BOMBARDIER
Toronto (de Havilland)
PROPRIETARY INFORMATION

PPS 1.35

PRODUCTION PROCESS STANDARD

Machining of Titanium Alloy

Issue 3
- This standard supersedes PPS 1.35, Issue 2.
- Vertical lines in the left hand margin indicate changes over the previous issue.
- Direct PPS related questions to PPS.Group@aero.bombardier.com or (416) 375-4365.
- This PPS is effective as of the distribution date.

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1 Scope

1.1 This Production Process Standard (PPS) specifies the procedure and requirements for machining of titanium alloy parts.

1.1.1 This PPS complements the engineering drawings that specify its use as an authorized instruction and the procedure specified must be followed to ensure compliance with all applicable specifications. In general, if this PPS conflicts with the engineering drawing, follow the engineering drawing. The requirements specified in this PPS are necessary to fulfil the engineering design and reliability objectives.

1.1.2 Refer to PPS 13.26 for the subcontractor provisions applicable to this PPS.

1.1.3 Procedure or requirements specified in a Bombardier BAPS, MPS, LES or P. Spec. **do not** supersede the procedure or requirements specified in this PPS. Similarly, the procedure and requirements specified in this PPS are not applicable when use of a BAPS, MPS, LES or P. Spec. is specified.

2 Hazardous Materials

2.1 Before receipt at Bombardier Toronto (de Havilland), all materials must be approved and assigned Material Safety Data Sheet (MSDS) numbers by the Bombardier Toronto (de Havilland) Environment, Health and Safety Department. Refer to the manufacturer's MSDS for specific safety data on any of the materials specified in this PPS. If the MSDS is not available, contact the Bombardier Toronto (de Havilland) Environment, Health and Safety Department.

3 References

3.1 PPS 1.09 - Drilling and Reaming.

3.2 PPS 13.26 - General Subcontractor Provisions.

3.3 PPS 20.03 - Fluorescent Penetrant Inspection.

3.4 PPS 27.04 - Edge Finishing Titanium Parts.

3.5 PPS 30.14 - Heat Treatment of Titanium Alloy.

3.6 PPS 31.09 - Cleaning of Titanium and Titanium Alloys.

4 Materials and Equipment

4.1 Materials

4.1.1 Titanium alloy, as specified on the engineering drawing.

4.1.2 Cutting fluid (e.g., Trimsol). Except as noted, cutting fluids used in machining titanium must be free from halogen, chlorinated or sulphur compounds. Sulpho chlorinated oil may be used in tapping, and drilling and reaming deep holes.

4.2 Equipment

4.2.1 Standard metal cutting machines equipped with lines, pumps, nozzles etc, to provide constant flow of cutting fluid to the workpiece during machining.

4.2.2 Appropriate supports and fixtures, to add rigidity to machining operations.

5 Procedure

5.1 General

5.1.1 The following basic rules apply to all machining operations carried out on titanium alloy:

- Use slower cutting speeds.
- Employ high feed rates.
- Use sharp tools and replace at the first sign of wear.
- Use rigid set-up to prevent vibration and chatter.
- Flood, or spray mist, cool work piece during machining.

5.1.2 The use of marking or layout materials is strictly prohibited, unless it will be removed by trimming or machining.

5.1.3 Unless otherwise specified, machine titanium alloy parts in the annealed or solution heat treated condition, and then heat treat to specified requirements according to PPS 30.14, after machining.

5.1.4 If removal of the “alpha case” surface layer from hot rolled plate, forgings and extrusions has not been carried out by the supplier, machine (or chem-mill) a minimum of 0.030" from all faces before normal machining operations. For removal of alpha case, a carbide-tipped shell mill with 10 degrees negative radial rake and 5 degrees negative axial rake is recommended.

5.1.5 High speed steel (HSS) tools are generally preferred for machining titanium. If carbide tools are used, C-2 is generally the most suitable grade.

5.1.6 Immediately after machining, clean all titanium parts which have been exposed to cutting fluids according to PPS 31.09.

5.1.7 Do not allow cutters to dwell on the workpiece, or be returned across it without first being retracted.

5.1.8 Grinding of titanium to finish size is not recommended as inferior surface finish and high surface residual stresses result.

5.2 Milling

5.2.1 General

5.2.1.1 In order to minimize deflection and chatter, select a mill cutter with as many teeth as possible while still providing the necessary strength and chip clearance. If chip clogging becomes apparent, reduce feed accordingly or use a cutter with less teeth.

5.2.1.2 Machine close to the table, clamping the part frequently and using back-up blocks for thin wall sections.

5.2.1.3 Flood cool with cutting fluid while milling.

5.2.1.4 Rigidity in machine and set-up is essential when milling titanium in order to reduce deflection and backlash. Use short arbors, steady rests and overarm supports if possible, and keep gibs and slides snug. See Figure 1 for an example of a typical rigidity aid.

5.2.1.5 Climb milling reduces chip welding and tool chipping, and should be utilized in preference to conventional milling whenever possible.

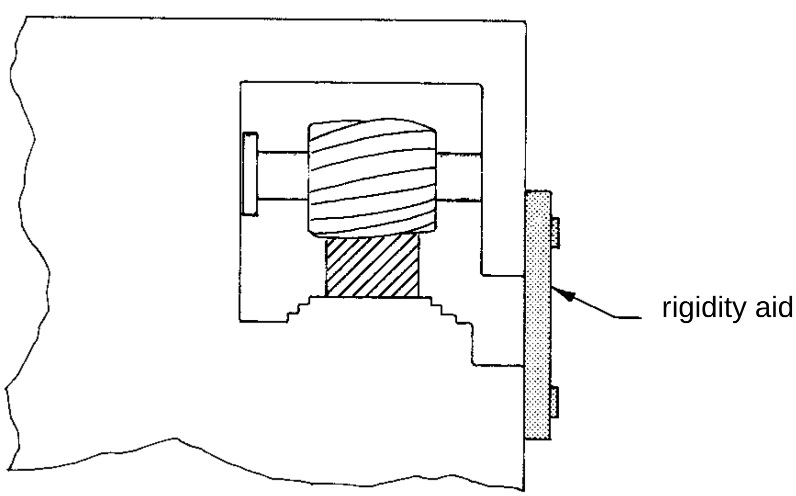


Figure 1 - Typical Rigidity Aid

5.2.2 End Milling

5.2.2.1 Peripheral end milling (milling with the periphery of the cutter as opposed to the end) will extend cutter life significantly (see Figure 2).

5.2.2.2 Cutters of up to 1" diameter and having 3 or four flutes are recommended for end milling; however, 2 flute cutters may be used with a corresponding reduction in linear feed.

5.2.2.3 In profiling end mill applications, cutters with the shortest flute length suitable for the cut depth, and largest flute depth with maximum core strength, are recommended.

5.2.2.4 Generally the axial depth of cut should be approximately half the diameter of the cutter for slot milling, but if long fluted cutters are used, depth of cut should be reduced accordingly to minimize deflection.

5.2.2.5 For closed end pocketing it is recommended that a starter hole first be drilled to depth.

5.2.2.6 If a roughing cut operation is being carried out on a stepped profile, a cutter with a 45° chamfer angle should be used, as cutters having a corner radius tend to burn and break down.

5.2.2.7 Refer to Figure 2 and Table 1 for data on peripheral milling of external surfaces.

5.2.2.8 Refer to Figure 3 and Table 2 for data on end milling of external surfaces.

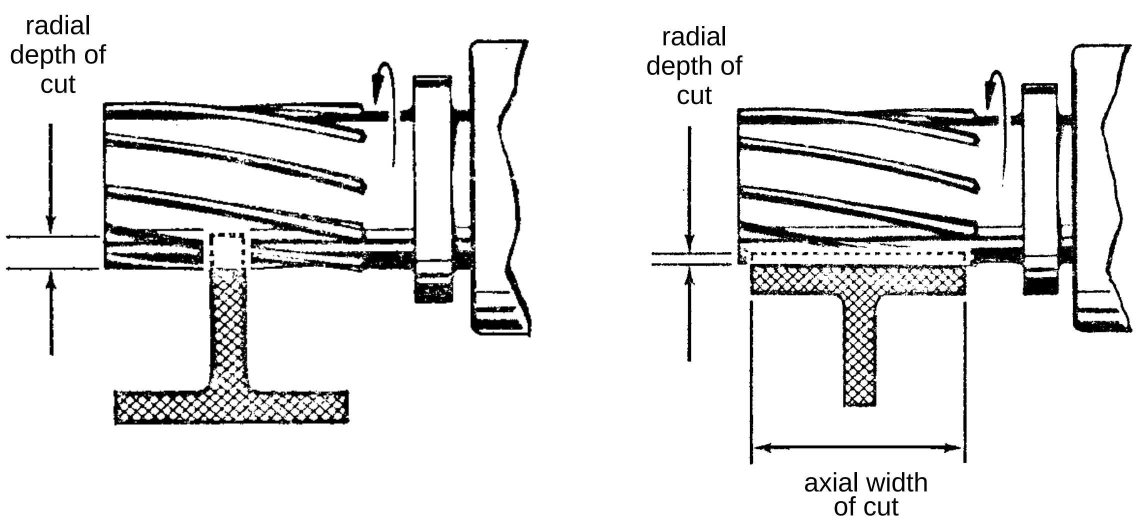


Figure 2 - Peripheral Milling of External Surfaces

Table 1 - External Milling Data

Titanium Alloy Ti-6Al-4V BETA III Alloy		Angles	Tool Geometry	
			Carbide	**Cobalt HSS**
		Radial Rake	0° - 2°	10° - 15°
		Helix	5° - 15°	15° - 30°
		Relief	10° - 20°	10° - 12°
Radial Depth of Cut (inches)	**Feed (I.P.T.) Maximum**	**No. Of Flutes**	**Cutting Speed (SFM)**	
0.025 - 0.050	0.17"	6	200	90
0.050 - 0.100	0.015"	6	175	70
0.100 - 0.200	0.012"	5	150	50
0.200 - 0.300	0.010"	4	125	40
0ver 0.300	0.008"	3	125	35

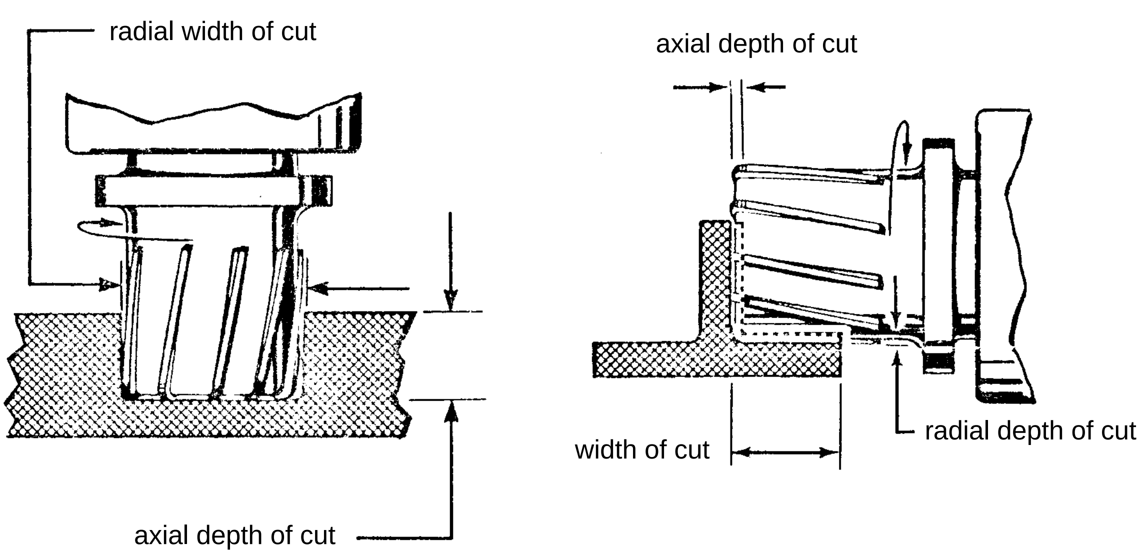


Figure 3 - End Milling of Internal Surfaces

Table 2 - Internal Milling Data

	Milling Data	Tool Material	
		Carbide (1)	Cobalt HSS
Titanium Alloy Ti-6Al-4V BETA III Alloy	Depth of Cut	up to 0.050"	
	Feed (IPT) (2)	0.005" - 0.008"	0.003" - 0.006"
	Cutting Speed	110 (SFM)	30 (SFM)
	Angles	Tool Geometry	
	Radial Rake	0°	5° - 10°
	Helix	10° - 15°	15° - 30°
	Relief	10° - 15°	10° - 12°

Note 1. Carbide cutters are not recommended if the diameter is less than 1 1/2 inches.
Note 2. Feed must be reduced as the size of the cut increases, or as endmill diameter is reduced.

5.2.3 Face Milling

5.2.3.1 HSS cutters are preferred for face milling titanium and do not tend to chip as readily as carbide cutters. If excessive chipping occurs, reduce cutter relief angles.

5.2.3.2 Always align the exit side of the cutter tangent to the edge of the part or cut, to reduce chip welding (see Figure 4).

5.2.3.3 If a fine finish is required when face milling titanium, grind the cutter end as shown in Figure 5.

5.2.3.4 Refer to Table 3 for data on face milling.

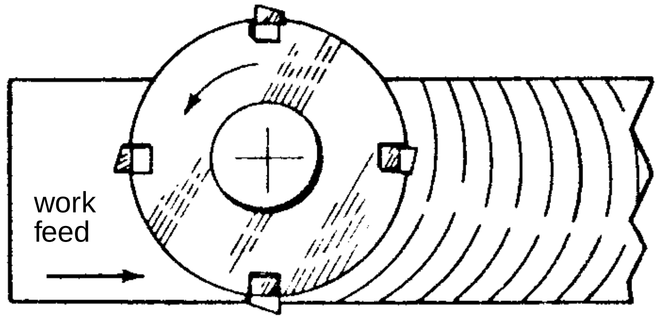


Figure 4 - Aligning the Cutter in Face Milling

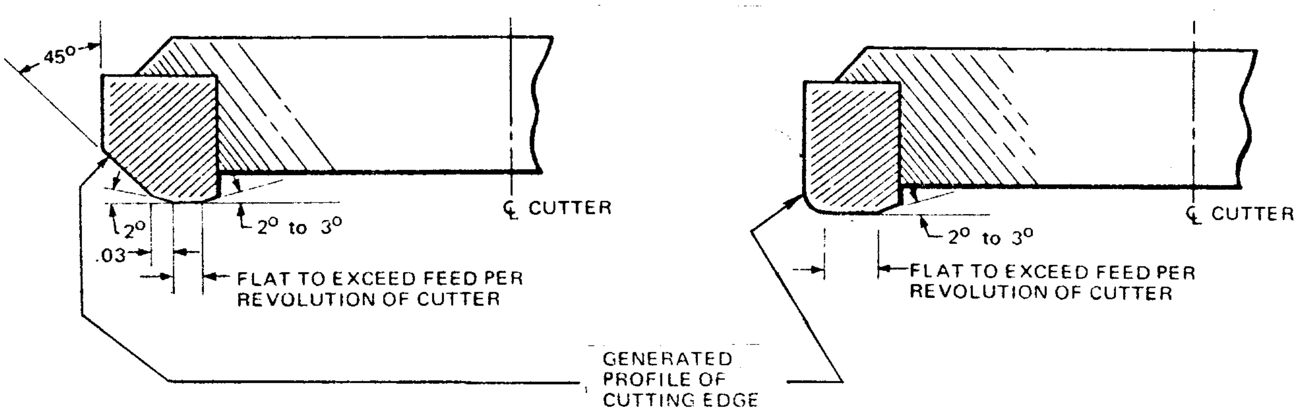


Figure 5 - Cutting Profile for Fine Finish in Face Milling

Table 3 - Face Milling Data

	Milling Data	Tool Material	
		Carbide	**Cobalt HSS**
Titanium Alloy Ti-6Al-4V BETA III Alloy	**Depth of Cut**	up to 0.050"	
	Cutting Speed	120 (SFM)	30 (SFM)
	Feed (IPT)	0.004" - 0.008"	0.004" - 0.008"
	Angles	**Tool Geometry**	
	Corner	45°	45°
	Axial Rake	0°	0°
	Relief Rake	0° - 10°	0°
	Relief	10°	10°
	ECEA	12°	6°

5.3 Turning and Boring

5.3.1 When boring titanium, the cutting loads should be greatly reduced as the rigidity of the boring bar diminishes.

5.3.2 Machine close to spindle, gripping work firmly in the collet, and use steady rests for slender parts. Use live centres at all times when turning titanium.

5.3.3 Keep toolbit overhang to a minimum to ensure rigidity.

5.3.4 Refer to Figure 6 and Table 4 for turning and boring data.

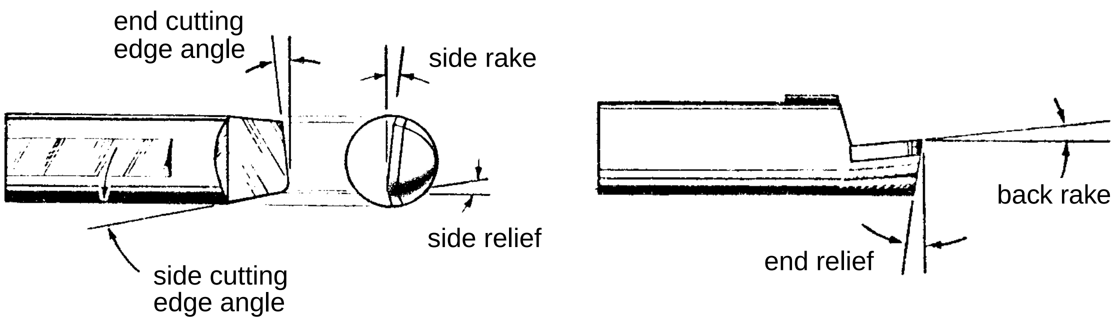


Figure 6 - Boring Cutter Geometry

Table 4 - Turning and Boring Data

	Machining Data	**Tool Material**			
		CARBIDE		**Cobalt HSS**	
		Depth of Cut (inches)			
		0.025	**0.150**	**0.025**	**0.150**
Titanium Alloy Ti-6Al-4V BETA III Alloy	**Cutting Speed (SFM)**	150	130	60	50
	Feed per Rev.	0.007	0.015	0.007	0.015
	Angles	**Tool Geometry**			
	Back Rake	0° - 5°		0° - 5°	
	Side Rake	0° - 15°		0° - 5°	
	End Relief (1)	5° - 10°		5° - 7°	
	Side Relief (1)	5° - 10°		5° - 7°	
	End Cutting Edge	6° - 10°		5° - 6°	
	Side Cutting Edge (2)	0° - 20°		5° - 6°	

Note l: To avoid flank smearing, relief angles should not exceed 10 degrees for facing, and should be at least 5° for all other operations.

Note 2: When using carbide tools, a side cutting edge angle of 15° or more should be used if pactical.

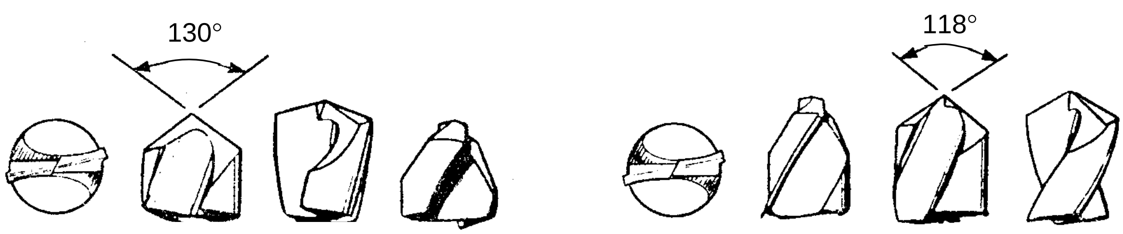
5.4 Drilling

5.4.1 Cobalt HSS split point drills having the shortest flutes possible for the required depth are recommended for drilling titanium (see Figure 7).

5.4.2 A positive feed should be maintained, to prevent galling and smearing of the cutting edges.

5.4.3 Check drills frequently during the drilling operation and replace immediately at the first sign of wear (feathered or discoloured chips, smearing).

5.4.4 When drilling deep holes, the drill should be retracted frequently to clear chips.



1/2" dia. or less **greater than 1/2" di**

Figure 7 - Split Point Drills

5.4.5 Flood cooling is effective only to a depth of 2.5 times the drill diameter; oil hole type drills should be used for drilling deep holes.

5.4.6 Utilize drill jigs and holding fixtures at all times when drilling titanium. Clamping should be positive and back-up plates of aluminum or soft steel may be used to absorb heat.

5.4.7 Refer to Table 5 and Table 6 for drilling data and conversion of SFM (surface feet per minute) to RPM (revolutions per minute).

Table 5 - Drilling Data

	Cobalt HSS		**Depth of Hole in Material**	**Cutting Speed (SFM)**
	Drill Dia.	**Feed IPR**		
Titanium Alloy Ti-6Al-4V BETA III Alloy	1/8"	0.002"	2D or less	25 - 30
	1/4"	0.004"	2D to 4D	15 - 20
	1/2"	0.006"	4D or more	15 - 20

Table 6 - Conversion of SFM to RPM

Dia.	RPM for given SFM									
	10	15	20	25	30	40	50	60	70	80
1/16"	611	917	1222	1528	1833	2445	3056	3667	4278	4889
1/8"	306	458	611	764	917	1222	1528	1833	2139	2445
3/16"	204	306	407	509	611	815	1019	1222	1426	1630
1/4"	153	229	306	382	458	611	764	917	1070	1222
5/16"	122	183	244	306	367	489	611	733	856	978
3/8"	102	153	204	255	306	407	509	611	713	815
7/16"	87	131	175	218	262	349	437	524	611	698
1/2"	76	115	153	191	229	306	382	458	535	611

5.5 Reaming

5.5.1 Both HSS and carbide reamers are suitable for reaming titanium.

5.5.2 Spiral fluted reamers are preferred to straight fluted reamers. Reamers having a minimum number of flutes (thus giving maximum tooth space) practical for the work are recommended.

5.5.3 Holes which are to be reamed to final size should be drilled or bored 0.010" - 0.015" undersize.

5.5.4 Refer to Figure 8 for reamer geometry and Table 7 for reaming data.

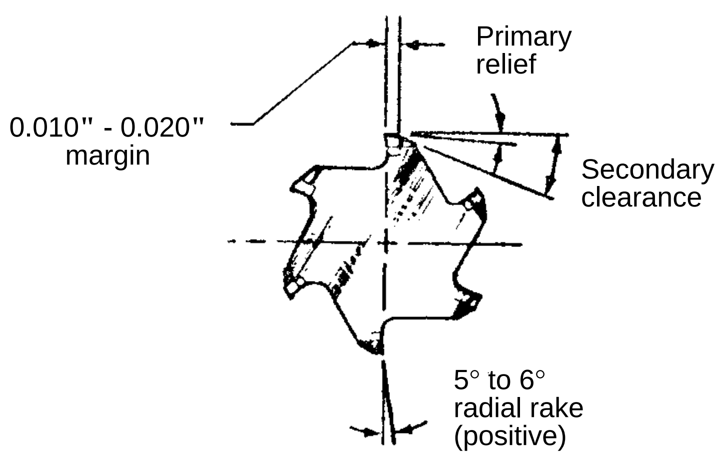


Figure 8 - Reamer Geometry

Table 7 - Reaming Data

	Operational Data	Tool Material	
		Carbide	Standard and HSS
Titanium Alloy Ti-6Al-4V BETA III Alloy	Speed-SFM	100 - 200	20 - 30
	Feed IPT (1)	0.005" - 0.015"	0.005" - 0.015"
	Angle	Tool Geometry	
	Clearance	10° - 15°	
	Relief	5° - 10°	
	Margin	0.010" - 0.020"	
	Radial Rake	5° - 6°	
Note l: Feeds should be increased in proportion to the diameter of the hole.			

5.6 Tapping

5.6.1 Spiral pointed, interrupted flute taps of HSS material are preferred for tapping titanium.

5.6.2 Nitrided taps are recommended, to minimize the adhesive tendency of titanium to the tap.

5.6.3 Two-fluted taps should be used for holes up to 5/16" diameter, and three-fluted taps for hole diameters greater than 5/16" diameter.

5.6.4 Taps should be examined before use for signs of smears on the tool flanks, as this can result in tool failure.

5.6.5 Holes drilled for tapping must show no evidence of burning or roughness, and must not vary in diameter.

5.6.6 Power feed should be used whenever possible; sulpho chlorinated cutting oil is recommended for lubrication.

5.6.7 Refer to Table 8 for data on tapping.

Table 8 - Tapping Data

Titanium Alloy Ti-6Al-4V BETA III Alloy	**Operational Data**	**Tool Material**
		HSS
	Speed SFP	10 - 20
	Tool Angle	**Tool Geometry**
	Spiral Point	10° to 17°
	Spiral	110°
	Relief	2° to 4°
	Cutting Rake	6° to 10°
	Heel Rake	-3°
	Chamfer	5 threads

5.7 Band Sawing

5.7.1 For cutting titanium using a band saw, use of 1", high speed steel blades are recommended.

5.7.2 Work thickness determines the number of blade teeth per inch (see Table 9). The thicker the workpiece the less number of teeth are recommended.

5.7.3 The blade should be eased into the work before the feed is fully applied, and positive feeds should be maintained once the work has started. When the material thickness is 1" or greater, power feed should be employed.

5.7.4 For heavy section band sawing it is recommended that a drilled hole pattern be produced around the required profile, leaving approximately 0.060" webs between each hole. This method facilitates sawing and greatly reduces the time taken for the operation.

5.7.5 For band sawing data, see Table 9.

Table 9 - Band Sawing Data

Material Thickness	Teeth per inch	Feed (IPM)
0.090"	24	15" Manual
0.25"	l0	6" Manual
0.50"	10	2" Manual
1.0"	6	0.30" Power
2.0"	6	0.09" Power
4.0"	3	0.05" Power

5.8 Tool Failure

5.8.1 Tools may fail abruptly when machining titanium and therefore cutter condition must be periodically observed during entire machining operation. To prevent tool and workpiece from consequent damage, the following should be observed:

- Watch for chip welding.
- Watch for changing shape or colour in chips.
- Listen for different cutting action sound.

5.8.2 Replace tools at the fist sign of wear.

5.9 Post Machining Processing

5.9.1 After machining, process parts as follows:

Step 1. Edge finish machined part edges according to PPS 27.04.

Step 2. Surface finish machined parts according to the engineering drawing.

Step 3. Fluorescent penetrant inspect all parts according to PPS 20.03.

6 Requirements

6.1 Machined parts must conform to the dimensional requirements of the engineering drawing.

6.2 Parts containing cracks are not acceptable.

7 Safety Precautions

7.1 In certain conditions titanium can be a fire hazard. If excessive sparking occurs during machining, increase the coolant flow rate accordingly. Collect chips, turnings etc. regularly. Do not allow sludge-like waste to dry out before removal. In the event of fire, use of dry powder type extinguishing agent is recommended. Do not apply water directly to a titanium fire; direct water at the base or surrounding area of the fire.

8 Personnel Requirements

8.1 Personnel responsible for machining of titanium alloys must have a good working knowledge of the procedure and requirements as specified herein and must have exhibited their familiarity to their supervisor.

9 Special Points to Note

9.1 As titanium is susceptible to surface contamination which may cause cracking during fabrication or in service, take the following precautions during handling and working of titanium parts:

- Platings or alloys of lead, tin, cadmium, zinc, silver and bismuth shall not be used as tools, locating pins, nuts, bolts, shop aids, clamps, fixtures, or other assembly and installation tooling.
- Cleaning of titanium shall only be carried out according to PPS 31.09.