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Design and Manufacturing of Marine Propeller

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Abstract
The present work is aimed at the fabrication of propeller blade using Aluminium-24345 material. It is high corrosive resistant, light in weight and easy to maintain. A propeller has a complex geometry and requires high end modelling in its software. The solid model of propeller blade is developed in CATIA V5 R20. By using this model, propeller was manufactured using CNC machine. CNC machining is one of the rapid manufacturing processes for producing metal parts. In this approach, the model is used to generate CNC code with the help of MASTERCAM MILL X6 software and the obtained code is uploaded to CNC machine using Post processor. CNC fabrication technology is unique in that fully dense metal components with properties which are similar to that material can be fabricated. The CNC machining process has the potential to fabricate complex internal features not possible using existing manufacturing processes.

Keywords: *Modelling of propeller blade, propeller blade manufacturing, CNC coding, post processor*

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INTRODUCTION

In this advanced time of science and technology, it has become an important issue to use our non-traditional resources as a source of energy. One of such important fields is under water platform of sea for which a lot of research work has been done to develop underwater vehicles and to observe its various effects. Propeller is one of the most important parts of underwater vehicle for propulsion system. Strength of the propeller blade is one of the most important aspects for the proper performance of the whole underwater vehicle.

Propeller blades are usually made of conventional metallic elements such as aluminium alloy, stainless steel etc. Propeller dynamics can be modelled by both, the Bernoulli's principle and Newton's third law. A pressure difference is created on the forward and aft side of the blade and water is accelerated behind the blades and thereby the ship moves forward as every action has equal and opposite reaction. The thrust from the propeller is transmitted to move the vehicle through a transmission system which consists of a rotational motion generated by the main engine crank shaft, intermediate shaft and its bearings, stern tube shaft and its bearing and finally by the propeller itself.

Computer Numerically Controlled (CNC) machining of propeller blades was pioneered in the 1970’s by KaMeWa (AB Karlstad Mekaniska Werstads) in Sweden and in the1980’s by the Bird Johnson Company (now Rolls-Royce Naval Marine) in Walpole Mass [1, 2]. During the last 20–25 years, CNC milling machines have been generally accepted as the preferred way of machining of propellers and propeller blades. Even with this wide acceptance of CNC machining technique, producing a propeller or a propeller blade with class S tolerances remains a challenge. Class S tolerances are the tightest tolerances in ISO 484/1 and ISO 484/2 manufacturing standards for propellers [3, 4].

DESIGN OF PROPELLER

Propeller design analysis aimed at obtaining minimum power requirements, cavitation, noise, vibration and maximum efficiency conditions at an adequate revolution [5].

The initial design variable requirements of the propeller are given below:

1. Delivered power (*kW*)=15 kW,
2. Propeller rate of rotation (rpm) =780 rpm,
3. Speed of ship (m/s) =7.08 m/s,
4. Number of blades =5.

A marine propeller is designed based upon required thrust and torque. The required thrust and torque was calculated using the formulas:
Power = Velocity × Thrust
15000=Thrust×7.08
Therefore, Thrust =2118.64 N
$P=2\pi NT/60$
Therefore, Torque =183.64 N-m
By assuming a factor of safety 1.25, the required thrust and torque were calculated:
Thrust =1.25×2118.64=2648.30 N
Torque =1.25×183.64=229.55 N-m

The above design variables were used to develop thickness and width of profiles (aerofoil) at various sections of the blade using NACA series.

GEOMETRIC MODELING OF PROPELLER BLADE

The modeling of propeller was done in CATIA V5 R20. The shape of the blades of a propeller is usually defined by specifying the shapes of sections obtained by the intersection of a blade by coaxial right circular cylinders of different radii. These sections are called radial sections or cylindrical sections. Since all the propeller blades are identical, only one blade needs to be defined [6]. The non-dimensional geometry data of the propeller was converted into point co-ordinate data to generate the expanded sections. The detailed design of a propeller therefore essentially consists in designing the expanded sections at a number of radii, usually at r/R=0.2, 0.3... .1.0, where R=0.5D is the propeller radius (Figures 1 and 2).

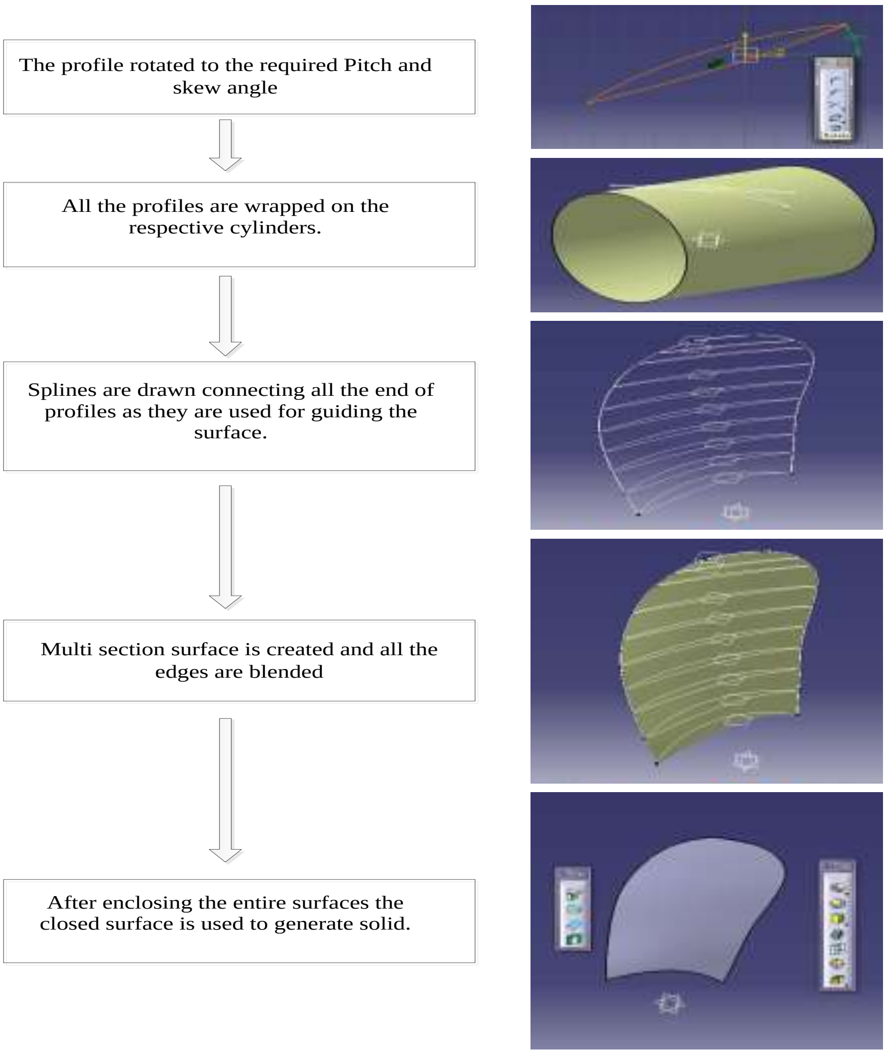

Fig. 1: *Modeling of Propeller Blade.*

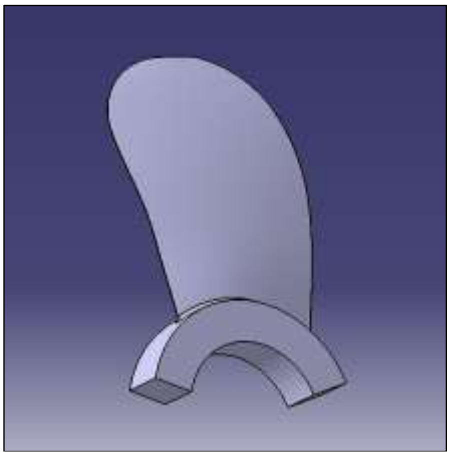

Fig. 2: *3D Model of Single Blade Propeller Created in CATIA.*

Dimensions of Propeller Blade
Length of propeller blade: 149.69 mm,
Width of propeller blade at Root section: 94.0 mm,
Outer diameter of Hub: 140 mm,
Inner diameter of Hub: 90 mm,
Thickness of blade at Root section: 11 mm.

BLADE MANUFACTURE

CNC machining is one of the rapid manufacturing processes for producing metal parts. In this approach, the model is used to generate CNC code with the help of MASTERCAM MILL X6 software and the obtained code is uploaded to CNC machine using Post processor. CNC fabrication technology is unique in that fully dense metal components with material properties that are similar to that of wrought materials can be fabricated. The CNC machining process has the potential to make complex internal features not possible using existing manufacturing processes [7].

CNC Programming
We can proceed to CNC programming only after a smooth 3D model of the propeller blade has been created. CNC programs for machining of blades were created using commercially available software packages: MASTERCAM and HYPERMILL. Machining of the propeller blade is a challenging process due to the precision of the seal surfaces. Therefore, only the programming strategies for CNC milling of blade surfaces will be discussed here.

Manufacturing Process for CNC Machining of Propeller Blades
Machining of propeller blades is most conveniently done on a vertical milling machine. For illustration purposes, a CNC propeller manufacturing process shall be described which was developed for machining of propeller blades for the Halifax Class Canadian Patrol Frigates (CPF) [8]. The manufacturing process for propeller blades consists of five distinct operations:

1. Top Roughing,
2. Top Finishing,
3. Bottom Roughing,
4. Bottom Finishing, and
5. Parting of Blade.

The propeller blade is machined with the special fixture which holds the propeller blade in a horizontal orientation providing unhindered access to the propeller blade foot and overhang. Propeller blade surfaces, fillets and palm are machined with the propeller blade bolted and pinned in the horizontal orientation on a fixture attached to the table of the milling machine [8,9]. The 3-Axis CNC machine used to manufacture the propeller blade is shown in Figure 3.

Fig. 3: *3-Axis CNC Machine Used for Machining of the Blade.*

Operation 1: Top Roughing of the Blade

The blade model is imported to MASTERCAM MILL X6 software to generate the CNC code (Figure 4). Certain steps need to be followed to obtain the CNC code.

The top roughing of the blade surface consists of five distinct tasks:

STEP 1: Importing Model to Software and Selection of Tool.

Selection of tool is very important in CNC milling process. Here tool of 12.0 mm diameter is selected with spindle speed of 1800 rpm and feed rate of 500 mm/min. Roughing tool specifications and tool path parameters are taken as shown in Figures 5 and 6.

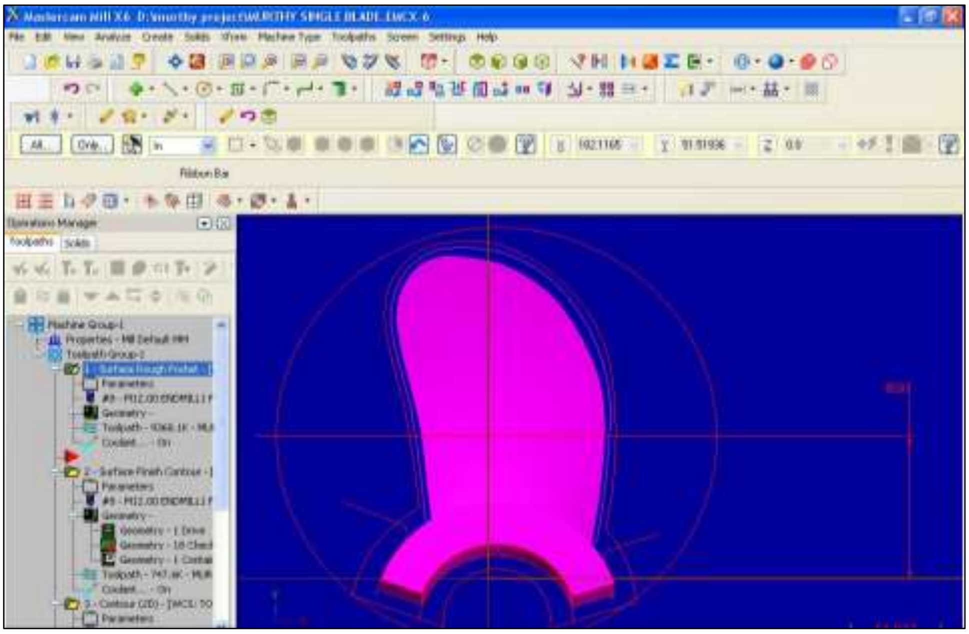

Fig. 4: *Single Blade Model Selection in MASTERCAM.*

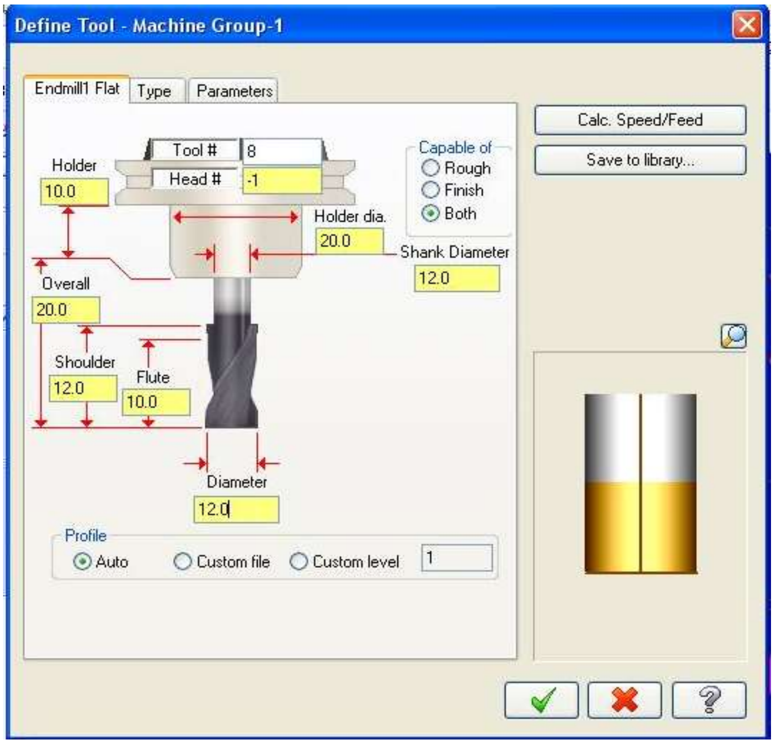

Fig. 5: *Roughing Tool Specifications.*

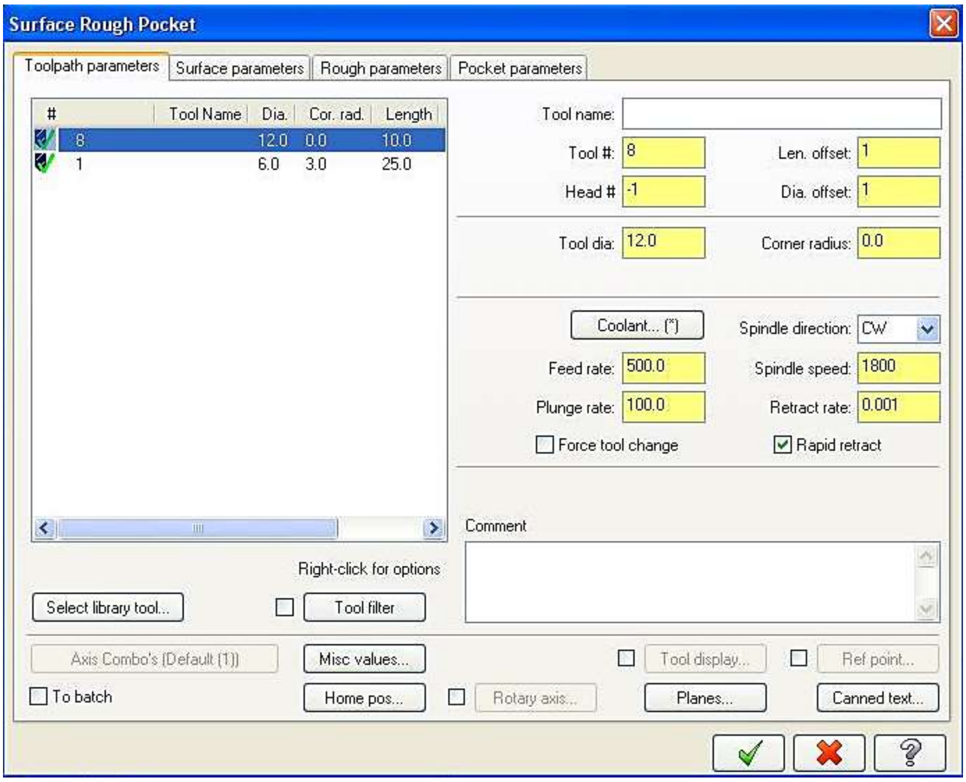

***Fig. 6:** Tooth Path Parameters for Top Roughing of Blade.*

STEP 2: Tool Path Generation and Simulation.

The tool path is generated in MASTERCAM on the model of the blade as shown in Figure 7 and the simulation of roughing operation on the surface of the blade is shown in Figure 8.

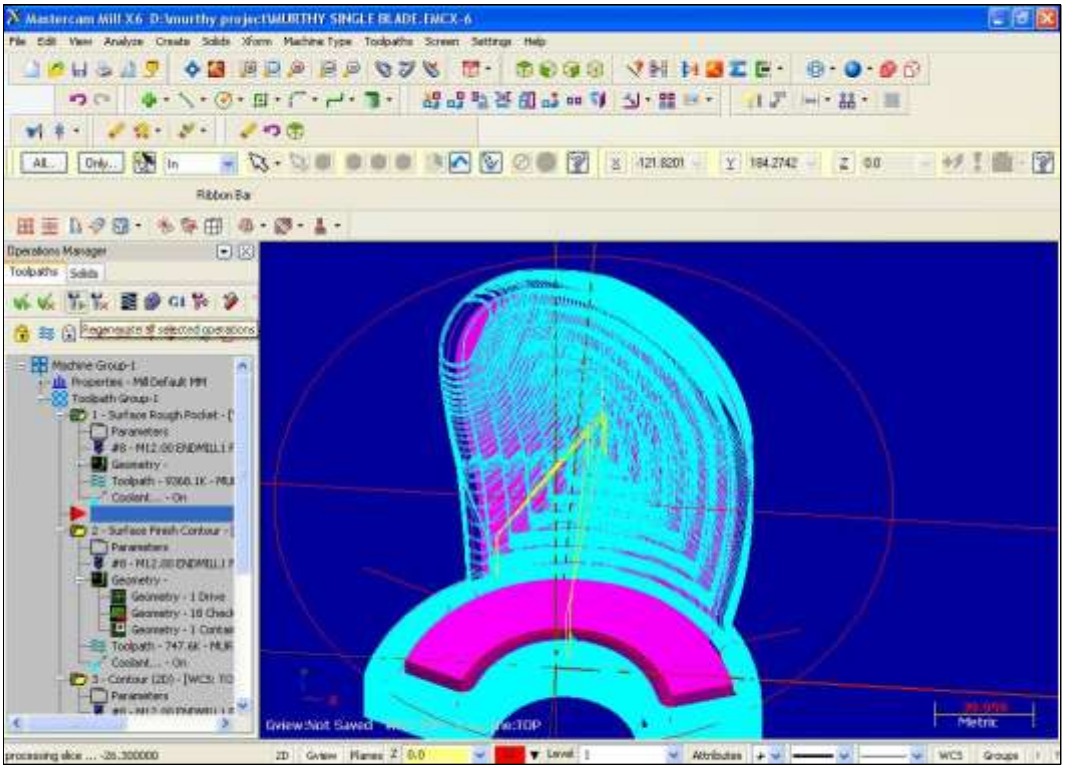

***Fig. 7:** Tool Path Generation on Top Surface of Blade.*

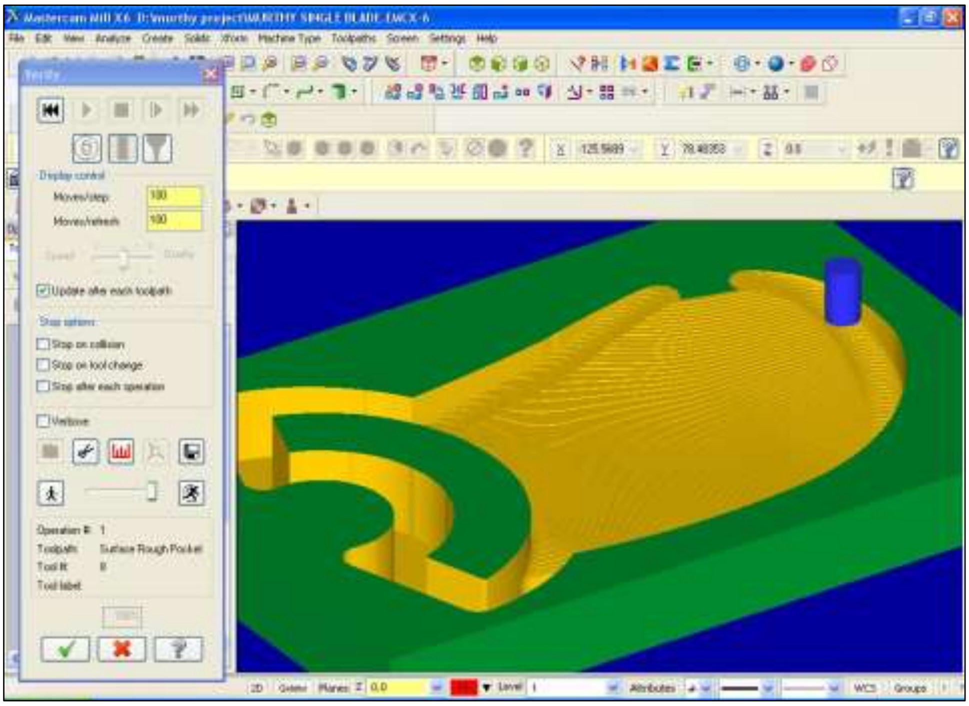

Fig. 8: *Simulation of Top Roughing of Blade.*

STEP 3: CNC Code Generation.

After the completion of tool path generation in MASTERCAM software, CNC code is generated using code generation option for the top roughing of the blade. The obtained CNC code is shown in the Figure 9. This code is uploaded into CNC machine using post-processor.

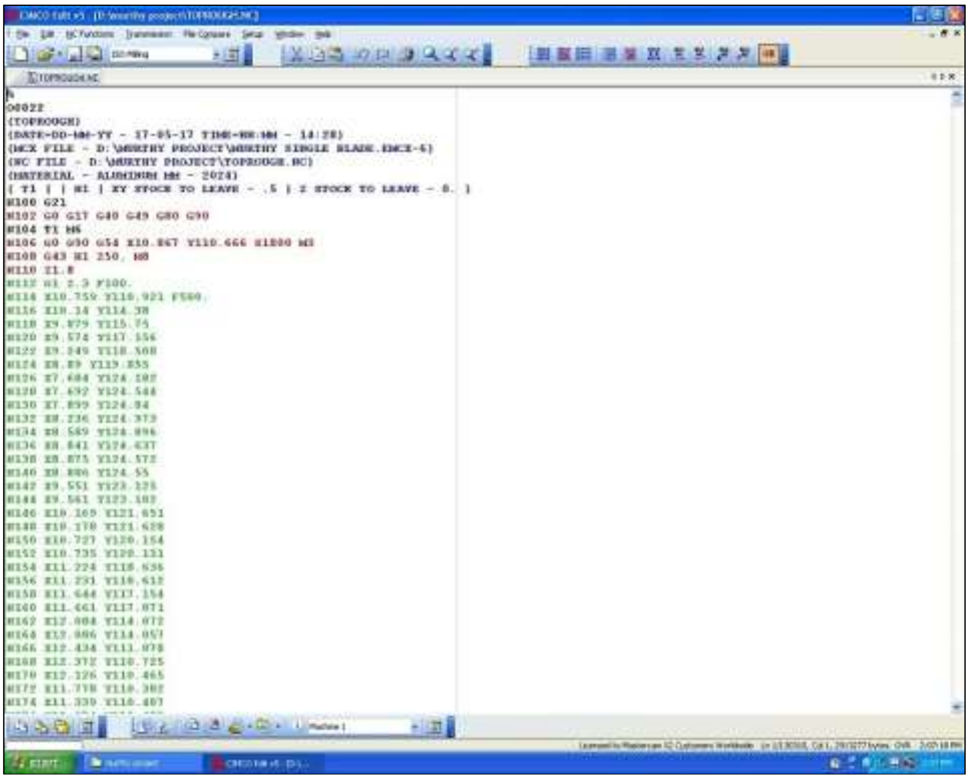

Fig. 9: *CNC Code Generated for Top Roughing of Blade.*

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STEP 4: Loading Raw Material to CNC Machine.
Raw material of Al-24345 of 260 mm diameter and 30 mm thickness is loaded into CNC machine and fixed as shown in Figure 10.

Fig. 10: *Raw Material Fixed in CNC Bed.*

STEP 5: Machining of Top Surface of the Blade for Roughing Operation.
After uploading the CNC code to the machine, the blade is machined until the process is completed and the rough milling of the blade surface is shown in Figure 11 after completion of the operation.

Fig. 11: *Rough Milling of the Blade Surface.*

Operation 2: Top Finishing of the Blade
For finishing operation, tool of 6.0 mm diameter is selected with spindle speed of 1800 rpm and feed rate of 500 mm/min and the tool specifications are taken as shown in Figure 12.
The top finishing of the Blade of blade surfaces consists of four distinct tasks:
STEP 1: Importing Model to Software and Selection of Tool.

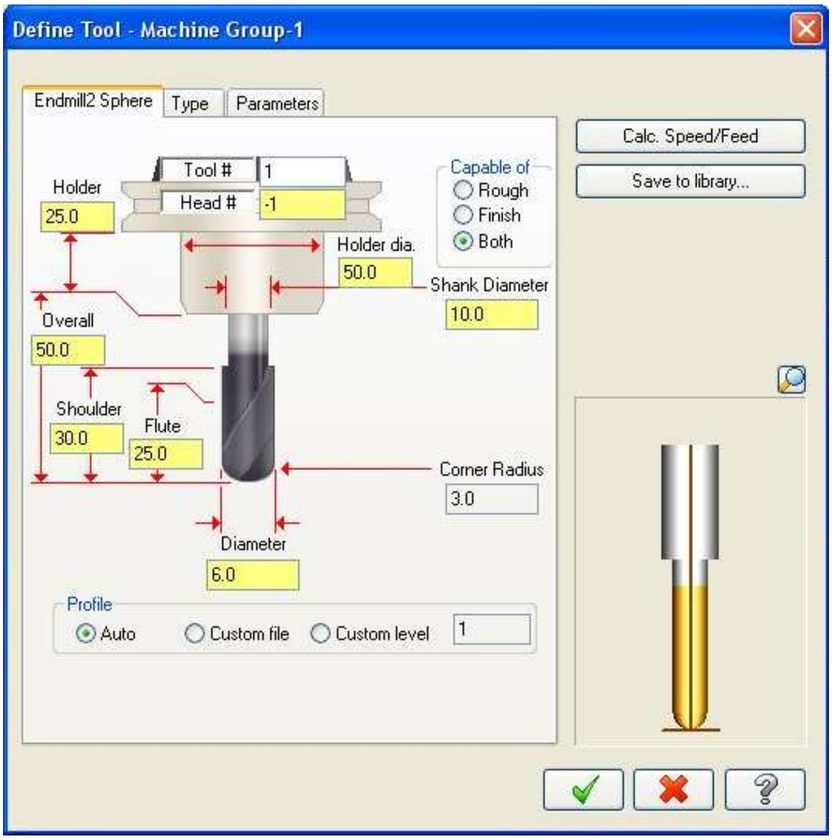

Fig. 12: *Finishing Tool Specifications.*

STEP 2: Tool Path Generation and Simulation. The tool path is generated in MASTERCAM on the model of the blade and the simulation of finishing operation on the top surface of the blade is shown in Figure 13.

STEP 3: CNC Code Generation.

After the completion of tool path generation in MASTERCAM software, CNC code is generated using code generation option for the top finishing of the blade. The obtained CNC code is shown in the Figure 14. This code is uploaded into CNC machine using post-processor.

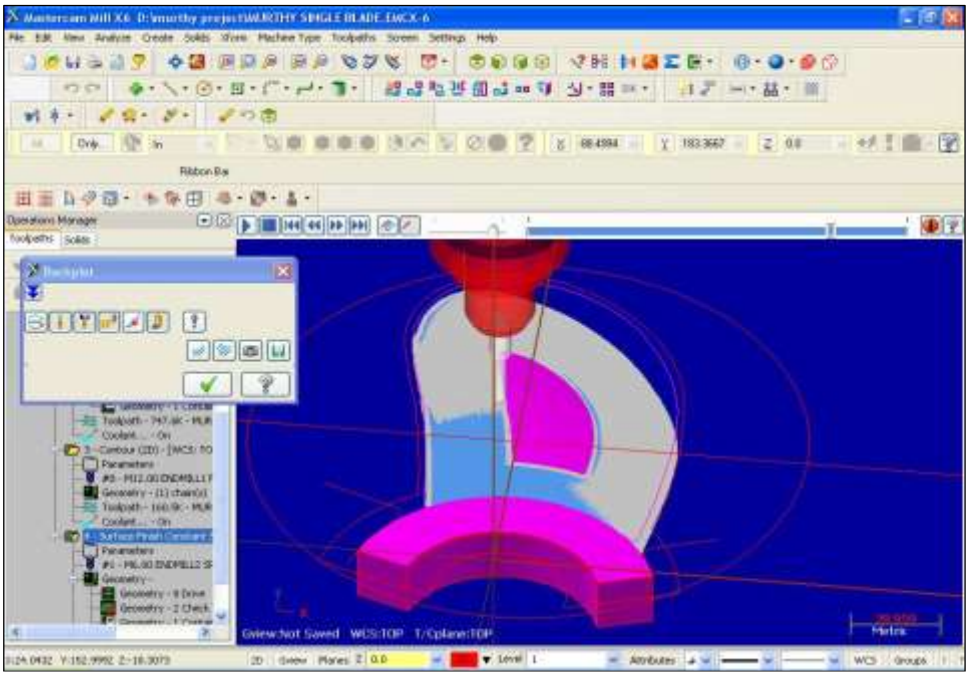

Fig. 13: *Simulation of Top Finishing of Blade.*

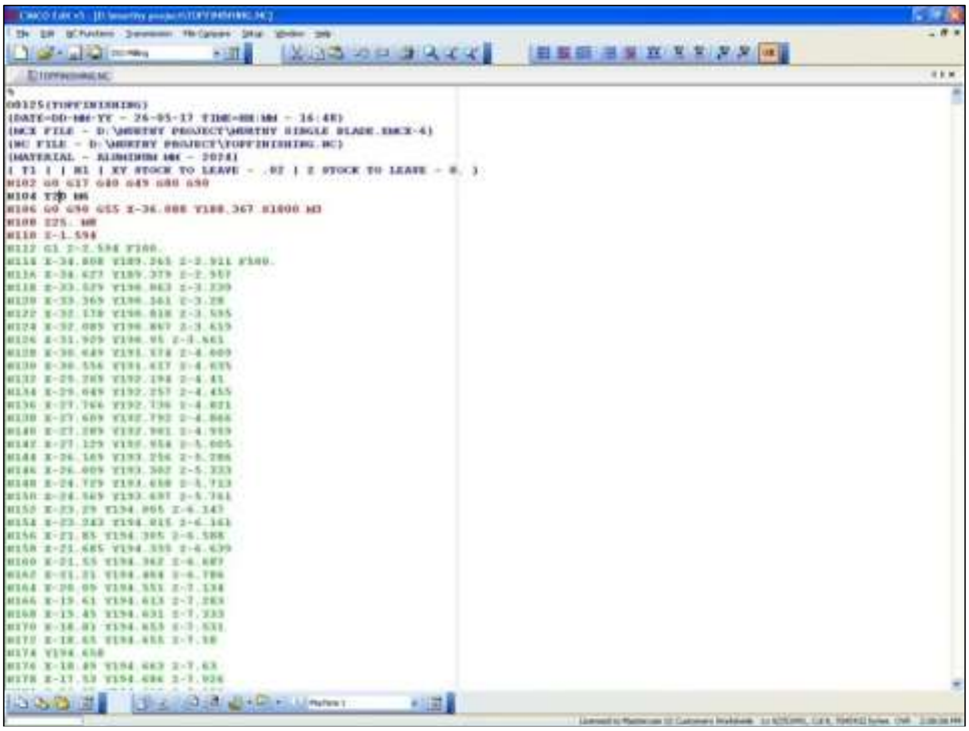

Fig. 14: *CNC Code Generated for Top Finishing of Blade.*

STEP 4: Machining of Top Surface of the Blade for Finishing Operation.

After uploading the CNC code to the machine, the blade is machined until the process is completed and the finishing of the blade surface is shown in Figure 15 after completion of the operation.

Operation 3: Bottom Roughing of the Blade

The tool path is generated for the bottom roughing operation of the blade in MASTERCAM as shown in Figure 16 and simulation is shown in Figure 17.

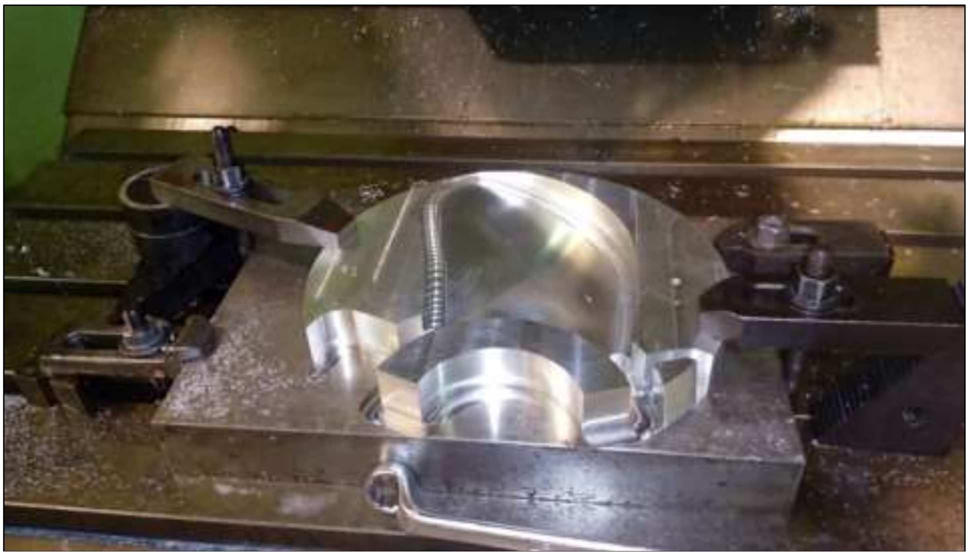

Fig. 15: *Finished Top Surface of Blade.*

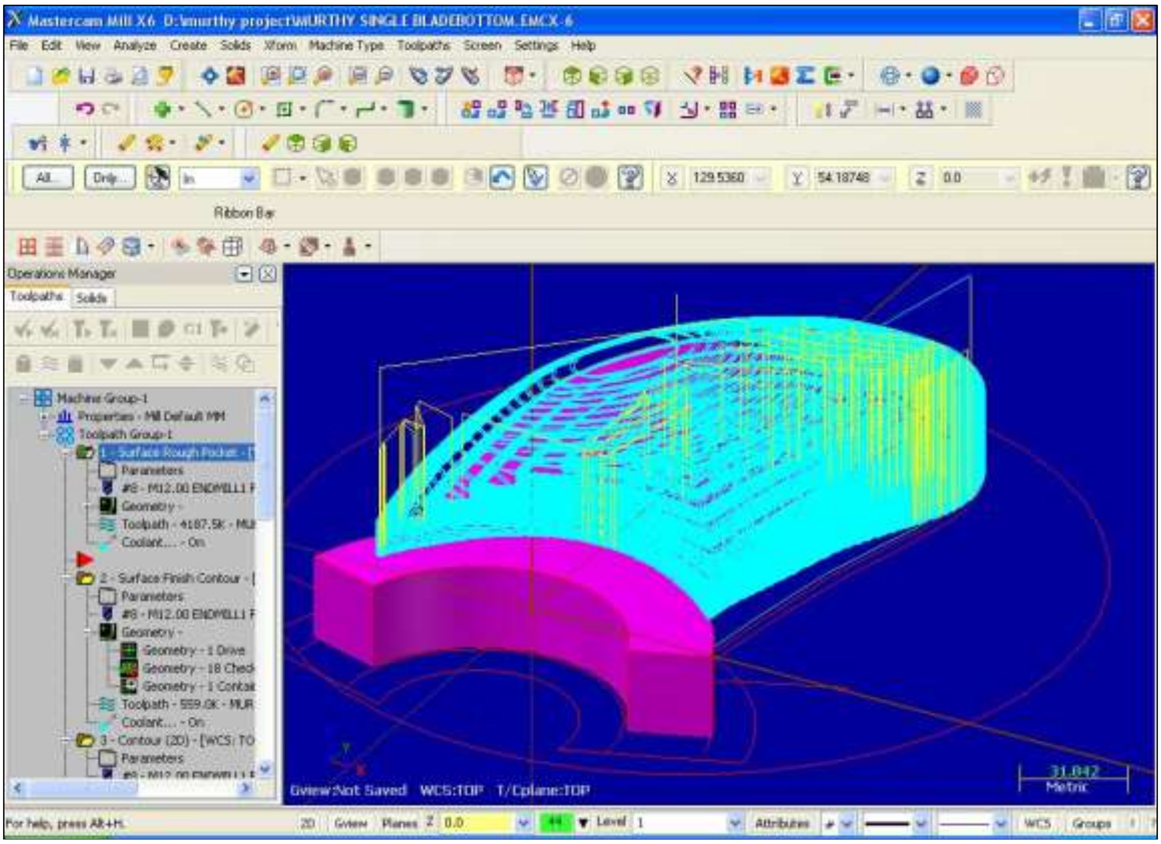

Fig. 16: *Tool Path Generation for Bottom Roughing of Blade.*

Operation 4: Bottom Finishing of the Blade

The tool path is generated in MASTERCAM on the model of the blade and the simulation of finishing operation on the bottom surface of the blade is shown in Figure 18.

Operation 5: Parting of the Blade

The partition of the blade from the raw material is to be done after finishing operation on the blade surface. The parting tool path generation and simulation are shown in Figure 19.

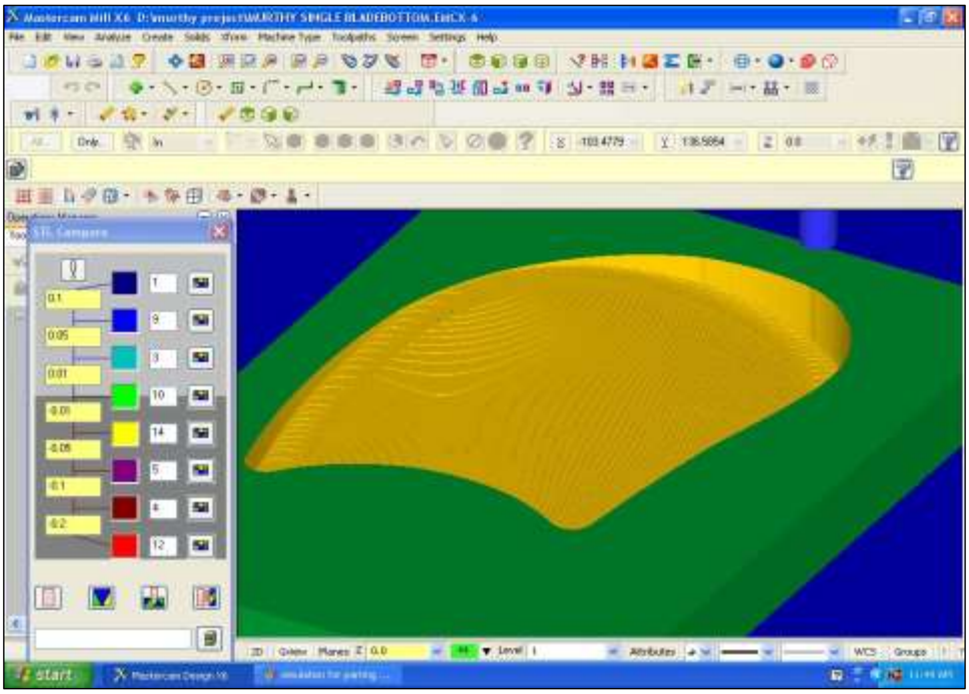

Fig. 17: *Simulation for Bottom Roughing of Blade.*

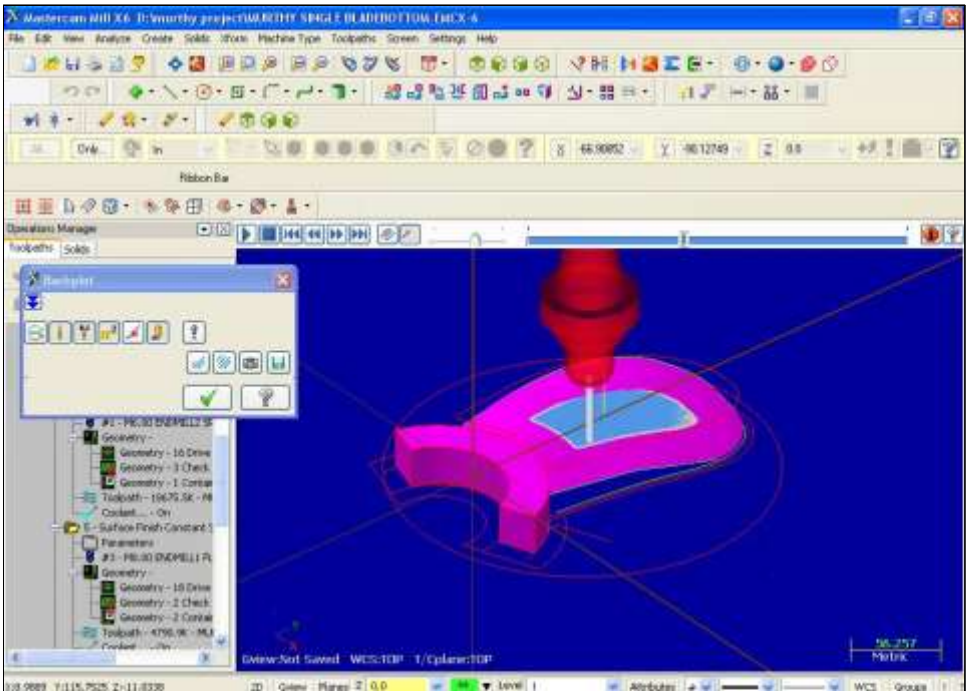

Fig. 18: *Simulation for Bottom Finishing of Blade.*

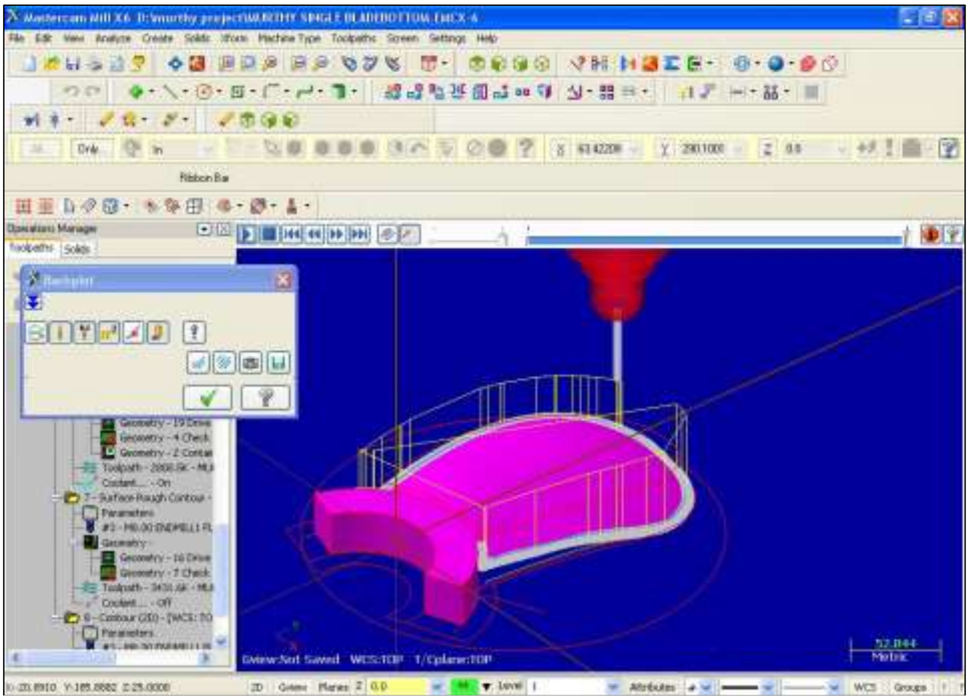

Fig. 19: *Tool Path Generation for Parting of the Blade.*

Propeller blade which is CNC machined to final form and finish is shown in Figure 20.

Fig. 20: *Manufactured Propeller Single Blade Model.*

CONCLUSIONS

- The design was done based on required thrust and torque and modeling of propeller was carried out in CATIA V5R20 software and is imported into ANSYS workbench 15.0 to carry out CFD and acoustic analysis. The propeller is assumed to be operated at 780 rpm with flow velocity of 7.08 m/s.
- In propeller manufacturing the CNC technology was adopted to produce the propeller to increase the mechanical property, quality and productivity. A fabrication protocol has been developed for manufacturing of propeller. Propeller blades which are CNC machined to final form and finish have, besides the exceptional accuracy demonstrated, the additional advantage of excellent blade to blade repeatability which effectively eliminates balancing adjustments. Elimination of the hand finishing step from the propeller manufacturing process results in cost-cutting measures for the manufacturer.

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