Simulation and Performance Test of CNC Machining Center

by

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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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A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
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(MECHANICAL ENGINEERING)

Approved by

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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.

NGO DINH PHUONG

ABSTRACT

This project focused on checking the performance of 5 axis machining center and involved simulation of machining process and performance test of Mazak 5-axis Machining Center. The testpiece for simulation and performance test was selected based on BS 4656 Part 30 -1992. From the three dimensional model of the testpiece, process planning was done and followed by the selection of machining parameters. Virtual reality simulation was carried out by Unigraphics NX3 to generate NC code and estimate machining time. NC codes were then transferred to Mazak CNC to machine the testpiece. The performance test was conducted in Metrology Laboratory after the testpiece was machined. Surface finish of the testpiece was measured by roughness tester and accuracy test was done on Coordinate Measurement Machine. The dimensions and surface finish were recorded and compared to the requirement of BS 4656 Part 30 -1992 and BS 4656 Part 38 -1995. Test results obtained showed that Mazak 5 axis machining center produced parts with surface roughness and accuracy that meets the specified standards. Recommendation was also given for further improvement.

ACKNOWLEDGMENT

This thesis and the results of my Final Year Project could not have been accomplished without the help of many lecturers, technicians, friends and family. Especially, I would like to express my deepest appreciation to Associate Professor, Dr. Mohd Amin Abd Majid, my project supervisor who has contributed tremendous knowledge and guidance with willingness to share without demanding any return; also to Mr. Hafiz and Mr. Zamil, technicians in Manufacturing and Metrology Laboratory, who have given all the necessary instruction to help me operate and control the Mazak and CMM machine; and last but not least to my parents who have always given me full support and love.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

A machining center is an advanced, computer-controlled machine tool that is capable of performing a variety of machining operations on different surfaces and different orientations of a workpiece without having to remove it from its work holding device.

Performance characteristics of a CNC milling machine depends on many factors, some of them are machining tool path, machining parameters, tool shapes and materials. The accuracy and repeatability of machine also affects the topography of the workpiece.

With the development of CNC machine and Computer Aided Manufacturing software, the programming of machine has become much easier. By utilizing those manufacturing tools, a simulation of machining process can be done to estimate the machine time and surface quality of the workpiece. Therefore, an optimized machining parameter and tool path can be established to improve the performance of the component.

This project also used the latest technology in measurement – Coordinate Measurement Machine (CMM). Unlike many other measurement systems, a contact CMM has the ability to measure one, two, and three dimensional (1-D, 2-D, and 3-D) features. Based on this unique capability, CMM is the most appropriate equipment to be used in measuring the geometric dimensions in the performance test. It is also the most diverse piece of equipment in the world today, in the application of measuring geometric features on mechanical features of components.

1.2 PROBLEM STATEMENT

In machining, a large number of failures or poor performance of components are due to machining processes and machine performance characteristics. Long time usage of precision machine without calibration usually results in deviation of accuracy and surface finish of the product. This can create a substantial amount of time and money lost when the machine related factors for these failures are not correctly determined.

The difficulty of evaluating the performance of the machine is also obvious as the quality of the finished product in machining depends on many characteristics such as surface finish, flatness, circularity, concentricity, parallelism and dimensional accuracy. The performance test therefore must have the ability to measure all of these values of the finished product so that a complete and thorough evaluation of the machine can be established.

Therefore, adopting computer simulation to study the cutting parameters effects on the workpiece surface finish and dimensional accuracy prior to machining could assist in determining the appropriate paramters for performance test.

1.3 OBJECTIVE AND SCOPE OF STUDY

The objectives of the project are to simulate the cutting process of the testpiece based on BS 4656 Part 30 - 1992 standard by using CAM software and to conduct the performance test on a 5-axis Machining center.

1.3.1 Simulation

The simulation works were done by Unigraphics NX3 to determine the following:

- Cutting tool type, geometry and materials
- Machining parameters
- Tool path and cutter location
- Cutting time

- Testpiece surfaces after each step
- Generation of NC codes for performance test

1.3.2 Performance test

Performance test involved machining of the testpiece and were conducted based on BS 4656 Part 30 -1992 (specification for machining centres and computer numerically controlled milling machines, horizontal and vertical spindle types). Beside BS 4656 Part 30 -1992, BS 4656 Part 38 -1995 (specification for surface finish of testpiece) was also referred during the test.

After machining, the following properties were measured with the objective of determining the machine capability:

- Surface roughness
- Flatness
- Parallelism
- Circularity
- Concentricity
- Angularity
- Dimensional accuracy

CHAPTER 2

LITERATURE REVIEW

2.1 ROUGHNESS AND TEXTURE GENERATED BY END MILL

Shi Hyoung Ryua, Deok Ki Choib, Chong Nam Chu in 2005 [1] were conducting research on roughness and texture generated by end mill. This part summarizes and discusses on the results of their research.

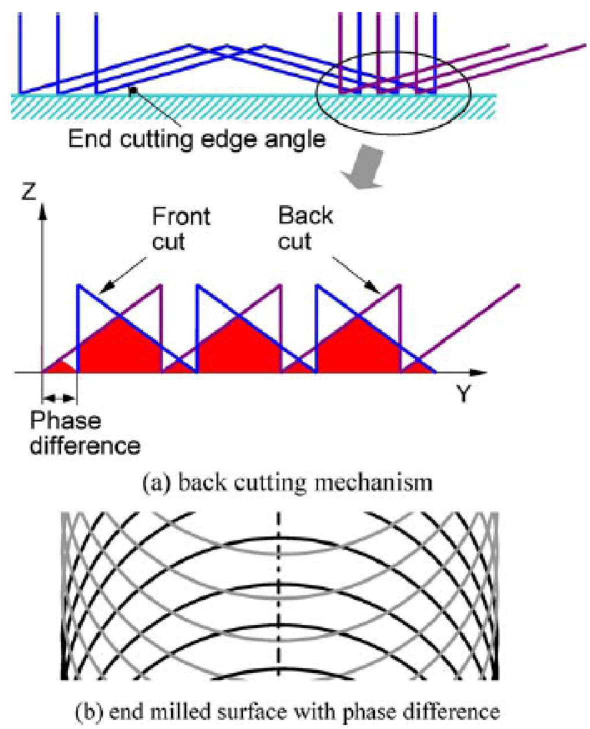


Figure 2.1: Bottom surface generation include back cutting [1]

Surface texture is produced by superposition of conical surfaces generated by the end cutting edge rotation. The machined surface is cut once again by the trailing cutting edge (Figure 2.1). This back cutting phenomenon is frequently observed on surfaces after finishing. Tool run-out (Figure 2.2) and tool setting error (Figure 2.3) including tool tilting and eccentricity between tool center and spindle rotation center are considered together with tool deflection caused by cutting forces. Tool deflection (Figure 2.4) affects magnitude of back cutting and the surface form accuracy. As a result, the finished surface possesses peaks and valleys with form waviness.

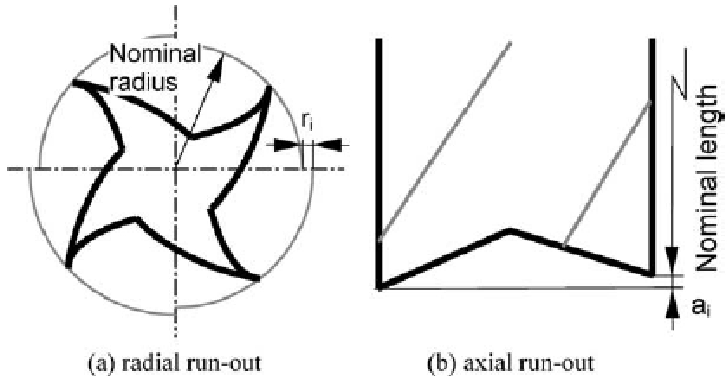


Figure 2.2: Tool run out [1]

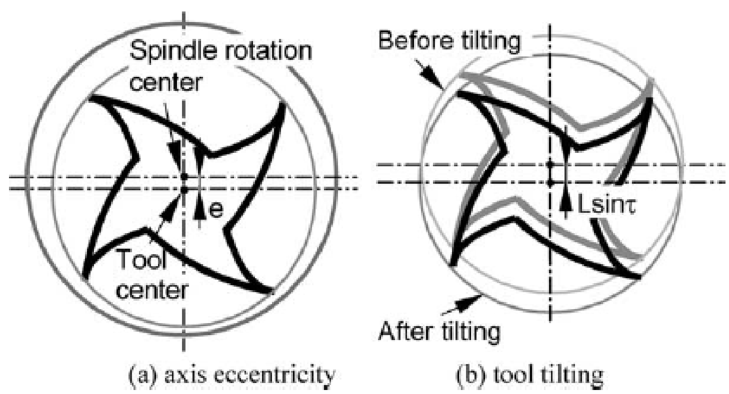


Figure 2.3: Tool setting error [1]

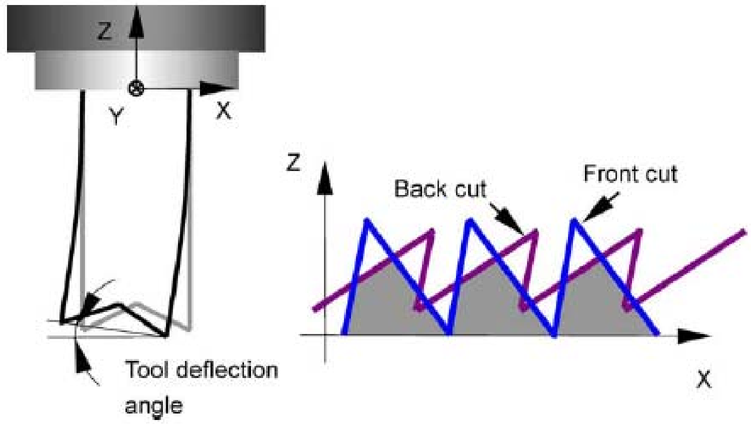


Figure 2.4: Effect of tool deflection on surface generation [1]

2.2 OPTIMIZATION OF FIVE AXIS MACHINING CENTER

Optimization of five axis machining center include many features and criteria such as the accuracy, length of the tool path, machining time, size of machining scallops, gouging avoidance, maximizing removal material, reducing tool wears… Many methods are applied to optimize the cutting processes. Experimental research was conducted with Taguchi methods in [2]. In that research, three cutting parameters including cutting speed, feedrate, and depth of cut are optimized with consideration of multiple performance characteristics like material removal rate, surface roughness, and burr height.

2.3 EVALUATION OF CNC MACHINE [3]

In NC machine tools, two major error sources are geometric error and machine control errors. Geometric errors include straightness, rolling, yawing and squareness error. Measurement of geometric errors can be done by using laser interferometer and ball bar [4, 5, 6]. However, there have not been many attempts to measure the controller error separately because of the complicated characteristics of the NC controller interfaced with the machine tool motion. Some researches have been done to study the definition of control errors and tried to formulate the error patterns into numerical forms.

However, they defined and formulated only a limited number of errors. Further, previous researchers were mainly concerned with measurement and experimental methodology, and analytical investigation of the ball-bar measurement method has not been made. Some field engineers do not like the no-load condition of the ball-bar test. However, they use the ball-bar test frequently because of its simplicity in testing NC machines at the final assembly stage.

2.4 DIMENSIONAL MANAGEMENT [7]

Dimensional management is a process by which the design, fabrication, and inspection of a product are systematically defined and monitored to meet predetermined dimensional quality goals. It is an engineering process that is combined with a set of tools that make it possible to understand and design for variation. Its purpose is to improve first-time quality, performance, service life, and associated costs. Dimensional management is sometimes called dimensional control, dimensional variation management or dimensional engineering.

A typical dimensional management system uses the following tools:

- Simultaneous engineering teams
- Written goals and objectives
- Design for manufacturability and design for assembly
- Geometric dimensioning and tolerance

2.5 STANDARD REVIEW

2.5.1 Machine performance standard [8]

Many standards have been established for performance test, including ISO, BS, DIN, and JIN. The following part lists common standards that are accepted worldwide:

ISO 230-1: 1996 – Geometry accuracy of machines operating under no-load or finishing operations

ISO 230-2:1997 – Determination of accuracy and repeatability of positioning of numerically controlled machine tool axes

ISO 230-3 – Determination of thermal effects

ISO 230-4: 1996 – Circular test for numerically controlled machine tools

ISO 230-5: Determination of the noise emission

ISO 230-6: Diagonal displacement test

BS 3800: Part 3: 1990 - General tests for machine tools. Method of testing performance of machines operating under loaded conditions in respect of thermal distortion

BS 4656:1:1981: Accuracy of machine tools and methods of test. Specification for lathes, general purpose type

BS 4656-28:1988: Accuracy of machine tools and methods of test. Specification for numerically controlled turning machines up to and including 1500 mm turning diameter

BS 4656-22:1988, ISO 3655-1986: Accuracy of machine tools and methods of test. Specification for vertical boring and turning lathes, single and double column types

BS 4656-29:1981: Accuracy of machine tools and methods of test. Specification for automatic lathes, multi-spindle (indexing drum) type

BS 4656-38:1995: Accuracy of machine tools and methods of test. Specification for surface finish of testpieces

ASME B5.54 - 2005 Methods for Performance Evaluation of Computer Numerically Controlled Machining Centers

2.5.2 Standards that were used in this project

a. BS 4656 Part 30 -1992: Specification for machining centers and computer numerically controlled milling machines, horizontal and vertical spindle types

Two basic categories of test are given in this Part of BS 4656: firstly, testing of the machine under no-load or finishing conditions. This category includes testing of the geometric and positioning accuracy of the machine. Secondly, testing of the machine under various loaded conditions. In this category, the influence on the accuracy of the machine of thermally-generated effects is measured and the metal removal rate achievable by the machine is assessed.

b. BS 4656 Part 38 -1995: Specification for surface finish of testpiece

This standard is used to measure the surface finish of any specimen produced which also indicate how the machine behave under load.

CHAPTER 3

METHODOLOGY AND PROJECT WORK

3.1 RESEARCH PROCEDURES

This project has two main parts. First part is simulation works on CAD-CAM softwares, second part is performance test on CNC machining center. The project duration is one year (two semesters). Works in first semester included studying on CAD / CAM and CNC technology, advanced metrology; the three dimensional model and process planning was also prepared in this semester. The project continued in second semester with simulation, machining and performance test.

3.2 PROJECT ACTIVITIES

3.2.1 Simulation

Simulation done on Unigraphics included the following steps:

1. Modeling
2. Process planning
3. Select cutting operations
4. Select cutting tool
5. Select workpiece and blank geometry
6. Set up machining parameters and tool paths
7. Simulate cutting process
8. Post process and generate NC code

A more detail flow chart of Unigaphics Manufacturing can be found in Figure 3.2

3.2.2 Machining

Machining works were carried out on Mazak Variaxis machining center available in Advanced Manufacturing Lab. Machining steps included:

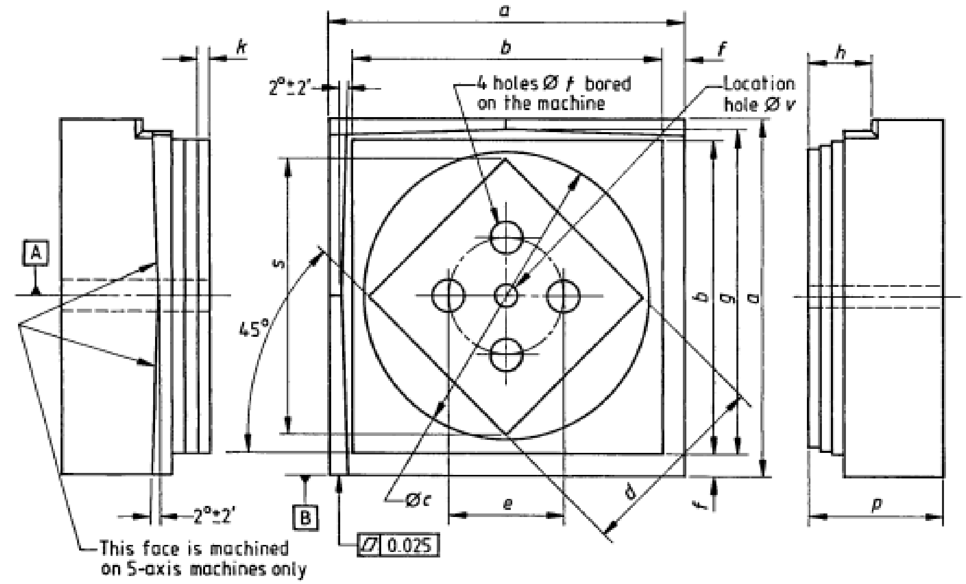
1. Material order
2. Material transportation
3. Surface preparation
4. Machine warm up
5. Material loading
6. Center point locating
7. Tool length compensation
8. Squaring
9. Program loading
10. Program verification
11. Program execution
12. Workpiece unloading
13. Machine clean up

3.2.3 Performance test

The nature of the test is machining a contoured testpiece under numerical control. The material of the testpiece is mild steel. Types and forms of tool, feed, depth of cut and cutting speed were determined by the characteristic of cutting process.

<u>Measuring instrument</u>: Roughness tester, Coordinate Measuring Machine

Figure 3.1 shows testpiece dimensions and tolerances



All linear dimensions are in millimetres.

All dimensions are in millimetres

Size[a]	*a*	*b*	*c* dia.	*d*	*e*	*f*	*g*	*h*	*k*	*p*	*s*	*t* dia.	*v* dia.
Large	300 to 250	250 to 200	246 to 196	171 to 136	100	25	263 to 213	50	8	114	242 to 192	25	25
Tolerance	0 – 0.1	0 – 0.1	0 – 0.1	0 – 0.1	± 0.025	0 – 0.1	0 – 0.1	+ 0.1 0	0 – 0.1	– 0.25 – 0.125	Ref.	+ 0.025 0	± 0.003
Small	150 to 125	125 to 100	123 to 98	85.5 to 68	50	12.5	131 to 107	25	8	57	121 to 96	12	12
Tolerance	0 – 0.1	0 – 0.1	0 – 0.1	0 – 0.1	± 0.025	0 – 0.1	0 – 0.1	+ 0.1 0	0 – 0.1	– 0.25 – 0.125	Ref.	+ 0.025 0	± 0.003

NOTE The apparent wide ranges for the sizes (e.g. *a* = 300 mm to 250 mm) are to give users an indication of the maximum and minimum dimensions to which the test piece can be machined, in order that it may be used several times, until the minimum dimension is reached, to conserve material.
The absolute minimum to which the test piece may be machined is limited only by the position of the holes (*e*) and the holding down screws. The size and position of the latter are at the discretion of the manufacturer.

[a] Two sizes of test piece are shown, to accommodate a range of different sizes of machining centre.

Figure 3.1: Dimensions and tolerances of testpiece

<u>Checks that were undertaken</u>:

1. Accuracy test and the requirement on parallelism, concentricity, circularity, angularity, flatness and positional accuracy

The standards specified that all of the above parameters should meet the following specifications. Parallelism within 0.02 mm, concentricity within 0.025 mm, circularity within 0.03 mm, angularity within ± 0^{o} 2’, flatness within 0.025 mm and positional accuracy specified in Figure 3.1

Accuracy tests were done by using Coordinate Measurement Machine (CMM). CMM defined planes and circles by touching probe on the testpiece. The number of touching points for each geometrical type is listed in Table 3.1. Among these geometries, lines were constructed by intersecting planes while points were defined by intersecting constructed lines. The geometrical dimensions of the testpiece were obtained by measuring the distance between two points on the features or the distance between one point and one plane.

Table 3.1: Number of touching points of the probe to define geometries

Geometry type	Name	Number of touch points	Name	Number of touch points
Plane	A	4	B	12
	C	12	D	12
	E	6	F	6
	G	12	H	12
	I	12	J	12
	K	12	L	12
	M	6	N	6
	O	6	P	6
	Q	6	R	6
	S	6	T	6
Circle	I	8	II	8
	III	8	IV	8
	V	8	VI	8

2. Surface finish test

The surface finish parameter measured is surface roughness. Roughness requirement of all surfaces according to BS 4656 is less than 1.6 μm. The measurement was done by using Roughness tester. Measuring length and speed for each surface are listed in Table 3.2

Table 3.2: Measurement parameters of roughness tester (surfaces refer to Figure 4.19)

Surface	Length (mm)	Speed (mm/s)	Surface	Length (mm)	Speed (mm/s)
A	100	5	B	18	5
C	28	5	D	101.6	5
E	18	5	F	18	5
G	18	5	H	8	5

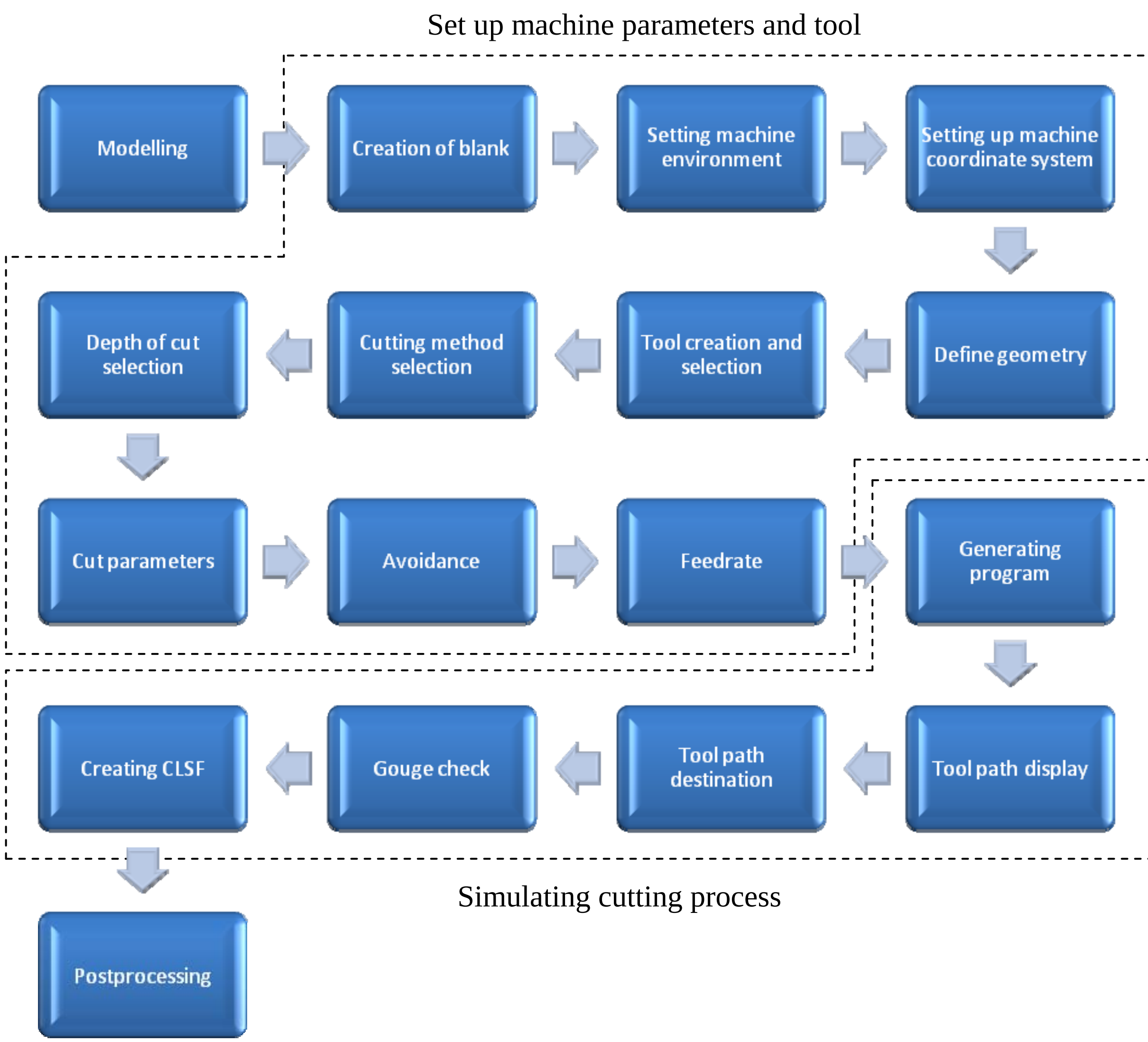


Figure 3.2: Process flow of Unigraphics manufacturing

3.3 TOOLS AND MATERIALS

The following parts list the tools and materials used in this project.

a. Simulation software:

- Unigraphics NX3: modeling, process planning, simulation and CLSF file generation
- Autocad 2006: Drafting
- IMSPost: Postprocessor used to translate cutter location files to NC code files

b. Machining:

- Mazak five axis machining center
- Clamps
- Cutting tools (face mill, end mill and drilling bits)

c. Measurement:

- Roughness tester
- Coordinate Measurement Machine

d. Materials:

- Mild steel block (300mm X 300mm X 128mm)

e. Miscellaneous:

- Lorry (for material transportation)
- Trolley

CHAPTER 4

RESULTS AND DISCUSSION

4.1 BED SIZE OF ROUGHNESS TESTER

Before selecting the standard size of the testpiece, the table size of the roughness tester was measured. The measurement indicated that the roughness tester's table was big enough to accommodate the testpiece.

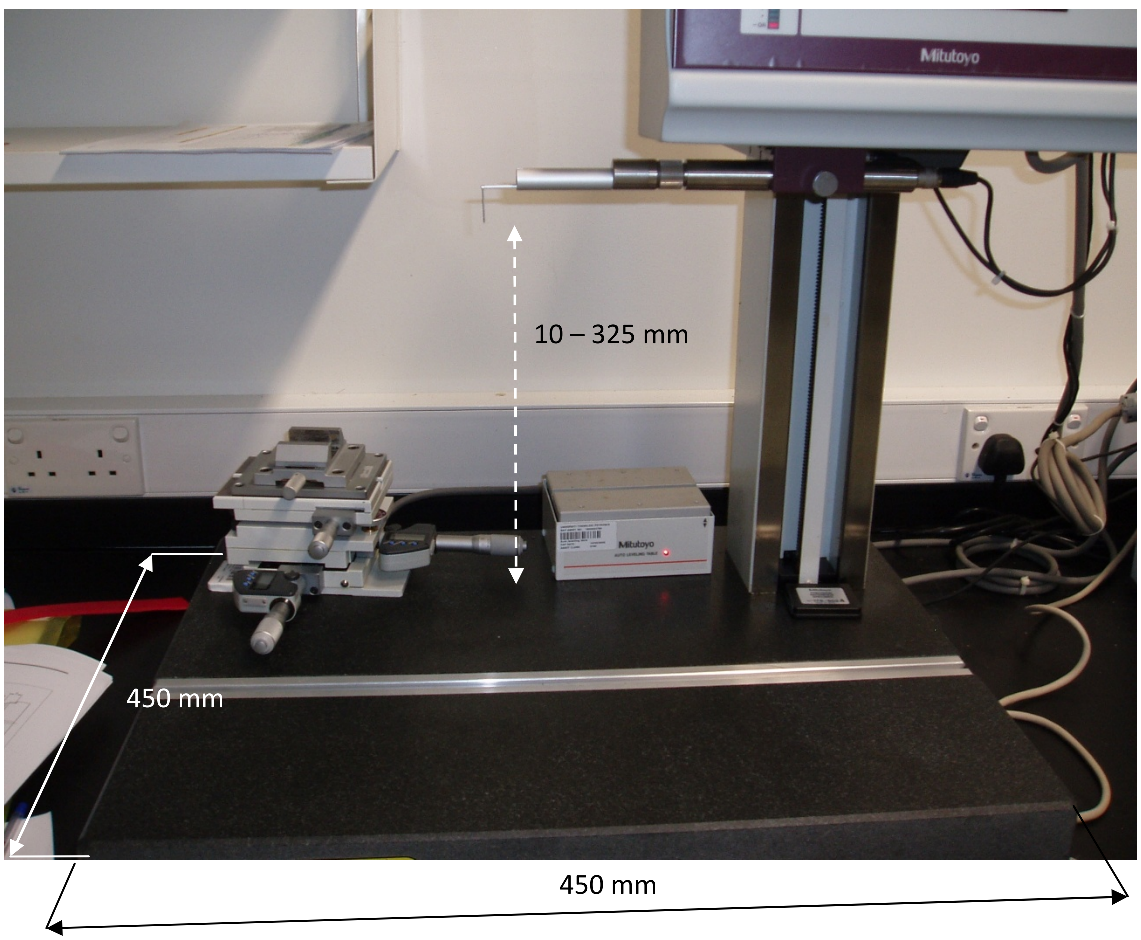


Figure 4.1: Roughness tester's dimension

4.2 MODELING

Figure 4.2 and Figure 4.3 show the 2D and 3D drawings of the testpiece. Dimensions were selected based on BS 4656-30.

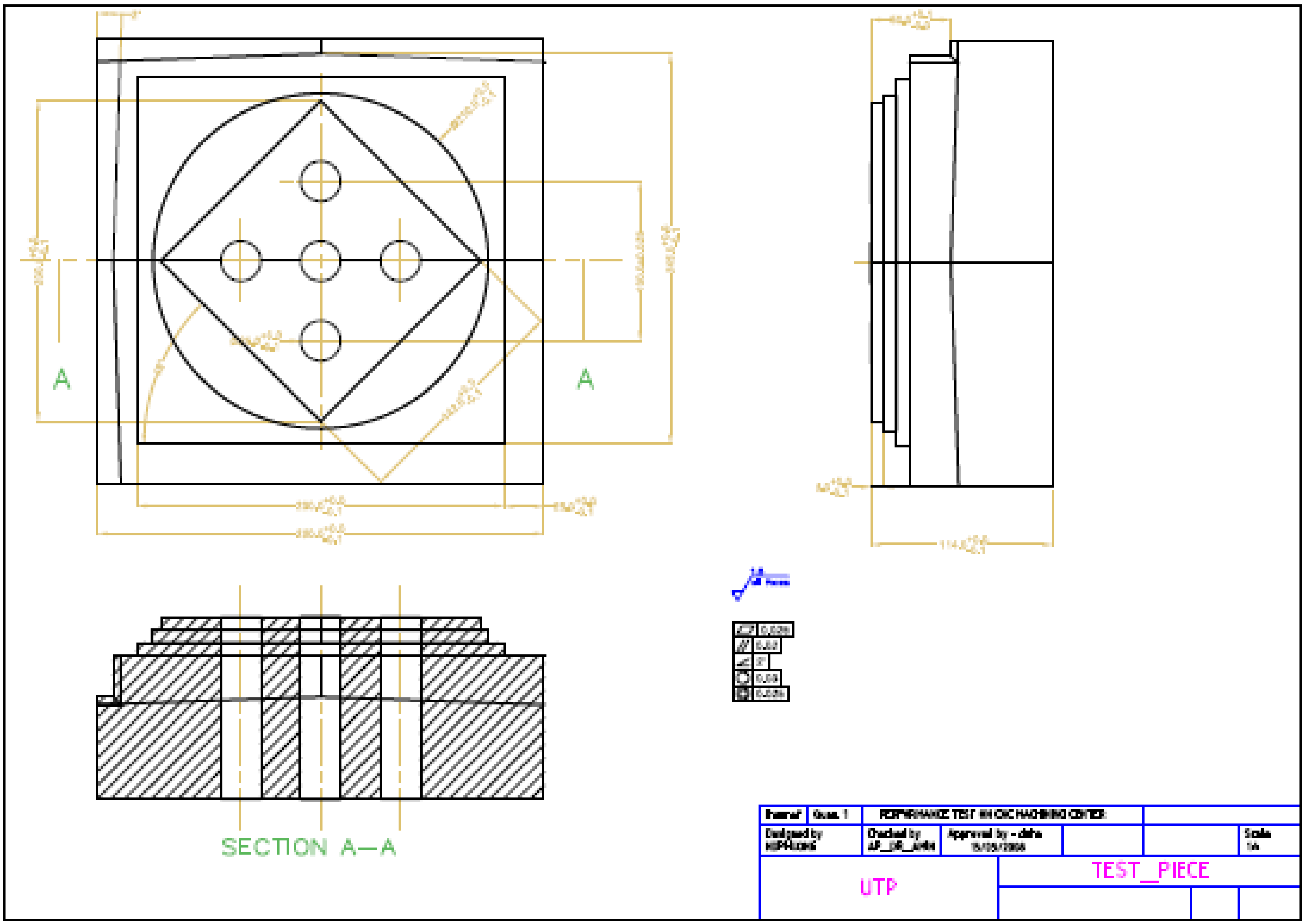
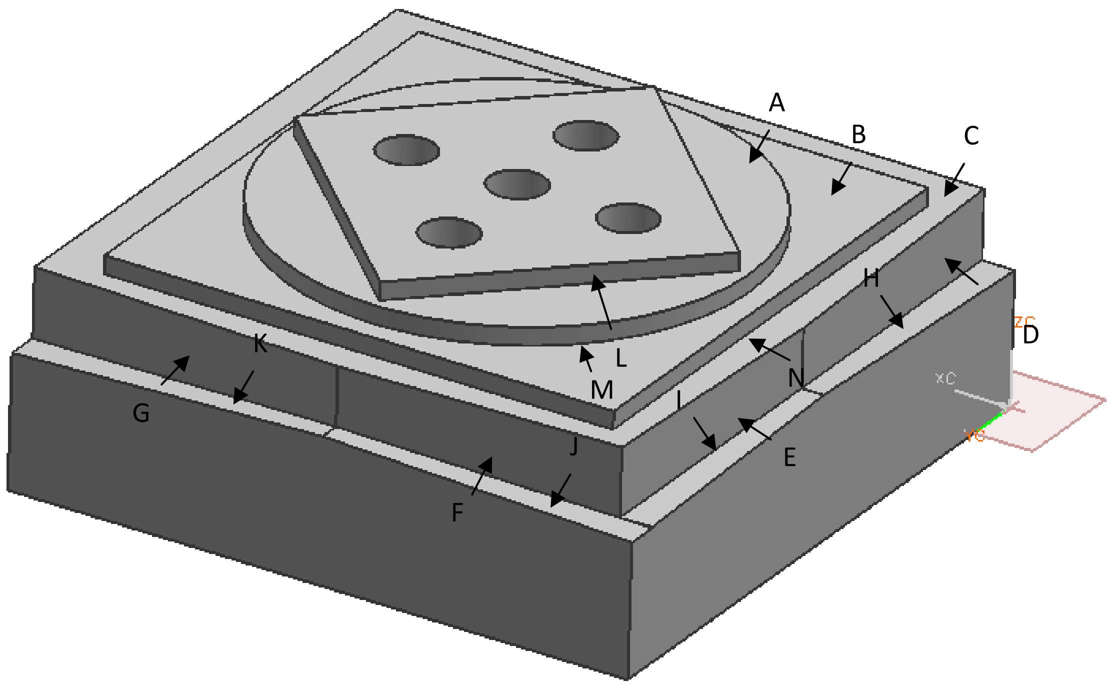


Figure 4.2: 2D drawing of testpiece



(b)

Figure 4.3: 3D model of testpiece (BS 4656)

4. 3 PROCESS PLANNING

The machining processes as shown in table 4.1 were carefully selected by analyzing the testpiece geometry and machine capability. The machining parameters for each process were also calculated as shown in table 4.3

Table 4.1: Process planning of part machining

<table>
<tr><td colspan="3">Route sheet</td><td colspan="4">Machine Shop</td></tr>
<tr><td colspan="2">Part no.
000001</td><td>Part name
FYP part</td><td>Planner
NDPhuong</td><td>Checked by</td><td>Date
02/14/08</td><td>Page
1/1</td></tr>
<tr><td colspan="2">Material
Mild Steel</td><td>Stock size
300 X 300 X 129 mm</td><td colspan="4">Comments:</td></tr>
<tr><td>No</td><td colspan="2">Operation description (surfaces refer to Figure 4.3)</td><td colspan="2">Tool</td><td colspan="2">Machine</td></tr>
<tr><td>10</td><td colspan="2">Squaring</td><td colspan="2">F1</td><td colspan="2" rowspan="19">5-axis machining center</td></tr>
<tr><td>20</td><td colspan="2">Rough face mill on face A</td><td colspan="2">E1</td></tr>
<tr><td>30</td><td colspan="2">Rough face mill on face B</td><td colspan="2">E2</td></tr>
<tr><td>40</td><td colspan="2">Rough face mill on face C</td><td colspan="2">E2</td></tr>
<tr><td>50</td><td colspan="2">Rough cavity mill on face J</td><td colspan="2">E2</td></tr>
<tr><td>60</td><td colspan="2">Rough cavity mill on face K</td><td colspan="2">E2</td></tr>
<tr><td>70</td><td colspan="2">Rough cavity mill on face I and H</td><td colspan="2">E2</td></tr>
<tr><td>80</td><td colspan="2">Finish end mill on face F and G</td><td colspan="2">E2</td></tr>
<tr><td>90</td><td colspan="2">Finish end mill on face D and E</td><td colspan="2">E2</td></tr>
<tr><td>100</td><td colspan="2">Finish end mill on face L, M, N</td><td colspan="2">E2</td></tr>
<tr><td>110</td><td colspan="2">Finish face mill on face A, B, C</td><td colspan="2">E2</td></tr>
<tr><td>120</td><td colspan="2">Finish face mill on face H</td><td colspan="2">E2</td></tr>
<tr><td>130</td><td colspan="2">Finish face mill on face I</td><td colspan="2">E2</td></tr>
<tr><td>140</td><td colspan="2">Finish face mill on face J</td><td colspan="2">E2</td></tr>
<tr><td>150</td><td colspan="2">Finish face mill on face K</td><td colspan="2">E2</td></tr>
<tr><td>160</td><td colspan="2">Spot drilling</td><td colspan="2">SD1</td></tr>
<tr><td>170</td><td colspan="2">8mm drilling</td><td colspan="2">D1</td></tr>
<tr><td>180</td><td colspan="2">16mm drilling</td><td colspan="2">D2</td></tr>
<tr><td>190</td><td colspan="2">25 mm drilling</td><td colspan="2">D3</td></tr>
</table>

Table 4.2: Tool geometry

Tool name	Description	Diameter	Tool length	Point angle	Flute length
SD1	Spot drilling tool	12.00 mm	50.00 mm	120.00 ^{o}	35.00 mm
D1	Drilling tool	8.00 mm	130.00 mm	118.00 ^{o}	75.00 mm
D2	Drilling tool	16.00 mm	130.00 mm	118.00 ^{o}	75.00 mm
D3	Drilling tool	25.00 mm	130.00 mm	118.00 ^{o}	75.00 mm
E1	End milling	16.00 mm	50.00 mm	0.00 ^{o}	40.00 mm
E2	End milling	10.00 mm	80.00 mm	0.00 ^{o}	40.00 mm
F1	Face milling	50.00 mm	25.00 mm	0.00 ^{o}	15.00 mm

The machining process continued with rough facing operations on surfaces A, B and C and rough cavity milling operations on surfaces J, K, I and H (surfaces are referred to Figure 4.3). These roughing operations removed most of the materials and prepared for the finishing operations.

Finishing process included operations from 80 to 150, the testpiece was machined until it reached the design dimensions.

Operations 160 to 190 are drilling operations. The process started with spot drilling to accurately locate the position of hole’s centers. Three subsequent steps were carried out to expand the diameters of the holes. The holes were drilled first with 8mm drill bit, then with 16mm drill bit and finally with 25 mm diameter drill bit to get the design hole diameters of 25 mm . The purpose of these subsequent operations was to reduce the cutting force on the drilling tools.

The complete machining parameters for each operation are listed in Table 4.3. The depths of cut for finishing face mill were determined to be smaller than those for roughing face mill while the steps over for finishing end mill were determined to be smaller than those for roughing end mill. An example can be seen from Table 4.3 in which the depth of cut for operation 20 was 5 mm while depth of cut for operation 110 was 0.5 mm.

Table 4.3 Machining parameters

No	Depth of cut	Step over (% D)	Surface speed (smm)	Feed/tooth (mm)	Spindle speed (rpm)	Feed rate (mmpm)
20	5	25	201.00	0.05	4000	800
30	5	25	147.00	0.0521	4700	735
40	5	25	125.00	0.0583	4000	700
50	5	10	109.00	0.0333	3500	350
60	5	10	94.00	0.0250	3000	225
70	5	10	94.00	0.0250	3000	225
80	5	10	125	0.0208	4000	250
90	5	10	125	0.028	4000	250
100	3	10	125	0.028	4000	250
110	0.5	25	141	0.0222	4500	300
120	0.5	10	125	0.0208	4000	250
130	0.5	10	125	0.0208	4000	250
140	0.5	10	125	0.0208	4000	250
150	0.5	10	125	0.0208	4000	250
160	N/A	N/A	21.28	0.0254	564	29
170	N/A	N/A	47.00	0.0144	600	13.77
180	N/A	N/A	47.00	0.0166	600	20
190	N/A	N/A	47.00	0.0166	600	20

4. 4 SIMULATION

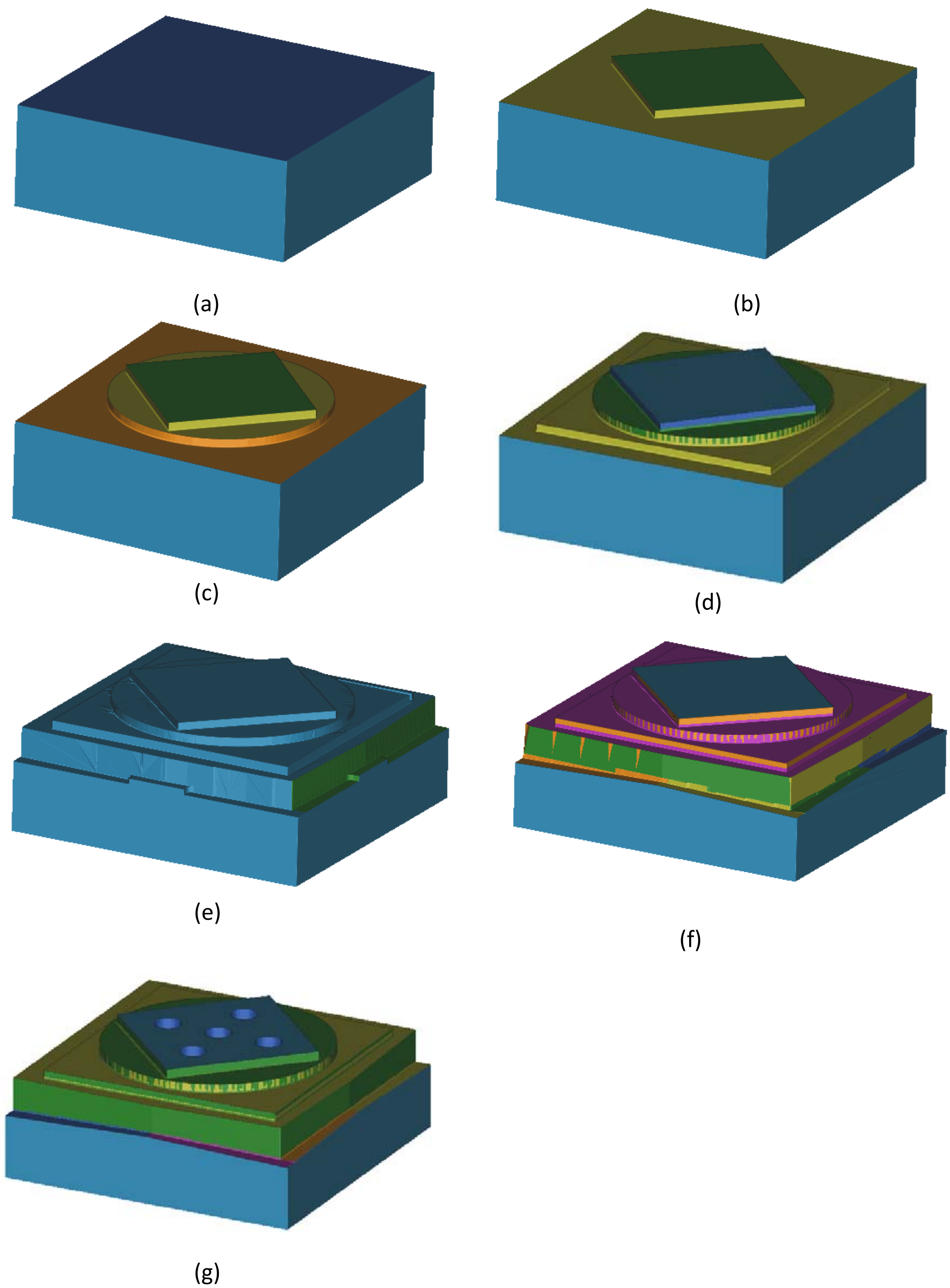


Figure 4.4: Simulation steps by Unigraphics. (a): Step 10, (b): Step 20, (c): Step 30, (d): Step 40, (e): Step 70, (f): Step 150, (g): Step 190

In this part, the sequences of operations, tool types and size, materials and were input to Unigraphics Manufacturing to simulate the cutting processes. Figure 4.4 shows the testpiece geometries after each step.

Five - axis vertical milling machine was selected as the virtual processor and the cutting was simulated in this machining environment. The simulation purpose was to visualize the movement of machine, to monitor the cutting tool conditions and machining parameters at during the cutting process. Figure 4.6 shows the Unigraphics interface, in which the values of machining time, tool coordinate, coolant status, feed rate and spindle speed can be read at any time during the simulation process.

Table 4.4: Operation time

Operation number	Time (hh:mm:ss)
20	01:11:30.4
30	00:59:44.7
40	00:32:34.4
50	00:20:08.5
60	00:54:38.4
70	01:29:35.3
80	00:07:20.3
90	00:07:22.0
100	00:22:29.0
110	02:56:16.0
120	00:47:10.9
130	00:39:47.6
140	00:55:14.3
150	00:58:20.7
160	00:12:13.2
170	01:42:40.5
180	01:45:03.8
190	02:15:09.9

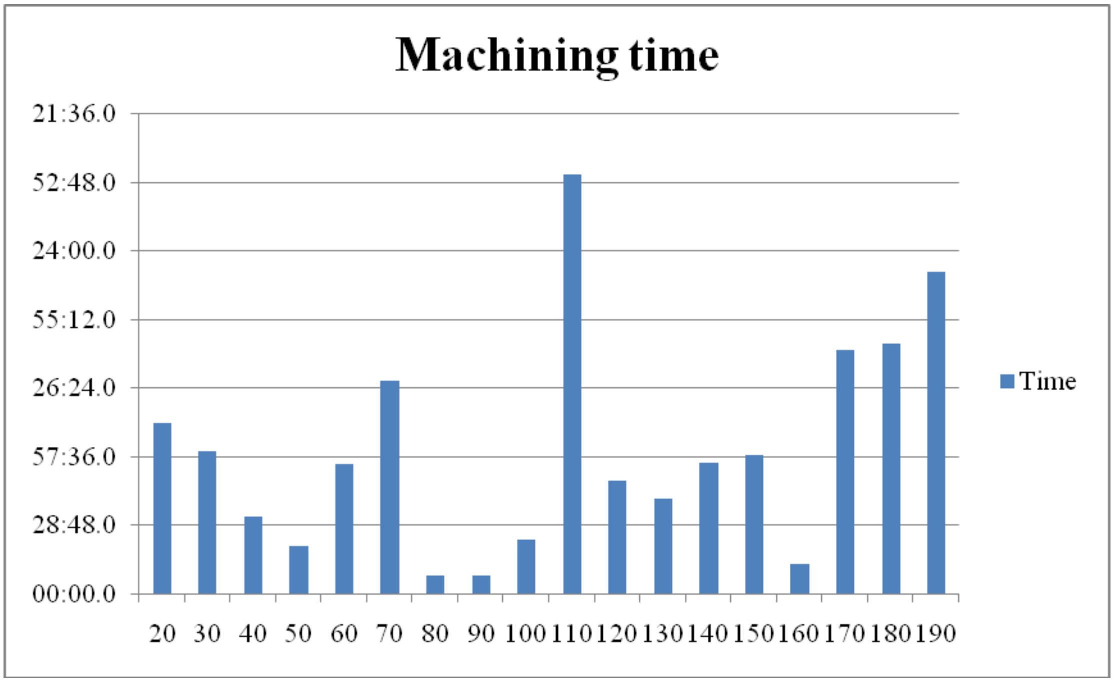


Figure 4.5 Machining time for each operation

Table 4.4 summarizes estimated machining time for each operation. These time were calculated by Unigraphics during the simulation process. As shown in Table 4.4, the longest operation was operation 110 which took 2 hours 56 minutes and 16 seconds to complete. This operation had the longest cutting time because it was the finishing operation of the most critical and largest surfaces (surface A, B and C) of the testpiece. Cutting tool for this operation was E2 (Table 4.2). The diameter of this cutting tool was 10mm while the step over for this operation was 25% (Table 4.3), which means the tool advanced 2.5 mm for each cutting pass. This was relatively small compared to the width and length of the cutting area. Therefore the machine need a large amount of time for this operation.

Operation had shortest cutting time (7 minutes and 20 seconds) was operation 80. In this operation, the depth of cut was 5 mm while the total depth was only around 25 mm. It means this operation only required five passes to finish. Operation 90 also has an approximately similar cutting time with operation 80 because they have similar size cutting areas.

Drilling operations also took a large amount of time. A total of 5 hours 42 minutes and 54 seconds were required to complete operation 170, 180 and 190. This allocation of time was because of the peck drill application. Peck drill is the operation that the drill bit moves beyond the drilling surface after it reaches a certain depth. The purpose of peck drill is to remove the metals chip produced by the drilling process. As the designed holes are very long (65 mm), without applying peck drill, the chips would be stuck in the holes and obstruct drilling motion and hence cause damages to the drill bits.

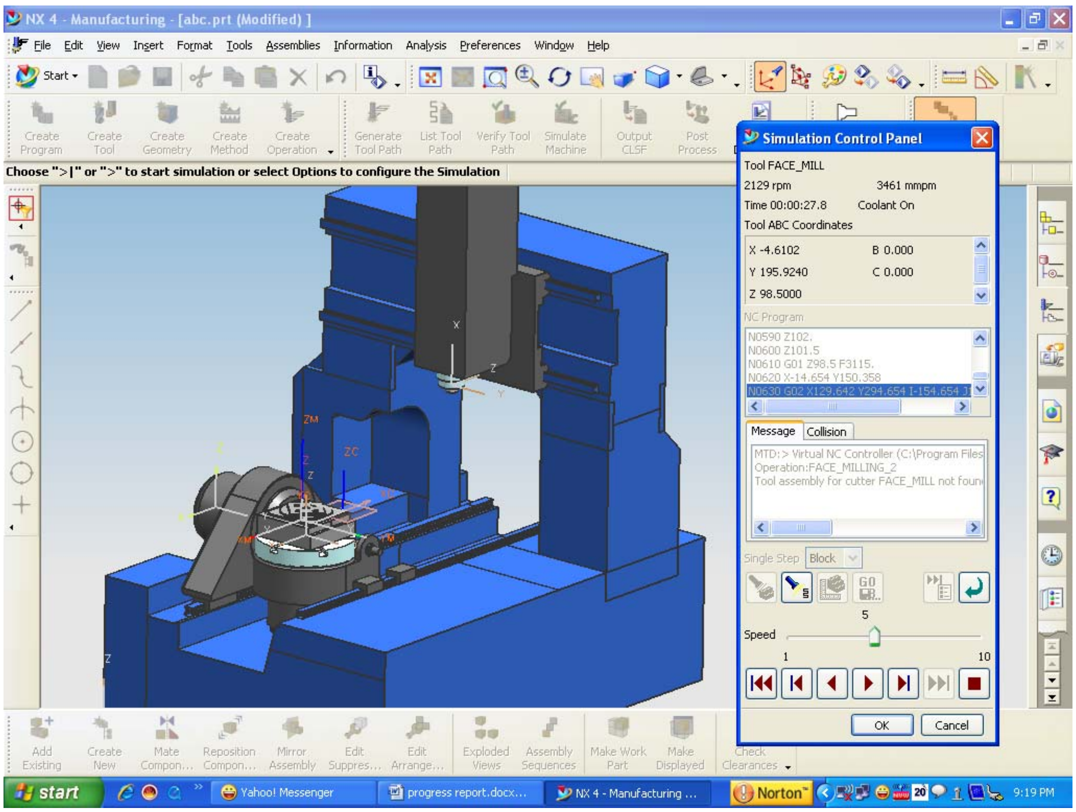


Figure 4.6: Virtual reality simulation interface

4.5 POST PROCESSING

After the model had been simulated, cutter locations were generated by Unigraphics and translated to NC code by IMSpost. Full and separate programs for each operation were then transferred to the CNC machine for actual machining works. A sample NC code can be found at the Appendix.

4.6 MATERIAL PREPARATION

Material (mild steel) was ordered and transported to the lab by using the lorry provided by the University Management. The material size was 300mm X 300mm X 128mm solid block. The material cost is RM438.00.

4.7 MACHINING

Machining works were carried out with cutting parameters as determined. Figure 4.7, Figure 4.8, Figure 4.9 show testpiece surfaces before and after machining.

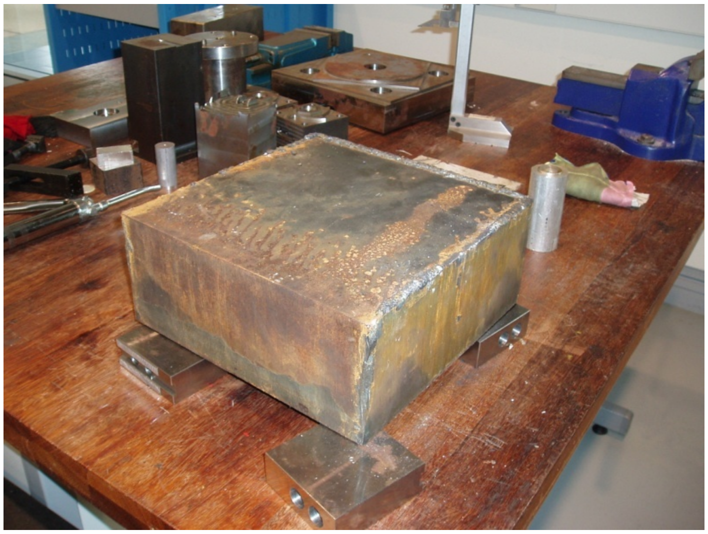


Figure 4.7: Workpiece before squaring

Figure 4.8: Workpiece after squaring

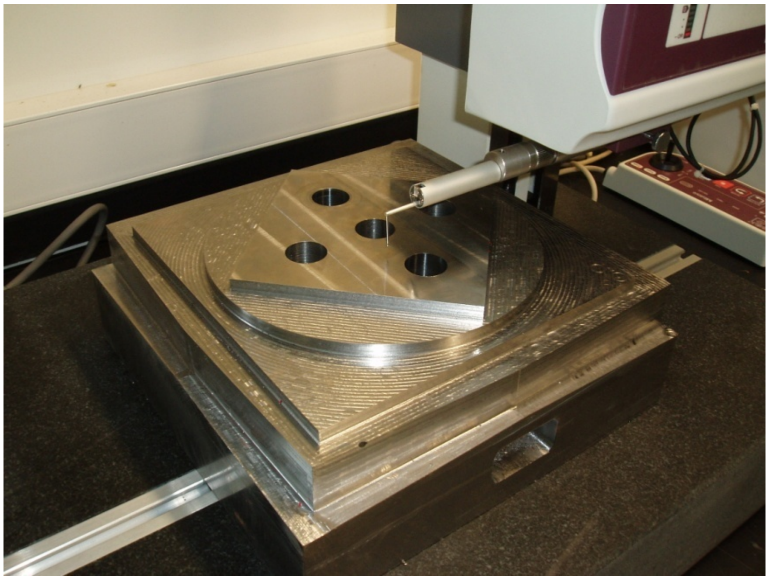


Figure 4.9: Workpiece after machined

Machining processes started with the squaring of the testpiece. This process took an extremely large amount of time with approximately one day to machine one surface. At least two tools were broken during the cutting processes even the feed rate and material removal rate were set to very low value. Machining could have not been done faster because of the surface hardness. This unusual hardness on the surfaces of the testpiece can be explained by the improper material preparation methods at the iron shop. The steel block was cut from the stock by oxygen cutting process. Oxygen cutting process generates high temperature to melt and remove the material. This high temperature however created a side effect which it harden the cutting surfaces of the material.

After squaring, the testpiece was machined according to the process planning, the cutting time was almost similar to simulation time.

4.8 MEASUREMENT

4.8.1 Surface roughness

Surface roughness of the testpiece was measured by using roughness tester at Metrology Laboratory. Table 4.5 lists the surface roughness data of the machined surfaces.

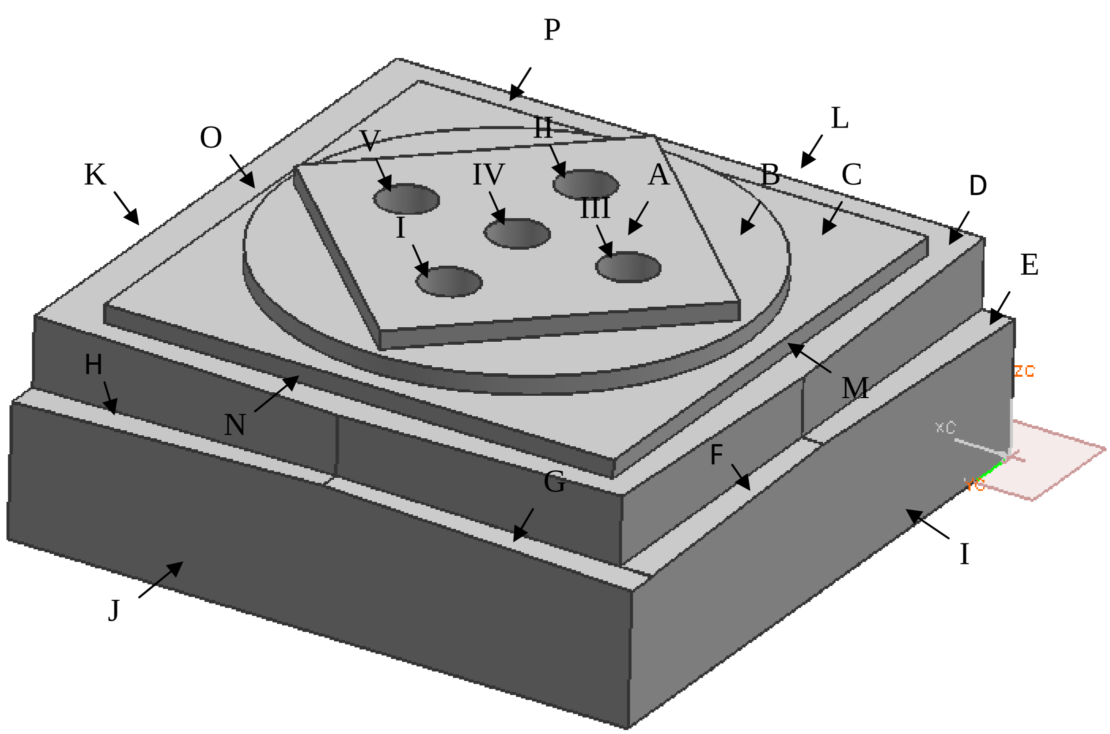


Figure 4.10: Workpiece surfaces and circles

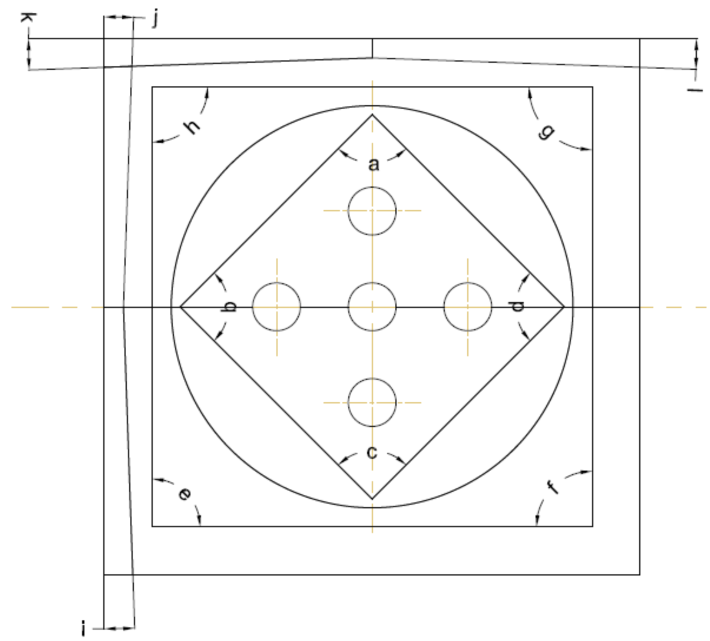


Figure 4.11: Workpiece angles

Table 4.5: Surface roughness (surfaces refer to Figure 4.10)

Surface	Measured data (μm)	Average roughness (μm)	Standard tolerance (μm)	Status
A	0.352, 0.401	0.377	1.6	Within tol.
B	1.235, 0.916, 1.417, 1.422, 1.146	1.227	1.6	Within tol.
C	1.272, 1.510, 1.299, 1.129	1.303	1.6	Within tol.
D	0.575, 1.133, 0.892	0.867	1.6	Within tol.
E	0.892	0.892	1.6	Within tol.
F	1.524	1.524	1.6	Within tol.
G	1.595	1.595	1.6	Within tol.
H	1.166	1.166	1.6	Within tol.
Average		1.149	1.6	Within tol.

Surface roughness of all faces were within tolerance with the maximum value of 1.595 μm (Table 4.5) and the average value of all surfaces measured was 1.149 μm. The standard tolerance is 1.6 μm. The main factor contributed was the stability of the machine. The results also proved the correct selection of spindle speed and feedrate during finishing process.

By comparing the roughness of the top surface and the remaining, a conclusion on the influence of tool type and diameter were made. Top surface were finished by using face mill tool with diameter of 50 mm while the others were finished by 10mm diameter end mill and 16 mm diameter end mill. The bigger the diameter of the cutting tool, the less number of passing times the cutting tool travels on the testpiece and hence less uting marks produced during the cutting process. Therefore tool F1 produced a better surface finish compared to tool E1 and E2.

The surface finish profile of surface A and E (surfaces refer to Figure 4.10) are shown on Figure 4.12 and Figure 4.13. The relationship between tool diameter and surface profile can clearly be observed in these two figures. The distance between two peaks in surface A's profile was approximately 45 mm while the distance between two peaks in surface B's profile was approximately 2.5 mm. They were also the step over distance of the respective finishing operations on surface A and surface B.

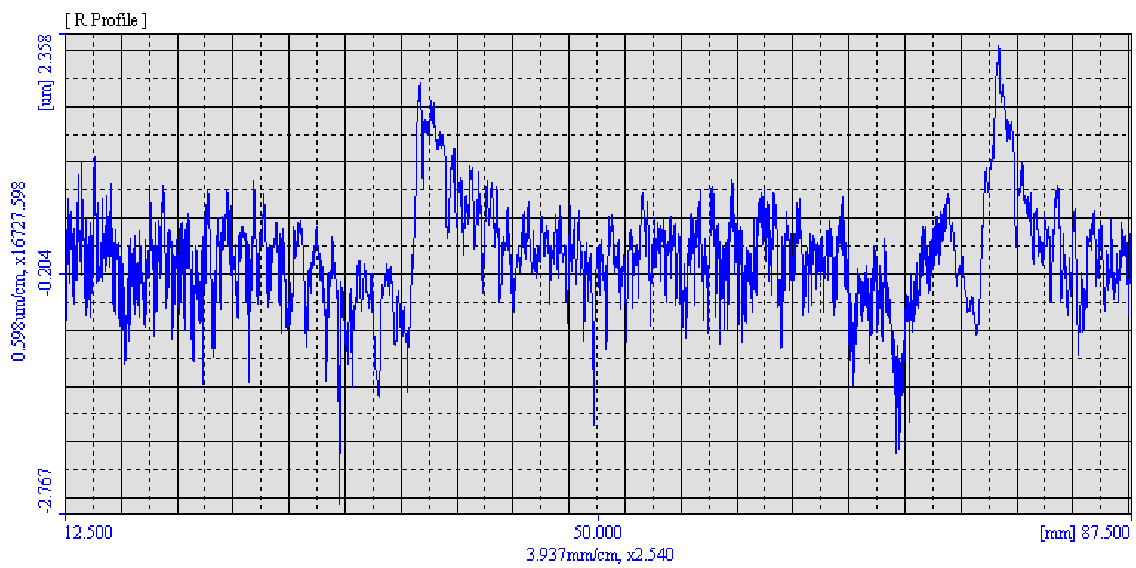


Figure 4.12: Roughness profile of surface A

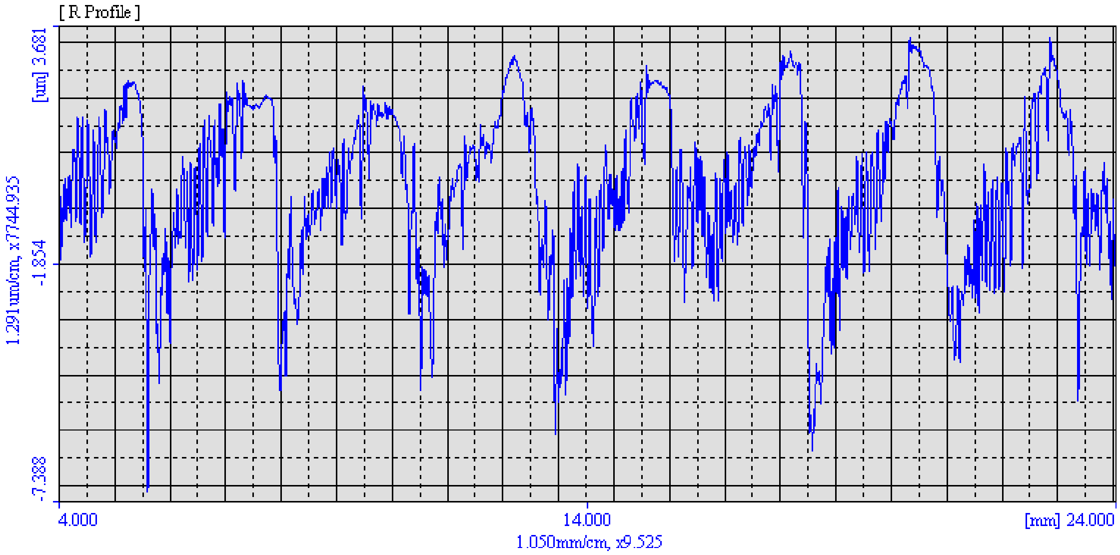


Figure 4.13: Roughness profile of surface E

4.8.2 Flatness

Measurement works were done by using Coordinate Measurement Machine at Metrology Laboratory. Table 4.6 lists the flatness data of the machined surface.

Table 4.6: Flatness (surfaces refer to Figure 4.10)

Surface	Measured data (mm)	Standard tolerance (mm)	Status
A	0.006	0.025	Within tol.
B	0.006	0.025	Within tol.
C	0.008	0.025	Within tol.
D	0.008	0.025	Within tol.
E	0.013	0.025	Within tol.
F	0.023	0.025	Within tol.
G	0.020	0.025	Within tol.
H	0.043	0.025	Out of tol.
Average	0.016	0.025	Within tol.

From the measurement results shown in table 4.6, all surfaces except surface H stay within flatness tolerance. The average flatness for all measured surfaces was 0.016 mm. From BS 4656 Pt 30-92, the standard tolerance for flatness was 0.025 mm.

Flatness of surface H was 0.043 mm and out of tolerance because of the fluctuated force on the cutting tool during finishing operation. As the roughing surface was done by using cavity milling, the material remained on surface H was very roughed. This layer of remaining material made the cutting force vary greatly during the finishing process and hence affected the flatness of surface H. Figure 4.4(e) shows the testpiece after roughing and the amount of material remained on surface H. However, in overall, the flatness was within tolerance.

4.8.3 Angularity

Measurement works were done by using Coordinate Measurement Machine at Metrology lab. Table 4.7 lists the angularity data of the machined angles

Table 4.7: Angularity of the testpiece (Angles refer to Figure 4.11)

Angle	Design value	Measured data	Deviation	Standard tol.	Status
a	90:00:00	89:59:58	0^o 0’ 2”	± 0^o 2’	Within tol.
b	90:00:00	90:00:04	0^o 0’ 4”	± 0^o 2’	Within tol.
c	90:00:00	90:00:21	0^o 0’ 21”	± 0^o 2’	Within tol.
d	90:00:00	89:59:54	0^o 0’ 6”	± 0^o 2’	Within tol.
e	90:00:00	90:00:37	0^o 0’ 37”	± 0^o 2’	Within tol.
f	90:00:00	89:59:07	0^o 0’ 53”	± 0^o 2’	Within tol.
g	90:00:00	89:59:03	0^o 0’ 57”	± 0^o 2’	Within tol.
h	90:00:00	90:00:41	0^o 0’ 41”	± 0^o 2’	Within tol.
i	02:00:00	02:00:36	0^o 0’ 36”	± 0^o 2’	Within tol.
j	02:00:00	01:59:40	0^o 0’ 20”	± 0^o 2’	Within tol.
k	02:00:00	02:00:20	0^o 0’ 20”	± 0^o 2’	Within tol.
l	02:00:00	01:59:45	0^o 0’ 15”	± 0^o 2’	Within tol.
Average			0^o 0’ 26”	± 0^o 2’	Within tol.

All the angles stayed within tolerance. The highest deviation was 57” at angle g, this deviation was still less than half of the standard tolerance which was 2’. The average deviation was 26”. So in overall, the angularities of the testpiece were conforming to the standards.

4.8.4 Circularity and concentricity

Measurement works were done by using Coordinate Measurement Machine at Metrology lab. Table 4.8 lists the circularity data of the machined circles

Table 4.8: Circularity (circles refer to Figure 4.10)

Circle	Measured data (mm)	Standard tolerance (mm)	Status
I	0.02	0.03	Within tol.
II	0.02	0.03	Within tol.
III	0.01	0.03	Within tol.
IV	0.02	0.03	Within tol.
V	0.02	0.03	Within tol.
VI	0.02	0.03	Within tol.
Average	0.02	0.03	Within tol.

Table 4.9: Concentricity (circles refer Figure 4.10)

Circle	Measured data (mm)	Standard tolerance (mm)	Status
IV & VI	0.007	0.025	Within tol.

All circularity and concentricity were within tolerance. The largest circularity was at circle V (0.02 mm) while the standard tolerance was 0.03 mm. From table 4.9, concentricity between circle IV and VI was 0.007 mm while the standard circularity was 0.025 mm. This high accuracy gained can be explained by the usage of spot drilling before drilling process.

4.8.5. Parallelism

Measurement works were done by using Coordinate Measurement Machine at Metrology lab. Table 4.10 lists the parallelism of the machined surface.

Table 4.10: Parallelism (planes refer to Figure 4.10)

Planes	Measured data (mm)	Standard tolerance (mm)	Status
A & B	0.01	0.02	Within tol.
C & D	0.01	0.02	Within tol.
I & K	0.28	0.02	Out of tol.
J & L	0.75	0.02	Out of tol.
M & O	0.87	0.02	Out of tol.
N & P	1.05	0.02	Out of tol.
Average	0.49	0.02	Out of tol.

From the results as shown in table 4.10, most of the surfaces were not in parallel. The standard tolerance value was 0.02 mm. Among six tests carried out, only parallelism of face A&B and face C&D were within tolerance with the parallelism of 0.01 mm

Among the faces that were not in parallel, parallelism of face I & face K (0.28 mm) and face J & face L (0.75 mm) were not satisfied because the initial squaring of the testpiece were machined and controlled manually by the operator.

The parallelism of face M& face O was 0.87 mm, relatively high compared to standard tolerance because of the narrow machining surfaces. The corner between face M, face N, face O, face P with face D was the critical area where it was finished by two operations 100 and 110 (Table 4.1), both end mill and face mill. Tool wear also contributed to these surface defects as the wearing was not uniform across the flute length. The depths of cut of all the operations were less than 5mm while flute length was 40 mm. Therefore, the area near the tip of the tool was worn more than the area far from the tip. This not-uniform condition created not-uniform surface, therefore affected the flatness and surface finish.

4.8.6 Dimension

Dimensions were measured by Coordinate Measurement Machine. Table 4.10 lists the dimension of the testpiece.

Table 4.11 shows that most of the dimensions were out of tolerance, only length e which had the average value of 99.999 mm was within tolerance.

The inaccuracy was mostly due to the programming technique in which the dimensions mentioned in the standard were used as the target dimension values for machining. However, the standard tolerance in most cases were +0 and -1 mm, which are unilateral tolerance or unequal bilateral tolerance, therefore a conversion to equal bilateral tolerance should had been done before programming. In addition, as designed, Unigraphics generated the M code where gouging is minimized, therefore positive deviations were observed at a number of dimensions including a, b, f, g, h and k.

The occurrence of dimensional errors such as dimension a (+0.36 mm) and dimension f (+0.56 mm) were also contributed by the manual squaring process. As mentioned above, in this process, the testpiece was machined and controlled manually by the operator; therefore no conclusion could be made for these two cases.

For the other dimensions, although the dimensions were out of tolerance, the deviation values were relatively small compared to the tolerance range. For example, measured data of dimension b was 230.05 mm; its deviation was 0.05 mm which was less than half of the tolerance range (0.1 mm). Therefore, a very good accuracy of dimension would be expected if the target dimension had been chosen correctly.

Table 4.11: Dimensional accuracy (Dimension refer to Figure 3.1)

Dimension	Measured data (mm)	Average (mm)	Aim (mm)	Standard tol. (mm)	Status
a	280.10; 280.20; 280.44; 280.67	280.36	280.00	280 +0 – 0.1	Out of tol.
b	230.04; 230.05; 230.05	230.05	230.00	230 +0 – 0.1	Out of tol.
d	142.01; 142.01; 141.86; 142.01	141.97	142.00	142 +0 – 0.1	Within tol.
e	100.007; 99.992	99.999	100.000	100 ± 0.025	Within tol.
f	25.14; 26.00; 25.98; 25.11	25.56	25.00	25 +0 – 0.1	Out of tol.
g	245.10	245.10	245.00	245 +0 – 0.1	Out of tol.
h	50.02	50.03	50.00	50 +0.1 - 0	Within tol.
k	8.10; 8.01; 8.10; 8.10	8.10	8.00	8 +0 – 0.1	Out of tol.

CHAPTER 5

RECOMMENDATION

For future development of the project, a research on the relationship between machining parameters and the surface finish, accuracy of the product should be carried out. This research would then be used for optimizing works with the aim at maximizing the capability of the machining center.

A comparison of different Computer Aided Manufacturing softwares should also be done to find the most suitable software that can generate the optimized tool path. This tool path must be as short as possible to lower production time while maintaining surface finish and accuracy of the product.

CHAPTER 6

CONCLUSION

Two main objectives of this project are simulation of the cutting process on the standard testpiece and measurement of the finished part to verify its conformation to BS standard.

Simulation was done on Unigraphics NX3 to select the machining parameters, generate tool paths and produce NC codes. Machining work was done on Mazak five axis machining center according to the NC codes generated by Unigraphics.

Performance tests were carried out later to measure the surface roughness, flatness, circularity, concentricity, parallelism and dimensional accuracy. Surface roughness average value stayed within tolerance with the average value of 1.149 μm and standard tolerance of 1.6 μm. Most flatness were also within tolerance with the average flatness of 0.016 mm and standard tolerance of 0.025 mm. Angularity was well within tolerance with the average value of only 26 seconds compared to the required tolerance of 2 minutes. Circularity and concentricity test gave very satisfactory results with the average value of circularity 0.02 mm and tolerance of circularity 0.03 mm; average concentricity of 0.007 mm and tolerance of 0.025 mm. However, the results of parallelism and dimensional accuracy test were not within tolerance. The reasons have been explained in the results and discussion part.

These results showed that many subjective factors affected the accuracy of the testpiece; however in overall, the machine performance was satisfactory, especially in surface finish characteristic. The deviations from the standard tolerances were also analyzed to draw out the sources of error for future improvement of the performance test.

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APPENDIX: SAMPLE NC CODE FOR OPERATION

```
N1 G17 G0 G40 G59 G21
G80 G90
N2 G91 G28 X0. Y0.
Z0.
N3 G90
N4 (NC OPERATION=
DRILLING  TOOLNAME=
DRILL25 )
N5 ( DIA= 25.0 CR=
0.0 FLAT ENDMILL  )
N6 M06 T27
N7 G90
N8 G61.1 M3 S600
N9 G1 X190. Y140. Z3.
A0. C0. M8 F2000.
N10 X190. Y140. Z-1.
A0. C0. F13.77
N11 X190. Y140. Z3.
A0. C0. F500.
N12 X190. Y140. Z1.
A0. C0.
N13 X190. Y140. Z-2.
A0. C0. F13.77
N14 X190. Y140. Z3.
A0. C0. F500.
N15 X190. Y140. Z0
A0. C0.
N16 X190. Y140. Z-3.
A0. C0. F13.77
N17 X190. Y140. Z3.
A0. C0. F500.
N18 X190. Y140. Z-1.
A0. C0.
N19 X190. Y140. Z-4.
A0. C0. F13.77
N20 X190. Y140. Z3.
A0. C0. F500.
N21 X190. Y140. Z-2.
A0. C0.
N22 X190. Y140. Z-5.
A0. C0. F13.77
N23 X190. Y140. Z3.
A0. C0. F500.
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A0. C0.
N25 X190. Y140. Z-6.
A0. C0. F13.77
N26 X190. Y140. Z3.
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F13.77
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A0. C0.
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A0. C0. F13.77
...
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A0. C0. F13.77
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N318 X90. Y140. Z3.
A0. C0. F500.
N319 X90. Y140. Z-28.
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A0. C0. F500.
N322 X90. Y140. Z-29.
A0. C0.
N323 X90. Y140. Z-32.
A0. C0. F13.77
N324 X90. Y140. Z3.
A0. C0. F500.
N325 X90. Y140. Z-30.
A0. C0.
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N326 X90. Y140. Z-33.
A0. C0. F13.77
N327 X90. Y140. Z3.
A0. C0. F500.
N328 X90. Y140. Z-31.
A0. C0.
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