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MODELING AND CAM SIMULATION FOR MANUFACTURING OF 3D SHROUDED IMPELLER USED IN CENTRIFUGAL COMPRESSOR

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ABSTRACT

Impeller is the most fundamental component of any turbo machinery, the complexity of its design varies from application point of view. Design and manufacturing of such components is a research interest with varying difficulty in the component geometries with complexity and between ranges of materials. To accomplish such complex task engineers need knowledge of design for manufacturing kind of tools which equips latest processes like scoop milling technology. To implement such new technologies one needs a pre planning right yet from design phase. To accommodate such complications in design phase tools like NXCAD and NXCAM modules has been used for modelling and tool path generation which is used to simulate manufacturing of a 3D shrouded impeller used in centrifugal compressor to alter the flow of fluids (gasses/ liquids). A three dimensional shrouded impeller has been modelled using NX CAD and tool path has been generated in view to simulate the manufacturing profiles of scoop milling process with the guided programmable pre and post processing by using NX CAM. By using this simulation, manufacturing of parts produced by CNC machine in computer can be virtually simulated which provides error free manufacturing of impeller from block to functional part.

Key words: *3D shrouded Impeller of centrifugal compressor, NX CAD/CAM, CNC simulation*.

1. Introduction

In a centrifugal compressor, energy is transferred from a set of rotating impeller blades to the gas. Advantage of centrifugal compressor is that they deliver high flow capacity per unit within installed space and weight that provides good reliability, and requires considerably low maintenance than reciprocating compressors. However, changes in the gas conditions may affect the performance characteristic of centrifugal compressors more than the performance of reciprocating compressor. The use of shrouded impeller is predominant in the gas and petrochemical industries to prevent from undesired spark ignitions due to thermal expansion of shaft in heavy load conditions. For such situations shroud will help to prevent the undesirable contact between blade and casing of the centrifugal impeller. The quality of impellers directly affects the performance of these machines which needs precision.

Design and manufacturing of an impeller deals with difficulty because of their complex geometry of vanes or blades. These are the machines which uses the centrifugal force of a fluid generated by the rotating impeller. For manufacturing such an impeller needs an accurate data, while modeling and digital prototyping for instances to provide related simulation data of the prototype which will later be manufactured with precision. Such data can be collected from virtual simulation of yet to be manufactured product in NX environment. NX CAM has been utilized for such simulation before the manufacturing of a functional device.Fig. 1 depicts the view of 3D shrouded impeller Rong-Shine Lin et al., introduced a paper proposed an expository approach for arranging a productive tool path for the machining free form surfaces on 3-axis milling machines.

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Fig. 1 3D shrouded Impeller

This technique has three stages: (1) the evaluation of the tool path interval, (2) the transformation from the path interval to the parametric interval, and (3) the blend of productive tool path arrangement [1]. Shang- Liang Chen et al., investigated about the advanced CAD/CAM technologies for manufacturing of impellers in centrifugal compressors. Reverse engineering, unigraphics NX (CAD/CAM) software, coordinate measuring machines (CMM) technologies were discussed in this paper. Finally they concluded that rough milling with the cavity mill, three axis milling machine tool which enhances the manufacturing efficiency and five axis machining of impeller blades which gives the good accuracy [2]. C. Tung et al., displayed an entire methodology for tool path planning and blade machining in 5 axis manufacturing. The genuine cutting contact and cutter areas can be controlled by lead and tilt edges. A genuine manufacturing process was proposed to separate the operation into three regions with five phases and to change the local tool orientation with an interactive algorithm [3]. Antonio Piratelli et al. presented a study of CAD/CAM processing of free-form surfaces, and steps involved in measurement, CAD model reconstruction, and CAM manufacturing were addressed and the deviations between points of the part surface and fitted CAD model were determined and well thought-out as evaluation parameters [4]. Huiwen Li et al., displayed another approach for assurance of proficient tool paths in the machining of molded surfaces utilizing 3-hub ball end processing. The principle objective is to keep the scallop stature steady over the machined surface to such an extent that repetitive instrument ways are limited [5]. Geng Lin et al., presented a paper in regards to obstruction free tool path produced in view of a heuristic going for better machining productivity.

For hazardous stances without of bound stance change on this device way, a mixture PSO (Particle Swarm Optimization) calculation is created to revise them [6]. Lo Chih-Ching et al., presented a new approach to CNC tool path generation, computer-aided design methods based on linear, curve, and surface interpolators are presented and analyzed, respectively [8].

2. Methodology

2.1 Method/ Approach

The procedure of this work involves the following steps:

Modeling of 3D Shrouded impeller by using NX CAD.Generating tool path and its simulation by using NX CAM. This work presents the development of tool-path generation for impellers using specialized milling technique which can be easy to use even for an inexperienced NX user. However, the study has its own limitations with its application, which uses specialized tools for material removal from a piece of block.

3. Modeling Of 3D Shrouded Impeller By Using NX CAD

Shrouded impeller comprises of hub or crown, to which shaft is fixed, Shroud ring or band, and a series of blades, which later fixed one end at the hub and another is fixed to shroud ring. The blades are spanned on the hub. Shroud ring can be viewed on top of the blades.

First of all the hub section is sketched and later its surface is generated using rotate option, so that hub is modelled. The hub model is presented in Fig. 2.

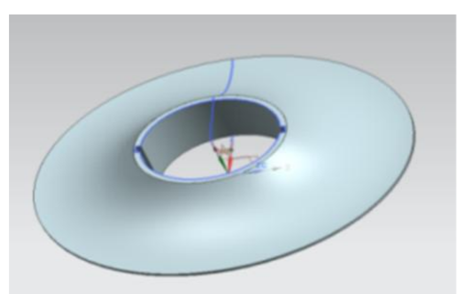

Fig. 2 Hub surface modelling

Blades are spanned over the hub. An outward curved blade section that is drafted on the hub surface by using characteristic curve feature, which is later used as a representative element to create a circular pattern with required number of blades as per design requirement.

The steps for required for a CAD model creation of impeller blade are as follows:

1. Creation of a characteristic curve using closed spline curve method.
2. Create a spline curve using the function [create curve] in UG CAD platform.
3. It consists of two functions [through points] & [create curve] which is selected to generate a closed curve. Always the blade curves are created using closed curves, so that making surfaces can become easy.
4. Selection of the function [points from file] to import the design data points into the CAD module that are necessary in the construction of blade surfaces later its boundary curves.
5. Once the spline curve have been generated, later the section curves that creates free-form surfaces are generated by using the following functions [tool box] → [free-form feature] → [through curves], generating 4 characteristic curves with direction display of each curve creates surfaces.
6. Once the blade surfaces are generated then the shroud is placed over its top section.

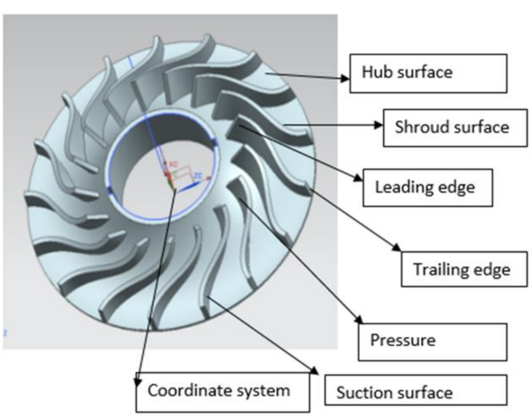

Fig.3 Hub with integrated blades

Shroud as an attachment component is sketched and later modelled using rotate option by rotating the base sketch of the shroud, so creating the shroud element which is placed over the blades top surface.

By using assembly module of NX CAD we assemble both hub-blade element and shroud element. The complete model of the impeller which is assembled in assembly module of the CAD environment, is shown in the Fig. 5.

In Fig. 3, Fig. 5 the definitions of respective surfaces have been presented, the details of elements have discussed in the modelling section.

This completes the modelling section and followed by generation of the tool path and its simulation in the CAM module. The complete simulation will be performed on a single block which after machining will transform into a functional impeller.

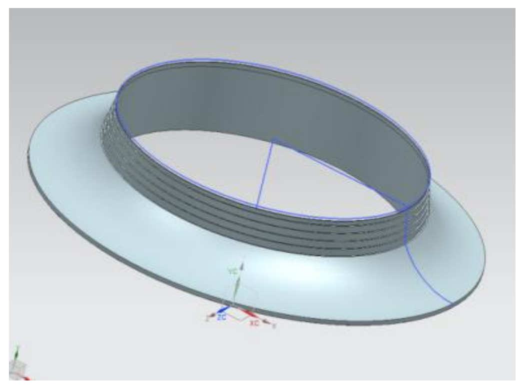

Fig. 4 Shroud surface modelling

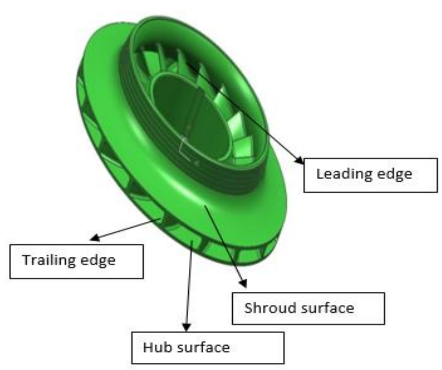

Fig. 5 Complete assembly of 3D Shrouded Impeller

4. Tool Path Generation Procedure For 3D Shrouded Impeller By Using NX CAM

Machining of an impeller straight from a block is so difficult because of the complex local curvatures of the blade surface both at suction as well pressure side.

Definitions for machining of a blade are ordered in nature by surfaces and boundary curve features.

A tool with pointed curve can reach the cut location where the local pivots are used for the purpose of removing material. This is performed with a specialized milling technique which scoops out the material from a piece of block. This is the primary removal procedure where after the finishing process is also performed.

To maintain the required surface finish secondary or tertiary operations are required. For this operation specialized tools are required. Finishing procedure is the last step in machining the complete impeller as a module from a raw single piece of blank.

This method proves to be appropriate as it machines out with a large cutting rate and improved surface quality for which the cutter need to pass a line of contact. A geometrical model based on the canonical representations in curvilinear coordinates has been developed for the same purpose where the blade shape is obtained from straight line elements on both the surfaces.

The machining of the impeller needs a complex curve generation for tool paths to process the material and create space between the blades which indeed creates the hub and shroud inner surfaces. Cavity mill technique is used for material removal process and creates the space between blades. For this operation a ball mill tool is used for machining the impeller. As each collision of the tool to remove the material is different the machining can be carried out using an appropriate algorithm based on NX CAM platform.

Here the machining of the impeller is carried out in three steps which are roughing, semi-finishing, and finishing. For this purpose, defining the machining area is important to generate a tool-path. Here the NX graphical interface is used so that the surface model generated in NX CAD module becomes the input to NX CAM module.

Definition of machining area is discussed as follows:

- NX CAD is used for defining machining area so, the surface model becomes input to NX CAM.
- From Fig – 6, that defines the boundary curves of hub, shroud with their respective boundary curves and blade with surface and boundary curves.

First machining coordinate system is selected for the cavity milling process. In this process one need to give cutter contact point, cutter location point, cut area and cut pattern and selection of tool axis data as the input to move forward for machining operation. After selecting the machining coordinate system, selection of geometry, type of machining operation, specifying the part model, specifying the boundaries of the raw material to be processed, selecting the cut area are the series of operations performed in NX CAM platform.

The commands required for placing the data such as specifications of the impeller geometry, step-over, diameter of the ball mill tool, federate, tolerance required for machining and machining allowance before the tool path is generated.

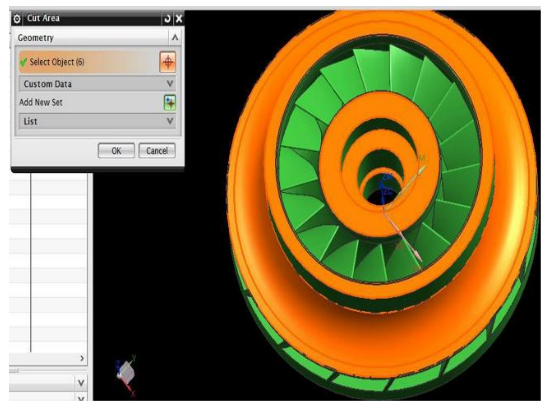

Fig. 6 Selection of cut are with surface and boundaries curves

Fig. 7 details the manufacturing machining environment which shows the frame of tool path generation.

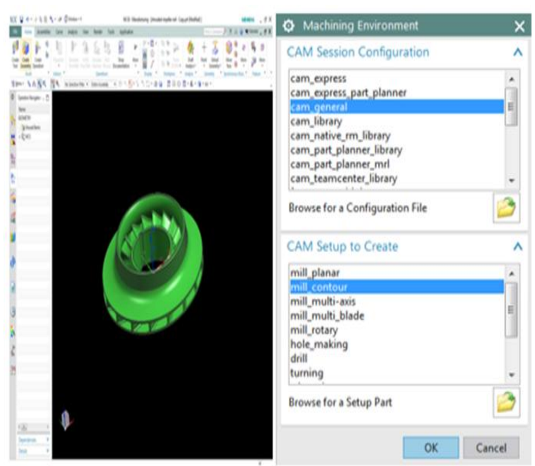

Fig. 7 Frame that shows tool-path generation module

For cavity milling to be performed, ball mill cutter is selected with required parameters and tool axis with path and method settings as well cut pattern and cut levels are defined in the next step. These parameters depends upon on the maximum distance,which calculates automatically as shown in Fig. 8.

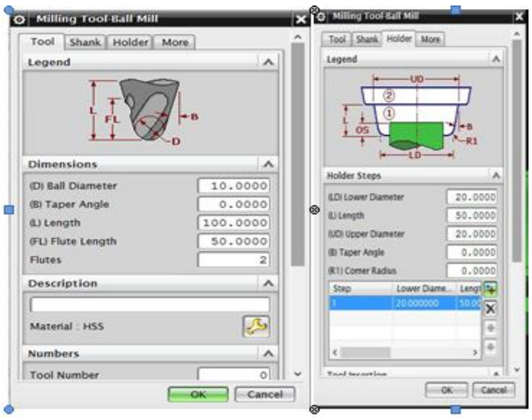

Fig. 8 Specifying a Tool Axis

After specifying the parameters, speed and feed are defined. Now with motion output type which may be a line or arc is selected to give a motion to the tool. Then program format NC or APT format is essential to specify and select the required format before further processing. By clicking GENERATE option the tool path can be generated according to the give input values. The tool path generation and its vector directional representation has been shown in Fig. 9 &Fig. 10.

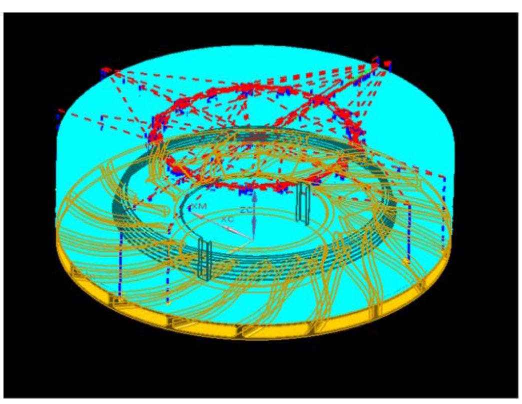

Fig. 9 Generation of tool path Step for shroud

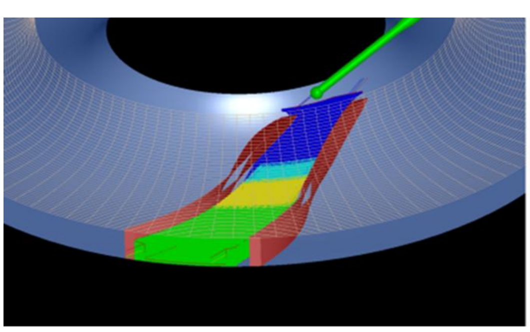

Fig. 10 Generation of tool path Step for vanes

The tool path that has been generated is verified by the 3D dynamics module which virtually performs the operation of the process by which the user can check and justify the tool path that has been generated automatically from the given input values. Fig. 11, shows the view of 3D dynamics performance to verify the roughing process which creates the shroud, vanes and hub boundaries. In this process various layers of machining can be viewed and visualized virtually.

In roughing operation the machining is performed and measured by its thickness and material left over. Later, semi-finishing and finishing operations are required to maintain the desired machining tolerance. Material left over after machining at roughing phase was made to be visualized in Fig. 13.

Now semi-finishing and finishing operations are performed so that the user can get clear and more sensible machining to obtain the perfect finishing. The operation and user definitions for both the operations are same as roughing.

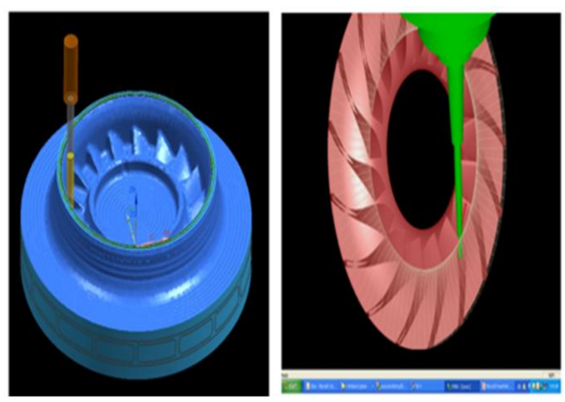

Fig. 11 verifying the material removal of shroud and vanes in 3D dynamics

Using 3D dynamics the blade boundary and surface curves can be cross checked for verification and validation. To make sure about the creation of shroud surfaces and shroud boundary curves which are necessary to form blade shape as desired, user can use 2D dynamics module.

The verification of shroud boundary curve generation can be viewed in the 2D dynamics module that can be visualized in the Fig. 12.

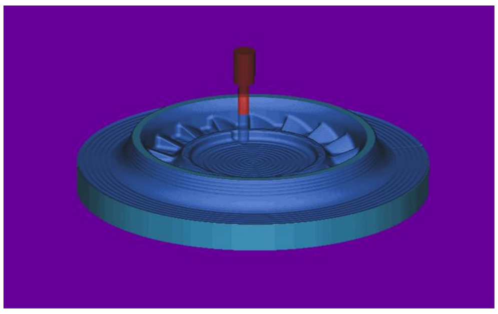

Fig. 12 Verifying the material removal in 2D dynamics

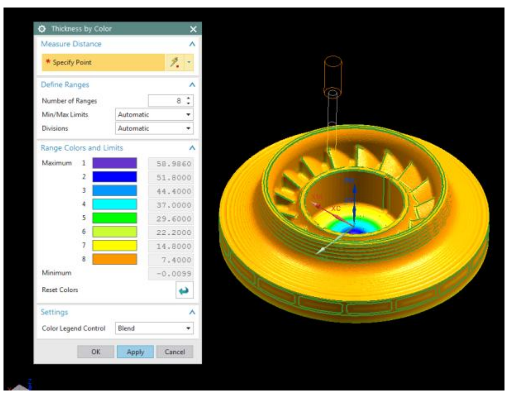

Fig. 14 shows the tool path generation required for semi-finishing operation.

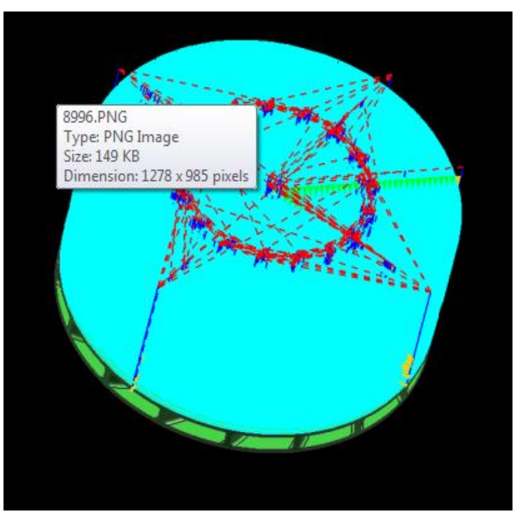

Fig. 14 Tool path generation for semi-finishing.

The curves are more precisely organised so that the semi- finishing operation opts a clear boundaries for hub, shroud and blades as well it creates a smooth curvature where required so that there exists no ribs or hitches.

Fig. 15 shows the visualization of semi-finishing operation which is used as a verification of the operation.

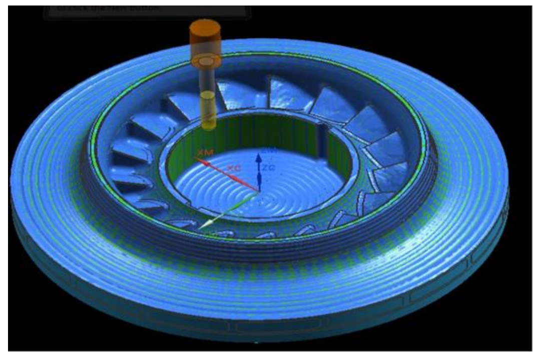

Fig. 15 Verification of semi-finishing in 3D dynamics

In finishing operation, the ball mill cutter machines out with one single pass of the tool-radius which is smaller than the edge interfacial fillets radius and hub surfaces are also precisely machined and finishing can be of very smooth. Visual inspection can be made easy if finishing is performed well.

In Fig. 16, the tool path generation of finishing operation has been showed which contributes the line contacts and boundary curves used for machining especially fine and smooth finishing.

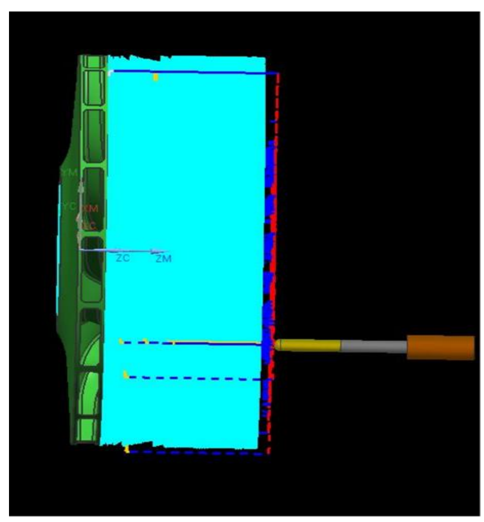

Fig. 16 Tool path generation for finishing operation

Fig. 16 shows the tool path that reaches the internal intricate regions which are complex for finishing operation due to the fact to maintain precise tolerances for a smooth functioning of the machine especially fluid flow should be smooth.

In Fig. 17 the verification of tool path generation can be visualized by using 3D dynamic module. This can establish a nice coherence to predict any tool cross over's or inefficient machining of the part.

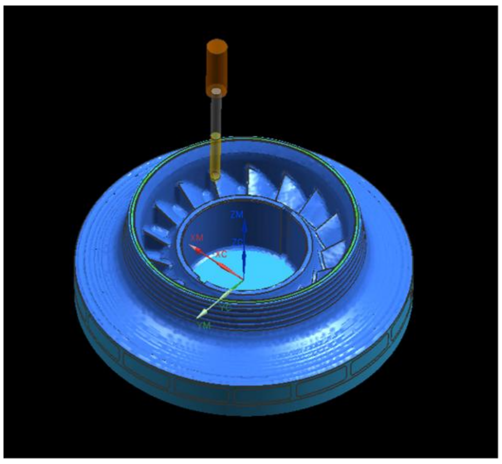

Fig. 17 Verification of finishing in 3D dynamics

Now a part file for the tool path will be generated so that acts as an event generator which will be transferred to the post processor that reads the series of events. In post processor, each event will be analysed and handled so that it passes the information contained in the definition file as instructions for machining. The post processed instructions will be written in the output file.

Tool path need to be customized to suit the unique parameters of each different machine/controller combination. This alteration method is called post processing. The result of post processed tool path is NC code. For using five axis machine,it is required that the numerical-control (NC) post processes the information to change the cutter location (CL) data (that define the tool path data with a CAM system) into the NC data that the machine can read. NC post process is the method of translating machining instructions of a CAM system into NC program code for a multi-axis machine.

In Fig. 18, the post processing tool box has been shown. In that window the user selects the five axis milling machine as the cavity milling is performed using five axis machine. Fig. 19, shows the process of post processing and its importance in the machining process using NX CAM environment.

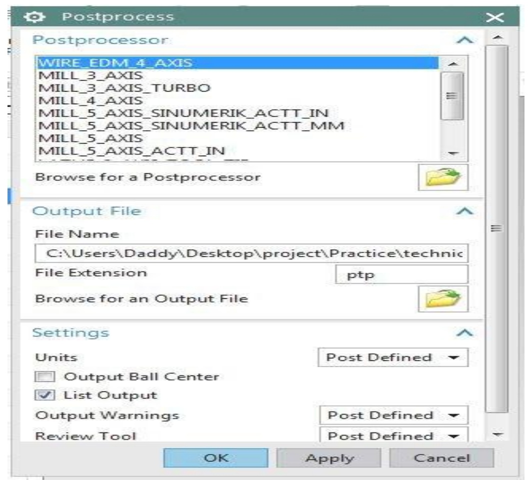

Fig. 18 Post processing tool box

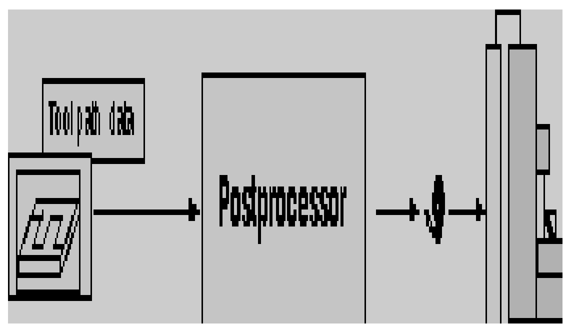

Fig. 19 Role of Post processing

In post processor, the NX tool path information is used as an input which yields machine intelligible NC code. In NX post processor there are different elements to handle. Event generator generates the series of events that is used for several sequential passes of ball mill tool. Next, event handler which handles and processes each event type takes part in the post builder platform. All the static information related to the machine tool and controller combination is stored in the definition file. The file sent to the machine where the machine reads and executes the machine tool is output file which stores all the information in the form of NC code.

Basic controller type has a controller library. The particular controllers contain NURBS output for the Fanuc, Siemens, and Heidenhain mill controls. Siemens mill manages 5 axis machines with a rotary head.G-codes and M-codes are assigned to manage various machine functions in G &M summary block.

The machine control events are given through G and M codes. These codes control the machine apparatus gadgets, for example, coolant, axles, tail stocks or braces and change modes, for example, incremental, supreme, reverse time, every moment, per unrest or consistent surface speed. Consequently the required NC program is made in yield document which is appropriate for CNC controller of 5-Axis machine to peruse and execute it. This program is straightforwardly sustained into the machine and any alterations can be effortlessly altered**.**

5. Conclusions

In this paper, impeller of centrifugal compressor was modelled and generated the tool paths, executed simulation of the impeller machining based on NXCAM platform, which also verifies the correctness of the machining program. This process reduces the cost of machining of an impeller, by which it improves the machining efficiency and quality. A solid foundation for the further research and development on the technology of virtual simulation five-axis CNC machining with tool arrangements and settings were explained in detail.

Parametric modelling is an excellent modelling tool which saves disk space, remodelling time, and improves flexibility while modelling.

Due to the design complexity of impellers, 5-axis CNC machines are the most suitable for machining impellers because of the flexibility of tool orientations that are necessary to machine the area between the twisted blades. Discussion on geometry selection, tool path verification, cut level, rough milling, finish milling tool selection laid forth, later NC code generation as on to post processing is explained.

This study can be used as a case which demonstrations the limitations of today's high-end CAD/CAM systems.

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