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CHAPTER 1

INTRODUCTION

1.1 Background of Study

The study relates to the type of impellers that is to be machined and more specifically relates to the process for manufacturing of pump impellers by using NC programming. A pump impeller is composed essentially of three major parts which are the hub portion, vanes and shroud portion. Traditionally there have been several ways to manufacture pump impellers which includes molding, casting, and machining with electron beam welding. Today we can find a wide variety of impellers that suits all sort of purposes. To date, there has been high precision impeller being machined by using Numerical Control Programming. Hence, this study relates to the manufacturing of various pump impellers by generating the NC Coding and simulating it with our own MAZAK by means of UNIGRAPHICS. By using NC machining we will be able to program and reprogram the machining process thus making the machining of a pump impeller more flexible.
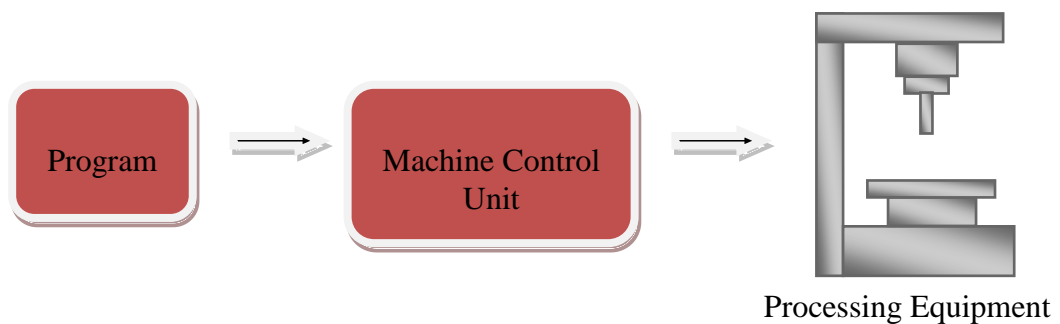
Figure 1.1: Basic Components of NC System.

1.2 Problem Statement

Machining a complex shape component using CNC Machining Center requires high level of knowledge in NC Programming. Mechanical students normally have basic knowledge on NC Programming. However, to achieve a certain degree of expertise in writing NC program for complex shape requires a lot of practices and time. This could be overcome by having a module which could demonstrate to students the procedure and process of machining complex shapes. Impellers are among complex shapes to be machined. Thus, having a library of NC codes would assist and would reduce the time needed to generate the NC codes for the given complex shape.

1.3 Objective and Scope of Study

The main objective of this research is:

- To develop a library of NC code for impellers using UNIGRAPHICS for machining using CNC Machining Centre.

The scope of work for this project is to generate the NC code for the impellers using the available CAD/CAM system and CNC Machining Center at Universiti Teknologi Petronas precision machining laboratory.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Five axis machining refers to the ability of a CNC machine to move a part or tool on 5 different axes simultaneously where as five axes machining of a water pump impeller refers to the steps and procedures involve in machining a water pump impeller. Manufacturing a water pump impeller requires a series of processes and for designing the water pump impeller CAD/CAM software is adapted. Computer-aided design (CAD) is the process of utilizing computers to design and also create models and drawings according to specified dimensions and calculations. Computer-aided manufacturing on the other hand begins with a design model and ends with a physical object and hence CAD is critical to CAM. For this project UNIGRAPHICS NX3 and CATIA will be adapted as the CAD/CAM system.

2.2 Types of Impellers

An impeller is a core part of turbo machinery such as generator, turbo charger, compressor, diffuser and pumps. Most pumps apply the centrifugal effect that uses a rotating impeller to increase the velocity of the fluid. Centrifugal pumps are commonly used to move fluid or liquids through a piping system. The fluid enters the pump impeller along or near to the rotating axis and is accelerated by the impeller by flowing radial outward into a diffuser or volute chamber from where it exits into the downstream piping system. The impeller often discharges directly into the volute which is a spiral-shaped flow passage usually of circular or trapezoidal cross section.

2.2.1 Radial Impellers

Np = Non-Turbulent Power Number, Nq= Flow Numbers,
D/T= Impeller Diameter to Tank Diameter Ratio,
w_B/T = Baffle Width to Tank Diameter Ratio.

- RT3
- Rushton Turbine with 3 blades
- $\underline{Np=3.3}$, Nq=0.62* D/T=0.33, w_B/T=1/12
- $\underline{Np=3.4}$, Nq=0.62* D/T=0.33, w_B/T=0.1

- RT4
- Rushton Turbine with 4 blades
- $\underline{Np=4.3}$, Nq=0.68* D/T=0.33, w_B/T=1/12
- $\underline{Np=4.4}$, Nq=0.68* D/T=0.33, w_B/T=0.1

- RP4
  - Lightnin R200
- Paddle with 4 blades
- No disk (disc)
- Np=3.4, Nq=0.62*

- RP6
- Paddle with 6 blades
- No disk (disc)

- Holmes & Narver pumper mixer Lightnin R300

- Curved bladed pumper
  - Lightnin R320
  - Philadelphia Mixers CBT-6
- Pumper impeller used for solvent extraction mixer settlers
- 6-curved blades on one side of disk

Table 2.2.1 : Radial impellers courtesy of P.Csiszar.[19]

2.2.1 Axial Impellers

- PR-D
  - ○ Chemineer AP-3
  - ○ Lightnin A100 and A110
- Propeller - Down-pumping and Up-pumping
- N_p=0.32 for 1.0 pitch, D/T=0.35, w_B/T=0.1
- N_p=0.36 for 1.0 pitch, D/T=0.22, w_B/T=0.1
- N_p=0.62 for 1.5 pitch, D/T=0.22, w_B/T=0.1
- N_p=1.00 for 2.0 pitch, D/T=0.31, w_B/T=0.1

- 4PBT-D
  - ○ Chemineer P-4
  - ○ Lightnin A200
- Pitched blade turbine - Down-pumping and Up-pumping with 4 blades
- N_p=1.27, N_q=0.79

- Lightnin A6000 (down-pumper)
- Advanced fiber reinforced composite, utilizing highly corrosion resistant plastic matrix, with proplets
- N_p=0.23, N_q=0.59

- Lightnin A310 (down-pumper)
- N_p=0.30, N_q=0.56

Table 2.2.2 : Axial impellers courtesy of P.Csiszar.[19]

2.3 Water Pump Impeller

Water pump impeller is used mostly in centrifugal pumps that transfers or used to move liquids through a piping system. There are three types of impellers which are the open, semi-open and closed impeller. Water pump impeller is usually the semi-open type which incorporates a single shroud at the back of the impeller. It is constructed with a circular plate attached to the vanes. The vanes in a water pump impeller on the other hand can range from a single vane to multiple vanes. The most common use of water impeller vanes are 4 such as the figure below.
[1]
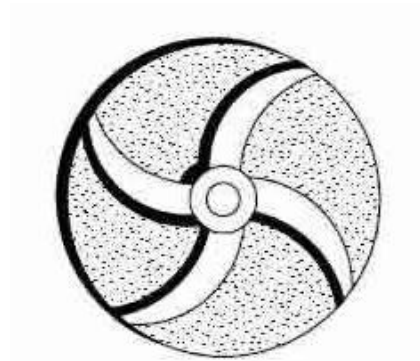
Figure 2.1: An example of a 4-vane water pump impeller.[1]

The design of an impeller can be classified into two types which are the splitter type and the non-splitter type. The shape of the impeller is composed of pressure and suction surface, splitter, training edge and leading edge as shown in the figure below:
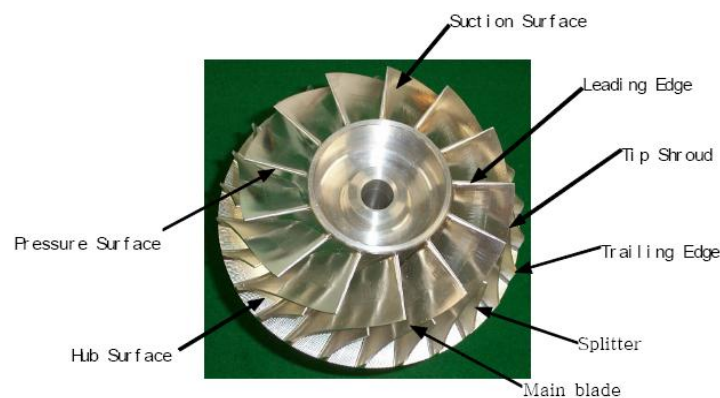
Figure 2.2: Parts of an impeller.[1]

10

Impellers are modeled using section curves. For an example, take two hub curves and two shroud curves generated by the compress ratio as shown in Figure 4. The blade is modeled with ruled surface and it forms perfect symmetry about the revolution axis. The leading edge is modeled with a fillet surface for fluent flow. An example of an impeller modeling(splitter type) is shown as in Figure 5 below: (Ref: 6).
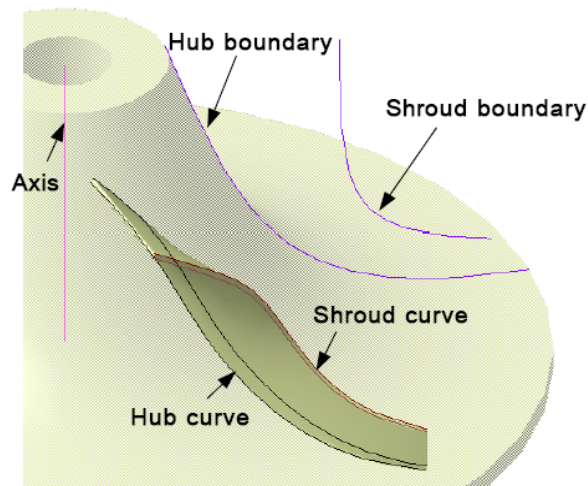
Figure 2.3: Impeller modeling curves.[1]
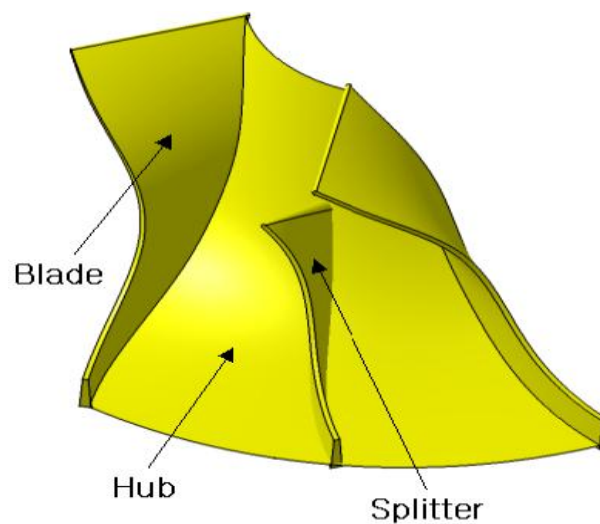
Figure 2.4: Impeller modeling of a splitter type.[1]

2.3 Fuel Pump Impeller

A fuel pump impeller is used in a fuel pump for a vehicle which comprises a driving motor, an impeller having a substantially circular shape, and a pump casing. The impeller includes a plurality blades of generally V-shape cross-section disposed along an outer-surface of the impeller with a plurality of blade grooves defined between the blades, the blade grooves in fluid communication with respective circular groove of the pump casing and casing cover wherein each of the blades includes a fuel inlet blade portion disposed at an inner area of the blade grooves and a fuel outlet blade portion disposed at an outer area of the blade grooves with a boundary portion disposed between the fuel inlet blade portion and the fuel outlet blade portion in which a front surface angle and a rear surface angle of each of the fuel inlet blade portion and the fuel outlet blade portion respectively varies relative to the length of each of the blades.
[8].
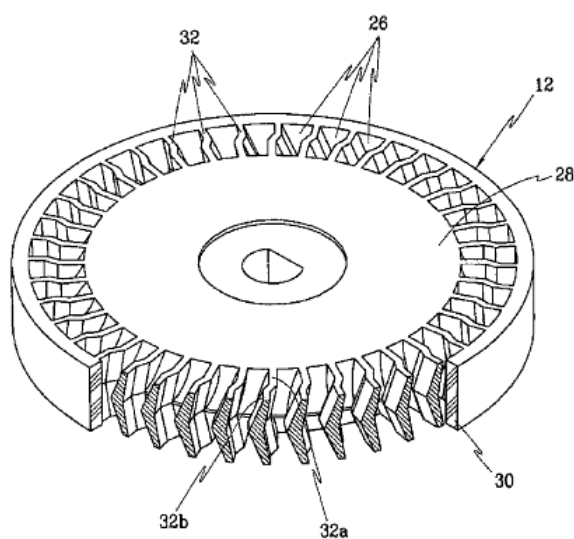
Figure 2.5: An example of a fuel pump impeller design.[8]

2.4 Turbo machinery Pump Impeller

Turbo machinery impeller comprises of a hub, a plurality of full blades equidistantly disposed on the hub in a circumferential direction and a plurality of splitter blades disposed between each adjacent two of the full blades wherein each of the splitter blades is shaped in such a way that a spanwise distribution of a pitchwise position of a leading edge of the splitter blade is determined according to a spanwise and pitchwise non uniformity distribution of fluid velocity of a fluid flowing into the splitter blade as illustrated by a schematic drawing shown below:
[9].
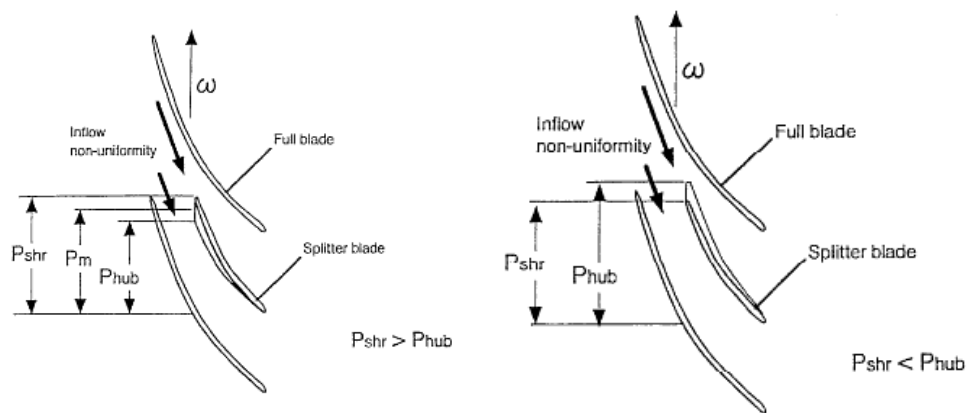
Figure 2.6: Shows a non uniformity distribution of fluid velocity of a fluid flowing into the splitter blade.[9]
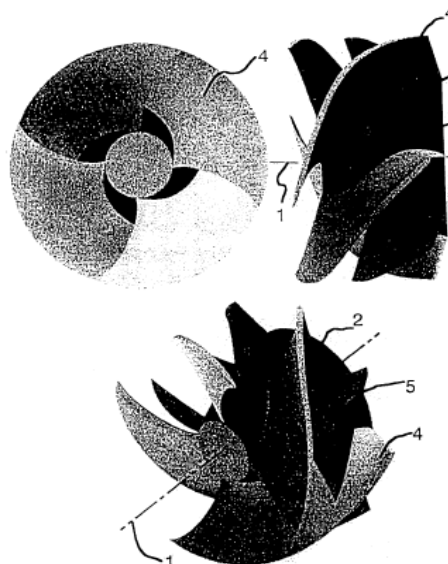
Figure 2.7: Multiple views of a turbo machinery impeller.[9]

2.5 Hydrofoil Impeller

A hydrofoil impeller includes three impeller blades attached to a hub. Each impeller blade includes a flat section and a curved section which terminates in a tip portion. The flat section has a root portion proximate the hub and which forms a predetermined root angle with respect to a plane perpendicular to the vertical axis of the impeller. The curved section is separated from the flat portion by a bend line. The curved section is bent downwardly from the plane of the flat section along the bend line. The bend line is oriented with respect to the impeller blades such that the blade tip angle is changed as the bend is formed. Accordingly, the bend is used to set the proper tip angle. The blade angle increases from the tip inward to the bend line then becomes a constant where attached to the hub. The camber increases from the tip inward to the bend line, then falls to zero where attached to the hub. [10].
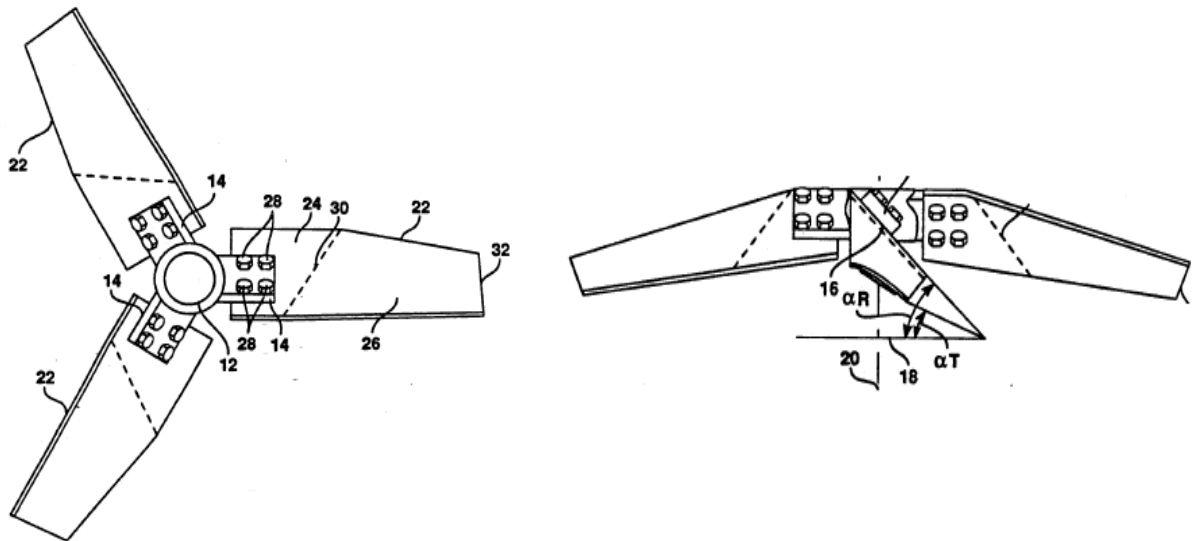
Figure 2.8: Multiple views of a hydrofoil impeller.[10]

2.6 NC Code Programming

NC Code or numerical control is a form of programmable automation in which the mechanical actions of a machine tool or other equipment are controlled by a program which contains coded alphanumeric data. By definition, the alphanumeric data represent relative positions between a workhead and a workpart as well as other instructions needed to operate the machine. The capability to change the program makes NC suitable for low and medium production. Writing a new program is way easier comparing to making major alterations in the processing equipment. To date, NC can be applied to a wide variety of processes and the application can be divided into two categories:

i) Machine tool applications – drilling, milling, turning and other metal working.

ii) Nonmachine tool applications – assembly, drafting, and inspection.

The coding system is within a block and is known as a block format and the typical sequence of steps in CNC Part Programming using Unigraphics or Mastercam for a sequence of milling and drilling operations are:

i)   Developing a CAD model.

ii) Orient the starting work piece relative to the axis system of the machine.

iii) Identify the work piece material and specified grade.

iv) Selecting the right operations that is to be performed.

v)   Selecting the cutting tool

vi) Enter applicable cutting parameters such as depth.

vii) Repeating steps 4 through 6 for each additional machining operation to be performed on the part.

viii) Selecting the appropriate postprocessor to generate the word address for the machine tool on which the machining job will be accomplished.

ix) Verify the part program by animated simulation of the sequence of machining operations to be performed on the part.

2.6.1 Selected NC Codes and Syntax

Interpolation (Axes Movements)

Moving the cutting tool in lines or arcs is achieved by interpolation between the start and end points. The start point is whatever XYZ position the tool is in just before the command. I, J, K, X, Y, Z, and F values must include a decimal point.

G00 X Y Z   Rapid traverse: Move as fast as possible to X,Y,Z (not necessarily a straight line).*Do Not use for cutting*, only positioning the tool outside the material.

G01 X Y Z F   Linear Interpolation: Move from start position to X,Y,Z in a straight line, at Feedrate of F inches/minute.

G02 X Y Z I J K F   Clockwise Circular interpolation: Move from start position to X,Y,Z along a clockwise arc, at a Feedrate of F. *Relative to the start point*, the arc center is defined by the vector $I\mathbf{i} + J\mathbf{j} + K\mathbf{k}$

G03 X Y Z I J K F   Counterclockwise Circular interpolation: Move from start position To X,Y,Z along a clockwise arc, at a Feedrate of F. *Relative to the start point*, the arc center is defined by the vector $I\mathbf{i} + J\mathbf{j} + K\mathbf{k}$
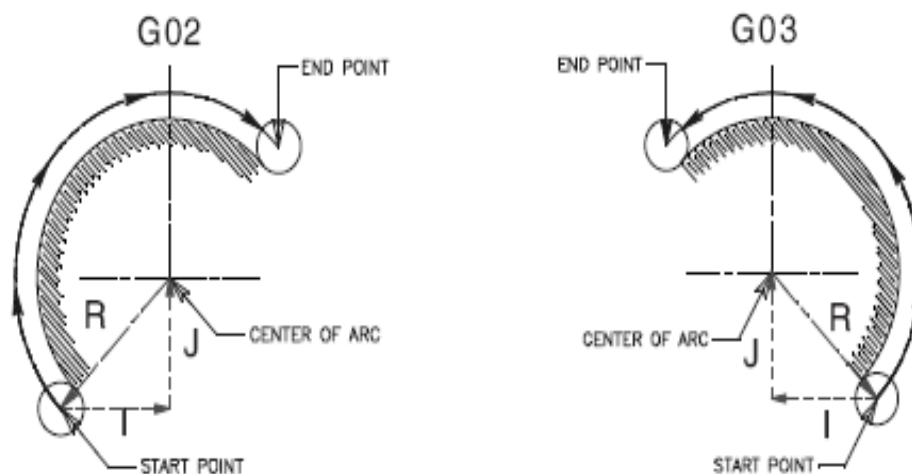
Figure 2.6.1 : Circular Interpolation Movement Command.

Miscellaneous Codes (M Codes)

Only one M code should be specified per NC block, and it should not be placed with a G code.

M03 Spindle Motor On. E.g.: `S1500 M03`
M05 Spindle Motor Off.
M06 Tool Change: Pause, turns off and retracts spindle. E.g.: `T2 M06`
M30 End of Program and reset to beginning.

Other Codes
      (…)   Comment
      ;   End of block

(N)	G	X Y Z	I J K	F	S	T	M
Line Number (Optional)	Motion Function	Endpoint Coordinates	Relative Arc Centre	Feedrate	Spindle Speed	Tool Number	Misc. Function

Table 2.6.1 : NC Word Order.

2.7 Method of Manufacturing Pump Impeller Using Casting.

Casting is a less costly method to produce pump impeller. It also lets the production of pump impellers by using hard materials. Materials are disclosed in which the formation of a selectively configured core produces an impeller casting tat does not need to be machined to receive the drive shaft and eliminates the need for employing a lead bit or soft insert.

Pump impellers are typically rotated within a pump casing by connection to the drive shaft of a motor. Impellers are generally formed with a central cavity or opening into or through which the terminal end of the drive shaft extends. The exact design and construction of the connection of the impeller to the drive shaft varies widely between types and models of impellers. Impellers that are made of softer metals may typically be machined to form a central cavity that will accommodate the end of the drive shaft.

The impeller is made in a mold which is shaped to produce a central cavity in the impeller. The central cavity of the casting is of imprecise dimension and finish which is permissible since the Babbitt formed in the central cavity compensates for any dimensional or finishing imprecision. Once the molten material of the impeller has hardened and casting is removed from the mold the central cavity is ready for the formation of the Babbitt. The center of the cavity is determined and a post-like implement or mandrel is positioned at the center of the cavity. Molten lead is then poured into the cavity and around the mandrel. When the lead has hardened, the mandrel is removed. The Babbitt may be formed with a particular shape that is dictated at least in part by the machining of the end of the drive shaft. The need to use a lead Babbitt, necessitated by the extreme hardness of the impeller material results in significant additional labor which increases the time and cost of manufacturing hard material impellers. More importantly however is the fact that lead Babbitt cannot be used in many applications because the lead seeps into and contaminates the water being processed. Also, formation of the lead Babbitt is a very toxic and dangerous process and is very costly as a result.

An alternative method of mounting impellers to drive shaft by casting is to provide a soft metal insert into the center of the impeller mold prior to pouring the molten material to form the impeller. The soft metal insert can be configured to provide contact with the impeller and to accommodate the drive shaft but is also machined to receive the drive shaft. Soft inserts are used when the type of fluid being pumped is incompatible with the lead of a Babbitt. The use of soft inserts, however also represents added cost and labor to the manufacture of the impeller because the machining required manufacturing the insert and the additional machining required to form the insert to the drive shaft.

Thus, it would be advantageous in the art to provide means for producing impellers from hard material which eliminates the need for a lead Babbitt or any other type of insert to accommodate the drive shaft and which eliminates the need to machine the impeller or drive shaft significantly reduces manufacturing costs, simplifies manufacture and provides a more environmentally safe impeller of very hard material.
[7].
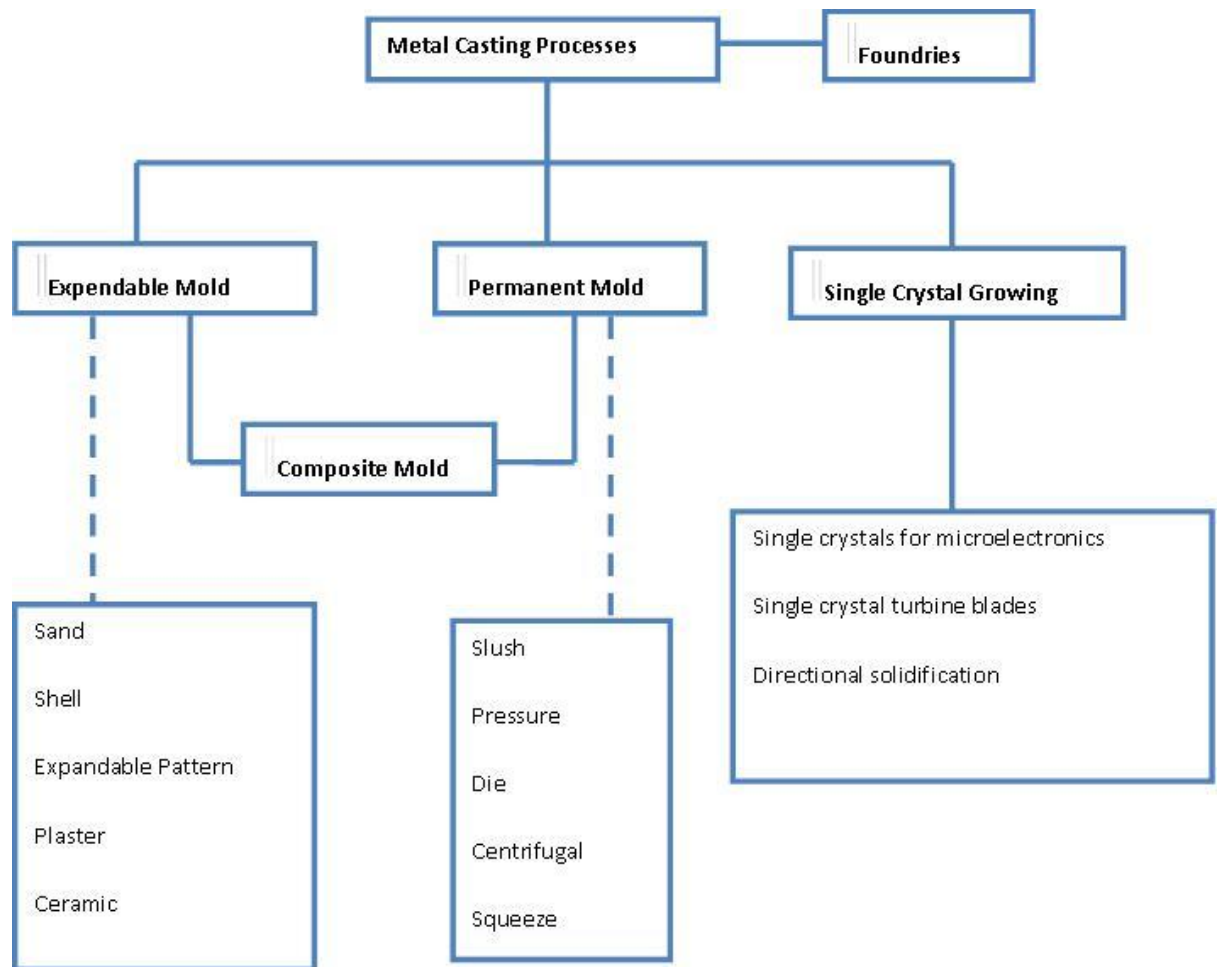
Figure 2.9: Metal Casting Processes.[7]

2.8 Method of Manufacturing Pump Impeller Using Lost-Foam Molding

As claimed in the United States Patent with Patent No:4891876 by Richard R. Freeman, it is said that there are 6 steps in manufacturing a water pump impeller with a central axial aperture and impeller vanes integral with disc portion. The steps are as follow:

a) Forming a female die complimentary to the shape that is to be made.

b) Positioning a former in said die to be located in the central axial aperture of the tubular hub portion of the impeller that is to be made.

c) Filling die with curable foam-like material thereby forming an impeller pattern which is mounted upon its former.

d) Curing given foam-like material of given pattern and removing the given pattern from the die.

e) Using given pattern or design to form an impeller casting mold.

f) Casting the given impeller in the mold during which the cured foam-like material of said pattern is destroyed without destroying and maintaining the former given central axial aperture of the tubular hub portion of said impeller.

The former may be a die insert which may be of stainless steel in the form of a short tube with radial outwardly extending flanges at one or both ends and with one or more peripheral and external ribs or other projections
[12].

2.9 Method of Manufacturing Pump Impeller Using Sheet-Metal Disk

An impeller formed from sheet-metal by stamping and bending at a low production cost capable of delivering an increased quantity of air at a reduced noise level and with reduced power consumption and enhanced efficiency. The method of manufacturing the impeller from sheet metal incorporates sufficient versatility to allow the blades of the impeller to be formed to any desired configuration in order to provide an optimum shape for the intended impeller use. The blades can be curved or twisted and can extend perpendicular from the sheet metal surface or at any desired angle for optimum utilization. Such an impeller is known as (DE-OS 15 03 633).

Although this type of impellers can be produced at low cost in the manner described above, they have two considerable disadvantages. One disadvantage is that only straight outwardly extending radial blades can be made on the impeller in the manner described above If the blades are to be only slightly curved an increased expense caused by tools and material (e.g. material having special deep-drawing properties) is required. By this method only slightly curved blades can be manufactured. Since in the case of the prior-art impeller, the blades are bent out of the area of the impeller and only a limited area of the sheet-metal disk is available for the effective area of the blades because for the folding step which is required when the blades are being bent, a given area is necessary where the sheet-metal disk is held. If the prior-art impeller is to deliver a greater quantity of air it is necessary due to its unfavorable aerodynamic properties either to drive the impeller at a high speed or to increase its diameter.

[13].
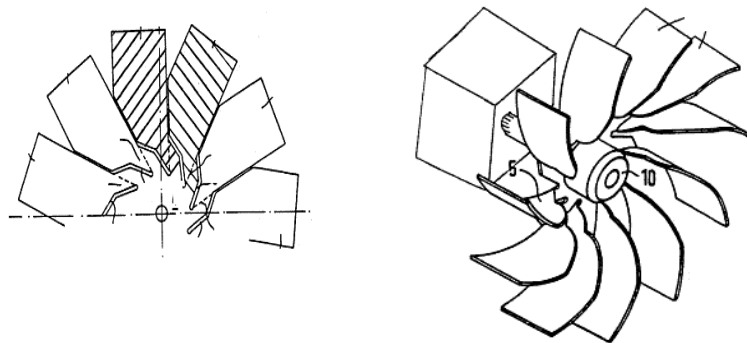
Figure 2.10: Example of an impeller made from sheet metal.[13]

2.10 Method of Manufacturing Using Solid Free Form Fabrication (SFF)

This invention relates to the use of solid freeform fabrication (SFF) technology in the manufacture of impeller blades. The impeller blades may be metal plated and further incorporated onto a rigid skeletal frame to allow for more desirable wear resistance and strength.

With the increased use of Computer Aided Design (CAD) solid modeling systems, a new technique of manufacturing technology has emerged that enables translation of the CAD output data into a three-dimensional physical object. This technology is commonly referred to as solid free form fabrication (SFF) or layer manufacturing which entails building an object on a layer by layer and point by point basis. CAD with SFF technologies allow for greater repeatability which allows for high quality mass production of the object. Forming objects automatically in three dimensions is useful in verifying a CAD database, evaluating design feasibility, testing part functionality, assessing aesthetics, checking ergonomics of design, aiding in tool and fixture design, creating conceptual models and sales/marketing tools, generating patterns for investment casting, reducing or eliminating engineering changes in production and providing small production runs.

On the other hand the resin material that are currently available for SFF are also subject to certain manufacturing and process limitations in structural stability and rigidity in chemical resistance and abrasion and also in manufacturing cost. [14].

2.11 Method of Manufacturing Using Electrical Discharge Machining

A process for manufacturing impellers of turbine pumps provides for subjecting disks corresponding to the impeller to be obtained to electrical discharge machining using tools in form of plates provided with radial slits extending along at least an arc of circumference and opening into hollow areas. A combined motion of rotation and translation is imparted to the disks thus generating twisted blades having a profile with defined geometric characteristics. A one-piece rotor can be manufactured employing open tools with slits formed along a semi circumference and two passages in succession of the work piece through the tools, moving the work piece with a combined motion of rotation and translation. An advantageous application of the articles manufactured by this process is for rotors of turbo molecular pumps since the compression ratio and the pumping speed are optimized and a considerable structural sturdiness of the article is obtained.
[15].
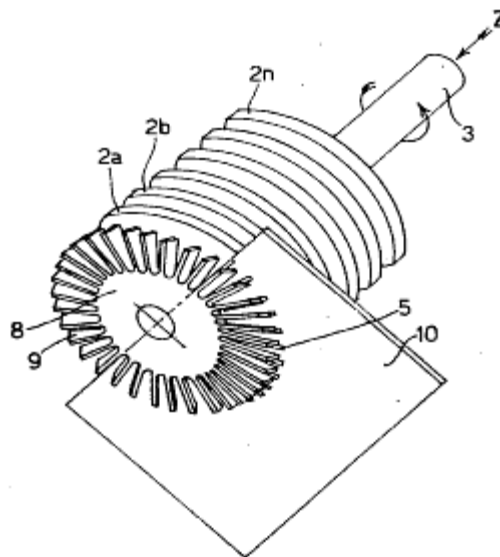
Figure 2.11: Example of an impeller being made from EDM operation.[15]

2.12 Machining – MAZAK

The machining procedure is as shown as in figure 6. Once the design by Unigraphics is done, the NC code will be generated and a simulation will be run by using MAZAK or mastercam. The water pump impeller will then be machined by MAZAK. The tool path generation process consists of two steps which are roughing and finishing. In roughing, the cutting area can be divided into two regions in a non-splitter type and two or three regions in a splitter type. The tool of the maximum size is selected for each divided region. The blades, hubs and leading edges are machined in the finishing. The blade can be finished with side-cutting and the hub being machine in an iso-parametric path. The one-way point milling method is used for the finishing of the leading edge.

[6]
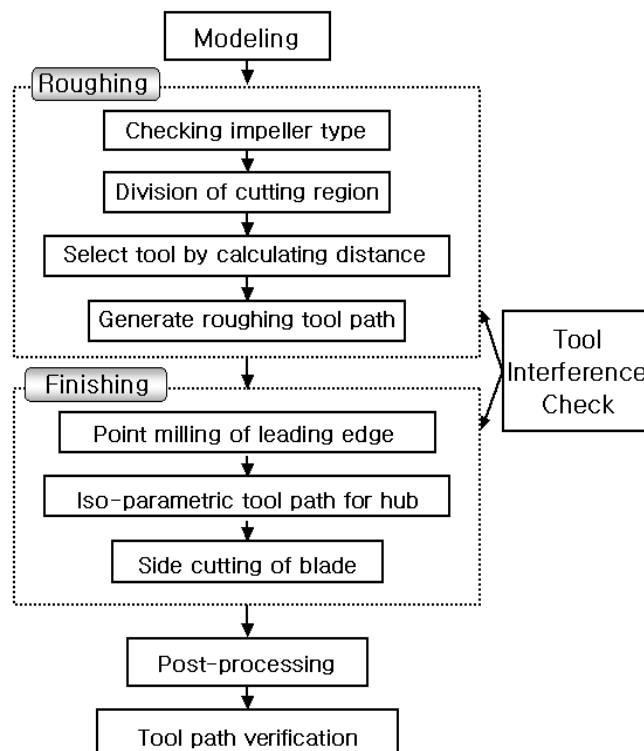
Figure 2.12: Machining Procedure.[6]

In Universiti Teknologi Petronas, we have the MAZAK Variaxis 630-5X and the MAZAK Integrex 200 III. The Variaxis 5-Axis Vertical Machining Center Series II provide high accuracy and rigidity for machining complex workpieces including helical features in exotic materials. The Variaxis Series models are available with 20 or 30 Horse Power, CAT #40 or CAT #50 spindle taper, and top spindle RPM of 12,000 or 10,000. Model ranges offer X, Y, Z travels from 20.08" x 20.8" x 18.11" to 28.74" x 33.46" x 22.05" and table sizes from 15.75" square to 28.74" x 19.69".

[17]

Figure 2.13: MAZAK Variaxis 630-5X.[17]

2.13 CAD/CAM System

CAD/CAM represents "computer-assisted design and computer-assisted manufacturing". CAD/CAM is concerned with the engineering functions in both design and manufacturing. Design engineering activities includes product design, engineering analysis and documentation of the design whereas manufacturing engineering activities are such as process planning and NC part programming. One of the main principal advantages of using CAD/CAM during the design phase is that complete documentation of the product and process can be generated for addition to the overall information data base. This particular data base represents a particular design and can be accessed to generate production schedules, material requirements, design dimensions, NC codes and any other useful documentation that is used for manufacturing process.

In this project, the CAD/CAM system that is adapted for designing the water pump impeller is the Unigraphics NX3. Unigraphics NX3 is one of the world's most advanced and tightly integrated CAD/CAM product development solutions. Spanning the entire range of product development, Unigraphics delivers immense value to enterprises of all sizes. It simplifies complex product designs, thus speeding up the process of introducing products to the market. The Unigraphics software integrates knowledge-based principles, industrial design, geometric modeling, advanced analysis, graphic simulation, and concurrent engineering. The software has powerful hybrid modeling capabilities by integrating constraint-based feature modeling and explicit geometric modeling. In addition to modeling standard geometry parts, it allows the user to design complex free-form shapes such as airfoils and manifolds. It also merges solid and surface modeling techniques into one.
[16]

CHAPTER 3

METHODOLOGY

3.1 Project Flowchart

```
┌─────────────────────────┐
│   Recognition of Need   │
└─────────────────────────┘
             │
             ▼
┌─────────────────────────┐
│   Problem Definition    │
└─────────────────────────┘
             │
             ▼
┌─────────────────────────┐
│       Literature        │
│        Review           │
└─────────────────────────┘
             │
             ▼
┌─────────────────────────┐
│       Choosing          │
│    Impeller Type        │
└─────────────────────────┘
             │
             ▼
┌─────────────────────────┐
│  Generating Impeller    │
│   Design in CATIA       │
└─────────────────────────┘
             │
             ▼
┌─────────────────────────┐
│  NC Code Generation     │
│     (Unigraphics)       │
└─────────────────────────┘
             │
             ▼
┌─────────────────────────┐
│     Store In Library    │
└─────────────────────────┘
             │
             ▼
┌─────────────────────────┐
│      Evaluation         │
└─────────────────────────┘
             │
             ▼
┌─────────────────────────┐
│     Presentation        │
└─────────────────────────┘
```
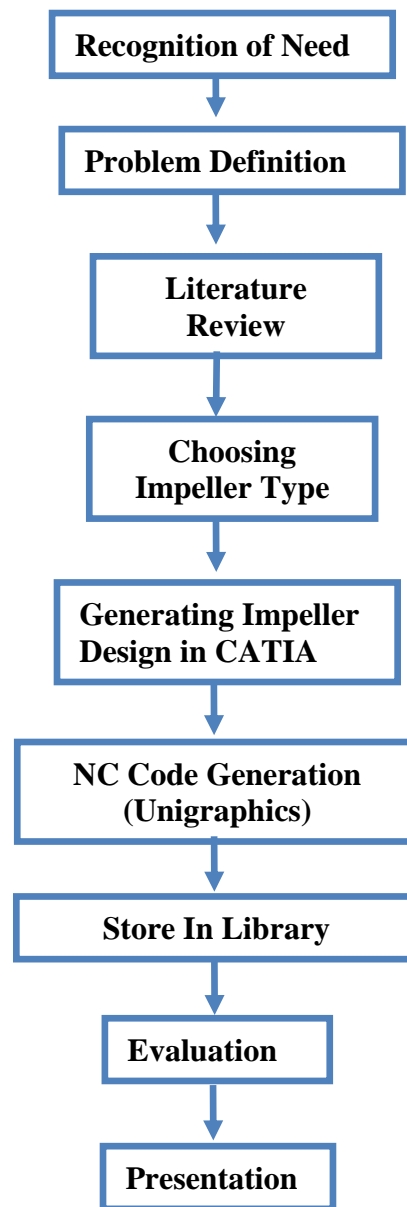
Figure 3.1: Project Flowchart.

3.2 Choosing Impeller Type

Due to most manufacturers being discreet about their impeller exact dimensions, the impellers are selected based on availability in the market. One of the impeller is from a water pump and the exact dimensions have been taken by using a venire caliper from one of our mechanical department lab. The rest of the impellers were based on the outer dimension of this impeller. Since the other four impellers are of the mixing type, hence the outer dimension has got to be not more than 6 inches.

3.2.1 Geometric Design Concept

The pump impeller dimensions will be taken from the existing water pump impeller from the market dimensions. These dimensions are measured accurately by using a venire caliper. The water pump impeller dimensions act as a benchmark for the other 4 mixing type impellers design.

Outer Diameter - 120 mm

Hole Outer Diameter – 30 mm

Hole Inlet Diameter – 18 mm

Thickness – 10 mm

Height – 42 mm

Number of Blades – 9 blades

Figure 3.2: The water pump impeller.

3.3 Library Structure

Accessing Generated NC Code for Impellers.

```
[Obtain Permission] → [Get Password To Access Computer] → [Go To Desktoop] → [Open Folder NC Code Library]
                                                                                      ↓
[Done] ← [Run Unigraphics] ← [Select File Name]
```
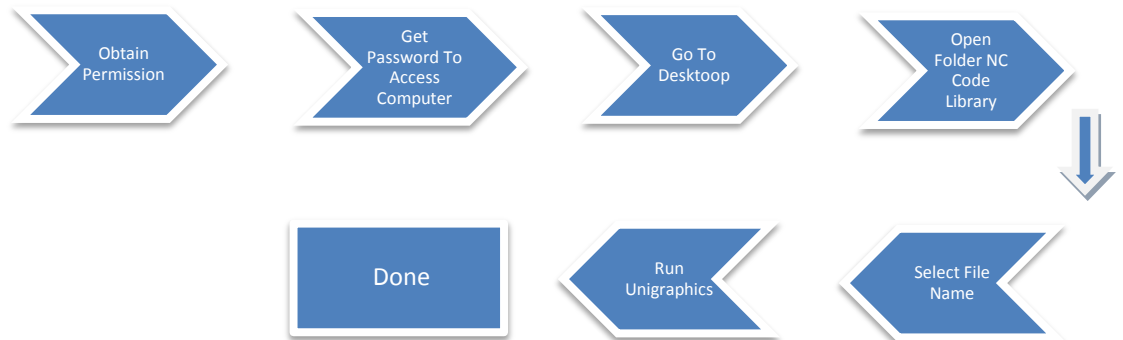
Figure 3.3 : General Procedure For Accessing Generated NC Codes.

Storing New NC Codes.

```
[Obtain Permission] → [Get Password To Access Computer] → [Go To Desktoop] → [Run Unigraphics]
                                                                                      ↓
[Done] ← [Save Completed Simulation Under NC Code Library Folder]
```
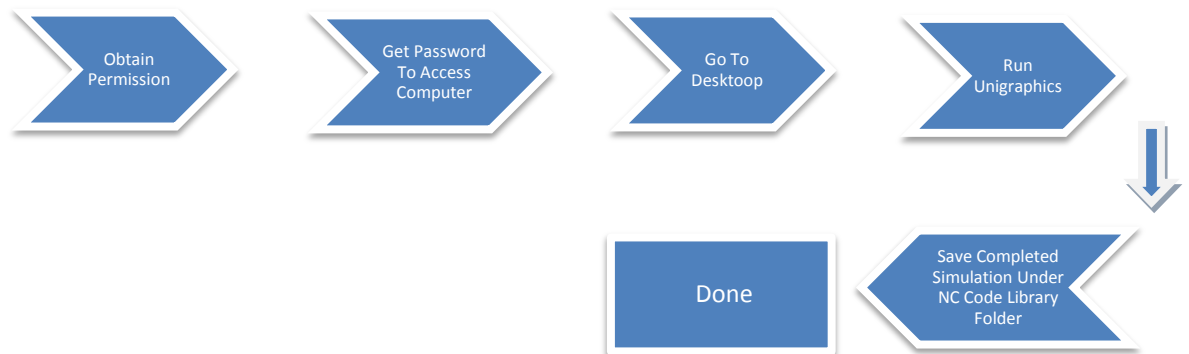
Figure 3.4 : General Procedure For Storing Newly Generated NC Codes.

3.4 Gantt Chart

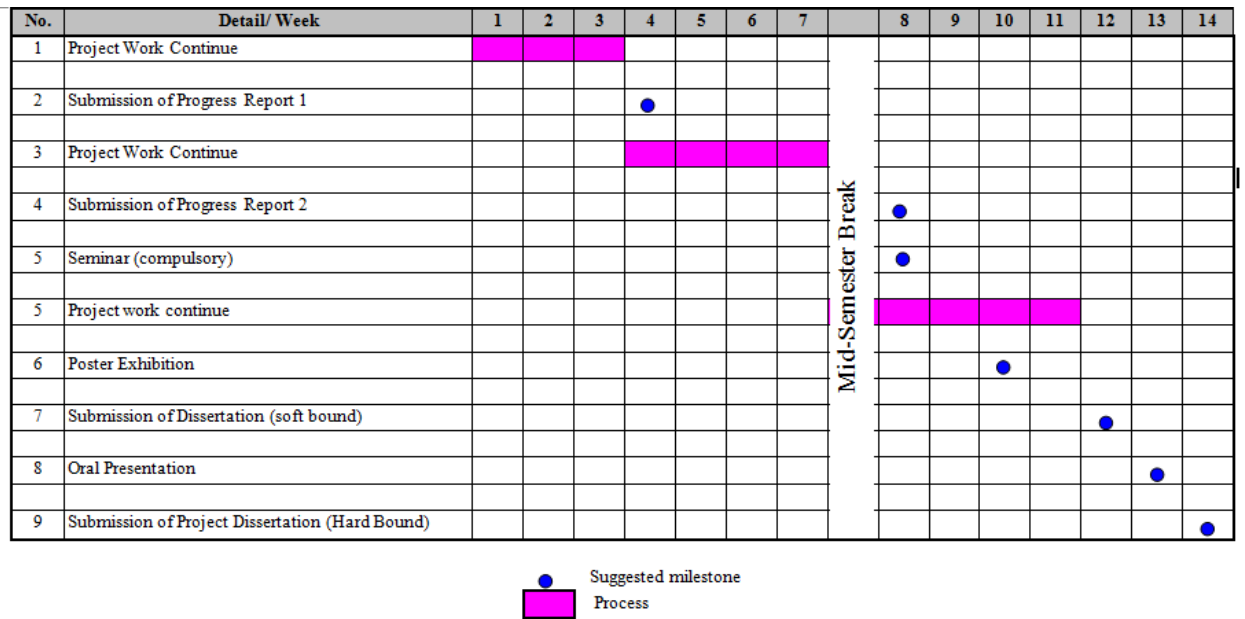| No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Project Work Continue	██	██	██												
2	Submission of Progress Report 1				●											
3	Project Work Continue				██	██	██	██								
4	Submission of Progress Report 2								Mid-Semester Break	●						
5	Seminar (compulsory)									●						
5	Project work continue									██	██	██	██			
6	Poster Exhibition											●				
7	Submission of Dissertation (soft bound)													●		
8	Oral Presentation														●	
9	Submission of Project Dissertation (Hard Bound)															●

● Suggested milestone
██ Process

Figure 3.5: Gantt Chart.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Generating the impeller design in CATIA

The design of the pump impeller is taken based on an existing water pump impeller. The exact dimensions for the diameter, blades, hub boundary are taken for the design process.
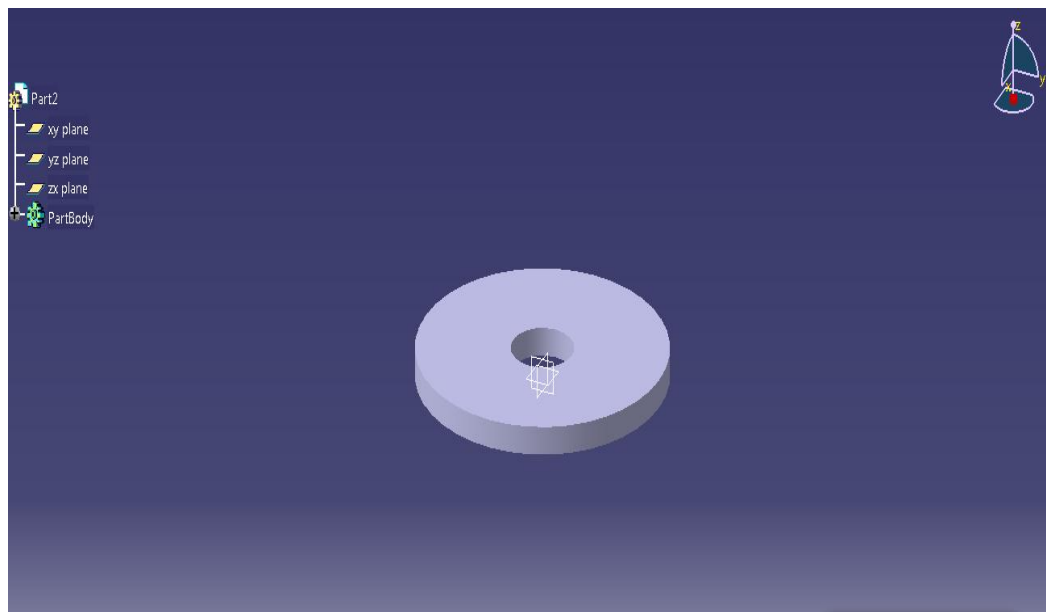

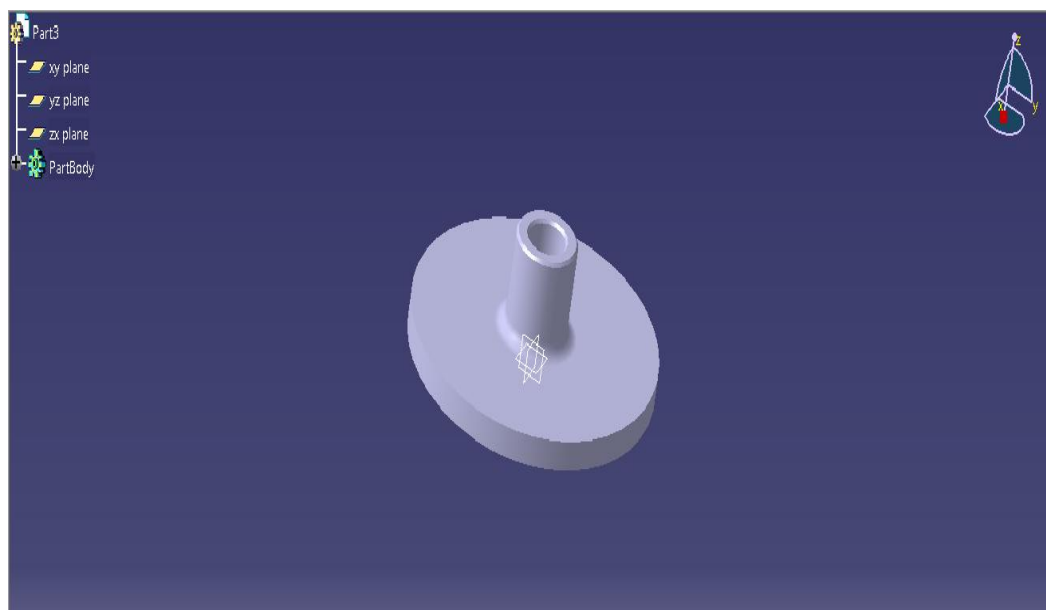**Figure 4.1: The design of the base of the water pump impeller.**

Figure 4.2: The design of the base and top of the water pump impeller.

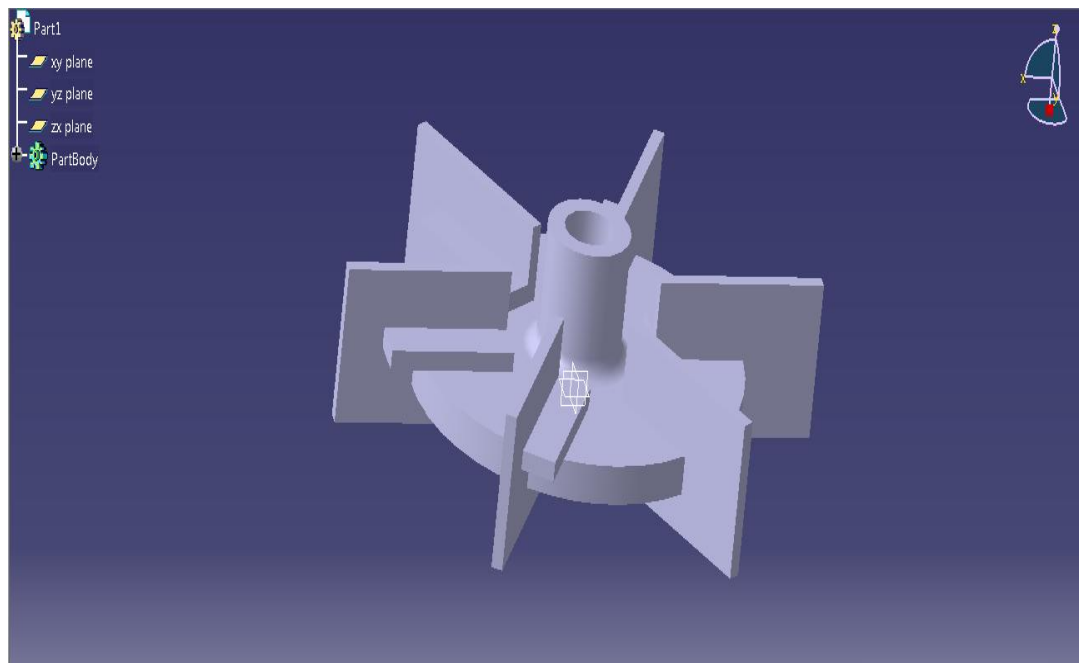**Figure 4.3: The complete design of the water pump impeller.**

Figure 4.4: The complete design of the RT6 mixing impeller.
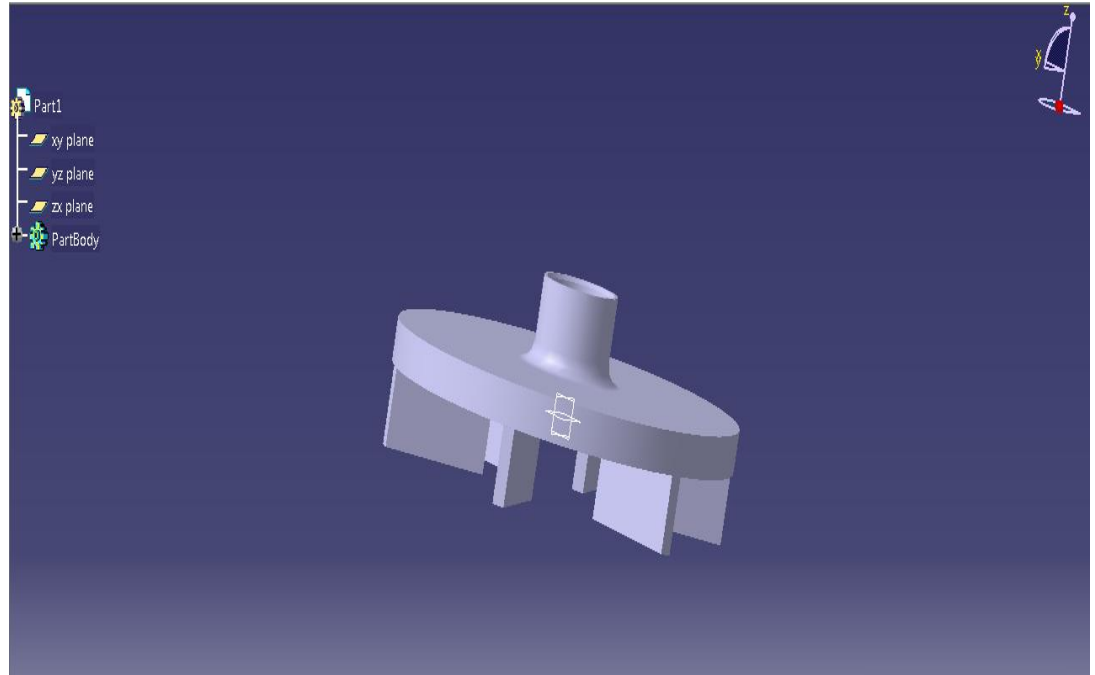
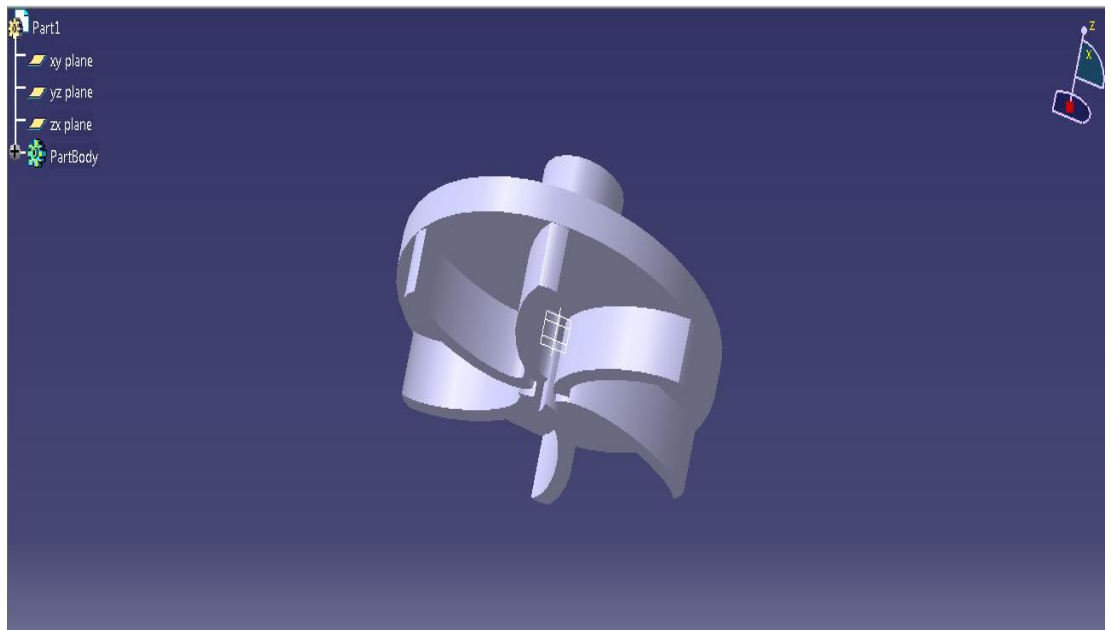**Figure 4.5: The complete design of the Holmes & Narver Pumper Mixer Impeller.**

Figure 4.6: The complete design of the Curved Bladed Mixing Impeller.

4.2 Tool Path Selection in UNIGRAPHICS

Before the tool path simulation is done, take into account what material that is to be used. In this case and based on readily available material in UTP, the material selected for the tool path simulation is aluminum. Hence, with this in mind set the parameters for roughing first.

In the figures below, first determine the type of operation that is to be performed. In this case is the zlevel_follow_core operation. Next select the geometry and blank surfaces. Then, determine the cut method, step over, percent and the global depth of cut for roughing purposes. The cut method would be the follow part and the step over would be the tool diameter. Percent is 50.0000 and the global depth of cut is 2mm.
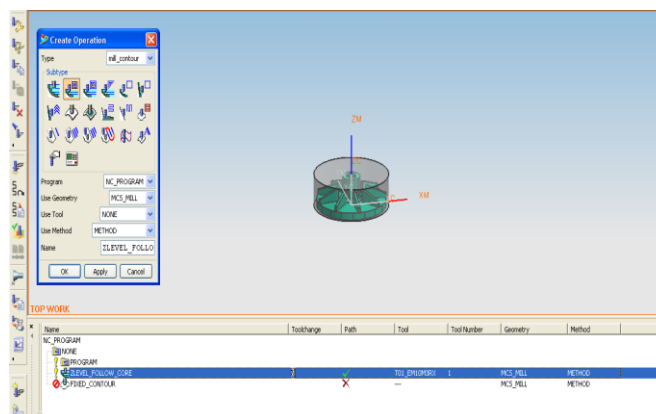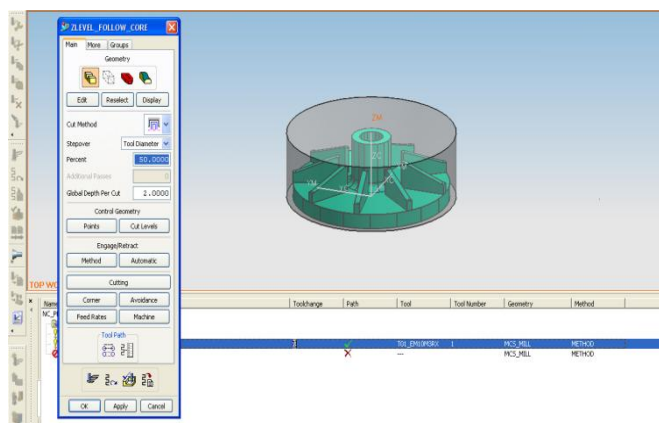

Figure 4.7: Zlevel_Follow_Core.

Figure 4.8: Geometry and Blank Surfaces.

Then, select the milling tool-5 parameters. Here key in the parameters for the milling tool and holder. The diameter for the tool is 10.0 mm, length is 50.0mm, flute length is 30.0 mm, number of flutes is 3, adjust register is 1 and tool number is 1. The values for the holder on the other hand are as follow: 1: diameter-36mm, length-18mm; 2: diameter-26mm, length-5mm; 3: diameter-36mm, length-90mm; 4: diameter-63mm, lengh-50 mm.
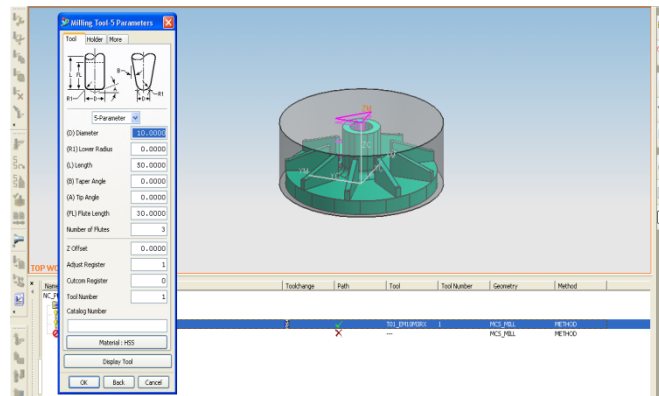

Figure 4.9: Milling Tool-5 Parameters (Tool).
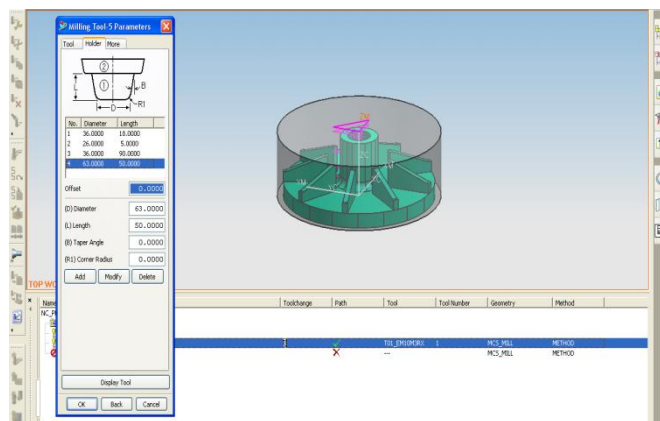
Figure 4.10: Milling Tool-5 Parameters (Holder).

After the settings for the tool and holder parameters has been done, then set the avoidance parameter which include the start point, return point and the clearance plane. Since, UNIGRAPHICS uses absolute point system, the start point and return point will both be positive 150 in the zc-axis direction. This would be the reference point and the safety distance for the tool to move about before, during and after machining operation.
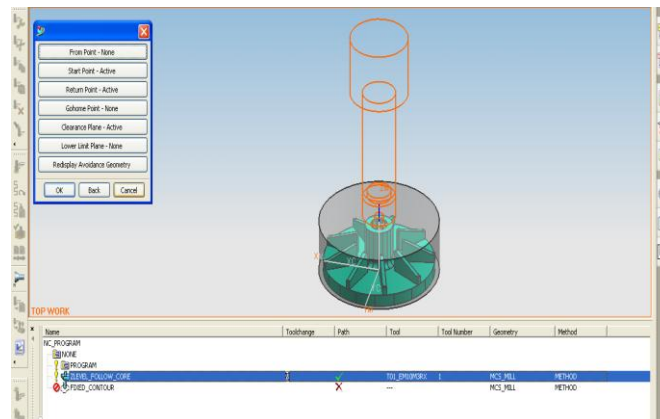
Figure 4.11: Avoidance Parameters.
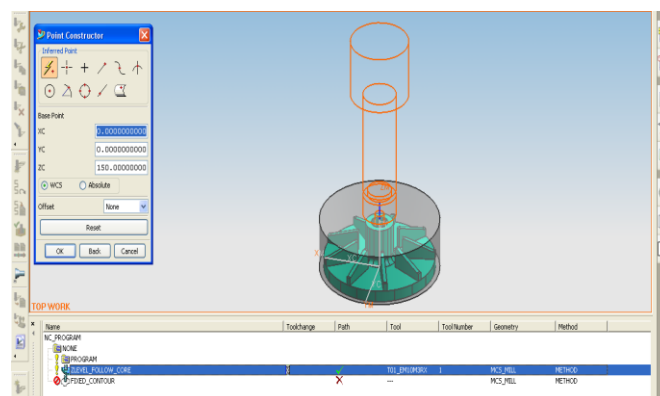
Figure 4.12: Start Point and Return Point.
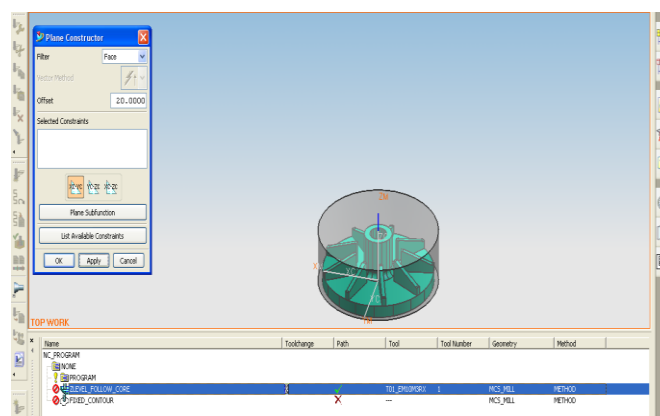
Figure 4.13: Clearance Plane.

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Now specify the cut parameters which include the strategy, stock, connections, and containment. Once all this parameters has been set which mostly are default values, specify the feed rate and speed.

Surface speed = 157 smm, Feed per tooth = 2 mm, Spindle speed = 5000 rpm

Rapid = 5000 mmpm, Approach = 1000 mmpm, Engage = 1000 mmpm,

First cut = 1500 mmpm, Step over = 1500 mmpm, Cut = 3000 mmpm,

Traversal = 5000 mmpm, Retract = 3000 mmpm, Return = 5000 mmpm.
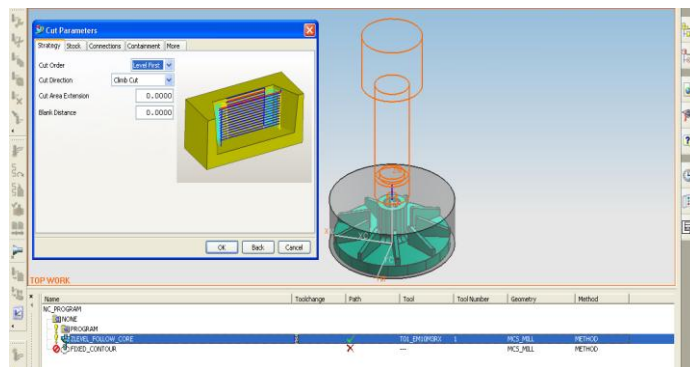
Figure 4.14: Cut Parameters.
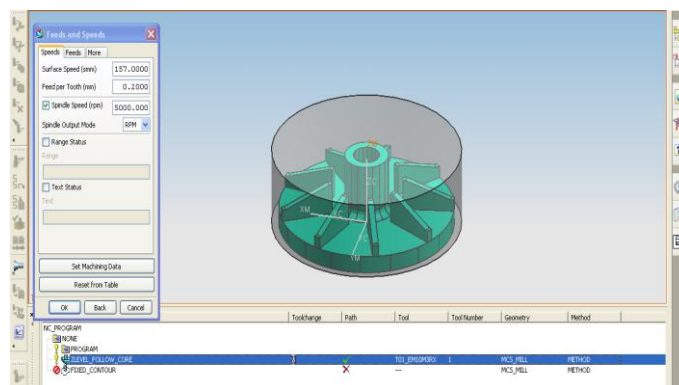
Figure 4.15: Speed Parameters.
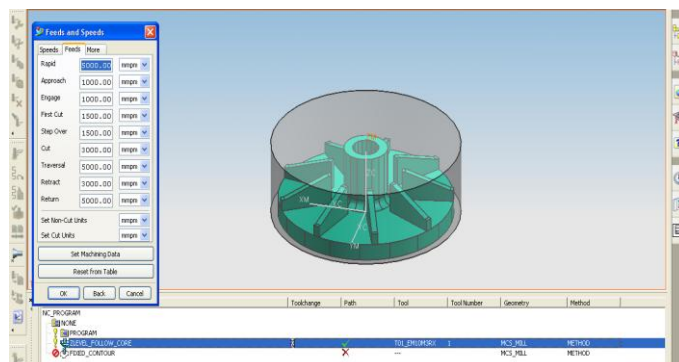
Figure 4.16: Feed Rate Parameters.

4.3 Tool Path Generation/Simulation in UNIGRAPHICS

Step 1: Roughing.

Figure 4.17: 1st Stage Roughing.

Figure 4.18: 2nd Stage Roughing.

Figure 4.19: 3rd Stage Roughing.

Step 2: Face Milling.
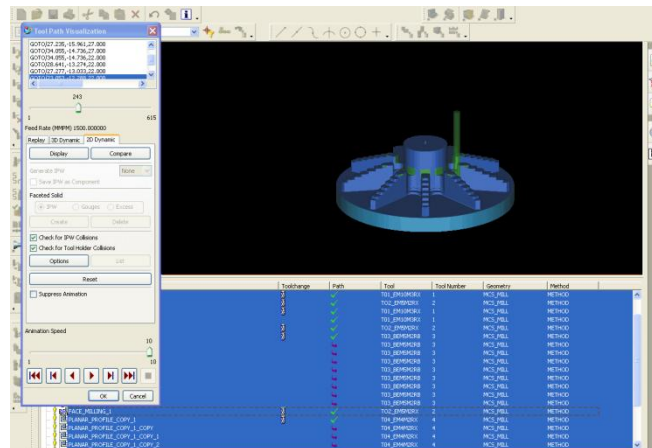
Figure 4.20: Face Milling (Around Hub).

Figure 4.21: Face Milling (Hub).
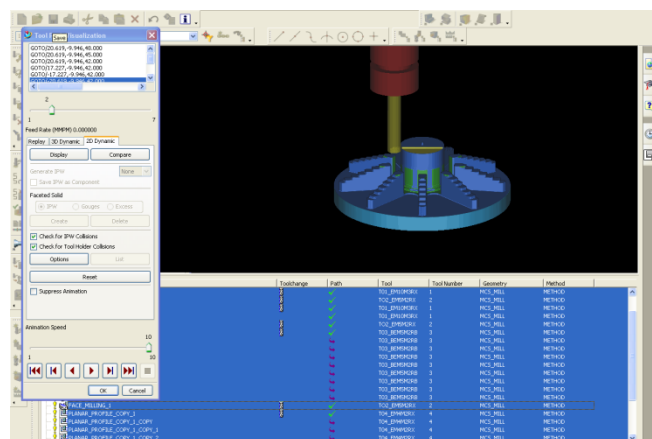
Step 3: Hole Drilling.
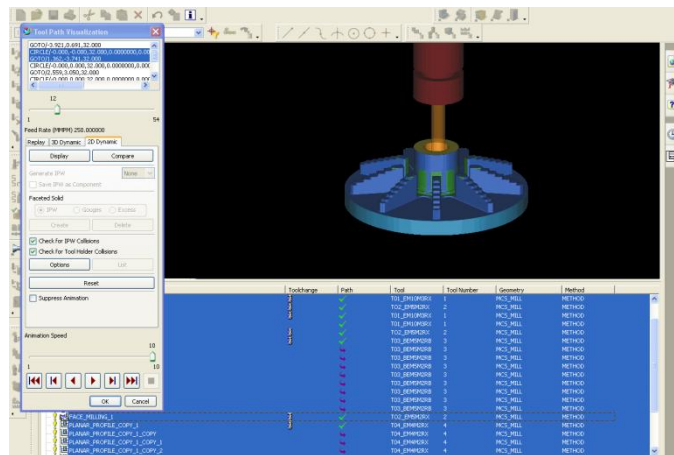
Figure 4.22: Hole Drilling.

Step 4: Blades Surface finish.
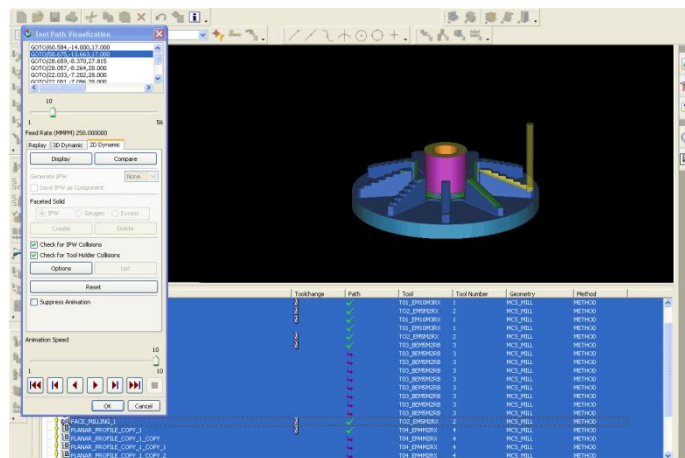
Figure 4.23: Initial Blades Surface Finishing.
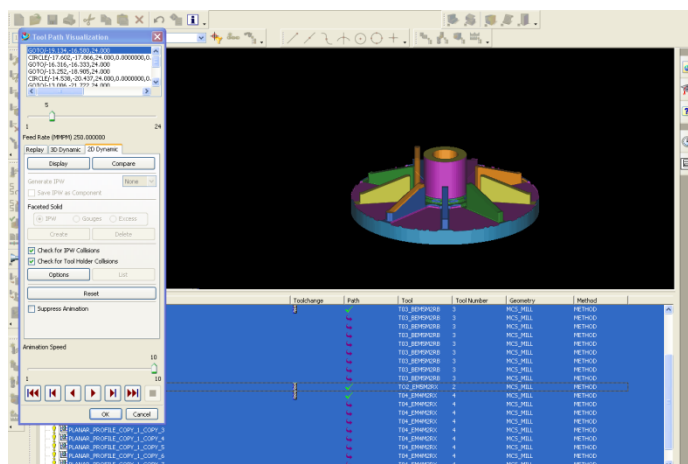
Figure 4.24: Final Blades Surface Finishing.

Step 5: Outer Diameter Surface finish.
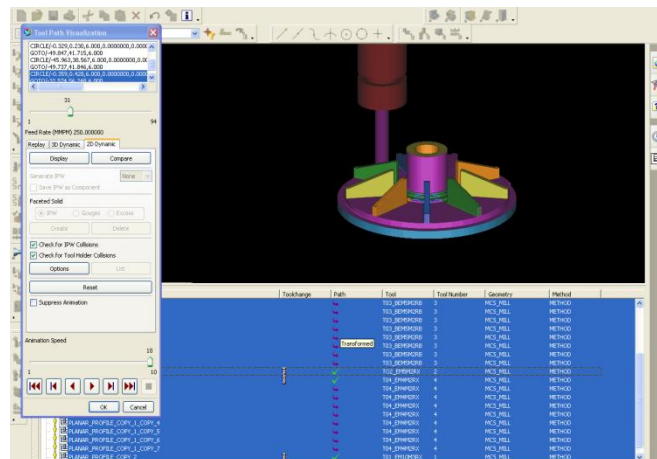
Figure 4.25: Outer Diameter Surface Finishing.

Step 6: Surface finish and Chamfering.
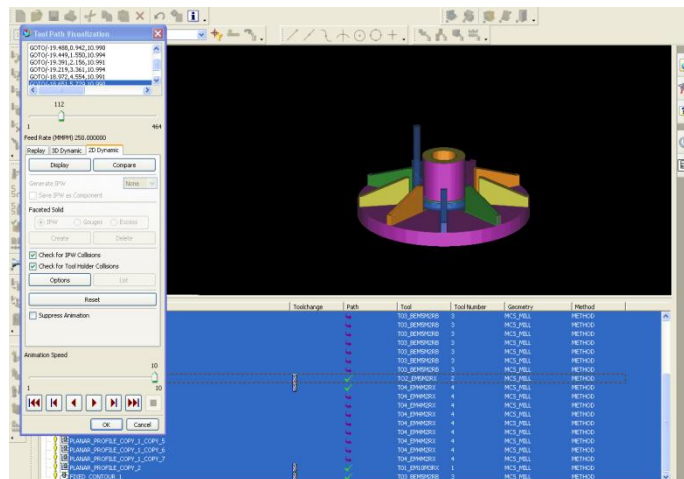
Figure 4.26: Chamfering.

Step 7: Completed Tool Path Generation/Simulation
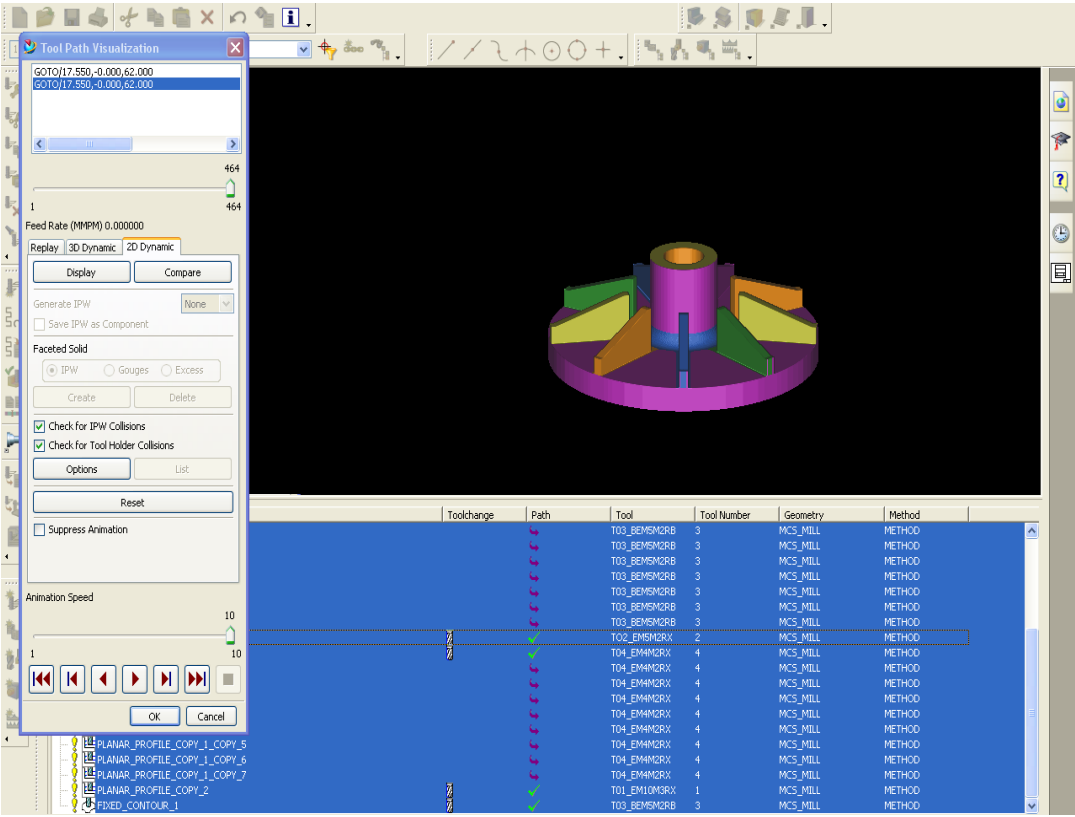
Figure 4.27: Completed Tool Path Generation/Simulation.

4.4 Completed Tool Path Generation/Simulation in UNIGRAPHICS.

Below are the results for the completed tool path generation/simulation done in Unigraphics for all of the impellers:
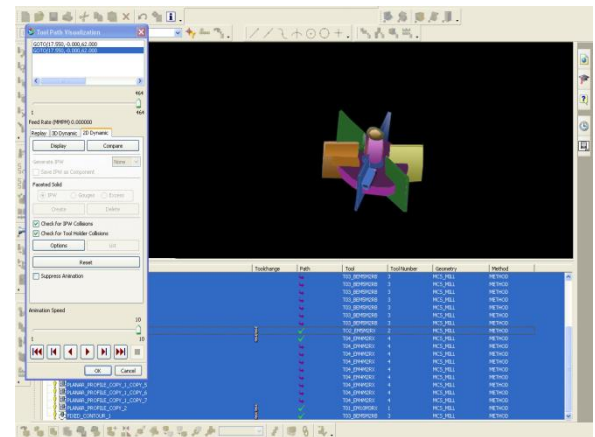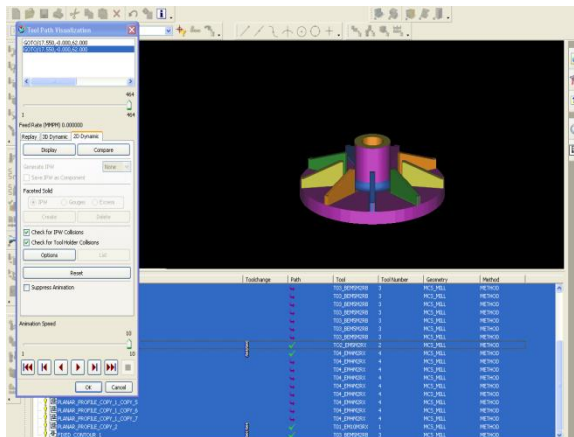
Figure 4.28 and 4.29: Completed Tool Path Generation/Simulation for Water Pump Impeller and RT6 Mixing Impeller.
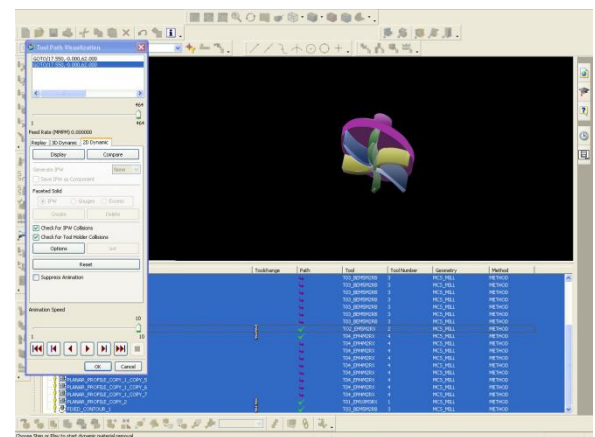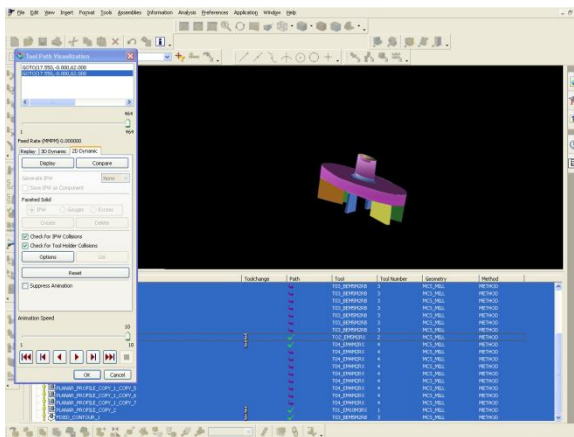
Figure 4.30 and 4.31: Completed Tool Path Generation/Simulation for Holmes & Narver Mixer Impeller and Curved Bladed Mixing Impeller.

4.5 NC Code for Water Pump Impeller.

The NC Code below is part of the whole program for the machining of the water pump impeller.

```
Oclsf impeller1
N1 G17 G0 G40 G54 G21 G80 G90
N2 G91 G28 X0. Y0. Z0.
N3 G90
N4 (NC OPERATION= ZLEVEL_FOLLOW_CORE
TOOLNAME= T01_EM10M3RX )
N5 ( DIA= 10.0 CR= 0.0 FLAT ENDMILL )
N6 M06 T1
N7 G90 G43
N8 G61.1
N9 G1 X0 Y0 Z150. A0. C0. F5000.
N10 X-68.701 Y.577 Z62. A0. C0. F1000.
N11 X-68.701 Y.577 Z46. A0. C0.
N12 X-68.701 Y.577 Z43. A0. C0.
N13 X-64.7 Y-11.412 Z43. A0. C0.
N14 X-64.318 Y-13.587 Z43. A0. C0. F3000.
N15 X-63.569 Y-16.611 Z43. A0. C0.
N16 G3 X-53.96 Y-37.494 Z43. R65.493 A0. C0.
N17 X-44.011 Y-48.823 Z43. R68.067 A0. C0.
N18 G1 X-43.288 Y-49.446 Z43. A0. C0.
N19 X-40.747 Y-51.579 Z43. A0. C0.
N20 G3 X-27.709 Y-59.575 Z43. R67.221 A0. C0.
N21 G1 X-27.709 Y-59.575 Z43. A0. C0.
N22 G3 X-1.63 Y-65.702 Z43. R65.551 A0. C0.
N23 G1 X-1.63 Y-65.702 Z43. A0. C0.
N24 G3 X8.149 Y-65.196 Z43. R63.294 A0. C0.
N25 G1 X8.149 Y-65.196 Z43. A0. C0.
N26 X8.15 Y-65.196 Z43. A0. C0.
N27 G3 X38.575 Y-53.189 Z43. R65.6 A0. C0.
N28 G1 X40.693 Y-51.622 Z43. A0. C0.
N29 X41.995 Y-50.536 Z43. A0. C0.
N30 X44.007 Y-48.827 Z43. A0. C0.
N31 X44.467 Y-48.366 Z43. A0. C0.
N32 X45.097 Y-47.784 Z43. A0. C0.
N33 G3 X63.786 Y-15.762 Z43. R65.619 A0. C0.
N34 G1 X64.042 Y-14.67 Z43. A0. C0.
N35 X64.317 Y-13.586 Z43. A0. C0.
N36 X64.656 Y-11.705 Z43. A0. C0.
N37 X65.081 Y-9.241 Z43. A0. C0.
N38 X65.435 Y-5.978 Z43. A0. C0.
N39 G3 X63.79 Y15.754 Z43. R65.559 A0. C0.
N40 X57.986 Y30.964 Z43. R67.432 A0. C0.
N41 G1 X57.361 Y32.051 Z43. A0. C0.
N42 X55.961 Y34.477 Z43. A0. C0.
N43 G3 X42.005 Y50.528 Z43. R66.109 A0. C0.
N44 X24.454 Y61.017 Z43. R66.825 A0. C0.
N45 G1 X20.416 Y62.484 Z43. A0. C0.
N46 G3 X-1.63 Y65.69 Z43. R66.208 A0. C0.
N47 X-20.414 Y62.483 Z43. R67.243 A0. C0.
N48 G1 X-21.185 Y62.209 Z43. A0. C0.
N49 X-24.45 Y61.018 Z43. A0. C0.
N50 X-25.534 Y60.542 Z43. A0. C0.
N51 X-25.536 Y60.541 Z43. A0. C0.
N52 G3 X-44.009 Y48.793 Z43. R65.751 A0. C0.
N53 X-55.961 Y34.476 Z43. R66.903 A0. C0.
N54 G1 X-56.102 Y34.234 Z43. A0. C0.
N55 X-57.985 Y30.968 Z43. A0. C0.
N56 X-58.519 Y29.883 Z43. A0. C0.
N57 X-58.52 Y29.881 Z43. A0. C0.
N58 G3 X-65.436 Y5.974 Z43. R65.706 A0. C0.
N59 X-65.083 Y-9.236 Z43. R68.158 A0. C0.
N60 G1 X-64.7 Y-11.412 Z43. A0. C0.
N61 X-59.776 Y-10.545 Z43. A0. C0. F1500.
N62 X-60.142 Y-8.468 Z43. A0. C0. F3000.
N63 G2 X-60.456 Y5.525 Z43. R63.158 A0. C0.
N64 X-54.067 Y27.607 Z43. R60.706 A0. C0.
N65 G1 X-54.049 Y27.642 Z43. A0. C0.
N66 X-53.571 Y28.613 Z43. A0. C0.
N67 X-51.777 Y31.726 Z43. A0. C0.
N68 X-51.678 Y31.896 Z43. A0. C0.
N69 G2 X-40.658 Y45.082 Z43. R61.903 A0. C0.
N70 X-23.593 Y55.934 Z43. R60.751 A0. C0.
N71 G1 X-23.558 Y55.949 Z43. A0. C0.
N72 X-22.586 Y56.376 Z43. A0. C0.
N73 X-19.489 Y57.505 Z43. A0. C0.
N74 X-18.81 Y57.747 Z43. A0. C0.
N75 G2 X-1.501 Y60.692 Z43. R62.243 A0. C0.
N76 X18.792 Y57.754 Z43. R61.208 A0. C0.
N77 G1 X22.659 Y56.349 Z43. A0. C0.
N78 G2 X38.811 Y46.681 Z43. R61.825 A0. C0.
N79 X51.669 Y31.91 Z43. R61.109 A0. C0.
N80 G1 X53.029 Y29.555 Z43. A0. C0.
N81 X53.605 Y28.552 Z43. A0. C0.
N82 G2 X58.937 Y14.55 Z43. R62.432 A0. C0.
N83 X60.46 Y-5.481 Z43. R60.559 A0. C0.
N84 G1 X60.128 Y-8.545 Z43. A0. C0.
N85 X59.732 Y-10.836 Z43. A0. C0.
N86 X59.427 Y-12.527 Z43. A0. C0.
N87 X59.184 Y-13.484 Z43. A0. C0.
N88 X58.925 Y-14.592 Z43. A0. C0.
N89 G2 X41.685 Y-44.129 Z43. R60.619 A0. C0.
N90 G1 X40.999 Y-44.763 Z43. A0. C0.
N91 X40.613 Y-45.15 Z43. A0. C0.
N92 X38.775 Y-46.711 Z43. A0. C0.
N93 X37.603 Y-47.689 Z43. A0. C0.
N94 X35.62 Y-49.156 Z43. A0. C0.
N95 G2 X7.532 Y-60.234 Z43. R60.6 A0. C0.
N96 G1 X7.518 Y-60.236 Z43. A0. C0.
N97 X7.505 Y-60.238 Z43. A0. C0.
N98 G2 X-1.501 Y-60.704 Z43. R58.294 A0. C0.
N99 G1 X-1.502 Y-60.704 Z43. A0. C0.
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N102 X-1.505 Y-60.704 Z43. A0. C0.
N103 G2 X-25.595 Y-55.044 Z43. R60.551 A0. C0.
N104 G1 X-25.596 Y-55.043 Z43. A0. C0.
N105 X-25.597 Y-55.043 Z43. A0. C0.
N106 G2 X-37.599 Y-47.693 Z43. R62.221 A0. C0.
N107 G1 X-40.05 Y-45.635 Z43. A0. C0.
N108 X-40.695 Y-45.08 Z43. A0. C0.
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N111 G1 X-59.423 Y-12.552 Z43. A0. C0.
N112 X-59.776 Y-10.545 Z43. A0. C0.
N113 X-54.852 Y-9.679 Z43. A0. C0. F1500.
N114 X-55.199 Y-7.704 Z43. A0. C0. F3000.
N115 G2 X-55.476 Y5.076 Z43. R58.158 A0. C0.
N116 X-49.614 Y25.333 Z43. R55.706 A0. C0.
N117 G1 X-49.579 Y25.402 Z43. A0. C0.
N118 X-49.157 Y26.259 Z43. A0. C0.
N119 X-47.451 Y29.218 Z43. A0. C0.
N120 X-47.395 Y29.314 Z43. A0. C0.
N121 G2 X-37.307 Y41.371 Z43. R56.903 A0. C0.
N122 X-21.65 Y51.328 Z43. R55.751 A0. C0.
N123 G1 X-21.581 Y51.357 Z43. A0. C0.
N124 X-20.723 Y51.733 Z43. A0. C0.
N125 X-17.794 Y52.801 Z43. A0. C0.
N126 X-17.209 Y53.009 Z43. A0. C0.
N127 G2 X-1.372 Y55.693 Z43. R57.243 A0. C0.
N128 X17.173 Y53.023 Z43. R56.208 A0. C0.
N129 G1 X20.86 Y51.683 Z43. A0. C0.
N130 G2 X35.617 Y42.834 Z43. R56.825 A0. C0.
N131 X47.379 Y29.34 Z43. R56.109 A0. C0.
N132 G1 X48.696 Y27.059 Z43. A0. C0.
N133 X49.223 Y26.143 Z43. A0. C0.
N134 G2 X54.084 Y13.347 Z43. R57.432 A0. C0.
N135 X55.484 Y-4.985 Z43. R55.559 A0. C0.
N136 G1 X55.174 Y-7.849 Z43. A0. C0.
N137 X54.808 Y-9.967 Z43. A0. C0.
N138 X54.537 Y-11.468 Z43. A0. C0.
N139 X54.327 Y-12.299 Z43. A0. C0.
N140 X54.064 Y-13.42 Z43. A0. C0.
N141 G2 X38.271 Y-40.476 Z43. R55.619 A0. C0.
N142 G1 X37.531 Y-41.16 Z43. A0. C0.
N143 X37.219 Y-41.472 Z43. A0. C0.
N144 X35.556 Y-42.885 Z43. A0. C0.
N145 X34.512 Y-43.755 Z43. A0. C0.
N146 X32.665 Y-45.122 Z43. A0. C0.
N147 G2 X6.914 Y-55.273 Z43. R55.6 A0. C0.
N148 G1 X6.888 Y-55.276 Z43. A0. C0.
N149 X6.861 Y-55.279 Z43. A0. C0.
N150 G2 X-1.372 Y-55.705 Z43. R53.294 A0. C0.
N151 G1 X-1.375 Y-55.705 Z43. A0. C0.
N152 X-1.377 Y-55.705 Z43. A0. C0.
N153 X-1.379 Y-55.705 Z43. A0. C0.
N154 X-1.38 Y-55.705 Z43. A0. C0.
N155 G2 X-23.48 Y-50.513 Z43. R55.551 A0. C0.
N156 G1 X-23.483 Y-50.512 Z43. A0. C0.
N157 X-23.485 Y-50.511 Z43. A0. C0.
N158 G2 X-34.453 Y-43.805 Z43. R57.221 A0. C0.
N159 G1 X-36.813 Y-41.825 Z43. A0. C0.
N160 X-37.377 Y-41.339 Z43. A0. C0.
N161 G2 X-45.755 Y-31.777 Z43. R58.067 A0. C0.
N162 X-53.877 Y-14.146 Z43. R55.493 A0. C0.
N163 G1 X-54.528 Y-11.516 Z43. A0. C0.
N164 X-54.852 Y-9.679 Z43. A0. C0.
N165 X-49.927 Y-8.812 Z43. A0. C0. F1500.
N166 X-50.256 Y-6.944 Z43. A0. C0. F3000.
N167 G2 X-50.497 Y4.628 Z43. R53.158 A0. C0.
N168 X-45.161 Y23.059 Z43. R50.706 A0. C0.
N169 G1 X-45.109 Y23.161 Z43. A0. C0.
N170 X-44.743 Y23.904 Z43. A0. C0.
N171 X-43.126 Y26.71 Z43. A0. C0.
N172 X-43.115 Y26.728 Z43. A0. C0.
N173 G2 X-33.956 Y37.661 Z43. R51.903 A0. C0.
N174 X-19.706 Y46.721 Z43. R50.751 A0. C0.
N175 G1 X-19.604 Y46.764 Z43. A0. C0.
N176 X-18.86 Y47.09 Z43. A0. C0.
N177 X-16.098 Y48.097 Z43. A0. C0.
N178 X-15.612 Y48.271 Z43. A0. C0.
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N509 X-8.699 Y-18.787 Z43. A0. C0.
N510 G2 X-12.563 Y-16.484 Z43. R22.221 A0. C0.
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CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Machining a complex shape component using CNC Machining Center requires high level of knowledge in NC Programming. From the results obtained, it can be concluded that the main objective of this research or dissertation has been accomplished. The library of NC codes for complex shapes, in this case pump impellers have been created from Unigraphics in order to be used for machining purposes in Universiti Teknologi Petronas CNC Machining Center. Thus, having this library of NC Codes for pump impellers would assist students and certainly reduce the setup time to generate the NC Codes for machining this specific type of impellers.

5.2 Recommendations

Since machining of a complex shape requires high level of competency and knowledge in NC Programming, a few recommendations can be done to further help the process of machining complex shapes and also help educate the less illiterate users or students when using CNC Machining Center. The recommendations are such as:

- To make an additional of NC Codes for other complex shapes to the existing library so that there would be a variety of complex shapes that would be available beforehand which can be used in machining processes.
- To produce a more appropriate procedure or guideline for the less iterate users or students to adhere and follow in order for them to be able to produce NC Codes of certain basic/complex shapes of their own.

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