



UNIVERSITI TEKNIKAL MALAYSIA MELAKA

**FIVE-AXIS TOOL PATH PROGRAMMING UTILIZING CATIA V5
FOR TURBINE BLADE: ALUMINIUM 6063**

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

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DECLARATION

I hereby, declared this report entitled “FIVE-AXIS TOOL PATH PROGRAMMING UTILIZING CATIA V5 FOR TURBINE BLADE: ALUMINIUM 6063” is the results of my own research except as cited in references.



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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:



ABSTRAK

Melalui kajian ini, semua maklumat, jurnal, artikel yang berkaitan dengan CAD/CAM, turbine blade dan five-axis machining pergerakan mata alat bagi peningkatan pengetahuan tentang projek ini. Pada masa kini, sesetengah masalah telah dihadapi berdasarkan turbine blade seperti kecacatan atas sebab manufacturing process. Objektive bagi projek ini ialah mengeluarkan give-axis machining pergerakan mata alat yang sesuai serta ketepatan bagi machined part. CAD model telah didapati dari GrabCAD. Perubahan telah dijalankan berdasarkan peralatan dan bahan mentah yang sedia ada. Aluminium 6063 telah digunakan sebagai bahan mentah bagi turbine blade. Five-axis machine yang code DMU 60 monoBLOCK telah digunakan bagi menghasilkan turbine blade serta strategi pemesinan telah disediakan melalui CATIA V5. Dalam CAD/CAM software, beberapa strategi telah digunakan seperti roughing process, multi-axis flank contouring, multi-axis sweeping dan isoparametric. Selepas proses pemesinan fizikal, penilaian telah dijalankan 3D Scanner serta its methodology. Keputusan yang didapati dari 3D Scanner telah dinyatakan perbezaan CAD model dengan bahagian dimesin fizikal melalui warna yang berbeza. Warna biru mewakili kelebihan pemotongan serta warna hijau mewakili kelebihan bahan.

Kata Kunci: Turbine Blade; Five-axis Pergerakan Tool; Mesin CNC; CATIA V5; Ketepatan

ABSTRACT

In this research, information's, journals and articles regarding CAD/CAM turbine blade and five-axis machining tool path have been searched for better acknowledgement and understanding. Currently, some problem has been occurred in turbine blade such as premature failure of blade caused by serious manufacturing defects. Objectives of this research are producing suitable machining cutting tool path utilizing CATIA V5 and accuracy is investigated. Turbine Blade CAD model has been selected from GrabCAD. Modification has been done based on limitation of equipment and raw material. Aluminium 6063 is used as raw material to machine turbine blade. DMU 60 monoBLOCK is used in machining turbine blade and machining program has been done by CATIA V5. In CAD/CAM software, machining strategies have been used to machine turbine blade are roughing process, multi-axis flank contouring, multi-axis sweeping and isoparametric. After physical machining process, analysis has been done through 3D Scanner and its methodology. Result from 3D Scanner show comparison between CAD model and physical machined part by different type of colour. Blue colour shows overcut while green colour shows undercut. Some recommendations such as smaller and tapered cutting tool has been suggested in part of future work.

Keywords: Turbine Blade; Five-axis Tool Path; CNC machine; CATIA V5; Accuracy

DEDICATIONS

To my beloved family



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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

CAM	=	Computer Aided Manufacturing
CAD	=	Computer Aided Design
CATIA	=	Computer aided three-dimensional interactive application
NC	=	Numerical Control
CNC	=	Computer Numerical Control
Ksi	=	Kilopound per square inch
IGES	=	Initial Graphic Exchange Specification
STEP	=	Standard Exchange of the Product Model
STL	=	Standard Triangle Language
UTeM	=	Universiti Teknikal Malaysia Melaka



CHAPTER 1

INTRODUCTION

1.1 Background

In current condition, there is a great importance in productive activity which is machining process for both indirectly for the manufacture of auxiliary elements and directly in the manufacture of components. Multiple fields related to the machining technology has evolved much in recent years such as the means of production, machining technology, tools for cutting, CAD/CAM or the sensors. Technique that applied in five-axis machining have been evolved rapidly with many CAD/CAM software developers. CAD/CAM software have addition function such as collision-avoidance capabilities and advanced simulation for five-axis program. CAD/CAM software is designed to cut the complex parts used in many areas such as die-mold, aerospace and medical machining applications. (Patrick Waurzyniak, 2007).

CNC machining means the physical machining process which is controlled under a NC program. A programmer must specify machine activity in NC program and cutting tool movement based on the sequence of the machining process. NC program execute instructions and interpret it through the machine control unit (MCU) of the NC machine. There are three types of NC programming which are manual programming, CAD- assisted programming and computer-assisted programming which based on the level of automation.

CAD systems is used to define, edit and verify the actual cutter motion and also to define the part geometry. This system can help in achieved high performance levels of automation. Nowadays, there are several CAD/CAM systems support the capability to

generate instructions of NC machining which based on the definition of geometry for a cutter and workpiece, such as CAD/CAM, CATIA and Computer vision.

Delcam plc (Birmingham, UK) has been develop CAM software and also made moves on the acquisition front, purchasing IMCS Inc. PartMaker (Fort Washington, PA) after their company buys Engineering Geometry Systems (Salt Lake City), developers of FeatureCAM. (Patrick Waurzyniak, 2007)

Recently, five-axis and multi-axis machining methods have been looked by CAM software suppliers to solidify their offerings for users trying to stay competitive by using more complex manufacturing techniques. In getting keen interest in multi-axis and five-axis machining, there are manufacturers who play important role such as Eastern European and Asian manufacturers. Aim of those manufacturers are getting lower cost for tools used in five-axis machine tools and intense competition from low-cost. To reduce setups on machining complex parts, new five-axis offerings add the ability.

Infinite probability things such as to shapes and the part sizes which can manufactured effectively by five-axis machining. The cutting tool on a center of five-axis machining moves across the linear axes which are X, Y and Z axes together with rotates on the B and A axes to machine the workpiece/ part from any direction. On the other hand, five-axis machining can manufacture five sides of a single part in single settings. (Mazak) Based on explanation of Gibbs (Rolls-Royce), Five-axis technology provides the user with the ultimate amount of control when applying tooling to a part. Because of this, collision avoidance, improved surface finish, and reduced tool wear are some of the benefits realized. (Stuart Nathan, 2015)

One of the leading solutions for product success is CATIA V5. CATIA V5 is a software that addresses all organizations related with manufacturing field which from minor independent manufacturer until their supply chains. CATIA software is suitable to a wide variety of industries such as industrial machinery and automotive, aerospace, electronics, building of ship, consumer goods and plant design. Nowadays, one of function using CATIA is designing anything in the world which from a clothing and

jewelry to an airplane. Product engineering in a fully-integrated manner with functional range and power is provided by CATIA to obtain the complete product development process. CATIA helps to increase response of enterprises to market needs shorten development cycles and facilitates reuse of product design knowledge.

An old method to create turbine blade was metalworking. To create turbine blades used for jet engines, the most basic and ancient methods of metalworking are casting process. If a fire can be heated until temperature which can melt a metal, a crucible is created to melt metal together with a mold (can withstand the heat) and cast complex forms of metal. “The blades operate in an environment several hundreds of degrees hotter than the melting point of the nickel alloy, but because of the cooling mechanisms, the metal is never above its melting point, even though the environment is.” (Neil Glover, Rolls-Royce). Not all material in making turbine blades is nickel alloy; family of alloys and ceramic materials also used in making turbine blades. A significant differentiation between temperature of external flow and surface temperature. Material with a high melting point is used in solving the problem and reduces the effective temperature over the surface of the used metal. (Stuart Nathan, 2015)

In the periodic table, the 13th element is aluminium which is a silvery-white metal. Aluminium is the metal that widely disseminated on Earth. This statement can be proved as more than 8% of the Earth's core mass is aluminium. After oxygen and silicon, the third most common chemical element on earth is aluminium. (Ivan Aivazovsky) There are increasing requirements for those projects which involved aluminium have become more familiar as aluminium has become an excellent alternative method of steel. In welding fabrication industry, many applications are applied together with the growth of aluminum. The advisable way to understand aluminium clearly is starting by become familiar with the aluminum designation system/ identification. Currently, many types of aluminum alloys are available and have their characteristics. Nowadays aluminum alloys make up a wide and multifunctional range of manufacturing materials which together with their various tempers. The difference between many available alloys and their various properties is very important step for optimum product design. (ESAB knowledge

center). One of aluminium alloys is 6xxx series are combination aluminium with silicon and magnesium. 6xxx series aluminium alloys are moderate in strength which is 200 to 350 MPa. Though the heat treatment processing or forming process, the strength of aluminium 6xxx series are achieved. (sapa:)

1.2 Problem statement

At present, one of causes failure of blade is manufacturing defects. Defects often occur as design specification of blades which based on CAD models or drawings are not follow during manufacturing process. One of the common defects is premature failure of blade as it is weakening the point that normal loads by serious manufacturing defects.

Turbine blades are designed for mass center location and optimum aerodynamics, resist extreme temperature, and avoid corrosion, and constitute of advanced metal alloy castings and composites to increase strength. Tight tolerances apply to both the geometry and alignment of turbine blades to guarantee optimum blade position and aerodynamic operation. (Nikon)

Currently, process of manufacturing turbine blades are castings, forgings, solid billets of titanium and stainless steel or bar stock. (Mark Albert ,2012) Many factors are important such as total cut time, depth of cut, spindle speed, an investment in the machine itself and tool life in determining material of manufacturing process. These factors contribute to cost of manufacturing and in turn the ability to efficiently and profitably machine selected material.

By machining, manufacturing defects of turbine blade may be reduced. Five-axis CNC machining is suitable to machine complex part. Five-axis CNC machining provides a high quality of product or part and given good positional accuracy. Simulation done in software such as CATIA V5 helps in determining defect occur before physical machining. This step helps in preventing wasted material.

1.3 Objectives

The objectives of this project are stated as below:

- a) To determine the suitable machining tool path in preparing the CAM program for a turbine blade utilizing CATIA V5 by validating the tool path in the real machining which is 5-axis machine.
- b) To investigate the effect of dimensional accuracy of a machined part in transferring the CAD/CAM data to the actual machined part.

1.4 Scope

In this research, things included and limitations of this project are discussed. There are limitations in this project as it is impossible to include everything in the project. This project is concerned on getting the suitable machining tool path generations in producing one turbine blade utilizing CATIA V5 as the main CAD/CAM software. Material used in validating the tool path for the physical machining is Aluminum 6063. CAD model of turbine blade is searched and verified by adviser. This step is very important in ensuring that the chosen CAD model fulfil the project requirement. Various five axis tool paths/ processes designed to obtain desired turbine blade. Processes that been selected in this research are roughing multi-axis sweeping, multi-axis flank contouring and isoparametric. Five-axis machine DMU 60 monoBLOCK is used to perform the machining. Accuracy of machined part has been analysis after physical machining. 3D Scanner which located in Rapid Prototyping Lab is used. 3D Scanner can provide fast and good accuracy result which shows comparison machined part with the original CAD model and define them based on different type of colour. Dimensional accuracy is important factor in machining turbine blade.

CHAPTER 2

LITERATURE REVIEW

2.1 Five-Axis Machining

A study which related with a new method for five-axis tool path optimization has conducted by Pascal Ray (2008) found that there is remaining some kinematic performance issues that have been introduced by tool path computation which can generate slowdown although scientific community has been study the main problems of five-axis. The goal of this study is to improve machine tool behavior without deterioration of milled part quality. The kinematic behaviour of the machine tool and the five-axis machining geometric method is necessary be confronted. There are a lot of researched in five-axis machining are focusing on methods to figure out tool axis orientation in order to improve or optimize such as:

- ❖ The control of interference between part and tool
- ❖ The quality of the milled surfaces is evaluated.
- ❖ The interpolation format of the tool path
- ❖ Free collision positioning of the tool under its environment

As mentioned in chapter one which is introduction, one of purpose of free-form surface machining is to minimize machining time while machining complex shapes that respect to the level of quality. Machine tool behavior and milling strategies are leading to achieve those aims of productivity and quality. The study proposed by Pascal Ray (2008) was dealing with the relation between productivity and quality. The method presented in this study is minimization the angular difference between curvature and two successfully tool axis orientations. After that, this method is applied to the rotation axis coordinates. The optimization of this study is a minimization of the movement which created by each

rotation axis.

The findings of the study written by Hsin-Pao Chen et al. (2009) can help in removing tool marks of blade surfaces through smoothing five-axis point milling cutter paths. Machining controlled by five-axis is certain manufacturing strategy to get a centrifugal compressor impeller efficiently which have characteristic that overlapping, surface texture and complex geometry with a specified dimensional tolerance. There are two challenge tasks needed during planning five-axis tool paths to mill impeller. Those tasks are required as they play role as part in the manufacturing process. Planning of tool paths in milling impellers by five-axis has faced one challenge part is making decision or linearization problems by suitable CL data without causing local gouge and global interference due to the curvature limitation between the impeller surfaces and cutter size. Another challenging that has been mention is CL data need to be further convert into NC data which depend on the setting of a selected five-axis machining tool. This study had focus on the reverse moving movements on axes along five-axis tool paths. Besides, the step of eliminating a gouge phenomenon on impeller surfaces is presented through five-axis CNC machine. During finishing process of milling centrifugal compressor impeller, tool path of linearization problems and reverse movements of moving axes along a five-axis without interference may causes tool marks leaved by cutter on the surfaces of impeller. Its three linear axes are used to machine an impeller by a common five-axis machine tool as guidance for its tool to specified CC (cutter contact) points which are to be milled on impeller surfaces. Besides, to adjust its axis of cutter to prevent collision, the two rotational which are rotating axes and tilt angle of the five-axis machine tool are utilize. In this study, to machine centrifugal compressor impellers is generated without any tool marks leaved on machined blade surfaces, a useful and reliable procedure which can be utilized has been established. There is a simple way which is the procedure can be used conveniently in determining initial five-axis accessible tool paths for roughing and semi finishing process in condition of considering a ball end mill and an end mill. Five-axis finish milling of an impeller consider successful as it does not leave tool marks on impeller surfaces, the effectiveness of this procedure has been experimentally confirmed. Demonstration by an experimental machining test which referred to a popular configuration of five-axis machines have

been done to verification of the algorithms and implementation of the procedure. The time of machining can be saved up to 23.57% with the spline tool paths. The proposed procedure can simply be modified to fit them for others five-axis machines with two rotational axes and three orthogonal translating axes. Thus, the future topic which can be discussed is the effect of machined impeller blade surfaces through reverse axes movements of five-axis machine tools. Figure 2.1 shows the pressure surface after removing tool marks in this finding while figure 2.2 shows model that has been used in this finding which is impeller.



Fig. 2.1 The Pressure Surface after Removing Tool Marks
(adapted from Hsin-Pao Chen et al. (2009))



Fig. 2.2 Impeller that been Machined.
(adapted from Hsin-Pao Chen et.al (2009))

Linjian Yang and Jinchun Feng (2011) identified some factors need to be considered when selection of the tool. For different types of machining efficiency and accuracy

requirements in the certain environments, different machine tools are chosen. In selection of tool, some parameters such as cutting parameter that related to blade and tool, machine power, the speed of milling material of blade and head are needed to be calculated. In addition, arbor, blade, cutter head and milling head need to be simulated and have interference checking depending on posterior simulation processing. Processing method and Cutter scheme needed modification while cutter interference exists. Finally, it must be ascertained that cutter has no problem in interference examination and simulation. In a follow-up study, Linjian Yang and Jinchun Feng (2011) also found that, in the machine power, machine tool stiffness and speed range of milling head must be sufficient during simulation. Different diameter cutters are utilized with these conditions to improve the efficiency of machining by calculating suitable diameter. At the same time protection of machine tool is paid attention.

Besides, selection of the parametric curve of tool trajectories as the machining direction of milling when machining blade profile is one of study done by Linjian Yang and Jinchun Feng (2011). This step helps to improve capability of cutting technology. Different knife-axial controlling methods and cutters are applied in different areas to improve efficiency of as possible. Based on simulating machining techniques, key techniques are proceeded with the development of computers. On the other hand, there are more preface needed to be consider regarding automatic programming when five-axis CNC machine is used to machine large blade. Verification of the simulation on computer is important step before machining. This step can be repeated modification and optimize processing scheme by machining simulation. Assembling precision in making uniform welding amount can be greatly improved through the CNC processing way of groove.

In process a machine tool or CAD/CAM technology is purchased, an important investment is required and it cannot be done without attentive consideration. Precision, flexibility and productivity will be limit as technology selected incorrectly. (Arslan et al., 2004), so companies usually pay attention on technical capabilities and performance than cost. Comparision between three-axis and five-axis CNC centers in free-form machining has been done. (WojciechZębala and MalgorzataPlaza ,2014) This information are useful although although hard material is not used in this project. This

study given briefly explanation about cost effectiveness between three-axis CNC centers and five-axis CNC centers. To machine of the parts, such as turbine blades, the material's properties and geometrical complexity are challenging part This study illustrate that if the algorithm works, the finish of the three-axis center surface machined achieved a similar standard as can be done on a give-axis center. In this paper, the assumption regarding a three-axis center cannot be compare under such overwhelming circumstances is challenged. Additionally, the machining time able to reduce more than 17% when compared to the machining time of the same three-axis machine in condition that the NC code is not maximized with the feed-rate adjustment algorithm. Cost model is used in comparing the effectiveness of cost for the two alternatives which authenticating the research contribution and application of software technology in machining complex geometries on a three-axis machine. This study demonstrates that if EV is integrated with the currently used process, a free-form complex shape can be manufactured by a 3-axis machine and the finish of the machined surface was improved almost two times.

Tunc L.T.1 et al. (2010) have study about using suitable process models to develop machining strategy for five-axis milling operations. Mechanical components having complex surface and geometries are required to be manufactured in tight tolerances due to increase demand for performance designs. The complex part surface must be generated to maintain the tolerance and dimensional integrity with minimized number of setups which requires tool positioning and contouring capability during manufacturing of high performance designs. The tool has two additional rotational degrees of freedom in order to meet the requirement in five-axis machine. Five axis milling has been widely utilized in automotive, die-mould industries and aerospace due to its advantage. In multi-axis machining that spherical tip of the tool provides high contouring capability to machine free form and sculptured surfaces, ball end mills are widely used. General ball end mills consist of a straight or conical body with taper angle β and a spherical tip with radius R which has shown though Figure 2.3.

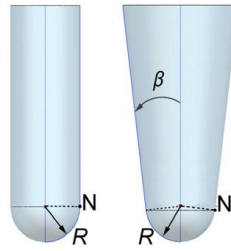


Figure 2.3 Types of General Ball End Mills.

(adapted from Tunc L.T.1 et al. (2010))

Generally, there are three stage such as finishing (f), semi finishing (sf) and roughing (r) are required in the design geometry is machined from the blank geometry. In many situation, roughing and finishing stages consist of single step while semi finishing stage require multiple steps to satisfy the desired dimensional tolerances that depend on the applied global strategy. Moreover, various considerations need to be taken into consideration and different constraints may limit the process. Figure 2.4 gives clearly view for comparison of machining strategies which has been stated in this finding.

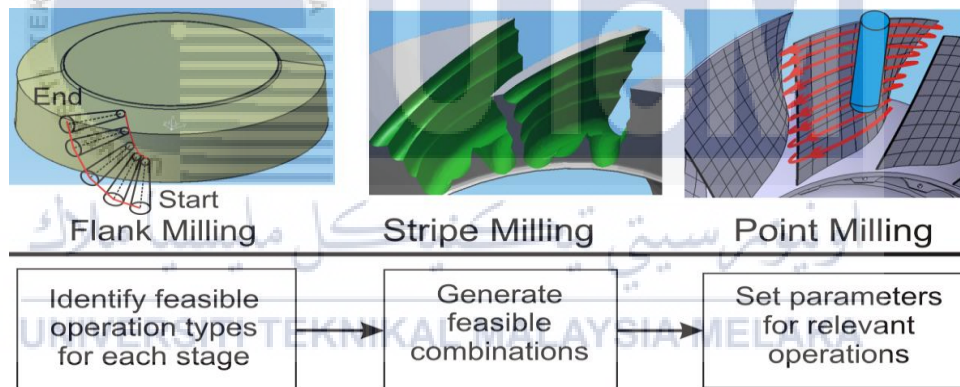


Figure 2.4: Comparison of Machining Strategies.

(adapted from Tunc L.T.1 et al. (2010))

A review about the field of computer-aided manufacturing has been introduced. For free-form surface, there are two types of representation which are the polyhedron surface and the tensor product parametric surface. In modelling, complex workpieces, both of representation have their several disadvantages. In 2014, a paper had been published by Wen-Feng Gan et al. which studied about five-axis tool path in machining T-spline surfaces. The probability of direct tool path generation on the T -spline surface has been discussed in this paper. Currently, T-spline surface has become the trend of free-form surfaces representation in the realm of CAE, animation and CAD design due to its robust

data structure and flexible topology. Although T-spline has become the famous but its application does not explore fully in manufacturing process. The advantage of T -spline is in CAM process, it is a mathematical representation of free-form surfaces which has been exploited by proposing an improved space-filling curve (ISFC) tool path planning algorithm. Additionally, disadvantages of T-spline such as unusual holes and boundaries in the pre-image also overcome. The efficiency and feasibility of the proposed method for T -spline surfaces tool path generation compared to commercial CAM system has been shows through the result in this finding. Moreover, only ordinary T -spline surface is discussing and consider in this journal. Figure below which is figure 2.5 represent a view of model gampad machined is zoom in by ISFC (Improved Space Filling Curve) and traditional SFC (Space Filling Curve).

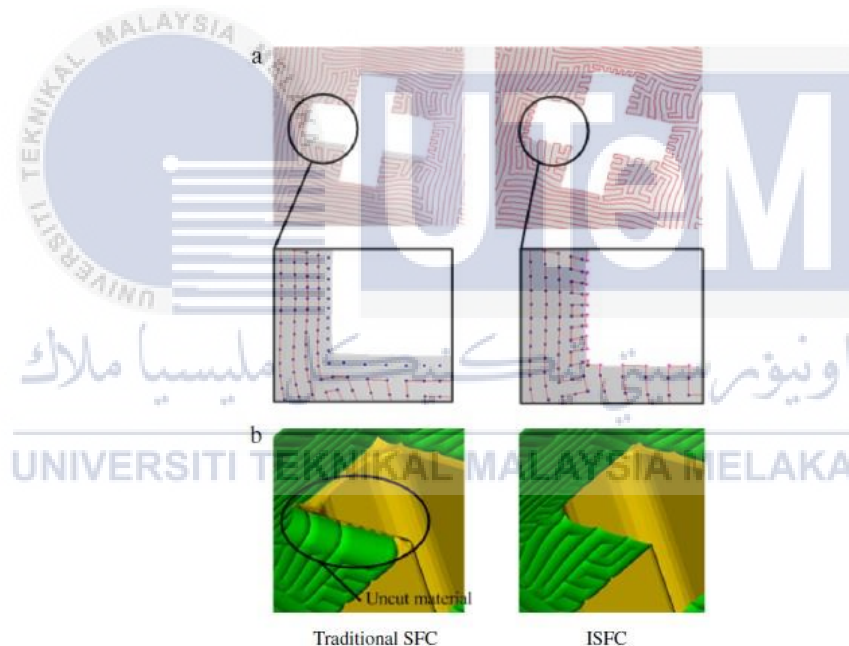


Figure 2.5: A View of Model Gampad Machined is Zoom In by ISFC (Improved Space Filling Curve) and traditional SFC (Space Filling Curve).

(adapted from Jian-Zhong Fu et al. (2014))

Prevention of five-axis singularities considering tool orientation angle changes can improved machined surface textures have been studied extensively. (Zhiwei Lin a,b, et al. ,2015). This finding focus on improve the machined surface textures in process of avoiding five-axis singularities by using the C-shape based tool orientation translation

method. Five-axis machine tools have characteristics high efficiency and high precision with the additional rotary axes. However, five-axis machine tools are still difficult/ hard to use even with today's CNC/CAM technologies. There are problems still exist in practical five-axis applications such as collisions and singularities. In all types of five-axis machine tools, there is singular problem hides no matter what are the configurations. The singular problem hides will only appear during the rotary axes traverse the singular point. In the orientation modification process, lacking control of the tool orientation is caused a cutting simulation in VERICUT reveals that irregular surface textures. In the previous tool orientation translation method, a modified particle swarm optimization (PSO) is intergraded into it. An optimal translating vector in the C-space is find so that the changed tool orientation angles can reach minimum values is objective of the PSO. The surface textures can be controlled by PSO. To verify the effect of the proposed method, there are three comparative cutting experiments with fillet end mills are carried out. Through experiment result of five-axis machining, the singular problems that cause irregular machined surface textures can be improved by optimally adjusting the translating vector in the tool orientation translation method. In this finding, the experimental results show 2 result which are with the five-axis singular problem can be avoided perfectly by the tool orientation translation method, and the machined surface textures can be greatly improved with the optimal translating vector found by the PSO. Notice that, modifications of the basic tool orientations are inevitable in many five-axis machining scenarios. For example, tool orientation smoothing, the singularity or collision avoidance and wide strip machining. Based on most of the previous literatures, it covers on these topics by neglecting the influences of orientation modifications on the machined surface textures. Based on the fact, the surface textures are related to the machining errors and therefore this issue deserve more research attentions.

In 2016, Zhu Yu et al. have focus on propose an optimization method in selection a tool orientation in machining a sculptured surface. This optimization method is 3+2-axis machining strategy. Method selection of sample points and the orientation of tool so the maximum average strip width could be model in selecting optimization method in 3+2-axis machining. In this survey, a fillet-end cutter is used as a novel tool orientation optimization method for 3+2-axis machining. An optimization model is established and

finding the Quasi-feasible sectors (QFS) domain are main issue to optimize tool orientation. Besides, Quasi-feasible sectors consist the best tool orientation could be found based on the projection planes and the normal vectors of sample points. QFS could help in finding the optimal tool orientation depend on a bunch of projection planes. According the optimized tool orientations, tool paths were generated and the sub-surfaces without disturbing could be used to mill. The method mention in this survey/ finding shows that it could be applied on the trimmed surface, the **blade on a blisk** and surface with a boss. Machining efficiency could be improved by decreasing the number of tool paths for 3+2-axis sculptured surface machining. This statement has been proved through machining results of the method. There are two figure which are Figure 2.6 and Figure 2.7 show method applied on blade of a blisk.

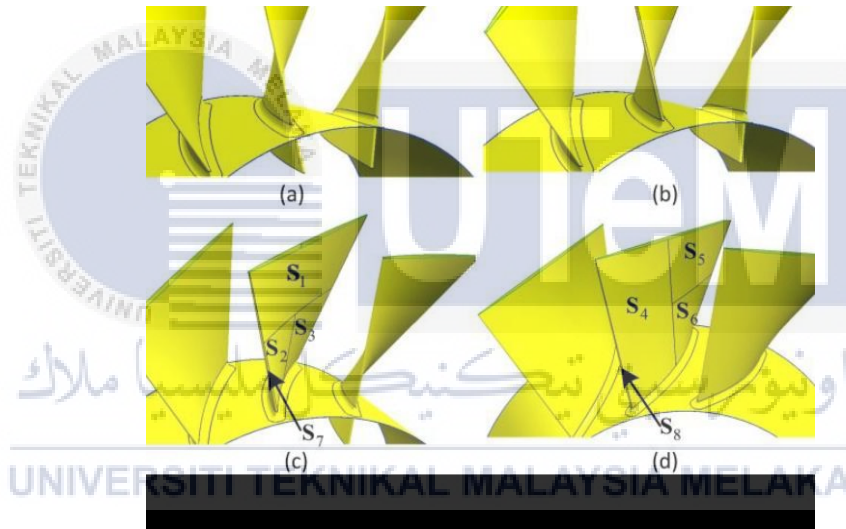


Figure 2.6: The Surface Partitioning and Model for A Blade of A Blisk. (adapted from Zhu Yu et al. (2016))

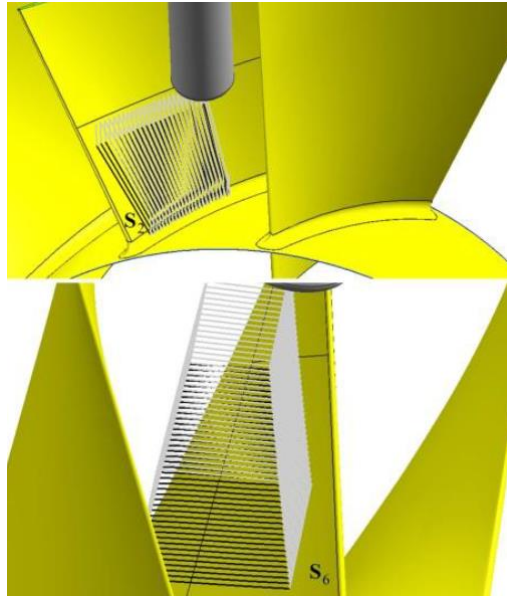


Figure 2.7: Tool Paths have been shown for Two Sub Surfaces.

(adapted from Zhu Yu et al. (2016))

In this survey cutting force, vibration, tool size and other issues are not considered. Furthermore, the method in improving speed of compute should be considered as well. However, conclusion of the findings (Zhu Yu et al. ,2016) has stated that there is an open question regarding the strategy to appropriately employ the 3+2-axis machining.

There is a current paucity of studies investigating complex milling tool bodies with a generalized stability and dynamics model. The complex milling tool have irregular cutting edges which suitable used in multi-axis milling operations. This studies have been done by Omer Ozkirimli et al. In milling operations, the most common limitation that caused decreased tool life, ham to machine tool spindle and poor surface quality is chatter vibrations. Chatter-free cut-ting conditions such as spindle speed and cutting depth can be selected by stability diagrams. Increased accessibility is offered by multi-axis milling where utilization of variety of edge geometries and cutting tools in order to improve productivity and stability of the processes of milling parts that have free form surfaces or geometrical constraints. Special tools ranging from taper end mills to process specific form tools which relevance with multi-axis orientations are utilized in order to machine the desired geometries effectively. The definitions of directional force vector and cutter workpiece engagement boundaries (CWEB) in such

case are very complex and cannot be defined analytically. For both the process and the tool to be defined in a generalized manner, prediction of stability diagrams for such variety of edge geometries and tool forms is required. A numerical frequency domain milling stability solution method is proposed with introduction of the effect of process damping. This introduction helps to predict the increase in the stability limits at low cutting speeds. One of case study in this studies is low speed flank milling. The stability of a roughing operation of a Ti6Al4V alloy integrally bladed rotor is investigated in this studies. In this studies, five-axis flank milling which operation that typically used in aerospace manufacturing is analysed. Five-axis flank milling operation is performed at slotting condition. To achieve an increased stability limit, spindle speed is selected with the effect of process damping, equal to the blade height. The process was observed to be stable along the tool path. Resulting surface in 900rpm of this studies shows no chatter marks are observed on machined surface. Figure illustrated flank milling operations in case study has been shown through figure 2.8.

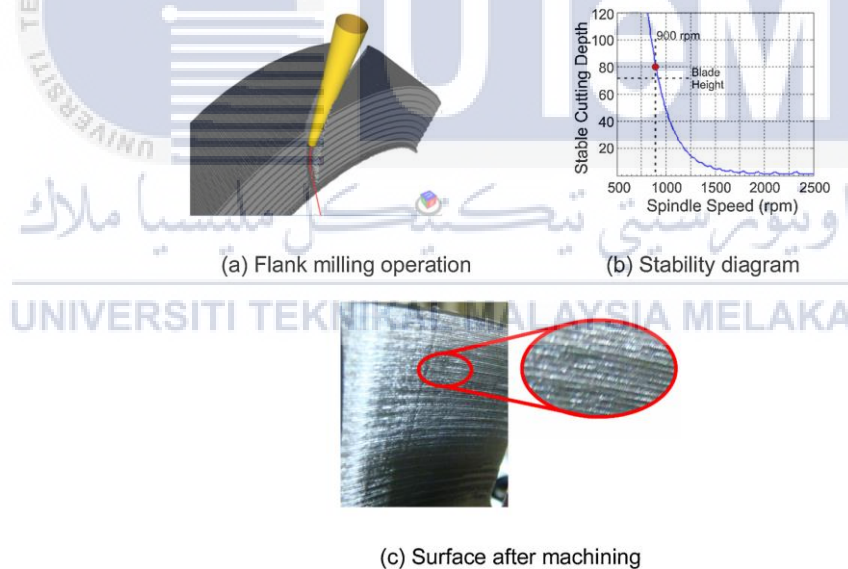


Figure 2.8: Flank Milling Operations in Case Study.

(adapted from Omer Ozkirimli et al. (2016))

“Mastercam X⁶ Introduction of Multiaxis Toolpaths” has emphasized the basic of five-axis toolpaths. A multiaxis machine is the additional axes available is stated in the tutorial. Five-axis machine is a machine which capable of handling five or more axes of motion instead of a straight forward machine with XYZ axes capabilities. The axes may

be in a different relationship or different orientation. This statement shows that the main point of machine has a much greater range of motion compare with a standard three-axis horizontal or vertical machine. The capabilities can be greatly enhanced by the added motion of a multiaxis machine, as well as expanding the variety of parts which can be machined. However, there really is no such thing as a “standard five-axis machine” due to the enhanced power of the machine. Almost every machine is unique in its axes combination, travel and rotation limits, orientation and controller. Common terms for multiaxis machines are head/table, table/table and head/head. Above terms describe the relationship of the rotary components on the machine. A table/table machine is the machine which has both rotary axes connected and attached to the table. Turning process in carrying on a rotary table. While a head/table machine has one rotary on the table and the other on the spindle which operate independently of each other. A machine has both rotary axes connected and attached to the spindle is a head/head machine. The machine axis zero is located on the face of the spindle. There are three controls separate multiaxis toolpaths from the typical two- and three-axis toolpaths such as Cut Pattern, Tool Tip Control and Tool Axis Control. The deciding factor in the ability to create efficient toolpaths for the particular machine is effective use of these controls. However, there is no substitute for experience and knowing your machine’s capabilities.

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2.2 Ball-end Milling process

In 2009, ErdemOzturk et al. published a paper in which they described effects of lead and tilt angle in 5-axis ball-end milling processes. Five-axis milling is widely used in aerospace, die-mold and automotive industries, where machining complex surfaces and geometries. (ErdemOzturk et al. ,2009) There are additional challenges when manufacturing of parts with complex surfaces such as contouring and tool accessibility. By increasing tool orientation capability, five- axis milling process provides greater accessibility. However, due to the complicated mechanics and process geometry, five-axis milling also brings extra difficulties during machining process. Lead and tilt angles as the special parameters of five-axis milling, there have significant

effects on the process dynamics and mechanics. However, studied based on those special parameters are very little. The subject of the study is lead and tilt angles effect on process mechanics, geometry and dynamics which those effects are not well known. There are a detailed analysis of lead and tilt angle effects on 5-axis ball-end milling operations through this finding. Firstly, effects of tool tip contact on the surface finish quality is presented in the paper together with conditions to avoid tip contact in terms of depth of cut and lead and tilt angles are stated. In this paper, experiment has been conducted based on the effects of lead and tilt angles on form errors, cutting forces, stability and torque. All effects of lead and tilt angles are investigated through modeling and verified. The result is shown that the cutting geometry, mechanics and dynamics vary sharply and non-linearly with lead and tilt angles. For the same material with various combination of lead and tilt angles, there can be quite different for its removal rate, stability limits and forces. The presented results in this paper show that enhance the understanding of lead and tilt angle effects on five-axis ball end milling operations is the effective way. (ErdemOzturk et al. ,2009) The capability of five-axis ball end milling in terms of enhanced accessibility and complex surface generation can be increased by lead and tilt angles. Moreover, they can also be used to increase the productivity and surface quality in five-axis ball-end milling processes. Figure 2.8 shows resulting surface after undergo test of this findings while figure 2.9 shows the tool tips mark observed in test 1, does not exist on the surface for the test 2. Figure 2.10 shows graph about effects of lead and tilt angles on maximum torque (a), maximum Fxy force for case1, b represents case2 and c shows tool deflection in the surface normal direction for case3.

Table 2
Conditions for the tool tip contact tests.

Test	Lead (deg.)	Tilt (deg.)	s (mm)	a (mm)	Tip contact
1	0	0	6	1.5	Yes
2	10	0	6	1.5	No

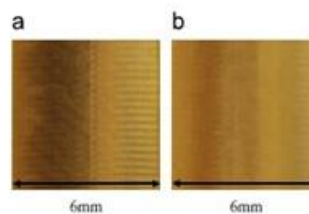


Figure 2.9 Resulting Surfaces after The Tests
(adapted from ErdemOzturk et al. (2009))

Effect of tilt angle on allowable step over while scallop height is fixed.

	Case 1	Case 2	Case 3	Case 4
Scallop height limit (mm)	2	2	1	1
Lead, tilt (deg.)	10, -35	10, -71	10, -35	10, -75
Allowable step over (mm)	8.94	11.28	6.63	7.84
Number of cutting steps	12	9	16	13

Figure 2.10: In Test 1, Tool Tips Mark has been Observed while Test Two does not Exist Tool Tip Mark on The Surface.
(adapted from ErdemOzturk et al. (2009))

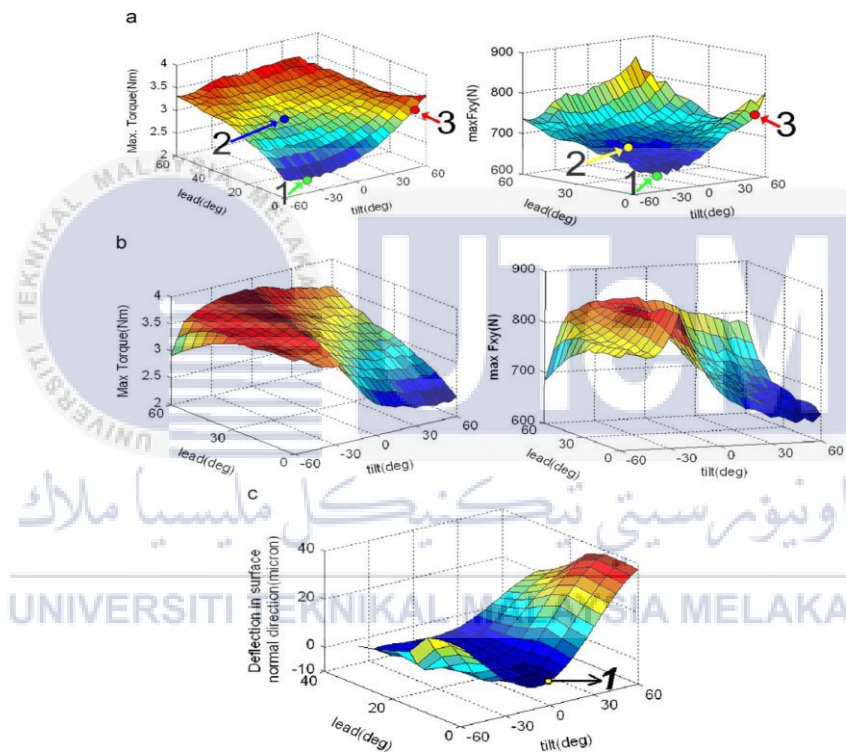


Fig.2.11: Lead and Tilt Angle Will Affected on Case 1 – Maximum Fxy Force, Figure B Represents Case 2 while Figure C Which Related with Tool Deflection for Case 3. (adapted from ErdemOzturk et al. (2009))

The finding about a solid modeler based engagement model for five-axis ball end milling are done by I. E. Yigit et al. Engagement between tool and workpiece at any location along the tool path is a key input for modeling of force and others analysis and optimization of milling processes, therefore accurate prediction is desired. Because of the complex geometrical involvement between the cutter and workpiece, five-axis

sculptured surface milling is a hard machining process. The engagement cannot be analytically created by using conventional methods because of the complexity of the process. To compute the engagement map, solid modeler is used which based on simulations. An efficient and comprehensive strategy for engagement modeling of ball end milling is presented through this study by using a solid modeling kernel, known as Parasolid. Through simulation of cutting force according to calculation of engagements and compare calculation with experimentally cutting forces, accuracy of the model is validated.

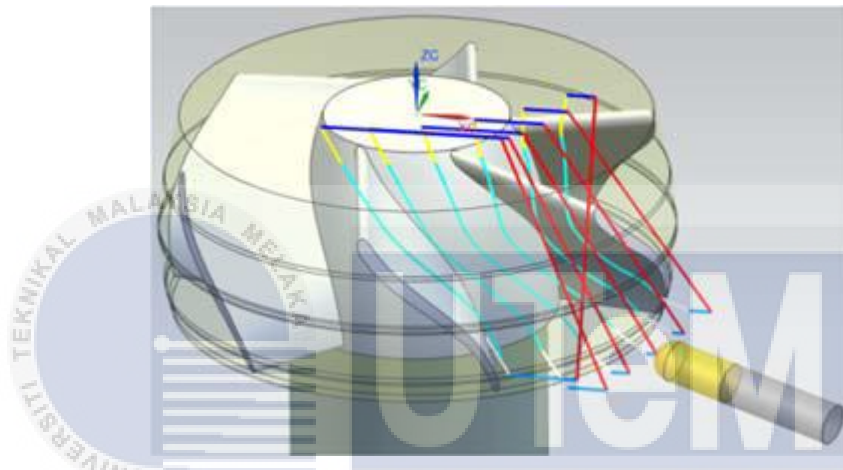


Figure 2.12: The Geometry Applied for Purpose of Simulation and Validation.

(adapted I. E. Yigit et al. (2015))

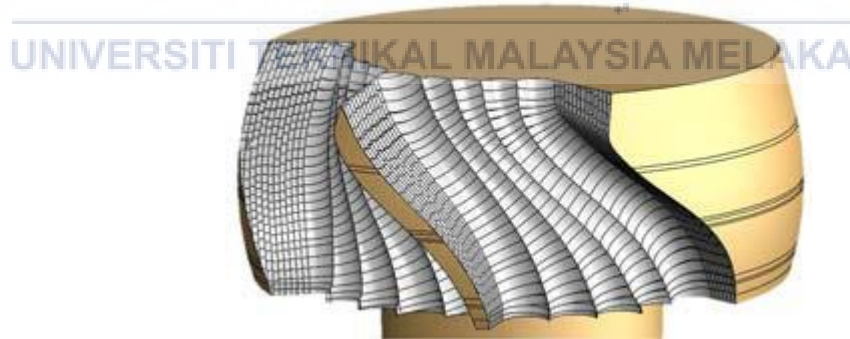


Figure 2.13: Geometry Output of Five-axis Machining of An Impeller has been

Shown by Developed through Developed Model

(adapted I. E. Yigit et al. (2015))

2.3 Five-axis Flank Milling

There has a study focused on review for five-axis flank milling. A state review about five-axis flank milling are done by Ramy F.Harik et al.(2013). Flank milling is of importance to machining complex parts such as turbine, blades, structural parts of aircraft and several types mechanical parts. Flank milling help in decreasing manufacturing time, reduces cost and enhances quality. A survey on flank milling is presented in this article and future considerations have been suggest guidelines to optimize flank milling tool path. Through article, strategies used in manufacturing and an introduction about math of ruled surfaces are first presented as preamble. The preface of article includes some useful information such as definition that might be use during merging the terms used throughout the various types of reviewed publications.

The generation in optimization tool path through reduction of error can be separated into the following:

- The ability to redress the tool path of twisted surfaces by calculating errors to gain a machined surface based on expected design.
- Pure geometrical errors such as undercut (falling short of removing all excess material) and over cut (excessive tool indentation in the surface) is minimized.
- Envelope surface is defined. In some condition, it is referring as machining surface, serving as tool path guides. This step is often defined as a transformation of the original surface along the local normal's.

-Tolerance with acceptable design limits is compared and surface roughness is predicted.

One of problem for suitability and tool adaptation for the manufacturing process at hand is using different tool geometries to solve the problem of manufacturing. In previous, a cylindrical shape flat tool is used, but recently, conical tools with different geometries have been used. Figure 2.14 shows different types of milling process such as end milling, flank milling and sweeping milling.

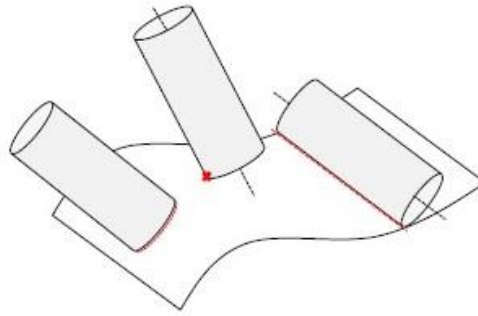


Fig. 2.14: Process of End Milling, Flank Milling and Sweeping.

Red colour shows contact locations of cutter with surface.

(adapted from Ramy F.Harik et al. (2013))

Fig. 2.15 depicts the main publications bring about the review of the concepts:

- Early Works has been done from 1979 to 2001. In 2001, survey is done by Monies et al. Initial simple positioning is included by Stute et al. The investigation of dual positions by Rubio et al., Liu had introduced SPO & DPO methods, the improvement of the latter done by Redonnet et al. together with Monies et al.
- From 2001 to 2011 is optimization of work. Two major publications stress this part which are Lartigue et al. and Bedi et al. Introduction about concept in building different enhancements of envelope surfaces, which are optimization of rotating axis, incorrect computation between theoretical surface and envelope and connecting the cutter radius to an error. The second proposed tangential positioning was improved by Menzel et al. and Jerar and Lid. Other techniques of optimization also were presented by Gong et al. The latter was extended by Zhu and Xing.

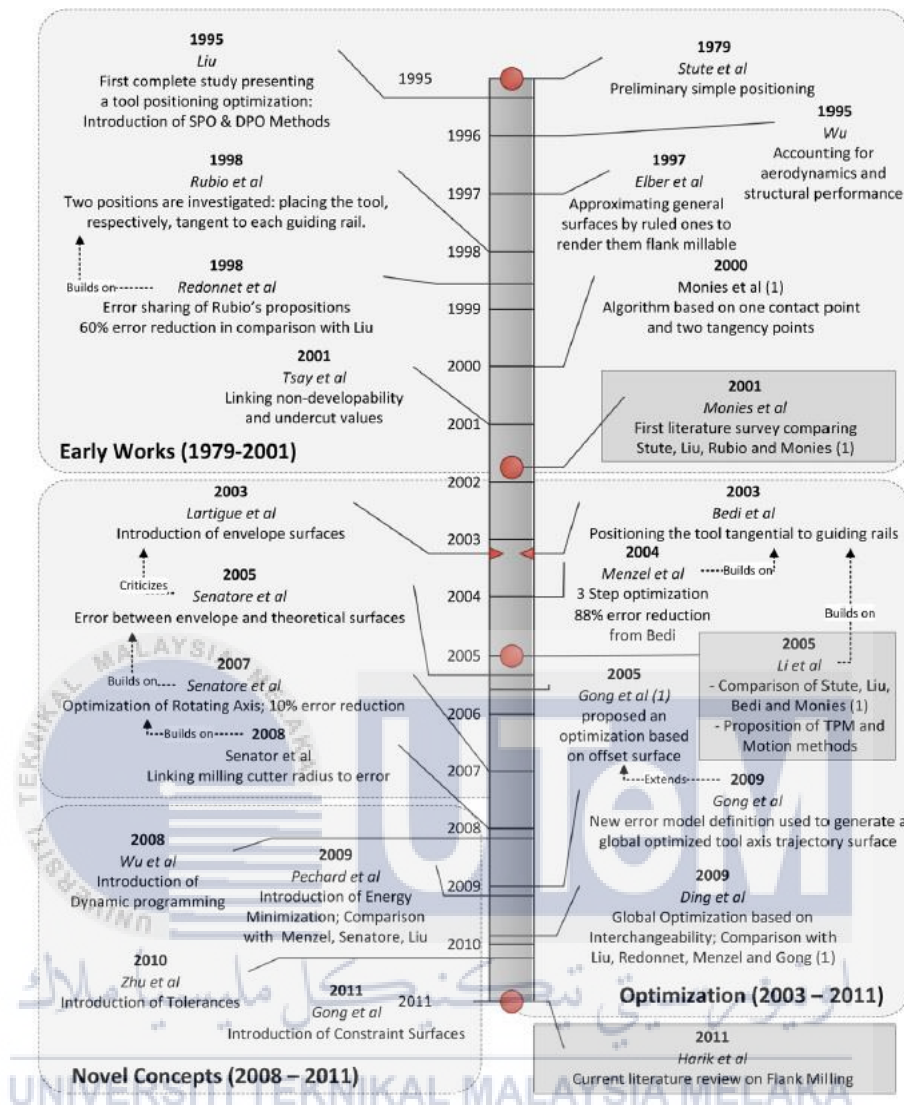


Figure 2.15: References of Main Generation of Flank Milling Toolpath.

(adapted from Ramy F.Harik et al. (2013))

At first stage, more general sweep milling is used. Studies of numerical control in machining free form surfaces was started where techniques of interpolation were developed to ensure laconic, machining accuracy and safe of curved objects. Trajectories has been improved based on the geometry inputs (chordal deviation and scallop heights) rather than aimed abstract algebraic quantities. Some conclusions can be done from this review of the literature which are:

(1) the development of optimal flank milling tool path is focused by most paper. To reduce errors of geometrical machining between the designed surface and the tool

envelope surfaces is the objective.

(2) On ruled surfaces, flank milling technology are widely used due to cutting tools are all ruled surfaces. However, to flank milling general free-form surfaces, which closed to ruled surfaces, some methods have also tried. At this stage, machining mistake from tool trajectories planning maybe negligible.

(3) To reduce machining error simultaneously and improve machining strip width are the aims of the flank milling. This idea can be extended to more general free-form surface than quasi ruled surfaces or more ruled surfaces. Things to be concerned of this idea is way to determine suitable machined surface by using flank milling technology. Extend flank milling to more common cutting tools for many common surfaces is meaningful to enhance machining efficiency.

(4) After comparison between flank milling with end milling, result shows that flank milling has higher cutting forces. This result may cause extra errors is generated and lead to more cutting tools deformation. There are some other relevant factors which apart from the cutting force, such as the parameters and tool geometry of flank milling. In future work, more attention will be paid in optimization of the machining parameters which based on the roughness of machined surface or cutting force.

This study contributes to our knowledge by addressing an important issue which is machining accuracy. A finding was published about improvement of machining accuracy in five axis flank milling of ruled surfaces has been published in 2008. Focus studies in this finding is improving the tool path planning in machining the ruled surface. The objective of the present work paper is to develop a new adjustment method in improving machining accuracy of tool path in five-axis flank milling of ruled surfaces. (C.H. Chua, 2008). Since 1980s, Five-axis machining has received many attention for research community and the industry area and the research community. Five-axis machining offers numerous advantages compared three-axis machining, example fewer setups and higher production rate with two extra rotational degrees of freedom. Therefore, five-axis machining is widely used to manufacture complex geometries like turbine blade, impeller and moulds. There are two different types milling methods for five-axis CNC machining which are point milling and flank milling. The cutting edges near the end of a tool used in removing material is one methods of milling - point milling. For flank

milling, the side face of a cutter is used in the machining process. An appropriate is selected according to the cost, workpiece surface finish, geometry, surface finish and machining time. The milling process that suitable for the part consisting of ruled surfaces is flank milling. In practice, CAD/CAM systems is used in planning the tool path of multi-axis machining because of its complexity. However, the resultant machining accuracy and the capability of the machine tools are not considered in the systems of this findings. In this finding, author investigates the effect of the sampling time in NC controller on five-axis flank milling of ruled surfaces to solve/overcome the problem. The machining errors bring by linear interpolation between cutter locations has been focused through this finding. Based on a bisection method, an adjustment rule of feedrate that automatically controls the tool motion at feedrate-sensitive corners is proposed. Therefore, this step helps in improving the machining accuracy and limiting the maximum machining errors. Verification the effectiveness of the suggested method which mention above, experimental cuts are carry out on different ruled surfaces. This method can enhance the machining quality in five-axis flank milling in both operation and simulation is supported by the result shows. CMM (coordinate measurement machine) is indicated to show that the measurement result of both machined parts for the machining error in the feedrate-sensitive areas on the machined surfaces is significantly reduced. The errors occur in this finding can be reduced by further implementation process. Figure 2.13 shows graph about error-measuring result of surface a and figure 2.14 shows finished part after undergo machining process.

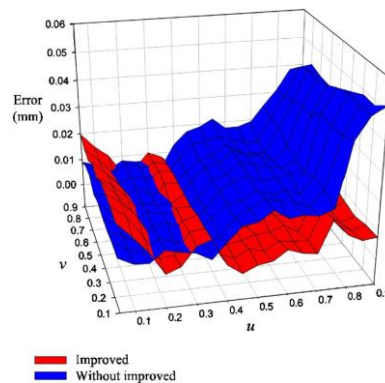


Fig. 2.16: Surface A Error-measuring Result.

(adapted from C.H. Chua et al. (2008))

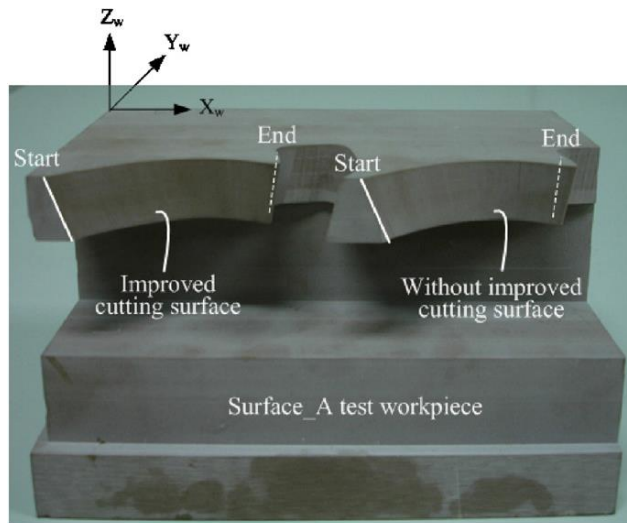


Figure 2.17: Finished Part

(adapted from C.H. Chua et al. (2008))

2.4 Turbine blade

Rong Zhang et al. (2015) identified toolpath generation of a mesh blade according linear morphing cone by five-axis finishing toolpath. In aero-engines, blisk is an essential component. There is one critical machining requirement for blades on blisk by using five-axis tool path is boundary-conformed which use to maintain good aero-dynamic performance. Most of the existing popular toolpath generation methods are unable to meet the requirement for a blade model as a point cloud or mesh. A study of five-axis toolpath generation method for a discrete blade on blisk is presented to address/solve this issue. (Rong Zhang et al. ,2015) Linear Morphing Cone(LMC) which sets the boundary of the blades the constraint is an idea that first proposed. Experiments on discrete blades are carried out by using the proposed toolpath generation method. The results of experiments show that the generated toolpaths are both boundary-conformed and uniform. This finding proposes a five-axis tool path generation method for a mesh model blade on a blisk which based on a concept Linear Morphing Cone(LMC). The special property of boundary-conforming and meets the specified cusp height requirement at the sometime is important factor of a concept Linear Morphing Cone

(LMC). For meshed blade machining on blisk, the tool path generation method is very useful. Figure 2.15 and figure 2.16 illustrate tool path of meshed blade 1 and meshed blade 2.

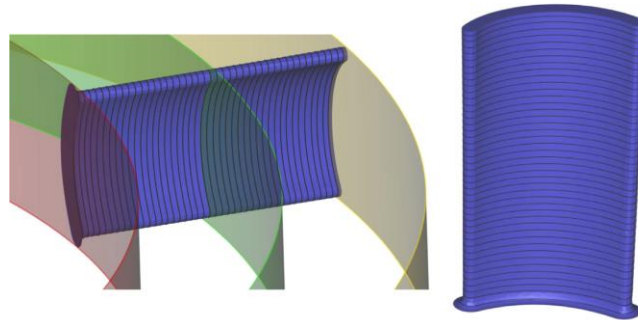


Figure 2.18: (a)Cone defining the boundary of meshed blade1;
(b)generated toolpath.

(adapted from Rong Zhang et al. (2015))



Figure 2.19: (a) Cones defining the machining region for meshed blade2;
(b)the generated toolpath for the given region

(adapted from Rong Zhang et al. (2015))

2.5 Accuracy of Five-axis machining

A technical information has been examined influence of position measurement on accuracy in five-axis machining. (Dr. Johannes Heidenhain GmbH, 2011). In the competition for machine tools, Productivity and accuracy are two important attributes. In the purpose of increasing productivity, five-axis provides considerable potential. Five-axis machining permits higher metal removal rates than three-axis machining in

many cases. As a reduction of time required for resetting, it may lead to significantly shorten production. Machines need to provide high accuracy over the entire working space as there is significantly larger traverse ranges of linear axes which usually required for 5-axis machining. Moreover, attainable workpiece accuracy can be greatly influenced by the two rotary axes in a five-axis machine tool. In many areas of metal-cutting machining by now, five-axis machining has become indispensable. There are clear economic advantages result of the capability to machine workpieces completely in one setup. One of the advantage is the door-to-door time of a part can be significantly reduced and this action may dramatically increase part accuracy. The cutting speed at the tool tooth can be held within narrow limits even on complex contours by five-axis simultaneous machining. The attainable surface quality has significant benefits due to this setting. Low weight and high strength are important factor for the space industry and aeronautics, five-axis machining opens new opportunities for reducing weight without loss of component strength in structural components. The inclination of the tool can be adjusted with respect to the workpiece surface in five-axis machining. Precise position measurement in the feed axes directly at the moving machine elements is imperative in preventing faulty workpieces. Requirements on the accuracy of the feed drives can be stringent by precise machining with five simultaneously moving feed axes place. The errors of the additionally required tilting axes and rotary can lead to significant limitations on workpiece quality which depending on the type of position measurement.

2.6 Aluminum

Below shows characteristics of aluminium alloys by ESAB KNOWLEDGE CENTER (2014).

1xxx Series Alloys are non-heat treatable with ultimate tensile strength of 10 to 27 ksi. The pure aluminum series is often referred as 1xxx series alloys required to have 99.0% minimum aluminum. These alloys are selected primarily when considered for fabrication due to their superior corrosion resistance such as excellent electrical conductivity as in

bus bar applications or in specialized chemical tanks and piping. However, these alloys would seldom be considered for general structural applications and have relatively poor mechanical properties.

2xxx Series Alloys are aluminum / copper alloys as copper additions ranging is from 0.7 to 6.8%. These alloys are high performance and high strength alloys that are often used for aircraft and aerospace applications. 2xxx series alloys have excellent strength within a wide range of temperature. Together with high strength 2xxx series filler alloy, these base materials are often designed to match their performance. However, 2xxx series alloys are sometimes can be welded with the 4xxx series fillers which consist silicon or silicon and copper, dependent on the application and service requirements.

3xxx Series Alloys are non-heat treatable and are type of the aluminum / manganese alloys (manganese additions ranging from 0.05 to 1.8%). 3xxx series alloys have good corrosion resistance although these alloys have moderate strength. Besides, 3xxx series alloys have a good formability and are suitable used at elevated temperatures. Currently, 3xxx series alloys are one of the major component for heat exchangers in vehicles and power plants. Another uses of 3xxx series alloys are pots and pans. Although 3xxx series alloys have moderate strength but these alloys are often preclude from consideration for structural applications.

4xxx Series Alloys are the aluminum / silicon alloys as silicon additions ranging is from 0.6 to 21.5%). Silicon can reduces its melting point when added to aluminum and it may improves its fluidity when molten. A number of these silicon alloys have been designed to have additions of magnesium or copper although silicon is independently in aluminum which is non-heat treatable which provides them with the ability to respond favorably to solution heat treatment. Basically, as 4xxx series alloys are heat treatable filler alloys that only used when a welded component is to be subjected to post weld thermal treatments.

5xxx Series Alloys are the aluminum / magnesium alloys. In 5xxx series alloys, magnesium additions ranging is from 0.2 to 6.2%. These alloys have the highest strength among the non-heat treatable alloys. Due to these alloy series are readily weldable, they

are used for a wide variety of applications such as transportation, shipbuilding, bridges, pressure vessels and buildings. With more than 3.0% magnesium in alloys of this series, these alloys are not recommended for elevated temperature service above 150 deg F due to their potential for subsequent susceptibility and sensitization to stress corrosion cracking. On the other hand, base alloys with less than approximately 2.5% magnesium with the 5xxx or 4xxx series filler alloys are often successfully welded. Aluminum 5052 is generally recognized as the maximum magnesium content base alloy. This alloy is not recommended to weld material in this alloy series because of problems associated poor as-welded mechanical properties and associated with eutectic melting. To generally match the base alloy composition, the higher magnesium base materials are only welded with 5xxx filler alloys.

6XXX Series Alloys are the aluminum / magnesium - silicon alloys. Magnesium and silicon are added of around 1.0% in 6xxx series alloys. These alloys are found widely throughout the welding fabrication industry, incorporated in many structural components and used predominantly in the form of extrusions. , To provides this material its ability to become solution heat treated for improved strength, addition of magnesium and silicon to aluminum produces a compound of magnesium-silicide. They should not be arc welded autogenously as these alloys are naturally solidification crack sensitive. 6xxx series alloys are usually welded with both 4xxx and 5xxx filler materials which dependent on service and application requirement.

7XXX Series Alloys are heat treatable alloy with ultimate tensile strength of 32 to 88 ksi. These alloys are the aluminum / zinc alloys. Additions of zinc from ranging 0.8 to 12.0% can comprise some of the highest strength aluminum alloys. 7xxx series alloys are often used in high performance applications such as competitive sporting equipment, aerospace, and aircraft. This series incorporates alloys similar as the 2xxx series of alloys which are considered unsuitable candidates for arc welding, and others, which are often arc welded successfully. Aluminum 7005 is the commonly welded alloys in this series which are predominantly welded with the 5xxx series filler alloys.

Designation system of wrought aluminium alloy has been shown through figure 2.20 while figure 2.21 display different advantage of aluminium with different combination of material.

WROUGHT ALUMINUM ALLOY DESIGNATION SYSTEM

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

Figure 2.20: Designation System of Wrought Aluminium Alloy

Sources: <http://www.alcotec.com/us/en/education/knowledge/techknowledge/understanding-the-alloys-of-aluminum.cfm>



Figure 2.21: Different Advantage of Aluminium With Different Combination of Material.

Sources: <http://www.aluminiumdesign.net/design-support/aluminium-alloys/>

CHAPTER 3

METHODOLOGY

In this section, planning is important factor to ensure that process flow undergo smoothly. Flow chart gives briefly view of step/ procedure. Elaboration of each step act as guideline of the project to ensure that project can be done successfully. Flow chart is included in this section. Main instrument which will be use in this project are CATIA V5 (main CAD/CAM software) and 3D Scanner. In CATIA V5, workbenches used are sketcher, part design, assembly design and advanced machining. Each workbench performs different function in this project. Accuracy of machined part will be analyzed by using 3D Scanner which available in Rapid Prototyping Lab. Function of flow chart is act as guideline of the project. Material used in this project is Aluminium 6xxx series.

Period for completing final year project (FYP) divide into two phase which is phase 1(fyp1) and phase 2(fyp2). Phase I includes introduction of the project, literature reviews and flow of this project (methodology) and finding CAD model of turbine blade. While phase II include CAM program preparation and machining process, discussion, conclusion and further recommendation of this project.

3.1 Project planning

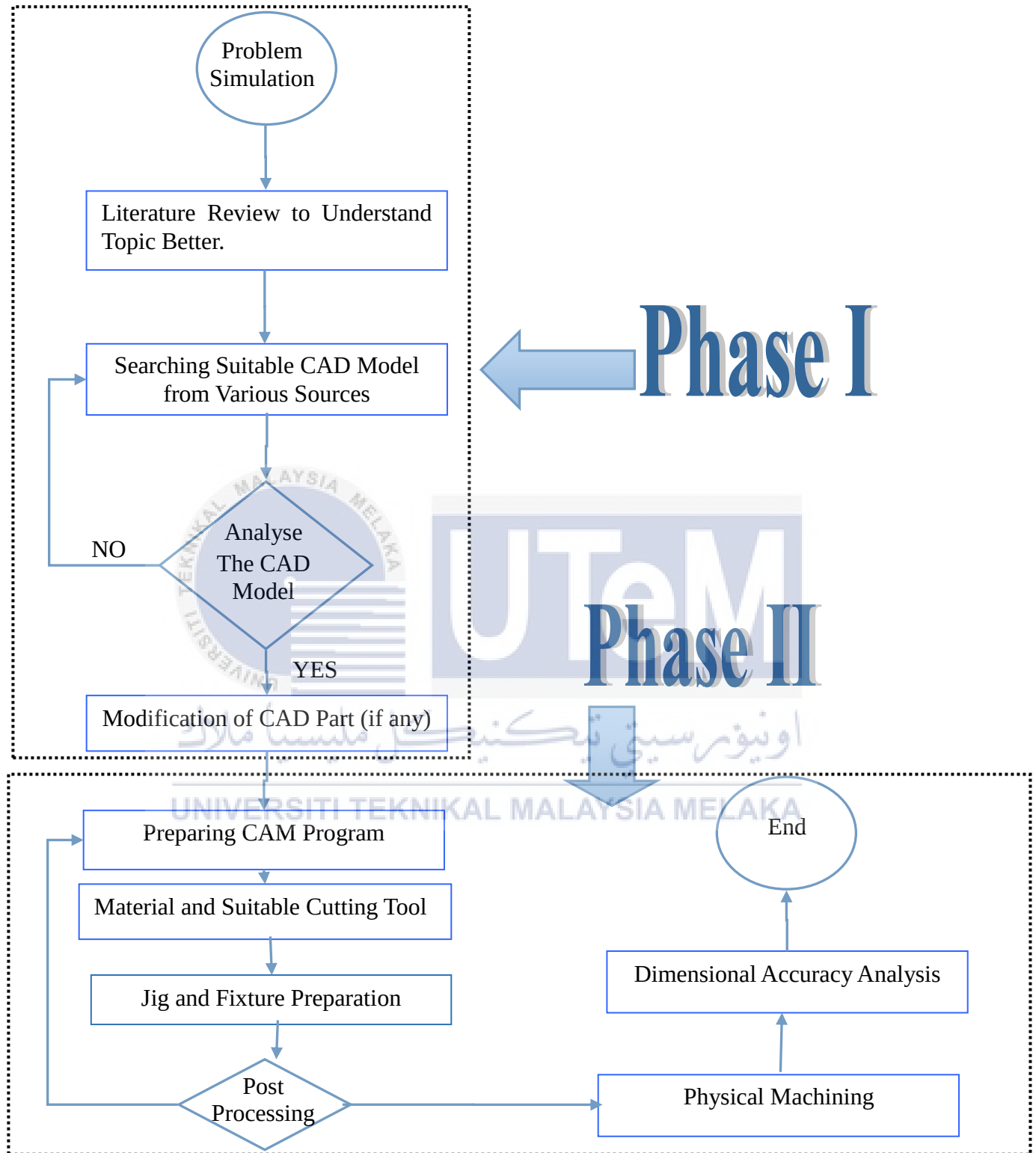


Figure 3.1: Flow Chart of Methodology

A. PROJECT PLANNING																																				
Listdown the main activity for the project proposal. State the time frame needed for each activity.																																				
	2015/2016_																		2016/2017_																	
Project Activity																																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1) Problem formulation																																				
2) Literature review to understand the topic better																																				
3) Project proposal document																																				
4) Searching suitable CAD model from various resources.																																				
5) Verification of the CAD model.																																				
6) Modification the CAD part																																				
7) Prepare material and suitable cutting tool.																																				
8) Preparation of CAM program.																																				
9) Presentation of proposal																																				
10) Jig and Fixture Preparation																																				
11) Post processing																																				
12) Physical machining and analysis																																				
13) Dimensional Accuracy Analysis																																				
14) Document or repeat verify																																				
15) Presentation of project																																				

3.2 Phase I

3.2.1 Problem Simulation

Before starting project, problem simulation is done. Various problems that exist in the market and society have been discussed in details. One of the problems is manufacturing defects also one of the leading cause of blade failure. Defects occur when blades is not manufactured according to the design specifications based on drawing / CAD model. Besides, inaccuracies in blade geometry and positioning may cause untimely blade failure. Tight tolerances apply to both the geometry and alignment of turbine blades to ensure optimum blade position and aerodynamic operation.

Above problems can be solved by validated five-axis machining tool path using CATIA V5 and using Aluminum 6063 in the physical machining. Dimensional accuracy of the machined part (turbine blade) is verified by 3D Scanner.

3.2.2 Literature Review to Understand Better The Topic.

All information and journal related are searched for better understanding about project title. Journals which related with five-axis machining tool path machining, turbine blade, aluminium, flank milling and accuracy of five-axis machining are searched to help to come understand deeply and give clear view about project title. In this stage, proposal is done based on all information available. Proposal is a plan or suggestion in formal form which put forward for consideration or discussion by others. Problem statement, background, objective, expected result and methodology are listed out in proposal. Planning is done to give an idea and guideline of project to run smoothly and achieving the goals of projects.

3.2.3 Searching Suitable CAD Model and Verification.

In this section, turbine blade CAD model is the main focus. Firstly, turbine blade CAD models universal formats in format of STEP file, IGES or STL are searched. File which can be open directly through CATIA V5 is file CAD part. STEP (standard exchange of the product model) is most stable CAD file while IGES (initial graphic exchange specification) has limitation which is only saving of surface part. STL (standard triangle language) is based CAD file while suitable for 3D printing or 3D model. Currently, there are another CAD model format which is Parasolid which is most stable model but this format required license to open the file. CAD model maybe in surfaces form and cloud points. Step which is CAD model can be obtained from various sources such as GRABCAD, Google searching, local company etc. There are various types of turbine blade CAD model from different field such as turbine jet engine, gas turbine blade, wind turbine blade and aerospace turbine blade which are in different angle and different number of blades/blisks. Aerospace turbine blade CAD models which can be opened by CATIA V5 were in the first to be considered. CAD part format can directly open through CATIA V5. Although IGES, STEP and STL format can be opened through CATIA V5 but they need to save in other format for modification process such as change dimension or making stock of the CAD part. After searching, elimination process is done to ensure suitable aerospace turbine blade is selected. Suitable turbine blade CAD model is selected based on machine limitation and cutting tools available in the lab. Figure 3.2 shows turbine blade that have been selected.

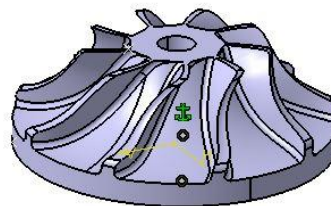


Figure 3.2: Selected CAD Model -Turbine Blade

Discussion and verification are done with advice of adviser. Modification for selected CAD model is there is any requirement after discussion with adviser. One of the reasons was du of modification is limitation of equipment available in the lab such as type of machine used, cutting tools and fixtures. Example cutting tool available in the lab for end mill was minimum 3mm and maximum 16mm while limitation of ball mill was 6mm. CAD model Modification is done through CAD part of CATIA V5. CAD model has been resize based on available raw materials. Table 3.1 category scaling ratio based on different plane.

Table 3.1: Scale Ratio of CAD Model

Modification of Plane	Scaling Ratio
YZ plane	0.8
ZX plane	0.8
XY plane	0.7

After modification (if necessary), dimension of CAD part /model is measured and list down. Those dimensions are very useful in doing CAM program. Before proceed to assembly process, stock is created and axis system is set at center of stock. Dimension of stock is 100mm x 100mm x 50mm. Hole will be made in order to clamp raw material on suitable jig. Drilling process and tapping process have been done for clamping process. Dimension of hole is diameter 8.5mm with deep 10mm. M10 is used in tapping process. The setting of axis system to ensure machining process can be done smoothly. Figure 3.2 figured out CAD model (Turbine Blade) with combination of stock and plane system.

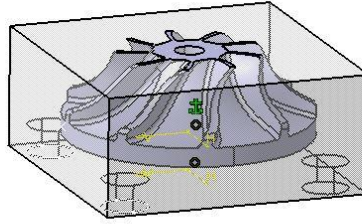


Figure 3.3: CAD Model (Turbine Blade) with Stock and Plane system

3.2.4 Assembly process of CAD part

Plane system is created with three plane (home, approach and retract) and one point (start point). Each plane is created with different distance based on xy plane, such as home = 100mm, rapid = 30mm and approach = 10mm. Start point is placed in home plane. Assembly process for CAD part/ model and plane system is done in assembly process workbench. Figure 3.4 shows plane system used in this part operation.



Figure 3.4: Plane System

Axis system of CAD part is assembled with axis system of plane system. Assembly process helps in giving visual view before preparing CAM program. Through assembly process, cutting plan and cutting strategy can be planned through

assembly process. Example through assembly process, position of first position of tool during machining process is known. Last preparation before preparation of CAM program is determining type and range of cutting tool which available in the CNC laboratory. Figure 3.5 related with assembly CAD model and plane system

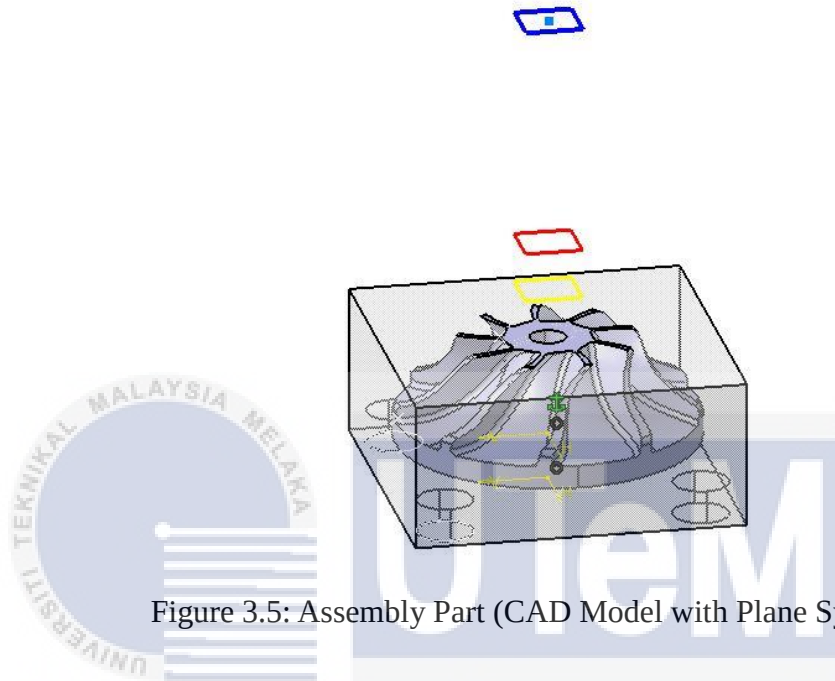


Figure 3.5: Assembly Part (CAD Model with Plane System)

3.3 Phase II

3.3.1 Material and Suitable Cutting Tool

Preparation of raw material and suitable cutting tool are next step after setting CAM program. Based on goal of project, aluminum 6063 will be used as raw material in order of machining turbine blade. There is different type of cutting tool with different material which are tungsten, carbide, high carbon steel and etc. Different type of cutting tools can be used in different conditions. Example, carbide cutting tool can be used in high speed cutting process. As mention above, surface roughness is not the part of the research's aims, therefore high speed machining is not necessary. Range of end mill tool which available in CNC lab is 3mm to 16mm

while limitation of ball mill tool is 6mm. Cutting diameter, overall length, reached length, shank diameter, and cutting length of tool need to be determine before selection of suitable cutting tool. After getting dimension of cutting tool, it is selected based on dimension of CAD model and machining process that plan to be used. Different diameter of tool will be used in different machining process. End mill with diameter 10mm and 6mm are selected in this project. End mill will be used in roughing process and multi-axis flank contouring. Tool that will be used in multi-axis sweeping is ball mill with diameter 6mm. Besides, ball mill with diameter 6mm also will apply during isoparametric process. Table 3.2 provided detail of cutting tools used in this research. One the other side, figure 3.6 and figure 3.7 shows information related with cutting tools.



Table 3.2: Detail Dimension of Selected Cutting Tool

Tool	Dimension	Process involved
Flat End Mill diameter 10mm	$D_b = 10\text{mm}$ $D = 10\text{mm}$ $L_c = 27\text{mm}$ $L = 75\text{mm}$ $l = 32\text{mm}$	✧ Roughing
Ball Mill diameter 6mm (short shank)	$D_b = 6\text{mm}$ $D = 6\text{mm}$ $L_c = 10\text{mm}$ $L = 51\text{mm}$ $l = 15\text{mm}$	✧ Multi-axis sweeping ✧ Isoparametric
End Mill diameter 6mm (4 flutes)	$D_b = 6\text{mm}$ $D = 6\text{mm}$ $L_c = 17\text{mm}$ $L = 60\text{mm}$ $l = 20\text{mm}$	✧ Roughing ✧ Multi-axis flank contouring

References: D_b = shank diameter, D = cutting diameter, L_c = reach length, L = overall length and l = cutting length.

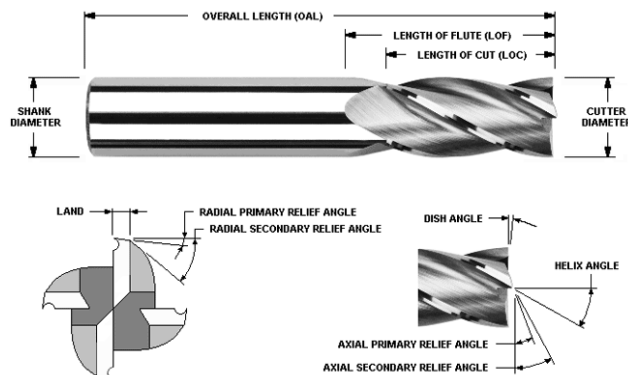


Figure 3.6: Detail Regarding Cutting Tool

http://www.harveytool.com/secure/Content/Images/terminology_end_mill.gif



Figure 3.7: List of Cutting Tool Used

3.3.2 Preparation of CAM Program

Assembly product will be open through advanced machining workbench. CAM program is prepared through advanced machining workbench. First step of CAM program is setting part operations which include type of machine, machining axis (axis system), part to be machined and stock for visual simulation. In this project, jig also been selected as reference in simulation process. Figure 3.8 gives briefly view about setting of part operation.

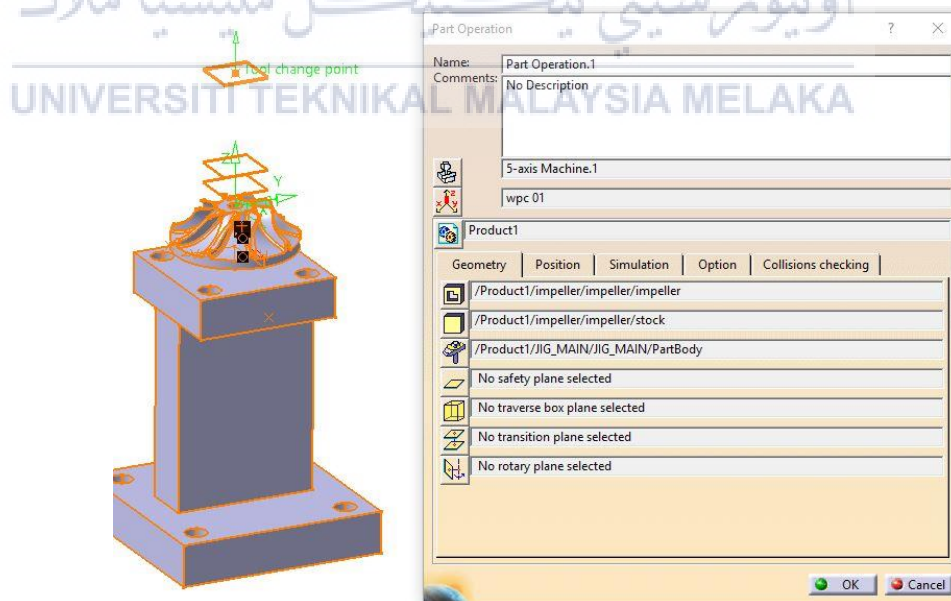


Figure 3.8: Setting of Part Operation

Tools are selected after setting off part operation based on analysis that has been done. After setting up of cutting tools, suitable machining process such as isoparametric, roughing, multiple-axis flank machining and multi-axis sweeping process are picked. Different cutting tool is used for different machining process.

End mill 10mm and end mill 6mm is used for both roughing and multiple axis flank machining. In multi-axis sweeping process, ball mill 6mm is used. Roughing is first step to be done after getting rough part of turbine blade. Double roughing process is required for this project to reduce the materials removal though each roughing process. Multi-axis flank contouring is used in machining blade of turbine blade. Multi-axis sweeping suitable for removing space/ part between two blade. Outer shape of turbine blade can be done by isoparametric. Flow chart shows in figure 3.9 provide widely view about sequence of manufacturing process.



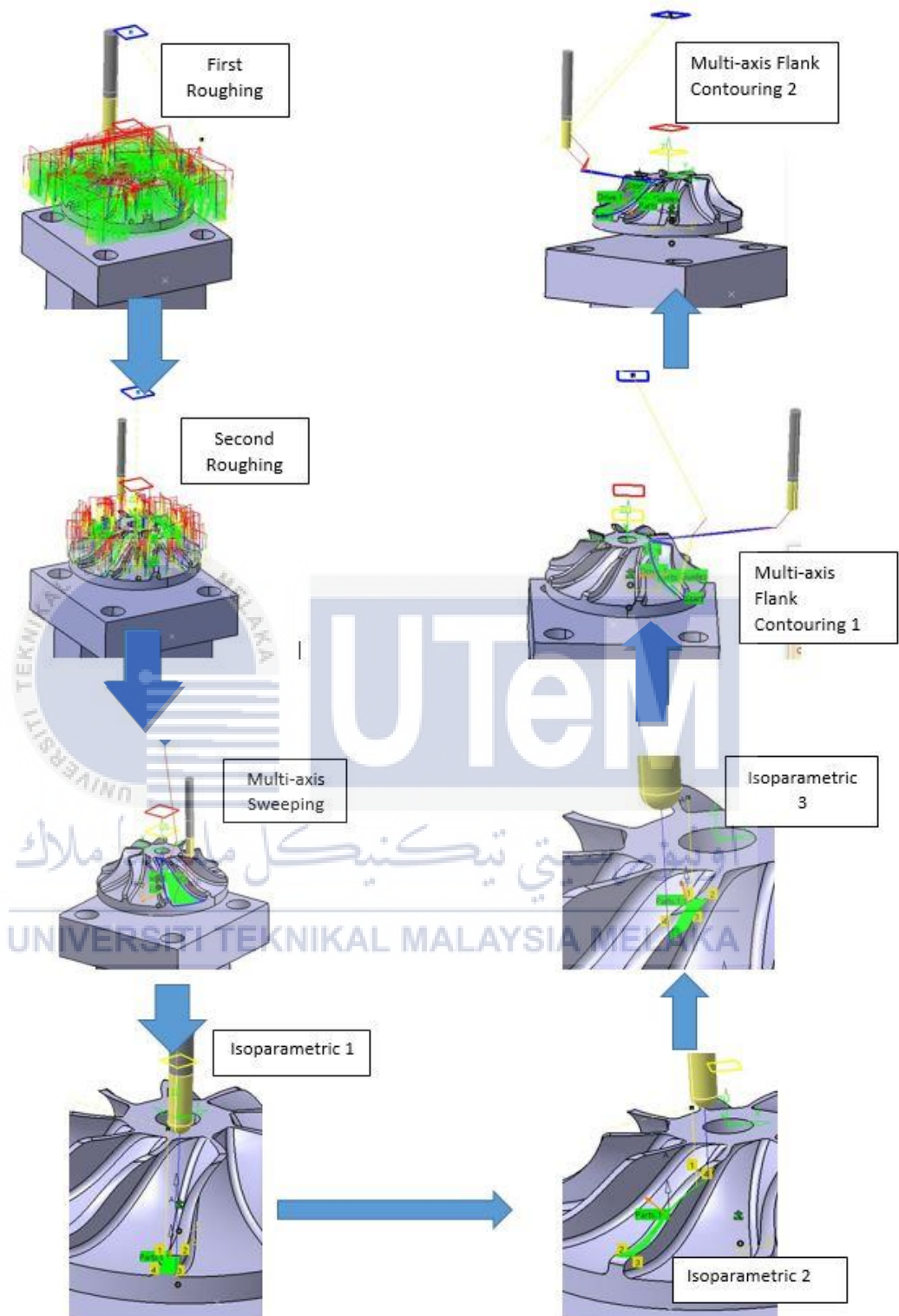


Figure 3.9: Flow Chart of CAM Machining Process

Above process flow shows process in manufacturing one blade. As all the blades are identical with each other, same manufacturing processes are used to machine other eight blades. Each process has different pages of setting. There is machining strategy, machining geometry, cutting tool, machining parameter and macro setting. Under machining process, cutting tool which shows lighting symbol is not allowed. This symbol shows that tool used are not didn't define properly under selected machine.

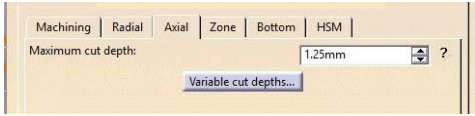
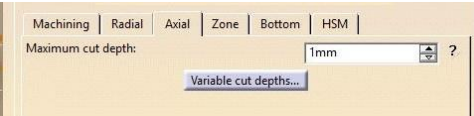
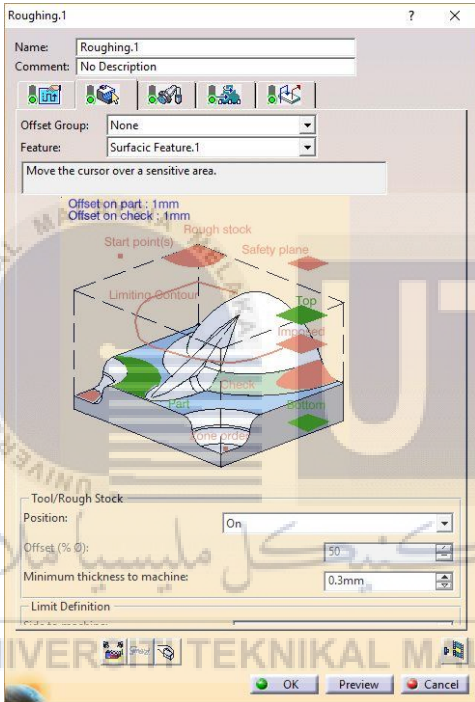
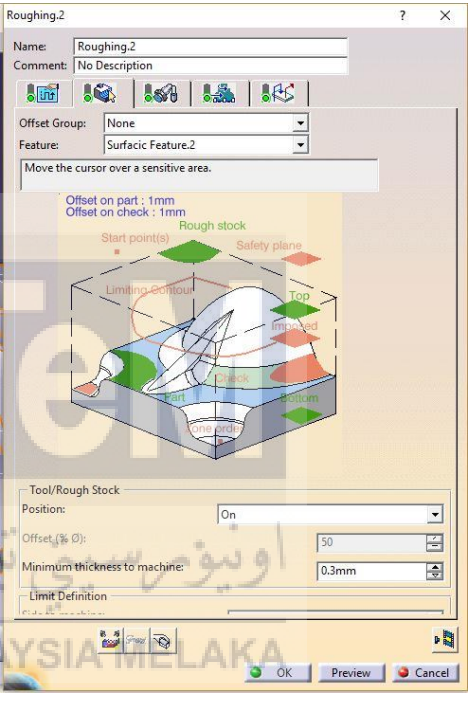
Machining geometry is one of important setting as it may affect surface which involved in machining process. Machining strategy involve in setting maximum depth of cut, cutting path etc. Strategy used may affect tool life. Macro setting is set to prevent cutting tool damage CAD part/ workpiece. Detail setting of each process used in CATIA V5 will be shown below by figure through print screen. Different types of material have different machining parameter. In this project, value of feedrate and spindle speed are set based of type of material used => aluminum. Research is done before setting suitable feedrate and spindle speed. As surface finish is not objective of this project, therefore high speed machining is not required for machining turbine blade.

3.3.2.1 Process Roughing

First machining process is roughing process. Roughing process helps in removing unwanted part roughly (left 1mm for part). There were two roughing processed in this project which are first roughing and second roughing. End Mill with diameter 10mm is used in first roughing while second roughing is done by End Mill diameter 6mm. Tool used (3rd tab) has mention before while macro setting (5th tab) remained the same though two roughing process. Page four (machining parameter) is set based on machine capability. Stock of second roughing is part that have been machined in process roughing1. Detail setting of parameters such as machining strategy and geometry strategy can be obtained through table 3.3. Figure 3.10 and figure 3.11 provide clearly view

regarding simulation of first roughing and second roughing process.

Table 3.3: Setting of Roughing Process

First Roughing	Second Roughing
1. 1st tab (Strategy strategy) 	1. 1st tab (Strategy strategy) 
2. 2nd tab (Geometry strategy) 	2. 2nd tab (Geometry strategy) 

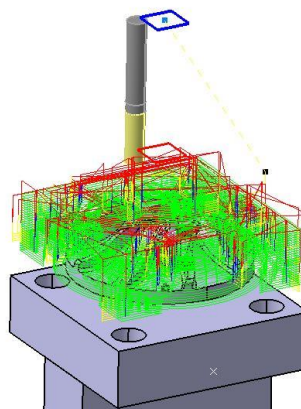


Figure 3.10: First Roughing

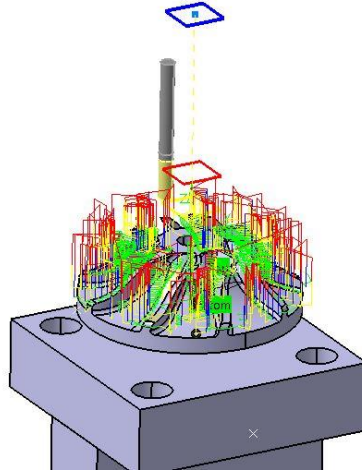


Figure 3.11: Second Roughing

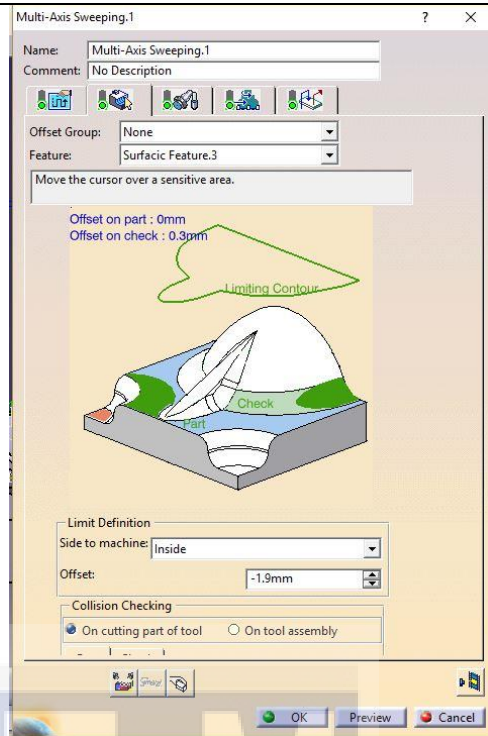
3.3.2.2 Process Multi-Axis Sweeping

Multi-axis sweeping is a process done after roughing process. Process multi-axis sweeping is applied in the space/ gap between two blades. From visual view, angle of each blade is similar but due to different setting of view direction, machining direction and start direction, lead and tilt angle for some blades is not similar with others. Besides, there are slightly different for each approach and retract in macro setting. In geometry strategy, identical part is selected with different limit contour. Offset is one of important issue in this process as it helps in allowing part undergoes machining process. Below table 3.4 shows few strategies which are machining strategy, geometry setting and macro setting. Besides, another table which is table 3.5 shows lead and tilt angle for each space between blades. Labeling of spaces are based on name of each multi-axis sweeping process. Figure 3.12 is labelling of number on space between blades based on labelling of Multi-axis sweeping.

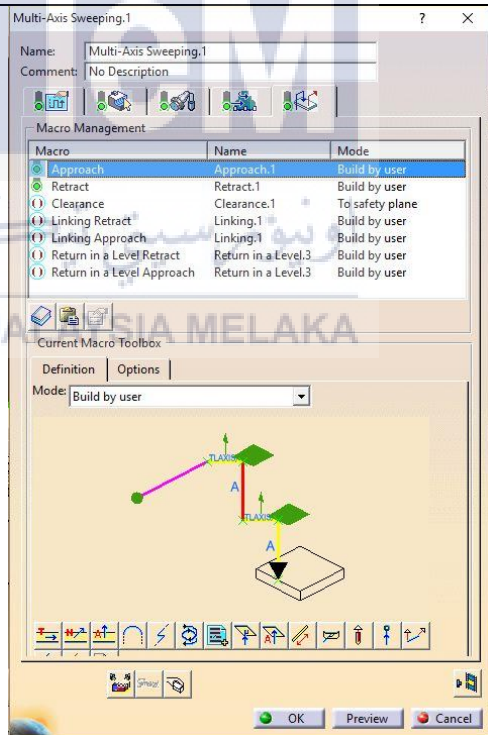
Table 3.4: Setting of Multi-axis Sweeping

Strategy	Figure
1. 1 st tab (Machining Strategy)	The figure displays two screenshots of the 'Multi-Axis Sweeping' dialog box in a CAD software. The top screenshot shows the 'Machining' tab selected, with the following settings: Name: Multi-Axis Sweeping.1, Comment: No Description, Scallop height: 0.01mm, Distance between paths: 5mm, Number of paths: 1, and Stepper side: Right. The bottom screenshot shows the 'Tool Axis' tab selected, with the following settings: Name: Multi-Axis Sweeping.1, Comment: No Description, Tool axis mode: Lead and tilt, Guidance: Fixed lead and tilt, Lead angle: -8deg, Tilt angle: -13deg, Min lead angle: -89deg, and Max lead angle: 89deg. Both screenshots include a 3D model of a swept surface and a diagram of the tool axis directions (V, S, A).

2. 2nd tab (Geometry Strategy)



3. 5th tab (Macro Setting)



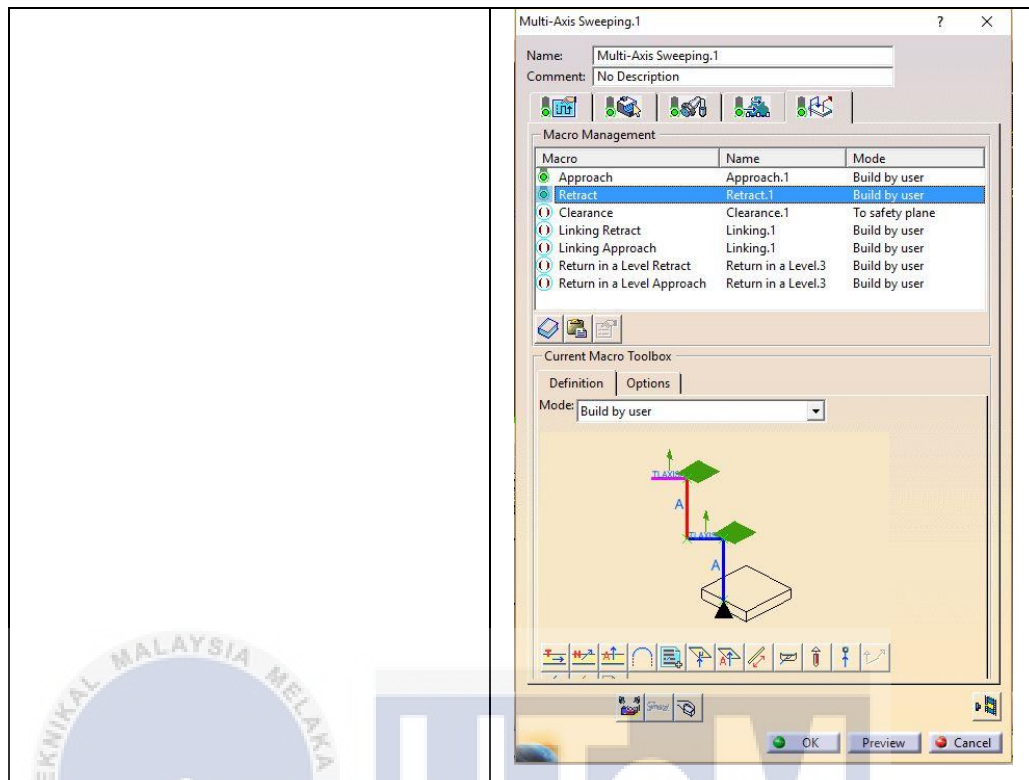


Table3.5: List of Lead and Tilt Angle for Each Multi-Axis Sweeping.

Multi-axis sweeping	Tilt Angle (degree)	Lead Angle (degree)
Multi-axis sweeping 1	-8	-13
Multi-axis sweeping 2	-5	-10
Multi-axis sweeping 4	-5	-15
Multi-axis sweeping 5	5	10
Multi-axis sweeping 6	5	-10
Multi-axis sweeping 7	5	-10
Multi-axis sweeping 9	5	10
Multi-axis sweeping 11	5	10
Multi-axis sweeping 12	-5	10

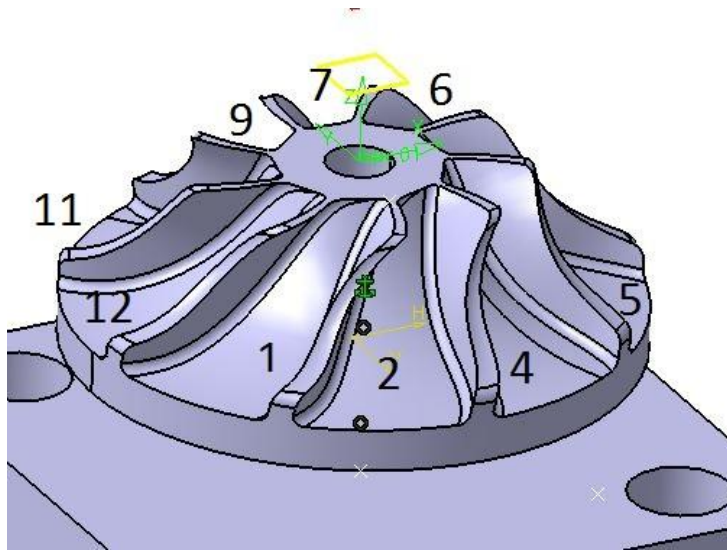


Figure 3.12: Labelling Number on Space between Blades based on Labelling of Multi-axis sweeping

3.3.2.3 Process Isoparametric

After two multi-axis sweeping and roughing process, isoparametric process is introduced. There are three isoparametric set in this project. Those isoparametric have different geometry parameter. Different surface has been select in different type of isoparametric. This statement can be proved through simulation of process isoparametric. As nine blades of turbine blade has same identity, therefore only one blade is used as example in the project. Same with roughing process, tool (3rd tab) has been selected before this process. Different tool and parameter is good message. Table 3.6 display simulation of isoparametric on different machining surface. Below table 3.7 shows page/setting that have been modified in process isoparametric such as machining strategy, geometry setting and macro setting. Those strategies have been same for isoparametric top, isoparametric center and isoparametric bottom.

Table 3.6: Tool Path of Isoparametric on Different Machining Surface

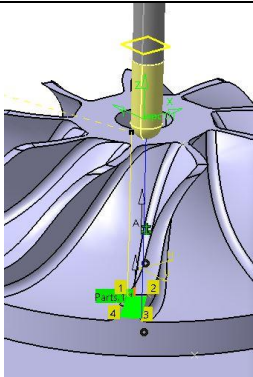
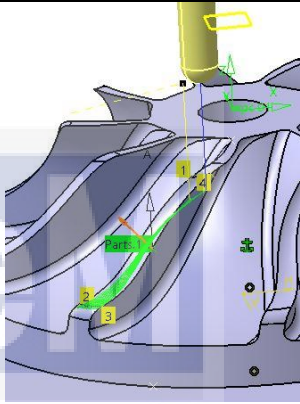
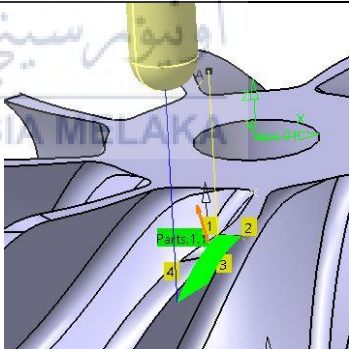
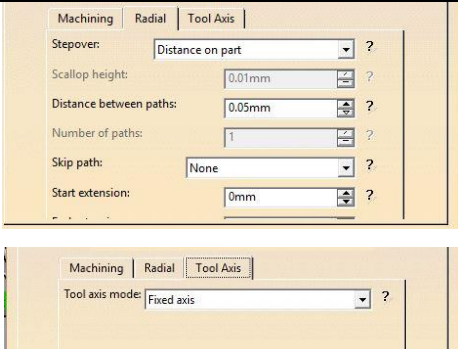
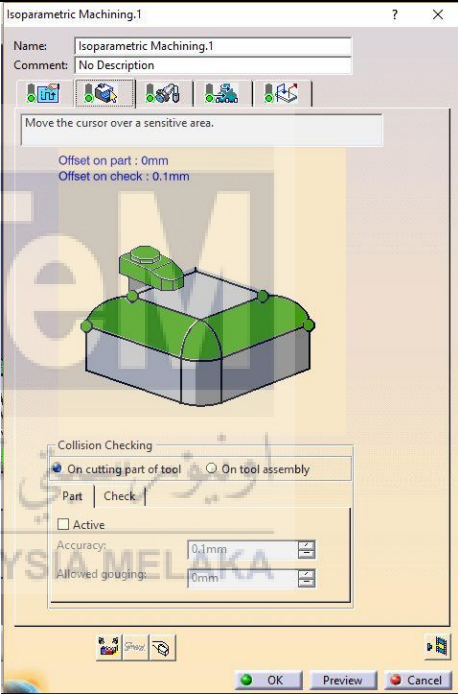
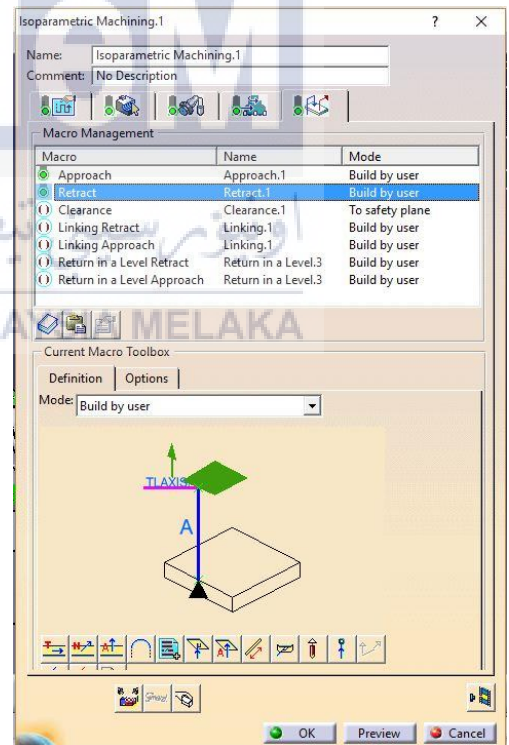
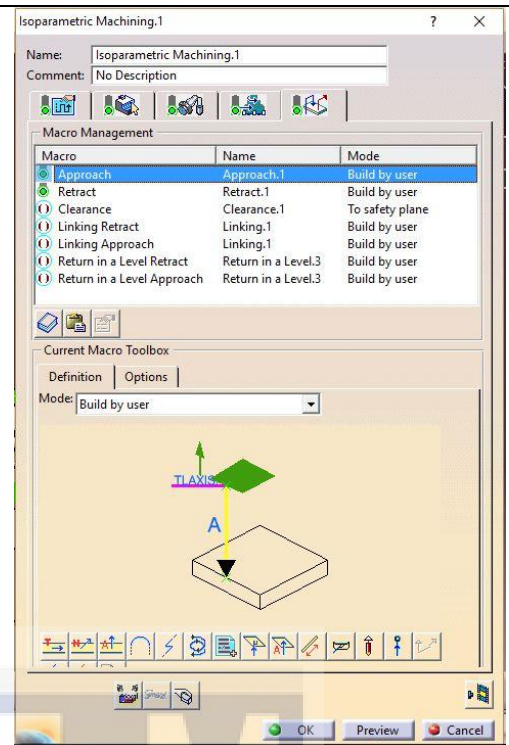
Isoparametric	Simulation figure
Isoparametric top	
Isoparametric center	
Isoparametric bottom	

Table 3.7: Setting of Isoparametric

Strategy	Figure
1. 1 st tab (Machining Strategy)	
2. 2 nd tab (Geometry Strategy)	

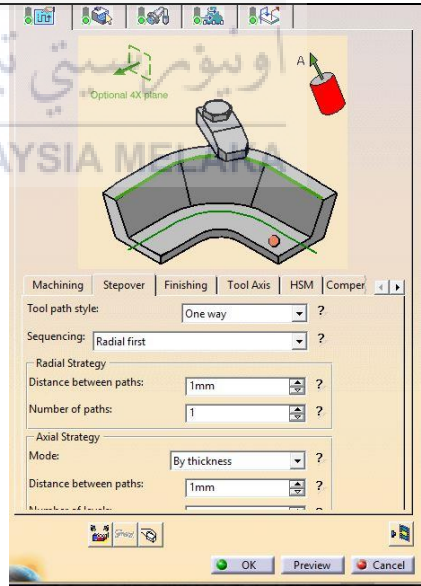
4. 5th tab (Macro Setting)



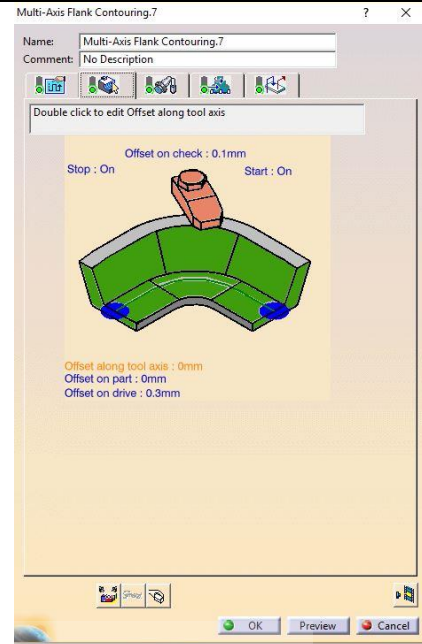
3.3.2.4 Process Multi-Axis Flank Contouring

Final machining process in this project is process multi-axis flank contouring. This process has been applied in both sides of the blade. Combin Parelm is guidance of tool axis that been used in this process. Tanto Fan and Combin Tanto is not suitable used in this project as it will reduce thickness of the blade. Offset of 0.3mm on the drive is set in 2nd tab for front of blade while offset 0.1mm on drive is set for back of blade. Offset set in geometry strategy can help in avoiding overcut during machining. Selection of auxiliary guiding element is important step as guideline for tool path. Macro setting and parameter setting were left the same for every blade. Below table 3.8 shows setting of strategy for machining strategy, geometry setting and macro setting. Simulation of front and back of blade has been shown through figure 3.13 and figure 3.14.

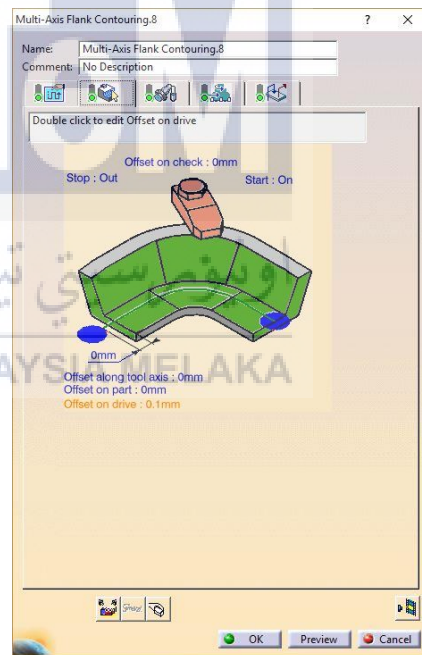
Table 3.8: Setting of Multi-Axis Flank Contouring

Strategy	Figure
1. 1 st tab (Machining Strategy)	

2. 2nd tab (Geometry Strategy)

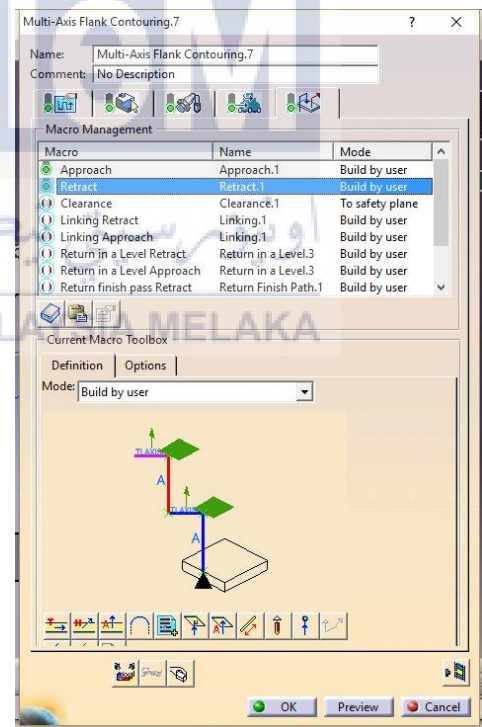
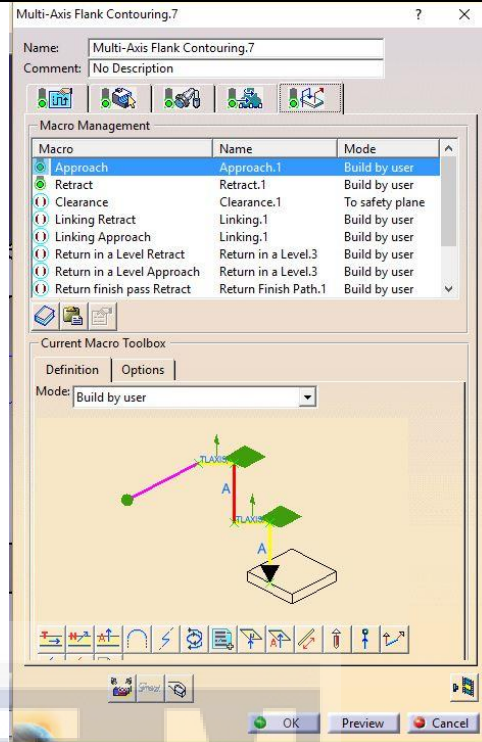


(geometry strategy for front of blade)



(geometry setting for back of blade)

4. 5th tab (Macro Setting)



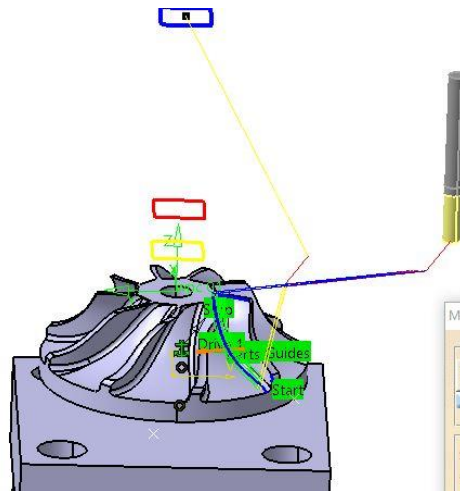


Figure 3.13: Tool Path for Front of Blade

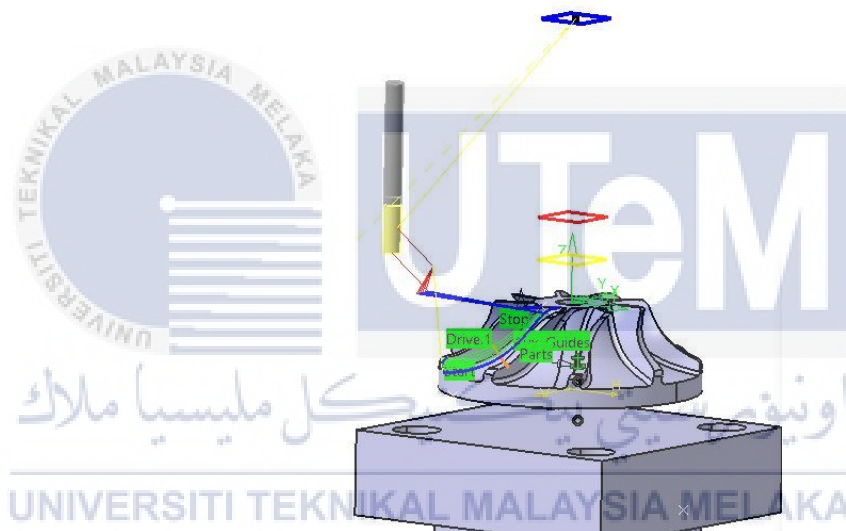


Figure 3.14: Tool Path for back of blade

3.3.3 Jig and Fixture Preparation

Jig is clamping device which clamp part during CNC machining process. Minimum distance between tilted mill head and rotary table is 160mm. Based of capability of DMU 60 monoBLOCK, minimum height of product must exceed 160mm to prevent problem of undercut. In this research, height of raw material only 50mm, therefore jig is required in CNC machining process. Besides, one function of

jig is preventing collision between mill head and rotary table. Design of jig is based on design of previous jig which has been used. Modification is done after discussion with supervisor (SV); dimension of jig has been set and drawing is done by CATIA V5. Raw Material have been cut in FTK milling and turning lab which are 210mm x 101mm x 50mm (bottom part), 110mm x 101mm x 50mm (top part) and cylinder part diameter 51mm with length 120mm (center part). As raw material is not flat and square, therefore squaring process is required to get square part. In squaring process, end mill and face mill cutting tools are used. Four holes have been done through drilling process. Four holes are drilled to clamp part during CNC machining. At the center of top and bottom square part, hole with dimension 10mm is drilled to ease assembly process. Turning is done on center cylinder part to fix the part with top and bottom of center part. After all machining processes perform then welding process taken place in joining all parts together. As raw material used in making jig is aluminium, therefore Tungsten Inert Gas Arc Welding (TIG) is chosen to welding those part. Multi-view of jig shown through figure 3.15 while real part of jig has mention in figure 3.16.

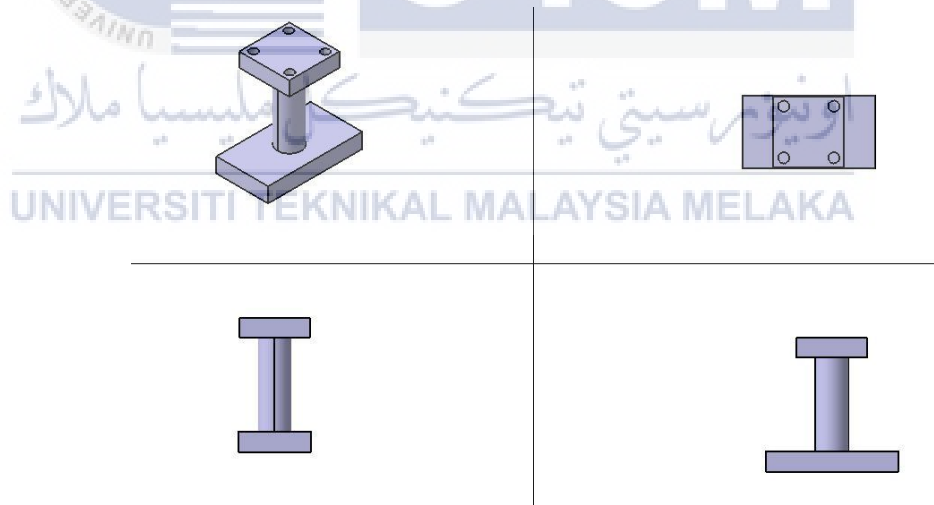


Figure 3.15: Drawing of Jig



Figure 3.16: Jig for CNC Five-axis Machining

3.3.4 Post Processing

Post processing step between CAM and physical machining. This step is very important to ensure that CAM program can be translated well for physical machining. APT format is modified and converted into NC program to suit a machine (tool and control system). (P. Radhakrishnan, S. Subramanyan, V. Raju). Different types of machine have different type of controller. Post processing may help in preventing any accident happen by adjusting/ editing some command. Format which understood by the controller is posted by post processing. Controller used in this project will be based on availability in the CNC lab which is IMS customise controller. In this research, APT file saved from CATIA V5 must be convert into .H file which suitable for Heidenhain controller by specific post processor. Flow chart of converting from APT file to .H file can be obtained through Figure 3.17.

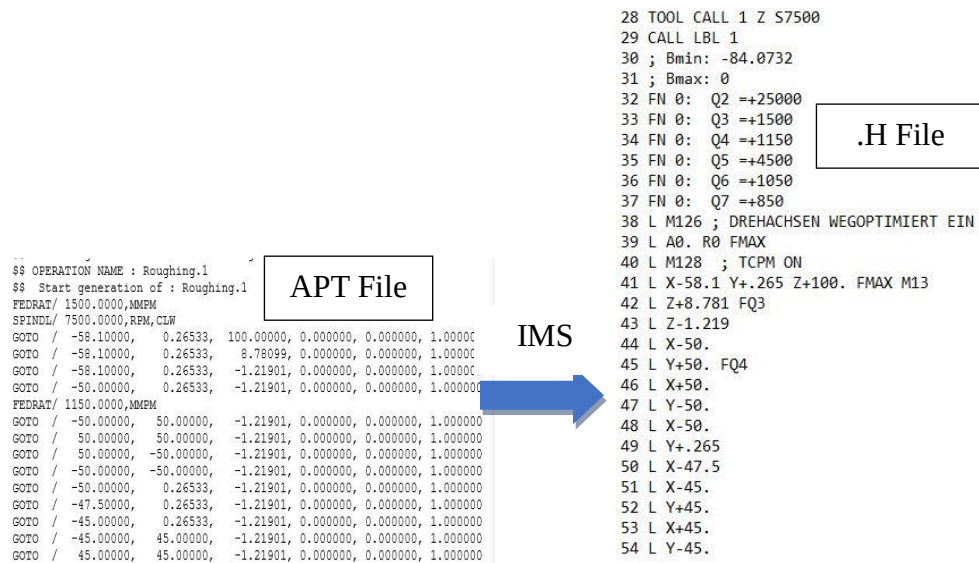


Figure 3.17: APT file Convert to .H File.

3.3.5 Physical machining

As .H file can work successfully in CNC machine controller, this shows that CAM program can undergo physical machining. Physical machining is done through five-axis machine. Five-axis machine that has been used in this project is DMU-60 monoBLOCK and it is five-axis sided machine. Below have attachment shows technical data and real machine of DMU 60 monoBLOCK machine which are figure 3.18 and figure 3.19.

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/s ²	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)		
Swivel range (0 = vertical / -90 = horizontal)	degrees	+30 / -120
Swivel time	sec	1.5
Max. acceleration	°/s ²	2,300
Rapid traverse	rpm	35

Figure 3.18: Technical Data of DMU 60 monoBLOCK Machine



Figure 3.19: DMU 60 monoBLOCK machine

First step of physical machining is preparing tool that have been selected which are End Mill diameter 10mm, End Mill diameter 6mm and Ball Mill diameter 6mm. Clamping jig and workpiece into DMU-60 monoBLOCK machine is next step. Before starting applied program, spindle speed, depth of cut and sequence of each process need to be concerned which similar with setting in CAM program. Dry cut is done before running program to prevent any accident happen. Figure 3.20 shows

First blade is undergone machining process to ensure NC code can function well in physical machine. After successfully done the first blade, program in continue running for another 8 blades. Duration of finishing one turbine blade is approximately 7 hour. Physical machining in first blade can be seen through figure 3.21.



3.3.6 Dimensional Analysis

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inspection an object. Latest technology of 3D Scanner is scanning physical part without have a contact with it. Function of 3D Scanner is scanning real-world objects and reform it in digital world which in complete model. Turbine blade is made by aluminium with shying surface, therefore SKD-S2 Aerosol is applied on the surface on turbine blade before scanning process. This step helps for easy analysis machined part. There are three step during scanning process which are scan, align and merge. Turbine blade is medium part, therefore lens FOV 200 is used in scanning process. Scanning part is done few times (group) to obtain full shape of turbine blade. Step align helps to align all scanning figure and produce a complete scanned part. Merge is done and export in STL file after completion of all procedure. After scanning process, software used as support to provide methodology of scanning. Data from methodology is interpret to discuss the accuracy of machining processes that have been used. Details of interpretation are discussed in chapter 4. Figure 3.22 represent function of 3D scanner while figure 3.23 shows an example flow chart of 3D Scanner. 3D Scanner used in the lab shown through figure 3.24 while different between with and without spraying substances on turbine blade can obtained through figure 3.25.

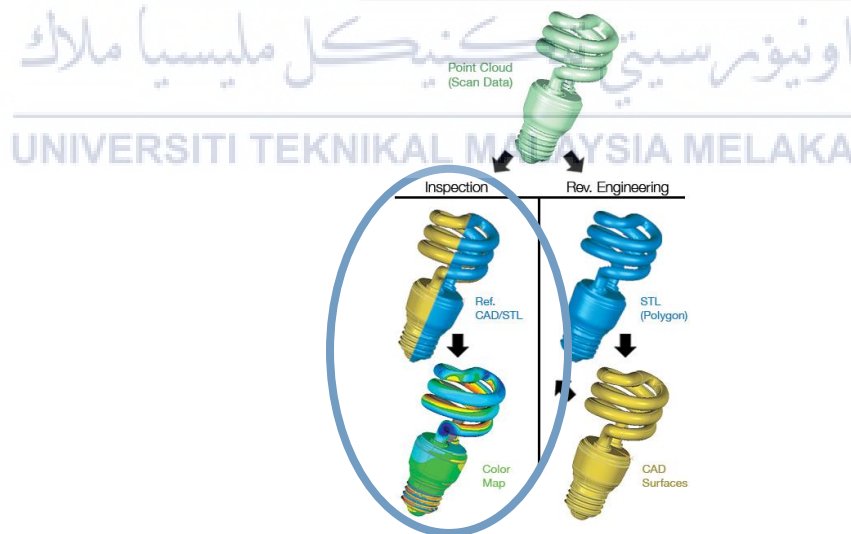


Figure 3.22: Function of 3D Scanner

<http://www.laserdesign.com/what-is-3d-scanning>

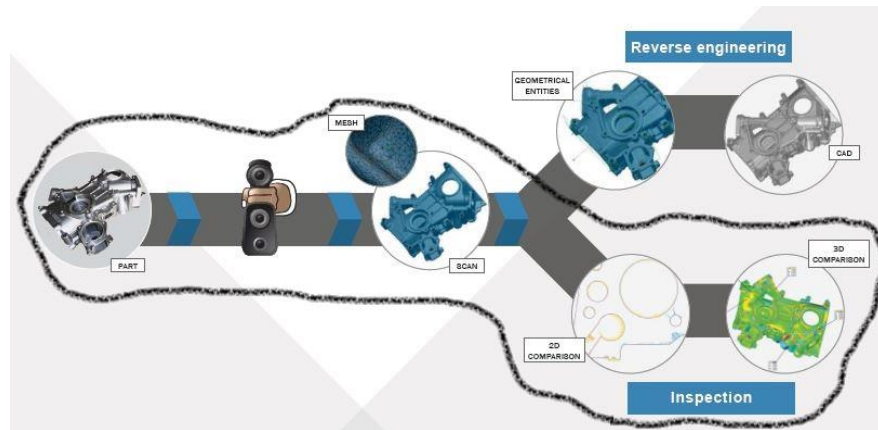
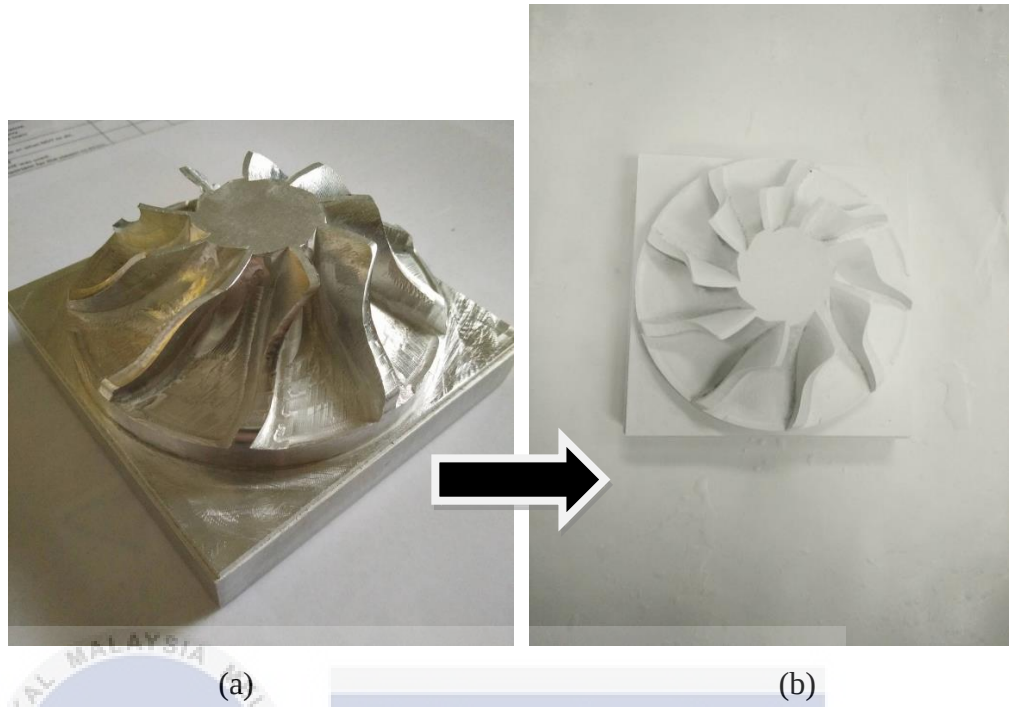


Figure 3.23: Example Flow Chart of 3D Scanner

http://www.creaform3d.com/sites/default/files/assets/technological-fundamentals/ebook1_an_introduction_to_3d_scanning_en_26082014.pdf



Figure 3.24: 3D Scanner Model



(a) (b)

Figure 3.25: a) Before Applying Spraying Substances on Turbine Blade.
b) After Applying Spraying Substances on Turbine Blade

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CHAPTER 4

RESULT AND DISCUSSION

In this section, result of physical machining and scanning process are discussed. Besides, few problems have been found after machining and analysis process. Those problems are such as problem regarding jig, problem based on machined part- turbine blade and accuracy of part based on result of 3D Scanner analysis and comparison between finished part with CAD model in CAD/CAM simulation. Problem on machined part which is turbine blade caused by setting of CAM program. Accuracy of turbine blade will be discuss based on result from 3D Scanner and CAD/CAM simulation. Comparison of real product and CAD model will be shown though figure. All problem will be discussed in this part while some action have been taken to reduce or eliminate those problems.



4.1 Result

Below figure which is figure 4.1 shows result of CAM program simulation. After all machining process running through simulation of CATIA V5, finished part – turbine blade is saved in CAD part format. This result can help to prevent getting undesired shape.

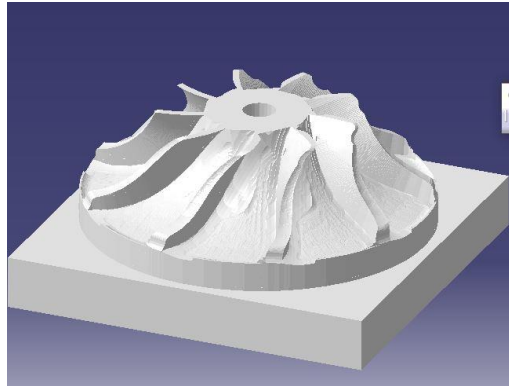


Figure 4.1: Result of CAM Program Simulation

Physical Machining part can be observed through figure 4.2. Some problem can be obtained after getting physical machining process. Discussion on physical machined part is required for further improvement.



Figure 4.2: Result of Physical Machining

Figure 4.3 shows result after running 3D Scanner. Few steps have been done by using 3D Scanner to obtain model of machined part. Due to limitation of 3D Scanner and shape of turbine blade, some minor part such as top corner of blade in physical machined part cannot be obtained.



Figure 4.3: Result of 3D Scanner

Result after analysis by software of 3D Scanner – methodology has been shown by figure 4.4. Result legend in figure 4.4 represent range and colour of result. From red colour to green represent undercut while blue colour to purple colour undercut problem.



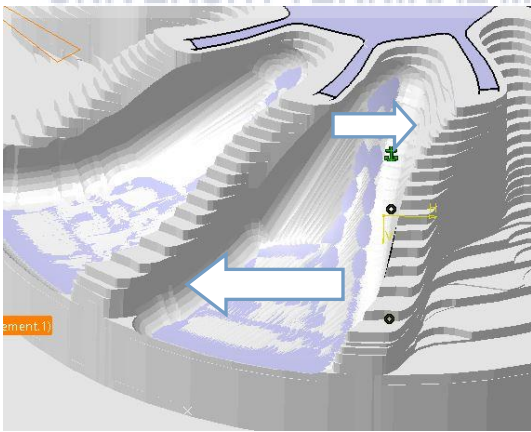
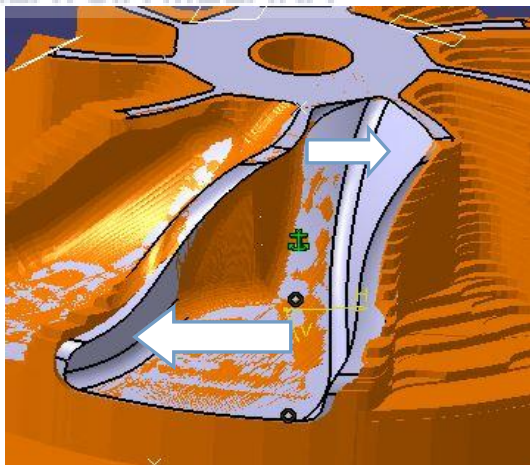
Figure 4.4: Comparison of Physical Product and CAD Model

4.2 Comparison between Finished Part and CAD Model in CAM Program

After all simulation of CAM program, finished part is saved. Comparison between finished part under CATIA simulation and CAD model is done. Comparison result help in analysis machining process before physical machining. To ensure that CAM program can machine desired shape successfully, comparison is required. Modification is done if there are any setting which affect dimension and shape of CAD model – turbine blade. By comparison among finished part done by CAM program simulation and CAD models, each tool path can be analysis. This step helps in reducing waste of raw material and preventing obtain undesired part after physical machining. However, post processing also important step before entering physical machining.

One of setting that has been changed after comparison was setting check and offset value in multi-axis Sweeping process. Though result of simulation, thickness of blade will be remove without check and offset value. Change have been done to obtain desired shape without reduce thickness of blade. Table 4.1 provide briefly view regarding comparison with and without setting of offset value and check.

Table 4.1: Comparison with and without Setting of Offset Value and Check

With check and offset value	Without check and offset value
	

Furthermore, another setting has been changed after simulation is guidance used in multi-axis flank contouring. Thickness of blade has been reduced if tanto fan is

applied, combin Parelm is selected after comparison. Therefore, different type of guidance will have different result on the thickness of the blade which display in table 4.2.

Table 4.2: Comparison between Tanto Fan and Combin Parelm

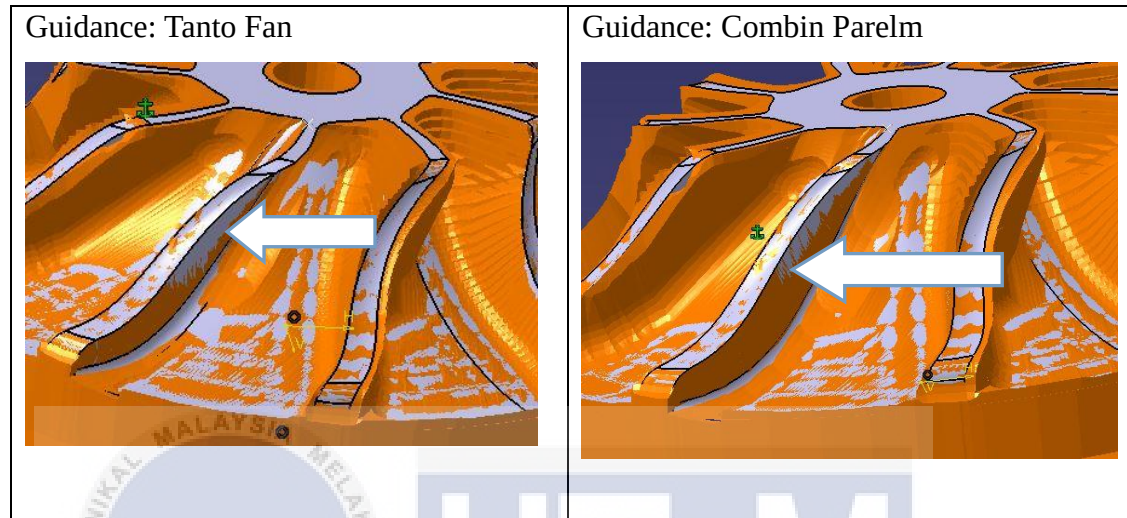


Figure 4.5 shows the comparison between finished part and CAD model. There is some overcut problem occurred after machining processes. However, excess material also left after running the program. White colour represents finished part while blue grey colour represents CAD model. Areas which do not consist of grey colour part shows problem of overcut. This assumption is done qualitatively without any measurement. Quantitative analysis is done through 3D Scanner analysis. Besides, result of simulation ensure that jig will not be machined during machining process. Square box will be left as it is support of part during five-axis CNC machining process.

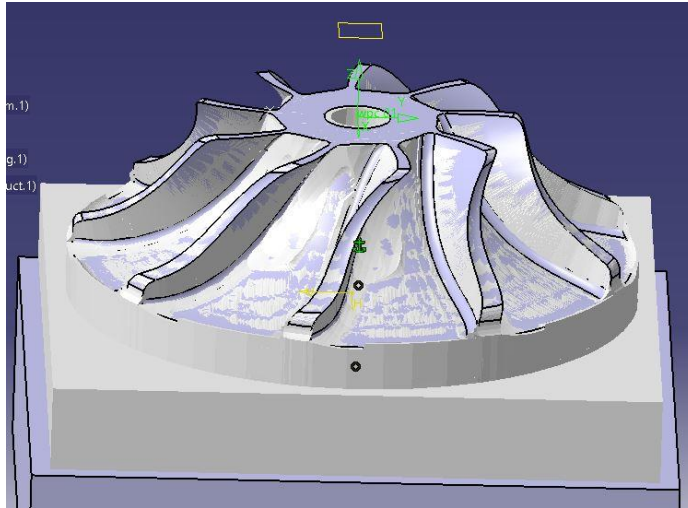


Figure 4.5: Comparison between Finished Part by CAM Program and Model

4.3 Problem Preparation of Jig

Jig is used to hold the raw material during CNC five-axis machining. Before physical machining process, jig is made. In making of jig, there are a problem has been faced which is welding problem in joining parts. Aluminium used for top and bottom part of jig is 7xxx series aluminium while center cylinder part is made by other aluminium series. This combination has increases difficulty of welding process. Different series of aluminium has its own properties, therefore they required different series of weld rod in welding process.

Welding problem has occurred which is welding rod is melt before it joins two part. This situation cannot be solved by pressing welding rod towards joined part. Welding problem result in incomplete fusion on weld joint. Besides, this welding problem also may affect weld penetration among joint. The deeper the weld penetration, the stronger the welding strength (weld's ultimate tensile strength and yield strength). However, incomplete fusion is mainly problem compared with weld penetration. In result, types of rod used need to be concerned before welding those parts. Under this situation, special rod is used to join those parts. Welding technique also required to weld joined part as it is 90 degree with one another. One of

suggestion to avoid this problem is using same series of aluminium in making jig. Rod using in welding process is easy to be define under this condition. Besides, related standard can be referring such as BS EN ISO 10042:2005. This standard is about focusing on quality levels - imperfection welding process of aluminium and its alloy. (TWI Group Website). Detail of fillet welding can be obtained in figure 4.6 while problem faced during welding jig is shown by figure 4.7. Figure 4.8 represent Welded jig.

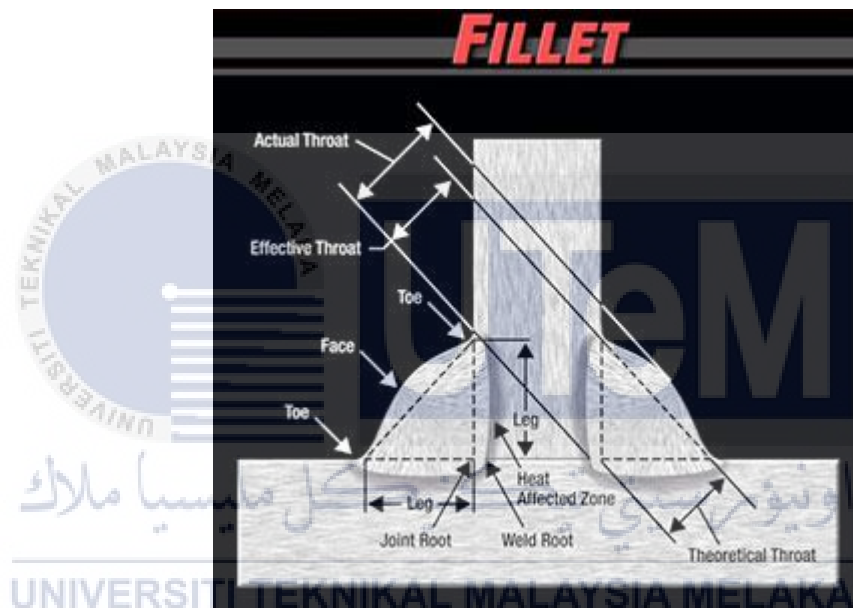


Figure 4.6: Fillet Welding



Figure 4.7: Problem during Welding Jig



Figure 4.8: Welded Jig

Before assembly square raw material on the jig, facing process is required. After jig is clamp on DMU 60 monoBLOCK machine table, facing process is required to ensure flatness of jig. Surface of jig will be affected on accuracy of machined part. Analysis of jig surface is done before clamping part on it. If jig surface is not flat, this will affect the flatness of clamping part and affect accuracy of machining process. Probe is applied after facing process to ensure surface of jig is flat. Besides,

to ensure joined part of jig is 90 degree, drill hole is done on the center of top, bottom part and cylinder part. This step helps in ensuring joined part is 90 degree between one another.

4.4 Machined Part Problem

After getting machined part, some problem has been listed such excess material on space between blades which is centre, top and bottom area of space between blades. Those problems mention above can be seen through figure 4.9.

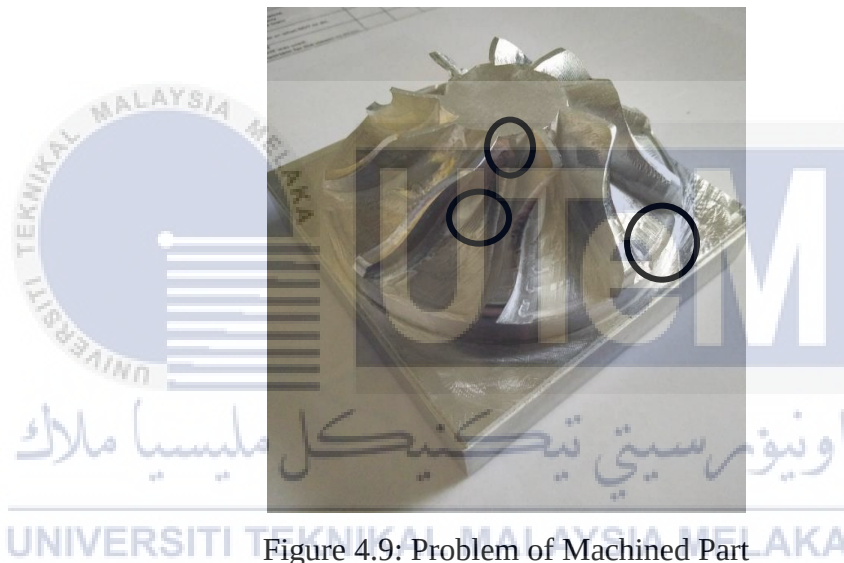


Figure 4.9: Problem of Machined Part

One of causes happen of this problem is offset setting in multi-axis sweeping. As limitation of available cutting tool, Ball Mill with diameter 6mm has been used in multi-axis sweeping process. Ball Mill with diameter 6mm cannot machine tight and confine area of surface between blades. Offset of the tool path needed to be adjust based on dimension of cutting tool to machine the space between two blade. Offset of tool path on 2nd tab which is geometry setting caused excess material on top and bottom of machined surface. Offset value set in machining process is displayed by figure 4.10.

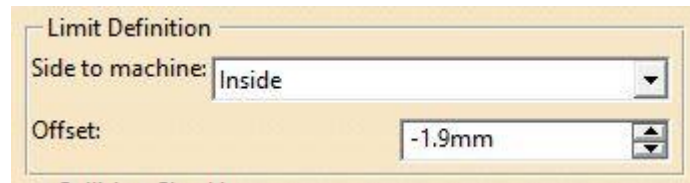


Figure 4.10 Offset of Tool Path

Besides, another cause is setting of start direction and view direction of multi-axis sweeping. In multi-axis sweeping, setting start direction and view direction will affect cutting tool path on the machine surface. Movement of cutting tool path also will affect cutting area of the process. This movement will affect on excess material left after machining process. Simulation of cutting tool path is illustrated through figure 4.11.

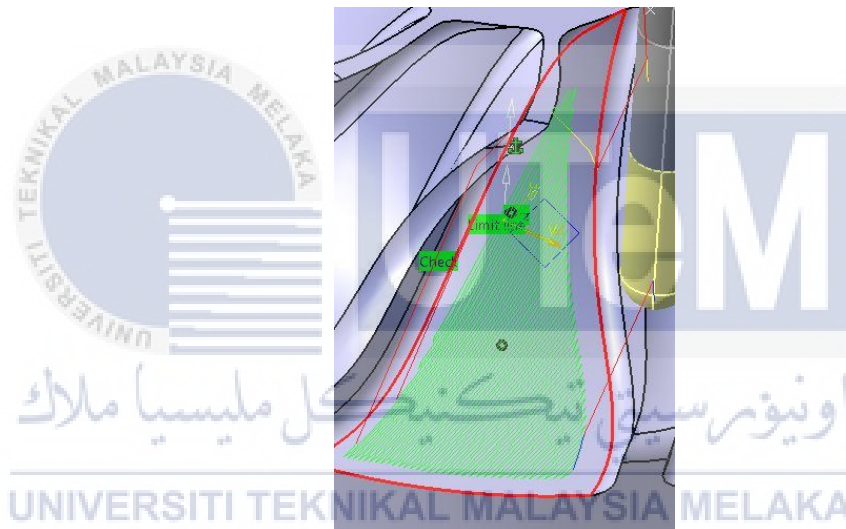


Figure 4.11: Cutting Tool Path

Excess material on bottom part of space between two blades is remove by filing process to remove sharp edge of the part. This action also can improve appearance of turbine blade.

4.5 Accuracy of Turbine Blade

In this project, 3D Scanner has been used as equipment in analysis accuracy of physical part. Initially, CMM (Coordinate Measured Machine) is planned to be used

as equipment of analysis. CMM (Coordinate Measured Machine) can provide accuracy of the part though graph. Due to the size of probe and minimum force required pressure occur during measuring process, dimension such as thickness of blade cannot be obtained correctly. 3D Scanner and conventional measurement by Vernier Calliper were the methods used in obtaining the comparison data. After discussion and comparison, 3D Scanner has been used. There are some minor parts of blade cannot be scanned by 3D Scanner. This problem may affect the accuracy of 3D Scanner result.

Although result of 3D Scanner shown in figure 4.12 and figure 4.13, most of machined part have few excess materials which represented by green colour while some area shows blue colour which has problem of overcut. Different ton of green colour show different amount of excess material in machined part after comparison with CAD model. Overcut problem has been occurred on the blades of turbine blade. There is material left on top part of surface between blades which does not removed through multi-axis sweeping. This condition is represented by yellow colour. Besides, above figure shows values of all area between blades after comparison between CAD model and model of machined part. Hole on the center of turbine blade is not machined in real machining process. Therefore, analysis of hole can be neglect.

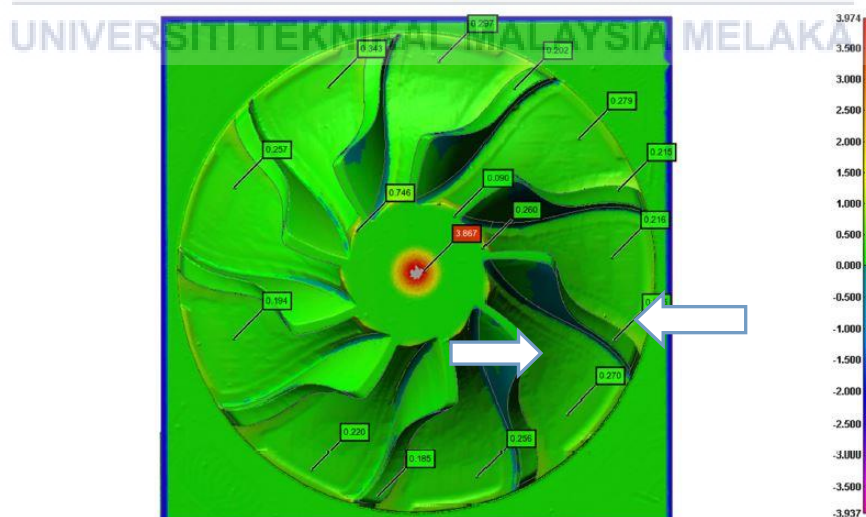


Figure 4.12: Overall Result of 3D Scanner

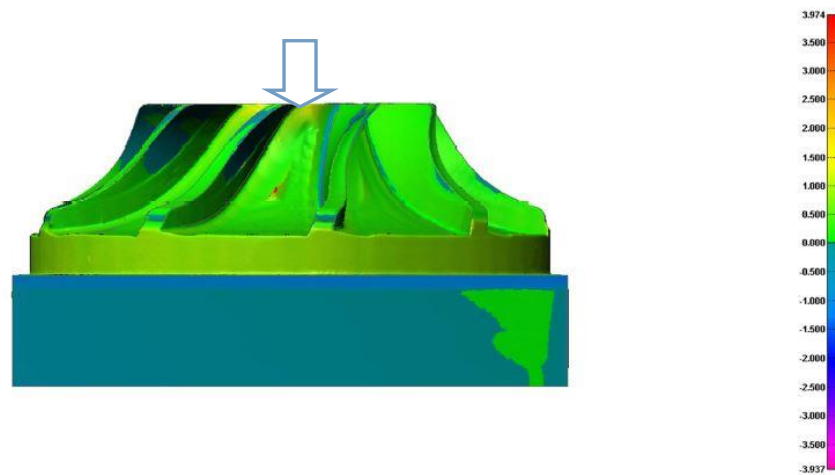


Figure 4.13: Side View of 3D Scanner Result

In metal machining process, there are three types of mechanical vibrations may be occurred such as free vibrations, self-excited vibrations and forced vibrations because of lack of dynamic stiffness of one or some elements caused by the cutting tool, the machine tool, part material and tool holder. (Guillem Quintana etc.). Vibration such as chatter may be occurred during physical machining that may affect accuracy of part. Chatter is self-excited vibrations as it is most uncontrollable and unexpected. Self-excited vibration will lead system to unstable. Chatter will cause unacceptable inaccuracy. (Guillem Quintana etc.) Therefore, unstable system may reduce accuracy of part. Example, vibration will cause reduction accuracy when machining space between multi-axis sweeping process. On the other side, vibration can be caused by lower tool rigidity. Therefore, low tool rigidity will reduce the dimensional accuracy. Capability of a machine to manufacture quality product can be determined through tool rigidity. (Rahman, M.A., Elfi, R.I.F., Dan, M.M.P., etc.)

Due to diameter of ball mill used is large, offset is required. Offset value is limit movement of cutting tool path. As mention above, excess material will be left on due to offset setting. Excess material also effect accuracy of the surface between blades. Besides, different lead and tile angles has been applied in machining surface between blades. For the same material with various combination of lead and tilt angles, there

may be a different for its removal rate, stability limits and forces. (ErdemOzturk et al. ,2009). Accuracy of part maybe effected through this setting.

Although cutting force is not included in the scope of this study, but it also one of factor which may influence performance of physical machining process. Different cutting force during machining process may affected performance of it. Therefore, accuracy of part may be effected by cutting force applied during physical machining.

Although CATIA V5 helps to generate APT file, but APT file cannot be directly applied on DMU 60 monoBLOCK machine. Post processor are required to change APT file into H. file which can be read by machine controller. IMS is post processor used by DMU 60 monoBLOCK. Through physical machining process, one of the condition that has been obtained is cutting tool path of multi-axis flank contouring and multi-axis sweeping are not smooth like simulation in CAM program. This situation may due to conversion done by post processor. APT file may not transfer effectively into .H file by current available post processor. Therefore, accuracy surface of blades will be affected.

Furthermore, cutting tool path for multi-axis flank contouring and multi-axis sweeping are two ways directions not one way direction cutting process. Forward and backward cutting direction may affect accuracy of machining part. However, two ways cutting process helps in reducing machining time. As mention above, cutting tool path in physical machining is not smooth like simulation in CAM program, therefore, two ways direction of cutting process may affect accuracy of part. Besides, there are many left material on surface between blades after process roughing 2. Many material need to be removed though multi-axis sweeping compare with other machining process.

CHAPTER 5

CONCLUSION AND FUTURE WORK

In this chapter, a conclusion is done based on project title and some recommendation are given for further improvement and analysis.

5.1 Conclusion

Many knowledge have been gain though final year project. Objective of project have been achieved as turbine blade has been successfully machined though five-axis CNC machine – DMU 60 monoBLOCK. Machining processes that have been plan in CAM program can be applied in real machining. Turbine Blade can be machined though standard process such as multi-axis flank contouring, roughing and multi-axis sweeping which available in CAD/CAM software, CATIA V5. Besides, available of cutting tool in CNC lab also is one of important consideration during preparation of CAM program. Post processor also cannot be ignored as it is converting APT file from CATIA to H. file that can read by DMU 60 monoBLOCK controller. As mention in discussion part, post processor may be affect cutting tool path due to its conversion. Accuracy of machined part can be seen through 3D Scanner analysis. There is a problem when analysis machined part which is size of probe CMM (Coordinate Measured Machine) is not suitable in measuring machined part. Result of 3D Scanner is used to understand accuracy of machined part by comparison between machined part and CAD model.

5.2 Future Work

There are many problem have been faced in this project. There are few suggestions are recommended for further improvement to close the gap in the future such as:

- 1) Tapered tool such as tapered ball end mill tool or end can be used to machine surface/ space between blades. Though this setting, rigidity of tool can be improved. With smaller cutting tool, offset value can be reduced while lead and tilt angle will be affected as dimension of cutting tool has been changed.
- 2) Smaller stylus can be applied during CMM (Coordinate Measured Machine) analysis. Small probe can measure tight and confine area of physical part and obtain data regarding accuracy of turbine blade.
- 3) CAM Program can be applied with different configuration of five-axis CNC machine. Different post processor can be applied with different five-axis CNC machine. There are many types of post processor are available in current market. Accuracy may not be same if applied different post processor is used.

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