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Integrated approach for milling impeller parts

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ABSTRACT
This paper presents an integrated approach for 4-axis milling impeller parts. Impeller blades are designed with a ruledsurface which is twisted to achieve the required performance. It can affect as an undercut or overcut on the part surface and collisions during machining. A method to manufacture impeller parts on a 4-axis machine is presented. Impeller 3D CAD models are implemented using geometric design parameters and CAM for 4axis Point Milling and Flank Milling are prepared under the SIEMENS UG NX. A postprocessor for desktop 4-axis CNC Mill using MATLAB® and a virtual machine tool simulator using VeriCUT® has been developed. Actual machining for impeller blades are done with Desktop 4-axis CNC Mill for the verification and validation purposes.

KEYWORDS
CAD; Design for Manufacturing (DFM); Integrated Design; Optimization

1. Introduction

Advanced Technology is emerging nowadays to minimize time and scrap which is major concern in industries. Most complex models can be fabricated by CNC machines like turbine blades, impellers, and propellers [7]. Recent advances in computer numerical control (CNC) machining technologies are discussed in [4]. The blade of impeller is usually designed with a ruledsurface which is normally twisted in design to achieve the required performance. It can affect as an undercut or overcut on the part surface and collisions during machining. The issues to satisfy the quality requirements, to reduce the machining time and to avoid the occurrence of collision become an integral problem [9]. The multi-axis toolpath generation using flank milling method has been discussed for the ruledsurface of helical rotor [2]. Authors discussed 5-axis machining on ruledsurface in [3]. Post-processing technology is the key to CNC automatic programming technology and important module of the CAD/CAM system. The NC machining Post-Processing technology based on Siemen UG NX is explained in [5]. Post-processing of tool path for multiaxis milling machines, generated by the CAD/CAM system is a critical activity in engineering work [11]. The technological process is important to enter the process of manufacturing of various precision engineering components of complex shape designed for the needs of automotive and aerospace industries [1]. A specialized program supporting new approach to integrated design and manufacturing processes in CAD/CAM systems plays a vital role in concurrent engineering concept, particularly when virtual processes are concerned [10]. Companies are always looking for new ways to increase productivity. 4-axis and 5-axis machines are just one of many alternatives that could possibly help increase productivity [6]. An excellent teaching contents and methods are discussed by [8]. In the process reform construction, the integration of product form design, analysis and automatic NC programming can drive the CAD/CAM theory teaching.

This paper describes an integrated approach from design to manufacturing using CAD/CAM technologies and developed post-processing program and virtual machine tool simulator. The remainder of the paper is organized as follows. First, an integrated for milling impeller parts is presented. Following to the overview of integrated approach, CAM for Impeller parts 3D CAD Models using SIEMENS UG NX is explained. This section also briefly describes the software tool used for the function listed. After the previous section, Development of Post-Processor for Desktop 4-axis milling CNC is presented. Development of Virtual Machine Tool for Desktop 4-Axis CNC Mill is shown. Finally, in the last two sections, results and discussion is discussed and finally a conclusion.

2. An integrated approach for milling impeller parts

The main objective of an integrated approach (See Fig. 1) is to satisfy the quality requirements, to shorten lead time

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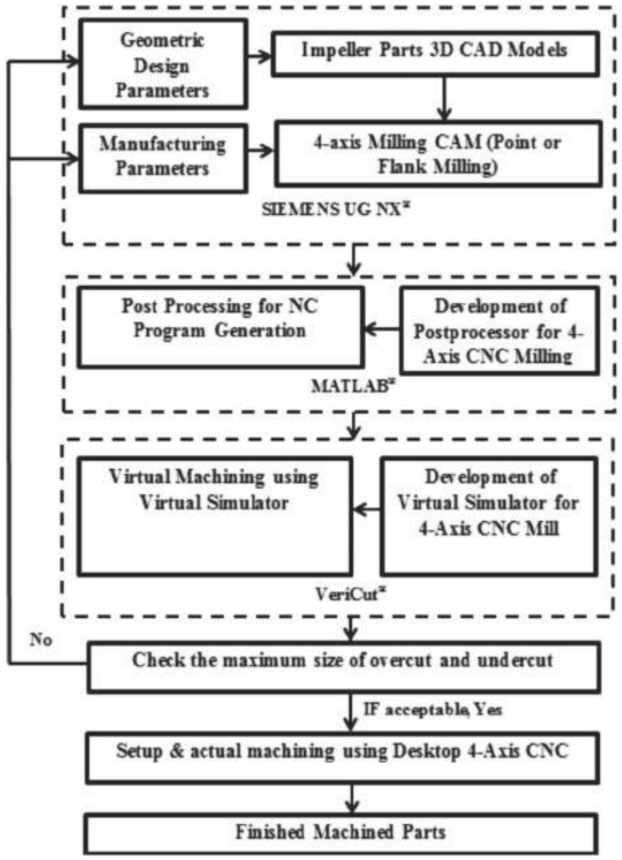


Figure 1. An overview of Integrated Approach for Milling Impeller Parts.

of pre-manufacturing and to avoid the occurrence of collision. Impeller parts 3D CAD models are implemented by geometric design parameters and 4-axis milling (point milling and flank milling) is applied for manufacturing impeller blades. Under the MATLAB® environment, a post processor is developed using transformation equations from workpiece coordinate to machine coordinate. A virtual simulator for desktop 4-axis CNC Mill is implemented using CAD models of machine tool. Verification and validation are done by virtual simulation and actual cutting. Maximum size of overcut and undercut are checked after virtual cutting. If designer satisfy the result, actual cutting will be performed using machine and workpiece setups. If not satisfied, design and manufacturing parameters will be reviewed again. A finished model will be processed until the acceptable level is reached. Finally, actual machining will be finalized.

2.1. CAM for impeller parts 3D CAD models using SIEMENS UG NX

The impeller part is a perfect example of a part which can be very efficiently designed with help of CAD/CAM technologies. The blade has a very complex geometric shape which makes it difficult to design without help of CAD/CAM systems like Siemens UG NX. The impeller 3D CAD models are implemented using the geometric constraints approach in UG NX. Main steps for creating Impeller parts 3D CAD Models using SIEMENS UG NX are shown in Tab. 1. Flank milling is applied for the impeller part type 1 and point milling is applied for the impeller part type 2. The variable streamline operation has been used to mill the blades (See Fig. 2). The projection vector is selected as toward line which means XC direction and the tool axis is selected as away from the line. Then the tool always move parallel to the blade's wall as shown in the Fig. 3.

Variable contour operation has been used to mill the body of the impeller part type 2 (See Fig. 4). Surface area selected as drive method, Normal to drive selected as projection vector and 4-axis relative to drive selected as the tool axis. Fig. 5 shows how to define the tool axis in the 4-axis relative to drive option.

2.2. Development of post-processor for desktop 4-axis milling CNC

This section describes how we apply inverse kinematics for post-processing. The kinematics chain diagram (Fig. 6) is drawn following to the real desktop 4-axis CNC Mill (Fig. 8). Fig. 7 presents a virtual model of desk 4-axis CNC Mill which will be used for the development of virtual simulator. Coordinates of frames shown in Fig. 9 are set for the transformation matrix equations (see Equations (1–14). Inverse kinematics is used and a program is developed using MATLAB®.

- O_1 to O_2 Coordinate Transformation

$$X_2 = X_1 + X_2^1 \tag{1}$$

$$Y_2 = Y_1 + Y_1^2 \tag{2}$$

$$Z_2 = Z_1 + Z_1^2 \tag{3}$$

- O_2 to Rotation A

$$X_2(A) = X_2 \tag{4}$$

$$Y_2(A) = Y_2\ Cos\ A - Z_2\ Sin\ A \tag{5}$$

$$Z_2(A) = Z_2\ Cos\ A + Y_2\ Sin\ A \tag{6}$$

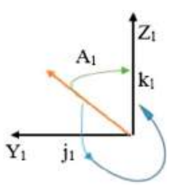
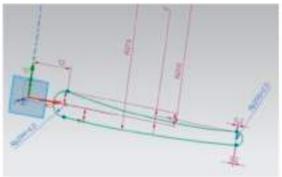
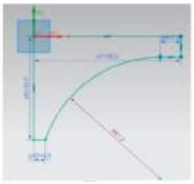
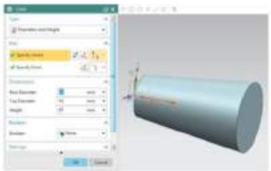
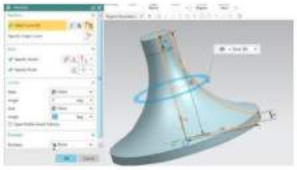
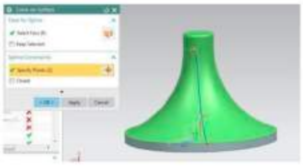
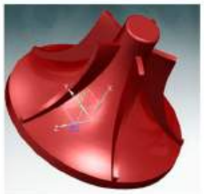


Table 1. Main steps for creating impeller parts 3D CAD Models using SIEMENS UG NX.

Step	Impeller Type 01	Impeller Type 02
1	 Sketch of the blade	 Sketch of the body
2	 Create Body of the impeller	 Revolve the body
3	 Extrude the blade	 Draw shape of the blade
4	 Completed model	 Completed model

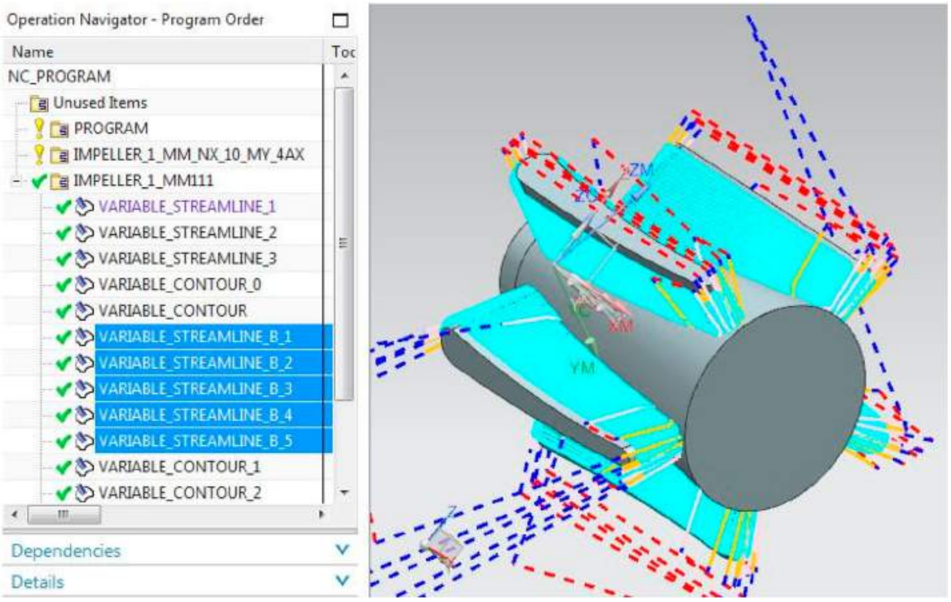


Figure 2. CAM Tool Path Generation (Flank Milling).

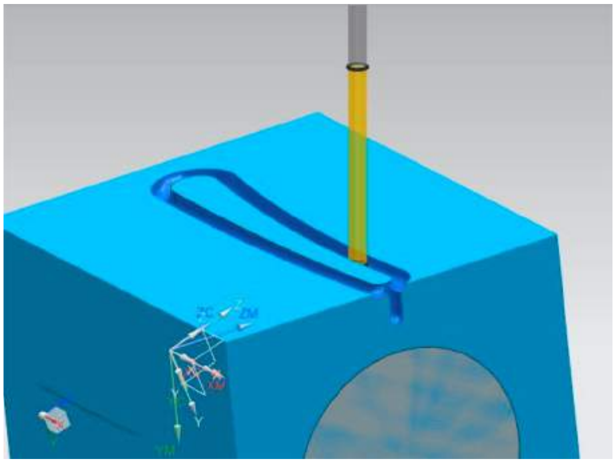


Figure 3. Movement of the tool.

$$A_1 = \arctan\left(\frac{j_1}{k_1}\right) \tag{7}$$

$$A_2 = 2\pi - A_1 \tag{8}$$

- O_2 to O_3 Coordinate Transformation

$$X_3^w = X_2(A) + X_2^3 + X \tag{9}$$

$$Y_3^w = Y_2(A) + Y_2^3 + Y \tag{10}$$

$$Z_3^w = Z_2(A) + Z_2^3 \tag{11}$$

- O_3 to Tool Coordinate Transformation

$$X_3^T = 0 \tag{12}$$

$$Y_3^T = 0 \tag{13}$$

$$Z_3^T = Z_T^3 + Z \tag{14}$$

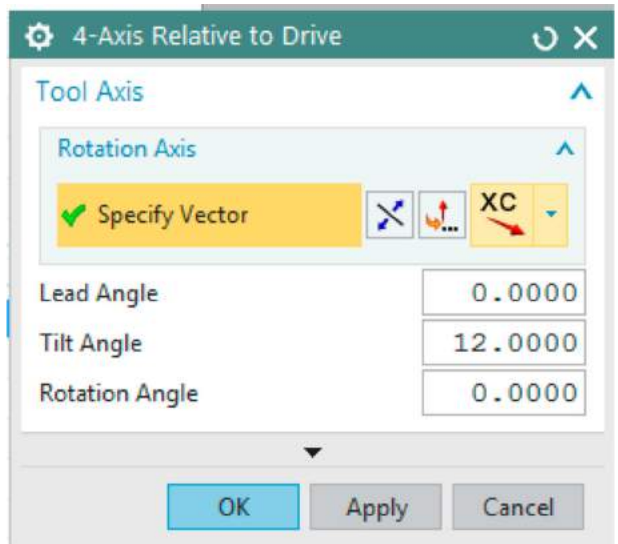


Figure 5. Define tool axis.

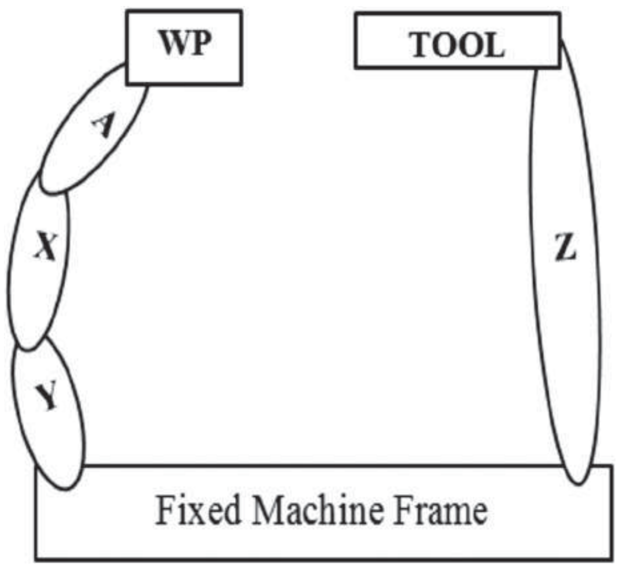


Figure 6. Kinematics Chain Diagram.

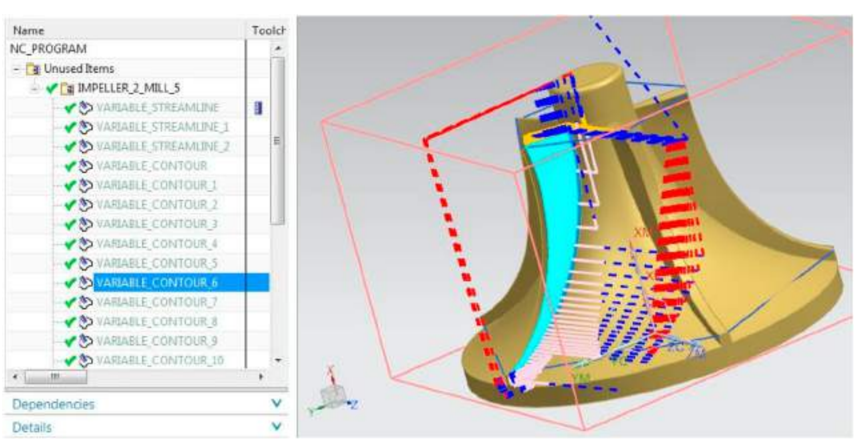


Figure 4. CAM Tool Path Generation (Point Milling).

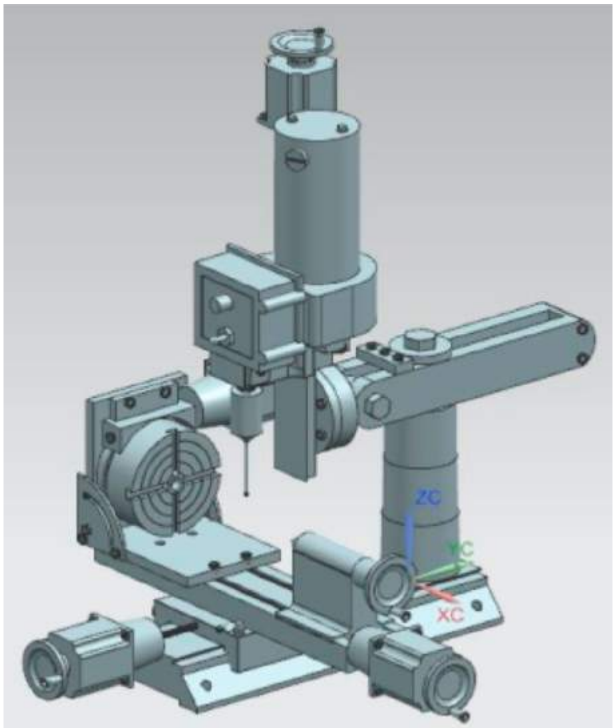


Figure 7. A Virtual Model of Desktop 4-Axis CNC Mill.

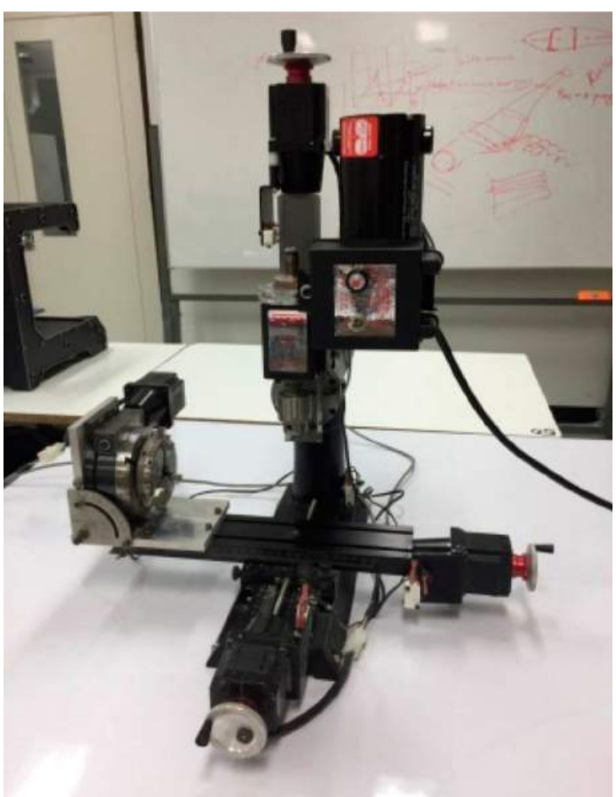


Figure 8. A Real Desktop 4-axis CNC Mill.

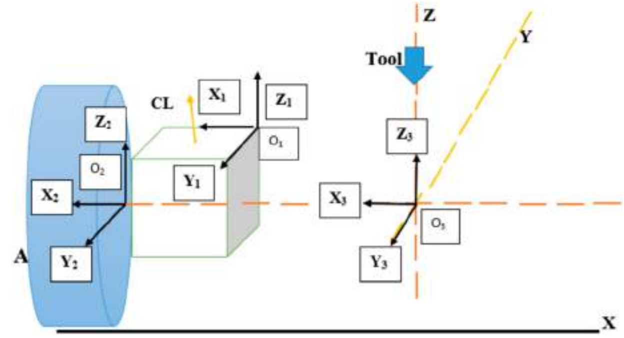


Figure 9. Coordinates of frames for Post-processing.

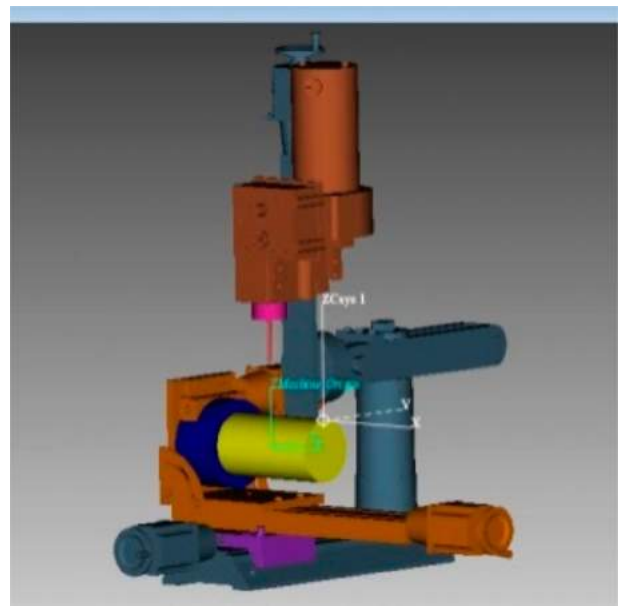


Figure 10. Completed model implemented in VeriCut®.

2.3. *Development of virtual machine tool for desktop 4-Axis CNC Mill*

A virtual machine tool (see Fig. 10) is constructed using VeriCut® after importing CAD models of Desktop 4-axis CNC Mill. Kinematic links are set and machine setup and parameters are set following to the real CNC machine. Verifying calculation's results by using postprocessing under Matlab and virtual simulation test under the Vericut are analyzed first. After moving three translational axis and one rotational axis from calculated values, the CL vector coincided with the tool (See Fig. 11–12).

After verification and validation of the model, virtual cutting on impeller parts (Type 1 & 2) are performed (See Fig. 13 & 14).

3. Results and discussion

Tab. 2 shows the parameters and results of 4-axis machining on impeller blades. By using this approach, designer

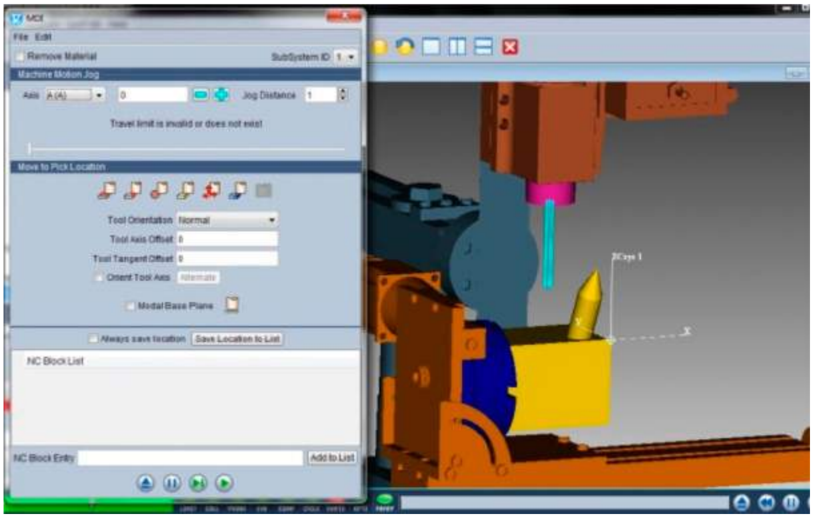


Figure 11. Initial Position of the machine.

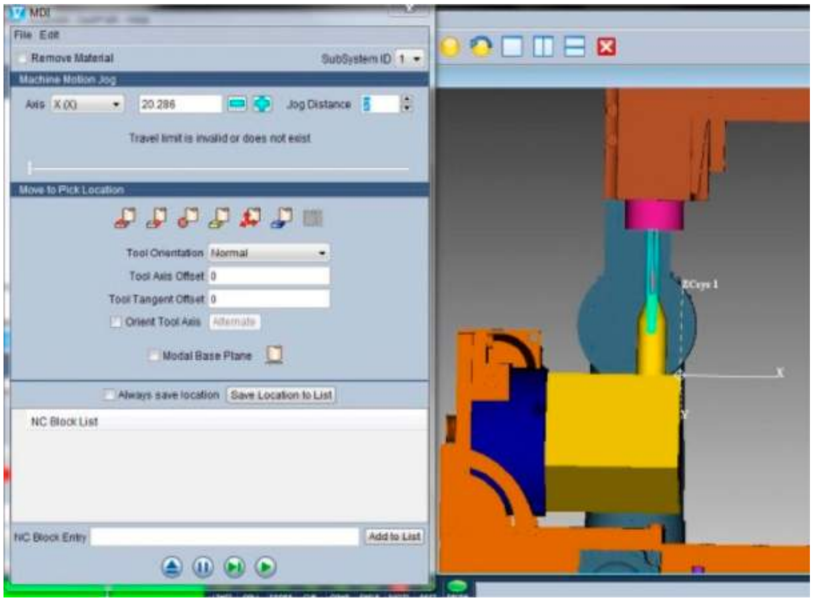


Figure 12. Final Position of the machine.

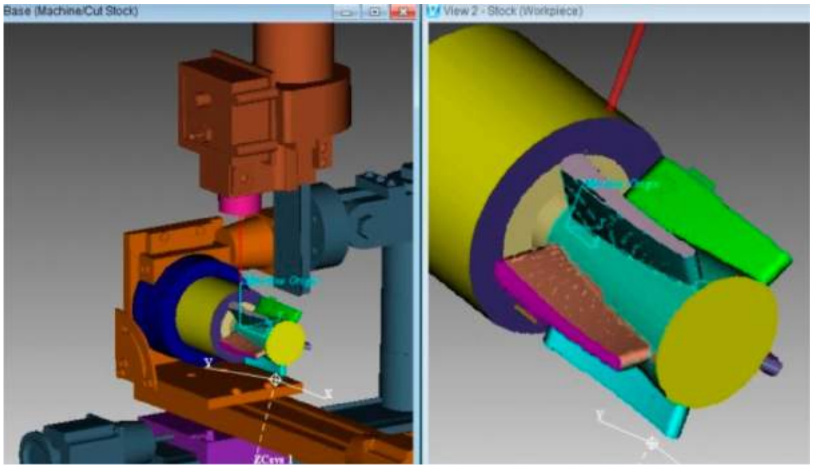


Figure 13. Virtual Cutting Simulation for Impeller Type 1.

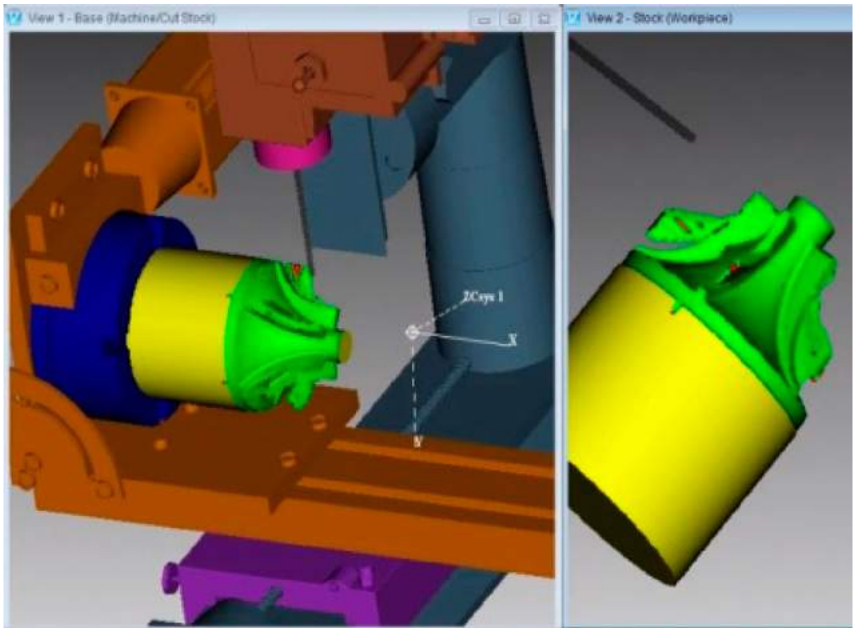
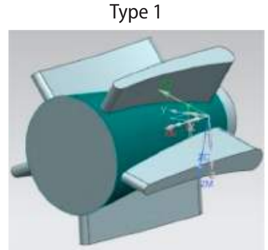
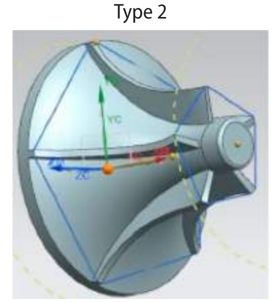


Figure 14. Virtual Cutting Simulation for Impeller Type 2.

Table 2. Result and parameters of 4-axis machining impeller blades.

Impeller 3D CAD Models using geometric design parameters	Impeller Model Type 1	Impeller Model Type 2
		
Manufacturing Parameters set for toolpath generation in CAM & Actual Cutting		
Type of Milling	Flank Milling	Point Milling
Drive Method	Streamline or Surface Area	Surface Area
Projection Vector	Toward Line (+XC)	Normal to Drive
Tool Axis	Away from Line (+XC) or Swarf Drive	4-axis relative to Drive (+XC)
Feed rate (mm/min)	80	90
Tool Dia (mm)	3 mm Flat End Mill	3 mm Flat End Mill
Results of Actual Cutting on an Impeller Blade		
Finished Blade after Actual Cutting on Desktop 4-axis CNC Mill		
Machining Time (min/Blade)	31	50
Maximum Size of undercut (mm)	0.64	0.31
Maximum Size of overcut (mm)	4.98	4.77

can check the output of maximum undercut and overcut until target is achieved.

4. Conclusions

An integrated approach for milling impeller blades are discussed and presented. A post-processor for desktop 4-axis CNC Mill and virtual machine tool simulator has been developed for a real 4-axis CNC. By using CAD/CAM technologies and developed programs, actual cutting on impeller blades are performed. Programs are verified and validated. By using this approach, reducing lead time, increasing quality and avoiding collision can be achieved. Besides this advantage, this tool can be used for teaching students as an educational tool.

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