST10-907-A | | |
| DRILL SIZE | 20 SFM MAX RPM (WET) | 30 SFM MAX RPM (WET) | FEED (IPR) | 15 SFM MAX RPM (WET) | 20 SFM MAX RPM (WET) | FEED (IPR) | 30 SFM MAX RPM (WET) | 50 SFM MAX RPM (WET) | FEED (IPR) |
| 1/16 - NO. 40 | 850 | 1275 | 0.0015 | 600 | 850 | 0.0015 | 1275 | 2100 | 0.0015 |
| NO. 30 - 5/32 | 500 | 750 | 0.0020 | 375 | 500 | 0.0020 | 750 | 1250 | 0.0020 |
| NO. 10 - 7/32 | 375 | 550 | 0.0020 | 300 | 375 | 0.0020 | 550 | 900 | 0.0030 |
| 1/4 | 300 | 450 | 0.0030 | 225 | 300 | 0.0030 | 450 | 750 | 0.0040 |
| 3/8 | 200 | 300 | 0.0040 | 150 | 200 | 0.0040 | 300 | 500 | 0.0040 |
| 1/2 | 150 | 225 | 0.0040 | 110 | 150 | 0.0040 | 225 | 400 | 0.0060 |
| 5/8 | 125 | 190 | 0.0040 | 90 | 125 | 0.0040 | 190 | 325 | 0.0060 |
| 3/4 | 100 | 150 | 0.0060 | 75 | 100 | 0.0040 | 150 | 250 | 0.0080 |
| 1 | 75 | 110 | 0.0060 | 50 | 75 | 0.0040 | 110 | 200 | 0.0080 |

| HOLE DEPTH (DRILL DIAMETERS) | CUTTING SPEED (SFM) [2] (WITH CUTTING FLUID) |
|---|---|
| LESS THAN 2D | 25-30 |
| 2D-4D | 15-20 |
| MORE THAN 4D [1] | 15-20 |

[1] USE OIL-HOLE DRILLS OR PECK DRILLS ONLY. DO NOT USE CONVENTIONAL DRILLS

[2] $$\text{RPM} = \frac{\text{SURFACE FEET PER MINUTE X 12}}{\text{DRILL DIAMETER IN INCHES X 3.1416}} = \frac{\text{SURFACE FEET PER MINUTE X 4}}{\text{DRILL DIAMETER IN INCHES}} \text{ (APPROXIMATE)}$$

$$\text{SFM} = \frac{\text{RPM X DRILL DIAMETER IN INCHES X 3.1416}}{12} = \frac{\text{RPM X DRILL DIAMETER IN INCHES}}{4} \text{ (APPROXIMATE)}$$

Drilling Data
Figure 4

8. REAMING

A. Tolerance and tool life are controlled by reamer geometry, cutting speeds and feeds. Cutting fluids must be used.

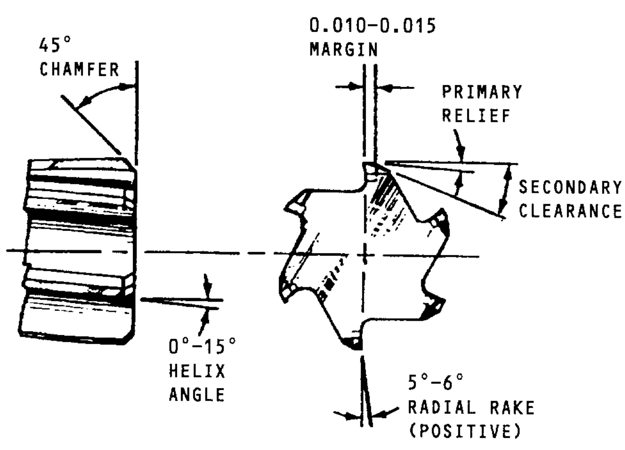
B. Standard high speed steel or carbide insert reamers can be used. But standard high speed steel is satisfactory for most applications. Straight-flute chucking reamers with maximum margins (such as 0.010-0.015 inch) are recommended.

C. See Figure 5 for recommended controls.

D. Close-toleranced holes are not easy to ream in titanium. Careful control of reamer geometry and shop procedures can give a tolerance of -0.0000/+0.0015 inch. When you machine ream, cut a minimum of 1/64 (0.0156) inch on the diameter for holes up to 5/16 (0.3125) inch diameter. For larger holes, a 1/32 (0.0312) inch cut on the diameter could be necessary to remove drill marks.

| REAMER SIZE (INCHES) | SPEED (RPM) | FEED RATE (INCHES PER TOOTH) [1] |
|---|---|---|
| 5/32 | 240-480 | 0.0006-0.0008 |
| 3/16 | 200-400 | 0.0006-0.0008 |
| 1/4 | 150-300 | 0.0008-0.0010 |
| 5/16 | 120-240 | 0.0008-0.0010 |
| 3/8 | 100-200 | 0.0008-0.0010 |
| 7/16 | 90-180 | 0.0008-0.0010 |
| 1/2 | 75-150 | 0.0008-0.0010 |
| 9/16 | 70-140 | 0.0010-0.0012 |
| 5/8 | 60-120 | 0.0010-0.0012 |
| 3/4 | 50-100 | 0.0010-0.0012 |
| 7/8 | 45-90 | 0.0010-0.0012 |
| 1 | 40-80 | 0.0010-0.0012 |
| 1-1/8 | 35-70 | 0.0010-0.0012 |
| 1-1/4 | 30-60 | 0.0010-0.0012 |
| 1-3/8 | 27-55 | 0.0010-0.0012 |
| 1-1/2 | 25-50 | 0.0010-0.0012 |

[1] INCHES PER REVOLUTION = INCHES PER TOOTH TIMES NUMBER OF TEETH




INSERT TYPE REAMER

Reaming Data
Figure 5

9. SANDING

A. Titanium can be sanded manually or with power tools. The power tools must not hold the abrasive tightly against the surface. The operation must not make sparks or melted fine particles.

B. For class 1 and 2 surfaces, the surface speed of the power sanding tool must be a maximum of 2000 surface feet per minute, measured at the abrasive.

C. Do not stop the sander in one location as you sand. Do not let the surfaces become too hot. If color changes occur that cannot be removed with solvent, the part must be rejected.

D. Class 1 surfaces which are sanded must be shot peened (SOPM 20-10-03).

10. OTHER FINISHING OPERATIONS

A. Hone with 120-grit or finer stones at a speed less than 150 surface feet per minute.

B. Do not use abrasives bonded to a rigid backing (other than the hones) on BAC5492, class 1 or 2 surfaces.

C. Do not use wire brushes as a finishing operation on BAC5492, class 1 or 2 surfaces unless there will be a subsequent operation to remove the wire brush marks.

D. Break sharp corners and remove burrs with hand scrapers or files. Rotary files can be used if this does not make the surface too hot and cause color changes.

11. STRESS RELIEF AFTER MACHINING

A. It is not necessary to bake titanium for stress relief after the machining operations.