Computer-Aided Inspection Approach Using 3D Digitizer

By

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CERTIFICATION OF APPROVAL

COMPUTER AIDED INSPECTION APPROACH FOR CHECKING DIMENSIONS OF MACHINED COMPONENTS

by

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TRONOH, PERAK

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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.

NOOR MAISARAH BINTI KAMARUDIN

ABSTRACT

An inspection is, most generally, an organized examination or formal evaluation exercise. It involves the measurements, tests, and gauges applied to certain characteristics in regard to an object or activity. This project related to inspection using 3D scanning device, digitizer. Renishaw Cyclone 3D laser digitizer was used to perform a computer-aided inspection on test piece with dome shaped contour with 50mm diameter. Results obtained indicate that the dimensions captured by digitizer deviate range by 0.02 to 0.03mm with an average of 0.026mm. In order to establish more definitive result, further research need to be done to cover various dimensions so as statistical analysis could be done to establish the deviation. Recommendation was given for further improvement.

ACKNOWLEDGEMENT

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY

An inspection is, most generally, an organized examination or formal evaluation exercise. It involves the measurements, tests, and gauges applied to certain characteristics in regard to an object or activity. The results are usually compared to specified requirements and standards for determining whether the item or activity is in line with these targets [1].

Automated measurement and inspection is based on various online sensor systems that monitor the dimensions of parts while they are being made and, if necessary, use these measurements as input to make correction [1]. Computer-aided inspection will reduce inspection time compare to the traditional method. Using automated measurement system, it will automatically detect any dimensional vary.

As a rule, CMMs are better suited to measure geometric parts where basic dimensions, whole locations, diameters, flatness and roundness measurements are required to accept or reject types of applications. Mean while, 3D Laser scanning tends to be better suited for the measurement and inspection of contoured surfaces and complex geometries which require massive amounts of data for their accurate description and where doing this is impractical with the use of a touch probe [2].

Computer-aided inspection can be improved by using 3-D scanning device. In Universiti Teknologi PETRONAS (UTP) mechanical workshop, digitizer (3-D scanning device) can be used to perform a Computer-Aided Inspection (CAI) on test piece with contour or complex shape. The dimension of the original and the piece product can be analyzed for inspection purposes.

1.2 PROBLEM STATEMENT

There are many methods to do measurement and inspection on manufacturing product. Manufacturing product with simple shape can be easily measured but not for complex shapes such as round and contour surface. Measurement usually consumes lot of time. Thus, there is a requirement to reduce it. This study is to use digitizer to explore the possibility to overcome this problem.

1.3 OBJECTIVES

This project objective is to assess the ability of 3D Digitizer to check dimension of machined part.

1.4 SCOPE OF STUDY

This project related to CAD/CAM, machining and inspection where those three are linked together. CAD/CAM is used in modelling and creates NC part programming which used in manufacturing. The part machined by CNC machine; MAZAK Variaxis 630-5X and then inspected by computer-aided inspection. This study access the ability to perform inspection using 3D laser digitizer as inspection device. Inspection focuses on deviation of original dimensions, between drawing and dimension obtained from digitizer.

CHAPTER 2

LITERATURE REVIEW

2.1 INSPECTIONS

An inspection is, most generally, an organized examination or formal evaluation exercise. It involves the measurements, tests, and gauges applied to certain characteristics in regard to an object or activity. The results are usually compared to specified requirements and standards for determining whether the item or activity is in line with these targets [1].

Computer numerical controlled (CNC) tools boost efficiency by speeding throughput, but machining leaves tool marks that cross over one another in various directions, requiring hand polishing and blending to smooth surfaces. Not only does this add time to the process, but it also removes additional metal assisting flow by reducing restrictions, but a head with mismatched port volumes. Hence, the product that is machined must be inspected to make sure that the dimensions are within tolerances levels. The inspection can be carried out with different methods.

The accurate tracking of tool-paths on five-axis CNC machine tools is essential in achieving high speed machining of dies, molds, and aerospace parts with sculptured surfaces. Because traditional CNCs control the tracking errors of individual drives of the machine, this may not lead to desired contouring accuracy along tool-paths, which require coordinated action of all the five drives [2].

As the machine has been producing a certain part with acceptable dimension, there are factors that contribute to the subsequent deviation in the dimensions of the same part produced by the same machine [2].

There are several technical as well as human factors involved in inaccuracy of parts machined such as:

- Statics and dynamics deflection of the machines because of vibration and fluctuating forces are caused by machine characteristics and variation in the properties and dimensions of the incoming material.
- Distortion of the machine because of the thermal effects caused by such as in temperature of the environment, of metalworking fluids, and the machine bearings and various components.
- Wear of tools, dies and molds can affect the dimensional accuracy of the parts produced.
- Human errors and miscalculations.

2.2 COMPUTER-AIDED INSPECTION (CAI)

It is impossible to identically size each port volume by hand, or to accurately replicate an "ideal" port design on another head. It's also time-consuming, often taking a highly skilled person up to 40 hours to complete a set of heads - making a very inefficient process [8].

CAI is to inspection the dimension of the product using computerized method. The principle and importance of the inspection are basically same with other inspection but different in term of method and procedures used. In CAI, product will be scan using devices such as Coordinate Measurement System (CMM) or 3D scanner. CAI will reduce inspection time compared to the traditional method. Using automated measurement system, it will automatically detect any dimensional vary.

Automated measurement and inspection is based on various on-line sensor systems that monitor the dimensions of parts while they are being made and, if necessary, use these measurements as input to make correction [1]. General characteristics and selection of measuring system are as shown in **Table 2.1**.

Table 2.1: Characteristic of Measuring Instrument [5].

Accuracy	The degree of agreement of the measured dimension with its true magnitude
Amplification/ magnification	The ratio of instrument output to the input dimension
Calibration	Adjusting or setting an instrument to give readings those are accurate within a reference standard.
Drift/stability	Instrument's capability to maintain its calibration over a period of time
Linearity	The accuracy of the readings on an instrument over its full working
Precision	Degree to which an instrument output to the input dimension
Resolution	Smallest dimension that can be read on an instrument.
Sensitivity	Smallest different in dimension that an instrument can distinguish.
Speed of response	How rapidly an instrument indicates the measurement, particularly when a number of parts are measured in rapid succession.

2.3 DIMENSION AND MEASUREMENT

As result of the mentioned factors, the dimensions of parts will vary, thus making continuous monitoring during production necessary. There are several geometry parameters for test. Listed in **Table 2.2** is the common geometry.

Table 2.2: Basic Geometry Parameters [5]

Parameter	Description
Straightness	Straightness is a condition where an axis or element of a surface is a straight line. A straightness tolerance specifies the tolerance zone within which an axis or all points of the considered element must lie.
Parallelism	Condition of a surface or axis equidistant at all point.
Angularity	Is the condition of a surface or axis that is at some specific angle (other than 90°) from datum or plane axis.
Perpendicularity	Is the condition of a surface, median, planed or axis is at 90 ° angles to a datum plane or axis.
Circularity	Exist when all the elements of a circle are the same distance from the centre. Cross-sectional tolerance which results in a feature that must lie between two concentric circles.
Position	True-position exists when the axis of the hole at all points must lie within the specified cylindrical tolerance zone having its centre located at true position.
Cylindricity	Is similar to circularity in that both have a radius tolerance zone. Blanket tolerance that results in a feature lying between two concentric cylinders.

2.4 3D LASER SCANNING

Laser scanning systems utilize laser-triangulation based technology. The heart of the technology is a dual camera probe which emits a diode based laser beam from the centre as shown in the **Figure 2.1** and **Figure 2.2.** The beam is split into a plane of laser light that comes out of the probe and shines below on the surface of the object being scanned. Thus it forms a profile on the surface of the part.

The shape of that single "2D" profile is recorded by the digital CCD and subsequently, based on the calibration and look up tables of the lasers, a Z position is determined and stored for each pixel value by the software. This location along with the machine axes positions are used to compute the X, Y, and Z coordinates of the points along that profile. Hundreds and thousands of similar profiles are thus collected as the probe marches over the object and the stores this information into a database for later retrieval. Each profile comes into the database as a single polyline entity with point distributed along the length of the line. These polylines are also displayed graphically on the computer screen as they are gathered.

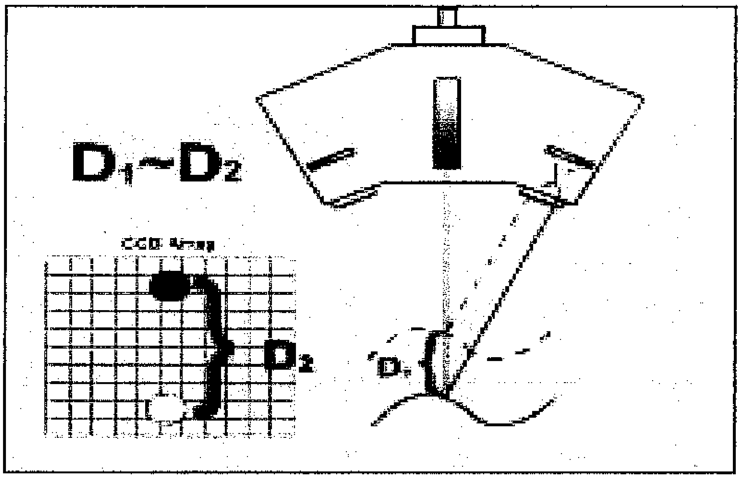

Figure 2.1: Working Principle of Laser Scanning [3]

A two-dimensional CCD (Charge Coupled Device) array similar to the one used in a home video camera is mounted on either side of the probe. They reside inside two identical optical sensors. The reflected light form the profile on the surface of the object activates the pixels on the array inside one of the two sensors. The reason for having two sensors instead of one is that if for some reason the view of the profile on the surface of the object is blocked for one sensor there is always the second sensor that can pick up the same profile. The user can toggle between the two sensors but only one is active at one time.

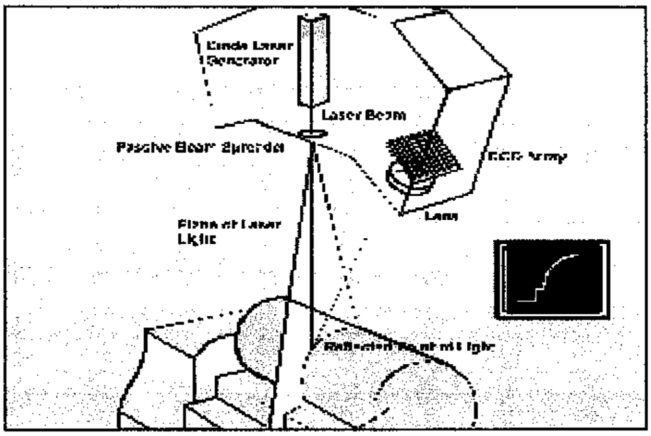

Figure 2.2: Working Principle of CCD [3]

Some are information and characteristics of 3D laser scanning digitizer:

Accuracy – The standard laser resolutions are 0.0004" and 0.0008". The volumetric accuracy specifications are based upon our ability to digitize a ball-bar oriented several ways within the work envelope and have the measured length of the ball-bar vary by no more than the stated accuracy of the machine. A ball-bar is defined by the American Society of Mechanical Engineers (ASME) in their standards document, ASME B89.1.12M-1990, as a rigid bar to which a precision tooling ball is mounted on each end.

Speed – The laser has exposure settings that need to be adjusted depending upon the nature of the object being scanned. In general, dark coloured objects require longer exposure settings than light coloured objects and longer exposure settings require the system to operate at slower velocities if data integrity is to be maintained. The point sampling distance requested by the user also affects scanning speeds.

Shapes for digitized – In addition to XYZ positioning, Laser Design supports computer controlled object rotation and laser orientation. This allows scanning of virtually every side of a 3D object and eliminates the traditional problem of scanning undercuts.

As the technology improve rapidly, 3D laser scanner brought advantages especially in measurement and inspection purposes. Hence the development of CAD/CAM also parallel with the technology developing. The main advantages of laser scanning: [4]

- The primary advantage of laser scanning is that the process is non-contact, fast and results in coordinate locations that lie directly on the surface of the scanned object. This allows fragile parts to be measured and makes the scanned coordinate locations especially useful to CAD/CAM systems where splining or surfacing through true surface coordinates is desirable.
- The laser's high resolution and thinner beam also permits scanning of highly detailed objects where mechanical touch probes may be too large to accomplish the task. Also, while many touch probe systems attempt to compute true surface coordinates by sensing probe deflection, there are certain geometries where probe deflection can be "fooled".
- once true surface coordinates have been collected for an object, a single set of data can be used to generate roughing and finishing tool paths for machining, feed CAD/CAM and analysis software, drive rapid prototyping equipment, and allow "electronic archiving" of physical objects.

2.5 3D DIGITIZER

Digitizer is a device for converting analogue electric signals of an absolute or relative position on the tablet surface to digital X, Y, and Z coordinates. This process yields vector data consisting of points, lines, and polygons that will need to be edited. By positioning a pointing device containing a magnetic coil (cursor or pen stylus) on the tablet surface which is embedded with a grid of wires, a signal is generated. The resolution, or density of wires in the grid, varies from 1,000 to 10,000 lines per inch. **Figure 2.3** is the general 3D scanning device use in industry.

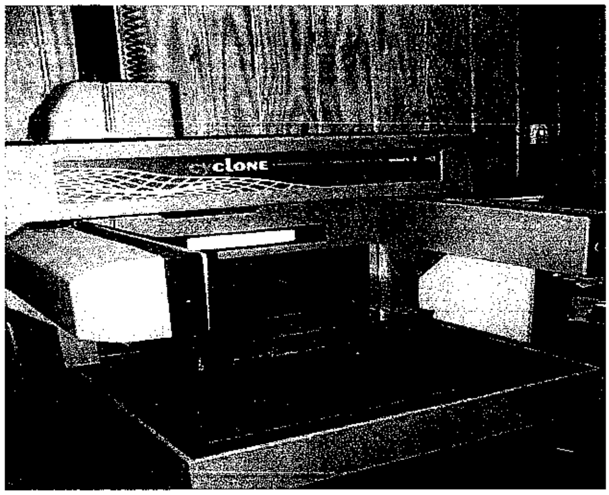

Figure 2.3: Renishaw Cyclone 3D Scanning System [3].

A continuous-contact reverse-engineering tool, the Cyclone probes port and combustion chamber wall surfaces collecting dimensional data to produce a 3-D wireframe model of the internal features, as shown in **Figure 2.4**. A three-axis digitizer, the Cyclone is fitted with probe styli and a special fixture that rotates the head in the A (rotation about the X-axis) and B (rotation about the Y-axis) axes to allow access to hard-to-reach port areas.

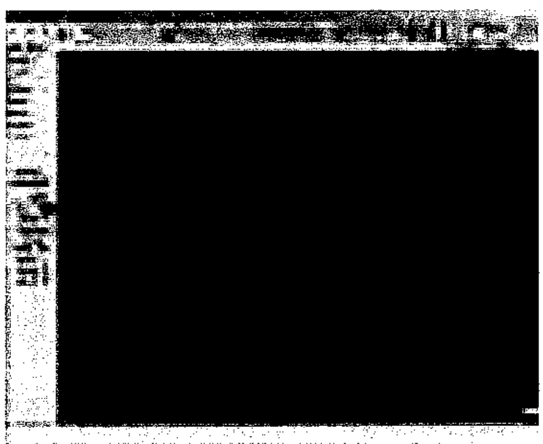

Figure 2.4: Example Result From the 3D Digitizer [3]

Because the Cyclone is a continuous-contact digitizer, probing routines can be done much more quickly than point-to-point probing on a machine tool, effectively cutting the scanning routine from days to hours.

As the Cyclone probes within the port, rotary encoders register the angular position of the fixture and a digital display shows position to 0.001 degree. When all areas of the intake port that can be reached from the intake side of the head are probed, the head is rotated to finish probing the intake port through its valve opening, begin probing the exhaust port through its valve opening, and completely probe the combustion chamber. The head is then rotated again to finish probing the exhaust port from the exhaust side of the head.

Accurate to within 0.002 inches, the continuous-contact Cyclone scans at a rate of 140 points per second at a maximum scanning speed of 118 inches per minute. States below are benefits of 3d digitizer:

- The software processes data from a 3-D point cloud from a laser scanner, eliminating the need for slower and more time-consuming CMM measurements.
- The software provides a graphical comparison of the manufactured part compared to the CAD model, automatically performing first-article inspection, tool validation, wear analysis, object alignment, and 2-D and 3-D dimensional analysis.

2.6 DIGITIZER COMPONENTS

The two major components in a high-speed digitizer's analogue front end are the analogue input path and the analogue-to-digital converter (ADC). As shown in **Figure 2.5**, the analogue input path attenuates, amplifies, filters, and/or couples the signal to optimize the digitization by the ADC. The ADC samples the conditioned waveform and converts the analogue input signal to digital values that represent the conditioned input signal.

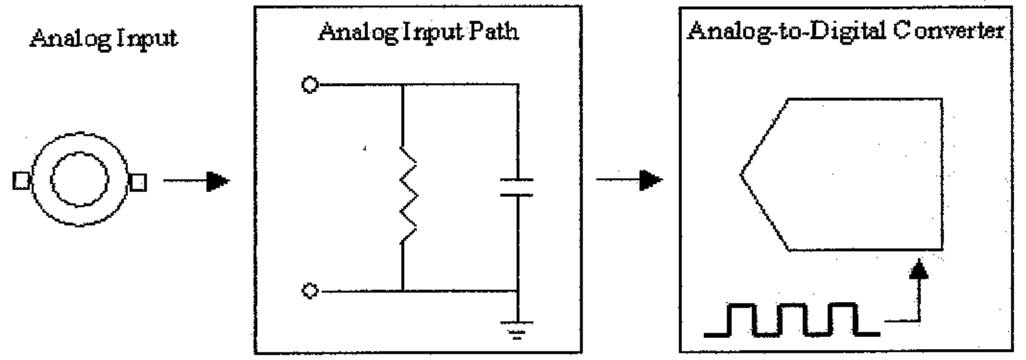

Figure 2.5: Digitizer Components [10]

Bandwidth describes the analogue front end's ability to get a signal from the outside world to the ADC with minimal amplitude loss. Sample rate is the frequency at which the ADC converts the analogue input waveform to digital data. The Nyquist Theorem explains the relationship between the sample rate and the frequency of the measured signal.

Sample rate is not directly related to the bandwidth specifications of a high-speed digitizer. Sample rate is the speed at which the digitizer's ADC converts the input signal, after the signal has passed through the analogue input path, to digital values that represent the voltage level. This means that the digitizer will sample the signal after any attenuation, gain, and/or filtering has been applied by the analogue input path, and converts the resulting waveform to digital representation as presented in **Figure 2.6.**

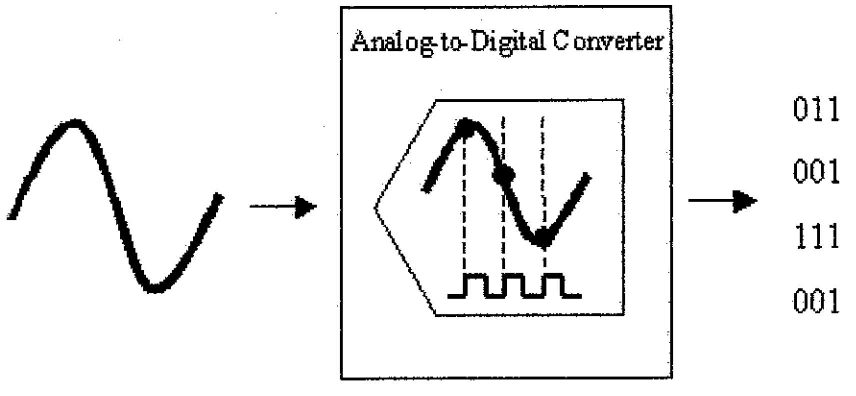

Figure 2.6: Sample rate.[10]

The sample rate of a high-speed digitizer is based on the sample clock that tells the ADC when to convert the instantaneous analogue voltage to the digital values. National Instruments high-speed digitizers support a variable effective sample rate derived from the maximum sample rate of the device. For example, the NI 5112 has a maximum sample rate of 100 Megasamples/second (MS/s) and can be set to rates of (100MS/s)/n, where n = 1,2,3,4,....

2.7 CNC MILLING MACHINE

Numerical control (NC) is a form of programmable automation in which the mechanical actions of a machine tool or other equipments are controlled by a program containing coded alphanumerical data.

A milling machine is a power-driven machine used for the complex shaping of metal parts. Its basic form is that of a rotating cutter or end mill which rotates about the spindle axis (similar to a drill), and a movable table to which the work piece is affixed. That is to say the cutting tool generally remains stationary (except for its rotation) while the work piece moves to accomplish the cutting action. Milling machines may be operated manually or under computer numerical control [8].

The highly-rigid, built-in tilting rotary table, unique to the Variaxis Series, allows workpieces with complex contours and features to be finished in just a single machine setup. It has tremendous weight capacity and will increase machining accuracy while reducing cycle time. 5-axis, simultaneously controlled machining with Variaxis is ideal for aerospace components as well as prismatic parts in steel and Aluminium.

For greater productivity, the Variaxis is available with a 2-pallet changer system. Or, team it with a Palettes system and the Variaxis becomes its own powerful cell. Variaxis main characteristics are as follow:

- Simultaneous 5-axis control
- Table tilts up to 150° (a-axis) and Table rotates up to 380° (c-axis)
- Minimal thermal distortion – cooled ball screws and spindle
- Mazatrol matrix CNC control

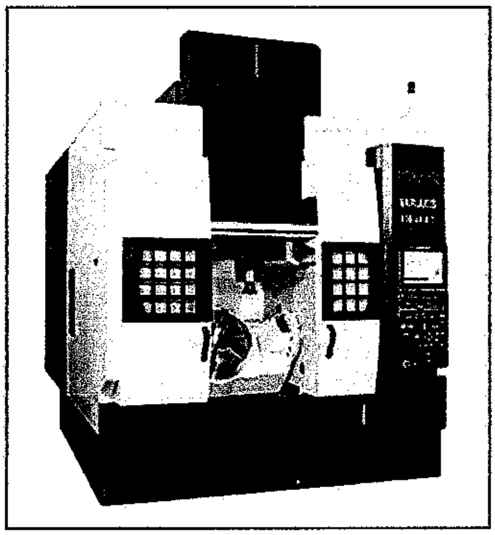

Figure 2.7: MAZAK Variaxis 630-5X. [11]

2.8 CNC CONTROL

CNC control will interpret a CNC program and activate the series of commands in sequential order. As it reads the program, the CNC control will activate the appropriate machine functions, cause axis motion, and in general, follow the instructions given in the program.

Along with interpreting the CNC program, the CNC control has several other purposes. All current model CNC controls allow programs to be modified (edited) if mistakes are found. The CNC control allows special verification functions (like dry run) to confirm the correctness of the CNC program. The CNC control allows certain important operator inputs to be specified separate from the program, like tool length values. In general, the CNC control allows all functions of the machine to be manipulated [12].

2.9 NC PART PROGRMMING

NC part programming consists of planning and documentations the sequence of processing steps to be performed on an NC machine. It can be done by translating a representation of the geometry of a drawing, first into a specification for the operations to be carried out by the machine tool, and then into a program of instructions for the controller.

The documentation portion of part programming involves input medium used to transmit the program of instruction to the NC machine control unit (MCU). The traditional input medium dating back to the first NC machines in the 1950s is 1-inch wide punch tape. More recently, the use of magnetic tape and floppy disks have been growing in popularity as storage technologies for NC. The advantage of these input media is their much higher data density.

2.9.1 Manual Part Programming

In manual programming, the programmer prepares the NC code using low-level machine language. The machining instructions are prepared on a document called part program manuscript. Basically, the manuscript is a listing of the relative cutting tool or workpiece positions which must be followed in order to machine the workpiece. A punched tape is then prepared directly from the part programmer manuscript [9].

2.9.2 CAD/CAM part programming

A CAD/CAM system is computer interactive graphics system equipment with software to accomplish certain task in design and manufacturing and to integrate the design and manufacturing functions. One of the important tasks performed on a portion of the procedures usually done by the part programmer instead done by the computer. CAD/CAM system generally provides facilities to display the programmed motion cutter with respect to the workpiece, which allows visual tool moves.

2.9.3 G-code and M-code

Some G words alter the state of the machine so that it changes from cutting straight lines to cutting arcs. Other G words cause the interpretation of numbers as millimeters rather than inches. While still others set or remove tool length or diameter offsets. Most of the G words tend to be related to motion or sets of motions.

Table 2.3 shows list of G codes that the currently available:

Table 2.3: G Code List

G0 rapid positioning G1 linear interpolation G2 circular/helical interpolation (clockwise) G3 circular/helical interpolation (c-clockwise) G4 dwell G10 coordinate system origin setting G17 XY plane selection G18 XZ plane selection G19 YZ plane selection G20 inch system selection G21 millimeter system selection G40 cancel cutter diameter compensation G41 start cutter diameter compensation left G42 start cutter diameter compensation right G43 tool length offset (plus) G49 cancel tool length offset G53 motion in machine coordinate system G54 use preset work coordinate system 1 G55 use preset work coordinate system 2 G56 use preset work coordinate system 3 G57 use preset work coordinate system 4	G58 use preset work coordinate system 5 G59 use preset work coordinate system 6 G59.1 use preset work coordinate system 7 G59.2 use preset work coordinate system 8 G59.3 use preset work coordinate system 9 G80 cancel motion mode (includes canned) G81 drilling canned cycle G82 drilling with dwell canned cycle G83 chip-breaking drilling canned cycle G84 right hand tapping canned cycle G85 boring, no dwell, feed out canned cycle G86 boring, spindle stop, rapid out canned G87 back boring canned cycle G88 boring, spindle stop, manual out canned G89 boring, dwell, feed out canned cycle G90 absolute distance mode G91 incremental distance mode G92 offset coordinate systems G92.2 cancel offset coordinate systems G93 inverse time feed mode G94 feed per minute mode G98 initial level return in canned cycles

M words are used to control many of the input and output functions of a machine. M words can start the spindle and turn on mist or flood coolant. M words also signal the end of a program or a stop within a program. The complete list of M words available to the programme is included in **Table 2.4**.

Table 2.4: M Word List

M0 program stop	M9 mist and flood coolant off
M1 optional program stop	M26 enable automatic b-axis clamping
M2 program end	M27 disable automatic b-axis clamping
M3 turn spindle clockwise	M30 program end, pallet shuttle, and reset
M4 turn spindle counterclockwise	M48 enable speed and feed overrides
M5 stop spindle turning	M49 disable speed and feed overrides
M6 tool change	M60 pallet shuttle and program stop
M7 mist coolant on	
M8 flood coolant on	

CHAPTER 3

METHODOLOGY

3.1 PROJECT FLOW

The structure of the project flow consists 5 phases. **Figure 3.1** shows flow and activities for each phase.

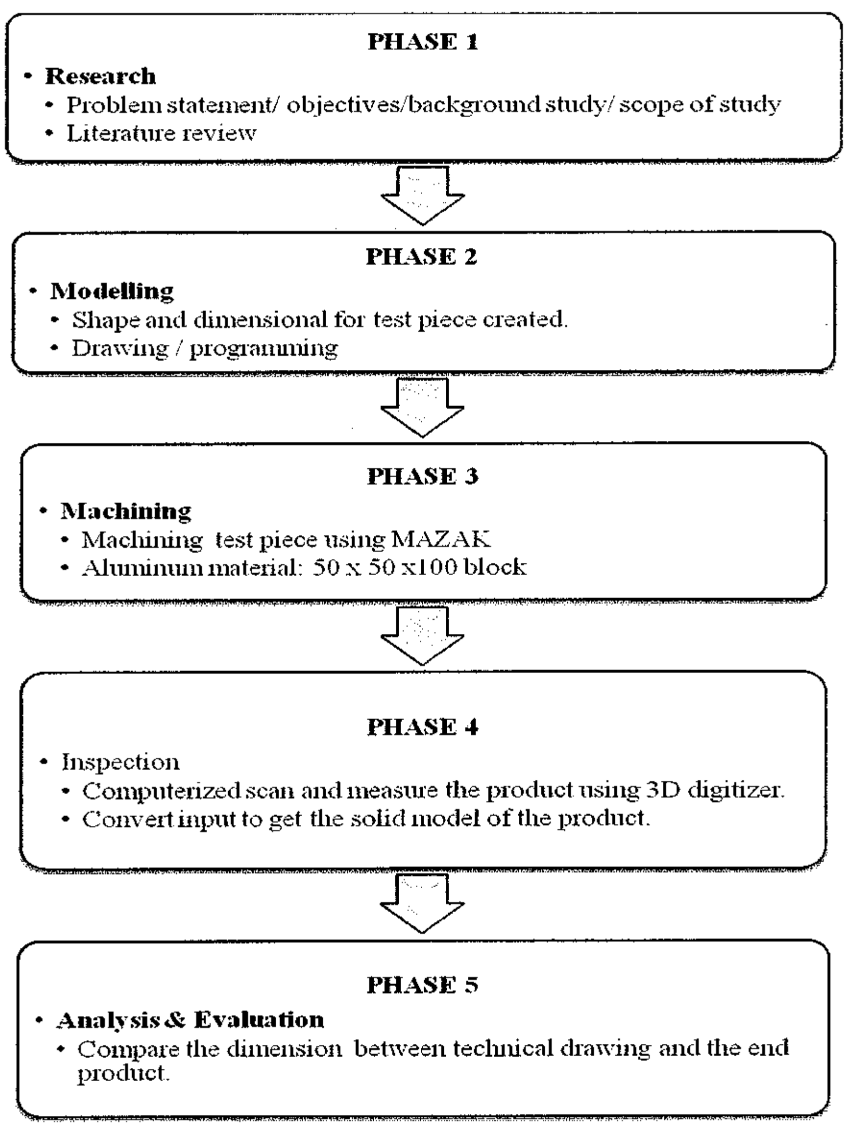

Figure 3.1: Project Flow Diagram

Phase 1: *Research* – this phase contains background study and analyses critical components of the study including problem statement, objectives, scope of study, literature review, methodology and relevant information regarding research.

Phase 2: *Modelling* – Test piece created based on the specification to meet the objective of project. Using CAD/CAM, NC program for machining process created.

Phase 3: *Machining* – machining of test piece are done using CNC machine, MAZAK Variaxis 630-5X.

Phase 4: *Inspection* – Inspect the dimension of machined test piece. In this approach, digitizer is used in inspection of test piece besides using conventional test measurement.

Phase 5: *Analysis and evaluation* – results from digitizer scanning been analyzed and evaluate. This measurement is important to prove that inspection can be done using digitizer and this method is more reliable compare to the conventional measurement.

3.2 MODELLING

The modelling of test piece was based on dome shape. The shape has contour and it was complex to measure using conventional measurement devices. Drafting on model for test piece was done using AutoCAD. Test piece dimension included on the drawing. The dome has diameter of 50mm. **Figure 3.2** shows 2D drawing of the dome shape.

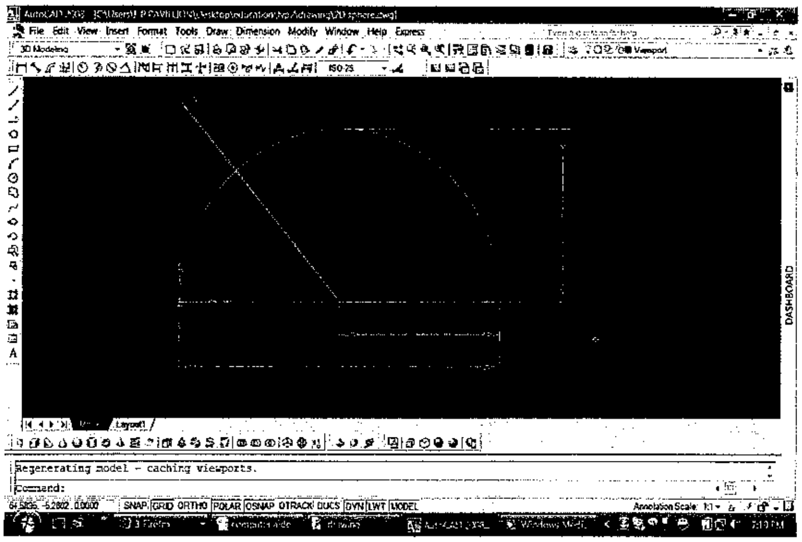

Figure 3.2: 2D drawing using AutoCAD.

Solid modelling for the test piece was done using Unigraphics NX3. Base on the dimension decided, 3D solid model created, shown in **Figure 3.3**.

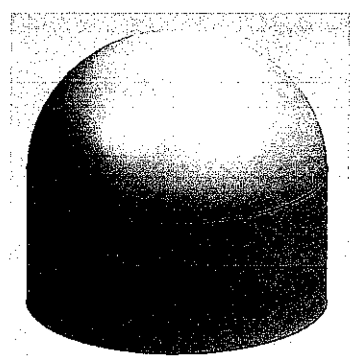

Figure 3.3: 3D dome shape for test piece.

After drawing was confirmed, the next step was proceeding with the simulation of the test piece.

3.3 SIMULATION

Simulation was done using Unigraphics NX3. Based on the solid modelling for this project, simulation and tool paths were created.

Simulations done in Unigraphics NX3 consist of the following action:

1. Modelling
2. Select cutting tool
3. Select test piece and blank geometry
4. Set up machining parameters and tool paths
5. Simulate cutting process
6. Generate NC code.

3.4 MACHINING PROCEDURES

Test piece was machined on MAZAK Variaxis, CNC machining centre available in Advanced Manufacturing Lab. The machining steps are as shown in **Figure 3.4**:

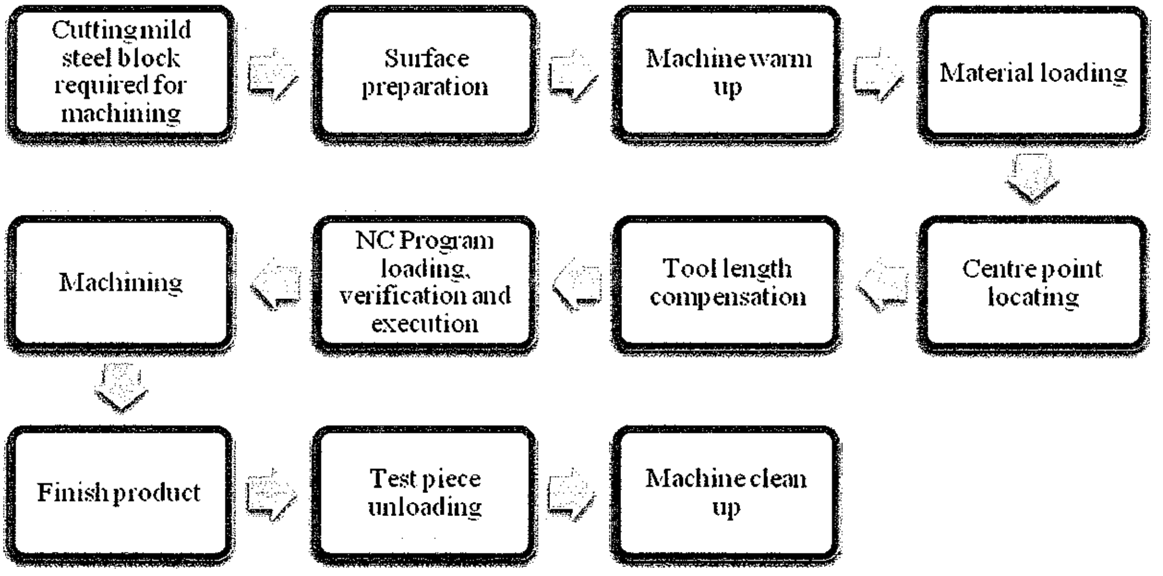

Figure 3.4: Machining Procedures of Test Piece

3.5 INSPECTION PROCESS FLOW

Inspection of the test piece was done after test piece was machined. **Figure 3.5** shows computer-aided inspection process flow approach for project.

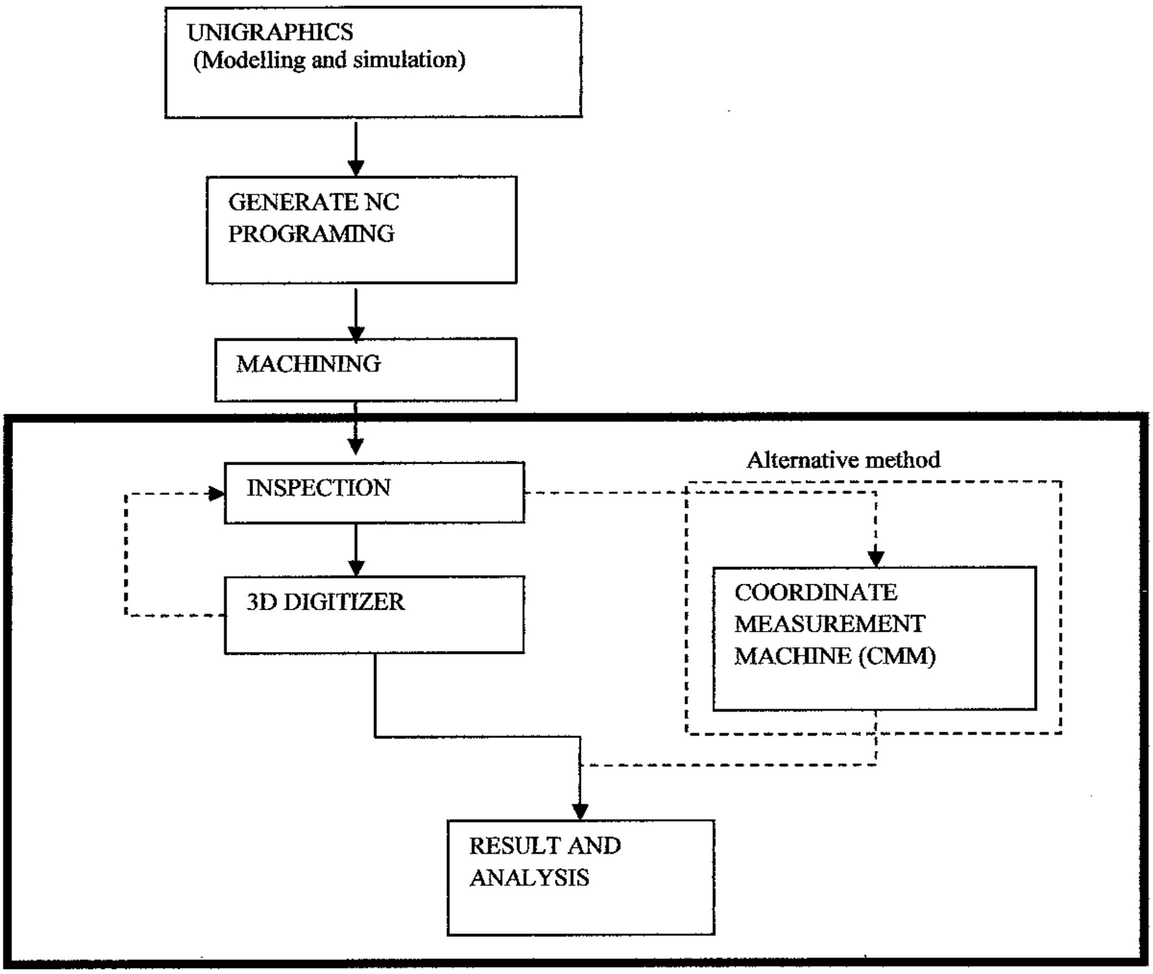

Figure 3.5: Computer-Aided Inspection Process Flow.

Modelling and NC part programming was done in Unigraphics NX3 and continued by machining using MAZAK Variaxis 630-5X from Advanced Manufacturing Lab. Measurement and inspection was done using computer-aided inspection approach by Renishaw Cyclone 3D laser digitizer.

3.6 TOOL REQUIRED

In order to execute the project, the necessary tools had been identified. These tools can be either hardware or software.

Machines:

- MAZAK Variaxis 630-5X – used to machine the test piece
- Mazatrol Fusion 640M CNC control – used to write NC part programming
- Renishaw Cyclone 3D laser digitizer – used to scan and measure test piece.
- 10" Bend Saw – cut material block.
- Conventional Milling Machine.

Hardware:

- Vernier callipers
- Clamp

Material:

- 50x50x100 Aluminium block

Software are written programs or procedures or rules and associated documentation pertaining to the operation of a computer system and that is stored in read or write memory. The software that have been used in the project:

Software:

- AutoCAD 2008 – use to create 2-D part drawing.
- Master CAM V8– Process planning and NC programming
- CATIA V5R6 – used to create 3-D solid model.
- Unigraphics NX3 – for 3-D solid modelling

CHAPTER 4

RESULT AND DISCUSSION

4.1 TEST PIECE

This project aims to measure solid object which contains complex shape using computer-aided inspection approach. As for the test object, author has done a research and decided to use dome shape. The dome has diameter of 50mm. This shape was chose because of the shape characteristics:

- The curve surface on top of the solid object are categorise as a complex shape because it is difficult to be measured manually. Measurement methods for simple shape such as straight line are different from complex shape.
- For the project purpose, dome is simple and easy to inspect and monitor.

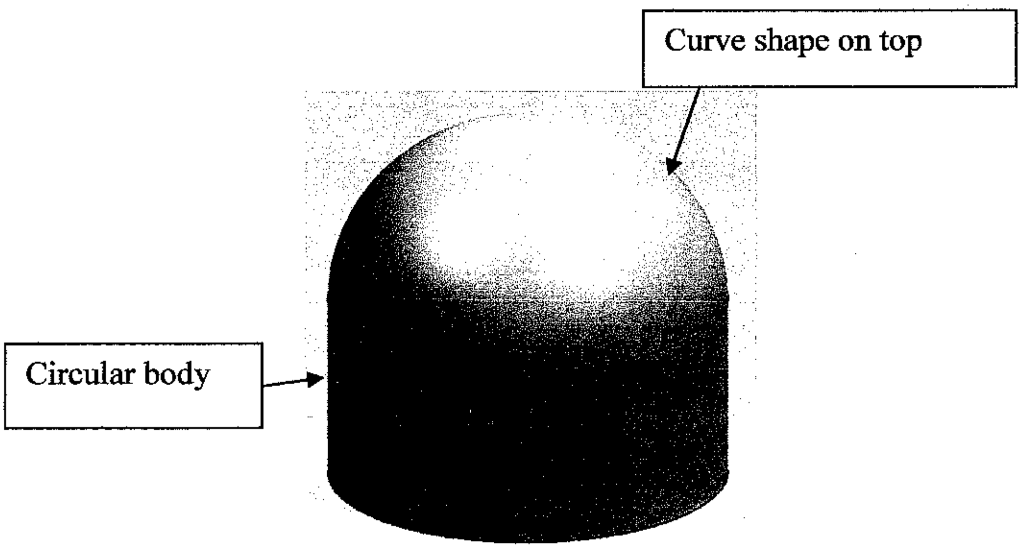

Figure 4.1: Test piece solid model.

4.2 MODELING

The draft drawing for this project product modelling was done using AutoCAD 2008 while solid modelling was done in UGS NX3. **Figure 4.2** and **Figure 4.3** shows the 2D and 3D drawings of the test piece.

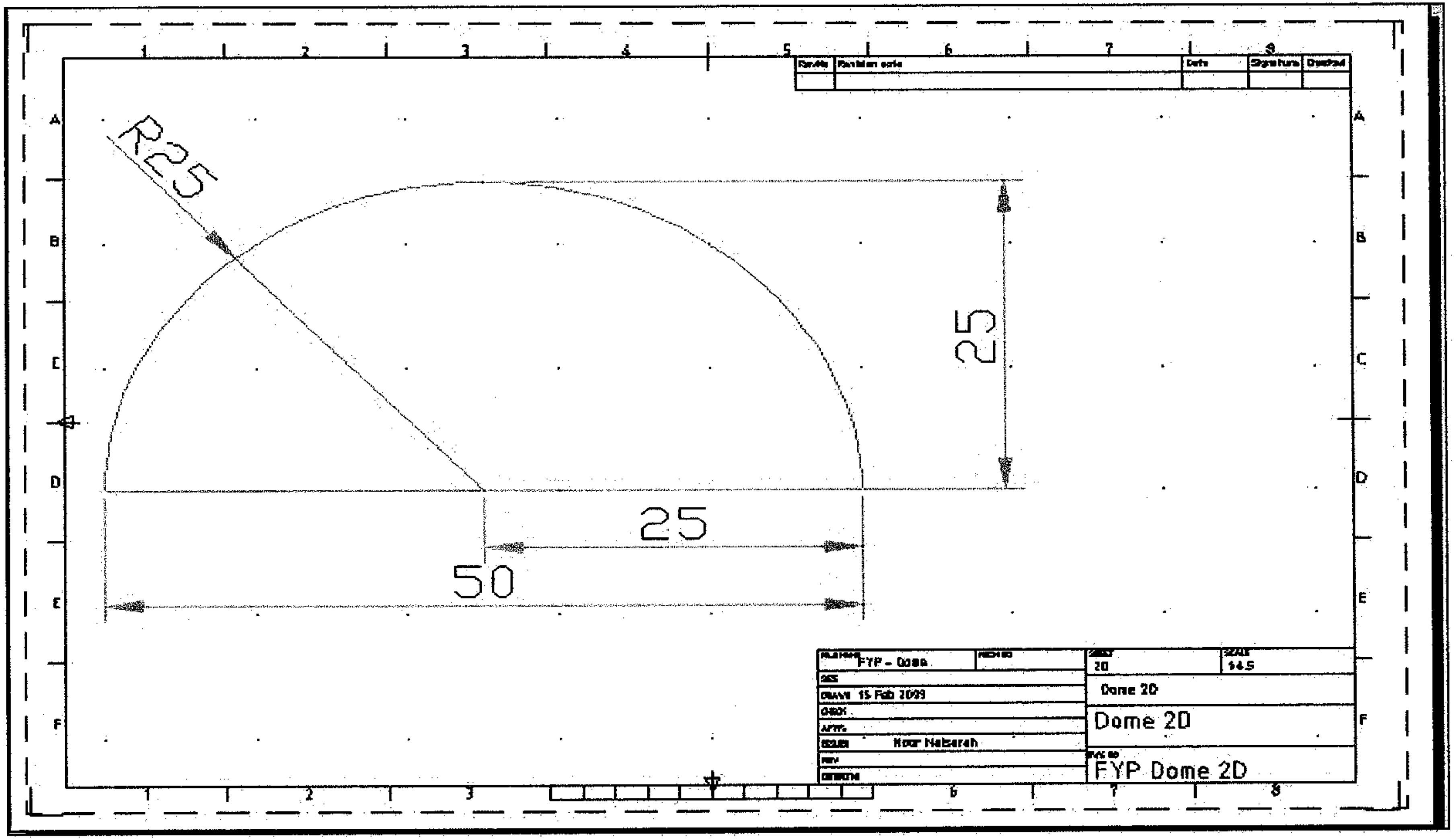

Figure 4.2: 2D Drawing of Test Piece.

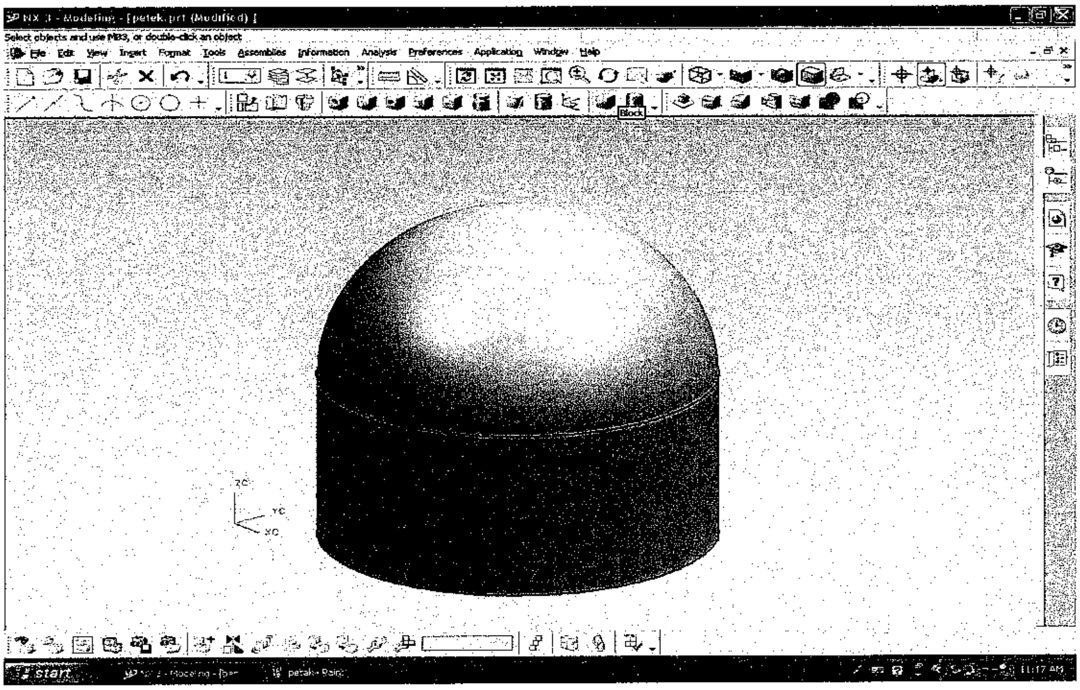

Figure 4.3: 3D Drawing of Test Piece Using Unigraphics.

4.3 SIMULATION

Simulation is part of the process planning for machining test piece; tool path has been created for the solid modelling. All the data such as cutting speed, cutting tool, feed rate, spindle speed and other necessary data were insert for the simulation. Error was displayed when there are incorrect data . NC program was created base on data inserted during the simulation process. **Figure 4.4** and **Figure 4.5** show the on going simulation during the simulation process.

For simulation process, dummy block was created in order to complete required process. Dummy block is a imaginary block which dimension is not the same with size of the true solid block that will be use. This is due to NX 3 requirement; raw material must be bigger than the dimension of the object to be machined.

During the simulation process, tool path shown machining process for the test piece using CNC machine; MAZAK Variaxis 630-5X. This process show step by step cutting process by Unigraphics.

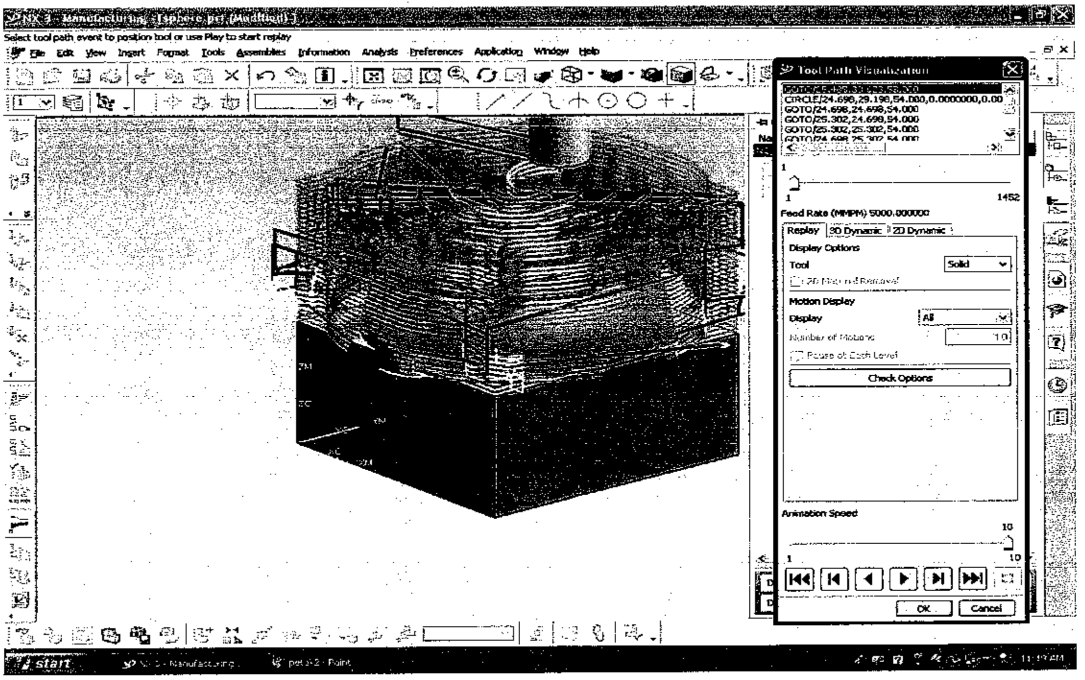

Figure 4.4: Simulation Process Using Unigraphic NX3.

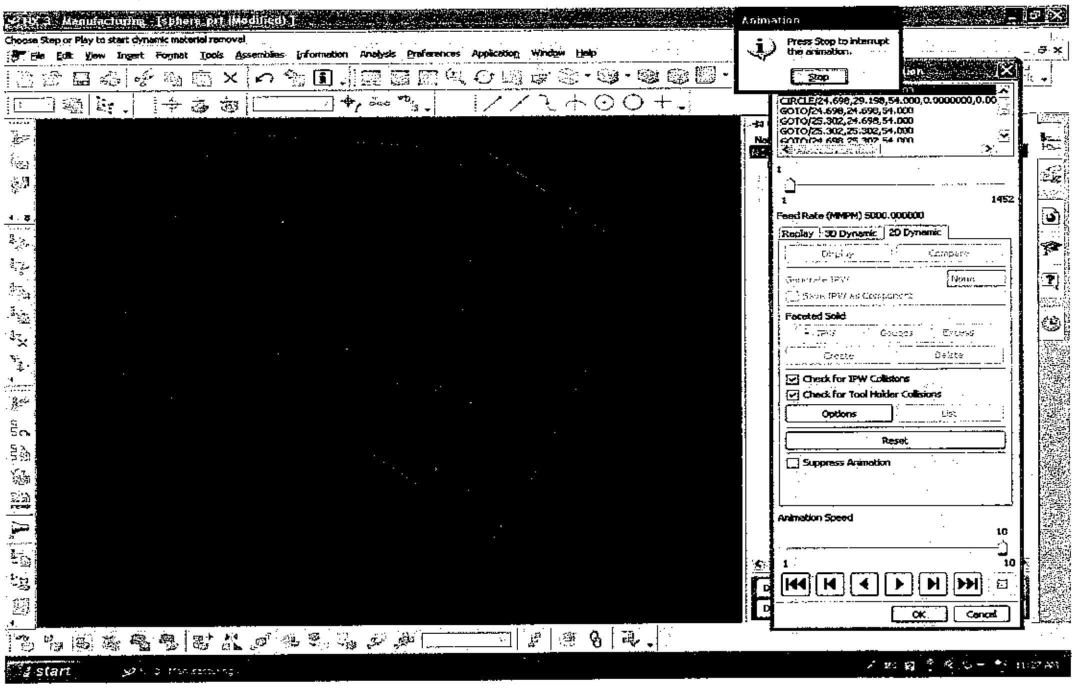

Figure 4.5: Tool Path Simulations Review

4.4 NC PART PROGRAMMING

The NC code part program shows in **Figure 4.6** is generated in by Unigraphic NX3 software. Part program shown are the first 50 line of the NC programming of project. A complete NC code for test piece consists of 14,914 lines. NC parts programming as shown contains G-code and M-code. Refer to **Appendix 1** and **Appendix 2** for further information of G-code and M-codes.

```
N1 G17 G0 G40 G54 G21 G80 G90
N2 G91 G28 X0. Y0. Z0.
N3 G90
N4 (NC OPERATION=
ZLEVEL_FOLLOW_CORE  TOOLNAME=
MILL_ROUGH_1010 )
N5 ( DIA= 10.0 CR= 0.0 FLAT
ENDMILL  )
N6 M06 T15
N7 G90 G43
N8 G61.1
N9 S10000 M3
N10 M8
N11 G05P2
N12 G1 X0 Y0 Z150. A0. C0. F5000.
N13 X49.17 Y63.156 Z70. A0. C0.
F2500.
N14 X49.17 Y63.156 Z54.75 A0. C0.
N15 X49.17 Y63.156 Z49.75 A0. C0.
F1500.
N16 X52.938 Y60.156 Z49.75 A0.
C0.
N17 G2 X60.156 Y52.938 Z49.75
R45.293 A0. C0. F6000.
N18 G1 X60.156 Y52.938 Z54.75 A0.
C0. F3000.
N19 X60.156 Y52.938 Z55. A0. C0.
N20 X31.371 Y63.156 Z55. A0. C0.
N21 X31.371 Y63.156 Z49.75 A0.
C0. F1500.
N22 X38.952 Y60.156 Z49.75 A0.
C0.
N23 X42.097 Y58.911 Z49.75 A0.
C0. F6000.
N24 X43.885 Y57.877 Z49.75 A0.
C0.
N25 G2 X57.877 Y43.885 Z49.75
R38.293 A0. C0.
```

```
N26 G1 X58.911 Y42.097 Z49.75 A0.
C0.
N27 X60.156 Y38.952 Z49.75 A0.
C0.
N28 X60.156 Y38.952 Z54.75 A0.
C0. F3000.
N29 X60.156 Y38.952 Z55. A0. C0.
N30 X63.156 Y.982 Z55. A0. C0.
N31 X63.156 Y.982 Z49.75 A0. C0.
F1500.
N32 X60.15 Y-2.825 Z49.75 A0. C0.
N33 X58.554 Y-4.846 Z49.75 A0.
C0. F6000.
N34 X57.793 Y-5.614 Z49.75 A0.
C0.
N35 X57.793 Y-5.614 Z54.75 A0.
C0. F3000.
N36 X57.793 Y-5.614 Z55. A0. C0.
N37 X63.156 Y-.209 Z55. A0. C0.
N38 X63.156 Y-.209 Z49.75 A0. C0.
F1500.
N39 X55.744 Y-7.679 Z49.75 A0.
C0.
N40 X54.91 Y-8.52 Z49.75 A0. C0.
F6000.
N41 X52.82 Y-10.156 Z49.75 A0.
C0.
N42 X52.82 Y-10.156 Z54.75 A0.
C0. F3000.
N43 X52.82 Y-10.156 Z55. A0. C0.
N44 X63.156 Y18.649 Z55. A0. C0.
N45 X63.156 Y18.649 Z49.75 A0.
C0. F1500.
N46 X60.156 Y11.051 Z49.75 A0.
C0.
N47 X58.959 Y8.021 Z49.75 A0. C0.
F6000.
N48 X56.833 Y4.27 Z49.75 A0. C0.
N49 X53.306 Y-.198 Z49.75 A0. C0.
N50 X50.25 Y-3.278 Z49.75 A0. C0
```

Figure 4.6: An Initial Portion of NC Code Generate By Unigraphics NX3

The first ten lines show the initial stage of NC programming for machined the test piece. The first 4 lines contain the initial coordinate and other information regarding machining process. Line N4 indicates the machining process which is milling process while line N5 contains the cutting tools information, flat endmill with diameter of 10mm. Line N9 represent spindle information, and the spindle speed was at 10,000 RPM clockwise. The rest of the programming contains machining process for the test piece.

Refer to appendix section for part programming contains:

Appendix 3: Initial portion of NC Parts Programming for Test Piece.
Appendix 4: Middle portion of NC Parts Programming for Test Piece.
Appendix 5: End portion of NC Parts Programming for Test Piece.

4.5 MACHINING OF TEST PIECE

Since the dimension of test piece is 50 mm diameter, Aluminium block 50x50x100 was prepared for machining. 10" Bend Saw was use to cut Aluminium block into required size. **Figure 4.7** show the test piece block before machining.

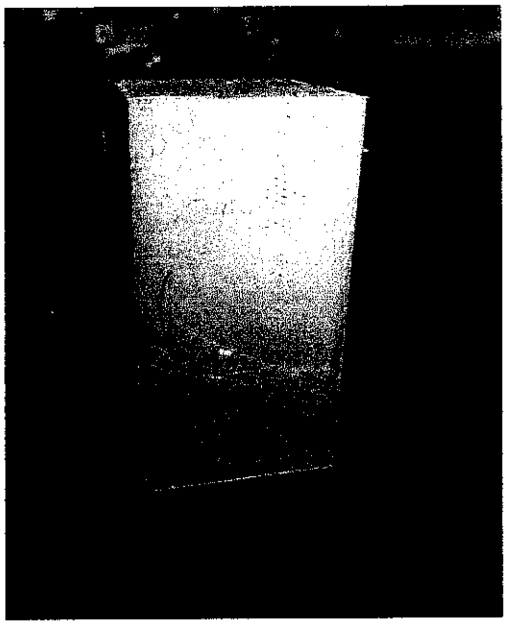

Figure 4.7: Aluminium Metal Block 50x50x100.
(Raw block)

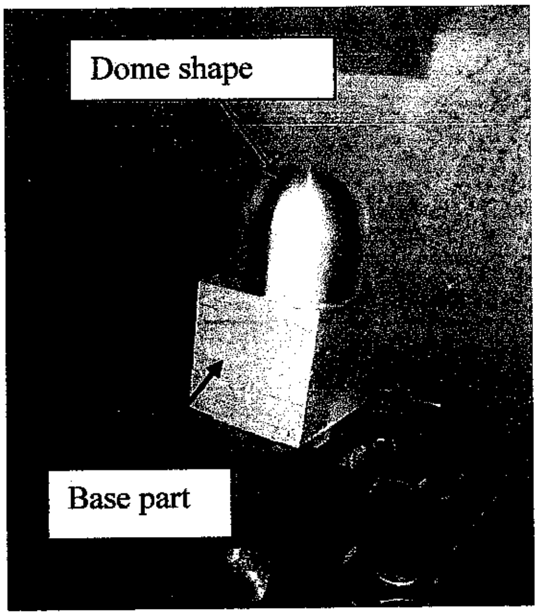

Figure 4.8: Test Piece after Machined.

Figure 4.8 shows the test piece after machined using CNC MAZAK Variaxis 630-5X. Base part then cut using Bend Saw to 5mm thick and followed by conventional milling machine for surface finishing. Base part must be flat so that it will not affect digitizer process.

4.6 3D SCANNING USING DIGITIZER

In general, there will be errors of size in any machined work piece. The actual dimension will be different from nominal dimension. These errors should be within certain given limits by tolerances and determined by the dimensional measurement to guarantee the product quality. Test piece of this project was measured using Renishaw Cyclone 3D laser digitizer available in Advanced Manufacturing Laboratory. **Figure4.9** shows scanning process by Digitizer.

Procedure for simple measurements on a digitizer includes:

- Calibration of the probe system.
- Define datum on the work piece.
- Perform measurement.
- Compute the required dimensions from measurements made.
- Assess conformance to specification.

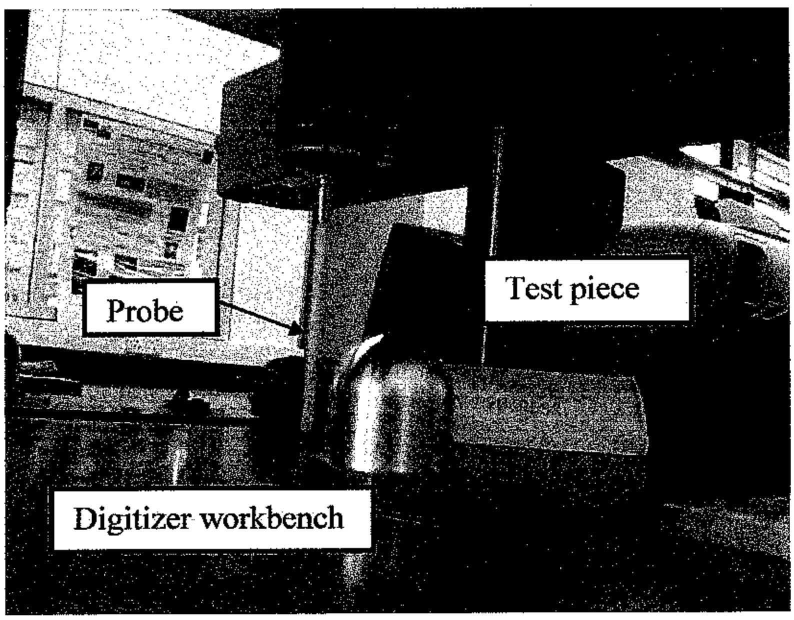

Figure 4.9: Scanning Process by Digitizer

4.6.1 Calibration

The probe for digitizer was calibrated before starting any scanning or measurement. Ball probe type with diameter of 8mm was used in this project. **Table 4.1** shows the information of the probe consists of standard diameter, calibrated output and the probe diameter deviation.

Table 4.1: Digitizer Probe Data

Type of probe	Ball
Standard Diameter	8.00 mm
Calibrated Diameter	7.998mm
Probe deviation	= 8-7.998 = 0.002mm

Calibration was performed because there is uncertainty in instruments. There are many uncertainties that affect the precision and accuracy of a measurement system.

These uncertainties depend on:

- The performance limit of instruments
- The difference between different operators in operating procedure, technique etc.

4.6.2 Output

The result from the digitized was in cloud point form. Result can be saved in any of CAD/CAM file. **Figure 4.10** shows result from digitizer process in form of Initial Graphics Exchangeable Specification (IGES) format.

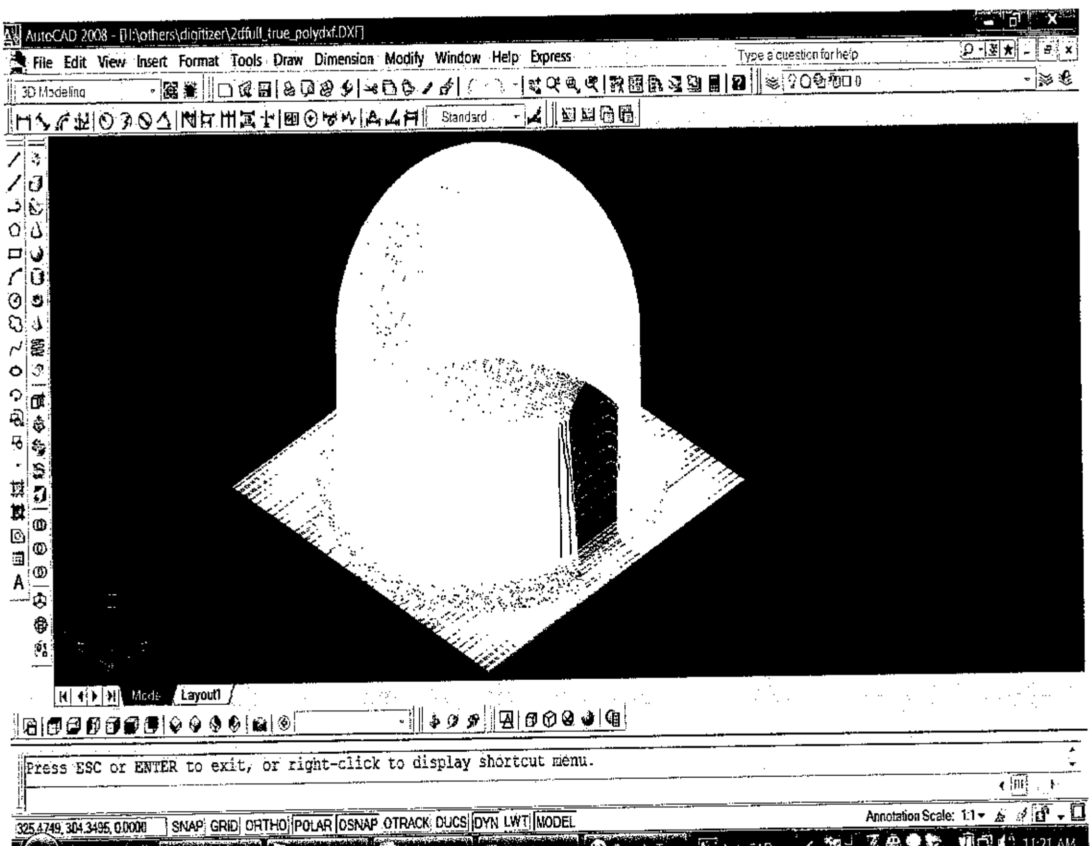

Figure 4.10: Cloud Point from Digitizer Output in AutoCAD 2008.

Cloud point was transformed into solid modelling using CAD. Solid model of the test piece was then compared with the original dimension. The deviation of dimension was taken for results.

4.7 MEASUREMENT

Measurement of the dome size was taken by digitizer. **Figure 4.11** shows sample of measurement taken by digitizer and **Table 4.2** contains data collected for several measurements.

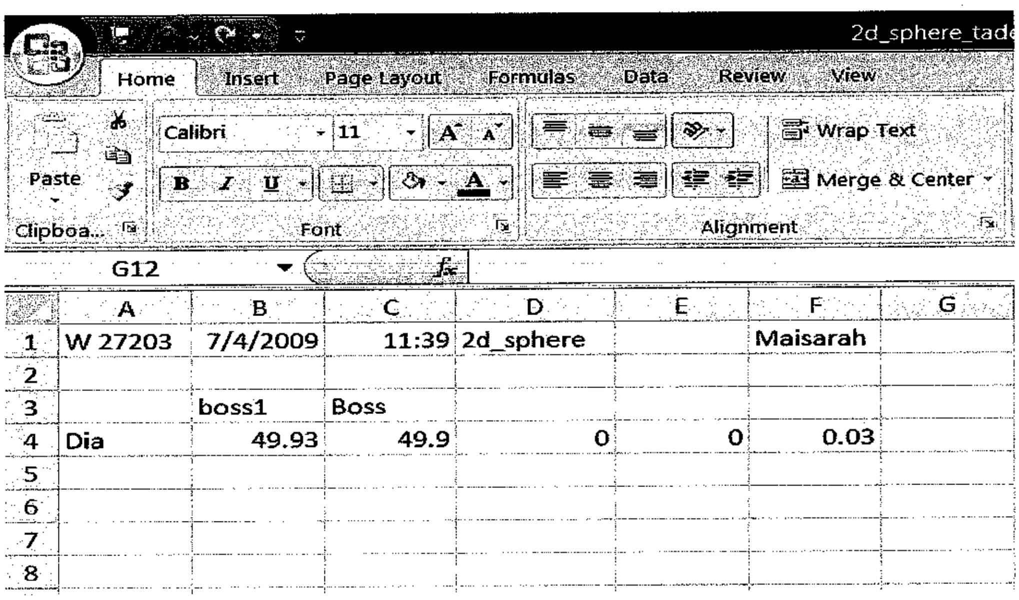

Figure 4.11: Sample Dimension Taken From Digitized Process.

Table 4.2 shows the tabulated results from Digitizer measurement which are used to calculate the average value and deviation of test piece measurement.

Table 4.2: Data of Dome Measurement.

		Initial value (mm)	**Value (mm)**	**Error / Deviation**
1	Diameter	49.93	49.90	0.03
2	Diameter	49.94	49.91	0.03
3	Diameter	49.93	49.91	0.02
4	Diameter	49.95	49.92	0.03
5	Diameter	49.94	49.92	0.02

From the measurement taken, the value of the dome shape contour diameter obtained from digitizer operation is in range 49.93mm to 49.94mm with deviation from 0.02mm to 0.03mm.

Mean diameter of the dome shape test piece was calculated as below:

$$\text{Mean diameter} = \sum \frac{total\ diameter}{n}$$

$$= \sum \frac{49.90 + 49.91 + 49.91 + 49.92 + 49.92}{5}$$

$$= \underline{\underline{49.912\ \text{mm}}}$$

Mean deviation obtained for the shape as follow:

$$\text{Mean deviation} = \sum \frac{total\ deviation}{n}$$

$$= \sum \frac{0.03 + 0.03 + 0.02 + 0.03 + 0.02}{5}$$

$$= \underline{\underline{0.026\ \text{mm}}}$$

Average measurement of dome diameter is 49.912 mm and average of deviation 0.026mm. From the average deviation obtained, the digitizer capability was determined as 0.026mm. The digitizer can measure the test piece and deviation shows the capability of the digitizer which is small and can be use as an inspection device.

Dimensional deviation of dome shape test piece might be due to the following reasons:

- Statics and dynamics deflection of the machines because of vibration and fluctuating forces are caused by machine characteristics and variation in the properties and dimensions of the incoming material.
- Distortion of the machine because of the thermal effects caused by such as in temperature of the environment, of metalworking fluids, and the machine bearings and various components.
- Wear of tools, dies and molds can affect the dimensional accuracy of the parts produced.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The project adopted 3D digitizer for inspection of 50mm dome shaped aluminium test piece machined using CNC machine. The dimensions obtained from the digitizer were compared with designed dimensions. The digitizer capability was determined as 0.026mm. Based on the findings, the digitizer can be used as 3D scanner device to check dimension of machined part.

5.2 RECOMMENDATION

In order to establish more definitive result, further research need to be done to cover various dimensions so as statistical analysis could be done to establish the deviation.

Further research should be carried on to identify the causes of deviation in particular with regard various parameters involved in machining that can affect the machined parts.

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[11] 20 May 2009. <http://www.plm.automation.siemens.com.shtml >

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[13] 21 May2009<http://www.cncci.com/resources/articles/what%20is%20cnc.htm>

APPENDIX 1: G-CODE LIST

G0 rapid positioning	G58 use preset work coordinate system 5
G1 linear interpolation	G59 use preset work coordinate system 6
G2 circular/helical interpolation (clockwise)	G59.1 use preset work coordinate system 7
G3 circular/helical interpolation (c-clockwise)	G59.2 use preset work coordinate system 8
G4 dwell	G59.3 use preset work coordinate system 9
G10 coordinate system origin setting	G80 cancel motion mode (includes canned)
G17 xy plane selection	G81 drilling canned cycle
G18 xz plane selection	G82 drilling with dwell canned cycle
G19 yz plane selection	G83 chip-breaking drilling canned cycle
G20 inch system selection	G84 right hand tapping canned cycle
G21 millimeter system selection	G85 boring, no dwell, feed out canned cycle
G40 cancel cutter diameter compensation	G86 boring, spindle stop, rapid out canned
G41 start cutter diameter compensation left	G87 back boring canned cycle
G42 start cutter diameter compensation right	G88 boring, spindle stop, manual out canned
G43 tool length offset (plus)	G89 boring, dwell, feed out canned cycle
G49 cancel tool length offset	G90 absolute distance mode
G53 motion in machine coordinate system	G91 incremental distance mode
G54 use preset work coordinate system 1	G92 offset coordinate systems
G55 use preset work coordinate system 2	G92.2 cancel offset coordinate systems
G56 use preset work coordinate system 3	G93 inverse time feed mode
G57 use preset work coordinate system 4	G94 feed per minute mode
	G98 initial level return in canned cycles

APPENDIX 2: M-CODE LIST

M0 program stop	M8 flood coolant on
M1 optional program stop	M9 mist and flood coolant off
M2 program end	M26 enable automatic b-axis clamping
M3 turn spindle clockwise	M27 disable automatic b-axis clamping
M4 turn spindle counter clockwise	M30 program end, pallet shuttle, and reset
M5 stop spindle turning	M48 enable speed and feed overrides
M6 tool change	M49 disable speed and feed overrides
M7 mist coolant on	M60 pallet shuttle and program stop

APPENDIX 3: INITIAL PORTION OF NC PART PROGRAMMING FOR TEST PIECE

```
N1 G17 G0 G40 G54 G21 G80 G90
N2 G91 G28 X0. Y0. Z0.
N3 G90
N4 (NC OPERATION= ZLEVEL_FOLLOW_CORE
TOOLNAME= MILL_ROUGH_1010 )
N5( DIA= 10.0 CR= 0.0 FLAT ENDMILL)
N6 M06 T15
N7 G90 G43
N8 G61.1
N9 S10000 M3
N10 M8
N11 G05P2
N12 G1 X0 Y0 Z150. A0. C0. F5000.
N13 X49.17 Y63.156 Z70. A0. C0.
F2500.
N14 X49.17 Y63.156 Z54.75 A0. C0.
N15 X49.17 Y63.156 Z49.75 A0. C0.
F1500.
N16 X52.938 Y60.156 Z49.75 A0. C0.
N17 G2 X60.156 Y52.938 Z49.75
R45.293 A0. C0. F6000.
N18 G1 X60.156 Y52.938 Z54.75 A0.
C0. F3000.
N19 X60.156 Y52.938 Z55. A0. C0.
N20 X31.371 Y63.156 Z55. A0. C0.
N21 X31.371 Y63.156 Z49.75 A0. C0.
F1500.
N22 X38.952 Y60.156 Z49.75 A0. C0.
N23 X42.097 Y58.911 Z49.75 A0. C0.
F6000.
N24 X43.885 Y57.877 Z49.75 A0. C0.
N25 G2 X57.877 Y43.885 Z49.75
R38.293 A0. C0.
N26 G1 X58.911 Y42.097 Z49.75 A0.
C0.
N27 X60.156 Y38.952 Z49.75 A0. C0.
N28 X60.156 Y38.952 Z54.75 A0. C0.
F3000.
N29 X60.156 Y38.952 Z55. A0. C0.
N30 X63.156 Y.982 Z55. A0. C0.
N31 X63.156 Y.982 Z49.75 A0. C0.
F1500.
N32 X60.15 Y-2.825 Z49.75 A0. C0.
N33 X58.554 Y-4.846 Z49.75 A0. C0.
F6000.
N34 X57.793 Y-5.614 Z49.75 A0. C0.
N35 X57.793 Y-5.614 Z54.75 A0. C0.
F3000.
N36 X57.793 Y-5.614 Z55. A0. C0.
N37 X63.156 Y-.209 Z55. A0. C0.
N38 X63.156 Y-.209 Z49.75 A0. C0.
F1500.
N39 X55.744 Y-7.679 Z49.75 A0. C0.
N40 X54.91 Y-8.52 Z49.75 A0. C0.
F6000.
N41 X52.82 Y-10.156 Z49.75 A0. C0.
N42 X52.82 Y-10.156 Z54.75 A0. C0.
F3000.
N43 X52.82 Y-10.156 Z55. A0. C0.
N44 X63.156 Y18.649 Z55. A0. C0.
N45 X63.156 Y18.649 Z49.75 A0. C0.
F1500.
N46 X60.156 Y11.051 Z49.75 A0. C0.
N47 X58.959 Y8.021 Z49.75 A0. C0.
F6000.
N48 X56.833 Y4.27 Z49.75 A0. C0.
N49 X53.306 Y-.198 Z49.75 A0. C0.
N50 X50.25 Y-3.278 Z49.75 A0. C0.
N51 X45.875 Y-6.702 Z49.75 A0. C0.
N52 X42.229 Y-8.859 Z49.75 A0. C0.
N53 X38.952 Y-10.156 Z49.75 A0. C0.
N54 X38.952 Y-10.156 Z54.75 A0. C0.
F3000.
N55 X38.952 Y-10.156 Z55. A0. C0.
N56 X.982 Y-13.156 Z55. A0. C0.
N57 X.982 Y-13.156 Z49.75 A0. C0.
F1500.
N58 X-2.825 Y-10.15 Z49.75 A0. C0.
N59 X-4.901 Y-8.511 Z49.75 A0. C0.
F6000.
N60 X-5.775 Y-7.637 Z49.75 A0. C0.
N61 X-5.775 Y-7.637 Z54.75 A0. C0.
F3000.
N62 X-5.775 Y-7.637 Z55. A0. C0.
N63 X-.257 Y-13.156 Z55. A0. C0.
N64 X-.257 Y-13.156 Z49.75 A0. C0.
F1500.
N65 X-7.637 Y-5.775 Z49.75 A0. C0.
N66 X-8.511 Y-4.901 Z49.75 A0. C0.
F6000.
N67 X-10.156 Y-2.818 Z49.75 A0. C0.
N68 X-10.156 Y-2.818 Z54.75 A0. C0.
F3000.
N69 X-10.156 Y-2.818 Z55. A0. C0.
N70 X18.649 Y-13.156 Z55. A0. C0.
N71 X18.649 Y-13.156 Z49.75 A0. C0.
F1500.
N72 X11.051 Y-10.156 Z49.75 A0. C0.
N73 X8.021 Y-8.959 Z49.75 A0. C0.
F6000.
N74 X4.27 Y-6.833 Z49.75 A0. C0.
N75 X-.241 Y-3.271 Z49.75 A0. C0.
N76 X-3.271 Y-.241 Z49.75 A0. C0.
N77 X-6.833 Y4.27 Z49.75 A0. C0.
N78 X-8.959 Y8.021 Z49.75 A0. C0.
N79 X-10.156 Y11.051 Z49.75 A0. C0.
```

```
N80 X-10.156 Y11.051 Z54.75 A0. C0.
F3000.
N81 X-10.156 Y11.051 Z55. A0. C0.
N82 X-13.156 Y48.987 Z55. A0. C0.
N83 X-13.156 Y48.987 Z49.75 A0. C0.
F1500.
N84 X-10.15 Y52.827 Z49.75 A0. C0.
N85 X-8.52 Y54.91 Z49.75 A0. C0.
F6000.
N86 X-7.705 Y55.719 Z49.75 A0. C0.
N87 X-7.705 Y55.719 Z54.75 A0. C0.
F3000.
N88 X-7.705 Y55.719 Z55. A0. C0.
N89 X-13.156 Y50.311 Z55. A0. C0.
N90 X-13.156 Y50.311 Z49.75 A0. C0.
F1500.
N91 X-5.614 Y57.793 Z49.75 A0. C0.
N92 X-4.846 Y58.554 Z49.75 A0. C0.
F6000.
N93 X-2.818 Y60.156 Z49.75 A0. C0.
N94 X-2.818 Y60.156 Z54.75 A0. C0.
F3000.
N95 X-2.818 Y60.156 Z55. A0. C0.
N96 X-13.156 Y31.371 Z55. A0. C0.
N97 X-13.156 Y31.371 Z49.75 A0. C0.
F1500.
N98 X-10.156 Y38.952 Z49.75 A0. C0.
N99 X-8.859 Y42.229 Z49.75 A0. C0.
F6000.
N100 X-6.702 Y45.875 Z49.75 A0. C0.
N101 X-3.278 Y50.25 Z49.75 A0. C0.
N102 X-.198 Y53.306 Z49.75 A0. C0.
N103 X4.27 Y56.833 Z49.75 A0. C0.
N104 X8.021 Y58.959 Z49.75 A0. C0.
N105 X11.051 Y60.156 Z49.75 A0. C0.
N106 X13.622 Y53.645 Z49.75 A0. C0.
F5000.
N107 X16.199 Y54.662 Z49.75 A0. C0.
F6000.
N108 X18.727 Y55.276 Z49.75 A0. C0.
N109 X20.99 Y55.71 Z49.75 A0. C0.
N110 X25. Y56.019 Z49.75 A0. C0.
N111 X28.438 Y55.754 Z49.75 A0. C0.
N112 X32.415 Y55.214 Z49.75 A0. C0.
N113 X39.042 Y52.592 Z49.75 A0. C0.
N114 X40.383 Y51.817 Z49.75 A0. C0.
N115 G2 X51.817 Y40.383 Z49.75
R31.293 A0. C0.
N116 G1 X52.592 Y39.042 Z49.75 A0.
C0.
N117 X54.899 Y33.212 Z49.75 A0. C0.
N118 X55.261 Y31.557 Z49.75 A0. C0.
N119 G2 X54.763 Y16.701 Z49.75
R30.119 A0. C0.
N120 G1 X54.489 Y15.761 Z49.75 A0.
C0.
N121 X52.628 Y11.047 Z49.75 A0. C0.
N122 X51.007 Y8.188 Z49.75 A0. C0.
N123 X48.057 Y4.451 Z49.75 A0. C0.
N124 X45.589 Y1.963 Z49.75 A0. C0.
N125 X41.919 Y-.909 Z49.75 A0. C0.
N126 X39.14 Y-2.553 Z49.75 A0. C0.
N127 X33.103 Y-4.942 Z49.75 A0. C0.
N128 X31.328 Y-5.31 Z49.75 A0. C0.
N129 G2 X16.926 Y-4.827 Z49.75
R30.537 A0. C0.
N130 G1 X15.87 Y-4.532 Z49.75 A0.
C0.
N131 X11.047 Y-2.628 Z49.75 A0. C0.
N132 X8.188 Y-1.007 Z49.75 A0. C0.
N133 X4.418 Y1.969 Z49.75 A0. C0.
N134 X1.969 Y4.418 Z49.75 A0. C0.
N135 X-1.007 Y8.188 Z49.75 A0. C0.
N136 X-2.628 Y11.047 Z49.75 A0. C0.
N137 X-4.662 Y16.199 Z49.75 A0. C0.
N138 X-5.364 Y19.09 Z49.75 A0. C0.
N139 X-5.759 Y21.632 Z49.75 A0. C0.
N140 X-5.93 Y25. Z49.75 A0. C0.
N141 X-5.783 Y27.901 Z49.75 A0. C0.
N142 X-5.314 Y32.162 Z49.75 A0. C0.
N143 X-2.553 Y39.14 Z49.75 A0. C0.
N144 X-.909 Y41.919 Z49.75 A0. C0.
N145 X1.963 Y45.589 Z49.75 A0. C0.
N146 X4.451 Y48.057 Z49.75 A0. C0.
N147 X8.188 Y51.007 Z49.75 A0. C0.
N148 X11.047 Y52.628 Z49.75 A0. C0.
N149 X13.622 Y53.645 Z49.75 A0. C0.
N150 X16.192 Y47.134 Z49.75 A0. C0.
F5000.
N151 X18.32 Y47.974 Z49.75 A0. C0.
F6000.
N152 X20.213 Y48.434 Z49.75 A0. C0.
N153 X21.92 Y48.761 Z49.75 A0. C0.
N154 X25. Y48.998 Z49.75 A0. C0.
N155 X27.698 Y48.79 Z49.75 A0. C0.
N156 X30.63 Y48.392 Z49.75 A0. C0.
N157 X35.986 Y46.273 Z49.75 A0. C0.
N158 X36.88 Y45.756 Z49.75 A0. C0.
N159 G2 X45.756 Y36.88 Z49.75
R24.293 A0. C0.
N160 G1 X46.273 Y35.986 Z49.75 A0.
C0.
N161 X48.182 Y31.162 Z49.75 A0. C0.
N162 X48.424 Y30.058 Z49.75 A0. C0.
N163 G2 X48.041 Y18.655 Z49.75
R23.119 A0. C0.
N164 G1 X47.859 Y18.028 Z49.75 A0.
C0.
N165 X46.297 Y14.074 Z49.75 A0. C0.
N166 X45.181 Y12.105 Z49.75 A0. C0.
N167 X42.809 Y9.099 Z49.75 A0. C0.
N168 X40.929 Y7.205 Z49.75 A0. C0.
N169 X37.963 Y4.884 Z49.75 A0. C0.
N170 X36.052 Y3.753 Z49.75 A0. C0.
N171 X31.089 Y1.789 Z49.75 A0. C0.
N172 X29.906 Y1.544 Z49.75 A0. C0.
N173 G2 X18.805 Y1.917 Z49.75
R23.537 A0. C0.
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N174 G1 X18.101 Y2.113 Z49.75 A0.
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N176 X12.105 Y4.819 Z49.75 A0. C0.
N177 X9.078 Y7.209 Z49.75 A0. C0.
N178 X7.209 Y9.078 Z49.75 A0. C0.
N179 X4.819 Y12.105 Z49.75 A0. C0.
N180 X3.703 Y14.074 Z49.75 A0. C0.
N181 X2.026 Y18.32 Z49.75 A0. C0.
N182 X1.508 Y20.455 Z49.75 A0. C0.
N183 X1.214 Y22.348 Z49.75 A0. C0.
N184 X1.079 Y25. Z49.75 A0. C0.
N185 X1.198 Y27.34 Z49.75 A0. C0.
N186 X1.541 Y30.462 Z49.75 A0. C0.
N187 X3.753 Y36.052 Z49.75 A0. C0.
N188 X4.884 Y37.963 Z49.75 A0. C0.
N189 X7.205 Y40.929 Z49.75 A0. C0.
N190 X9.099 Y42.809 Z49.75 A0. C0.
N191 X12.105 Y45.181 Z49.75 A0. C0.
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N195 X20.442 Y41.286 Z49.75 A0. C0.
F6000.
N196 X21.699 Y41.591 Z49.75 A0. C0.
N197 X22.851 Y41.812 Z49.75 A0. C0.
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N199 X26.958 Y41.827 Z49.75 A0. C0.
N200 X28.846 Y41.57 Z49.75 A0. C0.
N201 X32.93 Y39.954 Z49.75 A0. C0.
N202 X33.377 Y39.696 Z49.75 A0. C0.
N203 G2 X39.696 Y33.377 Z49.75
R17.293 A0. C0.
N204 G1 X39.954 Y32.93 Z49.75 A0.
C0.
N205 X41.465 Y29.111 Z49.75 A0. C0.
N206 X41.586 Y28.56 Z49.75 A0. C0.
N207 G2 X41.319 Y20.609 Z49.75
R16.119 A0. C0.
N208 G1 X41.228 Y20.296 Z49.75 A0.
C0.
N209 X39.966 Y17.1 Z49.75 A0. C0.
N210 X39.356 Y16.023 Z49.75 A0. C0.
N211 X37.56 Y13.748 Z49.75 A0. C0.
N212 X36.269 Y12.447 Z49.75 A0. C0.
N213 X34.008 Y10.677 Z49.75 A0. C0.
N214 X32.963 Y10.059 Z49.75 A0. C0.
N215 X29.075 Y8.52 Z49.75 A0. C0.
N216 X28.483 Y8.398 Z49.75 A0. C0.
N217 G2 X20.684 Y8.66 Z49.75 R16.537
A0. C0.
N218 G1 X20.332 Y8.758 Z49.75 A0.
C0.
N219 X17.1 Y10.034 Z49.75 A0. C0.
N220 X16.023 Y10.644 Z49.75 A0. C0.
N221 X13.737 Y12.449 Z49.75 A0. C0.
N222 X12.449 Y13.737 Z49.75 A0. C0.
N223 X10.644 Y16.023 Z49.75 A0. C0.
N224 X10.034 Y17.1 Z49.75 A0. C0.
N225 X8.714 Y20.442 Z49.75 A0. C0.
N226 X8.38 Y21.82 Z49.75 A0. C0.
N227 X8.187 Y23.065 Z49.75 A0. C0.
N228 X8.088 Y25. Z49.75 A0. C0.
N229 X8.179 Y26.779 Z49.75 A0. C0.
N230 X8.396 Y28.761 Z49.75 A0. C0.
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N233 X12.447 Y36.269 Z49.75 A0. C0.
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N235 X16.023 Y39.356 Z49.75 A0. C0.
N236 X17.1 Y39.966 Z49.75 A0. C0.
N237 X18.763 Y40.623 Z49.75 A0. C0.
N238 X19.165 Y32.918 Z49.75 A0. C0.
F1500.
N239 X19.94 Y33.53 Z49.75 A0. C0.
N240 X20.126 Y33.635 Z49.75 A0. C0.
N241 X21.334 Y34.112 Z49.75 A0. C0.
N242 X22.563 Y34.597 Z49.75 A0. C0.
F6000.
N243 X23.185 Y34.748 Z49.75 A0. C0.
N244 X23.782 Y34.863 Z49.75 A0. C0.
N245 X25. Y34.957 Z49.75 A0. C0.
N246 X26.219 Y34.863 Z49.75 A0. C0.
N247 X27.061 Y34.748 Z49.75 A0. C0.
N248 X29.874 Y33.635 Z49.75 A0. C0.
N249 G2 X33.635 Y29.874 Z49.75
R10.293 A0. C0.
N250 G1 X34.748 Y27.061 Z49.75 A0.
C0.
N251 G2 X34.597 Y22.563 Z49.75
R9.119 A0. C0.
N252 G1 X33.635 Y20.126 Z49.75 A0.
C0.
N253 X33.53 Y19.94 Z49.75 A0. C0.
N254 X32.311 Y18.397 Z49.75 A0. C0.
N255 X31.609 Y17.689 Z49.75 A0. C0.
N256 X30.052 Y16.47 Z49.75 A0. C0.
N257 X29.874 Y16.365 Z49.75 A0. C0.
N258 X27.061 Y15.252 Z49.75 A0. C0.
N259 G2 X22.563 Y15.403 Z49.75
R9.537 A0. C0.
N260 G1 X20.126 Y16.365 Z49.75 A0.
C0.
N261 X19.94 Y16.47 Z49.75 A0. C0.
N262 X18.397 Y17.689 Z49.75 A0. C0.
N263 X17.689 Y18.397 Z49.75 A0. C0.
N264 X16.47 Y19.94 Z49.75 A0. C0.
N265 X16.365 Y20.126 Z49.75 A0. C0.
N266 X15.403 Y22.563 Z49.75 A0. C0.
N267 X15.252 Y23.185 Z49.75 A0. C0.
N268 X15.159 Y23.782 Z49.75 A0. C0.
N269 X15.097 Y25. Z49.75 A0. C0.
N270 X15.159 Y26.219 Z49.75 A0. C0.
N271 X15.252 Y27.061 Z49.75 A0. C0.
N272 X16.365 Y29.874 Z49.75 A0. C0.
N273 X16.47 Y30.052 Z49.75 A0. C0.
N274 X17.689 Y31.609 Z49.75 A0. C0.
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APPENDIX 4: MIDDLE PORTION OF NC PART PROGRAMMING FOR TEST PIECE

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N7000 X50.827 Y-10.156 Z35.75
A0. C0.
N7001 X63.156 Y24.994 Z35.75
A0. C0.
N7002 X63.156 Y24.994 Z30.5 A0.
C0. F1500.
N7003 X60.156 Y14.751 Z30.5 A0.
C0.
N7004 G2 X59.009 Y11.437 Z30.5
R36.476 A0. C0. F6000.
N7005 X35.264 Y-10.156 Z30.5
R36.589 A0. C0.
N7006 G1 X35.264 Y-10.156 Z35.5
A0. C0. F3000.
N7007 X35.264 Y-10.156 Z35.75
A0. C0.
N7008 X3.252 Y-13.156 Z35.75
A0. C0.
N7009 X3.252 Y-13.156 Z30.5 A0.
C0. F1500.
N7010 X-.832 Y-10.156 Z30.5 A0.
C0.
N7011 G2 X-10.156 Y-.819 Z30.5
R43.411 A0. C0. F6000.
N7012 G1 X-10.156 Y-.819 Z35.5
A0. C0. F3000.
N7013 X-10.156 Y-.819 Z35.75
A0. C0.
N7014 X24.96 Y-13.156 Z35.75
A0. C0.
N7015 X24.96 Y-13.156 Z30.5 A0.
C0. F1500.
N7016 X14.737 Y-10.156 Z30.5
A0. C0.
N7017 G2 X11.44 Y-9.014 Z30.5
R36.416 A0. C0. F6000.
N7018 X-6.833 Y6.918 Z30.5
R36.411 A0. C0.
N7019 X-10.156 Y14.736 Z30.5
R36.209 A0. C0.
N7020 G1 X-10.156 Y14.736 Z35.5
A0. C0. F3000.
N7021 X-10.156 Y14.736 Z35.75
A0. C0.
N7022 X-13.156 Y46.745 Z35.75
A0. C0.
N7023 X-13.156 Y46.745 Z30.5
A0. C0. F1500.
N7024 X-10.156 Y50.826 Z30.5
A0. C0.
N7025 G2 X-5.51 Y56.173 Z30.5
R43.56 A0. C0. F6000.
N7026 X-.83 Y60.156 Z30.5
R43.532 A0. C0.
N7027 G1 X-.83 Y60.156 Z35.5
A0. C0. F3000.
N7028 X-.83 Y60.156 Z35.75 A0.
C0.
N7029 X-13.156 Y24.983 Z35.75
A0. C0.
N7030 X-13.156 Y24.983 Z30.5
A0. C0. F1500.
N7031 X-10.156 Y35.265 Z30.5
A0. C0.
N7032 G2 X-.613 Y51.171 Z30.5
R36.56 A0. C0. F6000.
N7033 X14.711 Y60.156 Z30.5
R36.532 A0. C0.
N7034 G1 X14.311 Y52.635 Z30.5
A0. C0. F1500.
N7035 G2 X16.677 Y53.437 Z30.5
R29.532 A0. C0.
N7036 X17.922 Y53.772 Z30.5
R29.532 A0. C0. F6000.
N7037 X33.53 Y53.359 Z30.5
R29.532 A0. C0.
N7038 X51.403 Y38.404 Z30.5
R29.529 A0. C0.
N7039 X52.509 Y14.033 Z30.5
R29.476 A0. C0.
N7040 X31.093 Y-3.989 Z30.5
R29.589 A0. C0.
N7041 X14.033 Y-2.512 Z30.5
R29.416 A0. C0.
N7042 X-.747 Y10.377 Z30.5
R29.411 A0. C0.
N7043 X-4.516 Y22.563 Z30.5
R29.209 A0. C0.
N7044 X4.285 Y46.17 Z30.5
R29.56 A0. C0.
N7045 X16.677 Y53.437 Z30.5
R29.532 A0. C0.
N7046 X17.922 Y53.772 Z30.5
R29.532 A0. C0.
N7047 X19.104 Y54.037 Z30.5
R29.532 A0. C0.
N7048 G1 X18.855 Y55.262 Z31.75
A0. C0. F3000.
N7049 X18.855 Y55.262 Z35.5 A0.
C0.
N7050 X46.851 Y63.156 Z35.5 A0.
C0.
N7051 X46.851 Y63.156 Z30.25
A0. C0. F1500.
N7052 X50.905 Y60.156 Z30.25
A0. C0.
N7053 G2 X53.75 Y57.857 Z30.25
R43.08 A0. C0. F6000.
N7054 G1 X53.971 Y57.662 Z30.25
A0. C0.
N7055 X54.276 Y57.369 Z30.25
A0. C0.
N7056 G2 X57.35 Y54.299 Z30.25
R27.755 A0. C0.
N7057 X60.156 Y50.982 Z30.25
R37.32 A0. C0.
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N7058 G1 X60.156 Y50.982 Z35.25
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N7059 X60.156 Y50.982 Z35.5 A0.
C0.
N7060 X25.418 Y63.156 Z35.5 A0.
C0.
N7061 X25.418 Y63.156 Z30.25
A0. C0. F1500.
N7062 X35.455 Y60.156 Z30.25
A0. C0.
N7063 G2 X38.554 Y59.075 Z30.25
R36.512 A0. C0. F6000.
N7064 X49.123 Y52.604 Z30.25
R36.08 A0. C0.
N7065 G1 X49.234 Y52.506 Z30.25
A0. C0.
N7066 X49.589 Y52.166 Z30.25
A0. C0.
N7067 G2 X52.148 Y49.611 Z30.25
R20.755 A0. C0.
N7068 X57.746 Y41.481 Z30.25
R30.32 A0. C0.
N7069 X60.156 Y35.476 Z30.25
R36.332 A0. C0.
N7070 G1 X60.156 Y35.476 Z35.25
A0. C0. F3000.
N7071 X60.156 Y35.476 Z35.5 A0.
C0.
N7072 X63.156 Y3.113 Z35.5 A0.
C0.
N7073 X63.156 Y3.113 Z30.25 A0.
C0. F1500.
N7074 X60.156 Y-.957 Z30.25 A0.
C0.
N7075 G2 X50.934 Y-10.156
Z30.25 R43.155 A0. C0. F6000.
N7076 G1 X50.934 Y-10.156
Z35.25 A0. C0. F3000.
N7077 X50.934 Y-10.156 Z35.5
A0. C0.
N7078 X63.156 Y24.487 Z35.5 A0.
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N7079 X63.156 Y24.487 Z30.25
A0. C0. F1500.
N7080 X60.156 Y14.524 Z30.25
A0. C0.
N7081 G2 X59.077 Y11.45 Z30.25
R36.332 A0. C0. F6000.
N7082 X40.67 Y-8.132 Z30.25
R36.155 A0. C0.
N7083 X35.5 Y-10.156 Z30.25
R35.816 A0. C0.
N7084 G1 X35.5 Y-10.156 Z35.25
A0. C0. F3000.
N7085 X35.5 Y-10.156 Z35.5 A0.
C0.
N7086 X3.116 Y-13.156 Z35.5 A0.
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N7087 X3.116 Y-13.156 Z30.25
A0. C0. F1500.
N7088 X-.93 Y-10.156 Z30.25 A0.
C0.
N7089 G2 X-2.378 Y-9.034 Z30.25
R43.069 A0. C0. F6000.
N7090 G1 X-2.54 Y-8.903 Z30.25
A0. C0.
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A0. C0.
N7092 X-3.787 Y-7.828 Z30.25
A0. C0.
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N7098 X24.699 Y-13.156 Z30.25
A0. C0. F1500.
N7099 X14.522 Y-10.156 Z30.25
A0. C0.
N7100 G2 X2.027 Y-3.593 Z30.25
R36.069 A0. C0. F6000.
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A0. C0.
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R40.8 A0. C0.
N7105 X-9.108 Y11.537 Z30.25
R34.316 A0. C0.
N7106 G1 X-9.138 Y11.616 Z30.25
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A0. C0.
N7108 X-10.156 Y14.502 Z30.25
A0. C0.
N7109 X-10.156 Y14.502 Z35.25
A0. C0. F3000.
N7110 X-10.156 Y14.502 Z35.5
A0. C0.
N7111 X-13.156 Y46.847 Z35.5
A0. C0.
N7112 X-13.156 Y46.847 Z30.25
A0. C0. F1500.
N7113 X-10.156 Y50.919 Z30.25
A0. C0.
N7114 G2 X-.921 Y60.156 Z30.25
R43.58 A0. C0. F6000.
N7115 G1 X-.921 Y60.156 Z35.25
A0. C0. F3000.
N7116 X-.921 Y60.156 Z35.5 A0.
C0.
N7117 X-13.156 Y25.542 Z35.5
A0. C0.
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N7119 X-10.156 Y35.479 Z30.25
A0. C0.
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R35.915 A0. C0. F6000.
N7121 X11.443 Y59.074 Z30.25
R36.58 A0. C0.
N7122 X14.545 Y60.156 Z30.25
R36.512 A0. C0.
N7123 G1 X14.187 Y52.632 Z30.25
A0. C0. F1500.
N7124 G2 X16.549 Y53.449 Z30.25
R29.512 A0. C0.
N7125 X35.967 Y52.571 Z30.25
R29.512 A0. C0. F6000.
N7126 X44.497 Y47.35 Z30.25
R29.08 A0. C0.
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A0. C0.
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R13.755 A0. C0.
N7129 X51.457 Y38.404 Z30.25
R23.32 A0. C0.
N7130 X52.571 Y14.033 Z30.25
R29.332 A0. C0.
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R29.155 A0. C0.
N7132 X18.907 Y-4.04 Z30.25
R28.816 A0. C0.
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A0. C0.
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C0.
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A0. C0.
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N7141 X14.033 Y52.571 Z30.25
R29.58 A0. C0.
N7142 X16.549 Y53.449 Z30.25
R29.512 A0. C0.
N7143 X18.972 Y54.062 Z30.25
R29.512 A0. C0.
N7144 G1 X18.717 Y55.286 Z31.5
A0. C0. F3000.
N7145 X18.717 Y55.286 Z35.25
A0. C0.
N7146 X46.945 Y63.156 Z35.25
A0. C0.
N7147 X46.945 Y63.156 Z30. A0.
C0. F1500.
N7148 X50.995 Y60.156 Z30. A0.
C0.
N7149 G2 X53.695 Y57.985 Z30.
R43.651 A0. C0. F6000.
N7150 G1 X54.009 Y57.711 Z30.
A0. C0.
N7151 X54.436 Y57.292 Z30. A0.
C0.
N7152 G2 X57.292 Y54.436 Z30.
R27.62 A0. C0.
N7153 G1 X57.826 Y53.893 Z30.
A0. C0.
N7154 X59.126 Y52.328 Z30. A0.
C0.
N7155 X60.156 Y50.966 Z30. A0.
C0.
N7156 X60.156 Y50.966 Z35. A0.
C0. F3000.
N7157 X60.156 Y50.966 Z35.25
A0. C0.
N7158 X25.734 Y63.156 Z35.25
A0. C0.
N7159 X25.734 Y63.156 Z30. A0.
C0. F1500.
N7160 X35.639 Y60.156 Z30. A0.
C0.
N7161 G2 X49.096 Y52.708 Z30.
R36.651 A0. C0. F6000.
N7162 G1 X49.253 Y52.571 Z30.
A0. C0.
N7163 X49.703 Y52.129 Z30. A0.
C0.
N7164 G2 X52.129 Y49.703 Z30.
R20.62 A0. C0.
N7165 G1 X52.628 Y49.195 Z30.
A0. C0.
N7166 X53.639 Y47.978 Z30. A0.
C0.
N7167 X55.127 Y46.01 Z30. A0.
C0.
N7168 X56.554 Y43.764 Z30. A0.
C0.
N7169 X56.609 Y43.672 Z30. A0.
C0.
N7170 G2 X60.156 Y35.627 Z30.
R36.565 A0. C0.
N7171 G1 X60.156 Y35.627 Z35.
A0. C0. F3000.
N7172 X60.156 Y35.627 Z35.25
A0. C0.
N7173 X63.156 Y2.948 Z35.25 A0.
C0.
N7174 X63.156 Y2.948 Z30. A0.
C0. F1500.
N7175 X60.156 Y-1.046 Z30. A0.
C0.
N7176 G2 X57.951 Y-3.735 Z30.
R40.8 A0. C0. F6000.
N7177 X51.024 Y-10.156 Z30.
R42.389 A0. C0.
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N7178 G1 X51.024 Y-10.156 Z35.
A0. C0. F3000.
N7179 X51.024 Y-10.156 Z35.25
A0. C0.
N7180 X63.156 Y24.266 Z35.25
A0. C0.
N7181 X63.156 Y24.266 Z30. A0.
C0. F1500.
N7182 X60.156 Y14.384 Z30. A0.
C0.
N7183 G2 X59.148 Y11.503 Z30.
R36.565 A0. C0. F6000.
N7184 X52.691 Y.884 Z30. R33.8
A0. C0.
N7185 X40.792 Y-8.13 Z30.
R35.389 A0. C0.
N7186 X35.65 Y-10.156 Z30.
R36.186 A0. C0.
N7187 G1 X35.65 Y-10.156 Z35.
A0. C0. F3000.
N7188 X35.65 Y-10.156 Z35.25
A0. C0.
N7189 X3.066 Y-13.156 Z35.25
A0. C0.
N7190 X3.066 Y-13.156 Z30. A0.
C0. F1500.
N7191 X-1.012 Y-10.156 Z30. A0.
C0.
N7192 G2 X-2.364 Y-9.12 Z30.
R44.163 A0. C0. F6000.
N7193 X-10.156 Y-1.055 Z30.
R41.903 A0. C0.
N7194 G1 X-10.156 Y-1.055 Z35.
A0. C0. F3000.
N7195 X-10.156 Y-1.055 Z35.25
A0. C0.
N7196 X24.096 Y-13.156 Z35.25
A0. C0.
N7197 X24.096 Y-13.156 Z30. A0.
C0. F1500.
N7198 X14.353 Y-10.156 Z30. A0.
C0.
N7199 G2 X11.427 Y-9.115 Z30.
R36.186 A0. C0. F6000.
N7200 X1.987 Y-3.636 Z30.
R37.163 A0. C0.
N7201 X-8.129 Y9.237 Z30.
R34.903 A0. C0.
N7202 X-10.156 Y14.351 Z30.
R33.521 A0. C0.
N7203 G1 X-10.156 Y14.351 Z35.
A0. C0. F3000.
N7204 X-10.156 Y14.351 Z35.25
A0. C0.
N7205 X-13.156 Y46.957 Z35.25
A0. C0.
N7206 X-13.156 Y46.957 Z30. A0.
C0. F1500.
N7207 X-10.156 Y51.004 Z30. A0.
C0.
N7208 G2 X-5.451 Y56.37 Z30.
R43.569 A0. C0. F6000.
N7209 G1 X-5.244 Y56.57 Z30.
A0. C0.
N7210 X-4.523 Y57.213 Z30. A0.
C0.
N7211 X-3.933 Y57.78 Z30. A0.
C0.
N7212 X-2.637 Y58.901 Z30. A0.
C0.
N7213 X-2.444 Y59.056 Z30. A0.
C0.
N7214 G2 X-1.02 Y60.156 Z30.
R43.747 A0. C0.
N7215 G1 X-1.02 Y60.156 Z35.
A0. C0. F3000.
N7216 X-1.02 Y60.156 Z35.25 A0.
C0.
N7217 X-13.156 Y25.733 Z35.25
A0. C0.
N7218 X-13.156 Y25.733 Z30. A0.
C0. F1500.
N7219 X-10.156 Y35.649 Z30. A0.
C0.
N7220 G2 X-.583 Y51.34 Z30.
R36.57 A0. C0. F6000.
N7221 G1 X-.48 Y51.44 Z30. A0.
C0.
N7222 X.232 Y52.073 Z30. A0.
C0.
N7223 X.785 Y52.605 Z30. A0.
C0.
N7224 X1.85 Y53.527 Z30. A0.
C0.
N7225 X1.947 Y53.604 Z30. A0.
C0.
N7226 G2 X14.35 Y60.156 Z30.
R36.747 A0. C0.
N7227 G1 X14.018 Y52.632 Z30.
A0. C0. F1500.
N7228 G2 X16.378 Y53.456 Z30.
R29.747 A0. C0.
N7229 X30.351 Y54.245 Z30.
R29.747 A0. C0. F6000.
N7230 X44.497 Y47.431 Z30.
R29.651 A0. C0.
N7231 G1 X45.003 Y46.934 Z30.
A0. C0.
N7232 G2 X46.934 Y45.003 Z30.
R13.62 A0. C0.
N7233 G1 X47.431 Y44.497 Z30.
A0. C0.
N7234 X48.152 Y43.629 Z30. A0.
C0.
N7235 X49.371 Y42.016 Z30. A0.
C0.
N7236 X50.59 Y40.099 Z30. A0.
C0.
N7237 G2 X52.621 Y14.033 Z30.
R29.565 A0. C0.
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APPENDIX 5: END PORTION OF NC PART PROGRAMMING FOR TEST PIECE

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N14675 X14.914 Y53.552 Z1.25
R30.198 A0. C0.
N14676 X17.304 Y54.284 Z1.25
R30.198 A0. C0.
N14677 G1 X16.988 Y55.493 Z2.5
A0. C0. F3000.
N14678 X16.988 Y55.493 Z6.25
A0. C0.
N14679 X47.96 Y63.156 Z6.25 A0.
C0.
N14680 X47.96 Y63.156 Z1. A0.
C0. F1500.
N14681 X51.892 Y60.156 Z1. A0.
C0.
N14682 G2 X60.156 Y51.913 Z1.
R44.206 A0. C0. F6000.
N14683 G1 X60.156 Y51.913 Z6.
A0. C0. F3000.
N14684 X60.156 Y51.913 Z6.25
A0. C0.
N14685 X28.655 Y63.156 Z6.25
A0. C0.
N14686 X28.655 Y63.156 Z1. A0.
C0. F1500.
N14687 X37.289 Y60.156 Z1. A0.
C0.
N14688 G2 X60.156 Y37.415 Z1.
R37.206 A0. C0. F6000.
N14689 G1 X60.156 Y37.415 Z6.
A0. C0. F3000.
N14690 X60.156 Y37.415 Z6.25
A0. C0.
N14691 X63.156 Y2.019 Z6.25 A0.
C0.
N14692 X63.156 Y2.019 Z1. A0.
C0. F1500.
N14693 X60.155 Y-1.894 Z1. A0.
C0.
N14694 G2 X51.866 Y-10.156 Z1.
R44.206 A0. C0. F6000.
N14695 G1 X51.866 Y-10.156 Z6.
A0. C0. F3000.
N14696 X51.866 Y-10.156 Z6.25
A0. C0.
N14697 X63.156 Y21.088 Z6.25
A0. C0.
N14698 X63.156 Y21.088 Z1. A0.
C0. F1500.
N14699 X60.156 Y12.605 Z1. A0.
C0.
N14700 G2 X47.505 Y-4.677 Z1.
R37.206 A0. C0. F6000.
N14701 X37.325 Y-10.156 Z1.
R37.223 A0. C0.
N14702 G1 X37.325 Y-10.156 Z6.
A0. C0. F3000.
N14703 X37.325 Y-10.156 Z6.25
A0. C0.
N14704 X2.034 Y-13.156 Z6.25
A0. C0.
N14705 X2.034 Y-13.156 Z1. A0.
C0. F1500.
N14706 X-1.886 Y-10.155 Z1. A0.
C0.
N14707 G2 X-10.156 Y-1.878 Z1.
R44.223 A0. C0. F6000.
N14708 G1 X-10.156 Y-1.878 Z6.
A0. C0. F3000.
N14709 X-10.156 Y-1.878 Z6.25
A0. C0.
N14710 X21.195 Y-13.156 Z6.25
A0. C0.
N14711 X21.195 Y-13.156 Z1. A0.
C0. F1500.
N14712 X12.654 Y-10.156 Z1. A0.
C0.
N14713 G2 X-10.156 Y12.701 Z1.
R37.223 A0. C0. F6000.
N14714 G1 X-10.156 Y12.701 Z6.
A0. C0. F3000.
N14715 X-10.156 Y12.701 Z6.25
A0. C0.
N14716 X-13.156 Y48.017 Z6.25
A0. C0.
N14717 X-13.156 Y48.017 Z1. A0.
C0. F1500.
N14718 X-10.155 Y51.936 Z1. A0.
C0.
N14719 G2 X-1.937 Y60.156 Z1.
R44.198 A0. C0. F6000.
N14720 G1 X-1.937 Y60.156 Z6.
A0. C0. F3000.
N14721 X-1.937 Y60.156 Z6.25
A0. C0.
N14722 X-13.156 Y28.866 Z6.25
A0. C0.
N14723 X-13.156 Y28.866 Z1. A0.
C0. F1500.
N14724 X-10.156 Y37.401 Z1. A0.
C0.
N14725 G2 X12.59 Y60.156 Z1.
R37.198 A0. C0. F6000.
N14726 G1 X12.593 Y52.626 Z1.
A0. C0. F1500.
N14727 G2 X14.914 Y53.552 Z1.
R30.198 A0. C0.
N14728 X34.748 Y53.627 Z1.
R30.198 A0. C0. F6000.
N14729 X54.897 Y29.834 Z1.
R30.206 A0. C0.
N14730 X43.278 Y.902 Z1.
R30.206 A0. C0.
N14731 X-4.345 Y17.689 Z1.
R30.223 A0. C0.
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N14732 X14.914 Y53.552 Z1.
R30.198 A0. C0.
N14733 X17.304 Y54.284 Z1.
R30.198 A0. C0.
N14734 G1 X16.988 Y55.493 Z2.25
A0. C0. F3000.
N14735 X16.988 Y55.493 Z6. A0.
C0.
N14736 X47.96 Y63.156 Z6. A0.
C0.
N14737 X47.96 Y63.156 Z.75 A0.
C0. F1500.
N14738 X51.892 Y60.156 Z.75 A0.
C0.
N14739 G2 X60.156 Y51.913 Z.75
R44.206 A0. C0. F6000.
N14740 G1 X60.156 Y51.913 Z5.75
A0. C0. F3000.
N14741 X60.156 Y51.913 Z6. A0.
C0.
N14742 X28.655 Y63.156 Z6. A0.
C0.
N14743 X28.655 Y63.156 Z.75 A0.
C0. F1500.
N14744 X37.289 Y60.156 Z.75 A0.
C0.
N14745 G2 X60.156 Y37.415 Z.75
R37.206 A0. C0. F6000.
N14746 G1 X60.156 Y37.415 Z5.75
A0. C0. F3000.
N14747 X60.156 Y37.415 Z6. A0.
C0.
N14748 X63.156 Y2.019 Z6. A0.
C0.
N14749 X63.156 Y2.019 Z.75 A0.
C0. F1500.
N14750 X60.155 Y-1.894 Z.75 A0.
C0.
N14751 G2 X51.866 Y-10.156 Z.75
R44.206 A0. C0. F6000.
N14752 G1 X51.866 Y-10.156
Z5.75 A0. C0. F3000.
N14753 X51.866 Y-10.156 Z6. A0.
C0.
N14754 X63.156 Y21.088 Z6. A0.
C0.
N14755 X63.156 Y21.088 Z.75 A0.
C0. F1500.
N14756 X60.156 Y12.605 Z.75 A0.
C0.
N14757 G2 X47.505 Y-4.677 Z.75
R37.206 A0. C0. F6000.
N14758 X37.326 Y-10.156 Z.75
R37.223 A0. C0.
N14759 G1 X37.326 Y-10.156
Z5.75 A0. C0. F3000.
N14760 X37.326 Y-10.156 Z6. A0.
C0.
N14761 X2.034 Y-13.156 Z6. A0.
C0.
N14762 X2.034 Y-13.156 Z.75 A0.
C0. F1500.
N14763 X-1.887 Y-10.155 Z.75
A0. C0.
N14764 G2 X-10.156 Y-1.878 Z.75
R44.223 A0. C0. F6000.
N14765 G1 X-10.156 Y-1.878
Z5.75 A0. C0. F3000.
N14766 X-10.156 Y-1.878 Z6. A0.
C0.
N14767 X21.195 Y-13.156 Z6. A0.
C0.
N14768 X21.195 Y-13.156 Z.75
A0. C0. F1500.
N14769 X12.654 Y-10.156 Z.75
A0. C0.
N14770 G2 X-10.156 Y12.701 Z.75
R37.223 A0. C0. F6000.
N14771 G1 X-10.156 Y12.701
Z5.75 A0. C0. F3000.
N14772 X-10.156 Y12.701 Z6. A0.
C0.
N14773 X-13.156 Y48.018 Z6. A0.
C0.
N14774 X-13.156 Y48.018 Z.75
A0. C0. F1500.
N14775 X-10.155 Y51.937 Z.75
A0. C0.
N14776 G2 X-1.937 Y60.156 Z.75
R44.198 A0. C0. F6000.
N14777 G1 X-1.937 Y60.156 Z5.75
A0. C0. F3000.
N14778 X-1.937 Y60.156 Z6. A0.
C0.
N14779 X-13.156 Y28.867 Z6. A0.
C0.
N14780 X-13.156 Y28.867 Z.75
A0. C0. F1500.
N14781 X-10.156 Y37.402 Z.75
A0. C0.
N14782 G2 X12.589 Y60.156 Z.75
R37.198 A0. C0. F6000.
N14783 G1 X12.592 Y52.626 Z.75
A0. C0. F1500.
N14784 G2 X14.913 Y53.553 Z.75
R30.198 A0. C0.
N14785 X34.748 Y53.627 Z.75
R30.198 A0. C0. F6000.
N14786 X54.897 Y29.834 Z.75
R30.206 A0. C0.
N14787 X43.278 Y.902 Z.75
R30.206 A0. C0.
N14788 X-4.345 Y17.689 Z.75
R30.223 A0. C0.
N14789 X14.913 Y53.553 Z.75
R30.198 A0. C0.
N14790 X17.303 Y54.284 Z.75
R30.198 A0. C0.
N14791 G1 X16.987 Y55.493 Z2.
A0. C0. F3000.
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N14792 X16.987 Y55.493 Z5.75
A0. C0.
N14793 X47.96 Y63.156 Z5.75 A0.
C0.
N14794 X47.96 Y63.156 Z.5 A0.
C0. F1500.
N14795 X51.892 Y60.156 Z.5 A0.
C0.
N14796 G2 X60.156 Y51.913 Z.5
R44.206 A0. C0. F6000.
N14797 G1 X60.156 Y51.913 Z5.5
A0. C0. F3000.
N14798 X60.156 Y51.913 Z5.75
A0. C0.
N14799 X28.655 Y63.156 Z5.75
A0. C0.
N14800 X28.655 Y63.156 Z.5 A0.
C0. F1500.
N14801 X37.289 Y60.156 Z.5 A0.
C0.
N14802 G2 X60.156 Y37.415 Z.5
R37.207 A0. C0. F6000.
N14803 G1 X60.156 Y37.415 Z5.5
A0. C0. F3000.
N14804 X60.156 Y37.415 Z5.75
A0. C0.
N14805 X63.156 Y2.019 Z5.75 A0.
C0.
N14806 X63.156 Y2.019 Z.5 A0.
C0. F1500.
N14807 X60.155 Y-1.894 Z.5 A0.
C0.
N14808 G2 X51.866 Y-10.156 Z.5
R44.207 A0. C0. F6000.
N14809 G1 X51.866 Y-10.156 Z5.5
A0. C0. F3000.
N14810 X51.866 Y-10.156 Z5.75
A0. C0.
N14811 X63.156 Y21.089 Z5.75
A0. C0.
N14812 X63.156 Y21.089 Z.5 A0.
C0. F1500.
N14813 X60.156 Y12.605 Z.5 A0.
C0.
N14814 G2 X47.505 Y-4.677 Z.5
R37.206 A0. C0. F6000.
N14815 X37.326 Y-10.156 Z.5
R37.223 A0. C0.
N14816 G1 X37.326 Y-10.156 Z5.5
A0. C0. F3000.
N14817 X37.326 Y-10.156 Z5.75
A0. C0.
N14818 X2.034 Y-13.156 Z5.75
A0. C0.
N14819 X2.034 Y-13.156 Z.5 A0.
C0. F1500.
N14820 X-1.887 Y-10.155 Z.5 A0.
C0.
N14821 G2 X-10.156 Y-1.878 Z.5
R44.223 A0. C0. F6000.
N14822 G1 X-10.156 Y-1.878 Z5.5
A0. C0. F3000.
N14823 X-10.156 Y-1.878 Z5.75
A0. C0.
N14824 X21.194 Y-13.156 Z5.75
A0. C0.
N14825 X21.194 Y-13.156 Z.5 A0.
C0. F1500.
N14826 X12.653 Y-10.156 Z.5 A0.
C0.
N14827 G2 X-10.156 Y12.701 Z.5
R37.223 A0. C0. F6000.
N14828 G1 X-10.156 Y12.701 Z5.5
A0. C0. F3000.
N14829 X-10.156 Y12.701 Z5.75
A0. C0.
N14830 X-13.156 Y48.018 Z5.75
A0. C0.
N14831 X-13.156 Y48.018 Z.5 A0.
C0. F1500.
N14832 X-10.155 Y51.937 Z.5 A0.
C0.
N14833 G2 X-1.938 Y60.156 Z.5
R44.197 A0. C0. F6000.
N14834 G1 X-1.938 Y60.156 Z5.5
A0. C0. F3000.
N14835 X-1.938 Y60.156 Z5.75
A0. C0.
N14836 X-13.156 Y28.868 Z5.75
A0. C0.
N14837 X-13.156 Y28.868 Z.5 A0.
C0. F1500.
N14838 X-10.156 Y37.403 Z.5 A0.
C0.
N14839 G2 X12.589 Y60.156 Z.5
R37.197 A0. C0. F6000.
N14840 G1 X12.591 Y52.626 Z.5
A0. C0. F1500.
N14841 G2 X14.913 Y53.553 Z.5
R30.197 A0. C0.
N14842 X34.748 Y53.627 Z.5
R30.197 A0. C0. F6000.
N14843 X54.897 Y29.834 Z.5
R30.207 A0. C0.
N14844 X43.278 Y.902 Z.5
R30.207 A0. C0.
N14845 X-4.345 Y17.689 Z.5
R30.223 A0. C0.
N14846 X14.913 Y53.553 Z.5
R30.197 A0. C0.
N14847 X17.303 Y54.284 Z.5
R30.197 A0. C0.
N14848 G1 X16.986 Y55.493 Z1.75
A0. C0. F3000.
N14849 X16.986 Y55.493 Z5.5 A0.
C0.
N14850 X47.96 Y63.156 Z5.5 A0.
C0.
N14851 X47.96 Y63.156 Z.25 A0.
C0. F1500.
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N14852 X51.892 Y60.156 Z.25 A0.
C0.
N14853 G2 X60.156 Y51.913 Z.25
R44.207 A0. C0. F6000.
N14854 G1 X60.156 Y51.913 Z5.25
A0. C0. F3000.
N14855 X60.156 Y51.913 Z5.5 A0.
C0.
N14856 X28.655 Y63.156 Z5.5 A0.
C0.
N14857 X28.655 Y63.156 Z.25 A0.
C0. F1500.
N14858 X37.289 Y60.156 Z.25 A0.
C0.
N14859 G2 X60.156 Y37.415 Z.25
R37.207 A0. C0. F6000.
N14860 G1 X60.156 Y37.415 Z5.25
A0. C0. F3000.
N14861 X60.156 Y37.415 Z5.5 A0.
C0.
N14862 X63.156 Y2.019 Z5.5 A0.
C0.
N14863 X63.156 Y2.019 Z.25 A0.
C0. F1500.
N14864 X60.155 Y-1.893 Z.25 A0.
C0.
N14865 G2 X51.866 Y-10.156 Z.25
R44.207 A0. C0. F6000.
N14866 G1 X51.866 Y-10.156
Z5.25 A0. C0. F3000.
N14867 X51.866 Y-10.156 Z5.5
A0. C0.
N14868 X63.156 Y21.089 Z5.5 A0.
C0.
N14869 X63.156 Y21.089 Z.25 A0.
C0. F1500.
N14870 X60.156 Y12.606 Z.25 A0.
C0.
N14871 G2 X47.505 Y-4.677 Z.25
R37.207 A0. C0. F6000.
N14872 X37.326 Y-10.156 Z.25
R37.223 A0. C0.
N14873 G1 X37.326 Y-10.156
Z5.25 A0. C0. F3000.
N14874 X37.326 Y-10.156 Z5.5
A0. C0.
N14875 X2.034 Y-13.156 Z5.5 A0.
C0.
N14876 X2.034 Y-13.156 Z.25 A0.
C0. F1500.
N14877 X-1.887 Y-10.155 Z.25
A0. C0.
N14878 G2 X-10.156 Y-1.879 Z.25
R44.223 A0. C0. F6000.
N14879 G1 X-10.156 Y-1.879
Z5.25 A0. C0. F3000.
N14880 X-10.156 Y-1.879 Z5.5
A0. C0.
N14881 X21.193 Y-13.156 Z5.5
A0. C0.
N14882 X21.193 Y-13.156 Z.25
A0. C0. F1500.
N14883 X12.653 Y-10.156 Z.25
A0. C0.
N14884 G2 X-10.156 Y12.701 Z.25
R37.223 A0. C0. F6000.
N14885 G1 X-10.156 Y12.701
Z5.25 A0. C0. F3000.
N14886 X-10.156 Y12.701 Z5.5
A0. C0.
N14887 X-13.156 Y48.018 Z5.5
A0. C0.
N14888 X-13.156 Y48.018 Z.25
A0. C0. F1500.
N14889 X-10.155 Y51.937 Z.25
A0. C0.
N14890 G2 X-1.938 Y60.156 Z.25
R44.197 A0. C0. F6000.
N14891 G1 X-1.938 Y60.156 Z5.25
A0. C0. F3000.
N14892 X-1.938 Y60.156 Z5.5 A0.
C0.
N14893 X-13.156 Y28.868 Z5.5
A0. C0.
N14894 X-13.156 Y28.868 Z.25
A0. C0. F1500.
N14895 X-10.156 Y37.403 Z.25
A0. C0.
N14896 G2 X12.588 Y60.156 Z.25
R37.197 A0. C0. F6000.
N14897 G1 X12.591 Y52.626 Z.25
A0. C0. F1500.
N14898 G2 X14.912 Y53.553 Z.25
R30.197 A0. C0.
N14899 X34.748 Y53.627 Z.25
R30.197 A0. C0. F6000.
N14900 X54.897 Y29.834 Z.25
R30.207 A0. C0.
N14901 X43.278 Y.902 Z.25
R30.207 A0. C0.
N14902 X-4.345 Y17.689 Z.25
R30.223 A0. C0.
N14903 X14.912 Y53.553 Z.25
R30.197 A0. C0.
N14904 X17.302 Y54.284 Z.25
R30.197 A0. C0.
N14905 G1 X16.986 Y55.493 Z1.5
A0. C0. F3000.
N14906 X16.986 Y55.493 Z70. A0.
C0. F5000.
N14907 X0 Y0 Z150. A0. C0.
N14908 G05P0
N14909 G91 G28 Z0. M9
N14910 G28 X0. Y0.M5
N14911 G28 A0. C0.
N14912 G0G28 X0. Y0.
N14913 (END OF OPERATION=
ZLEVEL_FOLLOW_CORE )
N14914 M30
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