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MANUFATURING SIMULATION AND OPTIMIZATION OF TURBINE BLADE DIE USED IN FORGING PROCESS

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Abstract:
The exact die cavity plays a vital role on the accuracy of turbine blade shape achieved. The co-ordinate measuring machine was used to generate the geometrical information of various cross sections of turbine blade. The curves related to cross sectional areas of turbine blade at various heights were generated using AUTOCAD. Curves were smoothened by using UNIGRAPHICS techniques. The optimized tool for roughing is dia32r2. Optimized method for finishing is on-part.

1. INTRODUCTION

Turbine and compressor blades for jet engines and gas turbines are forged from high-strength alloys and require close control of the process parameters. The forging process requires two dies halves viz., male and female. The design and manufacture of the dies require particular attention to impart geometry to the final product. For precision forging, the die surface must be corrected for local elastic deflections and thermal shrinkage. The design considerations accountable for the turbine blade die are:

- All the vertical lines defining the forging profile are to be replaced with sloped lines with draft angles to ensure separation between the die and work piece without any gripping or locking.
- The sharp corners could generate high stresses in the dies resulting in premature fracture. If the sharp intersections are replaced with blend radii many of the problems resulting from these intersections are overcome. The fillet and corner radii are defined with respect to the die surfaces as a consequence of many years experience.
- Unless the forging shape dictates otherwise the flash is placed centrally. The general flash geometry is fairly standard in design, being scaled in proportion to the forging dimensions. The flash landing is typically designed to have a length equal to three times the flash thickness The inclusion of a flash is important for two reasons firstly to allow for variations in the thickness of the forging as a result of the process. The amount of material that appears as waste in the flash gutter varies inversely with the forging thickness. The second purpose of the flash is to control the metal flow within the forging. The material forming the flash normally cools faster than the main body of the forging and hence results in the flow path to the flash being the most resistant in the forging. A consequence of this flow restriction is that the metal is forced to take an alternative route, the path of least resistance, which normally results in the filling of the deeper cavities.
- When there is a less metal flow over the surface of a die the less wear that dies surface would be subjected to. Therefore, more forgings can be produced without major changes in the forging Dimensions.
- The forgings are generally made at a temperature of 1150 to 1300^{0}C. At this temperature the material gets expanded and when it is cooled to the atmospheric temperature, its dimensions would be reduced. Hence a shrinkage allowance is added on all the linear dimensions

The exact die cavity plays a vital role on the accuracy of turbine blade shape achieved. Now a days CAD/CAM software tool has become a sophisticated tool to simulate the manufacturing process. A technique, which can extract the exact die cavity through the turbine blade shape, is a best feasible solution for qualitative and competitive manufacturing of turbine blades. The objectives of this work are:

- Use of blade cross sectional curves for the extraction of die cavities.
- Optimization of milling tools required for machining the die cavity.

2. METHODOLOGY

2.1 Modeling

The dies are designed around the blade profile. Large amounts of information are needed to define a complex blade profile. Standard drawings are normally accompanied by sets of data representing cross-sectional profiles. The cross-sectional data is to be read onto the computer disk. The stored cross sectional data is then converted into spline forms. The curves related to cross sectional areas of turbine blade at various heights were generated using AUTOCAD because Auto-CAD is the cheapest software when compared to UINGRAPHICS (UG).

The co-ordinate measuring machine was used to generate the geometrical information of various cross sections of turbine blade. While taking point information, Z- coordinate was kept constant. At different values of Z (at different heights of turbine blade) the point information was collected. This point information would be in the form of coordinates. By using this information the curves were generated as shown in Figure.2. These curves would represent the cross sections of turbine blade at different heights. These curves were used in developing the turbine blade. Steps for developing the turbine blade die curves are given below:

- According to parting plane location the blade curves were divided into two parts. One related to male die and the other one related to female die.
- These curves were offset according to the allowances to be given.
- Provisions were made for flash and gutter lands.
- Drafts were given for the curves.
- Fillet and corner radii were provided where two or more surfaces meet.

By considering the above all factors curves for female and male dies were produced as shown in Figure.3. The surfaces generated by the AutoCAD curves would not smooth. Curves were smoothened by using UG techniques. The commands like *throw* mesh curves were used for developing the surface. By using the *sane* command, the surfaces at root and pin were generated .By using *sew* command the sheet body was converted into solid body (Figure.4). Two surfaces were extracted from two sides of modeled component. These surfaces were used in core cavity extraction. The required size of blocks was taken according to sizes of core and cavity. These blocks were trimmed by using extracted surfaces. After trimming the blocks by surfaces both core and cavity were obtained (Fig. 5 and 6).

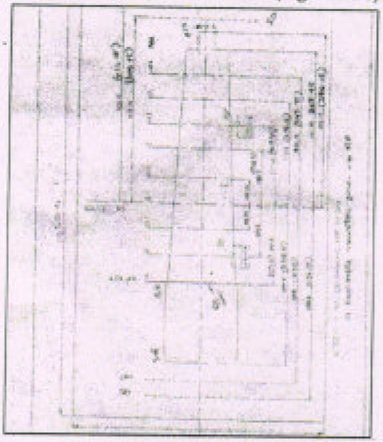

Figure.1 Turbine blade drawing

Figure.2 Cross sections of turbine blade at different heights

2.2 Machining

The basic setup procedure before the generation of tool paths is as follows:

- Viewing the model and setting the machine coordinate system (MCS)
- Material block definition

- Cutting tool definition
- Feed rate and spindle speed settings
- Rapid move heights
- Tool datum

In machine setup, the model was loaded in to UG manufacturing. It was adjusted so that whole model (i.e. cavity) is visible. Next the block definition was given i.e. the block was created by offsetting the bottom face up to the total height of the model. Clamping was used for holding of the core holder on bed (Figure.7).

Using various tool paths, different roughing programs were performed. Varoius tool paths were used to obtain different machining times and different amount of machined areas (Table-1). From these different tool paths the optimized one was selected. After selecting the optimized path the programs were generated with the optimized path by changing the different tools. From these programs the optimized combination was taken for the roughing operation.

For semi finishing operation dia20bnc tool was used. In this stock material was taken lesser than that taken in roughing. In this method material was removed along vertical walls. For this constant Z-level i.e. vertical milling was used. In finishing operation the total left over material in the semi finishing operation was removed. That means in this stock material was zero. Finishing operation was performed by using different drive methods (Table-2).

Figure.3 Cross sections of turbine blade at different heights

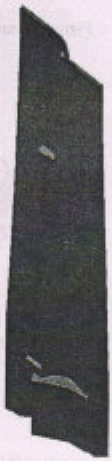

Figure.4 Turbine blade

Figure.5 Female

Figure.6 Male die

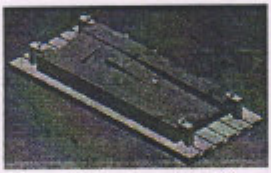

Figure.7 Clamping of the die

Table-1: Roughing operation with dia32r2 tool

Method	Zig	Zig-zag	Periphery
Step over	25mm	25mm	25mm
Step down	2mm	2mm	2mm
Stock	1mm	1mm	1mm
Feed rate	2000mm/min	2000mm/min	2000mm/min
Non cutting Feed rate	3500 mm/min	3500 mm/min	3500 mm/min
Time taken	10.64hr	9.543hr	10.39
Tool path length	127210mm	91060mm	383730mm

Table-2: Finishing by on plane drive method

Tool	Dia20bnc	Dia20bnc	Dia20bnc
Drive Method	On plane	On part	Spiral
Step over	1mm	1mm	1mm
Stock	0mm	0mm	0mm
Feed rate	3500mm/min	3500mm/min	3500mm/min
Non cutting Feed rate	6000 mm/min	6000 mm/min	6000 mm/min
Time taken	10.43hr	9.86hr	14.82hr
Tool path length	626030mm	4308620mm	626030mm

3. RESULTS AND DISCUSSION

3.1 Optimization of Tool and Method for Roughing Operation

The optimized method for roughing is periphery (Tabel-3). Zig method is taking more time when compared to zig-zag method. It is only one-way cutting. The unmachined area is more. Where as periphery method is also taking more time when compare to zig-zag method but in zig-zag method in every pass tool is touching wall of component.

In periphery method the machining would start from center and from onwards along the periphery. So every time tool is not touching the component. The machined area is almost same for zig-zig and periphery (Figure.8-10).

The optimized tool for roughing is dia32r2. In this, operations are performed keeping all parameters constant except changing tool. For all the tools time taken was same. But while using tool dia20r2 the left over material would be more due to high step over. In the same way the bigger tool would not go into the corners and into channel sections resulting the left over material would be more. When compared to these two tools the machined area is better by the tool dia32r2. So when all parameters are constant tool dia32r2 is a better solution (Table-4).

3.2 Optimization of Drive Method for Finishing Operation

Optimized method for finishing is ***on part***. In this generally stock material is taken as zero. That is no left over material should remain after this operation. For finishing operation different drive methods are used like ***on-plane***, ***on-part*** and ***spiral***. Generally ***on-plane*** is useful for those cavities, which are not having more corner radii sections, whereas ***spiral*** is suitable for circular cavities. ***On-part*** is suitable for those cavities having irregular sections with differed corner radii. Here for turbine blade diameter ***on-part*** is suitable. The machining would start from the top most plane and continue toward bottom side by removing material which was left over along with walls and floor. That means while machining 3D length must be considered. Therefore, for the die cavities ***on-part*** is preferred when compared to other methods (Table-5).

4. CONCLUSIONS

The following conclusions are drawn from the present work:

1. Modeling should be done properly for getting required corner radii and accuracy
2. Smooth surfaces on turbine blade are obtained by smoothening the curves that are imported from AutoCAD.
3. Machining time and machined area are depended on tool path selection. The optimized tool for roughing is dia32r2. Optimized method for finishing is ***on part***.

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Figure.8 Unremoved material by dia20r4

Figure.9 Unremoved material by dia32r2

Figure.10 Unremoved material by dia40r6

Table-3: Showing time taken for machining by different methods

Program name	Tool	Method	Step Over(mm)	Stock (mm)	Step Down(mm)	Time Taken (hr)	Tool Path Length (m)	Feed Rate (mm/min)	Non cutting Feed Rate (mm/min)
R32r2	Dia32r2	zig	25	1	2	10.64	127210	2000	3500
R32r2	Dia32r2	zig-zag	25	1	2	9.54	91060	2000	3500
R32r2	Dia32r2	Periphery	25	1	2	10.39	383730	2000	3500

Table-4: Showing and machining times by using different tools

Program name	Tool	Method	StepOver (mm)	Stock (mm)	StepDown (mm)	Time Taken (hr)	ToolPath Length (m)	FeedRate (mm/min)	NonCutting FeedRate (mm/min)
R32r2	Dia32r2	Periphery	25	1	2	10.39	383730	2000	3500
R20r2	Dia20r4	Periphery	25	1	2	10.39	383730	2000	3500
R40r6	Dia40r6	Periphery	25	1	2	10.39	383730	2000	3500

Table-5: showing machining times by different drive methods

Program name	Tool	Method	Step over (mm)	Stock (mm)	Time Taken (hr)	ToolPath Length (meter)	FeedRate (mm/min)	NonCutting Feed Rate (mm/min)
F20bnc-plan	20bnc	On-plane	1	0	5.99	626030	3500	6000
F20bnc-part	20bnc	On-part	1	0	9.86	4308620	3500	6000
F20bnc-spiral	20bnc	spiral	1	0	14.81	8465910	3500	6000