

**Fabrication of a Small Scale Model of Chancellor Award Trophy using  
CAD/CAM and CNC Milling Machine**

by

Ihsan Mohd Zain

Dissertation submitted in partial fulfilment of  
the requirements for the  
Bachelor of Engineering (Hons)  
(Mechanical Engineering)

JANUARY 2008

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# CERTIFICATION OF APPROVAL


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in partial fulfillment of the requirement for the  
BACHELOR OF ENGINEERING (Hons)  
(MECHANICAL ENGINEERING)

Approved by,

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(Dr Ahmad Majid Abdul Rani)

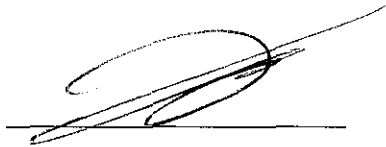
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January 2008

## **CERTIFICATION OF ORIGINALITY**

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

A handwritten signature in black ink, consisting of a large, stylized loop followed by several horizontal strokes, positioned above a solid horizontal line.

IHSAN MOHD ZAIN

## **ABSTRACT**

The Final Year Project (FYP) is to manufacture a small scale model of Chancellor Award Trophy using Computer Aided Design (CAD)/ Computer Aided Manufacturing (CAM) and Computer Numerical Control (CNC) milling. The main purpose of the project is to manufacture the model by utilizing the tools and machine provided in UTP. The objectives of this project are to create 2D and 3D model (CAD) drawing of the model, to define tool path for NC codes development (CAM) and to fabricate the model using CNC milling machine (CAM). Clear and sufficient understanding of CAD/CAM process and software is needed in order to create 2D and 3D drawing thus to generate NC codes for manufacturing. The methodology involve in this project are studying and research on CAD/CAM component and familiarization on Unigraphics NX software. Next is to come up with the 2D drafting and 3D solid model drawing of the model using Unigraphics NX software. Then, overall shape and dimension of the part from the drawing will be used to define tool path to allow the Unigraphics NX software to generate the coding for CNC machining. The end results of this project are; i) 2D drafting and 3D solid model drawing, ii) Tool path , iii) NC codes, iv) Small scale model of the trophy.

## **ACKNOWLEDGEMENT**

All praise be upon Allah s.w.t Almighty and peace upon Prophet Muhammad s.a.w. I would like to express my gratitude to all people that have been involved with this project, directly or indirectly.

First, my appreciation is to Dr Ahmad Majdi Abdul Rani and Mr. Hilmi Hussin, Lecturers of Mechanical Engineering Department, Universiti Teknologi Petronas, for their guidance, helps and understanding concerning this project.

I would also like like to extend my personal thanks to the Mr Hafiz Safian, Laboratory Technician of Mechanical Engineering Department, Universiti Teknologi Petronas, for his help, support and willingness to share his experience and guided me through this project.

Finally, I would like to thanks to my lovely parent for their continuous support and who has been my strength during my time of need.

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# CHAPTER 1

## INTRODUCTION

### 1.1 Problem Statement

The Chancellor Award trophy (Figure 2.1) is an expensive model that stands a price of thousands of ringgit. It is manufactured by Royal Selangor International Sdn Bhd, made of pewter (composed of tin, with a small proportion of copper and antimony). The high cost bear by the Universiti Teknologi PETRONAS can be reducing tremendously if the manufacturing of the model is done in the campus. Therefore, this project will come up with a small scale of the model (made of aluminum), using the provided in the UTP besides strong knowledge and skills of software (Unigraphics NX3) being applied during the CAD/CAM and manufacturing process.

### 1.2 Objective

The main purpose of this project is to come up with small scale model of the Chancellor Award Trophy. Below are the objectives of this project:

- To develop skills in modeling 2D/3D design and manufacturing using CAD/CAM.
- To generate NC codes for milling machine.
- To learn and understand how the tools and equipments involved works.
- To learn and understand various component of CAD/CAM

### 1.3 Scope of Study

The scopes of study of this project are

- Unigraphics NX 3 for CAD and CAM
- CNC Milling Machine (MAZAK VARIAXIS 630-5X)

## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1 CAD/CAM**

Computer-aided design (CAD) is mainly used as the tool that assists in 2D drafting and 3D solid model in designing and drawing the Chancellor Award Trophy (Figure 2.1). It involves both software and special-purpose hardware. The software to be use for CAD is Unigraphics NX 3. Unigraphics NX is a powerful CAD/CAM software developed by Siemens, it enable the drawing of the model of Chancellor Award Trophy, as the model is complex and difficult to draw. Thus from the drawing, information on size of raw material, tool selection, spindle speed, feeds and depth per cut to be used can be obtained. [1]

Computer-aided manufacturing (CAM) is used in manufacturing the model of Chancellor Award Trophy. CAM has been considered as an NC programming tool [2] in which 3D model of Chancellor Award Trophy drawn in Unigraphics NX, plus the defined part program is passed through processor and post processor in CAM module which is Unigraphics NX to generate codes that can be read by CNC machine control unit (MCU) to drive CNC machine tools. CAM is also help to check for programming inconsistencies, simulation, and calculates the detail path that the cutting tool's center line must follow to ensure the model can be manufactured [3].



Figure 2.1: Chancellor Award Trophy

Today's CAD technology can provide the engineer the necessary help in the following ways [4]:

1. CAD is faster and more accurate than conventional method
2. CAD would make the job of developing the model and associated drafting a very easy task
3. CAD enables to manipulate various dimensions, attributes and distance of the drawing elements.
4. Never have to repeat the design or drawing of any component, once a component has been made, it can be copied in all further works within seconds.
5. CAD can accurately calculate the various geometric properties including dimension of various component.
6. Modification of a model is very easy and would make the task of improving a given product is simple for the future requirement.

CAM advantages [5]:

1. Greater design freedom; Any changes that are required in design can be incorporated at any design stage without worrying about delay, since it is integrated with CAD
2. Increased productivity; It is possible to increase productivity since the total manufacturing activity is completely organized through the computer.
3. Greater operating flexibility; CAM enhances the flexibility in manufacturing methods and changing the product lines.
4. Shorter lead time; Lead times in manufacturing reduced.
5. Improved reliability; This is because of the better manufacturing methods and controls at the manufacturing stages.
6. Reduced maintenance; Since most of the components of a CAM system include integrated diagnostic and monitoring facilities.
7. Reduced scrap and rework; This is because of the use of CNC machines in the production, and the part programs being made by the stored geometry from the design stage.
8. Better management control; Since all the information and controlling functions are attempted with the help of computer.

## **2.2 Unigraphics NX (NX)**

NX is a next-generation digital product development system that helps companies transform the product lifecycle. With the industry's broadest suite of integrated applications, NX touches the full range of development processes in product design, engineering and manufacturing. NX delivers unified production-proven applications and process automation tools integrated into a single management and collaboration backbone. [6]

### **2.2.1 NX CAD**

NX is flexible in mechanical design and engineering. NX offers CAD solutions for the design of complex mechanical products. NX design applications include tools for, human modeling, modeling, assembly design, system-based modeling, user-defined features and etc. NX dynamically integrates CAD design with planning, simulation, manufacturing and other development processes to help ensure that design decisions can be made more quickly, with detailed knowledge of product performance and any potential manufacturability issues. [7]

### **2.2.2 NX CAM**

With NX CAM, NC programming and machining processes can reduce waste and boost productivity. Driven by the requirements of manufacturing companies worldwide, NX CAM offers great flexibility in machining methods and a wide range of machine tool programming capabilities. [8]

Some of the key features and benefits:

1. Advanced capability in key machining areas including High Speed Machining
2. 5-Axis machining and the support of multi-function machine
3. In depth functionality that gets the programming job done, even on the toughest parts.
4. Complete programming package with everything from a wide range of NC programming functions in the same system: turning, basic milling and drilling, fixed axis milling, variable axis milling, feature based automated programming, support for multi-function machining and wire EDM.



## 2.3 CNC Milling Machines

The horizontal CNC milling machine and vertical machining centre (VMC) (refer Appendix 1) are probably the most common CNC machines tools found in shops today. They are very agile machines and can be easily adapted to a great variety of work piece.

Vertical CNC milling machines are easy to load, and their operators have good visibility. Vertical CNC machining centers are usually consider good all purpose machine tools, but they are not as heavy duty as their horizontal. Chips can also be difficult to remove, as they tend to fall back into cutting zone.

Vertical machining centers are typically made in a bed-type construction, whereas a vertical CNC milling machine uses the knee and column construction. Knee and column machine tens to be fairly small and movable quill. Bed type construction is more readily larger machines.

Vertical machining centers are often manufactured with three linear axes of motion- much like a standard milling machine. But today, a fourth or fifth rotational axis is available such as MAZAK VARIAXIS 630-5X (Appendix 2) located in building 16 of UTP which will be use to fabricate the chancellor award trophy model of this project. This additional axis can be a simple rotary table or complex milling head that swivels.

The horizontal machining centers (HMC) are similar in construction to the conventional horizontal milling machine. However, its use is often very different. Conventional horizontal mills commonly use cutting that are mounted to an arbor. CNC horizontal mills seldom use arbor-mounted tooling. HMCs usually use spindle-mounted cutting tools in the same way a VMC. Actually an HMC is basically a VMC that has been tipped over 90 degrees.

There are some advantages to the HMC construction and configuration. First, the spindle is mounted to a stationary and extremely rigid base. This rigid construction is ideal for heavy cutting and high metal removal rates this brings us to the second advantage which the tools and the work piece are mounted horizontal. If we are going to remove a lot of material, then we are going to produce many chips. Chips that get stuck in the cutting zone can ruin the finish and destroy the cutting tools. The horizontal configuration allows gravity to help remove the chips.

The disadvantages of HMCs are that work piece is often mounted horizontally. It tends to be more difficult for the operator to hold and align heavy work piece while fighting gravity. Another disadvantage is that it can be difficult for the setup person and the operator to see the tool and cutting zone.

#### **2.4 Mazak Variaxis 630-5X**

Mazak Variaxis 630-5X is one type of vertical machining center, VMC. The main feature of Mazak Variaxis 630-5X is that it has highly-rigid, built-in tilting rotary table (5 axis machining) that allows workpieces with complex contours and features such as the Chancellor Award Trophy to be finished in a single machine setup. It has tremendous weight capacity and will increase machining accuracy while reducing cycle time.[9] The schematic diagram of Mazak Variaxis 630-5X is illustrated in Appendix 3.

There are five primary axes on Mazak Variaxis 630-5X, the X, Y, Z, A and C axis. X, Y, A and C axes control the table and position the spindle to the CNC program coordinates. The Z axis control and moves the spindle base on the program coordinates. Table 2.1 show the description of Mazak Variaxis 630-5X.

VARIAXIS main characteristics [9]:

- Simultaneous 5-axis control
- Table tilts up to 150° (A-axis)
- Table rotates up to 380° (C-axis)
- Minimal thermal distortion – cooled ball screws and spindle

Table 2.1: Description of Mazak Variaxis 630-5X

Description	Variaxis 630-5X
Pallet Size	24.8" x 19.6"
X, Y, Z Travel	24." x 30.1" x 20"
Spindle	12,000 rpm – 30 hp; (25,000 rpm OPT)
Tool Shank Type	MAS BT-40, CAT-40
Tool Storage Capacity	30; (40, 80 OPT)

## 2.5 Mazak Variaxis 630-5X's Components

Mazak Variaxis 630-5X also has the same basic components as any other CNC machining centers such as the main motor, the spindle, the frame and the way system and etc. It also has a computerized control and servomotors to operate the machine.

The main component of CNC machining centers are [10]:

- Control panel
- Headstock
- Spindle
- Table
- Tools Magazine
- Automatic Tool Changing Arm (ATC)
- Servomotor
- Ball screw
- Lubrication system

### **2.5.1 Control Panel**

The modern CNC machine tool is software driven. The computer controls are programmed instead of being hardwired. The control panel (Appendix 4) is where the machine operation buttons and knobs are located [10].

### **2.5.2 Headstock**

The headstock (Appendix 5) contains the spindle and transmission gearing which rotates the cutting tool [11]. The headstock spindle is driven by a variable speed motor (in RPM). Mazak Variaxis 630-5X's headstocks are equipped with a variety of motor sizes that have power up to 30 hp and spindle speeds from 12,000 to 25,000 RPM [9].

### **2.5.3 Spindle**

The spindle (Appendix 5) is design with a taper bore that accurately aligns each tool that is clamped into it. The tool is clamped using a drawbar mechanism and retention knob the spindle is design with two keys that align and drive the tools the tools change arm holds the tools on the V-flange when loading and unloading [10].

### **2.5.4 Table**

The table (Appendix 5) is designed to hold the workholding device, which holds the work piece while it is being machines. The workholding device such as milling vise or a fixture is clamped to the table using bolts and nuts. The table can be programmed or manually operated to move in the X an Y axes. For Mazak Variaxis 630-5X, the table can be rotated up to 380° (C-axis) and tilts up to 150° (A-axis). The pallet size of Mazak Variaxis 630-5X is 24.8" x 19.6".[9] This pallet system allows the operator to perform work such as loading and unloading the workpiece while the machine is machining another part.

### **2.5.5 Tool magazine**

The basis function of the tool magazine is to hold and quickly index the Mazak's cutting tools. Mazak Variaxis 630-5X is equipped with a tool magazine (Appendix 6) that can hold a range of 30 to 80 tools [9]. The tool magazine can automatically change the cutting tool with the tool change arm. It is also capable to do bidirectional movement which it selects the tools using the quickest path available [10].

### **2.5.6 Automatic Tool Change Arm (ATC)**

ATC (Appendix 3) is designed to grasp and then remove the CNC tool from the tool magazine and inset it into the taper bore of the spindle [11]. The Mazak Variaxis 630-5X's ATC arm aligns each tool with the bore and the drive keys and it can complete a tool change in either manual or automatic mode in approximately 5 to 10 seconds [9].

### **2.5.7 Servodrive Motors**

Mazak Variaxis 630-5X uses electric servomotors that turn ball screws which in turn drive the different axes of the machine tool [9]. Each axis has a separate servomotor and ball screw to control X, Y and Z axes independent of each other. The rotary table also has its own servodrive motor which to turn and tilt the table at A and C axes.

### **2.5.8 Ball Screw**

The rotary motion generated by the drive motor is converted to linear motion by recirculating ball screws. The ball lead screw uses rolling motion rather than sliding motion of a normal lead screw [10]. Some advantages of ball screws that are used in Mazak Variaxis 630-5X are; less wear, precise position, high speed capability and longer life than lead screw. It also has minimal thermal distortion as the ball screws have been cooled [9].

## 2.6 Cutting Tools

An end mill is a cutting tool design to cut both the end and the side. Standard end mill perhaps the most common cutting tools used in conventional and CNC milling. End mills are commercially available in various type and style. The most common material for end mill is HSS, but end mills are also made from solid billets of cemented carbide. HSS end mills are inexpensive and used extensively to machine ferrous and nonferrous materials. Conversely, solid carbide end mills are about 5 times as expensive as HSS and have more limited application in nonferrous and non metallic materials. Carbides tend to brittle; therefore, the sharp edges found on solid carbide end mills don not tend to hold up very well for ferrous machining applications. However, some of the newer carbide grades have been engineered for ferrous machining operations. [12]

End mill can be described by their geometric features, which include the number of teeth/flute, the end-cutting style and the edge profile. The most obvious feature of a standard end mill is the outside teeth. The spaces between the individual teeth, which are called flutes, are used to remove chips. Small end mills are most commonly made with two, three or four flutes, and each has it own advantage.[12] Geometric features of end mill is illustrated in Appendix 7.

Two flute end mills usually have large flute and therefore more room to accommodate chips. These are often used for machining aluminum and light metals because the chips tend to be larger due to increased feed used on soft materials. Two flute end mills can be used on steel, but this is not the best choice. Four flute end mills have smaller flute, but they are stronger and stiffer than two flute end mills. Four flute end mill have more cutting edges to do the work and are better value than two flute end mills.[12] Table 2.2 shows the advantages and disadvantages of flute.

End mills are also classified by the ability to perform plunge cutting. Plunge cutting is similar to drilling, where the end mill is pushed straight down into the workpiece.

Not all end mills have this ability; some are center cutting while the rest are non centre cutting. Standard two flute end mills are usually center cutting. Conversely, standard four flute end mills are not. It is much more difficult to grind the end of a four flute end mill into center cutting geometry, and, therefore, more expensive. Center cutting, four flute end mills are available from supplier and are commonly used in CNC machining but high cost. [12]

End mills may also have a number of different profiles. A standard end mill has a square profile. Therefore, an end mill can create flat surfaces and straight sides simultaneously and will leave a sharp inside corner. The sides can also be ground to profile other than square for example; it is common to create a radius on the corner in order to cut inside fillet on the workpiece. An end mill with a full radius on the profile is called a ball end mill (refer Appendix 8). Alternatively, a smaller radius might be ground on the corner to create bull-nose end mill. Ball end mill are readily available from industrial supplier, but bull nose end mill are often a special order. [12]

End mills with a corner radius are important in CNC machining because the radius can be used to create surfaces that would not be possible under ordinary circumstances. For example, a ball end mill can be used to create a curved or angled surface on a workpiece by taking cuts that estimate the true shape of the desired surface. The resulting surface will have slight scalloped appearance, but this can be improved by programming finer steps. [12]

One other notable end mill profile is the roughing end mill. Roughing end mill have a serrated profile ground into the outside diameter. The serration has the effect of lowering the cutting forces while machining at an unusually high feed rate. A roughing end mill should be used anytime there are large amount of material to remove. The cost a little more than comparably sized standard end mill, but the increased productivity will more than make up for the additional cost. The downside

of roughing end mills is that the serration leaves a rough surface on any side that was milled. Another finishing operation will be required to smooth the surface. [12]

### **2.6.1 Face mills**

Face mills cutters are designed for various applications such as rough milling, finish milling, milling soft material or hard materials. They are basically used to mill flat surfaces within specified tolerances of 0.001 – 0.01 inch and finish rang from fine to rough. Face milling cutters are available in various cutter diameters sizes that include 2 – 12 inches. The face mill is designed with axial and radial rake angles that range from positive to negative. The cutting is performed by the carbide inserts which are available in a variety of geometry shapes.

### **2.6.2 End Mills**

End mills (Appendix 9) are available in various style and cutter materials. End mills are used for various applications such as contour shapes, key slots, plunge cutting and circular shapes. Some common style include: 2-flute, 3-flute, 4-flute center cutting, single ended, double ended and ballnose. The materials that they are made from include HSS, coated HSS, carbide tipped, solid carbide, carbide insert and coated carbide. They generally range in diameter sizes from 0.061 – 3 inches.

### **2.6.3 Slot Mills**

Slot mills are available in various style and materials. Slot mills are typically used for cutting slots with larger than average depths. Some common styles include narrow slot cutter, variable width cutter, half side cutter, face cutter and shell mount type. The materials that they are made from are same as end mills. They are generally range in diameter sizes from 3 – 12 inches.



Table 2.2: End mill's flute advantages and disadvantages.

No. of Flutes	Advantage	Disadvantage
Two	<ul style="list-style-type: none"> <li>▪ More room for chip evacuation.</li> <li>▪ Center cutting.</li> <li>▪ Primarily for light metals.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Weak and tend to deflect under load.</li> <li>▪ Shorter tool life.</li> </ul>
Three	<ul style="list-style-type: none"> <li>▪ Often used for stainless steel.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Less widely available.</li> </ul>
Four	<ul style="list-style-type: none"> <li>▪ More teeth for increased productivity and tool life.</li> <li>▪ Used for steel.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Clog up in deep cuts.</li> <li>▪ Center cutting style is less common.</li> <li>▪ Expensive.</li> </ul>

#### 2.6.4 Selecting a Milling Cutter

Selecting a milling cutter is not a simple task. There are many variables and opinions to consider, but essentially the best thing to do is to choose a tool which will cut the material to the required specification for the least cost. The cost of the job is a combination of the price of the tool, the time taken by the milling machine, and the time taken by the machinist. Often, for jobs of a large number of parts, and days of machining time, the cost of the tool is lowest of the three costs. [13]

- Material: High speed steel (HSS) are the cheapest, and shortest lived cutters. Carbide tools are more expensive, but last longer, and so prove more economical in the long run.
- Diameter: Larger tools can remove material faster than small ones, therefore the largest possible cutter that will fit in the job is usually chosen.
- Flutes: More flutes allow a higher feed rate, because there is less material removed per flute. But because the core diameter increases, there is less room for swarf, so a balance must be chosen.

#### 2.6.5 Chip Formation

Although there are many different types of milling cutter, understanding chip formation is fundamental to the use of any of them. As the milling cutter rotates, the

material to be cut is fed into it, and each tooth of the cutter cuts away small chip of material. Achieving the correct size of chip is of critical importance. The size of this chip depends on several variables. [14]

- Surface cutting speed ( $V_c$ )

This is the speed at which each tooth cuts through the material as the tool spins. This is measured either in meters per minute in metric countries, or surface feet per minute (SFM) in America. Typical values for cutting speed are 10m/min to 60m/min for some steels, and 100m/min and 600m/min for aluminum. This should not be confused with the feed rate.

- Spindle speed (S)

This is the rotation speed of the tool, and is measured in revolutions per minute (rpm). Typical values are from hundreds of rpm, up to tens of thousands of rpm.

- Diameter of the tool (D)

- Feed per tooth ( $F_z$ )

This is the distance the material is fed into the cutter as each tooth rotates. This value is the size of the deepest cut the tooth will make.

- Feed rate (F)

This is the speed at which the material is fed into the cutter. Typical values are from 20mm/min to 5000mm/min.

- Depth of cut

This is how deep the tool is under the surface of the material being cut. This will be the height of the chip produced. Typically, the depth of cut will be less than or equal to the diameter of the cutting tool.

The machinist needs three values; S, F and Depth when deciding how to cut a new material with a new tool. But usually values of  $V_c$  and  $F_z$  are given from the tool manufacturer. S and F can be calculated from formula below:

Spindle Speed:

$$S = \frac{2\pi V_c}{D}$$

Looking at the formula for the spindle speed, S, it can be seen that larger tools require lower spindle speeds, while small tools may be able to go at high speeds.

Feed rate:

$$F = zSF_z$$

The formula for the feed rate, F shows that increasing S or z gives a higher feed rate. Therefore, machinists may choose a tool with the highest number of teeth that can still cope with the swarf load.

### **2.6.6 Conventional Milling versus Climb Milling**

A milling cutter can cut in two directions, sometimes known as climb or conventional. Mechanism of Conventional Milling and Climb Milling is shown in Appendix 10.

#### **Conventional Milling**

The depth of the cut starts at zero thickness, and increases up to the maximum. The cut is so light at the beginning that the tool does not cut, but slides across the surface of the material, until sufficient pressure is built up and the tooth suddenly bites and begins to cut. Conventional milling usually requires maximum hold down clamping force on the workpiece, is usually recommended for machining castings, forgings and hot rolled steel. Conventional milling is also recommended for finishing cuts and where long tool length may cause excessive chatter and poor surface finish. [15]

## **Climb Milling**

Each tooth engages the material at a definite point, and the width of the cut starts at the maximum and decreases to zero. The chips are disposed behind the cutter, leading to easier swarf removal. The tooth does not rub on the material, and so tool life may be longer. However, climb milling can apply larger loads to the machine, and so is not recommended for older milling machines, or machines which are not in good condition. This type of milling is used predominantly on mills with a backlash eliminator. It usually requires less clamping forces on the workpiece, is usually recommended for machining parts that are thin, parts that are difficult to hold down and when milling work hardened materials. Also, machining marks or surface breakouts are minimized with the climb milling method. [15]

## **2.7 Material**

### **2.7.1 Aluminum**

In this project, the author use aluminum as a raw material (refer Appendix 39). Aluminum is a soft, lightweight, malleable metal with appearance ranging from silvery to dull gray, depending on the surface roughness. Aluminum is nontoxic, nonmagnetic, and nonsparking. It is also insoluble in alcohol, though it can be soluble in water only in certain forms. The yield strength of pure aluminum is 7–11 MPa, while aluminum alloys have yield strengths ranging from 200 MPa to 600 MPa. Aluminum has about one-third the density and stiffness of steel. It is ductile, and easily machined, cast, and extruded.[16]

Aluminum is remarkable for its ability to resist corrosion and its light weight. Structural components made from aluminum and its alloys are vital to the aerospace industry and very important in other areas of transportation and building. Corrosion resistance is excellent due to a thin surface layer of aluminum oxide that forms when the metal is exposed to air, effectively preventing further oxidation. The strongest

aluminum alloys are less corrosion resistant due to galvanic reactions with alloyed copper. [16]

Aluminum is the most widely used non-ferrous metal. Global production of aluminum in 2005 was 31.9 million tonnes. It exceeded that of any other metal except iron (837.5 million tonnes). Relatively pure aluminum is encountered only when corrosion resistance and/or workability is more important than strength or hardness. A thin layer of aluminum can be deposited onto a flat surface by physical vapor deposition or (very infrequently) chemical vapor deposition or other chemical means to form optical coatings and mirrors.[16]

Pure aluminum has a low tensile strength, but when combined with thermo-mechanical processing, aluminum alloys display a marked improvement in mechanical properties, especially when tempered. Aluminum alloys form vital components of aircraft and rockets as a result of their high strength-to-weight ratio. Aluminum readily forms alloys with many elements such as copper, zinc, magnesium, manganese and silicon (e.g., duralumin). Today, almost all bulk metal materials that are referred to loosely as "aluminum," are actually alloys.[16]

### **2.7.2 Pewter**

The original Chancellor Award Trophy is made from pewter. Pewter is a ductile , highly crystalline tin-based metal alloyed with traditionally between 85 and 99 percent tin, with the remainder consisting of 1-15 percent copper, acting as a hardener to make it stronger with the addition of lead for the lower grades of pewter, which have bluish color.[17]

The metal generally has a dull grey finish. The tin content of most pewter exceeds 90%, although there are exceptions. The metal possesses a low enough melting point to make it easy for casting. Influence of the Cu addition of up to 5mass% to Sn on

the hardness was hardly recognized. However, Sb addition to Sn enhanced the hardness remarkably. Addition of both Cu and Sb to Sn effectively enhanced the hardness of the Sn-Cu-Sb ternary alloys. The cause of the ternary alloys strengthening is thought to be related to the hardening of metal during the annealing process.[17]

This metal resists corrosion from distilled, sea and soft tap water, but can be attacked by strong acids, alkalis, and by acid salts. Tin acts as a catalyst when oxygen is in solution and helps accelerate chemical attack. Similarly, tin is attacked only slowly by dilute acids such as hydrochloric acid (HCl) and sulfuric acid (H<sub>2</sub>SO<sub>4</sub>). Dilute acids are mixtures that contain small amounts of acid dissolved in large amounts of water. This property also makes tin a good protective covering. It does not react with acids as rapidly as do many other kinds of metals, such as iron, and can be used, therefore, as a covering for those metals.[17]

Table 2.3: Properties Comparison between Aluminum and Pewter

Properties	Aluminum	Pewter
<b>Melting Point</b>	660.32 °C	231.9 °C
<b>Atomic Weight</b>	26.98154	118.71
<b>Boiling Point</b>	2519 °C	2270 °C
<b>Density</b>	2.702g/cc	7.31g/cc
<b>Bulk</b>	76 GPa	58.2 GPa
<b>Rigidity</b>	26 GPa	18.4 GPa
<b>Young's</b>	70 GPa	49.9 GPa
<b>Brinell</b>	245 MN m <sup>-2</sup>	51 MN m <sup>-2</sup>
<b>Mohs</b>	2.75	1.5
<b>Vickers</b>	167 MN m <sup>-2</sup>	-

## 2.8 Boundary Geometry

In Cavity and Contour Milling, the following boundary creation options are available to define and modify cut regions. Within a specific geometry type (part, blank, or check), you should not select a mixture of boundaries and solid geometry. For example, if you select a body as part geometry, you should not select a part boundary.

Part allows you to specify geometry that will represent the finished part. Blank allows you to specify geometry that will represent the raw material you wish to cut away. A Blank boundary does not represent the final part and can be cut through or engaged into directly. The blue block that enclosed the trophy (part) in Appendix 11 represents blank or raw material.

Check enables you to define geometry you do not wish to violate such as clamps that hold the part. The areas where the Check Geometry overlaps the volume of material to be removed will not be cut you may specify a Check Stock value which defines the distance the tool will be positioned from the Check Geometry. The red block below the trophy in Appendix 11 represents check.

When the tool encounters Check Geometry, it will either cut around the Check geometry or it will retract depending on the status of Follow Check in the Cut Parameters dialog box.

## **2.9 Cutting Method**

### **2.9.1 Zig-Zag**

Zig-Zag creates a sequence of parallel linear passes that cut in opposite directions while stepping over in one direction. This cut type maximizes cutting moves by allowing the tool to remain continually engaged during stepovers. The result of cutting in opposite directions is a series of alternate Climb and Conventional cuts. Specifying Climb or Conventional as the cut direction does not affect the behavior of this cut type but does affect the direction of Wall Cleanup when used with this cut type.[18]

If a Cut Region Start Point is not specified, the first Zig cut starts as close as possible to the start point of the peripheral boundary. The processor attempts to maintain linear Zig-Zag cuts, but allows the tool to follow cut region contours within the limits of the stepover distance to maintain a continuous cutting motion.

In the Appendix 13, for example, the last Zig-Zag pass deviates from a straight line and follows the shape of the cut region in order to maintain a continuous cutting path. The system allows the tool path to follow cut region contours along Zig-Zag passes as long as the passes do not intersect. Zig-Zag passes may only deviate from a straight line path a distance of less than the stepover value. In cases where Zig-Zag passes cannot follow cut region contours without intersecting other passes, the system generates a sequence of shorter passes and traverses between subregions as illustrated in Appendix 14. Stepovers always follow cut region contours.[18]

### **2.9.2 Zig**

Zig creates a series of linear parallel passes that cut in one direction. Zig maintains a consistent Climb or Conventional cut and performs no contour cutting between consecutive passes unless required to do so by the specified Engage method. The



tool engages at the start point of the cutting pass and cuts to the end point of the pass. The tool then retracts, traverses to the start of the next pass, and begins cutting in the same direction. The figure illustrated in Appendix 15 is the basic sequence of Zig tool movements for a Conventional cut.[18]

Like Zig-Zag, Zig generates passes that follow cut region contours provided the passes do not intersect. In cases where Zig passes cannot follow cut region without intersecting passes, the system generates a sequence of shorter passes and traverses between subregions as illustrated in Appendix 16.

### **2.9.3 Zig With Contour**

Zig With Contour creates a Zig cut pattern that follows the contours of the cut region between consecutive Zig passes. It rigorously maintains a Climb or Conventional cut. The tool path is defined as either Climb or Conventional based on the first Zig pass along the edge of the cut region. Appendix 17 illustrates the basic sequence of Zig With Contour tool movements for a Climb cut.[18]

Each of the above tool movements are listed in sequence and described below.

1. Initial Engage avoids engaging directly into a pocket corner or along wall.
2. Initial Stepper
3. Initial cutting pass cuts in the opposite direction of the remaining Zig passes.  
This pass defines the operation as Climb or Conventional.
4. Stepper
5. First zig pass
6. Retract
7. Traversal
8. Engage
9. Stepper
10. Second Zig Pass
11. Stepper

The sequence of tool movements 6 through 11 continue to repeat. Zig With Contour cuts in a series of "loops" as illustrated in Appendix 18. The first loop has four sides, while all subsequent loops have only three sides.

The tool engages at the end of the bottom of the first loop. In the above example, this position is at the bottom right corner of the first loop. By doing this, the tool engages into the material to be removed and avoids engaging directly into the corner of a cavity or along a wall, producing a cleaner cut. The system defines the bottom side of each loop by the general direction in which the tool moves across the part as it progresses from one loop to the next. The tool progresses in a general direction from top to bottom of each loop.[18]

Once the first loop has been completed, the tool traverses to the beginning of the second loop. Because the bottom of the first loop corresponds to the top of the second loop, the second loop has only three remaining sides left to cut. The system therefore engages the second loop (in the above example) at the beginning of the left side. This pattern continues to repeat for subsequent loops.[18]

By understanding how Zig With Contour cuts in a series of loops, it becomes apparent why the first pass cuts in the opposite direction of the remaining Zig passes. The first pass is at the top of the loop while the subsequent passes are at the bottom of the loops.[18]

Stepovers are cutting moves and follow the cut region contours as illustrated in Appendix 19. Zig passes also follow cut region contours provided the contours do not cause the passes to intersect.[18]

Because all moves are cutting, the system does not recognize this cut type as having stepovers when you assign feed rates. The assigned cut feed rate therefore affects all cutting moves including stepovers.[18]

In cases where Zig passes cannot follow cut region contours because of intersecting passes, the system generates a sequence of shorter passes and traverses between subregions.[19]

#### **2.9.4 Follow Periphery**

Follow Periphery creates a cut pattern that produces a sequence of concentric passes following the contours of the cut region. The cut pattern will be generated by offsetting the peripheral loop of the region. When passes are overlapped with the inner shapes of the region, they will be merged to form one pass which then will be offset again to form the next pass. All passes within the machinable region will be closed shapes.[18]

Like Zig-Zag, Follow Periphery maximizes cutting moves by allowing the tool to remain continually engaged during stepovers. In addition to specifying the cut direction as Climb or Conventional, the Pocket Direction must be specified as Inward or Outward. Appendix 20 illustrates the basic sequence of Follow Periphery tool movements using a Climb cut and an Outward pocket direction.[18]

When using an Inward pocket direction, the side of the tool nearest the center of the cut pattern determines Climb or Conventional. When using an Outward pocket direction, the side of the tool nearest the edge of the cut region determines Climb or Conventional.

Appendix 21 show how a Climb cut when used in combination with an Inward pocket direction produces a Conventional cut along the wall on the first pass. To avoid this, you can add Part Stock to move the first pass away from the wall and then specify a Finish Pass. The Finish Pass will produce a final profile cut along the wall to remove the Part Stock and maintain the specified Climb cut.[18]

Tool Paths do not cross one another. In cases where one area requires more pocketing passes than another area, the tool traverses between the subregions to complete the larger area as illustrated in Appendix 22. If many traversals are required, Region Connection can be used to optimize the tool motion.[18]

Whenever the stepover is very large (stepover > 50% of the tool diameter, but < 100% of the tool diameter) some areas may not be cut between consecutive passes. For these areas, the processor will generate additional cleanup moves to remove the material.[18]

Diagonal tool movements called tusks are generated at the corners of inner passes to remove material from corners. Tusks in Appendix 23 become necessary when the stepover is large in relation to the tool diameter and there is no overlap between passes at the corners.

### **2.9.5 Follow Part**

Follow Part creates a cut pattern by forming an equal number of offsets (where possible) from all specified Part geometry. Unlike Follow Periphery which offsets only from the peripheral loop (defined by Part or Blank geometry), Follow Part creates the cut pattern by offsetting from all Part geometry whether it defines the peripheral loop, islands, or cavities. It therefore guarantees the tool will cut along all Part geometry and eliminates the need for an Island Cleanup Pass. Follow Part offsets from Blank geometry only when there is no defined Part geometry to offset

from (as in the case of facing regions). Part geometry defining cavities and islands is offset as illustrated in Appendix 24 to create a Follow Part cut pattern.[18]

Whenever the stepover is very large (stepover > 50% of the tool diameter, but < 100% of the tool diameter) some areas may not be cut between consecutive passes. For these areas, the processor will generate additional cleanup moves to remove the material.[18]

It is recommended to use Follow Part for cavity regions with islands. This will eliminate the need to use Follow Periphery with Island Cleanup. Follow Part will ensure that all Part geometry will be cut completely without setting any toggles. The system attempts to create an equal number of offsets from all Part geometry. Intersecting offsets do not cross, but trim to one another as illustrated in Appendix 25 and Appendix 26.[18]

Unlike Follow Periphery, Follow Part does not allow you to specify a Pocket Direction of Inward or Outward. Instead, the system determines the Pocket Direction (stepover direction) as always cutting toward the Part geometry. In other words, for each set of offsets, the offset closest to the Part geometry is the last cutting pass. For cavities, the stepover direction is outward (cutting passes get continually larger as they progress toward the Part), while for islands the stepover direction is inward (cutting passes get continually smaller as they progress toward the Part).[18]

## 2.10 Stepover and Scallop

Stepover in Appendix 27 controls the distance between successive Cut Passes. You may specify the Stepover in terms of the scallop size or the total number of Stepovers. The Stepover options vary depending on the Cut Type used.

Scallop allows you to specify the maximum allowable size of Scallops by specifying values for height, horizontal, and vertical distances. This method is useful for good Scallop Height Control when the Drive Surface is also used as the Part Surface. The system limits the size of the stepover to roughly less than two-thirds of the tool diameter regardless of what you specify as the scallop size. After selecting Scallop Height, the system provides the following options:[19]

### **1. Scallop Height**

Scallop Height is the maximum allowable height measured normal to the Drive Surface.

### **2. Horizontal Limit**

Using a flat bottom tool may result in large stepovers on the part floor. Horizontal Limit controls these large stepovers by restricting the distance a tool may move in a direction normal to the Projection Vector. This option helps you avoid leaving wide ridges on near horizontal surfaces by limiting the horizontal distance of the Stepover.

### **3. Vertical Limit**

Machining walls may result in large stepovers. Use Vertical Limit to control the size of these stepovers. Vertical Limit allows you to restrict the distance a tool may move in a direction parallel to the Projection Vector. This option helps you avoid leaving wide ridges on near vertical surfaces by limiting the vertical distance of the Stepover.

### **4. Number**

Number allows you to specify the total number of Stepovers for the Tool Path.

If the Cut Type you select is Follow Pocket, enter the Number of Stepovers for the First Direction (i.e., cut direction) and for the Second Direction (i.e., Stepover direction).

## 2.11 Surface Area Drive Method

The Surface Area Drive Method enables you to create an array of Drive Points that lie on a grid of Drive Surfaces (refer Appendix 28). This Drive Method is useful in machining very complex surfaces requiring a variable Tool Axis. It provides additional control of both the Tool Axis and the Projection vector.[20]

The Tool Path is created on the selected Part Surfaces by projecting points from the Drive Surfaces in the direction of a specified Projection Vector. If Part Surfaces are not defined, the Tool Path can be created directly on the Drive Surfaces. The Drive Surfaces need not be planar, but must be arranged in an orderly grid of rows and columns as illustrated in Appendix 29. Adjacent surfaces must share a common edge and may not contain gaps that exceed the Chaining Tolerance defined under Preferences. Trimmed surfaces can be used to define Drive Surfaces as long as the trimmed surface has four sides. Each side of the trimmed surface can be a single edge curve or comprised of multiple tangent edge curves that can be thought of as a single curve.[20]

The Surface Area Drive Method will not accept Drive Surfaces that are arranged in uneven rows and columns or that have gaps that exceed the Chaining Tolerance as illustrated in Appendix 30.

The Surface Area Drive Method provides maximum control of the Tool Axis. Variable tool axis options become available which allow you to define the Tool Axis relative to the Drive Surfaces. Additional Tool Axis control is sometimes necessary to prevent excessive tool undulations when machining very contoured Part Surfaces as illustrated in Appendix 31. In some cases, Drive Surfaces are created specifically to control the Tool Axis. In other cases, as illustrated in Appendix 32, existing surfaces are used as Drive Surfaces.[20]

The Surface Area Drive Method also provides maximum control of the Projection Vector. An additional Projection Vector option, Normal to Drive, is available. This option enables you to evenly distribute Drive Points on to very convex Part Surfaces (Part Surfaces whose relative normals exceed 180 degrees). Unlike a boundary, Drive Surfaces can be designed to wrap around the part surfaces to project Drive Points evenly on to all sides of the part as illustrated in Appendix 33.[20]

If the surfaces you wish to machine meet the criteria for Drive Surfaces (arranged in an orderly grid with no gaps) it may be preferable to generate a Tool Path directly on the Drive Surfaces (refer Appendix 34) by not selecting any Part geometry. Because Drive Points are not projected on to Part Surfaces, the Projection Vector definition becomes irrelevant. The Material Side vector direction determines which side the tool contacts when cutting directly on the Drive Surfaces. Material Side Vector should point towards the material to be removed.[20]

When creating a Tool Path directly on the Drive Surface, Tool Position should be toggled to Tanto. Depending on the Tool Axis used, On may violate the Drive Surface as illustrated in Appendix 35.

Drive Surfaces must be selected in an orderly sequence. They may not be selected randomly. The sequence in Appendix 36 in which you select adjacent surfaces defines the rows. When you finish selecting the first row, you must specify that you wish to begin selecting the next row. You must then select the second row of surfaces and all subsequent rows in the same order as the first.[20]

### **2.11.1 Normal to Drive**

Normal to Drive allows you to define a Variable Tool Axis perpendicular to the Drive Surface at each the Drive Point. Because this option requires a Drive Surface, it is only available if the Surface Area Drive Method is used. Normal to Drive can be



used to Control Tool Axis movement over very complex Part Surfaces as illustrated in Appendix 37.[20]

The Drive Surface (refer Appendix 11 and Appendix 37) was constructed specifically to control the Tool Axis as it machines the Part Surface. Because the Tool Axis follows the contour of the Drive Surface rather than the Part Surface, it has a much smoother Zig-Zag movement. You may machine the Drive Surface directly as illustrated in Appendix 38 when there is no defined Part Surface.

## **CHAPTER 3**

### **METHODOLOGY**

First step is to study and do some research regarding all the components, parts, equipments and tools that suitable to produce the model of Chancellor Award Trophy. Then, 2D and 3D drawing will develop using Unigraphics NX3 software. The drawing of the model is examined to establish the overall shape and dimension of the part, the accuracy required and the material from which is to be made. This information will enable the selection of the size of raw material, tooling, speed, feeds and depth of cut that should be used.

Then the part programming will be generated and defined. It contains two parts: The first one is geometrical data; contain the dimensional information that geometrically describes the part required. The second one is technological data; contain all the necessary data for the machine tool to select the required tooling in the correct sequence, cut at the correct speeds, feeds and depth of cuts and also the coolant control.

The part program is then passed to the processor (Unigraphics) to convert alphanumeric program into computer machine codes (NC codes). During the process, processor or CAM module which is Unigraphics will check for programming inconsistencies, simulation, expand shorthand instructions into full individual instructions and calculates the detail path that the cutting tool's center line must follow to ensure the required part is produced.

Before continuing to the next stage, those codes or programs need to check for gouges. If gouges found, the program must be corrected and check again. To turn the program into one that can be understood and acted upon by Mazak's machine control unit (MCU), it is put through the post-processor which also using Unigraphics. Finally Mazak will fabricate the module as required. Figure 3.1 below show the flow chart of the project.

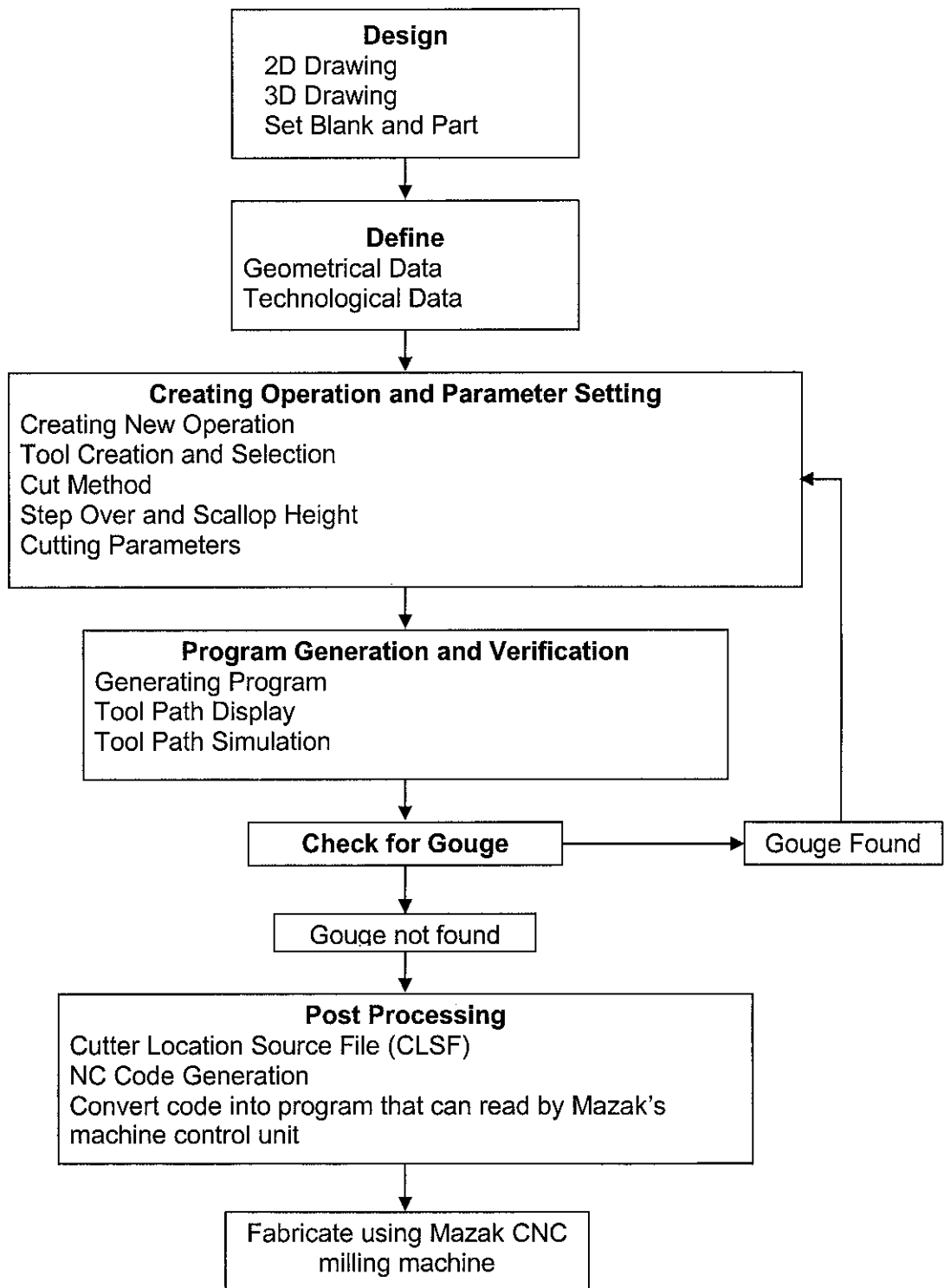


Figure 3.1: Flow chart of the project

## CHAPTER 4

### RESULTS AND DISCUSSION

#### 4.1 CAD Development

In order to create 3D design of the trophy of the Chancellor Award, the actual trophy was examined to get the dimension and shape of the trophy. Then the 3D model of the trophy is developed using Unigraphics NX3. Figure 4.1 until Figure 4.4 below are the illustrations of the steps involved during the development of CAD.

To begin the drawing, *Application>Modeling* tab was selected at the top menu of Ungraphics NX software. Then all the drawing menu and option will appear. The cylinder block was created first, then from the cylinder, operation like extrude, subtract, unite, taper and other operation was used to come up with the model that have almost the same shape as the original trophy. At the end, the author use face blend and edge blend option to smoothen the face and the edge of the trophy

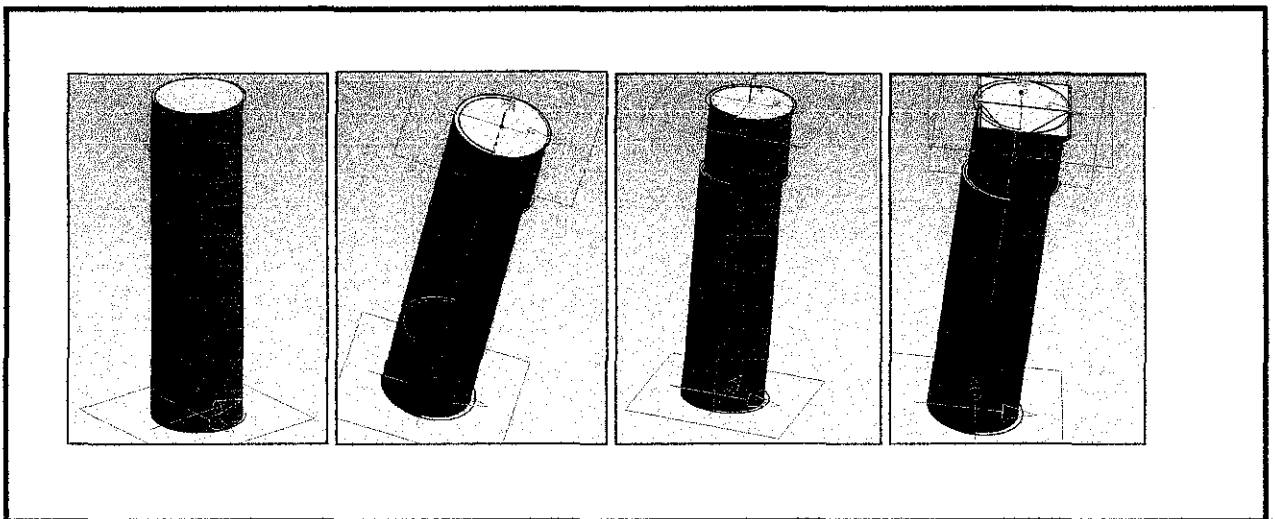


Figure 4.1: CAD Development

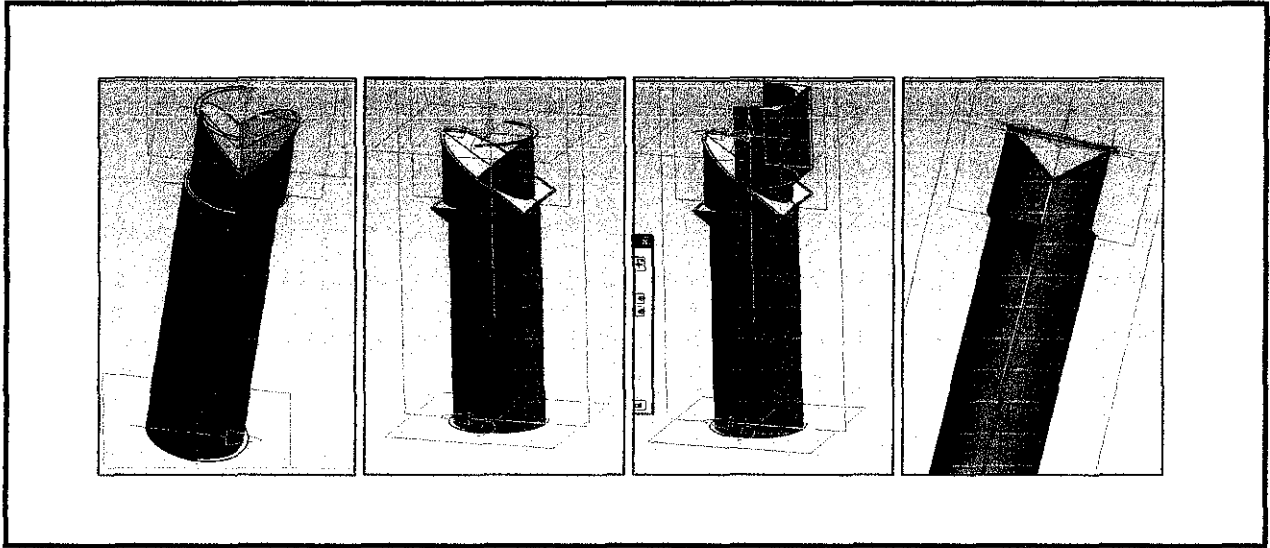


Figure 4.2: CAD Development

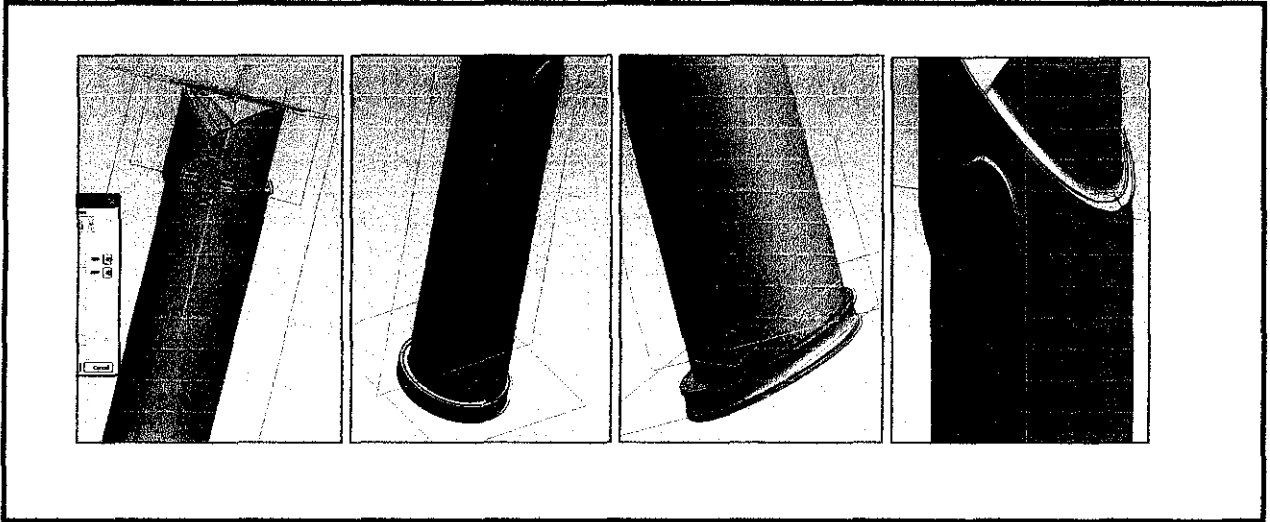


Figure 4.3: CAD Development

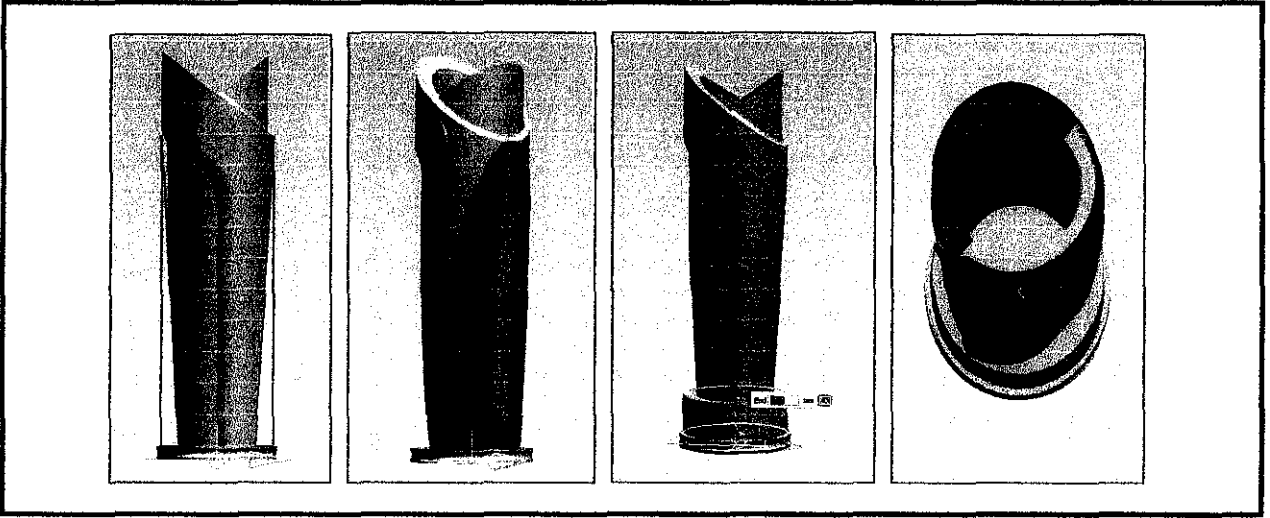


Figure 4.4: CAD Development



Figure 4.5: Front View

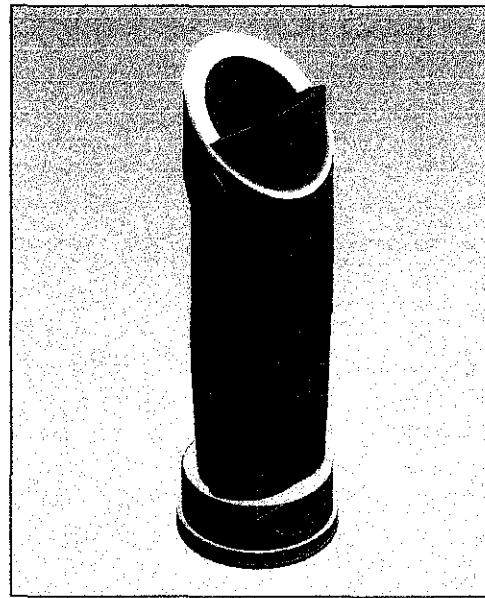


Figure 4.6: Isometric View

Figure 4.5 and figure 4.6 show the isometric view and back view of the model that has been created. The author also manages to develop the 2D drafting (Appendix 40) that shows the dimensional information of the model that was useful in CAM part.

## 4.2 CAM Development

### 4.2.1 Creating of Blank and Boundary Geometry

The data (shape and size) of the raw material for the design has to be put into Unigraphics NX before the CAM development start. This can be done in two ways. The first method is by creating the model of the raw material as a separate solid in the same file and assigning the solid as a blank. The second method is by letting the software decide the extreme dimensions of the designed part and if required, some offset values. For this project, the author uses the first option. A block was created to enclose the entire model as illustrated in Appendix 11. The block was assigned as a blank and the model was assigned as a part. There is also some part of the blank was set as a check where the clamp location situated. It is to make sure that the cutter will not collide with the clamp.

## 4.2.2 Setting Machine Environment

Before proceed to the next step, Unigraphics NX needs to be set into manufacturing configuration. This was done by selecting *Application>Manufacturing*. There are many different customized CAM session available for different machining operations. For this project, the entire process will be done through milling process. Next, in Machining Environment menu (refer Figure 4.7), *mill\_multiaxis* and *mill\_contours* were selected for CAM Session Configuration and CAM Setup respectively. Once this done, *Initialize* tab was clicked.

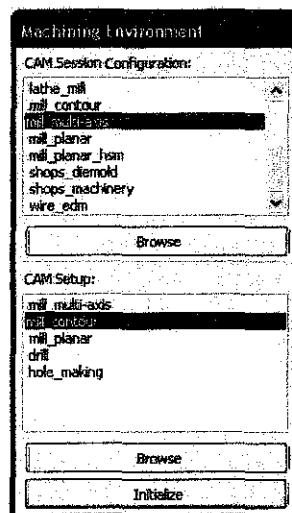


Figure 4.7: Machining Environment Menu

## 4.2.3 Coordinate System

To initiate the setup for programming, the *Geometry View* icon was clicked. *MCS\_MILL* was selected. After a pop up window (Figure 4.8) appeared, the MCS was placed at the top centre of the blank for multi-axis machining (variable contour operation) and right side of the blank for 3-axis machining (cavity mill operation) as illustrated in Figure 4.9. Then the MCS's new location was saved. The WCS also relocated to the same location as MCS.

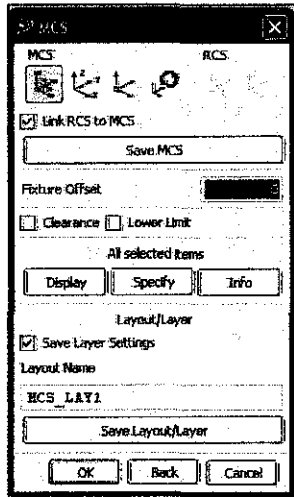


Figure 4.8: MILL\_ORIENT Dialog

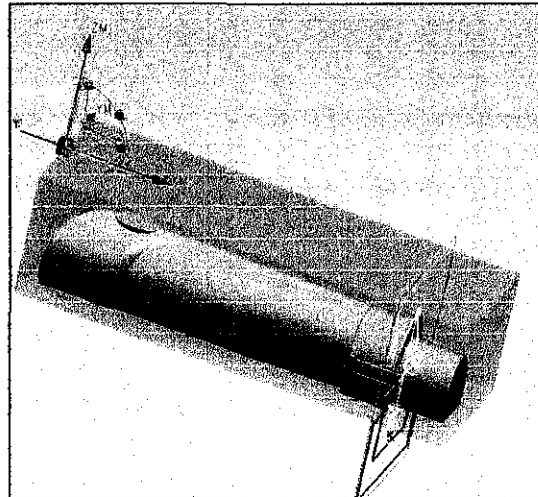


Figure 4.9: MCS and WCS Location

### 4.2.4 Geometry Definition

In *Geometry View* menu, *Workpiece* tab was clicked. A popup window appeared (refer Figure 4.10). Using this window, the part geometry, blank geometry and check geometry can be assigned. First the part or the model of the trophy were selected by clicking at the *Part* tab and then click to the trophy that has been drawn. Next, the blank geometry and the check geometry were selected using the same method. Once all three geometries have been selected (refer Appendix 11), **OK** was clicked. With that the part, blank and check geometry were assigned.

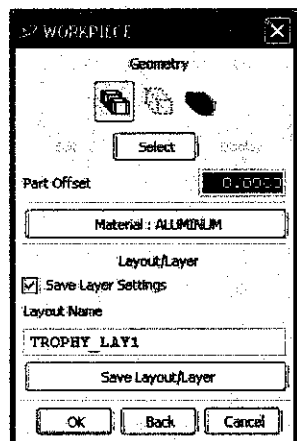


Figure 4.10: Geometry Dialog



## 4.2.5 Creating Tools

In this project, there are 4 tools that must be set up before create the operation. The first tool is the drilling tool which is used to drill 20mm hole at the centre top of the raw material. The second one is flat end mill tool which is used in roughing operation. Then, the ball nose end mill tool which is used in semi-finishing and finishing operation. The parameter, dimension and the tool number have been set at the Tool Parameter dialog (Figure 4.11).

Table 4.1: Tool Parameter

Drilling	Roughing	Semi-Finishing	Finishing
Diameter: 20mm	Diameter: 10mm	Diameter: 5mm	Diameter: 3mm
Length: 25mm	Length: 40mm	Length: 40mm	Length: 37
No. of Flute: 3	No. of Flute: 4	No. of Flute: 4	No. of Flute: 2
Tool Number: 18	Tool Number: 11	Tool Number: 14	Tool Number: 4
Tool Name: D1	Tool Name: R2	Tool Name: SF3	Tool Name: F4

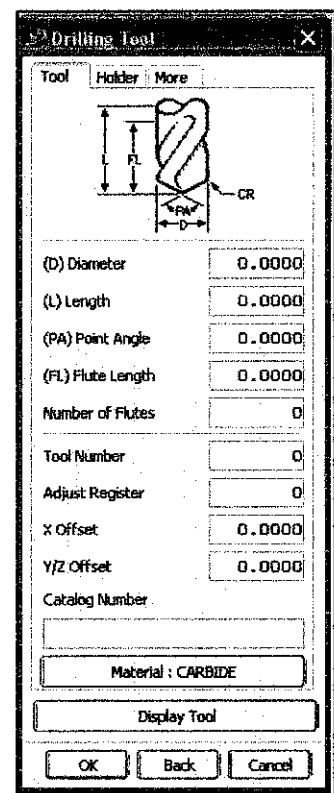
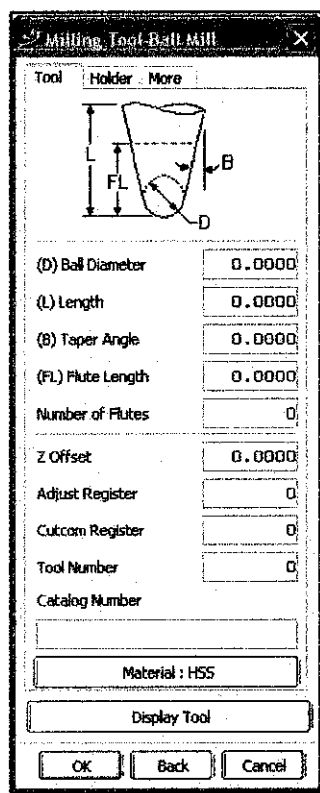
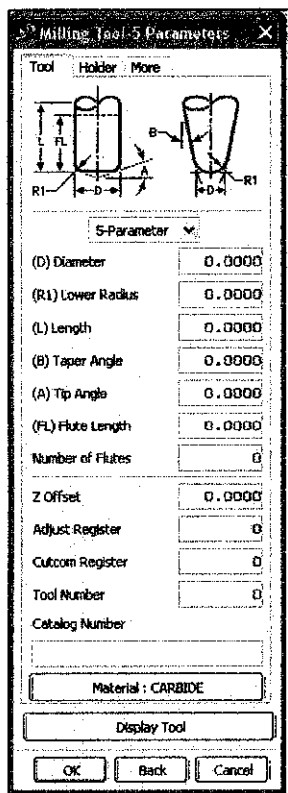


Figure 4.11: Tool Parameter Dialog

## 4.2.6 Creation Operation and Parameter Setting

**Create Operation** was clicked at the tool bar. A Create Operation window will appear. There are many operations that can be used to fabricate the trophy. In this project, the Variable Contour (multi-axis machining) and Cavity Mill (3-axis machining) Operation was used to generate the program and fabricate the model.

### Drilling

In Create Operation window, drill operation was selected then the drill operation window was popped up and all the parameters were set like the hole location, hole base and part surface. The drilling tool (D1) also been selected. The 20 mm diameter hole with 85 mm depth is drilled at the top center of the raw material. The purpose of using drilling operation is to reduce cutting time. If the author uses Cavity Milling Operation to cut the hole, it will consume a lot of time.

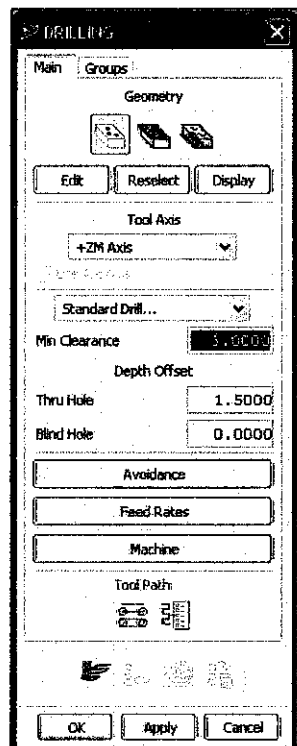


Figure 4.12: Drilling Operation Dialog

## Roughing, Semi-Finishing and Finishing

For Variable Contour, *mill\_multiaxis* was selected in *Type* and *Variable Contour* was selected in *Subtype* in the Create Operation window as illustrated in Figure 4.13. *Program*, *Geometry*, *Tool* and *Method* also been assigned at this stage. Then the Variable Contour window pop up and all parameters were set like the *drive geometry*, *tool axis*, *vector coordination*, *feed rate*, *spindle speed* (refer figure 4.16) *scallop* and *tools*.

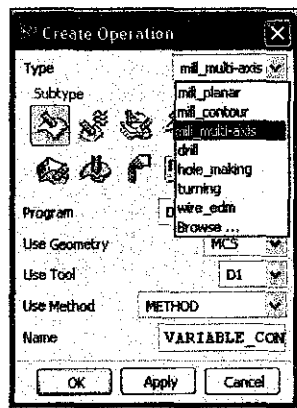


Figure 4.13: Create Operation Menu

For Cavity Milling, *mill\_contour* and *cavity mill* was selected as *Type* and *Subtype* respectively in Create Operation dialog, then all the parameter like *cut method*, *stepover*, *global depth per cut* and *feed rate* were set at the Cavity mill window.

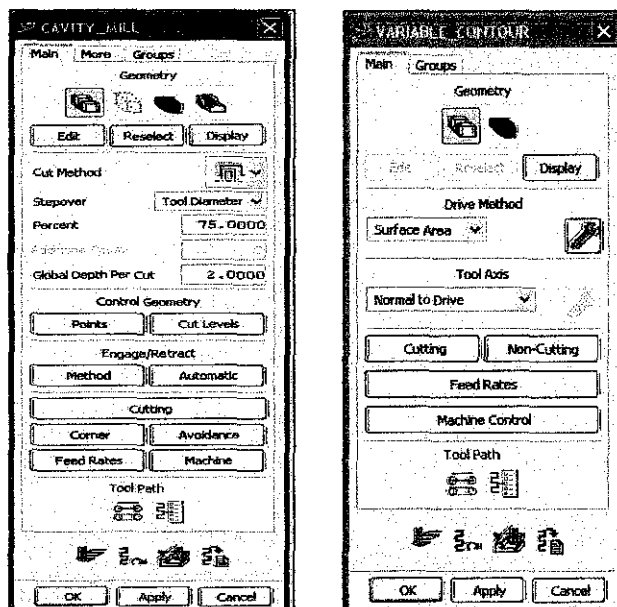


Figure 4.14: Cavity Mill and Variable Contour Menu

Any milling operation needs to be roughed before finishing. This is followed strictly in the industry. The purpose is to remove bulk material at a fast rate, without affecting accuracy or the finish job. Stock allowance is given to provide enough material for the finishing operation. Semi-finishing is done to remove uneven material and keep even part stock allowance for the finishing operations. Usually, semi finishing is easier once roughing is done. Finishing is done in order to get the accuracy according to the geometry of the design. This process is to ensure that every surface is properly machines. There will be more than one program dedicated for finishing purposes

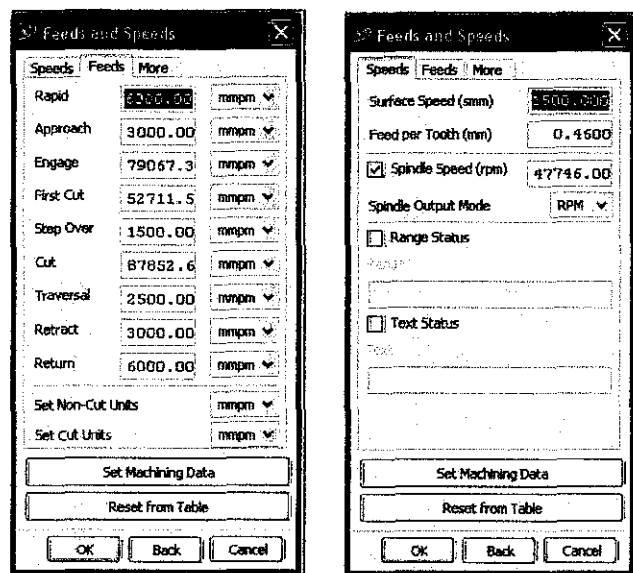


Figure 4.15: Feed Rate and Spindle Speed Dialog

**4.2.7 Generating Program**

After all parameter have been altered, the program can be generated by click at the generate icon. The software sliced the model into depths of cuts and creating tool path at every level.

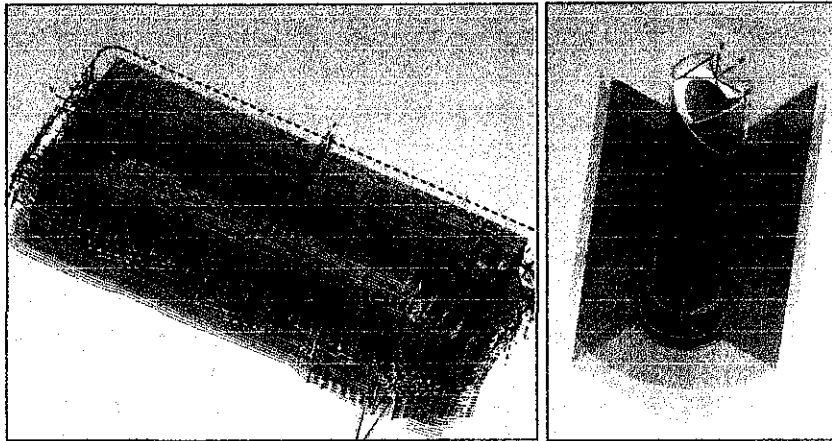


Figure 4.16: Program Generation

#### 4.2.8 Tool Path Display and Simulation

After the program is created, the program was checked to avoid improper and danger motions from being the cutting path. The program can be checked with tool path verification and gouge check.

Through verify, the cutter motion of the entire program was viewed. It showed how the tools engage and retract. The material removal was observed through graphical simulation. For this verification, *Tool Path>Verify* was selected. Then it was played and the tool path motion was observed. The tool path option can be observed in 3 modes *Replay*, *3D dynamics* and *2D dynamics*.

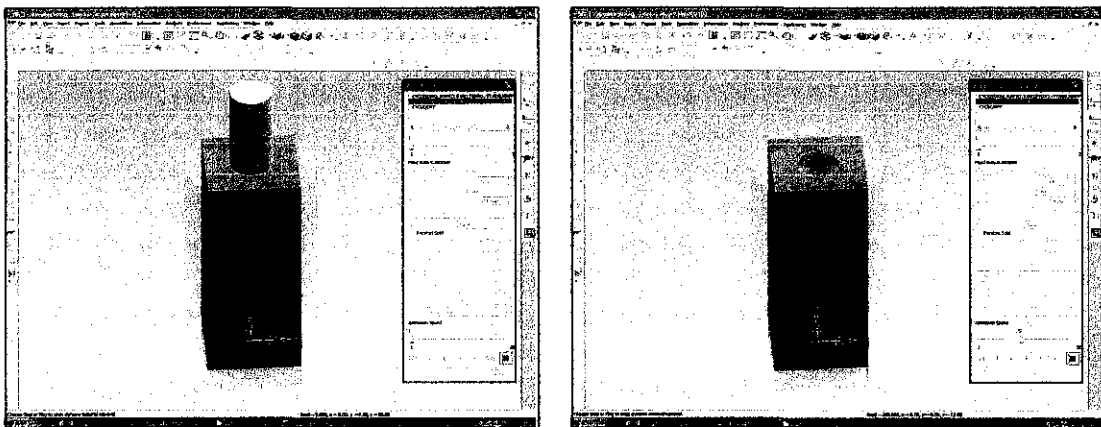


Figure 4.17: Tool Path Simulation for Drilling Operation

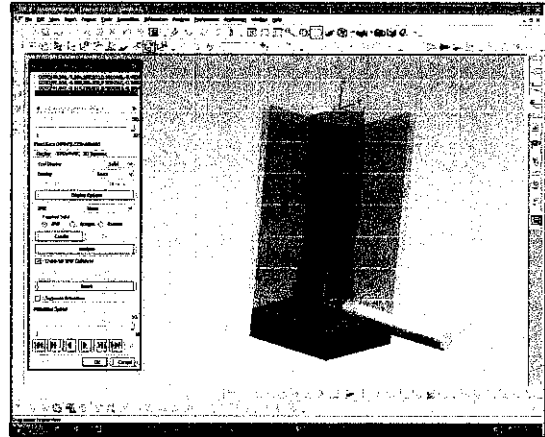
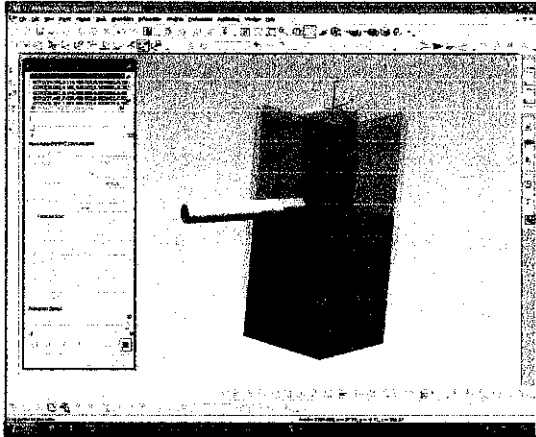


Figure 4.18: Path Simulation for Roughing (multi-axis)

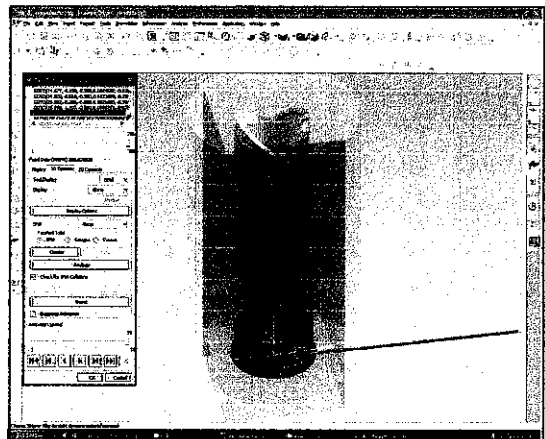
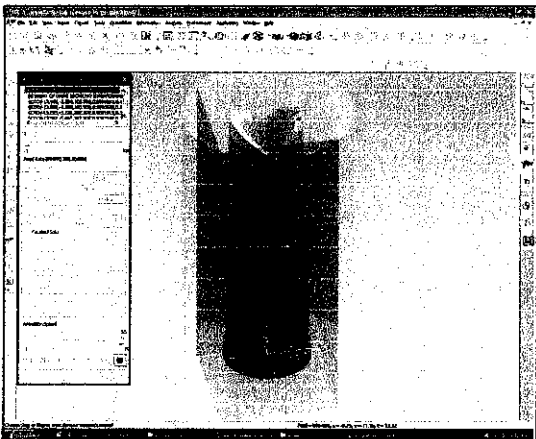


Figure 4.19: Tool Path Simulation for Semi-Finishing (multi-axis)

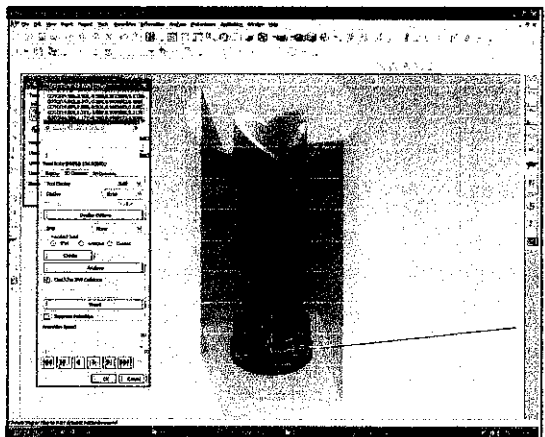
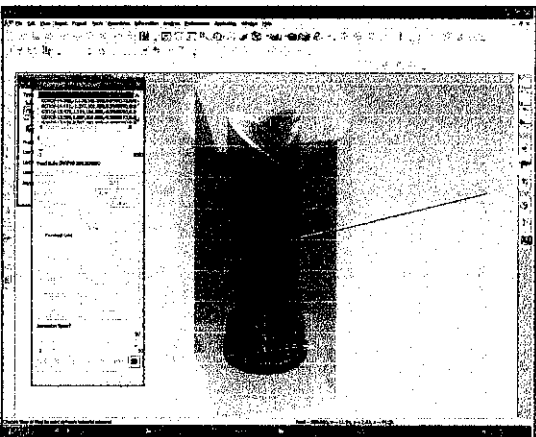


Figure 4.20: Tool Path Simulation for Finishing (multi-axis)

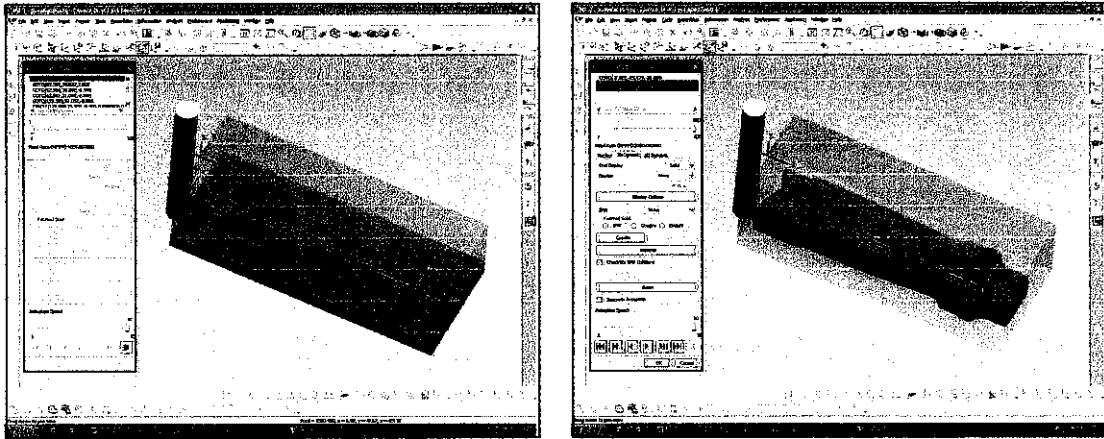


Figure 4.211: Tool Path Simulation for Roughing (3-axis)

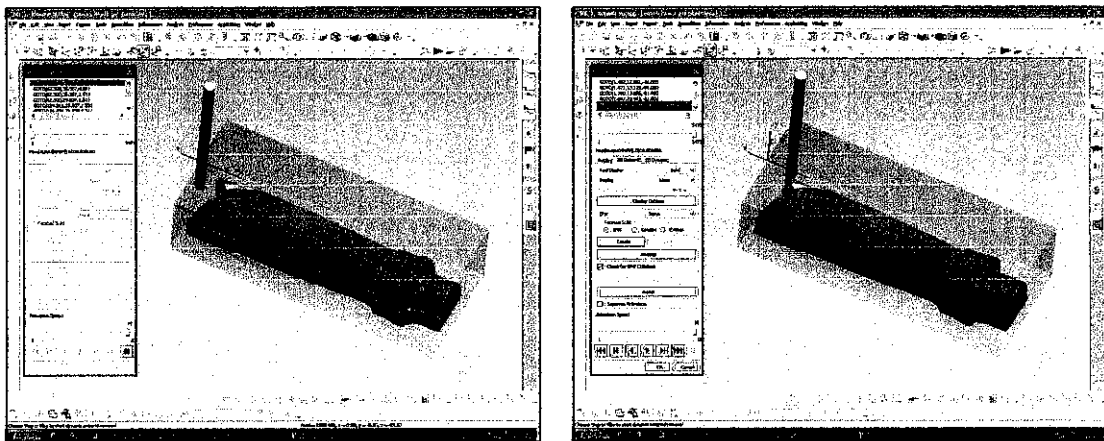


Figure 4.22: Tool Path Simulation for Semi-Finishing (3-axis)

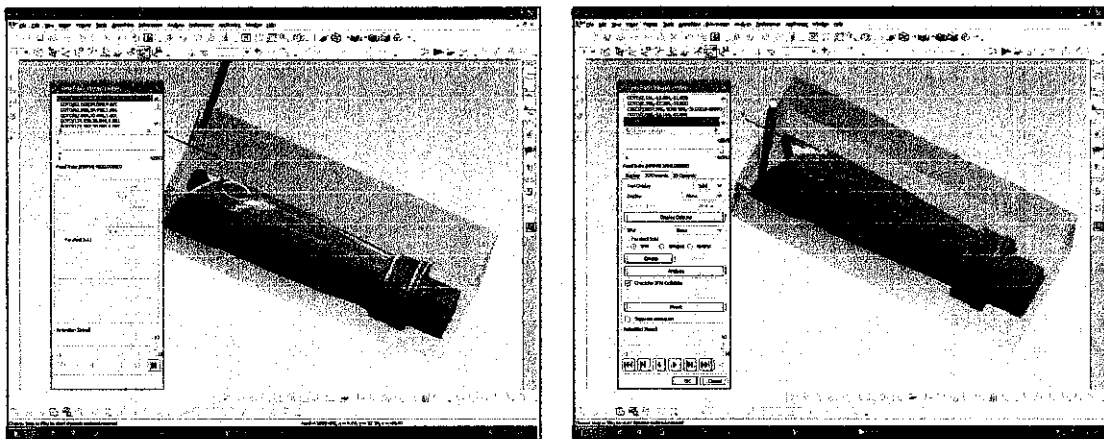


Figure 4.23: Tool Path Simulation for Finishing (3-axis)

## 4.2.9 Post Processing

After all the operation, tool path and programs (drilling, roughing, semi-finish and finishing) was generated and satisfied, the resulting tool path was stored as part of

the operation within the part file. Cutter Location Source File (CLSF) provides copy of these internal paths from the operations in the part file to tool paths. The content of the file contained the basic algorithm of the cutter motion without any information about machine codes and control systems. This file can be used for post processing for Mazak's machine control. The extension of the file created is (.cls).

Then the (.cls) file been put to post-processing to convert the generated program into G-Code and M-Code (standard format) so that it can be read by Mazak machine. The final output of post processing file is (.eia) and it can be transfer to the Mazak machine and then the model been fabricated accordingly.

### 4.3 Machine Setup

Here are several steps that need to do before fabricate the model which are:

1. Set up the vise and align it so that the vise is parallel to the tool axis.
2. Put and clamp the workpiece to the machine table (refer Figure 4.24)
3. Find the datum (0,0,0 point) with respect to the drawing (MCS and WCS) using edge/center finder as illustrated in Figure 4.25
4. Then transfer the program that has been post processed to Mazak machine.
5. At Mazak control unit, find the program that have been transferred and start the program.



Figure 4.24: Workpiece Setup



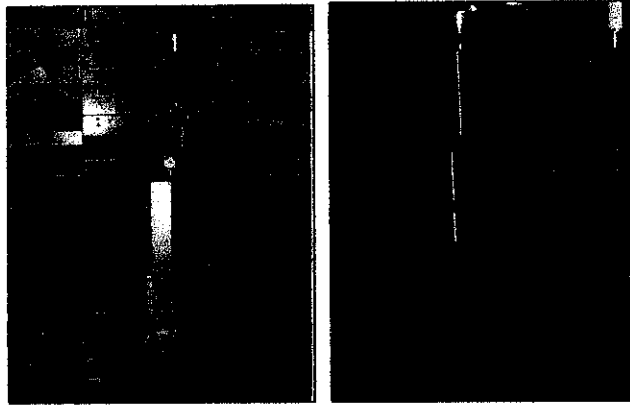


Figure 4.25: Setting up Datum

#### 4.4 End Product

Figures below illustrate the final product of this project. There are two types of products, the first one is the aluminum (Figure 4.28) and second one is wax (Figure 4.29).

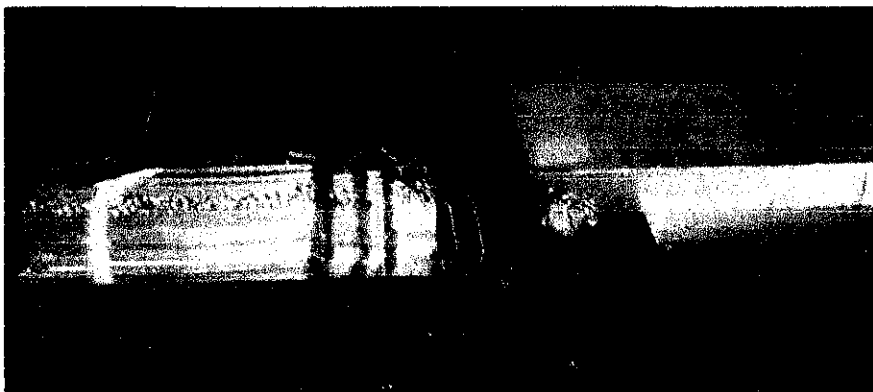


Figure 4.26: After Roughing



Figure 4.27: After Finishing

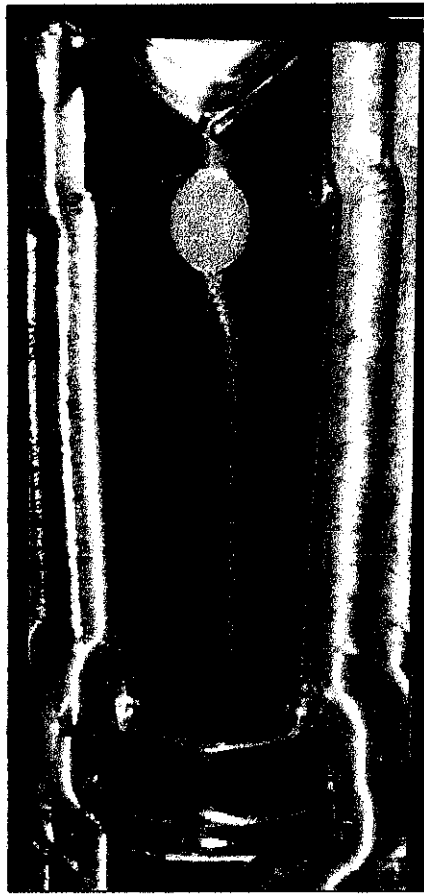


Figure 4.28: Final Product (Aluminum)

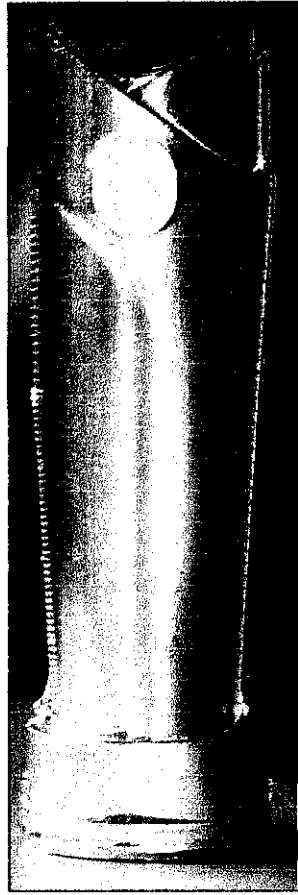


Figure 4.29: Final Product (Wax)

## 4.5 Problem Faced

During completing this project and in order to meet up with the objectives set up at the early development of the project, the author had encountered several problems and obstacles. These problems are directly and indirectly had interfered with the progress of the project. They are

1. The author was facing difficulties in understanding the software. Since there are limited skilled personnel around the campus to guide, the author had to seek for outside resources and do integrated research to help understanding the software.
2. The Mazak Variaxis is having some difficulties at the period of machining the trophy. The multi-axis failed to operate, even though according to the simulation, the problem is foreseen. The table seemed to rotate but the 'Z' axis is still and rigidly did not move. A lot of alterations were made to cater to the problem but the problem is still not solved.
3. The availability and the time-stringent for each user of Mazak also had caused several delays and bumpy roads towards the progress. The machine was unavailable to be used for maintenance purpose for quite several long period of time. Since, the time limit given is limited; user had to fully utilize the opportunity given to use the machine at very short time. Unfortunately there is individual taking longer time than scheduled and caused delayed to the people next on queue.

## **CHAPTER 5**

### **CONCLUSION AND RECOMMENDATION**

The CAD/CAM software, Unigraphics NX3, that was used for this project was indeed a powerful tool in assisting the manufacture process. The software had help in creating 3D model of the Chancellor Award Trophy. The features and tool available in the software has allowed user to accurately and effectively create a highly similar 3D design of the trophy. The software also allowed user to do modification to the 3D model without difficulties

Using the CAM feature available in Unigraphics NX3, the process to create the CAM program was quick and easy and the end result was highly satisfactory. CAM process like roughing, semi-finishing and finishing can be generated automatically by the software once all the necessary parameters are entered into the systems. Altering the CAM program was simple and the reliability of each program once it is altered can be easily determined using verification and gouge check features

Mazak Variaxis 630-5X is a powerful vertical machining center. The built-in tilting rotary table of Mazak Variaxis 630-5X allow model with complex contours and features such as the Chancellor Award Trophy to be finished in a single machine setup (5 axis machining). It also has excellence machining accuracy.

At the end of this project duration, the author had proven the objectives of the project are able to achieve. The Chancellor Award Trophy can be design and fabricate using the available amenities, thus this can reduced the cost tremendously. The detail of the cost estimation is included in Appendix 41.

In conclusion, this project had done its part in contributing to the university that by utilizing the available facilities, provided with skills and knowledge, the Chancellor Award Trophy is possible to be done in house.

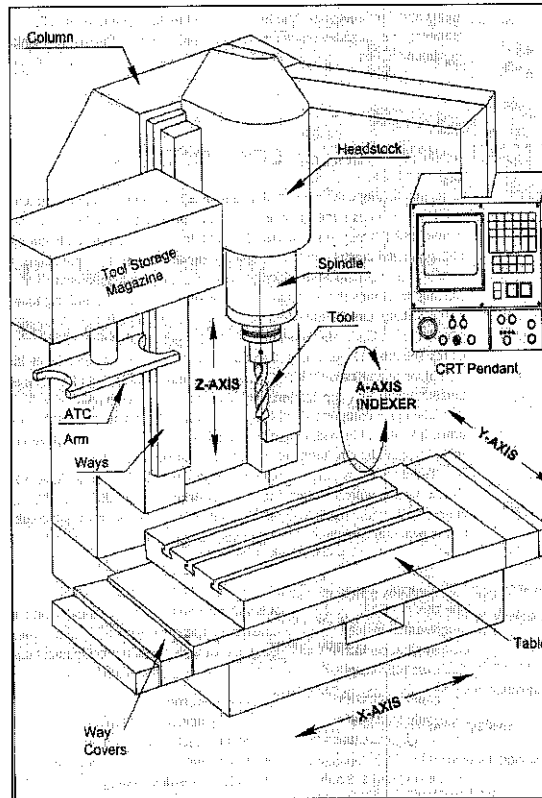
Here are suggestions by the author based on his observation/experience to the end of the project completion. These suggestions may help the future students in achieving better chances and quality in gaining maximum experience and utilization of the software.

1. It is important to ensure that the turn of Mazak Variaxis is properly obeyed. Since the time limitation for each user is quite stringent and limited, user has to adhere to the period of time given. This is important to ensure that the people in the queue neither will nor be affected and fair treatment will be given to all lined-up users.
2. The author had a hard time understanding the Unigraphic Software without professional help from individuals in the campus. Therefore, the author would like to suggest that the contract with the software developer is renewed so that students/users of the Mazak can turn to them for reference. Also, the author would like to suggest that the technician is skillful in order to assist the student and help out running the machine accordingly.
3. The author also faced a lot time-constraint issue since the machine maintenance service took quite a long time to be completed. Therefore, a proper scheduling in managing the time for maintenance is important since it will affect the flow of the project, as the completion of the project is highly dependent on the availability of the machine.

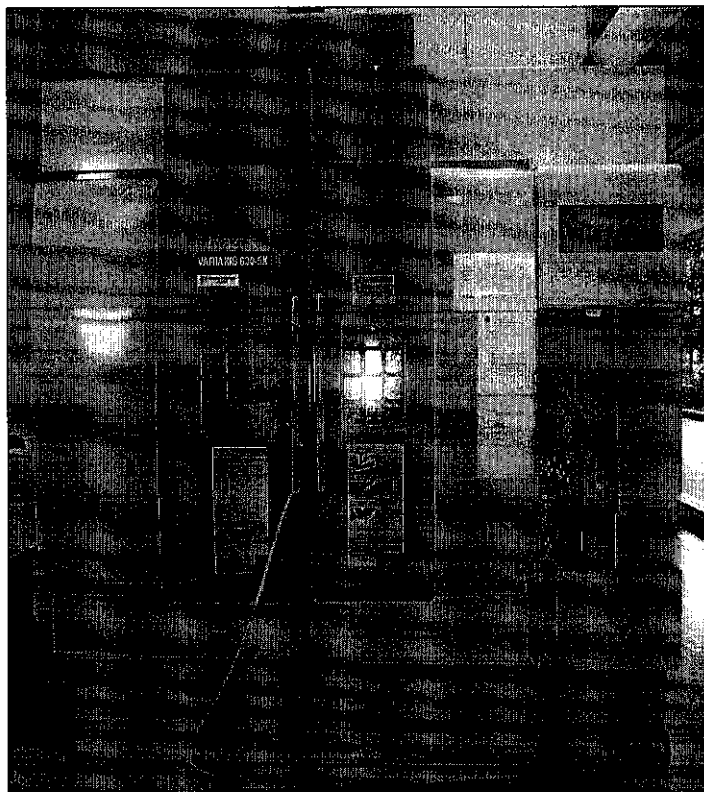
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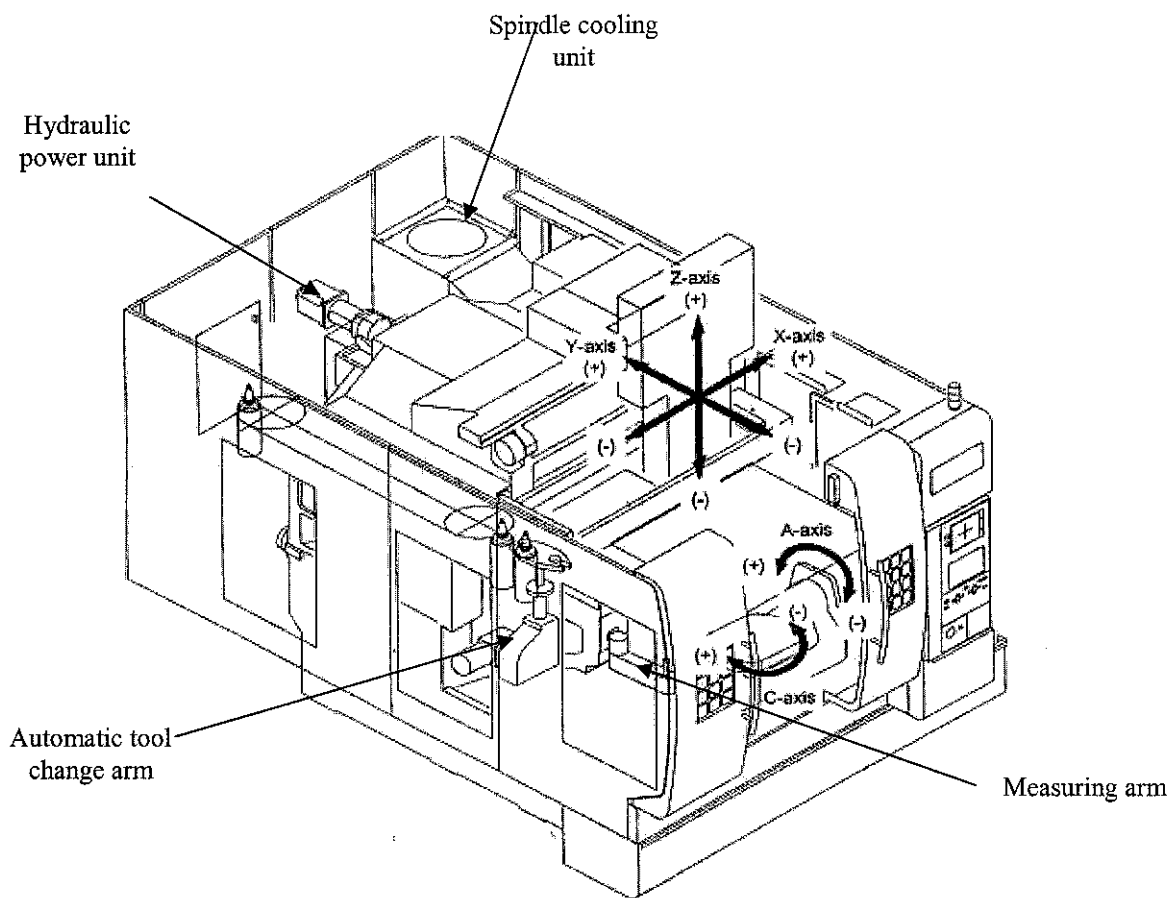
# APPENDIX



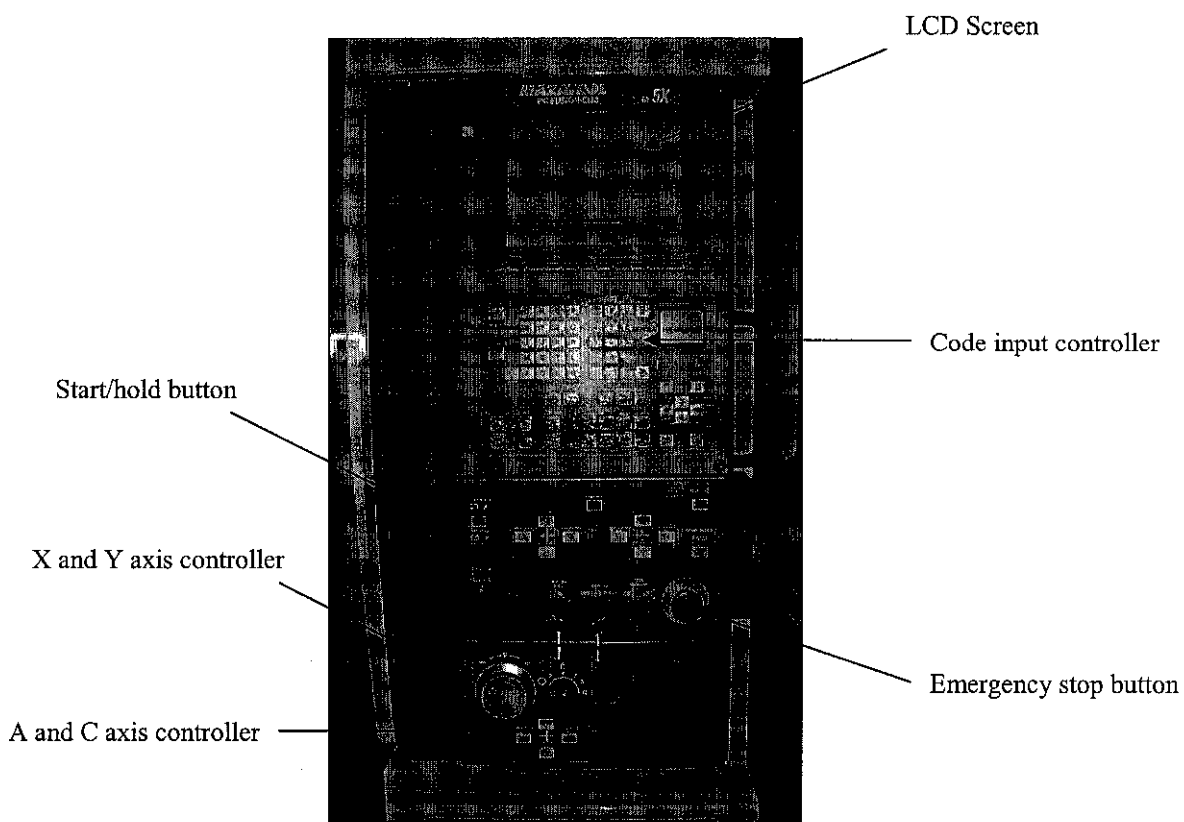
Appendix 1: CNC VMC



Appendix 2: Mazak Variaxis 630-5X

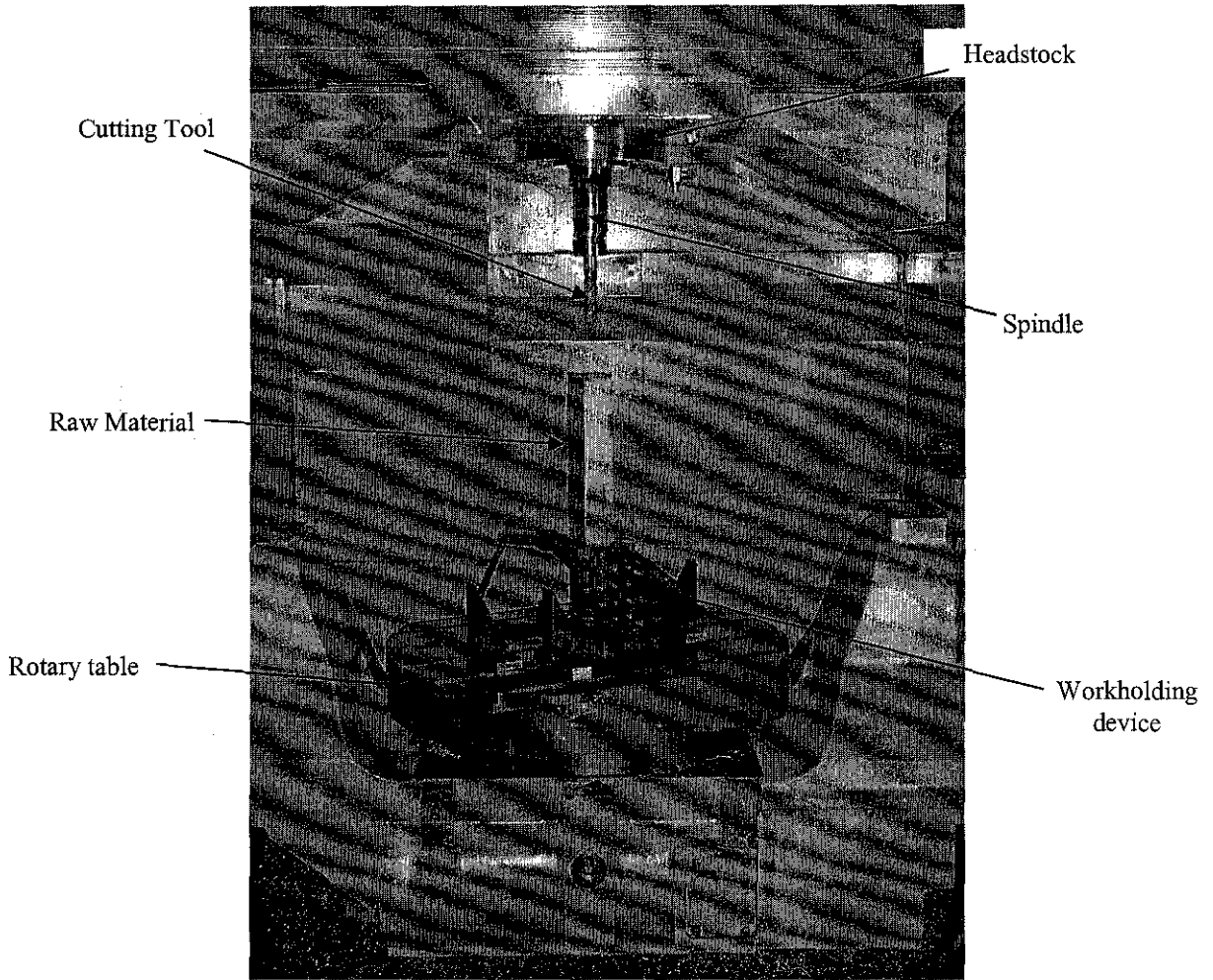


Appendix 3: Schematic Diagram of Mazak Variaxis 630-5X

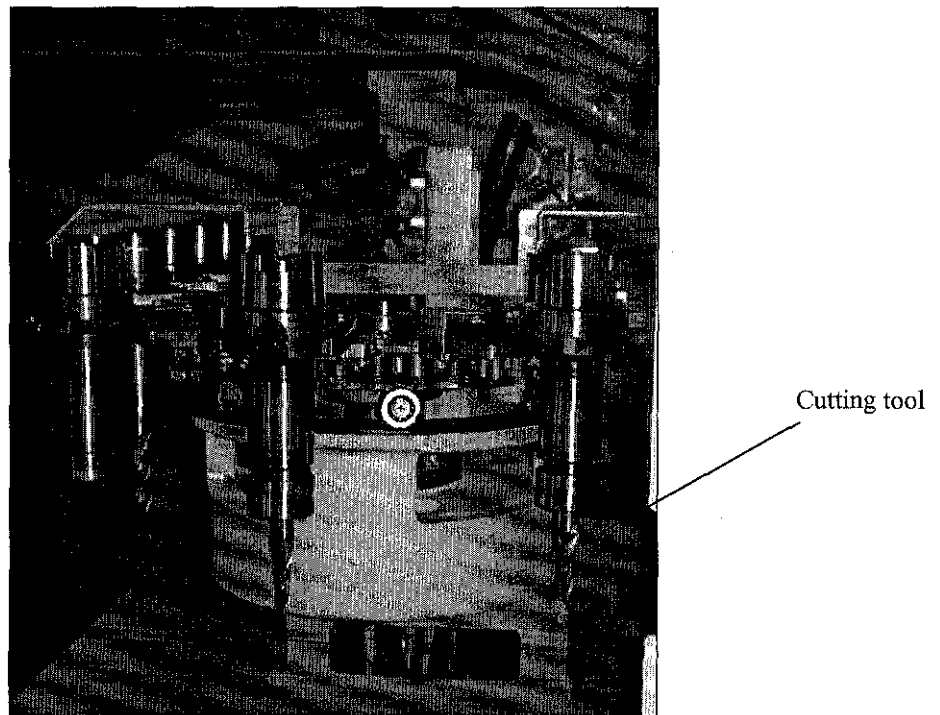


Appendix 4: Mazak Variaxis 630-5X's Control Panel

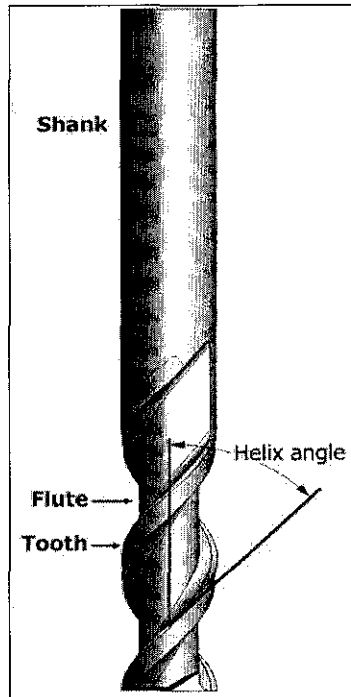




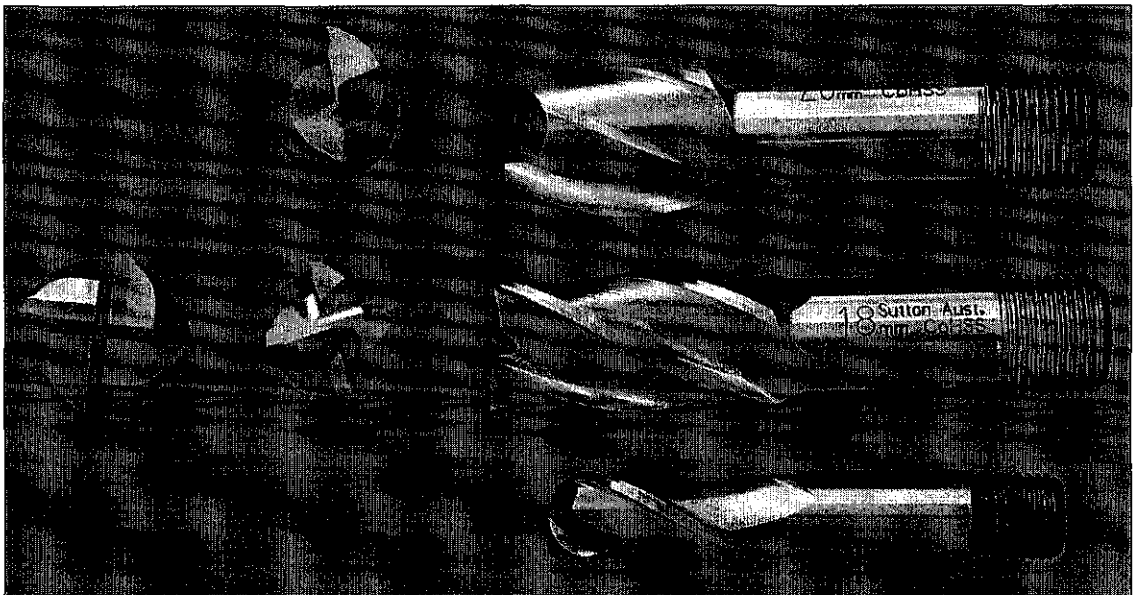
Appendix 5: Inside Mazak Variaxis 630-5X



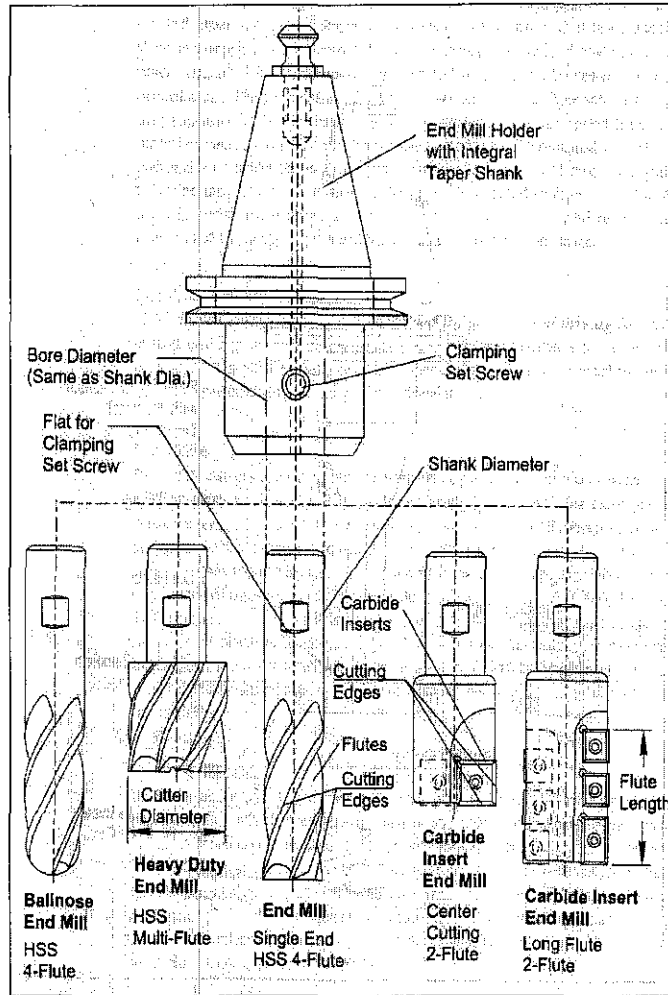
Appendix 6: Mazak Variaxis 630-5X's Tool Magazine



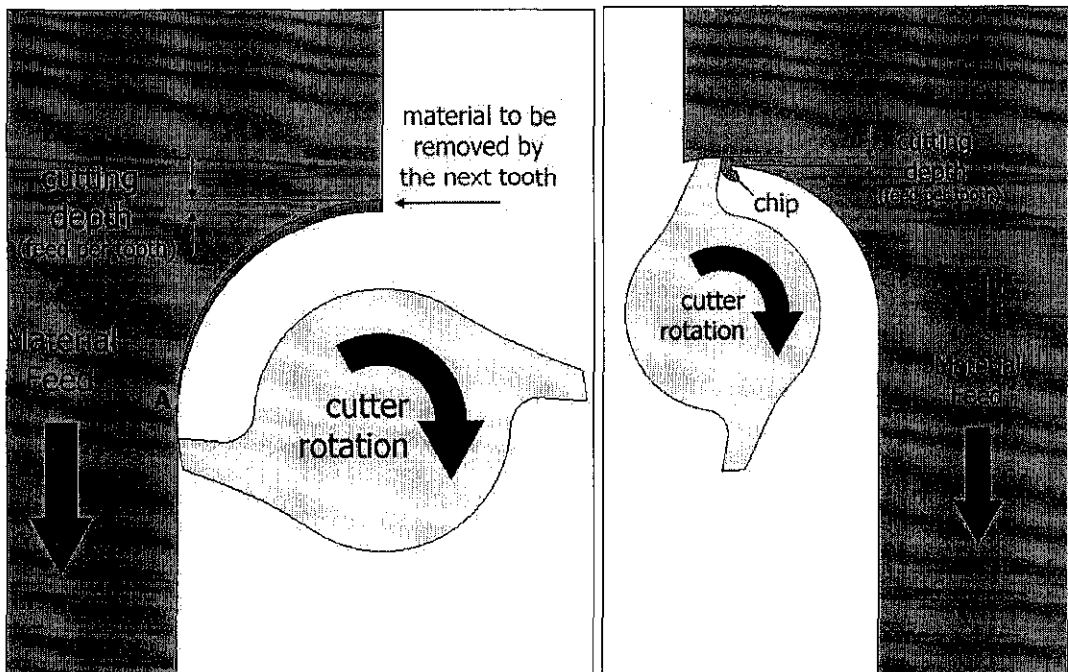
Appendix 7: Geometry Features of Flat End Mill



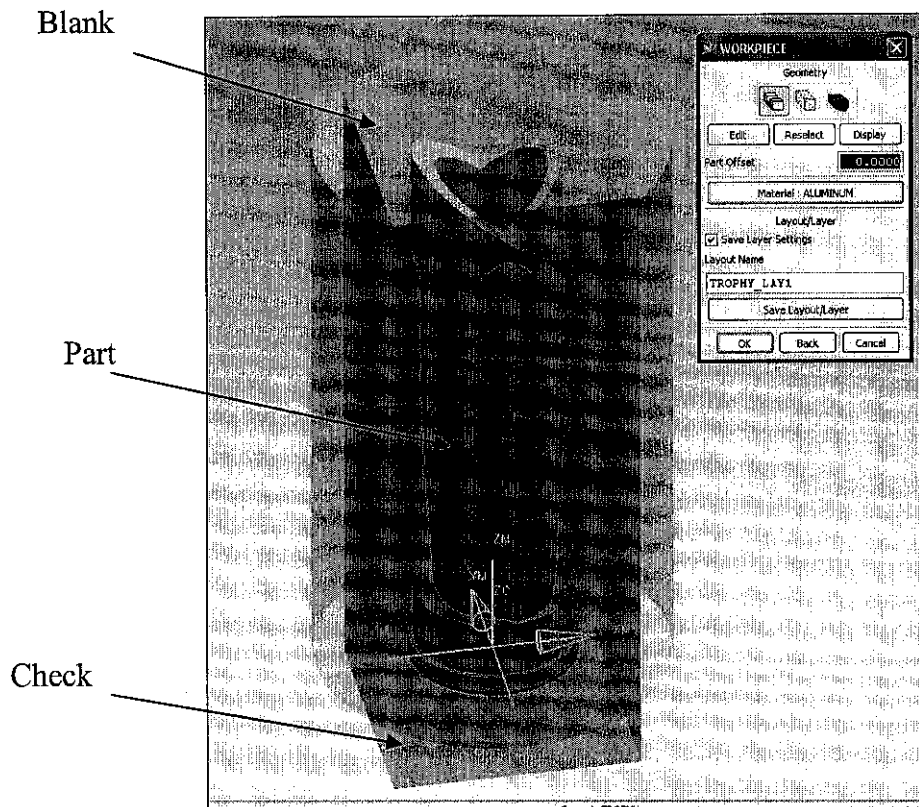
Appendix 8: From top; Slot mill, Flat end mill and Ball nose



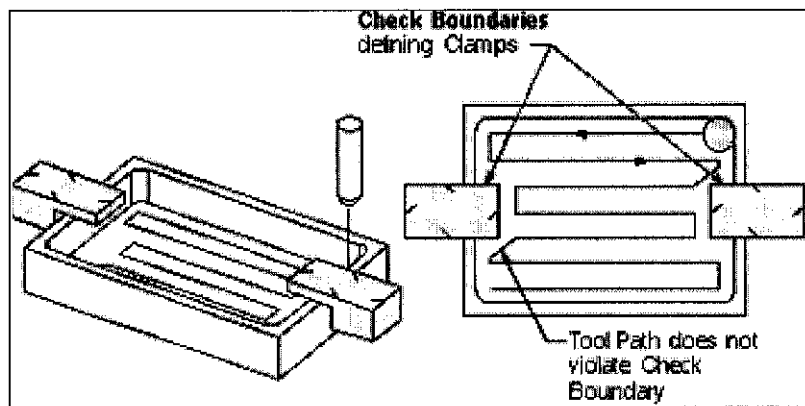
Appendix 9: CNC End Mill Holder and End Mill



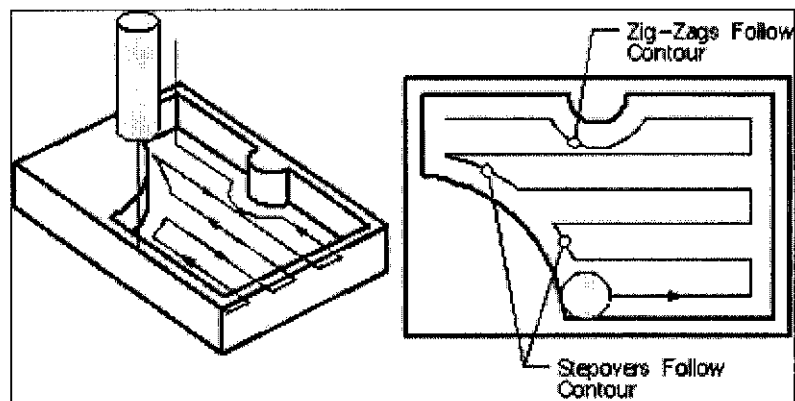
Appendix 10: Conventional milling and Climb milling



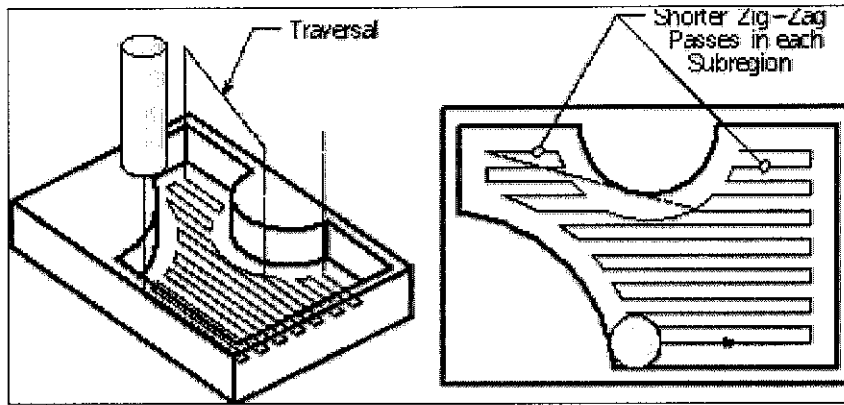
Appendix 11: Boundary Geometry



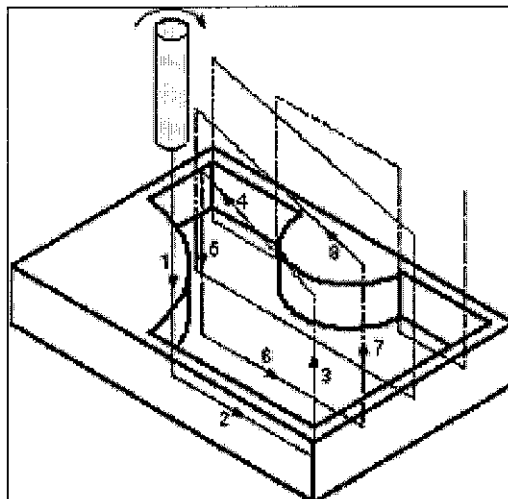
Appendix 12: Check Boundary



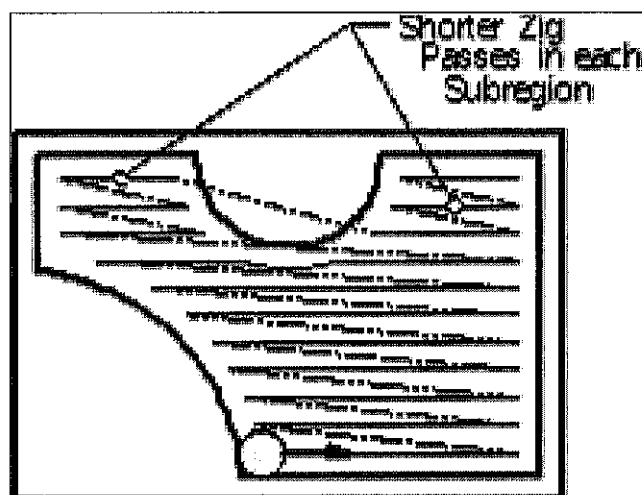
Appendix 13: Zig-Zag



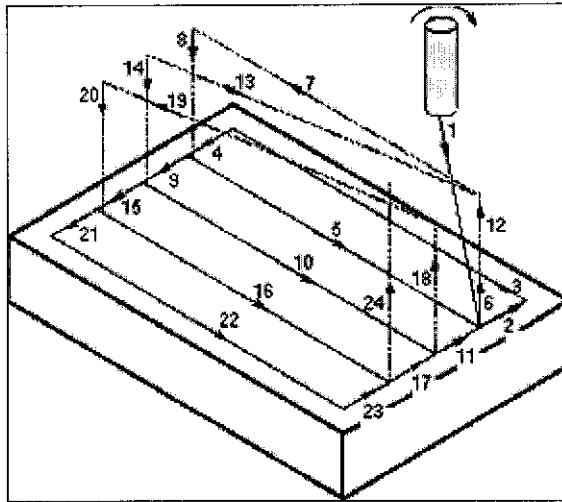
Appendix 14: Zig-Zag



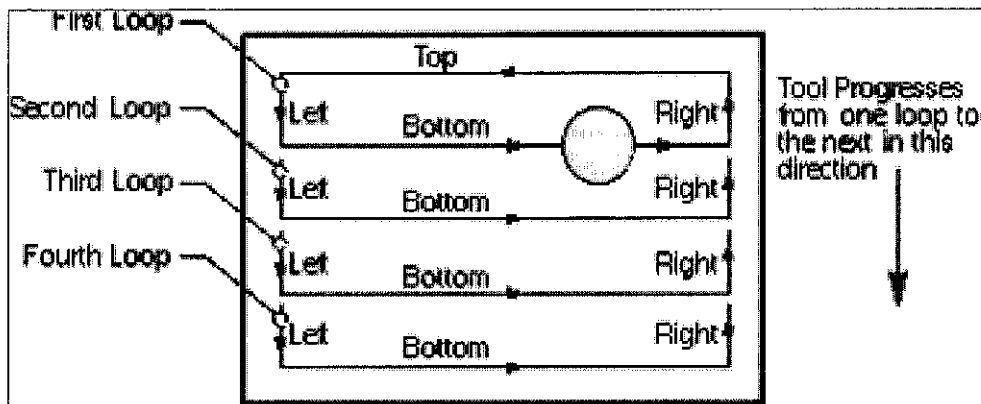
Appendix 15: Zig Tool Path – Conventional



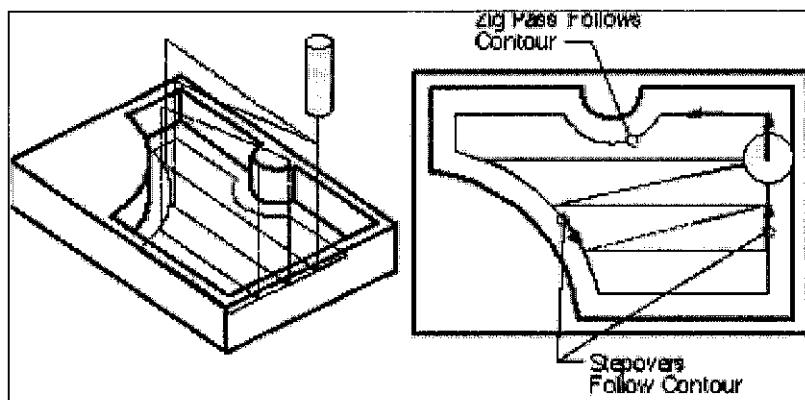
Appendix 16: Zig Tool Path - Conventional



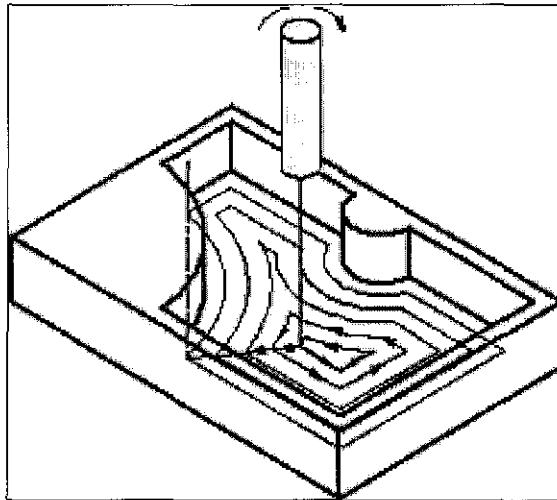
Appendix 17: Zig With Contour - Climb



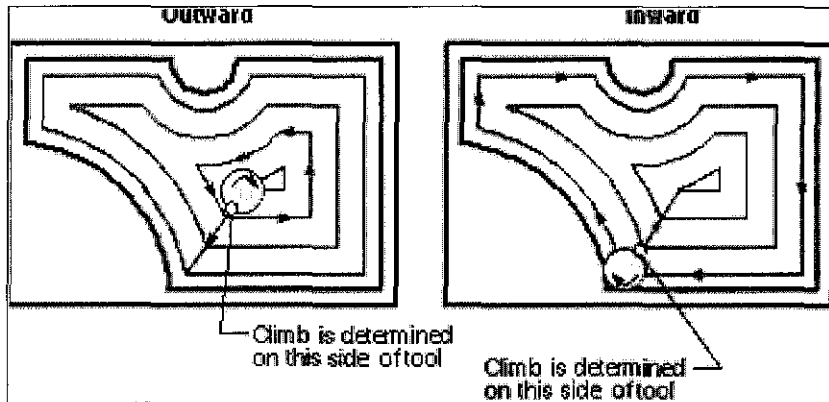
Appendix 18: Zig With Contour Loops



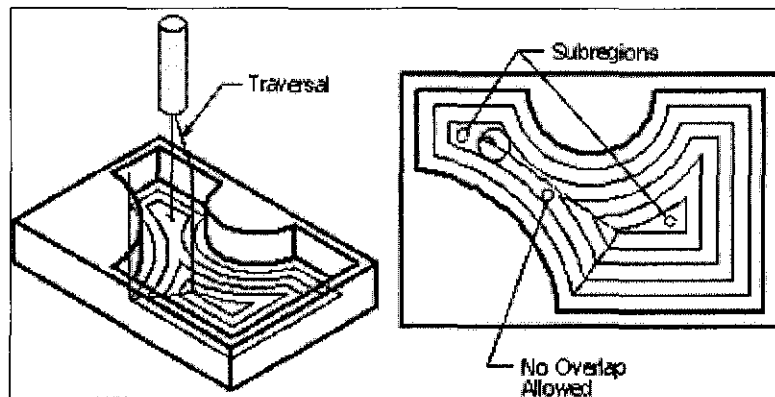
Appendix 19: Zig With Contour - Climb



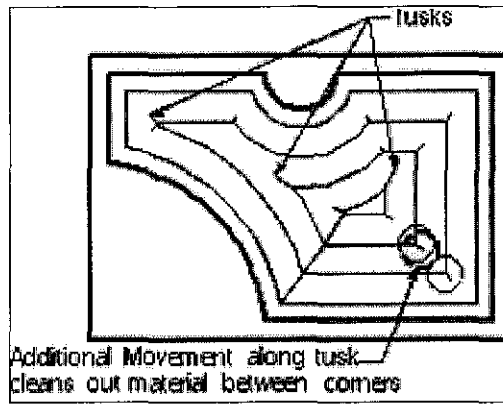
Appendix 20: Follow Periphery - Climb, Outward



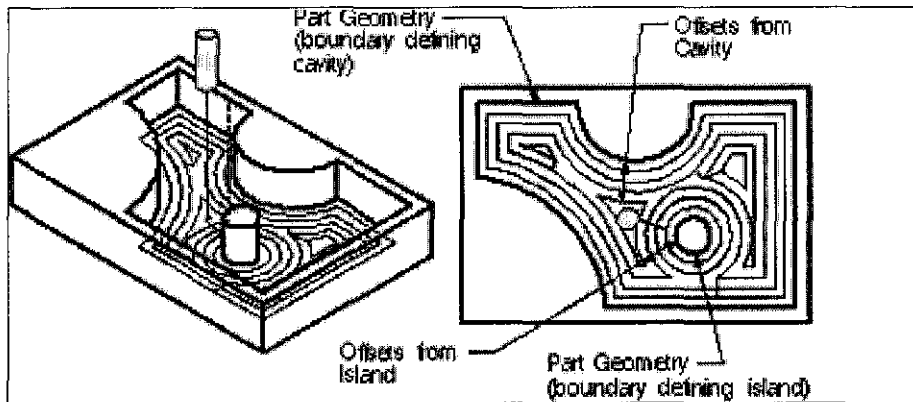
Appendix 21: Follow Periphery, Climb



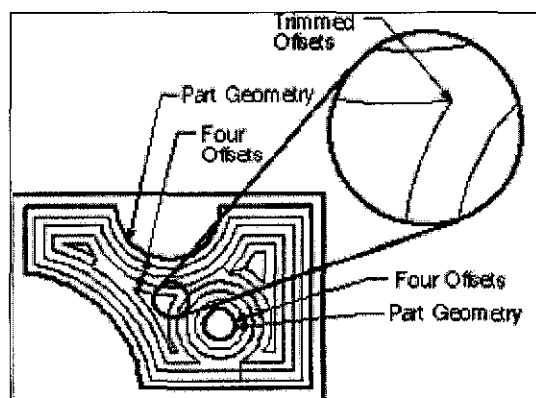
Appendix 22: Subregions



Appendix 23: Tusks

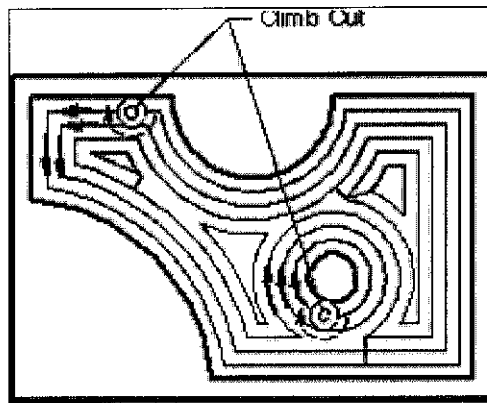


Appendix 24: Follow Part Cut Pattern

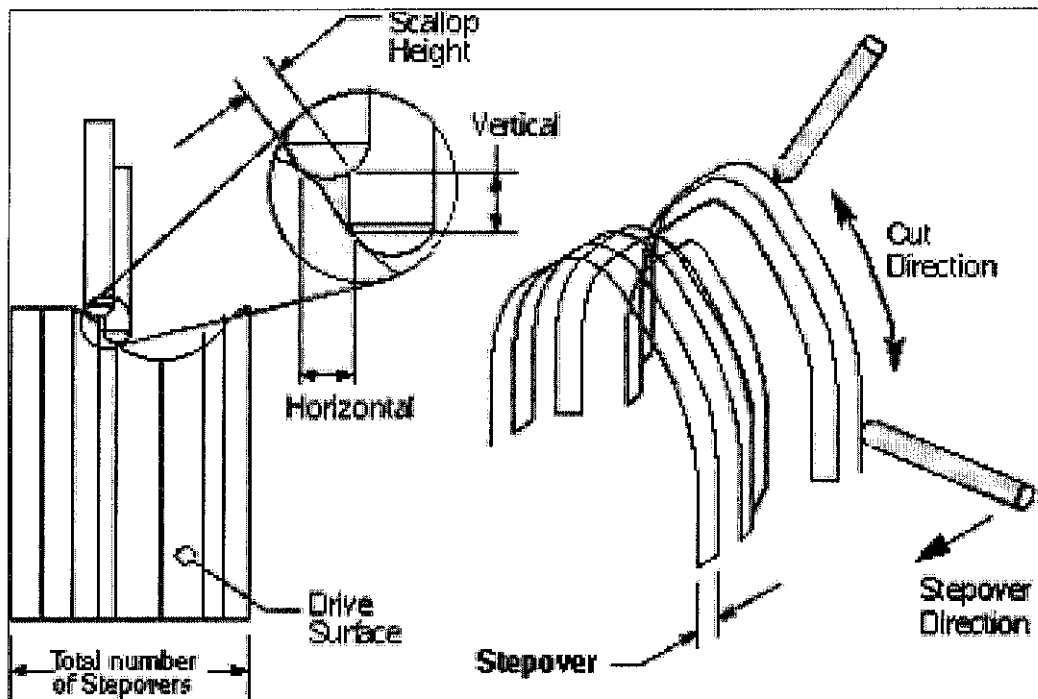


Appendix 25: Trimmed Offsets

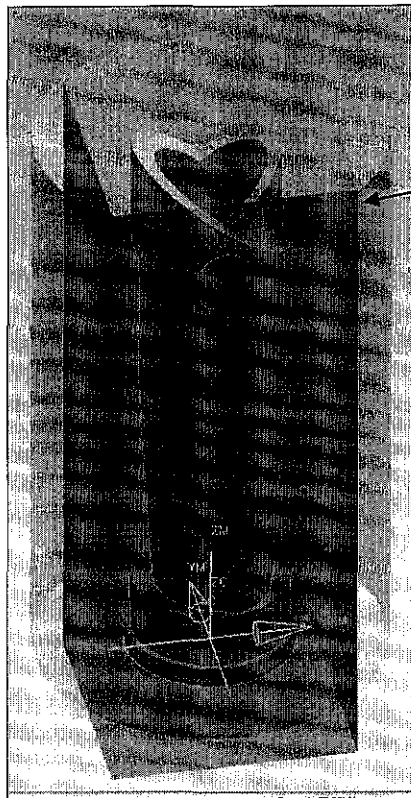




Appendix 26: Maintaining Climb Cuts

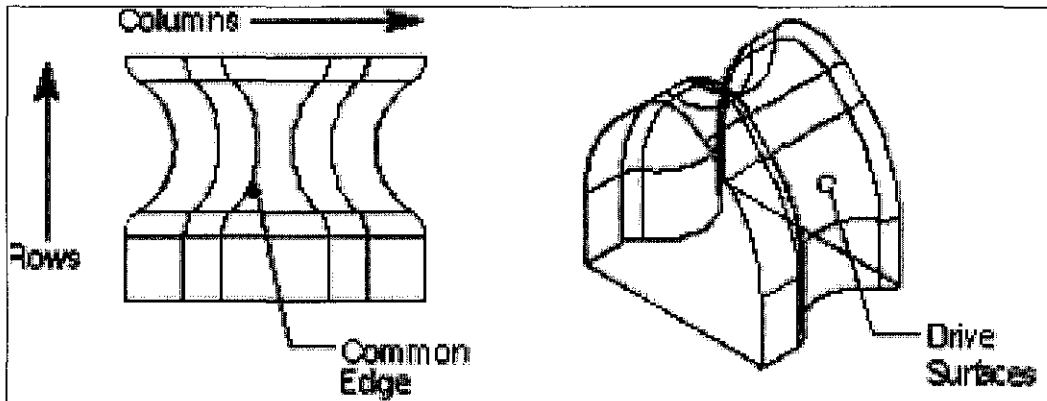


Appendix 27: Stepover

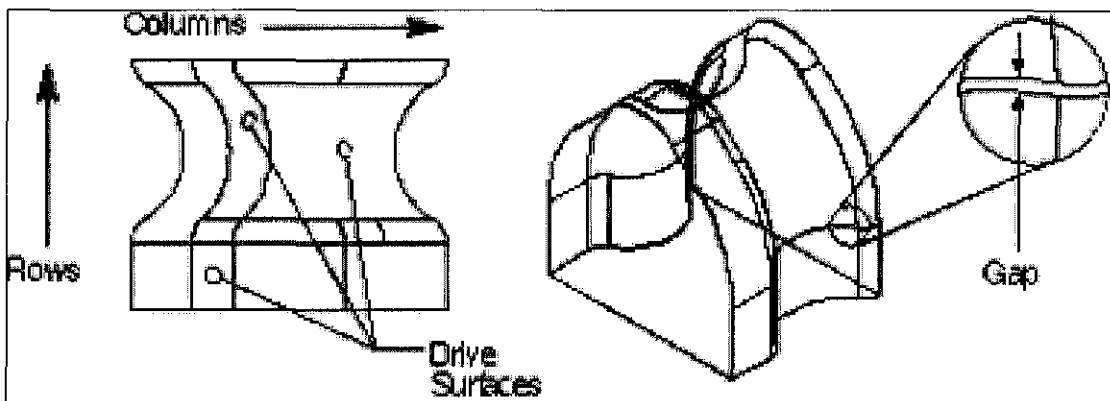


Drive Geometry

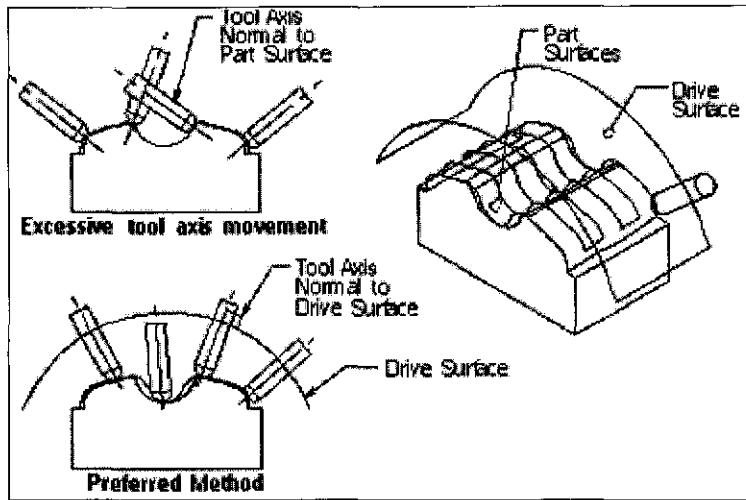
Appendix 28: Drive Geometry



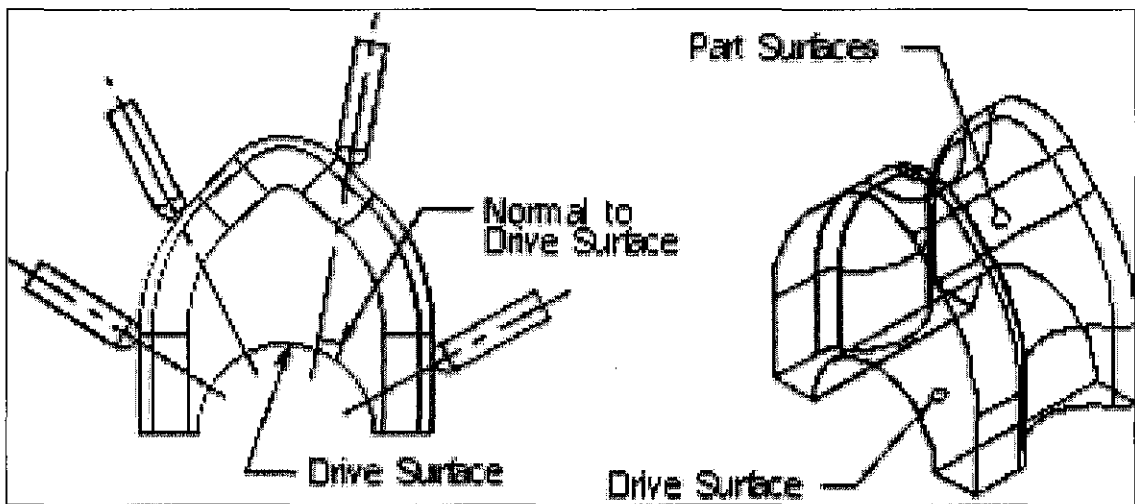
Appendix 29: Even Rectangular Grid of Rows and Columns



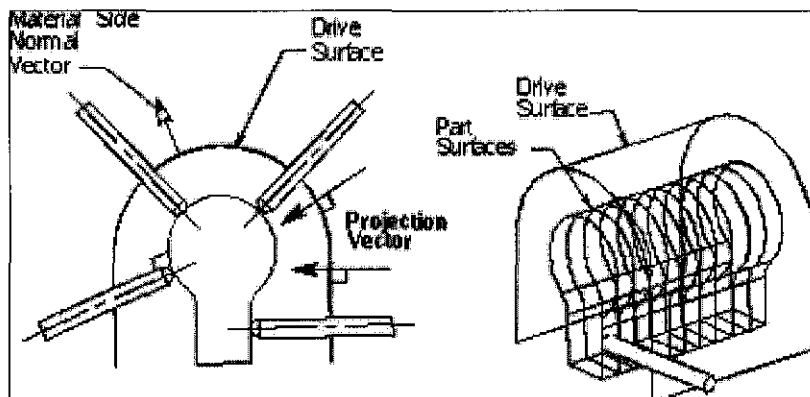
Appendix 30: Uneven Rows and Columns



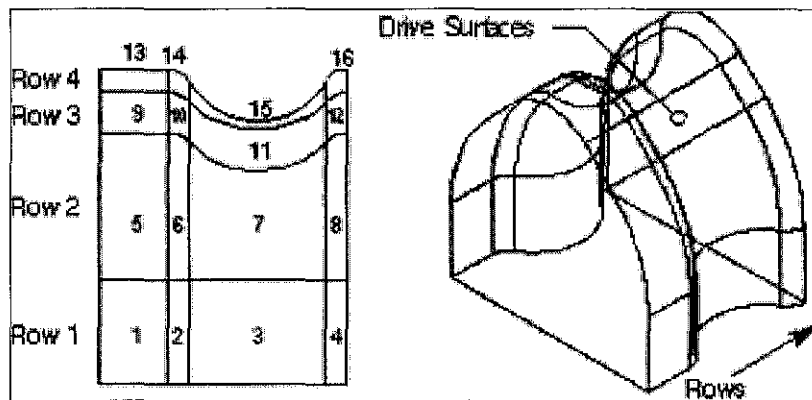
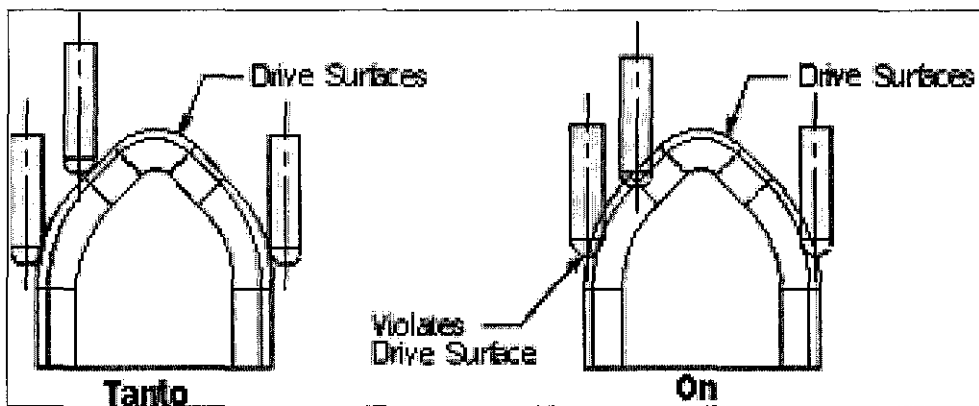
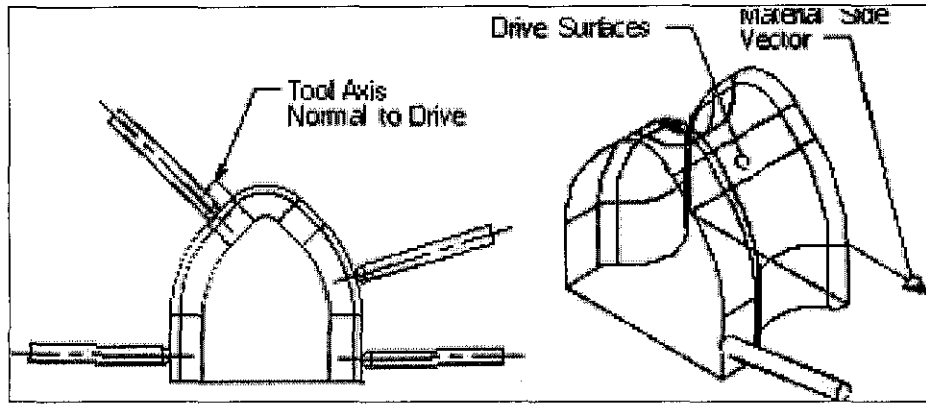
Appendix 31: Tool Axis Movement using Normal to Drive

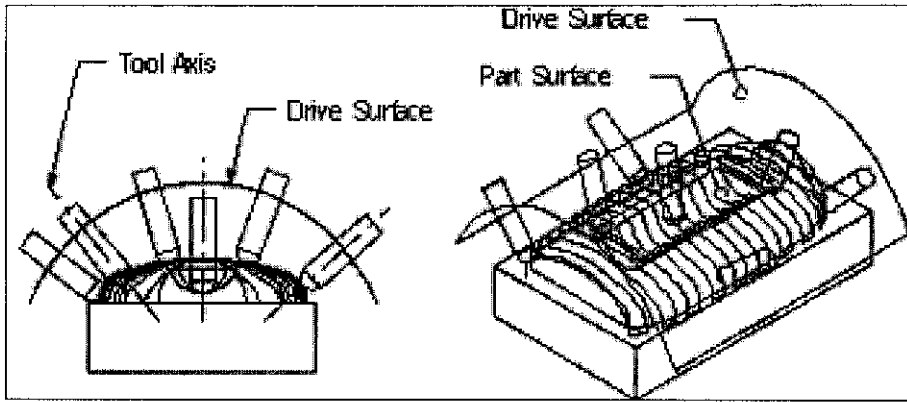


Appendix 32: Tool Axis Movement using Normal to Drive

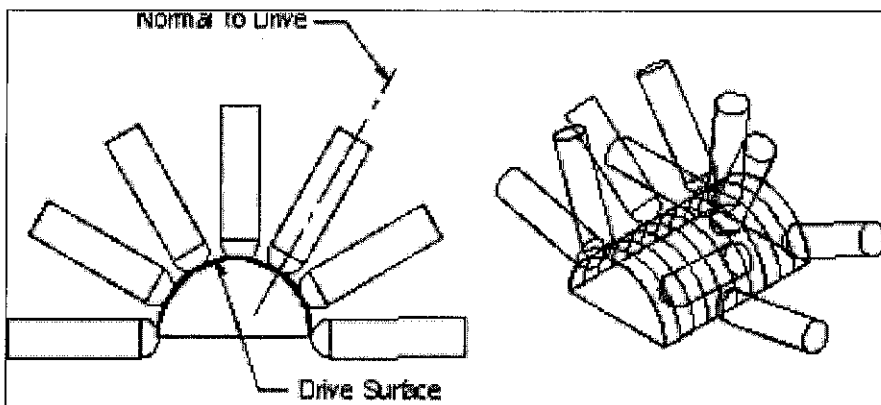


Appendix 33: Projection Vector is Normal to Drive Surface





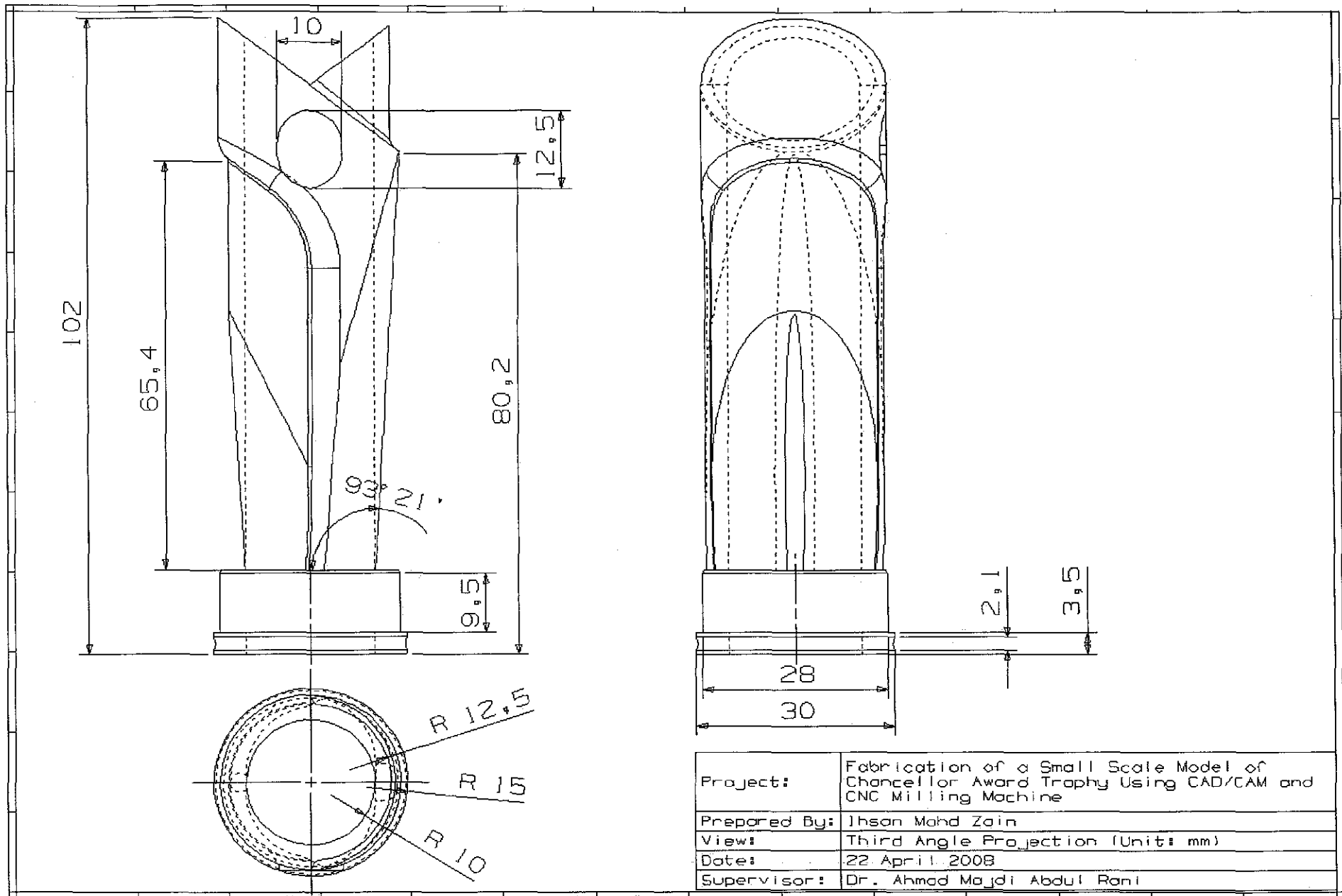
Appendix 37: Normal to Drive



Appendix 38: Normal to Drive Surface Directly on Drive Surface



Appendix 39: Raw Material - Aluminum



Appendix 40: 2D Drafting

### Appendix 41: Cost Estimation

Cost	Aluminum	Pewter
Material	RM 130	
Tooling <sup>1</sup>	RM 420	
Labor <sup>2</sup>	RM 56	
Electricity <sup>3</sup>	RM 20	
Contingency <sup>4</sup>	0.3	
Total	RM 814	RM3000 <sup>5</sup>

<sup>1</sup> Diameter 10mm = RM180  
 Diameter 5mm and 3mm = RM120 X 2

<sup>2</sup> Based on RM8 per hour  
 Machining time = 7 hour

<sup>3</sup> Based on assumption of 7 hour machining time.

<sup>4</sup> Other costs

<sup>5</sup> Information is based from lab technician