# UNIVERSITI TEKNIKAL MALAYSIA MELAKA

## FIVE AXIS TOOL PATH PROGRAMMING UTILIZING CATIA V5 FOR SINGLE BLADE

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering Technology (Process and Technology) (Hons.)

BY

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# DECLARATION

I hereby, declared this report entitled “FIVE AXIS TOOL PATH PROGRAMMING UTILIZING CATIA V5 FOR SINGLE BLADE” is the results of my own research except as cited in references.

**Signature** : ………………………

**Name** : **CHENG WEI CHIAT**

**Date** : ………………………

# APPROVAL

This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfilment of the requirements for the degree of Bachelor of Manufacturing Engineering Technology (Process and Technology) with Honours. The member of the supervisory is as follow:

……………………………….

(Project Supervisor)

# ABSTRAK

Disebabkan perniagaan aeronautic semakin dimemperluaskan, pembuatan enjin aero dengan menuntut produktiviti dan kualiti merupakan satu cabaran bagi bidang pembuatan. Kajian ini membentangkan pergerakan mata alat dengan menggunakan CATIA V5 untuk menghasilkan aeroangkasa bilah tunggal. Pemesinan lima paksi digunakan secara lebih meluaskan dalam pemesinan permukaan yang kompleks. Bahan mentah yang telah digunakan dalam kajian ini adalah aluminium yang telah biasa digunakan dalam pembuatkan komponen pesawat. Deckel Maho DMU 60monoBLOCK adalah pemesinan komputer lima paksi yang kawalan berangka digunakan dalam kajian ini. Secara umumnya, strategi pemesinan utama yang digunakan adalah multi-paksi heliks pemesinan. IMS post processor digunakan untuk menukarkan fail APT ke dalam fail .H. Sementara itu, cara untuk menyelesaikan masalah yang dihadapi semasa kajian ini akan dibincangkan dengan secara teliti. Untuk hasilan analisis, mesin mengukur koordinat digunakan untuk mengukur ketepakan dimensi dengan kaedah fizikal dan secara langsung. Keputusan telah dibincangkan dengan lebih lanjut dengan beberapa faktor yang berkemungkinan menyumbangkan kepada penyebab ketepatan. Antara beberapa faktor yang berkemungkinan adalah berkaitan dengan ketegaran bahan kerja dan getaran semasa proses pemesinan

# ABSTRACT

The expanding of the aeronautics business represents a challenge in aero engine manufacturing because of demanding productivity and quality of manufacturing increase. This research presents a tool path utilizing CATIA V5 for aerospace single blade. Five axis machining is widely used in machining of complex surfaces. Raw material used aluminium 6061 as this material is typically use in manufacturing aircraft components. DMG DMU 60 monoBLOCK which is one computer numerical control (CNC) machines is use in this research. Generally, the main machining strategy applied was multi-axis helix machining. IMS post processor to convert APT file into .H file. Meanwhile the way to troubleshoot was further discussed in detail this research. To analysis result, Coordinate Measuring Machine (CMM) is use to measure the dimensional accuracy by physical and directly probing method. The results were further discussed with few possible factors that contributed to result accuracy. Few possible factors mention in this research were strongly believed due to relate with rigidity of work piece and vibration during machining process.

# DEDICATIONS

I would like to dedicate to my beloved parents because of encourage me to do better in my life. Not to forget to my friends because of support and help me by giving information and opinion during the study.

# ACKNOWLEDGMENTS

First and foremost, I would like to thanks to my beloved university, Universiti Teknikal Malaysia Melaka (UTeM) giving me this opportunity to explore myself in new thing. I would like to thanks God for blessing, I have successfully complete my Final Year Project. High appreciate to my supervisor, En. Syahrul Azwan Bin Sundi @ Suandi and co-supervisor En. Muhammad Syafik Bin Jumali for the motivation and guidance during doing the research.

Special thanks to everyone who help me to accomplish the research. I would like to take this opportunity to express my gratitude to all technicians and assistance engineers in UTeM which given fully assistance to me for this research study.

Last but not the least, I am here to thank my family and friends for the continuously encouragement, care and support me toward this project.

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| | | |
|---|---|---|
| CNC | - | Computer Numerical Control |
| CAD | - | Computer Aided Design |
| CAM | - | Computer Aided Manufacturing |
| CATIA | - | Computer Aided Three-Dimensional Interactive Application |
| CMM | - | Coordinate Measuring Machine |
| CMCs | - | Composite Matrix Composites |
| NASA | - | National Aeronautics and Space Administration |
| ALCOA | - | Aluminium Company of America |
| NC | - | Numerical Control |
| WPC | - | Work Piece Coordinate |

# CHAPTER 1

## INTRODUCTION

### 1.0 Introduction

This chapter presents about project background of the proposed research. It also discusses problem statements, objectives, scope and organization.

### 1.1 Background

Aeronautic is a business in still developing sector and no doubt aircraft is an expensive process. The difficulty of manufacturing complex geometry aircraft parts especially engine part makes most of the components costly. Worldwide air traffic level prediction foresees a quick continuous development, expecting the number of planes to increase at a normal of more than three percent by 2030. The expanding of the aeronautics business represents a challenge in aero engine manufacturing because of demanding productivity and quality of manufacturing increase. (Kappmeyer et al., 2012) Blisk (Figure 1.1) is a turbo machine component that combine of both rotor disk and blades. There is also a design where disk and blades are fabricated in a single piece.

Figure 1.1: Assembled blade

These sharp edge (Figure 1.2) are required to be replace in case there are any damage to the blades beyond minor dents. Blisk can be fabricated by machining from a forged part, cast part or by welding blades to a disk. However, these techniques are usually not suggested in critical application by concern fatigue (Broomfield, 1986). The right way to manufacture components for the aerospace industry is critical, CNC machining allowing for the manufacture of perfect parts within special designed aerospace machining center. Aircraft engines are high technology product, the manufacture of which involves creative techniques. Aero-engines face up to the need of continuous improving of its technical capabilities in terms of achieving higher efficiencies with regard to lower fuel consumption, enhanced reliability and safety.



Figure 1.2: Blisk Blade

## 1.2 Problem Statement

CAM systems offer a variety of five axis tools path. The general problem with five axis machining is that five axes simply offer too much freedom. Selection of strategies for five axis tool paths is the challenge. The two degrees of freedom for the axis tilts result for any tool path position in an infinite number of correct tilt values which are still collision free but completely different. Finding the optimum angles is important. As a consequence, any CAM system needs parameters by the user in putting constraints to the tool path creation process (Endl and Jaje, n.d.). In addition, even when the combination of machine and control is operating very precisely, there would be contour deviations on the surface if no further measures were taken. Quality control is required to ensure blisk reliable performance. It is a big challenge to obtain high accuracy single propeller blade. Since propeller blades are machined first on one side and then on the other side, it is necessary to flip the propeller. Flipping propeller model on the machining fixture is not accurate enough. Small errors in position and orientation can result in very large errors at the tip and poor alignment between blade face and back surface. Therefore, initial set-up and alignment of rotary table is great importance for five axis machining.

To obtain high accuracy machined part and the way of programmer tailor CAM programming for machined part is a challenge for CAM users. The choice of five axis machining strategy depend on the material, machine, available tools, and holders. Additionally, the limited of the different rotation axes of milling machine should be considered when creating five axis tool path. However, five axis tool path may not run optimal on any machine by default setting.

## 1.3 Objectives

The objectives of this research are as follows:

a) To create and validate the five axis machining tool paths utilizing CATIA V5 for a single blade.
b) To investigate the effect dimensional accuracy on machined part to be compared to the CAD model.

## 1.4 Scope

This topic focus on getting the tool paths generation in order to produce at least a single blade utilizing CATIA V5 as the main CADCAM software. Aluminum is the material identified to be used in validating the tool paths for the physical machining. Only aluminium alloy being used in this research, other material not in consideration. Deckel Maho DMU 60 MonoBLOCK five axis machining centre used to perform the machining.

The measurement of machined part had undergo dimensional accuracy analysis to be compared to the original CAD model. Surface finish not be discuss in this research.

# CHAPTER 2

## LITERATURE REVIEW

### 2.0 Introduction

Literature review discuss about the relevant information and survey the literature in relevant area of study. At early stage of the studies, gather the reference books, research journals, online article, and magazine as the main sources of thesis guides. Followed by critically analyses the information to ensure that are relevance of this research by showing limitations of theories and points of view. This section included the principle of five axis machining, machining strategies, multi axis helix, multi axis flank machining, dimensional accuracy, and aluminum.

### 2.1 Five axis Machining



CNC milling machines are usually classified by the number of axis of motion. Literally, a three-axis milling machine able to perform machining process by moving a cutting tool along X, Y, and Z three linear axes. With use of end mill and unique fixture devices the three-axis milling machine can be very flexible and can be used to manufacture various kind of parts. While five axis milling machine is a combination of three linear axes plus two additional rotary axes (either a rotary axis with rotary table, compound rotary table, or a dual rotary axis) and provides flexibility and efficiency that three axis milling machine cannot be achieved. In other words, five axis milling machine able to produce much more complex shape by using a single set up without special cutting tools or fixtures with greater accuracy. Even the twisted impellers, turbine blades and compressor blade found in aircraft turbine engines can be produce by five axis machine. However, to produce a complex geometry parts is still a difficult task although the five axis machining have a lot of advantages and new possibilities. (López, 2005)

It is a challenging task for machining mechanical parts such as turbine blades, impeller and compressor blade with high dimensional accuracy and high geometrical complexity. In order to obtain ideal dimensional accuracy, the incline angle must be keep within the limits. Three-axis CNC are always falls out of the limits, therefore it is much harder to achieve required accuracy. Five axis CNC machining center can be easily corrected the tool position which need extra maintenance and cost. The extra cost can be cover by the benefits of lower tool wear, shorter planning and the quality of work is improved. In addition, five axis machining able to maintain constant cutting forces along the tool path by setting the feed rate which able to reduce machining time significantly. (Layegh et al., 2012).

### 2.1.1 Five axis CNC Milling Machine Configurations

Basically, machine tool has six degrees of freedom and can by moving tool at any position, while milling machine structure has five degrees of freedom. There are some common machine configuration for five axis that are available in current market. The most common types of five axis machining center are table-table, table-tool, table-tool (turn-mill), and tool-tool.

Table 2.1: Types of five axis machines

| i) Table-Table BC type | ii) Table-Tool BC type | iii) Table-Tool BC type (turn-mill) | iv) Tool-Tool AC type |
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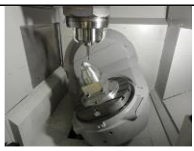
|  |  |  |  |

The first type of five axis machine is two rotary axes located on the table. B axis tilts around Y axis and C axis rotates around Z axis of the part. While the head is always stationary and linear motion is driven by the head. Its offer better undercut capabilities than other machine configuration.

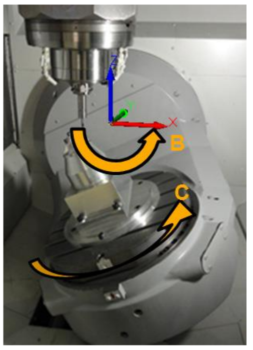



Figure 2.1: Table-Table BC type

The table still rotate in C axis but the head of machine can be tilt.

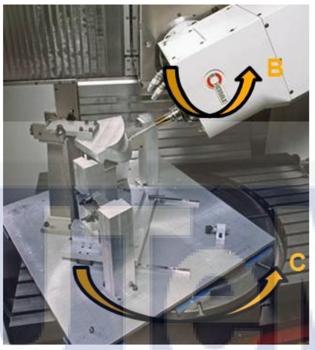



Figure 2.2: Table-Tool BC type

Turn-mill is the combination of milling machining center and turning machining. The turning spindle become the C-axis to rotate the part and the tilting of the tool is driven by the B-axis. The linear axis are located on lathe, with the Z- positioned horizontally along the spindle axis instead of vertically along the tool axis.

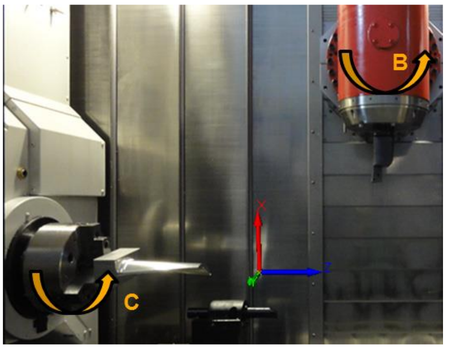



Figure 2.3: Table-Tool BC type (turn-mill)

Both rotary axes are located on the milling head to rotate and tilt the tool into desired position, while the table is stationary for AC type five axis milling machine center. This design allow to machine heavier parts compared to table-table type of machine. Because the table does not tilt, and is suitable for a very rigid setup for larger parts. Furthermore, the rotating head allows to use the shorter length tooling because the tool can enter or rotate around the part. With this, can greatly reduce the vibration of tool and increase the accuracy of parts.


Figure 2.4: Tool-Tool AC type

Every each of them has their own strength that makes them stand out among the choices. Other than the features such as maximum feed rate, spindle speed, automatic tool changers are important as in three axis machines, there are three main issues must considered for machine selection which are rigidity, work volume and accuracy. Rigidity is the need in all milling machining center due to able it to improve the positioning accuracy and higher material removal rates. For the most part, a more rigid machine will be more costly. Large size and hard material required higher rigidity of machine in order to perform well. The working volume of the machine is one of the important issue that define by the range of joint motions. Range of motion determines the maximum size of part and the ability of the cutting tool to access some functions on the part. Accuracy is very critical to machine performance. The phenomenon of positioning errors makes difficulty to predict the accuracy of a machined part.

### 2.1.2 Advantages of Five axis Milling Machining Center

With expanding the demand for the performance design, mechanical element having complex shape and accuracy are needed to be manufactured in tight tolerances. In manufacturing high end designs, the complex part has to be created by maintaining the dimensional accuracy with minimum number of setups which required tool positioning and contouring capability. Five axis milling has been widely used in automotive, aerospace and die-mold industries. These shapes are known as free form surfaces, which cannot expressed analytically with ease. Precision casting, forming, forging, injection, blowing, pressing and other are the production technologies that can effectively fabricated free form surfaces parts. Today, these complex shapes are possible to produce a complete part with five axis milling centres aided of CADCAM system by only one clamping (Pokorný et al, 2012).

## 2.2 Machining Strategies

There are several of tool path strategies selection in CAM systems and each of them are appropriate place in five axis. For a particular application, the suitable tool path strategies can be vary. It is depend on programmer experience, lesson learned from the past project and the actual machine configuration will playing the big role in selection. Therefore, different programmers to program a same part, the outcome will be likely to totally different machining strategies. Available tooling and specified material could play a critical role in selection of tool path strategies process.

The selection of machining strategy is very critical in achieving the aim of the research. Machining of turbine engine compressor, there are few universal strategies such as flank milling, point milling and plunge milling, while some local strategies such as zig, zig-zag, helical, raster and trochoidal milling. Munar summarized that five axis operation can be divided into two which is point milling or flank milling. Point milling is remove material by using the tip of the tool and usually applied to machine complex surface. The drawbacks of point milling is time consuming and the surface might require secondary process in order to remove the scallop height. The flank milling is removes material by using the side of tool, which higher machining efficiency and able to reduce the presence of surface scallops. (Munar et al., n.d.)

A study conducted by Budak et. al (2010), entitled to machine design geometry from the raw geometry there are three main stages such as roughing, semi finishing, and finishing. The semi finishing stage required multiple steps to obtain the desired dimensional tolerance. However, the roughing and finishing only need single step, depending on the applied strategy. He also claimed that the spindle torque, spindle power and axis speed limits of the machine tool also effect on the selected strategy as well. The aim of the roughing is to removing the nonessential volume as fast as possible. Therefore, the torque, power and cutting forces required are high. However the excessive amount of stock left after roughing will be continue remove in the next step. The chips load of semi finishing is normally less compared to roughing, therefore the power and torque required are lower. In obtaining the ideal design geometry and dimensional accuracy, the finishing stage is the most critical. In this stage, the chatter vibration must be reduced so that the desired part able to obtain. The amount left from of semi finishing stock is one of the most critical parameter that will effect work piece deflections and vibration. Also, the number of cutting passes will affect the chatter stability as well. The paper carried out experiment with three types of strategies which is flank milling (deep cuts), stripe milling (medium depths), and point milling (light cuts) in compared the process time, chatter stability, surface finish and tool deflections as well. The paper concluded that the chatter stability also base on the number of cutting passes, which accuracy will definitely effected by the chatter stability. Flank milling can be very high cutting depth that use the cutter side to perform the cutting process, while the point milling is make use of the cutter side to machine the surface by removing small depth.

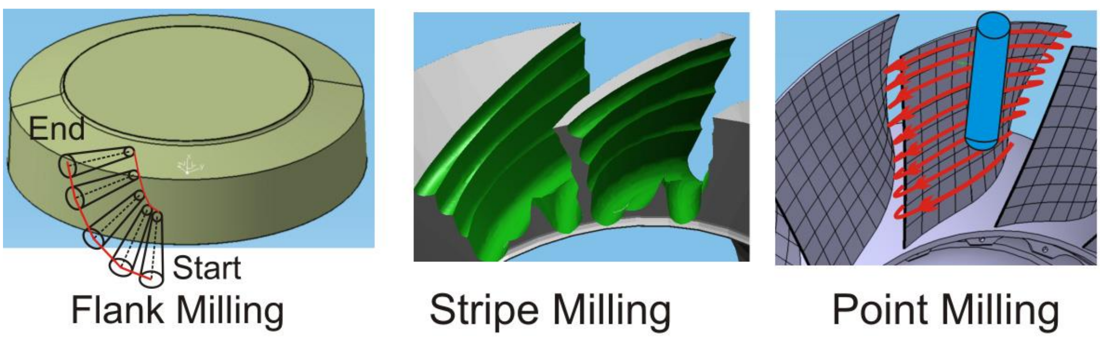



Figure 2.5: Machining strategies

The finding shows that the roughing stage can be perform by three of the strategy but the semi finishing and the finishing stage should apply point milling. In this case, the flank milling and stripe milling unable to fulfil the requirement to generate the design geometry. However, both of the strategy still can be applied in roughing stage and possibly for semi finishing stages. On the other than, the point milling is suitable for three of the stages because of the contouring capability. (Budak et al., 2010)

### 2.2.1 Flank Milling

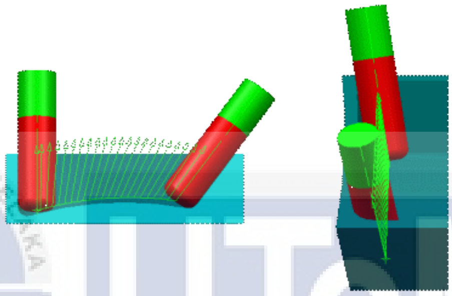


Figure 2.6: Flank Milling

Flank milling is very useful especially to machining aircraft parts, turbines, blades, impeller and others mechanical parts. The advantages of flank milling is able to improve the quality, reduce manufacturing time and cost. Harik, Gong, & Bernard (2013), study about optimal tool trajectories and tool geometry of flank milling. The study investigate minimum geometrical errors such as overcut which means over indentation of the tool in the surface, and undercut that less removal of all excessive material.

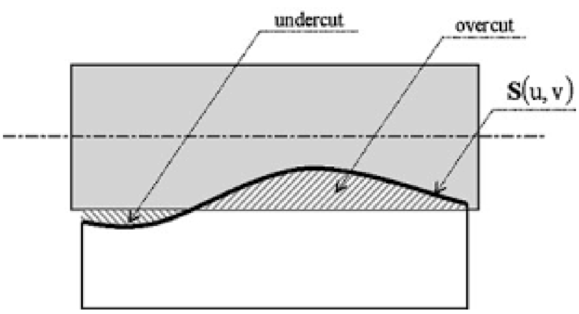



Figure 2.7: Overcut and undercut

### 2.2.2 Point Milling

Point milling is a machining strategy that using ball nosed cutter in tangential contact with a surface at the cutter contact point. Warkentin have studied the different between multi-point, inclined tool, and principal axis method that under category of positioning strategies. The experiment conducted using computer simulation as well as experimental cutting test. Inclined tool also known as Strutz milling is the method that cutting tool is inclined at a fixed angle and feed in a direction. While principal axis method is the tool inclined in the direction of minimum curvature instead of feed direction. In conclude, multi-point machining produce smaller scallops than other five axis techniques. It is very encourage to use in reducing finishing machining time of sculptured surface.(Warkentin et al., 2000)

Figure 2.8: Point milling



### 2.2.3 Inclined Tool

Incline angle of tool axis helps to improve surface roughness, reduce cutting force and improving production. At the end tip of ball end milling tool pushes material into work piece will causing undesirable effects such as chip contraction, increase cutting temperature, increase vibrations or creation of built up edge. These undesirable effects can be reduce with tilt of ball end mill or tilting work piece. Sadílek &R analyzed tilts of cutting tool in pick feed dirrection from 0 to 30 degree with increment of 5. The cutting force were measured with dynanometer and resulting almost 50 percent able to reduce if ball end mill being tilt in ranging of 15 to 30 degree. Decreasing of cutting force will inclucence on the cutting stability and vibration reduction. (Sadílek and R, 2009)

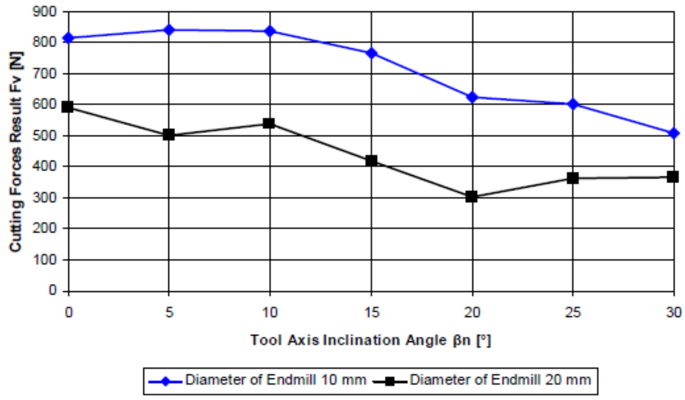



Figure 2.9: Cutting Force against Tool Axis Inclination Angle

## 2.3 Aluminum Alloy

Application of aluminum is critical for aerospace industry, automotive as well as sports equipment. “In 20 to 30 years, the entire hot section of a jet engine will be composite matrix composites (CMCs), except for the disk that holds the blades,” predicts Ajay Misra, the chieft of materials and structures at NASA’s Glenn Research Centre in Ohio. Airbus A350 is 53 percent composites, and the largest polymer composite is the lower wing. The left of the aircraft components contains 19 percent aluminum, 14 percent titanium, 6 percent steel and 8 percent of miscellaneous materials. While The Boeing 787 almost same contains which is 50 percent composites, 20 percent aluminum (for wing ribs that can be cut efficiently in one piece from a block), 10 percent titanium, and less than 10 percent of steel. The body material of Airbus A350 and Boeing 787 still contain nearly 20 percent of aluminum. The cost is playing with the major issue in aerospace, raw aerospace aluminum cost about $4 a pound, compared to $10 per pound for composite. The Aluminum Company of America (Alcoa) has produce more than 65 specifications of aluminum alloy for aerospace. The result stated that the structures are cheaper when compared to titanium and composites and up to 10 percent lighter than composites, refer to Alcoa’s Heinimann (Ben. et al (2015)

Aluminum alloys categorized by a group of number based of the material characteristic such as mechanical treatment, ability to respond thermal, and the alloying element added into the aluminum alloy (see table 2).

Table 2.2: Aluminum Alloy Designation System

| **Alloy Series** | **Principal Alloying Element** |
|---|---|
| **1xx** | 99.000% Minimum Aluminum |
| **2xx** | Copper |
| **3xx** | Manganese |
| **4xx** | Silicon |
| **5xx** | Magnesium |
| **6xx** | Magnesium and Silicon |
| **7xx** | Zinc |
| **8xx** | Other Elements |



The ductility decrease from 1000 to 7000 series, while the strength is increased. It is important to understand the differences between these alloys and their performance. 7000 series alloys are often used in high performance application such as sporting equipment, automotive, marine and aerospace parts due to their high strength and light weight that desired. In order to obtain the necessary strength, zinc additions ranging from 0.8 to 12.0%) and alloyed with copper to improve the corrosion resistance.

## 2.4 Dimensional Accuracy

Machining accuracy can considered to be one of the most important aspects in measuring machined part performance. (Koura and Ali, 2014) investigated on the effect of CNC cutting parameter on dimensional accuracy by using CMM. The studied concluded accuracy of machined part depends greatly on cutting condition such as spindle speed, feed rate, and depth of cut. There are some few potential factors that will affect the accuracy of machined part. Dimensional accuracy plays an important role on required tolerance and fit especially manufactured parts to be assembled. (Liu et al., 2002) discovered that cutting force will influence on the dimensional accuracy due to tool and work piece deflection. The selection of flute number, the axial depth of cut, the radial depth of cut and the feed rate carefully can reduce effectively the error of accuracy. In additional, Peter claimed that control chatter can improves the machine accuracy as well as surface finishing. By making the setup of tooling more rigidly the chatter can be reduced. Moreover, the finding said high spindle speed able to quiet down chatter. On the other hand, to increase the system's rigidity, perhaps by use shorter tool or better tool holder such as shrink fit that will have better grip of tooling. However, different combination of spindle speed, cutting tool used and tool holder will provide different result. The most common way to deal with chatter is to reduce the force and vibration by setting lower depth of cut. Choose an axial depth of cut around one of three of the diameter of cutting tool and use the tooling supplier recommendations to choose a chip load in order to obtain a better and stable milling speed.

# CHAPTER 3

## METHODOLOGY

### 3.0 Introduction

This chapter explain detail of how this study has been conduct. The methodology has divided into two phases. First phase included proposal of project, literature review and methodology planning. The study of various kind of machining strategies also included in semester 1. For semester 2 shall proceed to conduct the experiment and further discuss, follow by result discussion and lastly conclusion. The preparation of machine tools, raw material, and fixture available are required before continue with CAD editing and CAM programming. Before undergo physical machining process, CAM shall go through post processing to generate coding. Next, the detail set up and proceed to physical machining. The machined part has undergo dimensional accuracy measurement by CMM compared CAD model. Analyze obtained data for documentation purpose and further discuss.

### 3.1 Project Planning

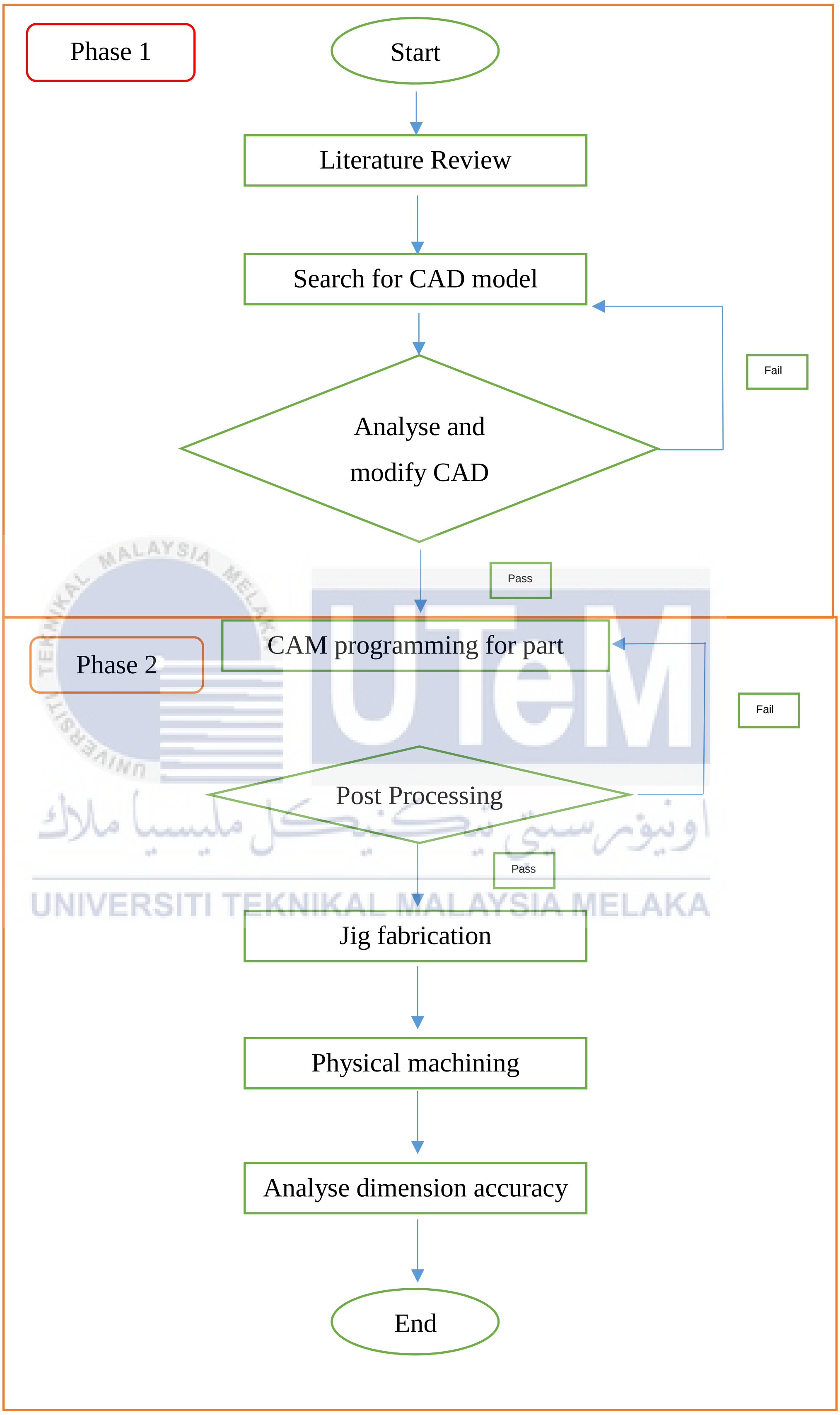



Figure 3.1: Flow Chart

### 3.1.1 Phase 1

From the flow chart above, the research begin from data gathering. Study relevant information about principle of five axis, machining strategies, dimensional accuracy as well as aluminum. The information was draw from academic journals, articles written, reference book, website and others sources. Literature review of the research has summarize the information which has been gathered for the purpose of understand how others conduct related experiment and what is the current tread about single blade and aerospace parts.

Few CAD model parts was get from GrabCAD, which is an internet sources that provided largest collection of free CAD files. Besides that, searching real product from industries is under progression. CAD part that found had been analyzed and choose the most appropriate for research (Figure 3.2: CAD Model). The CATIA file type of CAD model was found is better due to the history of part created are shown and ease to be modify.



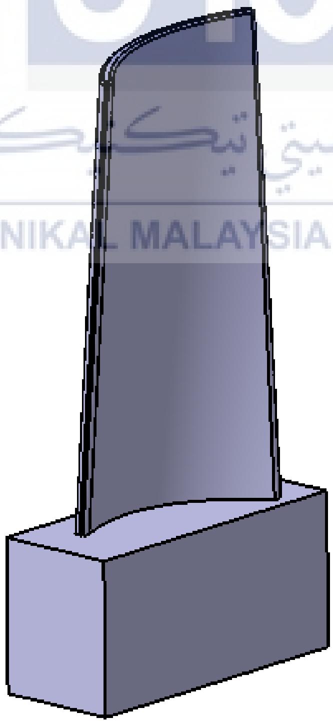


Figure 3.2: Original CAD Model

The analyzed part included the geometry of single blade, such as upper and lower contour, leading edge and trailing edge. Furthermore, modification is necessary to preserve the intellectual property of the CAD model obtained. Reserved few CAD model in case the chosen CAD model cannot be machining. The part scale down from original size of the part. The purpose of the scaling is to ease the machining process and the size to suit the stock available. Use minimum amount of stock material to reduce raw material cost, especially the aluminum with aerospace grade either six or seven series which are high cost. The CAD model has been scale down to appropriate size which is smaller than 150mm x 50mm x 150mm.

### 3.1.2 Phase 2

On the other hand, phase two of the research shall resume with the machine selection, machine tools, and jig of the stock on the machine tool table. Basically, phases 2 are process planning and physical machining. Machining strategy development and optimize with the great support of CATIA V5 software. Based on the part size and machining requirements, the BC types of five axis machine has been chosen to perform machining single blade. Tooling selection is very important because of it could affect the result of dimensional accuracy. The end mill diameter tool range would be around 6 to 12mm. Both flat end mill and ball end mill is required. In additional, end mill 40-45° helix angle shall be used in order to obtain high accuracy machined part (Izamshah et al. 2013) The number of flutes, length of cut, overall length, types of tool holder has to be consider because of the vibration definitely will affect the result of dimensional accuracy. There are carbine and tungsten end mill and high speed steel, HSS are available. High speed steel end mill is sufficient to machine Aluminum. Efficient fixture being used to ensure all sides of part are machinable and tool reachable.

The research continue with CAM process by using CATIA V5 as main CADCAM software. Various strategies being used in order to obtain best accuracy of machined part compared with CAD model. After study journals and data gathered, point milling strategy is more suitable to machining single blade compared to flank milling. Lower feed-rate and spindle speed could be used because of the research only focus on dimensional accuracy instead of surface finishing.

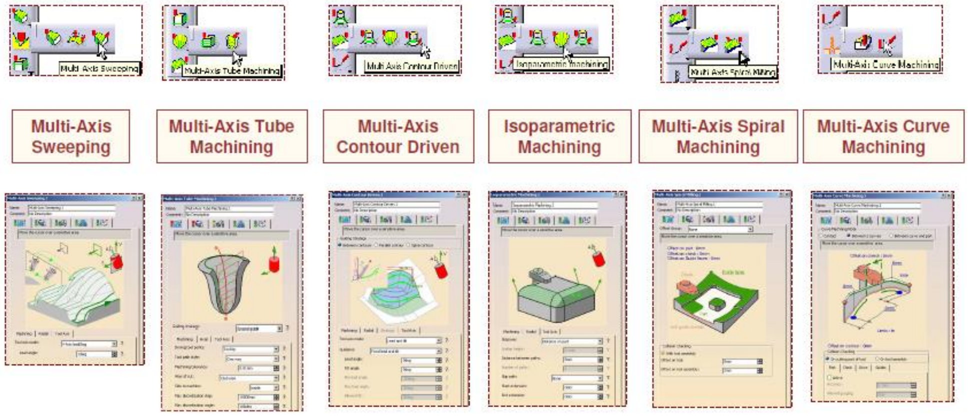



Figure 3.3: Machining strategies of CATIA V5

After use CATIA V5 software to visualize the simulation, it can be proceed with post processor to generate program. Post processor is an interface that links the NC machines and CAM system and it converts cutter location, CL data to machine code. Siemens NX- Post Builder processor used to generate NC code to allow CADCAM system communicate with the machine. If there are error detected while generating the codes, the CAM process has to be repeated modify before moving to the next step which is physical machining process. In other way, by modify the kinematic model of post processor can corrected the identified error. Within NX post processor, the machine parameters related to specific machine for example machine maximum travel limits, maximum feed rate, machine configuration, as well as machine controller used.

A small change in orientation can lead to a large rotary movement, and the way to prevent the potential for collision is minimize the number of five axis rotary movement. In additional, set up the end mill length of cut to suitable length which enable the tool to cut work piece. Shorter cutting tool length able to reduce vibration. Physical machining process could be proceed after detail set up. Dimensional accuracy test by using coordinate measurement machine (CMM) shall be conducted to analyze the result. Analyze the obtained result and compared to the CAD model. Research ending with report writing and discussion for future improvement.

## 3.2 Computer Aided Design (CAD)

### 3.2.1 CAD Model Modification

The original part dimension was measured as figure 3.4 and discussed with supervisor before modification that suitable undergo machining process. Bottom part of single blade was modified become rectangle shape as the research only focusing on the body part of blade instead of basement. The clamping method is simple with the rectangle basement that has been modified. Modification is necessary to preserve the intellectual property of the CAD model obtained. On the other hand, dimension of part is modified to suit the available stock.

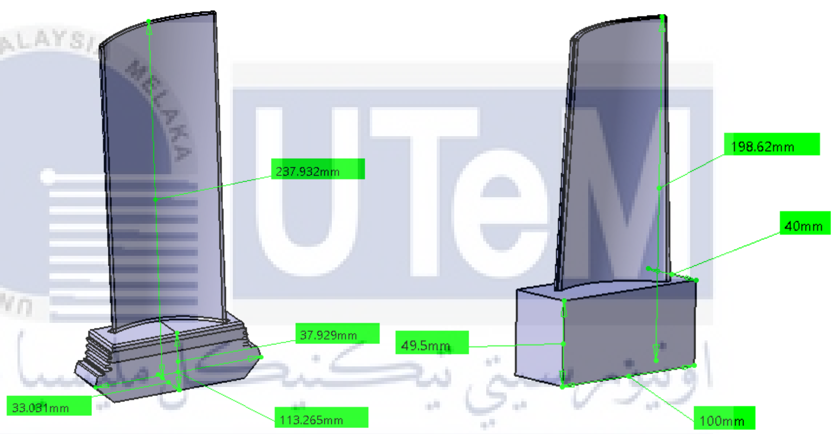





Figure 3.4: CAD Model modification

### 3.2.2 Stock

The aluminium raw material dimension is 200mm x 200mm x 40mm. By using wire cut machine, the raw material has been cut into 2 pieces equally. One of part is prepared as reserve stock in case there is any accident happened and avoid postpone the machining period. One of advantages of five axis machine is does not required precision squaring process compared with three axis with the condition that work piece coordinates is set up accurately. Lastly the stock dimension is set with size of 200 mm x 100 mm x 40 mm as shown in figure 3.5.

In physical machining, raw material clamped on the jig that fabricated. In order to clamp the product, bottom part of raw material is required to drill 2 holes with diameter 8.5mm and tapping with M10.

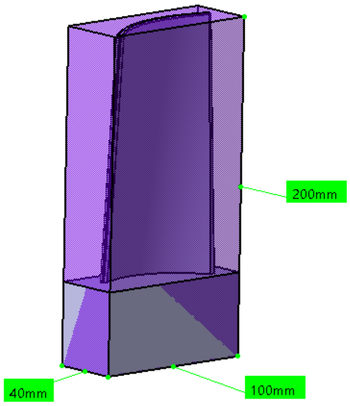



Figure 3.5: Stock dimension

### 3.2.3 Plane system

There are three planes are built in plane system as figure 3.6 with dimension of Z= +100mm which define as home, Z=+ 30mm as rapid plane and Z= +10mm as approach plane. A point was set at the top of plane system as home position. Axis system is set to further assembly process.

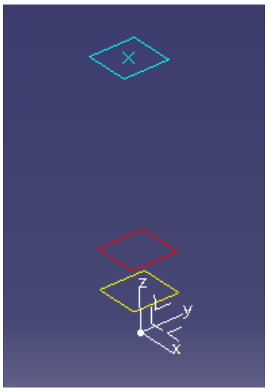


Figure 3.6: Plane System

### 3.2.4 CAD Model and Plane System Assembly

The main work piece coordinate (WPC) was assembled with plane system at the top centre of stock as figure 3.7. However, there is no cutting tool length that able to reach the bottom part of blade. Therefore, two plane systems have been set on both sides of single blade as reference plane for face roughing process.

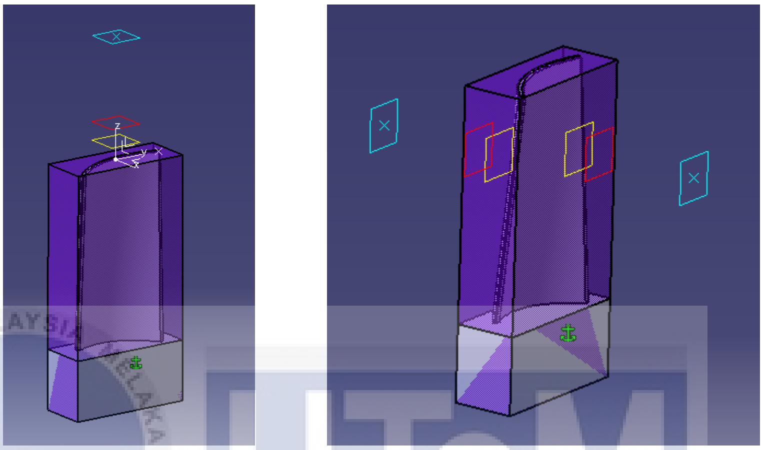


Figure 3.7: Assembled CAD model with plane system

## 3.3 Preparation

### 3.3.1 Cutting Tools

Checking available cutting tools in faculty is important before preparation CAM program. This step helps to ensure cutting tools used are available. Measurement cutting tool to obtain the details. Finalization of the suitable cutting tools that ready to use before physical machining process. Table 3.1 shown cutting tools that have been selected.

Table 3.1: Selected Cutting Tools

| Cutting tools | Dimension Details | Process involve |
|---|---|---|
| Flat end mill Ø12 mm<br>Material: High speed steel HSS uncoated<br>Flutes number : 4 | Db : 12mm<br>Lc : 30mm<br>L : 80mm<br>l : 38mm | Roughing |
| Ball end mill Ø6mm<br>Material: High speed steel HSS uncoated<br>Flutes number : 4 | Db : 6mm<br>Lc : 16mm<br>L : 60mm<br>l : 29mm | Semi – Finishing<br>Finishing |

References: Db: Shank diameter; Lc: Length of cut or flute length; L: Overall length; l: Reach length

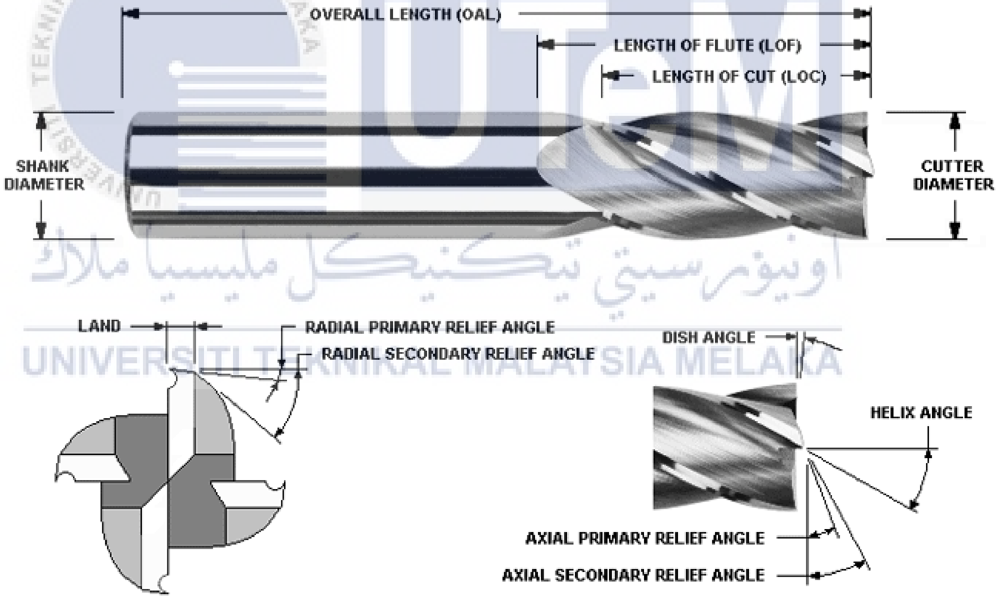



Figure 3.8: End mill terminology

### 3.3.2 Jig and Fixture

In order to perform physical machining on five axis machine for longer part with suitable strategy, an efficient jig is required. As jig able hold the part at appropriate position so that the cutting tool is reachable and machinable. To avoid the spindle head be collision when it turns to B+ 90 degree, the efficiency jig is required. It is the limitation of tilted angle of spindle head. Therefore, the minimum height design of jig must be 160mm and above. The most critical concern of the jig fabrication is the flatness of jig which it must be parallel with the machine table. Therefore, by the design of snap fit before welding process can helps to improve the stability. The fabrication process involved in jig are conventional milling, conventional lathe, drilling and joining with gas tungsten arc welding process. Figure 3.9 shows the CAD and real part of jig..

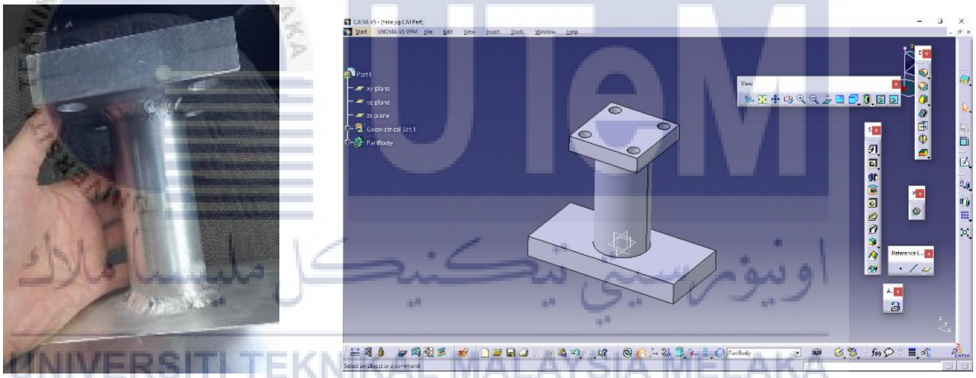




Figure 3.9: Jig and Fixture

## 3.4 Computer Aided Manufacturing (CAM)

### 3.4.1 Part Operations

CAM programming in this study is very important stage because it will affect the result. CAM program includes the tools movement and machining parameters. Firstly, as figure 3.10 CAM process in CATIA V5 starting with definition of part operation. The basic components in part operation that necessary set are type of machine, product or part, reference machining axis system, design part for simulation, and stock of product.

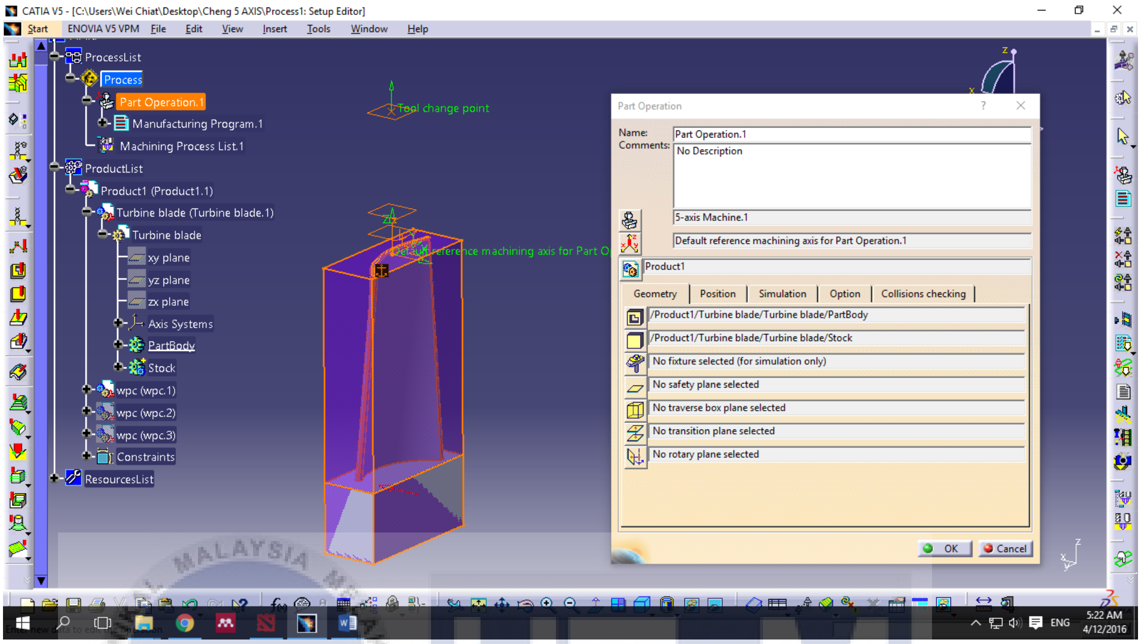



Figure 3.10: Part operations

#### 3.4.1.1 Define the Machine

In machine editor, five axis machine was selected due to the complexity of part and machining movement. The post processor words table was selected is IMSPPCC-V6. Pptable as figure 3.11.

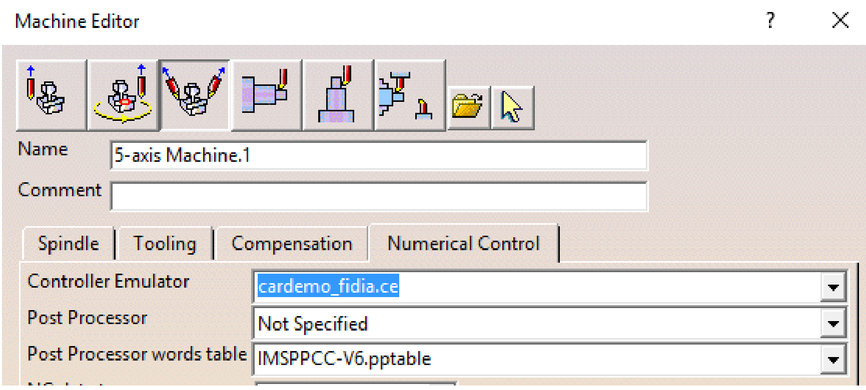



Figure 3.11: Selected machine and post processor

#### 3.4.1.2 Define Reference Machining Axis System

Axis system is selected on axis system that have been assembly during process of assembly as figure 3.12. Axis system always set at the origin of the part as it function as tool position before start and end of machining. Axis system helps to ensure movement of cutting tools will not damage the part or product before, during and after machining process.

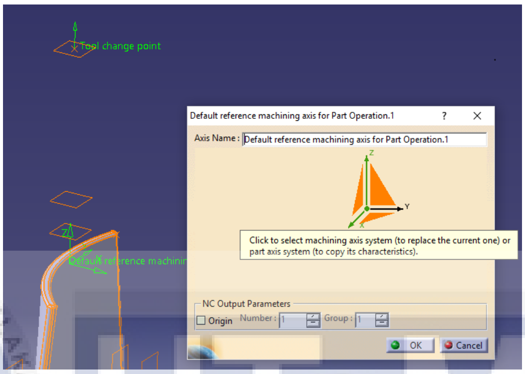



Figure 3.12: Selected reference axis

#### 3.4.1.3 Define the Product

Product in part operation is defined by browsing the CAD model product which consists of assembly plane system and stock in CATIA product file type as figure 3.13. Product defined in part operation is very important as it shows part that undergoes machining process during this part operation.

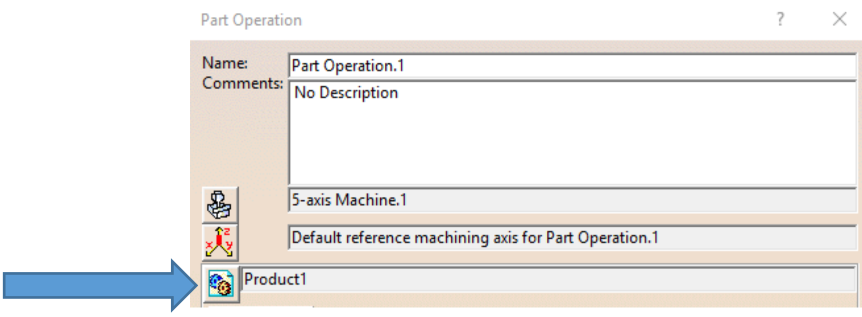



Figure 3.13: Selected product

#### 3.4.1.4 Define the Part

After defined product, cad part inside defined product was selected without selection of stock and plane system as figure 3.14. Hidden stock before the part is needed to avoid stock being selected and confusion on the selection.

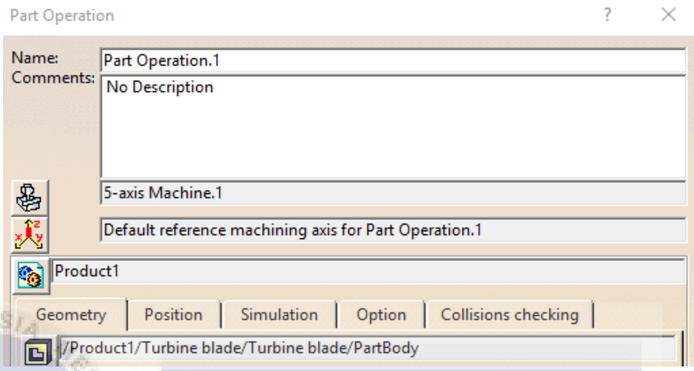



Figure 3.14: Selected Part

#### 3.4.1.5 Define the Stock

Stock will be selected after part have been selected as figure 3.15. Stock was selected appropriately after unhidden to provide the information for machine. This information helps in differentiate between part body and stock.

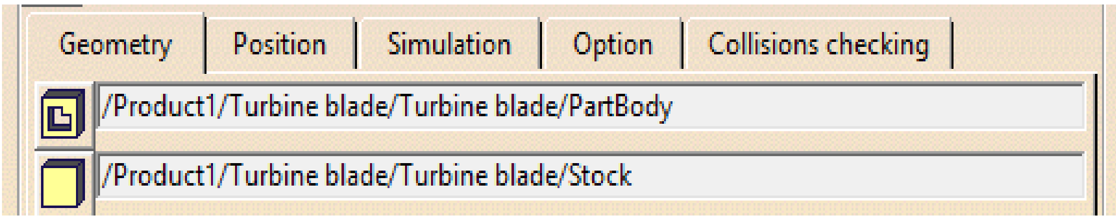



Figure 3.15: Selected Stock

#### 3.4.1.6 Define the Tool

Dimension, surface and the shape of the product in CAD was decided the appropriate tools for machining. Selection of cutting tools also depends on the machining strategy and the minimum radius of tip. Also, by using the efficient dimension of cutting tools are able to reduce the cutting time and increase the accuracy. Creation appropriate tools were required for machining process and the dimensional detail of each tools were filled. There were two cutting tools that being used which was End mill Ø12mm and Ball end mill Ø6mm as figure 3.16.

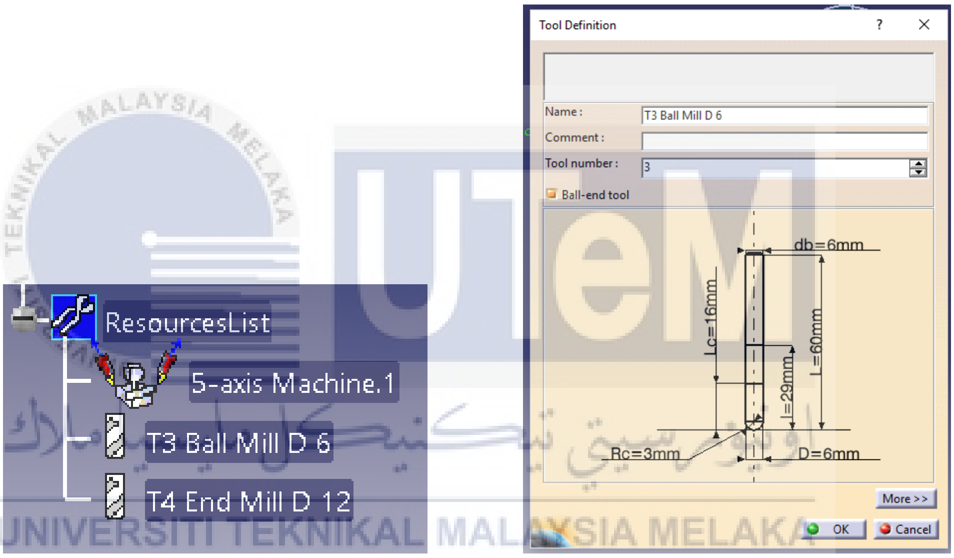



Figure 3.16: Selected tool

### 3.4.2 Manufacturing Program

Manufacturing program refers to the sequence of standard of process. Each machining process consists of setting of tool change, geometry to machine, strategy to machine and the macro. The machining process of this research shown in figure 3.17, and detail of each process further discuss.

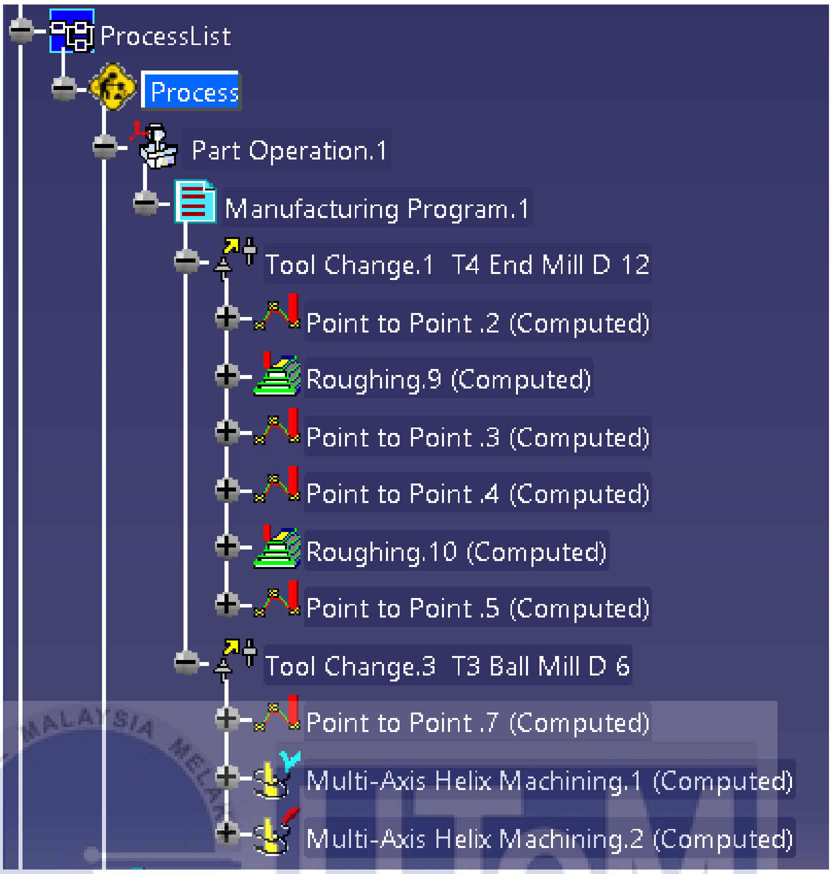



Figure 3.17: Five axis manufacturing program sequence

Machining strategy can be varied for every programmer, there is no standard way in setting of machining strategies. Ways to set machining strategies was depend on the knowledge and experience of CAM programmer. The machining planning strategy should be planned in early stage. Therefore, machining planning is important step before setting sequence of machining process. The flow chart of CAM process are shown at figure 3.18.

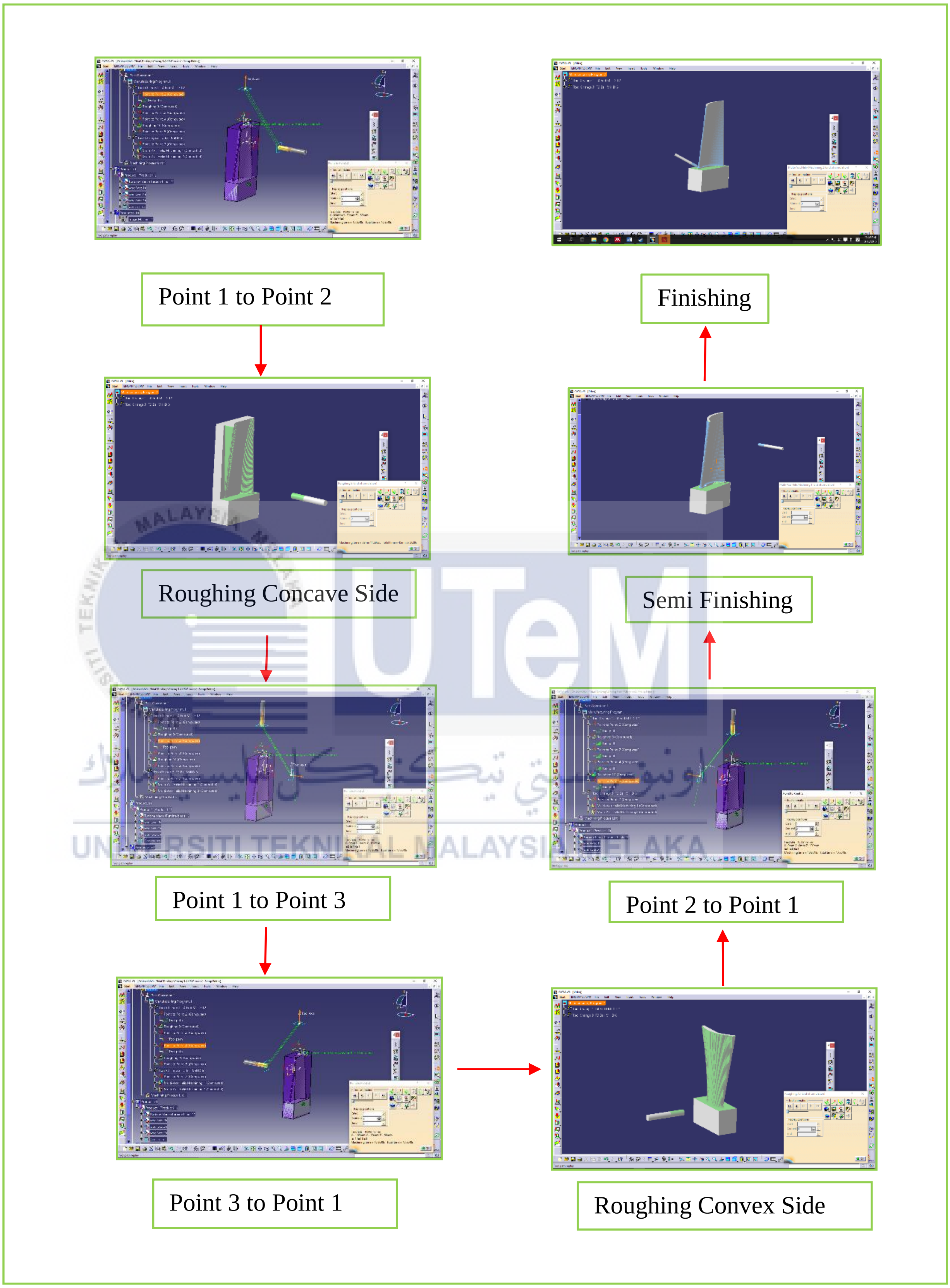



Figure 3.18: Flow chart of machining process perform

### 3.4.2.1 Point to Point operation

Due to short cutter cannot fully reach the bottom of part, it is impossible to perform roughing process without tilting the spindle head. It required to using point to point operation to allow tilting of spindle speed. The spindle head was tilted to B+ 90. In addition, the point to point operation can reduce the risk of collision. There are 3 main points in this program which point 1 at the top of part, and the other 2 points located at both sides of part. At the strategy page, two "GOTO POINT" were created and the appropriate current point and tool axis were chosen as this step is the most important in this setting. All point to point operations were repeated as stated in the flow chart of machining strategy planning.

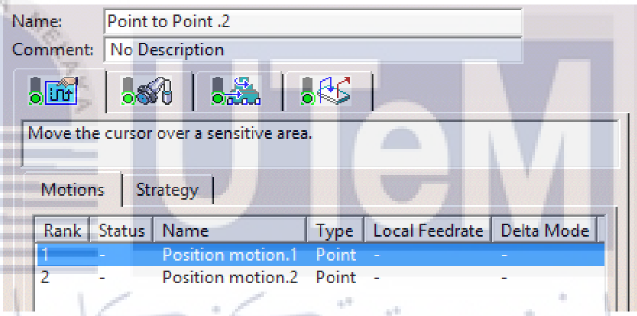



Figure 3.19: CAM setting of Point to Point operation 1



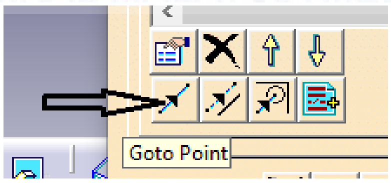



Figure 3.20: CAM setting of Point to Point operation 2

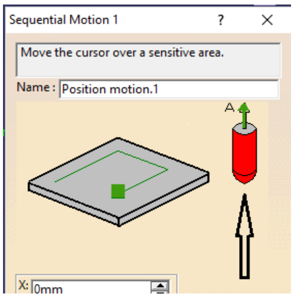



Figure 3.21: CAM setting of Point to Point operation 3

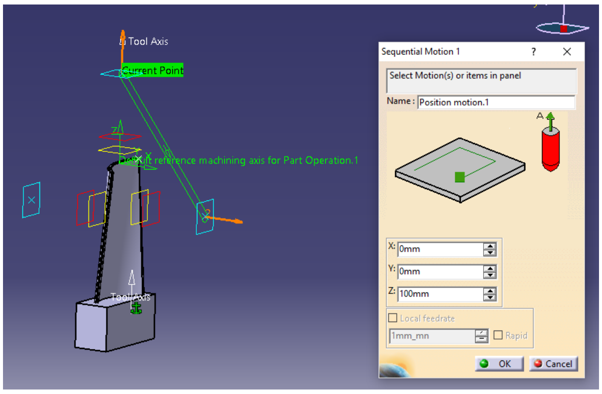



Figure 3.22: CAM setting of Point to Point operation 4

#### 3.4.2.2 Roughing operation

Roughing operation helps to remove non-essential material quickly and obtain machined part as close as possible to the desired shape. It can greatly reduce the cutting time. Roughing is initial process before semi finishing and finishing process are different machining processes. 1mm left by roughing process before part entering finishing process. By using 12mm diameter of flat end mill, strategy tab page was set up with the specific parameter as shown below. In axial page, maximum cut depth was set as 1mm; while the step over in radial page with 40 overlap ratios. Maximum depth of cut help to prevent damage of tool during machining process. The higher value maximum depth of cut, the higher the percentage damaging of tool. In machining tool path style, spiral type was selected. Climb cutting mode was chosen due to it can reduces the load from cutting edge, provide better surface finishing and improves tool life. Besides, value offset on part and offset on check are set as 1mm which means material left after roughing process. Purpose of excess material is to undergo semi finishing and finishing operation. Detail about settings have been shown by figures below.

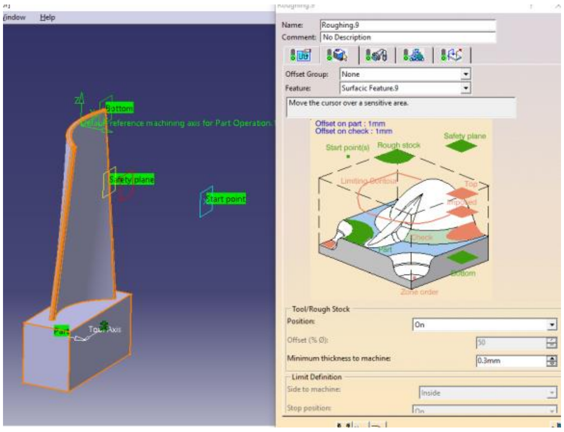


Figure 3.23: CAM setting of roughing operation 1 (Geometry Page)

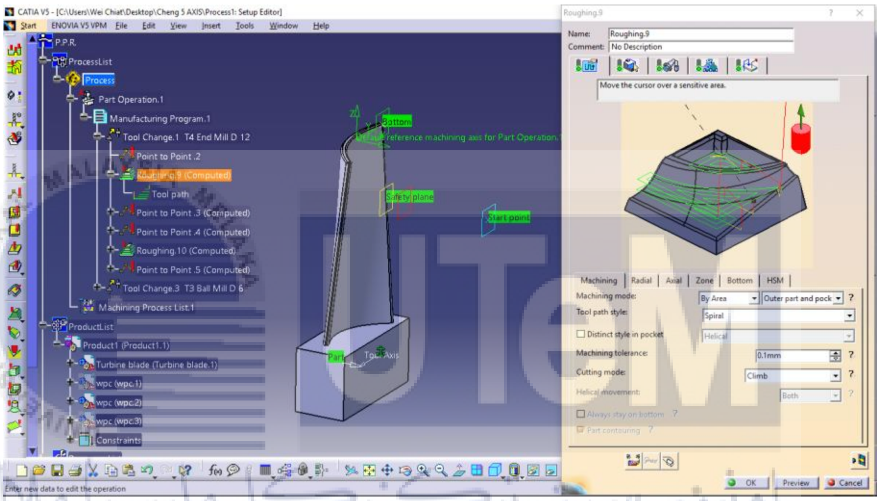


Figure 3.24: CAM setting of roughing operation 2 machining (Strategy Page)



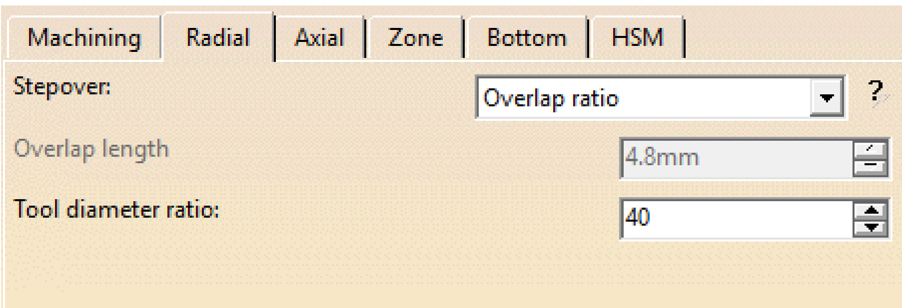



Figure 3.25: CAM setting of roughing operation 3, radial (Geometry Page)

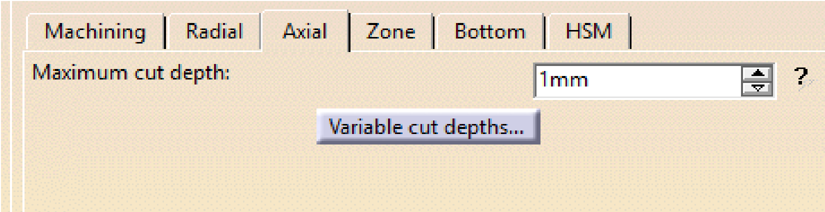



Figure 3.26: CAM setting of roughing operation 4, axial (Geometry Page)

#### 3.4.2.3 Multi-Axis Helix Machining operation

In multi-axis helix machining, there are a few critical selections at geometry page such as upper counter, lower counter, leading edge, and trailing edge. In first multi-axis helix machining operation, offset value 0.5mm has been set on offset on part as it is process of semi finishing; while the finishing has been done by setting 0mm offset value on part. In order to avoid collision of cutting tools body and raw material, offset value on check was set as 2mm for both semi finishing and finishing operation. As the research is only focus on body of blade which not include the bottom part, therefore the uncut material on the check (bottom part) will not in consideration of the result. Every setting regarding multi-axis helix machining have been shown through figures below.

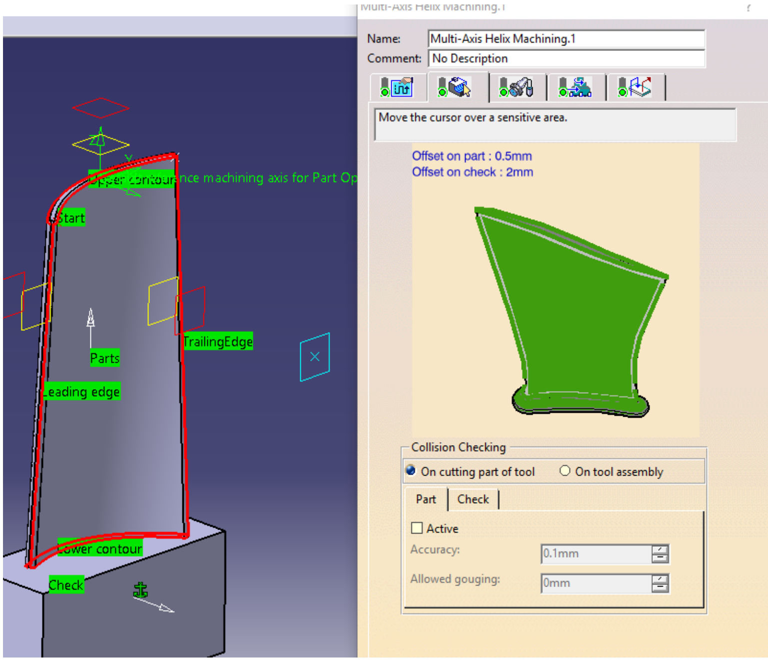



Figure 3.27: Geometry setting of CAM setting of multi axis helix machining operation

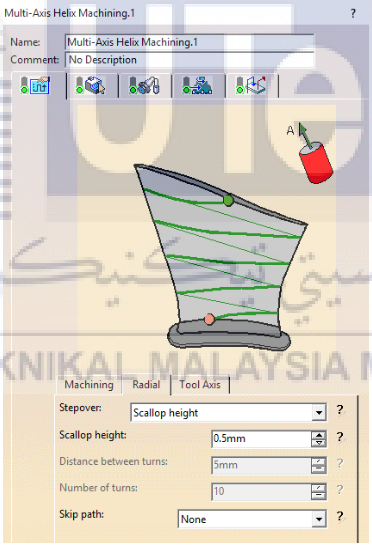





Figure 3.28: Radial on strategy page of CAM setting of multi axis helix machining operation

The tool axis tab page in strategy setting was set up as below which is tilt angle set was -20 while 0 degree was set in lead angle.

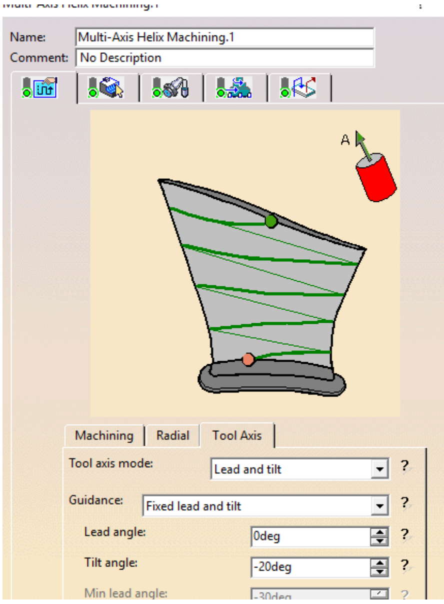



Figure 3.29: Tool axis on strategy page of CAM setting of multi axis helix machining operation

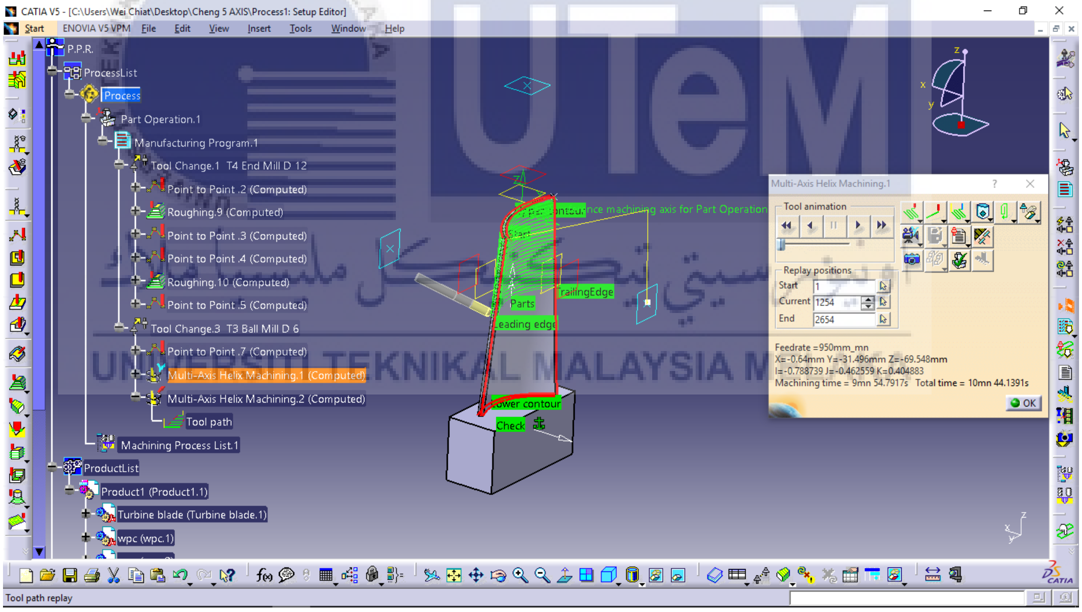





Figure 3.30: Tool path of multi-axis helix machining

## 3.5 Post Processor

Post processor helps to generate NC code and translate CADCAM programming language to machine. The “APT. source” format data generated by using CATIA V5. The detail setting on the few tab page refer to following figures. After that, with assist of IMS post processor the format has change to NC code from APT. source format. Without post processor, CAM program cannot be undergoing physical machining process in five axis machine. Different types of post processor have been used for different type of five axis machine. The program must edit by replacing M13 FMAX with FMAX M13. Last but not least, the data was changed to .H file for machine understanding file type. Figure 3.32 show differentiate between APT.source format and .H file.

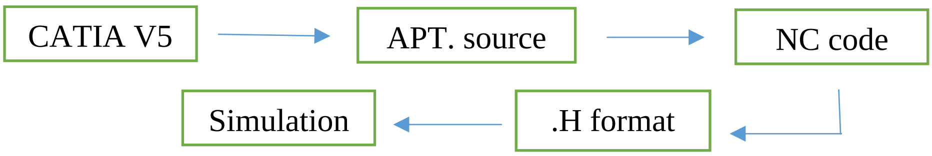
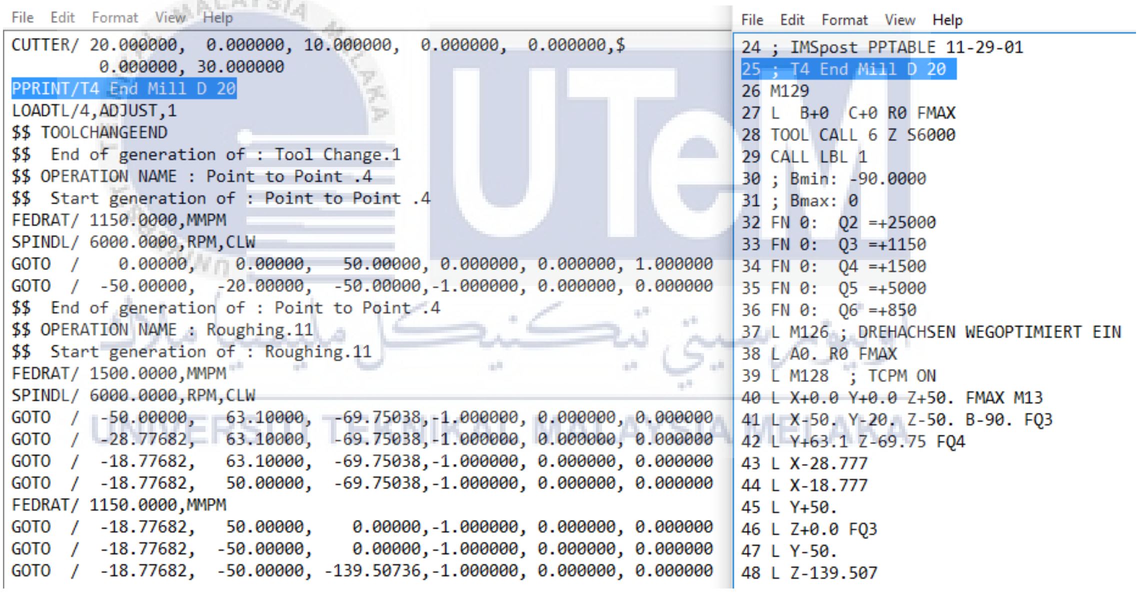



Figure 3.31: Flow chart of post processor



```
CUTTER/ 20.000000,  0.000000, 10.000000,  0.000000,  0.000000,$
         0.000000, 30.000000
PPRINT/T4 End Mill D 20
LOADTL/4,ADJUST,1
$$ TOOLCHANGEEND
$$  End of generation of : Tool Change.1
$$ OPERATION NAME : Point to Point .4
$$  Start generation of : Point to Point .4
FEDRAT/ 1150.0000,MMPM
SPINDL/ 6000.0000,RPM,CLW
GOTO  /    0.00000,   0.00000,   50.00000, 0.000000, 0.000000, 1.000000
GOTO  /  -50.00000,  -20.00000,  -50.00000,-1.000000, 0.000000, 0.000000
$$  End of generation of : Point to Point .4
$$ OPERATION NAME : Roughing.11
$$  Start generation of : Roughing.11
FEDRAT/ 1500.0000,MMPM
SPINDL/ 6000.0000,RPM,CLW
GOTO  /  -50.00000,   63.10000,  -69.75038,-1.000000, 0.000000, 0.000000
GOTO  /  -28.77682,   63.10000,  -69.75038,-1.000000, 0.000000, 0.000000
GOTO  /  -18.77682,   63.10000,  -69.75038,-1.000000, 0.000000, 0.000000
GOTO  /  -18.77682,   50.00000,  -69.75038,-1.000000, 0.000000, 0.000000
FEDRAT/ 1150.0000,MMPM
GOTO  /  -18.77682,   50.00000,    0.00000,-1.000000, 0.000000, 0.000000
GOTO  /  -18.77682,  -50.00000,    0.00000,-1.000000, 0.000000, 0.000000
GOTO  /  -18.77682,  -50.00000, -139.50736,-1.000000, 0.000000, 0.000000
```

```
24 ; IMSpost PPTABLE 11-29-01
25 ; T4 End Mill D 20
26 M129
27 L  B+0  C+0 R0 FMAX
28 TOOL CALL 6 Z S6000
29 CALL LBL 1
30 ; Bmin: -90.0000
31 ; Bmax: 0
32 FN 0:  Q2 =+25000
33 FN 0:  Q3 =+1150
34 FN 0:  Q4 =+1500
35 FN 0:  Q5 =+5000
36 FN 0:  Q6 =+850
37 L M126 ; DREHACHSEN WEGOPTIMIERT EIN
38 L A0. R0 FMAX
39 L M128  ; TCPM ON
40 L X+0.0 Y+0.0 Z+50. FMAX M13
41 L X-50. Y-20. Z-50. B-90. FQ3
42 L Y+63.1 Z-69.75 FQ4
43 L X-28.777
44 L X-18.777
45 L Y+50.
46 L Z+0.0 FQ3
47 L Y-50.
48 L Z-139.507
```

Figure 3.32: APT. source format converted to .H file

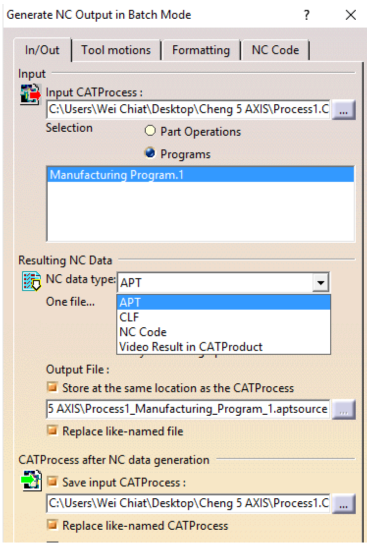



Figure 3.33: In/out page of Post process

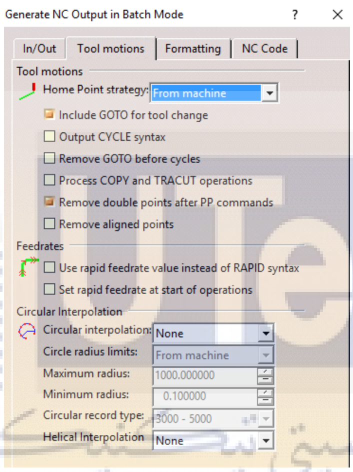



Figure 3.34: Tool Motions of Post process



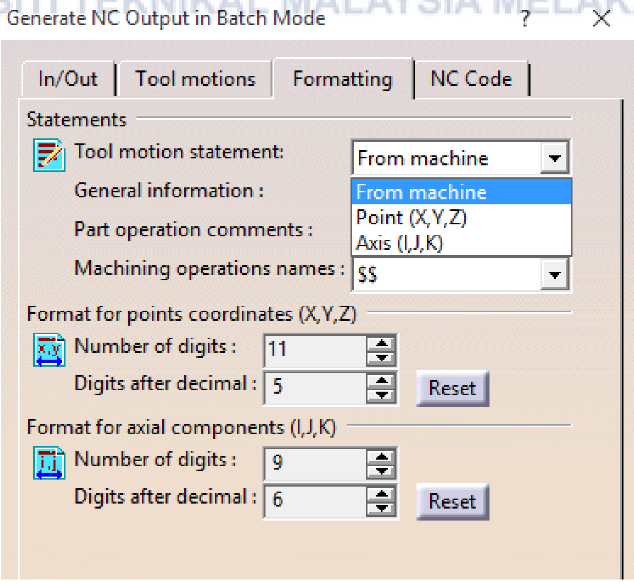



Figure 3.35: Formatting of Post Process

## 3.6 Physical machining

Deckel Maho DMU 60 MonoBLOCK five axis machine was used to perform the machining process in this research. The Deckel Maho DMU 60 MonoBLOCK with a wide range of application of complete machining with five sided and five axis simultaneous machining. The machining focus on five axis simultaneous machining with an NC controlled B-axis even negative angles and C-axis rotary table. The figure 3.36 shows the basic technical specification of the Deckel Maho DMU 60 MonoBLOCK.


Figure 3.36: Deckel Maho DMU 60 monoBLOCK



| | | DMU 60 |
|---|---|---|
| **Work area** | | |
| X / Y / Z-axis | mm | 730 (630)* / 560 / 560 |
| Max. rapid traverse | m/min | 30 |
| Max. feed rate | mm/min | 30,000 |
| Max. acceleration X / Y / Z | m/s² | 6 / 7 / 4 |
| **Main drive motor spindle** | | • |
| Output (40 / 100% DC) | kW | 15 / 10 |
| Max. torque (40 / 100% DC) | Nm | 130 / 87 |
| Max. spindle speed | rpm | 12,000 |
| **Manual swivel milling head** | | • |
| Swivel range (0 = vertical / –90 = horizontal) | degrees | +12 / –91 |
| **NC-controlled swivel milling head (B-axis)** | | o |
| Swivel range (0 = vertical / –90 = horizontal) | degrees | +30 / –120 |
| Swivel time | sec | 1.5 |
| Max. acceleration | °/s² | 2,300 |
| Rapid traverse | rpm | 35 |

Figure 3.37: Specification of Deckel Maho DMU 60 MonoBLOCK

After obtain NC codes from post processing, the simulation is the next step as figure 3.38. During simulation on controller, the error in program CC (centre circle) was happened as figure 3.39. The plane system should transform, but after post process it does not makes any changes.

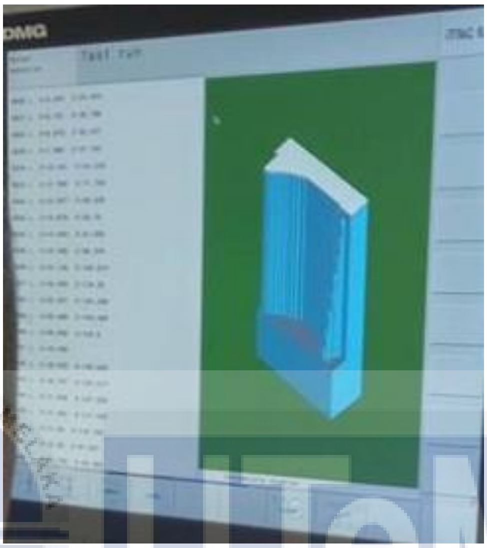


Figure 3.38: Simulation

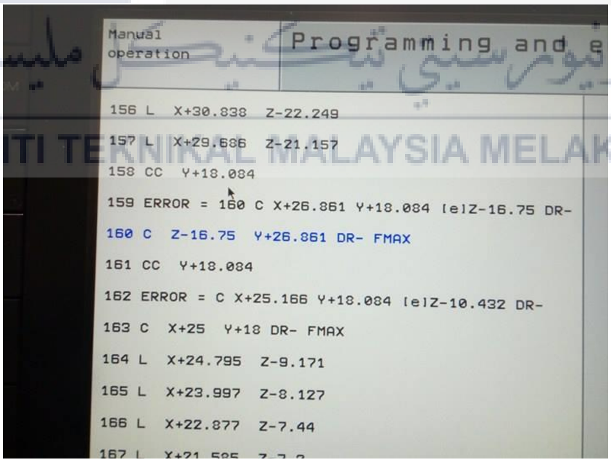



Figure 3.39: Error in Program

Troubleshoot with generates APT. source format from CATIA V5. The selection in formatting setting has been change to “Point (X, Y, Z)” coding which can be easily understand as figure 3.40. Also, modification of code by inserting B axis (B+0, B90) and C180 manually in program as figure 3.41.

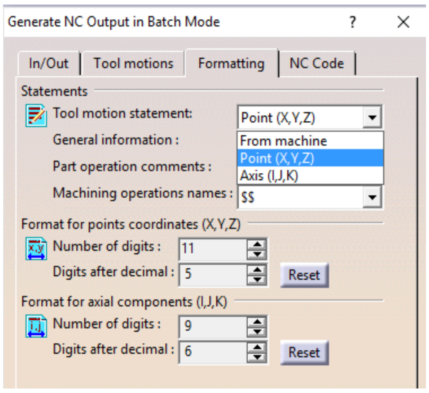
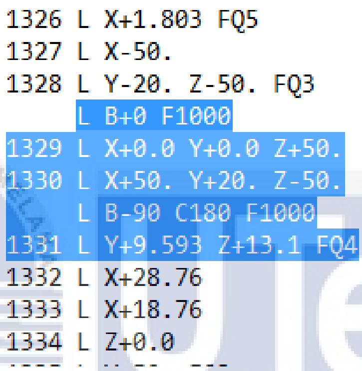



Figure 3.40: Troubleshoot formatting



```
1326 L X+1.803 FQ5
1327 L X-50.
1328 L Y-20. Z-50. FQ3
     L B+0 F1000
1329 L X+0.0 Y+0.0 Z+50.
1330 L X+50. Y+20. Z-50.
     L B-90 C180 F1000
1331 L Y+9.593 Z+13.1 FQ4
1332 L X+28.76
1333 L X+18.76
1334 L Z+0.0
```

Figure 3.41: Troubleshoot edit program



The simulation for roughing can be done but not for multi-axis helix machining. However, the test cut was still proceeded after installation of jig and set up with right tools. The roughing test cut for 30mm from top was done as figure 3.42 shown.

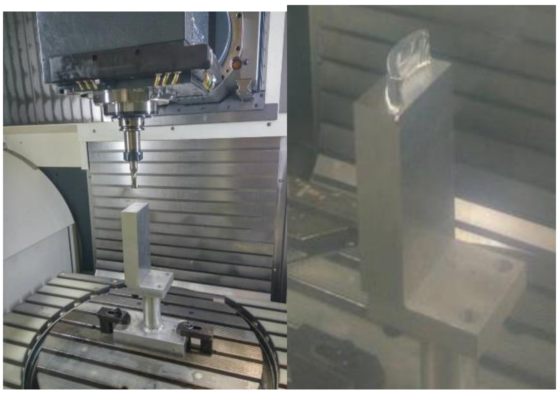


Figure 3.42: Roughing process with five axis machine

The machine error occurs while the five axis simultaneous machining process. Error in tool change as figure 3.43 shown and exchange buffer battery as figure 3.44 were shown below and currently it is far away capable to solve it.

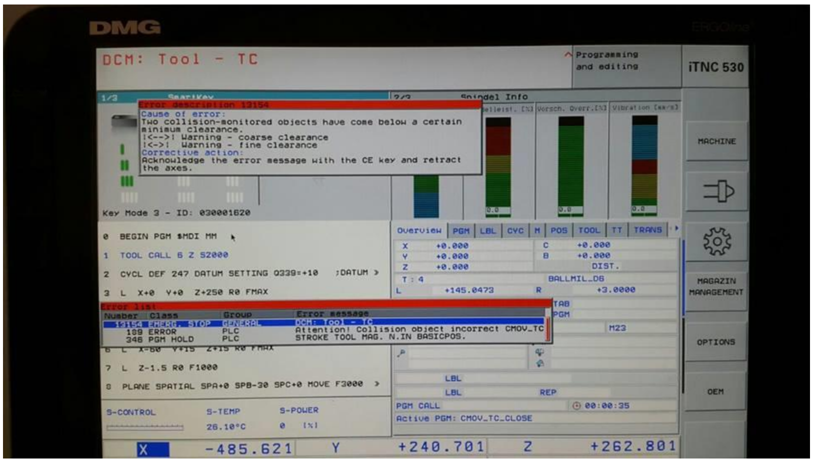



Figure 3.43: Error in Tool change

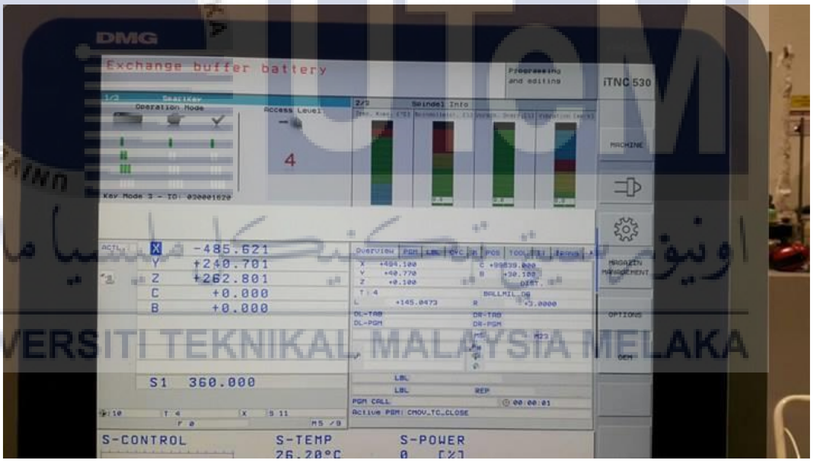



Figure 3.44: Error in Exchange buffer battery

## 3.7 Three axis CAM and Physical Machining

The three axis machining was the last option since the five axis machine is unavailable. Two work piece coordinates are required in three axis machining. After convex side of machining, changing position of the work piece around is required. Therefore, the dimension of part after machined might not good as five axis machined par. The part operation was setting as previous setting.

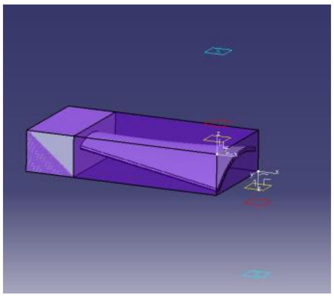


Figure 3.45: WPC set up in three axis machining

Flat end mill diameter 20mm and ball end mill diameter 6mm were selected. The manufacturing process in three axis machining was a straighter forward machining strategy for roughing phase can be employed. With the region of drive surface machining strategy was program with sweeping process. The sweeping process is used in semi finishing and finishing process by setting the offset value 0.5mm and 0mm on the part.



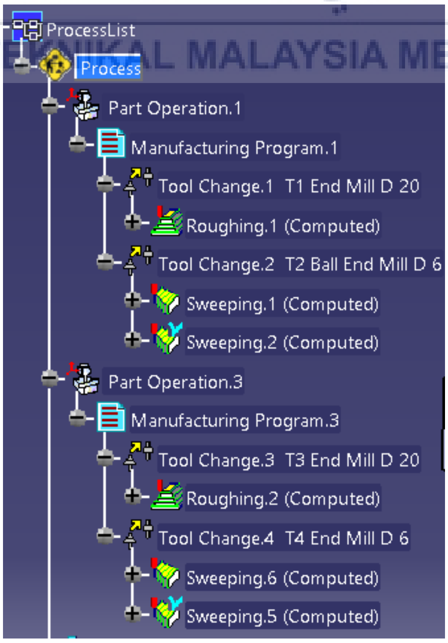



Figure 3.46: Three axis manufacturing program sequence

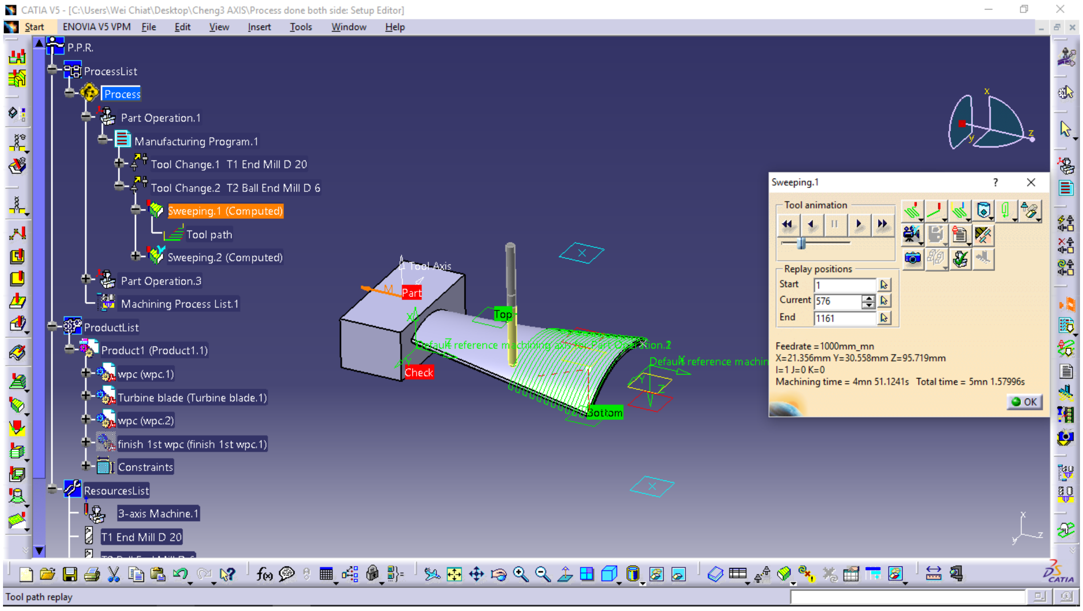



Figure 3.47: Tool path of three axis machining first WPC



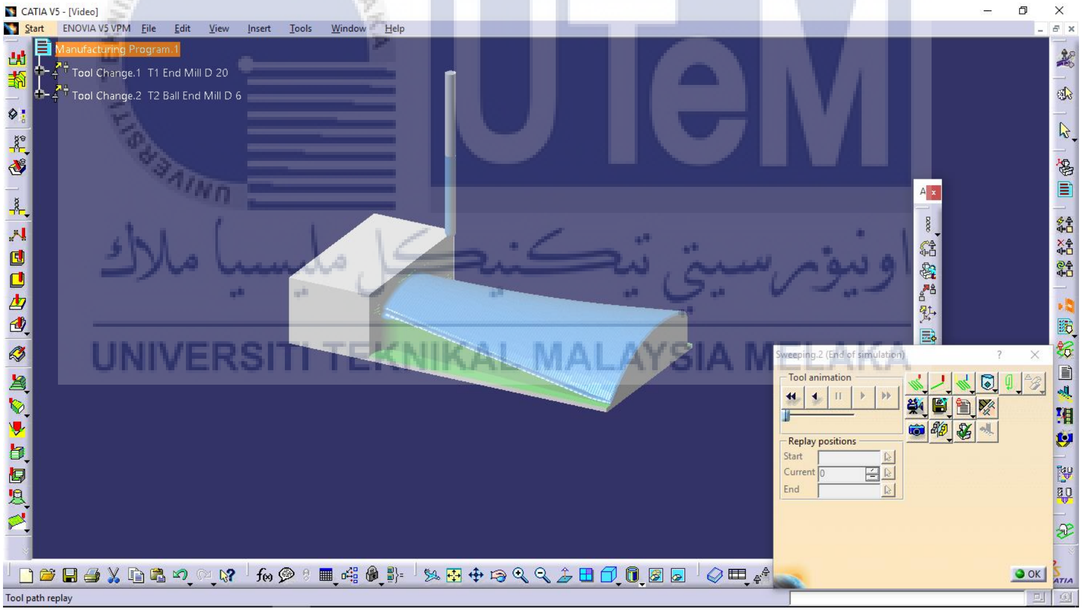



Figure 3.48: CAM result of three axis machining first WPC

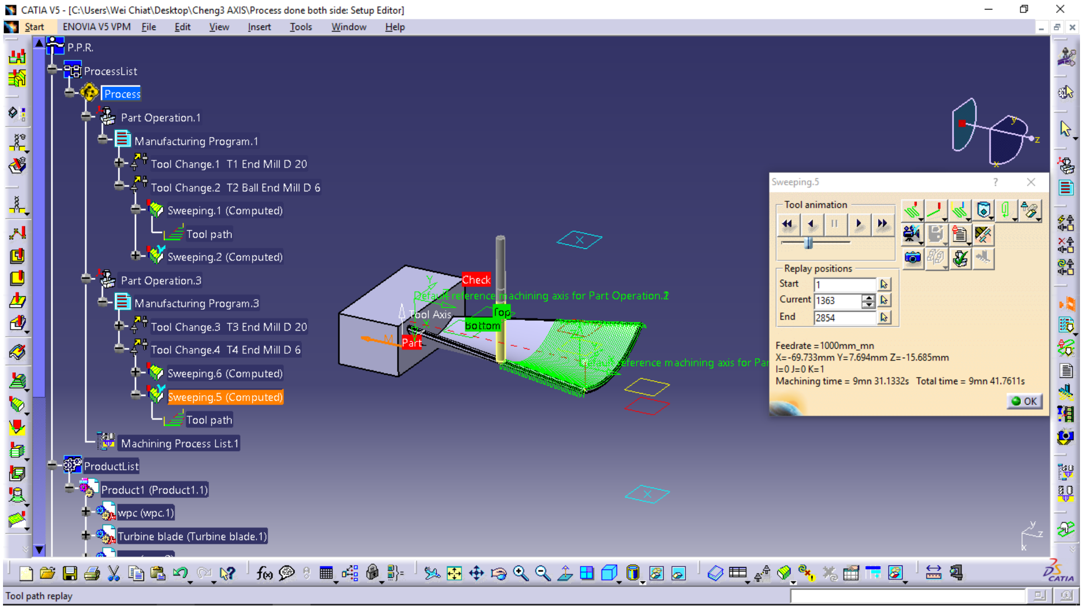



Figure 3.49: Tool path of three axis machining second WPC

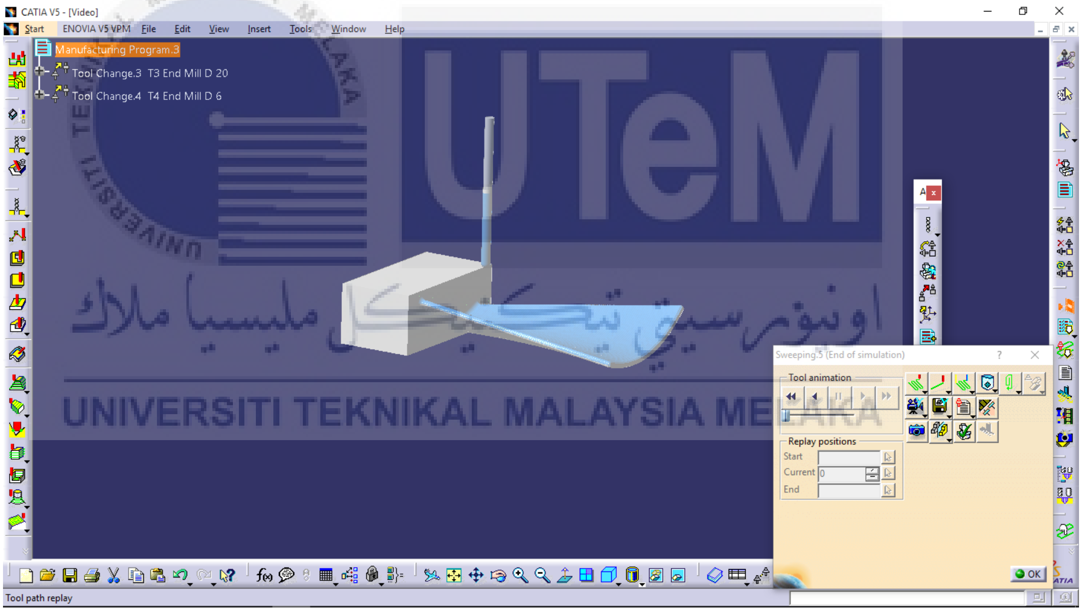



Figure 3.50: CAM result Three axis machining second WPC

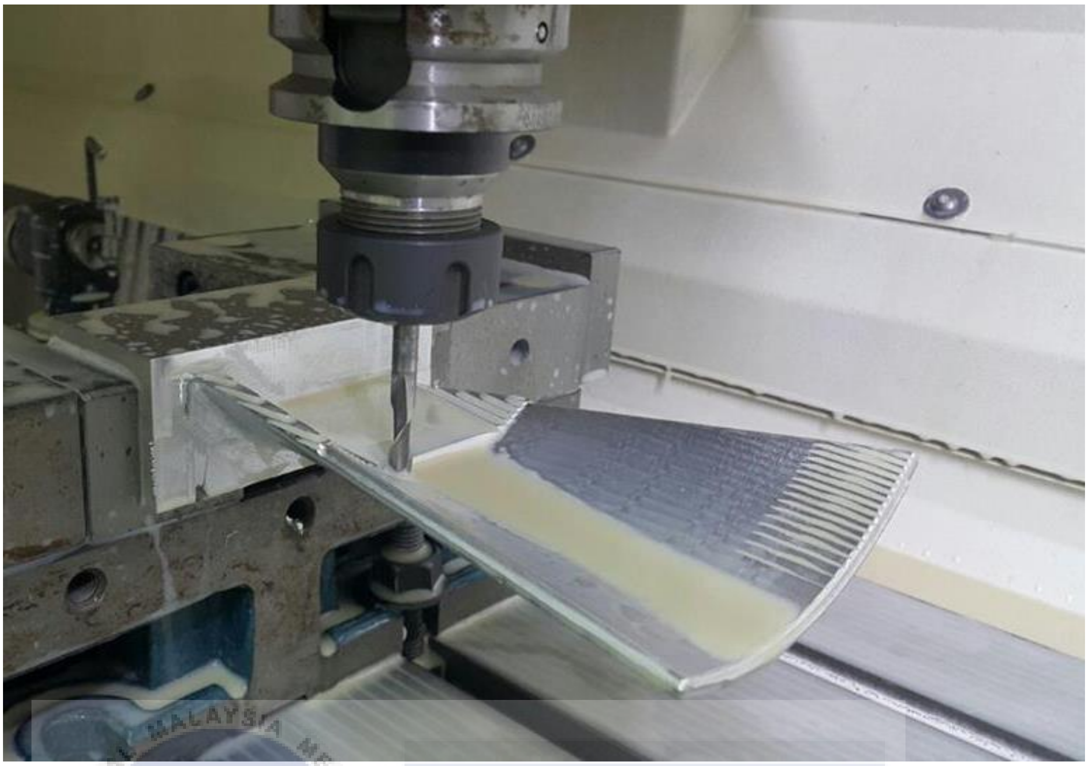


Figure 3.51: Physical machining in three axis machining

### 3.8 Measurement

Analysis of machined part is done by using CMM (Coordinate Measurement Machine) which available in FTK laboratory. As one of function of CMM is determining the geometric sizes of part but with limitation that part but be in plastic or metal. The procedure of the dimensional accuracy analysis of CAD model in CATIA program saved and transfer to the CMM. Probe is a one part in process analysis of accuracy. Probe is used to hold the stylus system while stylus system acts as positions the stylus system and be an adapter plate holds. CMM (Coordinate Measure Machine) that used in this project is CMM with interchange probe. CAD model import to CMM (Coordinate Measure Machine) in IGES format (Initial Graphic Exchange Specification). Other format cannot be used in CMM (Coordinate Measure Machine) software. Analysis concerned on curve of blade. Point obtained is plot along curve of blade. Six curves has been obtained from single blade which three curves for each surface of single blade. Analysis of the graphical result is done after CMM (coordinate measure machine) analysis. Process of accuracy analysis discussed by comparing data. Through graphical result, accuracy of CAD part determined by comparing difference between best fit of dimension get with each measured point. Undercut or overcut can be known though colour shows in graph. Discussion of graph is done in chapter 4.

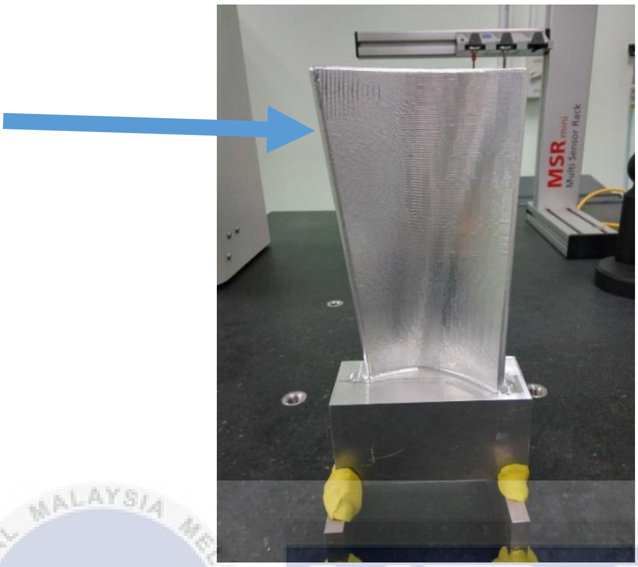


Figure 3.52: Process Analysis by CMM (Coordinate Measure Machine)

Figure 3.53: Measurement of Single Blade

# CHAPTER 4
## RESULT AND DISCUSSION

### 4.0 Introduction

This chapter discuss about the dimensional accuracy value for the machined part. The quantitative results are gained after complete dimensional analysis by Coordinate Measuring Machine (CMM); while qualitative result was drawn from CATIA V5 after running all CAM programming. Discussion of the experimental results are included in this chapter. This section explained the results obtained from this research and discussion about the problems of this research. Graph and table are included in this chapter to give widely view about quantitative results that done by CMM (Coordinate Measuring Machine).



### 4.1 Result and Discussion

#### 4.1.1 Comparison CAD model and CAM result

Qualitative result can be compared through the figures shown. The result of convex side of single blade with five axis machining CAM result is obviously better than result of three axis machining. There are certain parts on convex side of single blade have undercut problem which might be caused by the setting of scallop height is too large. Although there are undercut problem, both of the machining CAM result is still acceptable as figure 4.1 and figure 4.2 shown.

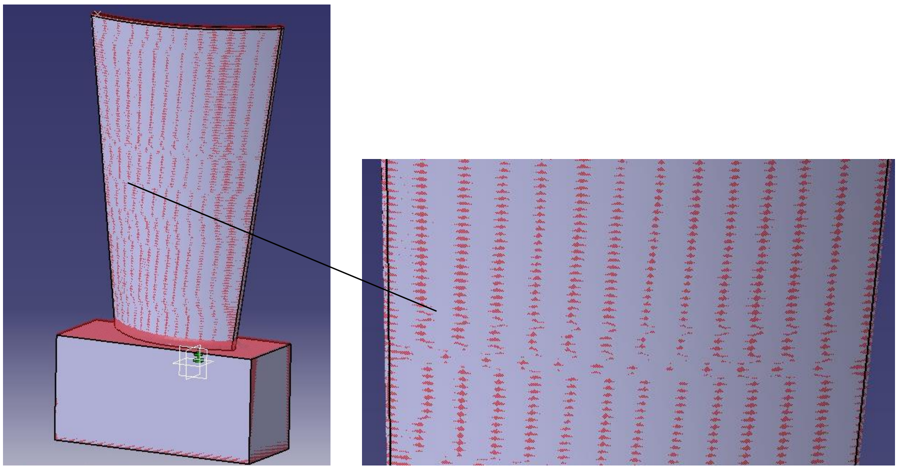


Figure 4.1: Comparison convex side CAM and CAD model done by five axis machining

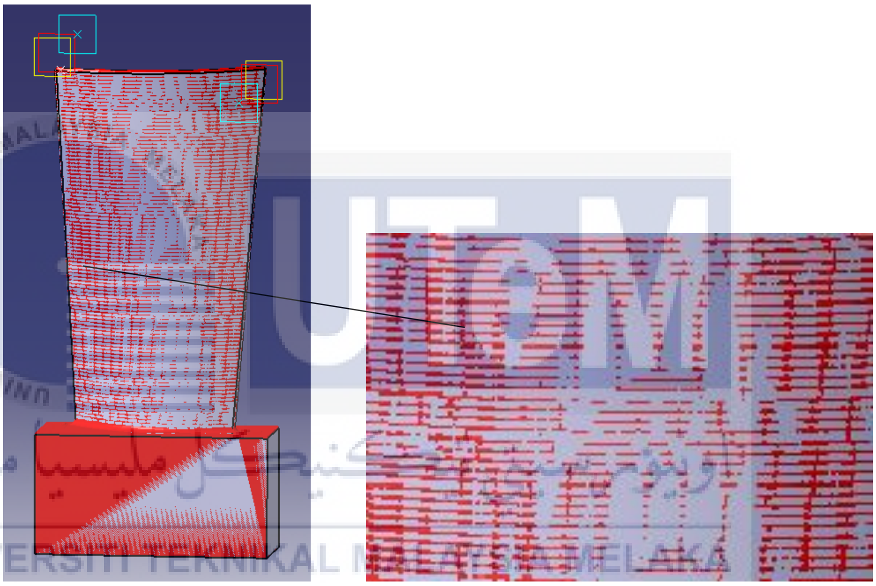




Figure 4.2: Comparison convex side of CAM and CAD model done by three axis machining

Result shows that concave CAM result not good compared to the convex side. This result can be proved as the excessive material which can observed significantly from figure 4.3 and figure 4.4. This condition might be caused by contouring surface of inner blade might be too small that lead to cutting tool cannot enter. Besides, the reduction of scallop height might help to improve the quality. From the observation of figures shown, the five axis machining still better than three axis machining.

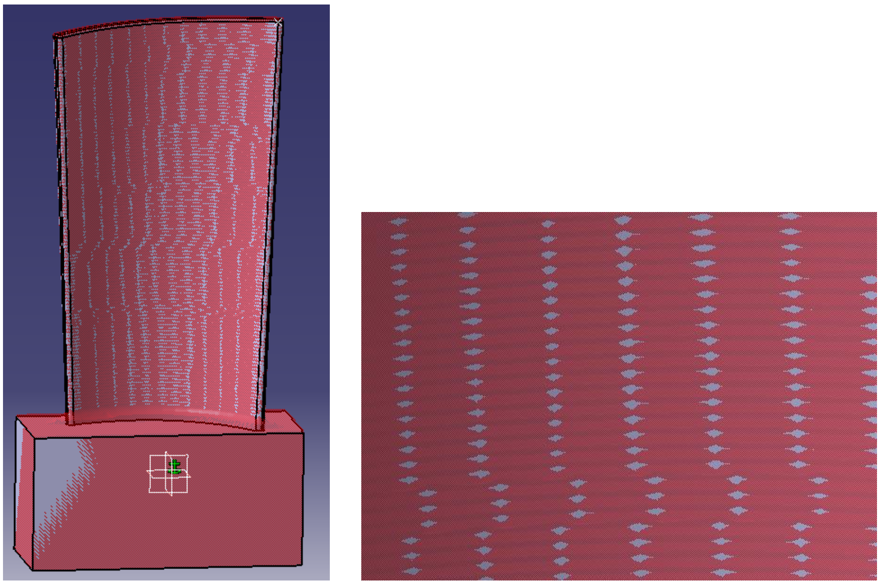


Figure 4.3: Comparison concave side five axis machining CAM and CAD model

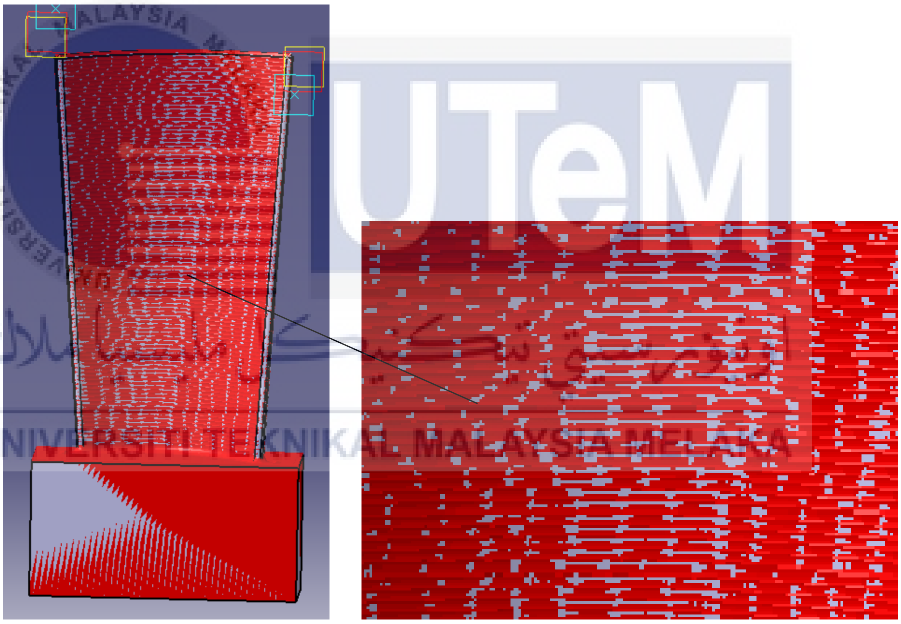




Figure 4.4: Comparison concave side three axis machining CAM and CAD model

Undoubtedly five axis machining better than three axis machining, because of the five axis machining only required single set up. Also, the cutting tool able to lead and tilt which can obtain better accuracy on contouring surface. However, it is only CAM result as reference that does not proven through physical machining and measurement.

### 4.1.2 Dimensional Accuracy Analysis

Data collected for this research is testing data before obtaining data. In this section the results of machining single blade obtained by three axis machining and measure the dimensional accuracy measurement based on the CMM. There were three curves taken on each side of single blade which were categorized into curve 1, curve 2, and curve 3 for concave side of machining; curve 4, curve 5, and curve 6 for convex side of machining were illustrated by figure 4.5 and 4.6. Meanwhile, the start and the end point of physical and direct probing was shown in same figure. The location of curve taking was randomly at top, middle and bottom of the part respectively.

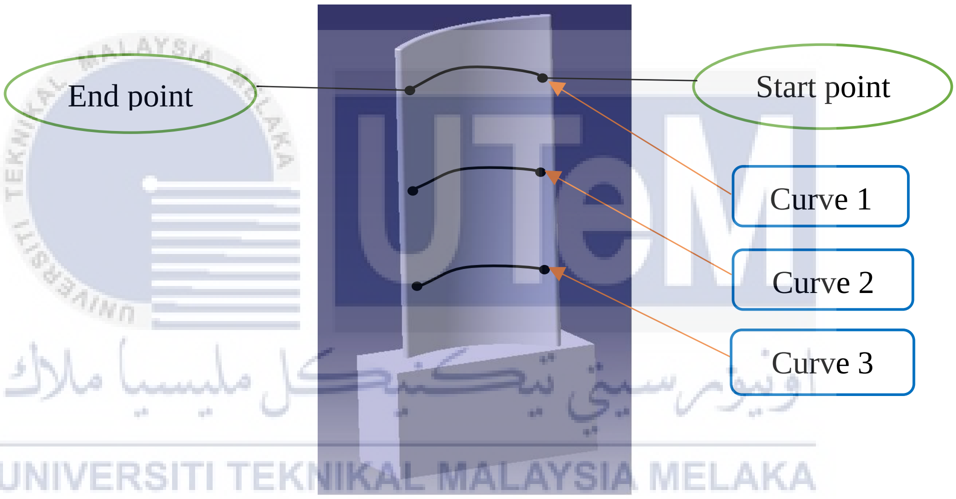




Figure 4.5: Start and End Point of concave side physical and direct probing curves

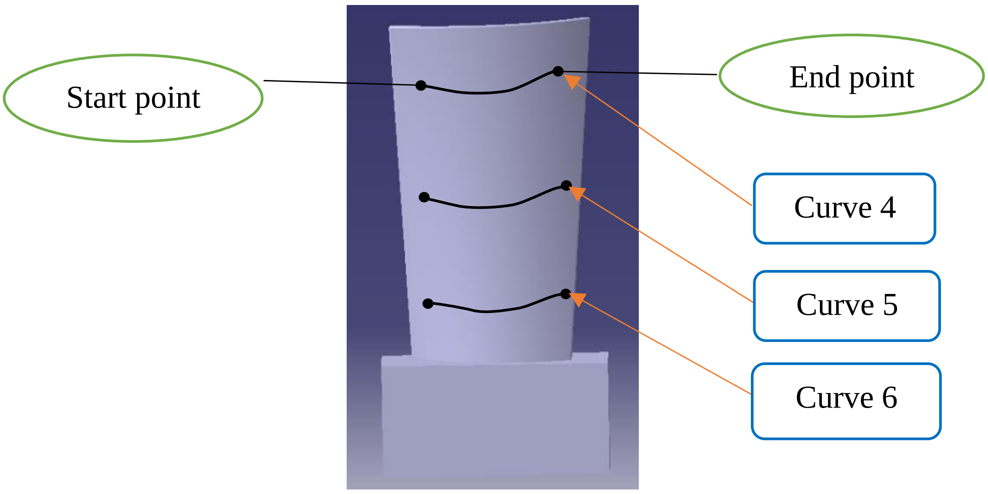



Figure 4.6: Start and End of Point of convex side physical and direct probing curves

The result was gained from the CMM by the measurement of each curve. Each of the reading was taking based on the best fit value given by the Calypso software. The best fit features were calculated the average best fit pattern from measured point to get a smooth pattern of curve and turn into sigma value. The tables below show the actual dimensional reading of concave side machined part that have been measured by using physical and direct probing method. The concave side of the measurement is referred to the second machine side

Table 4.1: Actual measurement result of concave side curves

| **Single blade side** | **Curves** | **Sigma σ (mm)** |
|---|---|---|
| **Concave side** | **Curve 1** | **0.0766** |
| | **Curve 2** | **0.0896** |
| | **Curve 3** | **0.0850** |



The table 4.2 shows the actual dimensional reading of convex side machined part that have been measured by using physical and direct probing method.

Table 4.2: Actual measurement result of convex side curves

| **Single blade side** | **Curves** | **Sigma σ (mm)** |
|---|---|---|
| **Convex side** | **Curve 4** | **0.0706** |

| | | |
|---|---|---|
| | **Curve 5** | **0.0868** |
| | **Curve 6** | **0.1089** |

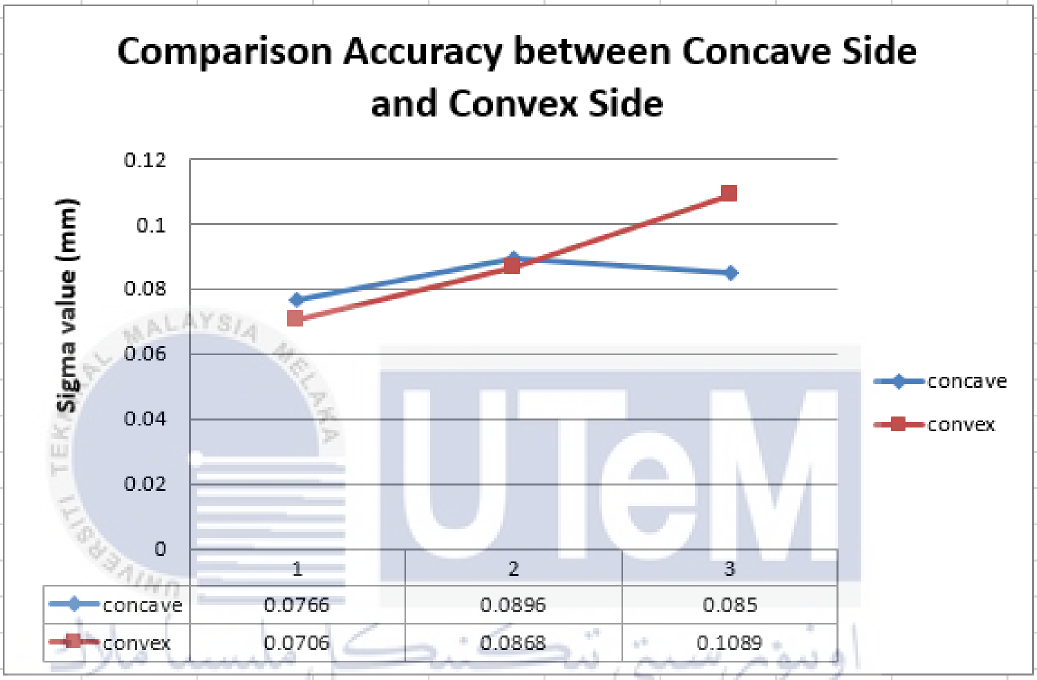



Figure 4.7: Best fits Accuracy of Concave and Convex



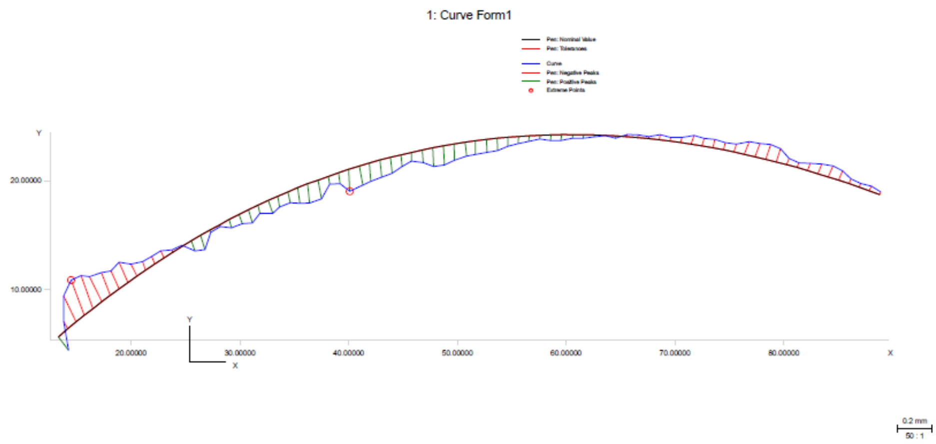
The best sigma value is curve 1 sigma as machining this section is in condition of solid block. This result maybe causes by vibration is less compared to curve 2 and 3. However, the curve 2 reading is slightly higher compared to curve 3 as it may be caused by excessive material left on surface after roughing process. In roughing process, end mill Ø20mm is used, therefore deeper surface of concave side cannot reach by end mill Ø20mm.

On convex side of blade, result of analysis show that sigma value of curve has been increase from curve 4 to curve 6. Machining process on convex side of blade is starting from curve 4 until curve 6. Sigma value of curve 4 is smaller than curve 5 and curve 6. This result describe that curve 4 has better surface accuracy among three curve during comparison between value of curve and value of best fit. This result may due to vibration occurred during physical machining process. Curve 5 has better sigma value than curve 6. There is less excessive material left in centre side of convex side of blade during roughing process compared with concave side of blade.  Therefore, curve 5 does not has large sigma value after CMM analysis.

Different between sigma values among same side of blade may be caused by vibration. During machining process, overhang tool may lead to chatter occurred.  Besides that, rigidity of stock also will effect on vibration. During three-axis machining process, less rigidity of stock has occurred due to clamping and cutting strategy of machining single blade. High vibration happen on second part operation as less material left. Chatter occurred during machining process may affect surface accuracy on both side of blades. Therefore, different sigma value has been obtained based on best fit curve.

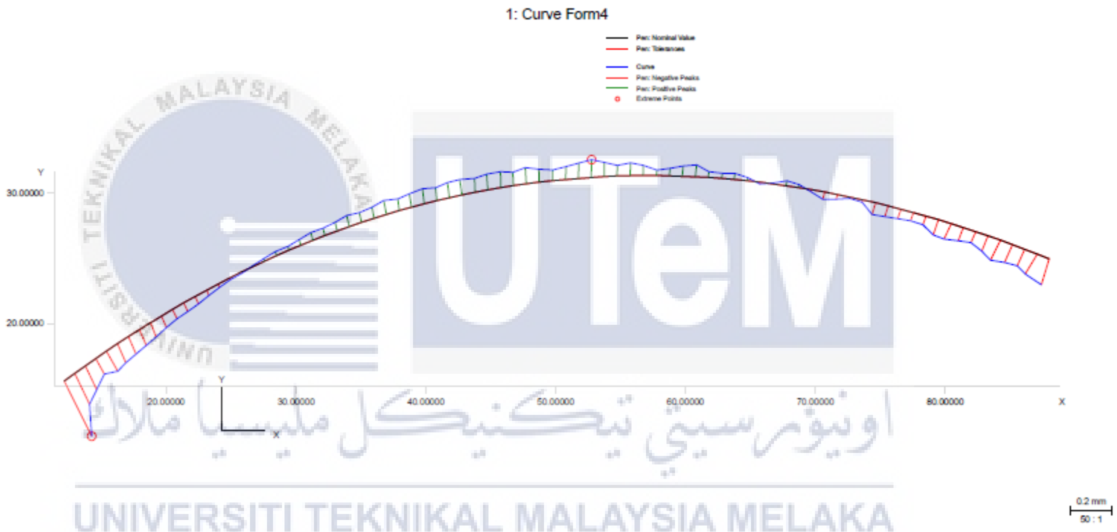
Furthermore, tool path setting for machining process also may influenced result after machining process. Tool path used in multi-axis sweeping is zig-zag. Zig-zag tool path can be reduced machining time. Tool axis motion has been fix to fixed axis as three-axis machine has been used. Possibility the zig-zag tool path reduces machining time but it affects accuracy of machined part. As result, different sigma values have been obtained by different cutting tool paths has been selected.

As mention above, there are excessive material left after roughing process on concave of the blade. During applying multi-axis sweeping on concave side of the blade, more material needed to be remove in curve 2 area after roughing process. This action may lead to decreasing accuracy of machining process compare with others surface or area of the convex side of blade. This reason may support by result of CMM (Coordinate Measured Machine) analysis as shown below.




| | Identifier | Sigma [mm] | Form [mm] | Number of Points | Lower Tol. [mm] | Upper Tol. [mm] | MinInd | Min Dev. [mm] | MaxInd | Max Dev. [mm] | Best Fit | X [mm] | Y [mm] | Z [mm] | | X | Y |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Curve Form1 | 0.07665 | 0.34000 | 82 | 0.00000 | 0.00000 | 4 | -0.21369 | 32 | 0.12631 | Translation | -2.36865 | -1.36075 | -0.01767 | Rotation | -0.07444 | -0.04373 |

Figure 4.8: Concave curve 1 result from CMM






| | Identifier | Sigma [mm] | Form [mm] | Number of Points | Lower Tol. [mm] | Upper Tol. [mm] | MinInd | Min Dev. [mm] | MaxInd | Max Dev. [mm] | Best Fit | X [mm] | Y [mm] | Z [mm] | | X | Y | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Curve Form4 | 0.07061 | 0.37951 | 81 | 0.00000 | 0.00000 | 81 | -0.29462 | 37 | 0.08490 | Translation | 0.61030 | -0.76856 | -0.00463 | Rotation | 0.07296 | 0.03407 | - |

Figure 4.9: Convex curve 4 result from CMM

# CHAPTER 5

# CONCLUSION

## 5.0 Introduction

All information and things done have been concluded in this chapter. Conclusion has been done based on chapter one to chapter four. Problems faced in this research also been concluded in conclusion part while some recommendations which related with research for further improvement have been mention in part of future work.

## 5.1 Conclusion

The main five axis machining strategy used in CAM process to machine single blade is multi-axis helix machining. The result in CAM shows the convex side is better than the concave side of blade. The post process was failed at the first trial and troubleshooting with regenerate the program by using CATIA V5. Also, modification and insert program manually B-axis and C-axis to overcome the problem. Unfortunately, the five axis machining was failed to proceed due to tool change errors and exchange buffer battery. Three axis machining was the last option to produce single blade. Sweeping is the machining strategy used for three axis machining. Coordinate measuring machine used to determine the dimensional accuracy of machined part. The physical and direct probing method was used in order to obtain the best fit of dimension accuracy. Due to the coordinate measurement machine is break down, therefore the auto CAD model probing method cannot be applied. Three curves measurement reading were taken from each side of blade. The smallest sigma on convex side of blade is 0.0706mm on curve 4. Possibility that the part was first cutting tool approach, high rigidity of solid block greatly reduce the vibration; while the largest sigma was the curve 6 with 0.1089mm. Thus, the different is 0.0383mm. It might be influenced by the less rigidity of stock after tip and middle part was machined and causing high vibration. In order to obtain the best result, reduce the scallop height to smallest value will lead to better accuracy. The smallest sigma on concave side of blade is 0.0766mm on curve 1; largest sigma 0.0896mm on curve 2. Hence, the value different between smallest sigma and largest sigma value on concave side of blade is 0.013mm.The reason might because of excessive material left after roughing on curve 2 is more can causing high vibration.

## 5.2 Future work

Multi axis helix machining shows great CAM result in CATIA V5. With the good machining strategy that machining from top to bottom with only single set up. Strongly believe that five axis machining can improve the accuracy significantly compared to three axis machining.

On the other hand, the machining can be perform by using new cutting tools and appropriate dimension. Besides that, the cutting tools parameter can be added into studies to control better accuracy of the point milling operations. Thus, the research can study the best machining strategies with control the precision and accuracy of the strategies being used included the cutting tools parameter such as depth of cut, step over distance, spindle speed and federate.

Additionally, the improvement on the older post processor software can be done by upgrading the version of the post processor might overcome the error. Also, The measuring method can be investigate by auto CAD model probing method in order to obtain the real measurement reading from machined part. Lastly, the topic can be narrow down into more specific tittle. However, the great deal of work have to make it a reality on the shop floor.

# APPENDICES

Appendix – Dimensional Experimental Result

# APPENDIX A

# DIMENSIONAL EXPERIMENTAL RESULT

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