# APPLICATION OF CNC SIMULATOR FOR CNC MACHINING VIA CAD/CAM

By:
**LAILISA NUR BINTI MISMAN**
(Matric no.: 120793)

Supervisor:
**DR. MOHD SALMAN BIN ABU MANSOR**

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**DECLARATION**

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by giving explicit references. Bibliography/references are appended.

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*Lailisa Nur Binti Misman 2017*

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# LIST OF ABBREVIATIONS

| Acronyms | Definition |
| --- | --- |
| 2D | Two Dimensional |
| 3D | Three Dimensional |
| CAD | Computer Aided Design |
| CAM | Computer Aided Manufacturing |
| CNC | Computer Numerical Control |
| DXF | Drawing Exchange Format |
| IGES | Initial Graphics Exchange Specification |
| MCS | Machine Coordinate System |

# LIST OF SYMBOL

| Symbol | Definition/Units |
| --- | --- |
| % | Percentage |
| π | Pi |
| Ø | Diameter |
| mm | Millimetre |
| rpm | Revolution per minute |
| ° | Degree |

**ABSTRAK**

Kebanyakan industri perkilangan menggunakan Reka Bantu Berbantu Komputer (CAD) dan Pembuatan Berbantukan Komputer (CAM) untuk mengubah sistem pembuatan dengan meningkatkan produktiviti pengeluaran. Tujuan utama Kawalan Numerik Komputer (CNC) Simulator adalah untuk mewujudkan proses pengeluaran dan komponen yang lebih cepat dan pantas dengan jumlah bahan yang banyak tetapi lebih tepat. Hal ini sekali gus dapat meminimumkan sisa dan bahan lebihan dan pada masa yang sama mengurangkan penggunaan tenaga dalam produksi. Pengggunaan CNC simulator sesuai untuk penggunaan CNC mesin. Sebelum pemesinan sebenar, beberapa simulasi harus dihasilkan untuk mengenal pasti kaedah pemesinan yang baik dan sesuai. Perisian CAD / CAM  sering digunakan untuk pemesinan prototaip dan bahagian siap. Dalam masa itu, parameter pemesinan boleh menjejaskan kualiti permukaan produk dalam pemesinan CNC. Selain itu juga, gabungan gerakan disegerakkan pada tiga paksi mengehadkan penggunaan mesin CNC seperti bentuk yang kompleks susah untuk dihasilkan. Tujuan penyelidikan ini adalah untuk mengenalpasti parameter pemesinan untuk CNC Simulator dan pemesinan sebenar. Hal ini, untuk membandingkan simulasi pemesinan yang menggunakan Simulator CNC yang berlainan antara satu sama lain. Tujuan lain adalah untuk mengenal pasti ketepatan simulasi dan pemesinan sebenar. CNC Keller, Mastercam X2 dan CATIA V5 digunakan untuk mengenal pasti kaedah yang berkesan untuk pemesinan bentuk geometri kompleks dalam mesin CNC; CNC 3-paksi mesin dan mesin CNC 5-axis. Dengan kombinasi orientasi yang berlainan, jumlah masa pemesinan dianggap sebagai criteria penting untuk mengatasi dan menyelesaikan masalah mada CNC mesin. Dalam kajian ini, perbandingan simulasi dibuat antara ketiga-tiga Simulator CNC dan pemesinan sebenar.

**ABSTRACT**

Most manufacturing industries use Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) transforms manufacturing system by improving productivity of production. The main purpose of Computer Numeric Control (CNC) Simulator is to create a faster production process and components and tooling with more precise amount of raw material thus minimizing waste, while simultaneously reduce energy consumption. This paper describes effective approaches of CNC simulators for CNC milling machine. Before real machining, several simulations are generated to identify excellent machining method. CAD/CAM software is most often used for machining of prototypes and finished parts. Machining parameters can affect the surface quality of product in CNC machining. The combination of synchronized movements on three axes restrict user machining a part with complex shape. The purpose of this research is to identify machining parameters for CNC Simulator and real machining. To compare machining simulations approached by using different CNC Simulators. Another purpose is to identify the accuracy of simulation and actual machining. CNC Keller, Mastercam X2 and CATIA V5 are used to identify the effective method to machining complex geometric shape in CNC machine; CNC 3-axis machine and CNC 5-axis machine. With different combinations of orientations sets, the total machining times were considered as the crucial of roughing and finishing. In the simulations studies, comparisons are made between those three CNC Simulators and real machining.

**CHAPTER 1- INTRODUCTION**

**1.1 Overview**

In recent year, development and production processes in industries have changed in a revolutionary way to leading the customer demands. Now, most manufacturing industries use Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) revolutionizes manufacturing system to improve the productivity of production. CAD/CAM refers to computer software that is used to both design and manufacture products. CAD/CAM systems offer an avenue for cost reduction with an increased degree of flexibility (Cogun, 1992).

One of the major CAD/CAM applications, used by the discrete-part manufacturing industry, is the production of finished parts with information extracted directly from design-drawing data (Rehg and Kraebber, 2005). One of CAM tool application is Computer Numeric Control (CNC) Simulator. CNC system can end-to-end the component design using CAD/CAM programs.

**1.2 CAD/CAM relations in CNC Simulator**

CAD is the use of computer technology for design and design documentation. The basic role of CAD is to precisely define the geometry of a design, as it is critical to all the subsequent activities in the product cycle (Xu and He, 2004). CAM is the models and assemblies created in CAD software to generate tool paths that drive the machines that turn the designs into physical parts. CAM involves milling, drilling, turning, punching, wire Electric Discharge Machining (EDM), knife, laser and plasma cutting and additive manufacturing (3D printing). The objectives for CAD/CAM are reducing costs, shortening time to market, and increasing product quality (Wener et al. 1995).

CNC simulator is a tool able to scrutinize different machining strategies not only rapidly but also without any damage, risk, waste or breaks. Moreover, industries which using simulation in position is to continuously analyse their procedures in order to optimize operations, lowering both costs and time, enhancing quality and

saving materials. CAD/CAM applications are used to design a product and program a manufacturing processes, specifically, CNC machining. CAD/CAM software is most often used for machining of prototypes and finished parts.

Highly complex parts in large varieties mostly are manufactured on CNC-controlled machine tools. These complex manufacturing processes need to be checked thoroughly before running at a real machine tool. Thus, the main purpose of CNC simulator is to running virtual process before goes through real machine. In order to construct processability, compatibility and machinability in CNC machine, several steps must be followed as a reliable manufacturing method to develop parts from CAD to fabrication. The following figure shows the CAD/CAM chain, starting in the CAD system where usually the target work piece was created (see Fig. 1.1). According to diagram, part model is constructed first by using CAD/CAM software. Then, CAM software has an integrated simulation by simulating the material removal at the work piece. The post-processor converts the file into the machine and CNC specific Numeric Control (NC) program, also known as G code. The G code can only be executed at control units of specific CNC manufacturers due to the fact that all manufacturers of control units use specialized functions that they included on top of the G code standard ISO 6983 (Klimant et al. 2014).
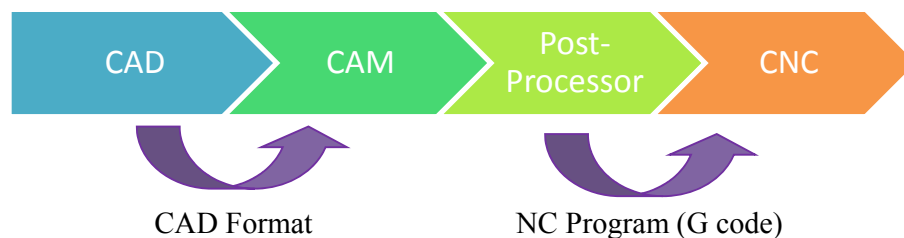


Figure 1.1: CAD/CAM Chain (Klimant et al. 2014).

The idea of CNC Simulator is to provide CNC users with versatile and contemporary full 3D CNC Machine Simulator with CAM capability. The CNC Simulator has become a whole suite of combination software tools for CNC community. The CNC simulator can be used to check the tool path, detect collisions, predict the surface roughness, and predict cutting forces for optimizing

the cutting parameters. It is a very useful tool in solid model designs which will help engineers to realize errors of the end product.

## 1.3 Fundamental of CNC Machining

CNC Machining is a process used in manufacturing industry that involves the use of computer to control machine tools. Recently, development in the application of CNC machining for rapid processes have led to a renewed interest in adopting this technology. CNC Simulator able to simulate the tool path and utilize lathe, routers, grinders and mills.

Part programming consist a sequence of instructions to be performed on the NC/CNC machine. In order to prepare part programming, the programmer decides the order of the machining operations required to produce a component (Rehg and Kraebber, 2005). The choice of the machining tool and cutting tools depends upon the operations. The following figure shows the step involved in the development of a part program (see Fig. 1.2). According to diagram, the first step is prepare the plan by study component drawing. The machine tool may select according to type of work and operations to be performed and select the drive axes. Selection of cutting tool is very vital function because many cutting are feasible for given operation. Then, determine the machining parameters such as feed rate, depth cut, spindle speed and etc. Make job and tool set-up plats to resolve the tool path. Next, right the part program and test it. Finally, document the program which involves part drawing, process planning sheet, tool card, setting card, and programming sheet.
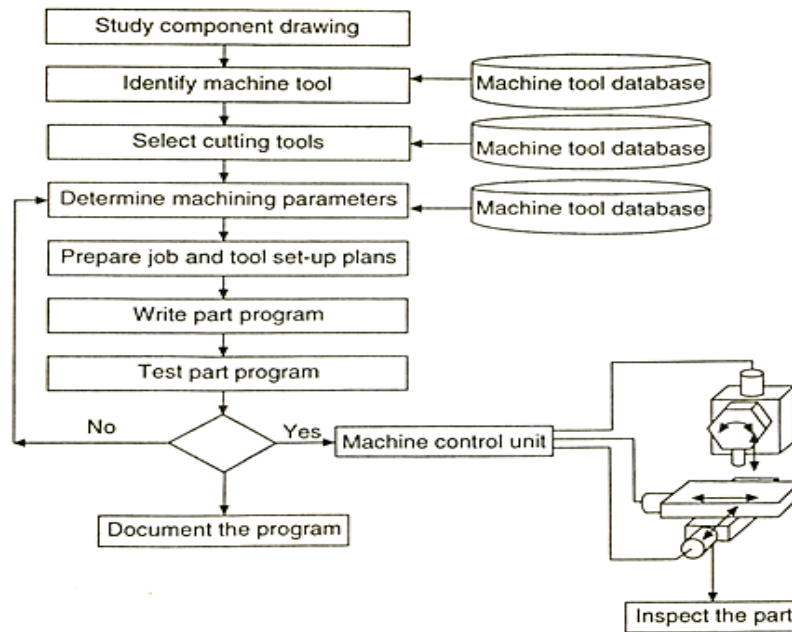
Figure 1.2: Step involved in the preparation of a part program. (Rehg and Kraebber, 2005).

CNC simulator can be used to check the tool path, to detect collisions, to predict the surface roughness, to predict cutting forces for optimizing the cutting parameters. The simulator can show the tool paths of machining process either in 2D and 3D view. Thus, CNC simulator can help to identify the machining parameters.

## 1.4 Machining Parameters in machining

Machining is any various processes to remove a piece of raw material by cut into a desired shape and size by a controlled material removal process. The machining parameters on CNC Simulators and CNC machine must be reliable in order to fabricate and analyse. In CNC Simulator, type of machining process used is crucial aspects because it will affect the surface quality of part. Cutting tool to remove excess material also need to wisely select due to it may affect the part quality. For a given cutting tool and operation selected, the appropriate process parameter have to be selected to ensure that cutting tool achieving the maximum metal removal rate in roughing operation, and the maximum machined surface

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coverage in finishing operations which are can be done by increasing the cutting speed, feed rate and depth of cut (Rehg and Kraebber, 2005).

Milling parameter:

Cutting speed, $V$, in peripheral milling is surface speed of the cutter can be define as:

$$V = \pi DN$$

(1.0)

Where, $V$ = Surface speed of cutter, m/min

$D$ = Cutter diameter, mm

$N$ = Rotational speed of the cutter, rpm

Feed rate, $v$, is linear speed of workpiece can be define as:

$$v = fNn$$

(2.0)

Where, $v$ = Feed rate, mm/min

$f$ = Feed per tooth, mm/tooth

$N$ = Rotational speed of the cutter, rpm

$n$ = number of teeth on cutter.

Sources: (Kalpakjian et al. 2010)

In the global market, other than producing new products with minimum cost and time, it is also necessary to achieve high quality (Lan. 2009). In production, machine must be able to do repeatable tasks with precision and accurate size although in mass production. This shows that manufacturing industries prefer producing high quality products for customer. Hence, quality aspects become a major concern and must be enforced on the part produced. In order to propose the improvements, further investigations on the process methodology are carried out.

## 1.5 Problem Statement

In developing simulation by using different methodology of CNC simulators, its require approach that contradicts common practice. The nature of machining processes either simulation and real machining involves considerable parameters.

The simulation parameters in CNC Simulator will deliberate compatibility and machinability in CNC machine. A study is needed to identify suitable machining parameters. Parameters of machining process can affect the surface quality of product. Proper selection of tool materials, cutting parameters, tool geometry and machine tools are essential to produce high-quality products (Bharilya et al. 2015). Control machining parameters can be increase machining times, and decrease surface quality by leaving tool mark on machining process (Castegnett et al. 2012). The simulation can show exact and accurate machining process tool path simulation and able to control machine tools. The issue here is how exact the simulation compared with real machining process.

Now, CNC machine are moving on complex trajectories in order to generate the shape of the machined part. However, certain shape such as helical surface or parts like turbine blade cannot be machined by combination of three translational movements (Bologa et al. 2016). Combination simultaneous movement on three axes not allows user machining a part with complex shape. Some testing and experiment need to be conducted to compare machine selection in CNC Simulator and actual machining. In higher flexibility of manufacturing process, machining complex surface can be attained by controlling the machining parameters (Carcia-Barbosa et al. 2014). In this work, the application of CNC simulator is focused and studied for CNC machining via CAD/CAM system.

## 1.6 Objectives of project

The objectives of this thesis are:

1. To identify the parameters for machining process when using CNC Simulator and CNC machine.
2. To compare the machining process between simulations using different CNC Simulator.
3. To study the accuracy of machining process from simulated simulations and real process.

**1.7 Scope of project**

The scopes of this project are start with literature review and develop a 3D model design. The first focus is investigating parameters in machining parameter for CNC Simulators and CNC Machine. Secondly, analyze simulated machining process from CNC Keller, Mastercam X2 and CATIA V5. Each result of simulations is compared with each other. Next, the model will be fabricated by using CNC machine. Then, the simulations will be compared with real machining process in term of time. Thirdly, investigate the accuracy of simulated simulation and real machining in term of dimension. The following figure show the step involving scope of project (see Figure 1.3).
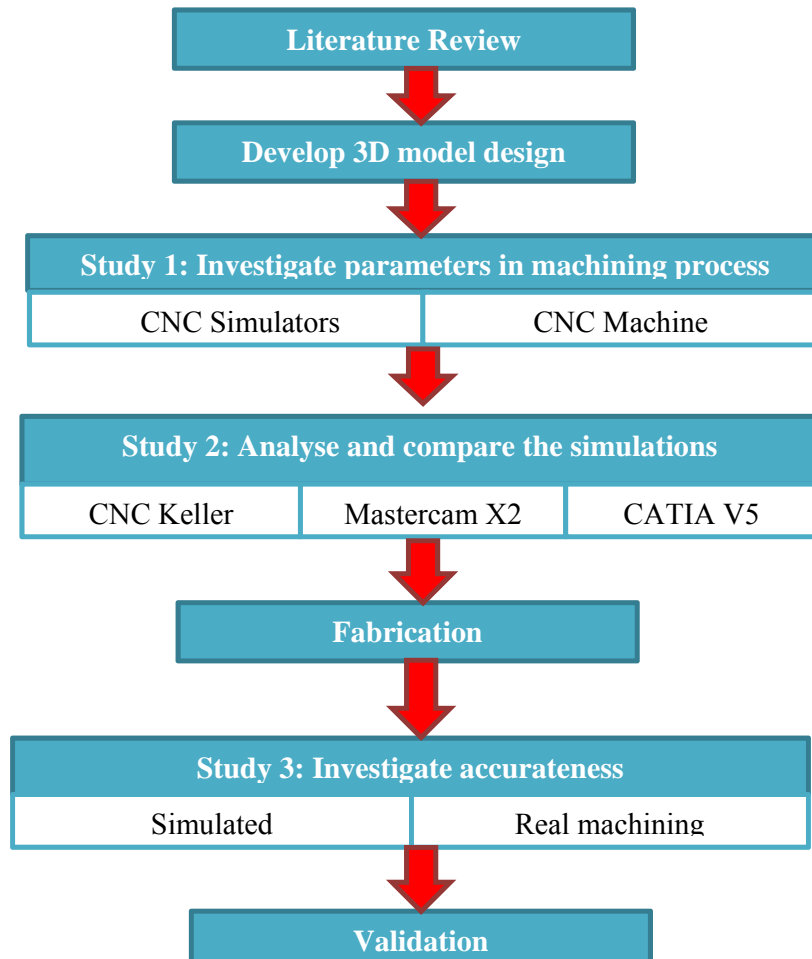


Figure 1.3: Structure and outcome of work.

## 1.8 Outline of project

The thesis has been organised in the following way:

**Chapter 1**: As described in the previous sections, this chapter provides a brief insight into CNC Simulator and the importance to manufacture and industry in producing products. It also introduces important parameters of using CNC machining to perform machining processes. Several inefficiencies in the approach are discussed which are later used to formulate the research objectives.

**Chapter 2**: The literature review begins by laying out previous developments related to CAD/CAM, CNC machining and CNC simulator. Numerous techniques are described based on the additive and subtractive processes. The researched approach is described in pros and cons term in CAD/CAM, machining parameter and CNC simulator.

**Chapter 3**: This section covers the methodology to successfully achieving research objectives. It is incorporates relation CNC machining with CNC simulation via CAD/CAM. Then, the entire review sections are specifically focused on approach to fabricate complex model start from machining simulation. Before executing real machining, preliminary studies were performed to validate the proposed approaches. Different methods are proposed based on cutting orientations. The studies attempt to interpret the objectives of this research.

**Chapter 4**: This chapter describes the work that has been performed while simulation and real machining. This section discussing simulation that fail and possible problem. Limitations and advantages of each simulation process are reviewed mainly to strengthen the argument for implementing CNC machining via CNC Simulator.

**Chapter 5**: This chapter describes the conclusion of work that has been performed while simulation and real machining. This section discussing achievement and objective review in work perform. Improvement on future work is necessary to has efficient result in future performance.

**CHAPTER 2- LITERATURE REVIEW**

**2.1 Overview**

CNC Simulator able to simulate the tool path in CNC lathe machine and CNC mills machine. The idea of CNC Simulator is to provide the CNC users with versatile and contemporary full 3D CNC Machine Simulator with CAD/CAM capability. The CNC Simulator has become a whole suite of combination software tools for CNC community. In this chapter, it can be divided into three sections.

**2.2 CNC Simulator in simulating machining process**

Before running real CNC machining tool, complex workpiece need to be checked thoroughly the process. Nowadays most NC programs are created via CAM tools. Kliment et al. (2014) describe these machine simulations check the functionality of the NC program either regarding processability or the compatibility with the CNC. Simulation allows a close to reality simulation of the real material removal executed and enables a comparison between the simulated work piece geometry and the target CAD geometry directly in a CAD program. Simulation can guarantees not only error-free in manufacturing processes, it also saves time for commissioning at the real machine, and idling can also be avoided. CAD/CAM systems have had significant technological improvements in development and application in CNC machining (Tariq et at. 2015)

CAM systems are used for preparing data and creating CNC programs for manufacturing components. Dubovska et al. (2014) investigate that CATIA V5 able to proves the relevance and coherence of the new technologies, materials, machinery, progressive methods and information tools that enable more efficient use of starting materials to produces lower costs. The usage of CNC system is widely used due to high accuracy in manufacturing, short production time, greater manufacturing flexibility, simpler fixturing, and reduced human error. Denkena and Koeller (2013) state virtual machine tool system deliver user a simulation and visualization of machining process in virtual environment and the process is same real machining.

Multi-axis CNC machine are well known for complicated part machining involving few time consuming set-ups, difficulties arise in generating collision-free tool paths and determining cutting parameters. Jang et al. (2000) investigate development a voxel-based simulator for multi-axis CNC machining. The simulator displays machining process in which the initial workpiece is incrementally converted into the finished part. The simulation process is accurate and almost exact to real process of machining but some divergence can be occur between simulation and real process of machining for example time complete for machining process for simulation is not exact with real process (Jang et al. 2000). The problems when using CNC machine tools is that after some operation time, the contouring errors are significantly increasing (Breaz et al. 2007). Control machining parameters can be increase machining times, and decrease surface quality by leaving tool mark on machining process (Castegnetti et al. 2012).

Based on Figure 2.1, a research by Valvo et al. (2012) about EMC2 (Enhanced Machine Control ver. 2) - an Open Source NC software running in Linux environment, has been successfully used as a numerical control system for a milling machine, proving great flexibility and adaptability. The EMC2 features, is powerful tool that able to control the machine-tool and to simultaneously show the virtual model, displaying the same behaviours of the real machine. The simulation limitation cannot display the chip removal, but only the tool path. This limitation may great help for designer and user to identify volume of removed material.
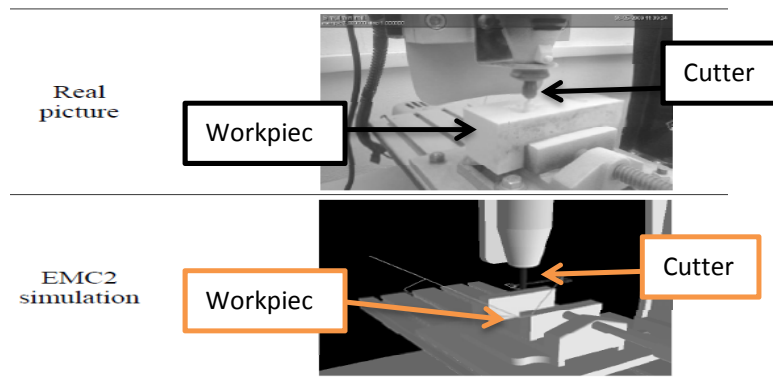


Figure 2.1: The different between real simulation and actual machining (Valvo et al. 2012).

On other hand, some CAD/CAM software allowed simulation of machining process of the surface with a high level of realism. An investigation by Carcia-Barbosa et al.

(2014) about a complex test surface was designed and machined by ball-end milling process on a vertical machining centre quipped with external fourth rotational axis by using simulation. Then, the real process being carries out as show in Figure 2.2.  The fabrication process occurred consistently with what visualized on simulation. However, the stiffness and accuracy of machining system is related to the total error of the machining system, this error involves the cumulative effect of several isolated error that can be classified as: geometric errors of machine components and structures, kinematic errors, error caused by cutting, and other sources of error will influences will be seen in the dimension, form or surface characteristics of a workpiece (Dornfeld et al. 2008).
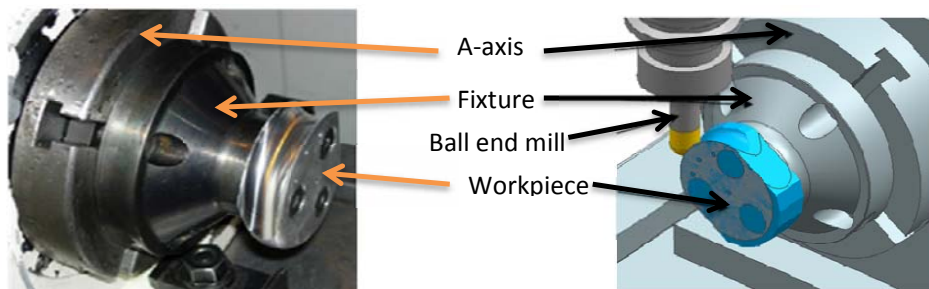


A-axis
Fixture
Ball end mill
Workpiece

Figure 2.2: The different between simulation test and actual test (Carcia-Barbosa et al. 2014).

Virtual manufacturing systems can provide useful means for products to be manufactured without the need of physical testing on the shop floor. As a result, the time and cost of part production can be decreased. The aim of the virtual machining is to reduce or even eliminate physical trials by simulating the physical operations in digital environments ahead of costly production as introduced by Altintas et al. (1991). The investigation is integration of cutting and grinding process models into CAM systems for the simulation of part machining operations in virtual environments. Most important components in virtual machining technology which affect are accuracy of prediction, computational speed and visualization of the operation. There are still challenges in achieving computationally efficient but accurate modelling of cutting forces, structural deformations and chatter stability when complex cutting tools. The virtual machining concept is illustrated in Figure 2.3. The CAD model of the part is used to generate NC programs in a CAM environment where the process planners design tool path strategies and select cutting conditions based on their experience.
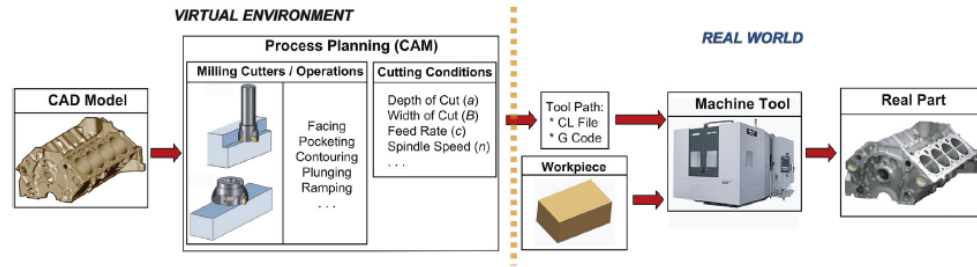
Figure 2.3: Virtual environment compared to real world (Altintas et al. 1991).

## 2.3 Machining parameters in machining process

Machining parameters such as speeds, feed rates and depths of cut need to be selected properly in order to improve the process efficiency and quality of the finished product. An optimization strategy is proposed to determine the most efficient machining parameters based on the process physics (Merdol et al. 2008). CNC machine can control the motions of the workpiece or tool, the input parameters such as feed, depth of cut, speed, and the functions such as turning spindle on/off, turning coolant on/off. The input parameter is importance to identify for machining process due it can affect the surface of product. The maximum spindle speed, rapid rate, pitch error compensation, communications protocol and backlash compensation are among the countless functions specified by parameters.

Bharilya et al. (2015) investigated optimization of machining parameters for turning operation with difference type of workpiece Aluminium, Brass and Mild Steel, which were machined on CNC machine and analyzed through cutting force dynamometer. Dynamometer is device used to measure cutting forces in machining operation. In the study they used different spindle speed, feed rate and depth of cutting for materials, including tool operation in machining operation on process parameter. At the end of the experimental, surface quality and uniformly were inspected. Spindle speed, feed rate and depth of cutting for materials, and tool operation in machining operation affect surface quality/finishing product. Thus, an optimum parameter need to determine in order to has better surface quality. Proper selection of tool materials, cutting parameters, tool geometry and machine tools is essential to produce high-quality products at low cost.

Production quantitative parameters, such as the machined surface quality, the cutting forces, the required power and the cutter wear, in the product design phase, contribute in the improvement of the machining result appraisal.

The parameter of CNC machine tool – progressive cutting tool – workpiece – fixture must ensure sufficient stiffness, which has a direct influence on the quality of the surface finish of the final product. This technological process is important to enter the process of manufacturing of various precision engineering components of complex shape design (Dubovska et al. 2014).

Liu and Cheng (2005) developed a model for the determination of peripheral milling dynamic parameters. The geometry and kinematics of the cutter are considered for the determination of the machined surface in milling processes. The surface roughness is being calculated.
Surface roughness parameters are considering the cutting speed, the feed, the depth of cut and vibrations as parameters and employ mathematical equations, such as the multiple regression equation for the determination of the surface roughness parameters (Lou et al. 1999).

## 2.3 Usage of CNC machine in fabrication process

The use of new CNC machines requires either a specific training for beginner users or a skill upgrading for veteran workers; for this reason a lifelong training system is often strongly requested (Valvo et al 2012). Soori et al. (2014) the present study dimensional, geometric and tool deflection errors are enforced on the G-Code of parts for producing a real 3D model of machined parts in the virtual environment. The 3D model is simulated by using three-axis milling operations. It can be conclude the geometric error modelling used can suitably simulate the errors of a 3-Axis. The system can be developed further to a CNC 5-Axis milling machine order to generate more sophisticated parts in the virtual environment.

CNC machine-tools are the most important technological equipment in industry. It is nowadays possible to produce very complex shapes by CNC machines and they often need sophisticated CAM systems, skilled users and a number of time-consuming tests in order to obtain the best results (Bologa et al. 2016). For these reasons, complex

manufacturing processes need to be checked thoroughly before running at a real machine tool. The simulation of the machining processes can be useful in preparation of production. It is an essential action to check the machining processes with simulation software in advance to prevent from lost.

## 2.4 Accuracy in virtual machining system compared actual machining

A new feature to detect collision-free toll path created successfully by using Voxel based machining simulator state one of the major problems when using CNC machine tools is that after some operation time, the contouring errors are significantly increasing (Breaz et al. 2007). The recommended solution in this case is to adjust the control parameters of the feed drives. The non-smooth variation of tool orientation can be increase machining times, and decrease surface quality by leaving tool mark on machining process investigated by Castegnetti et al. (2012). Some CNC machine such as multi-axis CNC machine are well known for complicated part machining involving few time consuming set-ups, difficulties arise in generating collision-free tool paths and determining cutting parameters (Jang et al. 2000). The simulator displays the machining process in which the initial workpiece is incrementally converted into the finished part. The voxel representation is used to efficiently model the state of the in-process workpiece, which is generated by successively subtracting tool swept volumes from the workpiece. Usage of voxel-based machining simulator is to reduce error occurring during milling on multi-axis CNC machines and increasing the productivity.

# CHAPTER 3-RESEARCH METHODOLOGY

## 3.1 Overview

The application of CNC Simulator has received considerable attention and the simulation studies described in previous chapter. Several researches have been conducted to deal with various problems related to the machining simulation of freeform surfaces on CNC machines.

In this chapter will highlight the methodology and outcomes of these experiments focusing on assessing the developed methods in the context of machining simulation, real machining and also examining the accuracy of the part produced. There are three main objectives of experiments:

1. To identify the parameters for machining process when using CNC Simulators and CNC machine. This approach will be able to identify either the part is processable, compatible and machinable.
2. To investigate the machining process flow between simulations using CNC Simulators and real process fabricated using CNC machine. The finding in simulations are evaluated in term machinable to produce complex shape and compared with real machining.
3. To study the accuracy for machining process from simulation and real process. This approach is evaluated in term of accuracy in time and part dimension.

## 3.2 Methodology

Flow work and method of the experiment is generally a guideline for solving problems. Figure 3.1 is show diagram of methodology guideline to achieve the project objectives. The guideline will help conducting experiment and make sure the experiment run smoothly and achieve the target.

The CNC Simulators; CNC Keller, Mastercam X2 and CATIA V5 are approached one by one. The first approach is focused on generating machining simulation in CNC Keller by using CNC 3-Axis milling machine. Second approach is focused on generating simulation in Mastercam X2 with different orientations setup.

Theoretically, this approach to identify which orientation set capable to machining the complex model by using CNC 3-Axis milling machine. Third approach is the model simulated by using CATIA with CNC 5-Axis milling machine. The machining parameters for each simulation are calculated and key-in inside the simulations. A simulation that capable to generate roughing operation till finishing operation is selected. Finally, the simulated model is fabricated. In order measure the performance of simulation and fabrication, the time taken for simulation and dimension are being highlight.
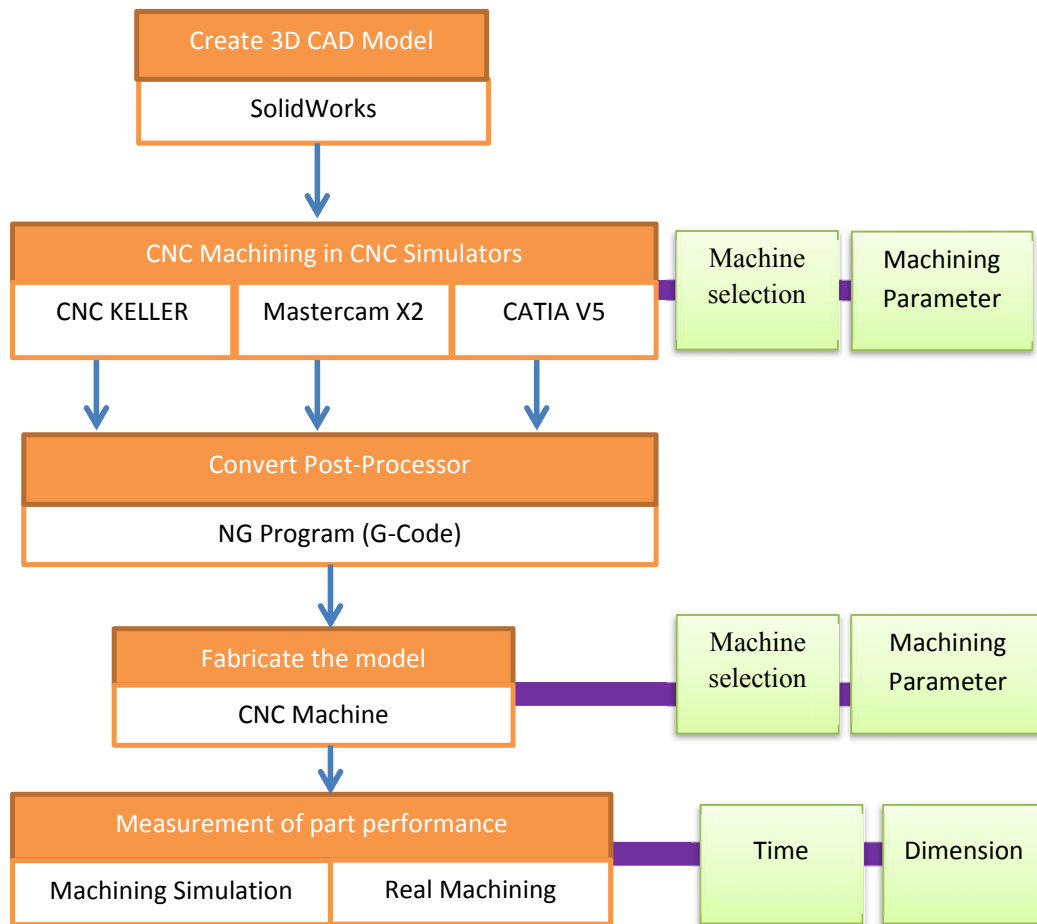


Figure 3.1: Diagram of methodology guideline in experiment.

The research starts by understanding the fundamental of CNC machine and CNC Simulators which are CNC Keller, Mastercam X2 and CATIA V5.

### 3.3 Development of 3D CAD model in SolidWorks

The experiment starts by constructing and developing a CAD model. In this case, the CAD model is constructed in SolidWork. SolidWorks do not have application of CNC simulator. Most CNC simulators can create design drawing and product models. The reason of using different CAD system is to investigate the capability of CNC simulators receiving transferred geometric information from other CAD/CAM system. In real industry, not all company in earth using same and uniform type of CNC simulators.

There are some factors relevant for milling include following (Kalpakjian et al. 2010):

- Standard milling cutters should be used as much possible, depending on part design features.
- Chamfers should be specified instead of radii; it is difficult to smoothly match various intersecting surface radii are specified.
- Internal cavities and pocket with sharp corners should be avoid because of difficulty of milling them, since cutting teeth or inserting have a finite edge radius. When possible, the corners radius should match the milling cutter geometry.

The constructed model by using SolidWorks software is show in Figure 3.2. Dimension sketch can be found in Appendix 1. The material use is stainless steel.
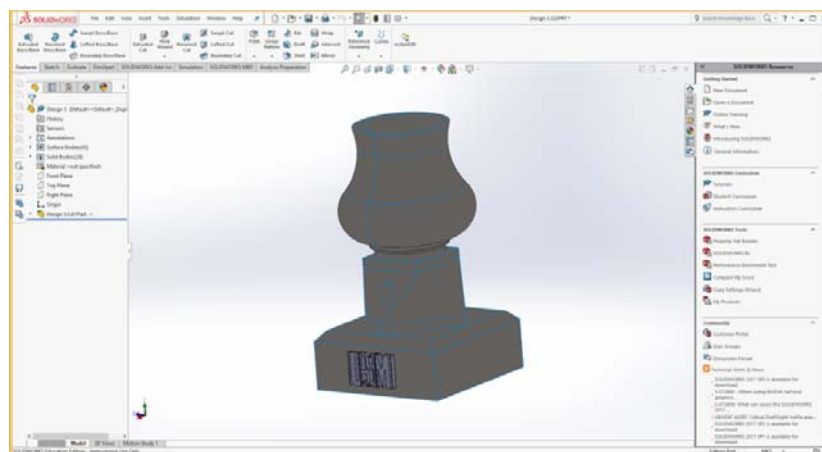


Figure 3.2: CAD model constructed in SolidWorks.

After 3D CAD model constructed, the exchange specification standard are changed into Initial Graphics Exchange Specification (IGES) and Drawing Exchange Format (DFX). Because of the availability of a wide variety of CAD system with different characteristic supplied by different vendors, effective communication and exchange of data between these systems is essential.

**3.4 Machining parameters**

Machining parameters such as speeds, feed rates and depths of cut need to be selected properly in order to improve the process efficiency and quality of the finished product. Based on Table 3.1 is general recommendation of feed and speed for milling operation. The material used is stainless steel. Thus, stainless steel is highlighted.

Table 3.1: General recommendation of feed/tooth and speed.

| Recommendation for milling operation | | |
|---|---|---|
| Material | Range of conditions | |
| | Feed/tooth (mm/tooth) | Speed (m/min) |
| Low-carbon and free-machining steels | 0.085-0.38 | 90-425 |
| Alloy steels | | |
|   Soft | 0.08-0.30 | 60-370 |
|   Hard | 0.08-0.25 | 75-460 |
| Cast iron, grey | | |
|   Soft | 0.08-0.38 | 90-1370 |
|   Hard | 0.08-0.38 | 90-460 |
| Stainless steel, | | |
|   Asthenic | 0.08-0.38 | 90-500 |
| High temperature alloys, | | |
|   Nickel based | 0.08-0.38 | 30-550 |
| Titanium alloys | 0.08-0.38 | 40-140 |
| Aluminium alloys, | | |
|   Free machining | 0.08-0.46 | 300-3000 |
|   High silicon | 0.08-0.38 | 370-910 |
| Copper alloys | 0.08-0.46 | 90-1070 |
| Plastics | 0.08-0.46 | 90-1370 |

(Sources: Kalpakjian et al. 2010)

Calculation to determine optimum feed/tooth and speed:

Feed/Tooth for Stainless steel $= \dfrac{0.38 - 0.08}{2}$

$$= 0.15 \text{ mm/tooth}$$

$$\approx 0.16 \text{ mm/tooth}$$

The average for Feed/Tooth is 0.15mm/tooth. Thus, slightly higher value than average value is selected which is 0.16mm/tooth.

Speed for Stainless steel $= \dfrac{500-90}{2}$

$$= 205 \text{ m/min}$$

$$\approx 210 \text{ m/min}$$

The average speed is 205 m/min. Thus, slightly higher value than average value is selected which is 210 m/min.

The milling parameters are determined using Equation 1.0 and Equation 2.0:

The cutting speed $V$, can be calculated from Equation (1.0):

$$V = \pi DN \tag{1.0}$$

Where, $D$ is cutter diameter (mm) and $N$ is rotational speed of the cutter (rpm).

Then, from the selection of speed and feed per tooth, feed rate, $v$, can be calculated from Equation (2.0):

$$v = fNn \tag{2.0}$$

Where, $f$ is feed per tooth (mm/tooth), $N$ is rotational speed of the cutter (rpm) and $n$ is number of teeth on cutter.

(Sources: Kalpakjian et al. 2010)

Example of calculation for CNC Keller:

Machining Trial 1 calculation

The cutting speed, $V$ is 210 m/min and cutting tool is Ø25.00 mm. Thus, it needs to find rotational speed of the cutter.

By using Equation 1.0, the Cutting Speed, $V = \pi DN$

Thus, the rotational speed of cutter, $N = \dfrac{V}{\pi D}$

$$= \frac{210}{\pi \; X \; (25^{-3})}$$

$$= 2673.80 \text{ rpm}$$

Based on table the feed per tooth, $f$ is 0.16 mm/tooth and the number of teeth, $n$ is 6.

By using Equation 2.0, the feed rate, $v = fNn$

$$= 0.16 \text{ x } 2673.80 \text{ x } 6$$

$$= 2566.85 \text{ mm/min}$$

The machining parameters for CNC Keller, Mastercam and CATIA are tabulated in section 4.2 and the detail of calculation can be found in Appendix 3.

**3.5 CNC machining in CNC Simulators**

In this experimental phase, the CAD model is imported into three type of CNC Simulators; CNC KELLER, Mastercam X2 and CATIA V5. This approach is to study the capability, machinability and processablity of the CAD model before undergoes real machining by using CNC machine. Figure 3.3 show the flow to generate simulation process to fabricate. The figure show summary flow from start to end of simulation program till fabrication.
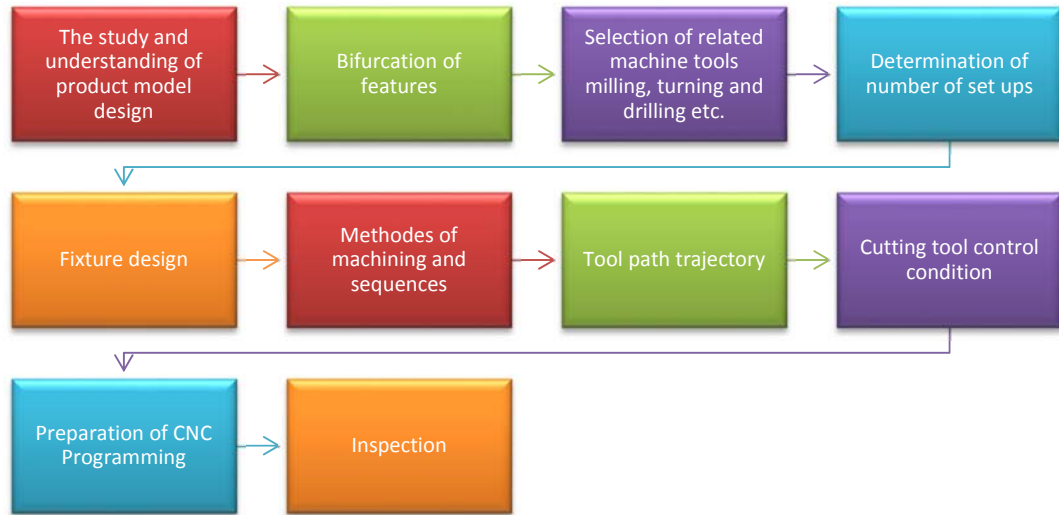
Figure 3.3: Flow using simulation to fabrication.

### 3.5.1 Setup and machining parameters in CNC KELLER

The first approach is implemented by is import model from SolidWorks into CNC Keller. Figure 3.4 show the CAD model imported into CNC Keller. The exchange specification used is DXF. The sketch of the model in DXF can be found in Appendix 2. The reason of using DXF exchange specification is described in section 4.3.1.
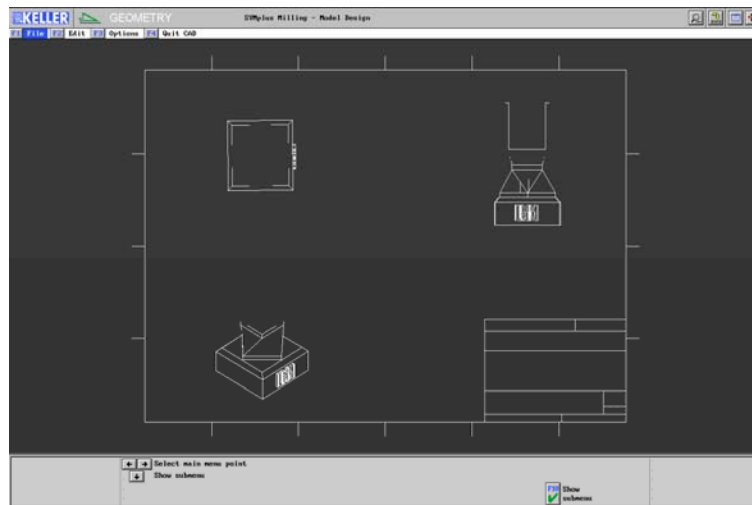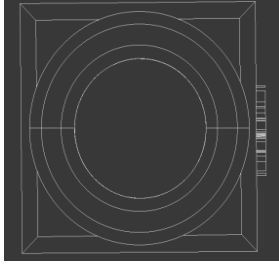


Figure 3.4: DXF file format imported into CNC Keller.

Two type of orientation setup is used in order to simulate the CAD model. In Table 3.2 shows the two type of orientation setup for CAD model that used in CNC Keller. This method used to identify which side of workpice able to generate better toolpath trajectory. This approach is to investigate the capability and machinability of CNC Keller by using CNC 3-Axis milling machine to simulate simulation by using different type of orientation.

Table 3.2: Machining parameters used as input data for CNC Keller simulation program

| Orientation set: | 0° | 90° |
|---|---|---|
| Type of view | Right | Top |
| View set |  |  |
| Stock Specification: | X: 133mm | X: 80mm |
| | Y: 90mm | Y: 90mm |
| | Z: 80mm | Z: 133mm |
| Material Selection: | Stainless steel | Stainless steel |
| Machine selection: | CNC 3-Axis milling | CNC 3-Axis milling |
| Roughing operation: | Surface | Surface |
| Type of tool: | Flat Endmill | Flat Endmill |
| Tool size (mm): | Ø25.00 | Ø25.00 |
| Tool length (mm): | 80.00 | 80.00 |
| Number of teeth: | 6 | 6 |

## 3.5.2 Setup and machining parameters in Mastercam X2

Second approach is executed by import model into Mastercam. Figure 3.6 show the CAD model imported into Mastercam. The data format that suitable to transfer CAD model is IGES.
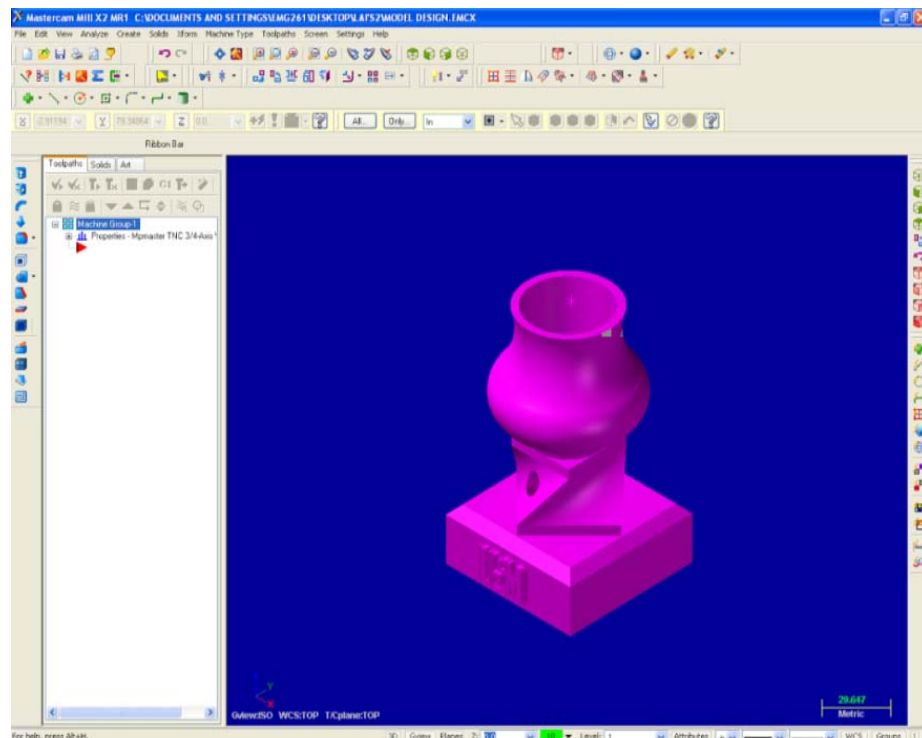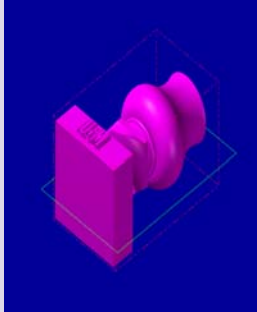


Figure 3.5: CAD model being imported into Mastercam.

Two type of setup is used in order to simulate the CAD model. In Table 3.3 show the two type of orientation for CAD model used in Mastercam. This method used to identify which side of workpice able to generate better toolpath trajectory for the workpiecet. This approach is to investigate the capability and machinability of Mastercam in CNC 3-Axis milling machine to simulate simulation by using different type of orientation.

Based on Table 3.3 summarizes the machining data for the models that was used as input for the simulation program.

Table 3.3: Machining parameters used as input data for Mastercam simulation program.

| Orientation set: | 0° | 90° |
|---|---|---|
| Model Orientation: |  |  |
| Stock Specification: | X: 80mm | X: 133mm |
| | Y: 90mm | Y: 90mm |
| | Z: 130mm | Z: 80mm |
| Material Selection: | Stainless steel | Stainless steel |
| Machine selection | CNC 3-Axis milling | CNC 3-Axis milling |
| Roughing operation: | Surface Rough Pocket | Surface Rough Pocket |
| Type of tool: | Flat Endmill | Flat Endmill |
| Tool size (mm): | Ø10.00 | Ø10.00 |
| Tool length (mm): | 130 mm | 130 mm |
| Number of teeth: | 6 | 6 |
| Cut depth (mm): | 130.00 | 80.00 |

### 3.5.3 Setup and machining parameters in CATIA V5

Third approach is the 3D cad model is simulated buy using CATIA. This approach is to identify the capability of CNC Simulator to machining a complex model. The CAD model is imported by using IGES format into CATIA.

In this experiment, one type of setup is used in order to simulate the CAD model. Figure 3.6 is show model imported into CATIA. This method used to identify capability of CATIA to simulate from roughing operating till finishing operation by using CNC 5-Axis milling machine.