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UC-38

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AFT SUPPORT
MACHINED FROM
TITANIUM

BDX-613-525

May, 1971

Prepared by:
J. M. Robb
Department 822

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Contract Number AT(29-1)-613 USAEC

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ABSTRACT

The aft support used on a large missile-component-type assembly is a complex, thin-walled structural member machined from titanium alloy 6AL-4V. It has threads and flanges for attachment and the titanium alloy provides the cantilever strength required in the next assembly application. Tolerances are extremely close and difficult to measure due to part size and flexibility. An initial production yield of less than 10 percent was obtained only by extensive rework. The development of adequate inspection methods enabled a thorough evaluation of process sequences, fixturing techniques, cutting tools, and process control procedures. This evaluation and subsequent modifications to the process resulted in a yield of more than 90 percent acceptable product. The process thus developed and recorded should be of significant benefit in developing future processes for machining similar thin-wall titanium parts.

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SUMMARY

Machining a 6AL-4V titanium forging to a piece part of complex configuration with close tolerances was complicated by the lack of specific information on the machining characteristics of this alloy and the low modulus of elasticity of titanium. The heavy forging provided the desired grain flow and draw characteristics but necessitated heavy initial cuts to economically remove material. As the piece part became thinner (final wall thickness--0.030 inch), it was necessary to provide special fixtures and rigid tool holders to prevent the material from deflecting under tool pressure. Because open setup inspections were generally unsatisfactory in obtaining sufficiently accurate data for process adjustment, final adjustment of the process was made only after check fixtures and gages were available. The sequence of final machining operations was revised when it became evident that some machining operations adversely affected the tolerances that could be held on succeeding operations. By additionally selecting the best cutting tools and by implementing special process control procedures, the total production process yield was improved from less than 10 percent to more than 90 percent acceptable product.

The experience obtained in developing these techniques is expected to be directly applied to future titanium machining of similar parts.

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DISCUSSION

SCOPE AND PURPOSE

Bendix Kansas City received a production assignment to fabricate the aft support, P/N 226381, from 6AL-4V titanium. The successful fulfillment of this assignment proved to be a challenge to Bendix' engineering and manufacturing capabilities for several reasons. Because of a lack of specific information regarding the machining characteristics of 6AL-4V titanium, the thin-wall part configuration, and the extremely close tolerance requirements, it was necessary to optimize and interrelate all parameters of the production process during the early production phase of this part. The sequence of machining, effects of clamping and holding the part, depth of cuts, and tool geometries all had significant dimensional consequences and each operation, in turn, had to be stabilized in order to form an optimum production process. It was essential that check fixtures and gages were available at the start of the final process adjustment in order to develop control limits. The following narrative is an account of how this production process was developed.

ACTIVITY

Development of Operational Sequence

The starting stock for machining was a heavy forging of 6AL-4V titanium developed for optimum grain flow and draw characteristics (Figure 1). Four rough operations and two semi-finish operations reduced the weight of the part from 56 pounds to 5.5 pounds and left approximately 0.03 inch on all surfaces for final machining. These operations required the optimization of feeds, speeds, and depths of cut. The tooling was rigidly constructed to accommodate high tool pressures resulting from heavy cuts necessary for economical material removal. Large quantities of chlorine-free coolant¹ were used to flood all turning operations. The parts were then thoroughly cleaned with alcohol to remove all traces of coolant and fingerprints in preparation for oven stress-relief.

The partial drawing of the aft support (Figure 2) shows some of the dimensions and tolerances required for the finished part (Figure 3). The original sequence of machining following the rough machining and stress-relief operations was as follows:

1. Finish long outside contour (7.845-inch length to datum -L- and 11.500 inch OD flange).

¹Vantrol 700 water soluble coolant

Figure 1. Titanium Forging From Which Part is Machined

Figure 2. Partial Drawing of Aft Support With Dimensions

Figure 3. Aft Support After Final Machining

2. Finish long inside contour (Datum -D- through angle surface and 7.595 inch ID flange).
3. Finish short outside contour (Datum -P- through angle surface, 8.860 inch OD and 9.225 inch overall height).
4. Finish short inside contour (flange datum -N- to top of part).
5. Finish Acme thread undercut (to hold .020/.024 wall thickness).
6. Finish the 9.756-12 Acme thread.
7. Finish the 8-3/4 - 16 thread.
8. Slot and drill the flanges.

The final developed sequence of machining operations was as follows:

1. Semi-finish long inside contour (IC).
2. Semi-finish datum -P- surface.
3. Finish long outside contour (OC).
4. Finish Acme thread undercut.
5. Finish short inside contour (IC).
6. Finish 8-3/4 - 16 thread.
7. Finish short outside contour (OC).
8. Drill tooling hole in outside flange.
9. Finish long inside contour (IC)
10. Finish 9.756 - 12 Acme threads.
11. Slot and drill the flanges.

The dimensional problem areas that were corrected by this sequence change are outlined below:

Parts received from the stress-relief operation were in a warped and out-of-round condition. The original processing sequence and tooling transferred these conditions from outside to inside through all succeeding operations (Figure 4). To correct this condition, semi-finish operations were then added

for the long IC and the datum -P- of the outside flange which resulted in a straight and round IC and a square datum -P-. As a result of locating on these improved surfaces when machining the long OC, the transfer of warped surfaces was eliminated and control was established for size and taper.

Originally, machining the undercut behind the Acme thread caused a flair-out of the thread because of the thin wall (Figure 5). By machining the undercut while the long IC was only semi-finished, the increased wall thickness reduced flair-out.

Because finishing of the long IC distorted other features of the part, operations for the short IC, 8-3/4 - 16 threads, and short OC were changed to precede the finish long IC to take advantage of the additional wall thickness at this stage. The short IC and 8-3/4 - 16 thread operations were further changed to precede the short OC operation to take advantage of the thicker outside flange.

After the short OC was finished, a new operation was added to drill a tooling hole through the outside flange to accept tooling for the long IC finish operation.

The long IC was the most critically toleranced contour surface and due to the number and lengths of cuts was also the most time-consuming operation. A change in tolerance from ± 0.0010 to ± 0.0015 inch increased acceptability of this feature but there was still taper in the critical zone "K". Assuming that tool and chuck pressures were the cause (Figure 6), a new NC tape incorporated three passes for zone "K" with the third pass also finishing the remaining IC. The first cut was 0.024-inch, the second cut was 0.003-inch, and the third pass was programmed the same as the second cut to remove only material left from the second cut. This technique was successful in removing less than 0.001 inch material from the critical zone "K" diameter during the final pass with 0.0005-inch taper or less in zone "K".

Tool pressure on the thin wall at the Acme thread operation caused growth in the Acme thread area and changed the constant relationship of the two OD's established at the long OC operation (Figure 7). The constant relationship was essential in order for the tooling to provide backup support when machining the long IC. Thus, by changing the sequence to cut the Acme threads after the long IC, the growth was predictable for the thread operation and the essential constant relationship of the OD's was not disturbed.

Development of Fixturing

Successfully holding and clamping the parts required detailed development of special fixturing techniques. All fixtures and tool holders were massively built for high rigidity to accommodate high tool pressures and compensate for the low modulus of elasticity characteristic of titanium.

Figure 4. Result of Warped Part After Heat Treat

THE FLAIR-OUT CONDITION IN THE ACME THREAD AREA CREATED TAPER ON THE FINISH LONG IC IN THE SAME AREA BECAUSE THE SPLIT SLEEVE COMPRESSED THE FLAIED THREAD BLANK. THIS RESULTED IN A STRAIGHT FINISH LONG IC WHEN HELD IN THE SLEEVE BUT THE THREAD BLANK AND IC FLAIED OUT WHEN REMOVED FROM THE SLEEVE.

Figure 5. Flair Out Caused by Machining Undercut on Thin Wall

Figure 6. Result of Tool Pressure When Making Too Large a Cut

Figure 7. Tool Pressure Caused Growth in Acme Thread Area

The original tooling for the semi-finish long IC was a three-jaw chuck with full wrap-around aluminum pads. This chucking method caused a scalloped and out-of-round condition which was transferred through succeeding operations (Figure 8). The three-jaw chuck was replaced by a hydraulic pot chuck with accurate pressure controls and a one-piece plastic sleeve (Figure 9) which minimized distortion of the part. Optimum hydraulic pressures had to be determined to hold the semi-finished IC to ± 0.001 and 0.001 inch maximum taper over the seven-inch IC. The semi-finished IC was measured at three heights off the machine with an average-diameter air gage.

During the finish long OC operation the part was held with a mechanically expanding mandrel which easily stretched the thin-wall part. A technique was developed to expand the mandrel and sufficiently contain the part while controlling expansion. The segments of this mandrel when expanded caused reproduction of scalloping in the OC of the part in the free state. This was dimensionally acceptable but undesirable for maximum control of the succeeding IC operation. Production continued with this mandrel until a self-contained hydraulic mandrel with a solid expanding OD was procured. This new mandrel eliminated the scalloped condition and by using a pressure gage to calibrate diameters versus pressures the expansion was more accurately matched to each individual part. Again, an average diameter air gage was used to measure the OC at three heights off the machine.

A hydraulic pot chuck and pressure control unit identical to that used on the semi-finish IC was also used to finish the long IC. The plastic sleeve was replaced with an aluminum split sleeve (Figures 10 and 11) because more rigidity was required for the thinner part walls. The split sleeve had a step cut in the ID to exactly match the step as previously cut in the part OC and thus provide maximum support in the critical area. A driver pin in the rear face of the sleeve matched the tooling hole in the outside flange of the part preventing part slippage. Cutting tool set surfaces were machined on the face of the chuck to establish home position of the NC tape. The finish long IC was checked at two heights in zone "K" with an average diameter air gage.

Rounding details machined to closely fit Datum -D- were added to several fixtures to eliminate distortion of the thin-wall parts during machining operations succeeding the finish long IC operation.

Development of Cutting Tools

Due to the machining characteristics of titanium (abrasiveness, toughness, poor heat conductivity), Carboloy 883, Kenametal K68, and Valenite VC2 carbide inserts in appropriate standard configurations were used on all turning operations for maximum efficiency. Positive rake angles of 5° to 10° provided the best cutting action with surface finishes better than 32 RMS consistently maintained. The rough operations were performed at 120 surface

THE SCALLOPS WERE MACHINED IN THE SEMI-FINISH IC WHERE EACH OF THE 3 CHUCK JAWS SQUEEZED IN THE WALLS OF THE PART.

Figure 8. Result of Three-Jaw Chuck on Machining

Figure 9. One-Piece Plastic Sleeve to Minimize Distortion

Figure 10. Aluminum Split Sleeve to Replace Plastic Sleeve

Figure 11. Aft Support in Aluminum Split Sleeve

feet per minute (SFM) with a feed rate of .010 inch per revolution (IPR) and depths of cuts up to 0.200 inch. The finish operations were performed at 185 SFM with a feed rate of 0.0042 IPR and depth of cuts ranging from 0.001 to 0.027 inch.

The form tool originally used to plunge cut the Acme thread undercut contributed to a 0.001 inch flair-out on the IC in the area of the Acme thread blank. This tool was replaced with a 0.030 inch wide carbide insert that was plunge-fed to depth and fed toward the thread to turn the undercut. This tool change together with the sequence change previously described eliminated the flair-out.

The thread hob originally used to cut the Acme threads created pressures which caused the long IC to grow and created an undesirable chatter finish. The hob was replaced with a single point carbide insert which minimized the growth of the long IC and eliminated the chatter.

Process Control Techniques

Because of the thin-wall characteristic of the part, special control techniques were developed to reliably predict and control part distortion resulting from expanding/contracting fixtures and cutting tool pressures. Previously discussed techniques include pressure controls to monitor hydraulic fixtures, calibration instructions for expanding fixtures, and average diameter inspection of the parts off the machine. Process control identification was maintained on all operations subsequent to stress-relief. The production operators were required to measure and record all critical dimensions on data sheets initialing each entry. These sheets provided data necessary to monitor and control such production variables as:

1. Hard and soft spots in the material.
2. Taper on the long IC and OC.
3. Quality of cutting tools supplied by various vendors.
4. Inadvertent variations in feeds, speeds, and depths of cut.
5. On-machine and off-machine inspection data.

ACCOMPLISHMENTS

1. Surface finishes obtained were consistently better than 32 RMS.
2. Yield was increased from 10 percent to 90 percent while maintaining production schedules.

3. A thin-wall titanium machining capability was established.

FUTURE WORK

Continuation of efforts will be directed to simplification of tools and additional control of cutting tool life. Positive results of this effort will depend upon the continuation of process monitoring and the judicious use of process controls.