**Research Article**

**NC Machining Simulation for Design and Manufacturing of Integral Impeller Based on UG NX 12.0**

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**Abstract:** Various advantages derive from applying 5-axis machines instead of using 3-axis machines. Main advantage is high flexibility in tool coordination in space and reduction of assembling time for complicated work piece, multiple barricade occurs during set-up process for the further procedures by using only 3-axis machining. Eliminating the extra fixture time maximum parts can be assembled in single or two set-ups by using 5-axis machining.

Integral impeller is absolute example that can be precisely designed and manufactured with high degree of flexibility in tool orientation by using CAD/CAM systems. Impellers are widely use in multiple industries such as aerospace, automobiles and biomedical industries and ship building industries. large amount of methods are proposed through researchers for impeller manufacturing. Most manufacturer use Master CAM, CATIA, UG NX, VERICUT, SolidWorks, Power mill for manufacturing of impellers. To overcome the issue of time consumption this paper explains useful strategies of machining impeller by integrating depth cut distance, change in feed rate and tool diameter by using 3 and 5-axis machining strategy simultaneously. Ball end rough milling and finishing test are conducted on aluminum workpiece. As production cost is directly linked with machining time, which is directly related with feed rate, and machining tool and machining method. This paper also describes validation analysis and brief comparison of time lag with the simulation. 3-axis machining strategy undermine because of its high ability of rigidity as compared to full five axis. Through this study, overall machining time can be reduced to 53.9 percent respectively and the cutting force model for 5axis ball end cutting force prediction is also illustrated with a carbide cutting tool.
Introduction
Various sizes of impellers are specifically designed due to its successive use in the field of aerospace, automobile, marine compressor and turbine component parts. Manufacturing of impeller is highly perplexed process because of its complex geometry. An impeller is a high-speed rotor with the basic requirement of operation at high RPM, high pressure and high temperature environment. Machining of impeller is one of the major influential setups for manufacturing industries because of many aspects, such as manufacturing cost, time, justification and pitfall collaborate in taking decision of transformation from 3-axis milling to 4-axis or 5-axis milling. complex part geometry can be machined on 3-axis machine but it require multiple setups and serious tool collision may occur during machining an impeller blades because table will move along X and Y direction in 3-axis CNC machine but it face limitation of tool movement in z-axis and cannot be freely move to prevent collision.

5-axis machining operation is selected because of its extensive improvement in efficiency and flexibility of tool orientation and reduction of cycle time and tool wear. Several NC machining researchers subsequently tried different methods to reduce the rough machining time by using 5-axis machining technique on impellers. Different studies have focused on creating tool paths to avoid tool collision with the workpiece, tool collision may occur due to local gouging between the cutter's buttock surface and the intended workpiece surface or interference between the tool shank and the workpiece. Y. Heo and W. Kim [1] Attempts to reduce the machining time of 5 axis NC machining by means of an effective, rough cut using tool path generation (TPG) system using 3-axis simultaneous control despite 5-axis NC unit. This method of rough machining on the impeller surface achieves its efficiency by taking the dominance of high-speed 3-axis machining, the rotating and tilting axes of the machine bed are set in advance with defined configuration in a given region. Conventional method tool path exploits all five axis iso-parametrically generate based on certain features curves such as hub curve and shroud curve. The main aim of the 5-axis TPG system is to maintain uniform height of the scallop towards the integrated point of the iso-parametric cutter.

Marciniak [2] confer about the machining time reduction of mold surface_face milling by using five-axis milling machine, if tool trajectory is appropriate adjusted with mold surface. Enhancement in the quality of surface and proficiency of machining method along with better command on the tool is the main intention of this research. This determination further rationalizes the current access in which the verdict of impeller blade is correspondent to the tool geometry with successive elevated efficiency.

Chao, Jun, and Yang [3] determine about the machining sculptured surface by adopting 5-axis machine which is much impressive aside from cramped to arched or extensive concave surfaces. The instant research verify that complicated binary-curved surfaces can also precise effectively and competently machined with sufficient awareness to the intrusion among tool and surfaces.
Quan. L and Yong zhang.W [4] elaborate a software arrangement for generative tool path subjected to etiquette blades surface area of impeller. Though both 3-axis and 5-axis machines have their own recognition. Even if 5 axis machining provides avert device accident with versatility and competency. Nevertheless, the necessary time to produce a single product is still substantial. (Heo Y and Kim W) , and (S. Kawabe and F. Kimura) , [1, 5] examined the roughing procedure of an impeller by partitioning and modified many times machining operation within individual parts Positioned on the top of the hub and shroud for accurate and desired dimensions by using reverse engineering technology for manufacturing. They recommended a tool path propagation process of 3-axis to accomplish CL data for rough machining process. Though extent researches did not ustify the consolidate diverse machining forms approach similarly 3 and 5 axis roughing and finishing operation.

Huiwen Li and Yung Feng [6] describe further access of efficient tool path for machining sculpt surfaces by taking advantage of 3-hub ball end processing. The fundamental intention of this approach is to maintain the uniform scallop elevation beyond the machined faced to the certain existent in order that continual mechanism are confined.

According to (Chuang LC ,Young H T) and Rehsteiner F [7, 8] illustrate the finishing of blades stream section for producing best quality of intrados and extrados with flow performance with highest time utilization in manufacturing development of an impeller. Moreover, impellers finishing problems reasonably concern with quality of geometry as well, despite of machining cost plays vital role in manufacturing process. Flank or point milling can be utilized to high surface distinction, but it also produces scallops in each path. Smooth surface can be generated with censor of scallops in case of single path usage, interference may conceive a divergence between the formal surface and machined surface well, toolpath optimization and tool geometry optimization can be used to shorten these interference errors.

Young H T and Chuang L C, Gerschwiler K [9] implemented peculiar technique five axis rough machining access in which he imposed blade bisection into various segments by applying different depth of cut for the improvement of effectiveness cutting.

It is well recognized that machining time reduce with the increasing amount of speed but increment of energy consumption take place. Oscar Velasquez and Dong-Won Kim [10] contour the application of several response optimization for the brief investigation on switch between machining time and rising energy By using rough machining on a 5-axis impeller to demonstrate the potential counter balance. Appropriate feed rate and cut width to balance exchange between energy and time are also introduced.

Around 70-75 percent rough machining cuts off material because it is not only the important factor to improve efficiency, but it also plays a vital role for the finishing process. Although several research papers suggest of using certain amount of tools with various diameters during rough
machining process, meanwhile this strategy could waste a lot of time. Usually, it is not too much beneficial to use more than two cutting tools specifically for impellers with smaller dimensions.

In this paper, grateful method applied for the reduction of machining time and cost in the impeller manufacturing industries. To compare the total machining time Non-splitter impeller is carried out with two types of machining strategies 3-axis cavity mill and full 5-axis unit, respectively. For this purpose, two types of tool path strategies are used to set up 3 and 5-axes accordingly. The overall machining time for roughing and finishing is formally contrasted with 3-axis cavity friction and full 5-axis machine alone, further details are discussed in this paper.

Materials and methods

2.1 Geometrical features of an Integral impeller
A non-splitter type integral impeller is employed the main principal distinction between the splitter and non-splitter impeller is the impeller blade configuration. The splitter type impeller has splitter blades of different design that overlap with fundamental blades, although the main objective or feature of the impeller remains the same as the wise non-splitter type impeller. Typical non-splitter impeller consists of eight similar swift blades and suction surface, pressure base, leading and trailing edge, blends, hub top, respectively. A rough-cut machining strategy and tool path of impeller consist of 3-axis cavity milling and fully five axis milling machine approach for improving machining time.

![Figure 1. Surface model of integral impeller](image)

2.2 Path planning for Roughing and Finishing strategies
Increasing the machining time roughing plays the most important role in the machining process for removing the bulk of the stock material. Metal should be removed as much as possible for time
improvements because it affects the performance of machining of impeller during the finishing process. Various method of machining strategy have applied in the research ,which consists of roughing strategy using 3-axis Cavity milling and fully 5-axis machining approach .Cavity Milling operations boost the productivity and reduce chatter and scrap it also produce elegant surface in fewer steps these are the main advantage of using cavity milling .In cavity milling tool path approximately remains short because of minimal tool path to horizontal it may leave more stock then desired ,we can reduce the remaining stock by modification of appropriate cut level parameters.

5-axis milling have distinct geometry as compared to 3-axis milling. Three-dimensional tool movement happens along the X - Y-Z coordinates. Two additional rotational movements as lead and tilt angle and three translation movements exist in 5-axis milling. Spontaneous unreformed chip thickness for ball-end tool can achieved as follow fig-2.

Assume a two fluted ball-end mill for which the cutter's cutting flute is presumed to be adjusted with the dynamometers X-axis and moves along a random direction. The angle between Y-axis of dynamometer Y_d and the cutter's first cutting flute is defined as the reference rotational angle (Gama r) for this location. The gamma rotation angle is he angle between the flute to cut and the direction to cross feed.

\[
(t_c)_k = t_x \times \sin(\beta) \times \sin(\alpha) \times \cos(\Omega) \pm t_x \times \cos(\alpha) \times \sin(\Omega)
\]  

\(1\)

To achieve the conversion from the coordinate frame (α-β-t) to the conversion matrix A of the feed coordinate is shown as

**Figure 2.** Rotatory coordinate transformation angles
\[
A = \begin{bmatrix}
-Sin (\alpha) \times Sin (\beta) & -Cos (\alpha) \times Sin (\beta) & -Cos (\beta) \\
-Sin (\alpha) \times Cos (\beta) & -Cos (\alpha) \times Cos (\beta) & Sin (\beta) \\
Cos (\alpha) & -Sin (\alpha) & 0 \\
\end{bmatrix}
\]

These matrices can be used to convert the feed coordinate system to the rotatory dynamometer frame

\[
B = \begin{bmatrix}
Cos(\Theta_R + \Theta) & -Sin(\Theta_R + \Theta) & 0 \\
Sin(\Theta_R + \Theta) & Cos(\Theta_R + \Theta) & 0 \\
0 & 0 & 1 \\
\end{bmatrix}
\]

\[
C = \begin{bmatrix}
Cos(\Theta_R) & -Sin(\Theta_R) & 0 \\
Sin(\Theta_R) & Cos(\Theta_R) & 0 \\
0 & 0 & 1 \\
\end{bmatrix}
\]

With the known reference rotational angle, forces in (X_d-Y_d-Z_d) can be determined as,

\[
\begin{bmatrix}
dF_X \\
dF_Y \\
dF_Z \end{bmatrix}_{RCD} = [B][A] \times \begin{bmatrix}
dF_X \\
dF_Y \\
dF_Z \end{bmatrix}
\]

In the case of uncertain rotational angle or complicated cutter geometry, the angle of misalignment can be determined by means of a simple slot cutting check

\[
\begin{bmatrix}
dF_X \\
dF_Y \\
dF_Z \end{bmatrix}_{RCD} = [C][B][A] \times \begin{bmatrix}
dF_X \\
dF_Y \\
dF_Z \end{bmatrix}
\]

In this approach two identical impellers are used to measure the machining time lag. 3-axis cavity rough strategy is used to remove the bulk of material from the stock in this step of roughening the 5-axis machine table is fixed. After first stage of roughing stage 5-axis tool path machining is applied on the impeller for Hub finishing, Blades finishing and Blends finishing strategies are applied for the removal of uncut material from the machined impeller respectively. 5-axis machining is applied on the impeller for smoothing of impeller surface. This procedure takes shorter time because the quantity of uncensored material left over is less.

However, it is not quite easy to remove large amount of material from a rough machining area because of highly twisted geometry of blades. All roughing and finishing processes are performed in a single 5-axis unit in this method. Hence, rough cut and finishing of blades and blends has to be well established in case of maximum metal removal rate without occurrence of any collision between the tool and impeller surface.
Results and Discussion

1.1. Simulation

Aluminium was selected as work piece material because of its high strength as most prominent used material for manufacturing of aircraft fittings and automobile parts, worm gears. Fig-4 shows the prepared raw stock with 53 mm height and 9 mm inner radius, 46 outer radius, 10 mm hub thickness. Fig-1 shows impeller design of non splitter impeller which has 8 swift blades.
Carbide coated ball end mill cutter with a diameter of 6 mm and a cutter length of 75 mm with a shank length of 45 mm with a constant depth per cut of a maximum distance of 4 mm, a spindle speed of 5000 rpm, a feed rate of 500 mm pm for a 3-axis cavity and a complete 5-axis rough milling and hub finish were selected for the maximum permitted traveling distance between impeller blades without collision.

![Figure 5.](image1)

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Second ball end cutter of 4mm diameter and 50 mm length with taper angle of 6 mm with 2 mm maximum cut step, 250 mmm feed rate, 6000 rpm spindle speed respectively were applied to optimize the cutting parameters in milling. simulated toolpath is generated by using NX12.0 CAM software. output of simulated machined workpiece are shown in fig-6.

![Figure 6.](image2)

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In simulation-based result, total machining time taken is compared to rough and finishing strategy using full 5-axis machining strategy. **Table-2:** describes the comparison of machining time, tool path parameters, spindle speed, feed rate and overall weight.

![Figure 7](image-url)

**Figure 7.** (a) 5-axis blades finishing “After 3-axis cavity” (b) Full-5 axis blades finishing Machining time of complete 3-axis cavity roughing (first stage) with using 5-axis finishing (second stage ) takes 13.2% less time as compared to use of full 5-axis roughing and finishing strategy . The findings shown are based on the elimination of weight volume between the blades and the impeller hub comprehensive cutting force and cutting model with 5-axis are shown to be in good agreement with simulation work.

![Figure 8](image-url)

**Figure 8.** (a) 5-axis blends finishing “After 3 axis cavity” (b) Full 5-axis blends finishing

1.2. Verification of simulation
A stock material normally cut by lathe machine and then fixed it on the table of 5-axis machine tool. The rough cut on 3-axis milling machine tool (cavity mill) also used for decrease of cutting tool cost in UG CAM in which rulled surface are pressure and suction surface respectively.

Fig-5: Shows the non-splitter impeller that consists of 8 blades with 45 degree angle between the blades in which clearly found that a large number of material remains uncut around impeller because during 3-axis cavity milling spindle shaft does not have any swirling capacity with its cross section twisted along Z-axis. Further remaining material were removed by 5-axis hub finishing, blades and blends finishing respectively due to variable tool axis rotation shown in Fig-7: and Fig-8: accordingly. Machining simulation results of two stage machining and fully 5-axis machining strategy are discussed in Table 01: with validation results respectively.

Two stage technique machining time takes 53.9 percent less than using complete 5 axis machining which has been expended to incorporate design feature. A machine data file or required NC code of 5-axis machine have generated through post process as shown in Fig 9.

Table 1. Simulation parameters and results

<table>
<thead>
<tr>
<th>Stock</th>
<th>S.N.</th>
<th>Machining Method</th>
<th>Time (min.)</th>
<th>Tool Dia.(mm)</th>
<th>Tool Length (mm)</th>
<th>Spindle Speed (RPM)</th>
<th>Feed Rate(mm/ m)</th>
<th>Initial Weight (N)</th>
<th>Final Weight (N)</th>
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<td>Stock</td>
<td>1 Stage</td>
<td>Cavity Rough Milling</td>
<td>16.34</td>
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<td>75</td>
<td>5000</td>
<td>500</td>
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<td></td>
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<tr>
<td>Stock</td>
<td>2 Stage</td>
<td>5-Axis Finishing</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td>Stock</td>
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<td>Hub Finishing</td>
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<td>181.27</td>
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<td>6000</td>
<td>250</td>
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<tr>
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<td>Blends Finishing</td>
<td>69.2</td>
<td>4</td>
<td>50</td>
<td>6000</td>
<td>250</td>
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<tr>
<td>Stock</td>
<td>Total</td>
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<tr>
<td>Stock</td>
<td>1 Stage</td>
<td>Full 5 axis Rough Milling</td>
<td>124.13</td>
<td>6</td>
<td>75</td>
<td>5000</td>
<td>500</td>
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<tr>
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<tr>
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<td>75</td>
<td>5000</td>
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Conclusion
The computer-aided technology for manufacturing of impeller are discussed in this research. Boundary representation cutter work piece and tool geometry based on a solid model is presented for the forecast cutting force in 5-axis ball-end mill. As machining tool cost and machining times plays a financially vital role in industrial sector. The main purpose of this research is to illustrate a useful method that can effectively diminish impeller-manufacturing time by integrating 3 and 5-axis machining method. A single non-splitter type with small twisted blades is simulated. It can be examined through simulation result that total machining time have been effectively reduced up to 53.9%. It is most important to note that machining time reduction varied with the geometry and complex form of the impeller blades. The findings are successfully checked by the impeller simulation, which shows that the combined 3-axis and 5-axis rough and finish machining is beneficial for the machining time. The prospective approach is useful with the efficiency of the NC system (3 + 2) axis. The configuration of this research is found very convenient for the machining of impeller with generation of suitable tool path and describe that during milling strategy by using the cavity mill process with three axis milling machine tool can increase manufacturing efficiency as compared to full five axis because of high rigidity of 3-axis milling.
References


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Dedication

Not mentioned.

Conflicts of Interest

There are no conflicts to declare.

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