INTEGRATION OF CAD / CAM FOR MANUFACTURING OF COMPLEX SHAPED COMPONENTS USING A ROBOTIC MANIPULATOR

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DECLARATION

I hereby declare that all unreferenced work described in this thesis is entirely my own, and no part of this work has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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INTEGRATION OF CAD/CAM FOR MANUFACTURING OF COMPLEX SHAPED COMPONENTS USING A ROBOTIC MANIPULATOR

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Abstract

The practical value and the features of 3D-CAD in geometry, machining and drawing interchange files for Wire Electric Discharge Machining (WEDM) are analyzed and described.

A simple practical set of methods in which a variety of 3D complex shape drawings suitable for WEDM could be easily created, analyzed and transferred to other forms for Wire Electric Discharge Machining have also been developed and are introduced here towards the aim of integrating of CAD-CAM based on AUTOCAD Release 11.

A communication protocol between CAD and CAM has been set up, that is to say , a DXF interface programme has been developed to communicate with AUTOCAD via the DXF mechanism to create a standard database which makes it possible to realise the integration of CAD and CAM.

A universal control programme has also been developed which is suitable for machining any kind of complex shaped model in WEDM.

Improving the accuracy of WEDM machining by means of integrating CAD and CAM is discussed.

Lastly, a number of WEDM tests have been performed by the way of integration of CAD and CAM which proved that the simulation cutting, the methods adopted, programmes developed and conclusions mentioned here are satisfactory.

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Chapter 1

INTRODUCTION

1.1 Background of this project

1.2 Wire Electric Discharge Machining (WEDM)

1.3 Integration of CAD and CAM

- 1.3.1 Computer Aided Design
- 1.3.2 Computer Aided Manufacturing
- 1.3.3 Integration of CAD and CAM

1.4 Plan and Aim of the present work

1.1 Background of this project

In a study prior to the present research project, a robotic manipulator had been designed, manufactured, commissioned and interfaced with a micro-computer for the manipulation of a workpiece in such a way that 3-dimensional complex shaped surfaces may be produced using a wire EDM machine in which the cutting forces are relatively negligible[1].

The manipulator is operated by four AC servo motors, two of them are for the linear manipulation along the X and Y axes and the other two motors are used for the manipulation of the rotary motions, alpha and beta around the X and Y axes respectively. The maximum X and Y axes linear travel for the manipulator is 100 mm and 120 mm respectively, and the angular cutting facility for alpha and beta is 70 degree and 65 degree respectively. For carrying out the test on the model material (polystyrene, up to 50 mm thick workpiece) and for simulating WEDM process a wire cutting unit had also been designed, and commissioned on which the cutting wire and a micro-switch is housed.

The interfacing system used for this manipulator was two PC23 indexers and four KS-drives. One PC23 indexer controls three motors and the other controls the fourth motor. There are approximately 80 PC23 commands which can be used for setting the process operating modes and motion parameters. There are approximately 40 KS-drive commands for setting the servo conditions on the KS-drive for system optimisation and to match the operating conditions described for the PC23 indexer [30-32].

A programmable voltage regulator (PVR) is used to change the voltage in the cutting wire through the micro-computer based software during the generation of the shape.The micro-switch on the cutting wire unit connected with the PC23 indexer is to check if the wire cutting rate is less than the workpiece feedrate so that a signal can be sent to the computer for retracing the workpiece cutting path.

Programs had been developed in BASIC to describe a number of geometrical models separately (totally 12 kinds of different shapes described by 8 programs), the corresponding control programmes also had been developed separately.

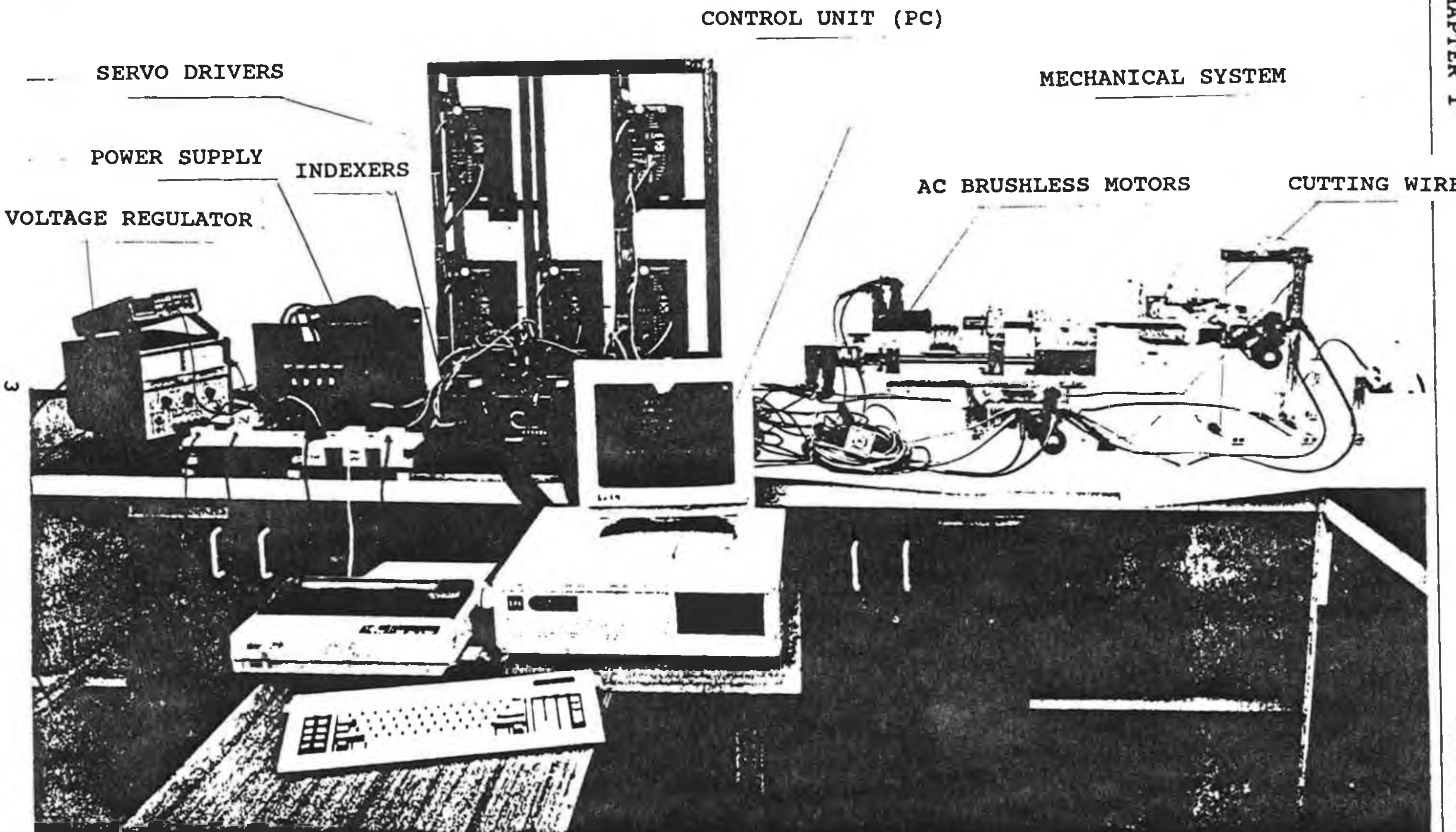


FIGURE 1.1 THE GENERAL LAYOUT OF THE EQUIPMENT

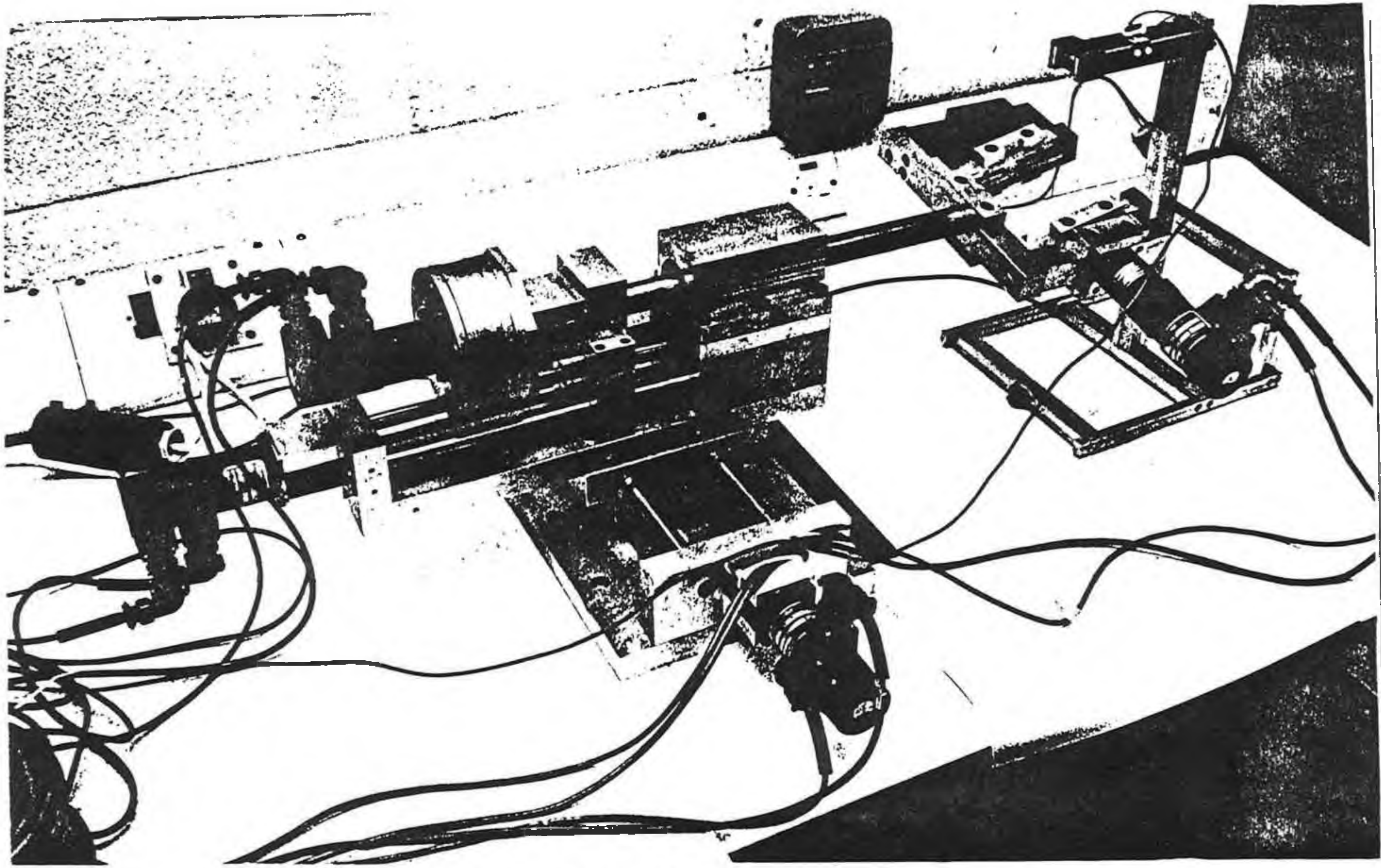


FIGURE 1.2 THE FOUR AXES PRECISION MANIPULATOR

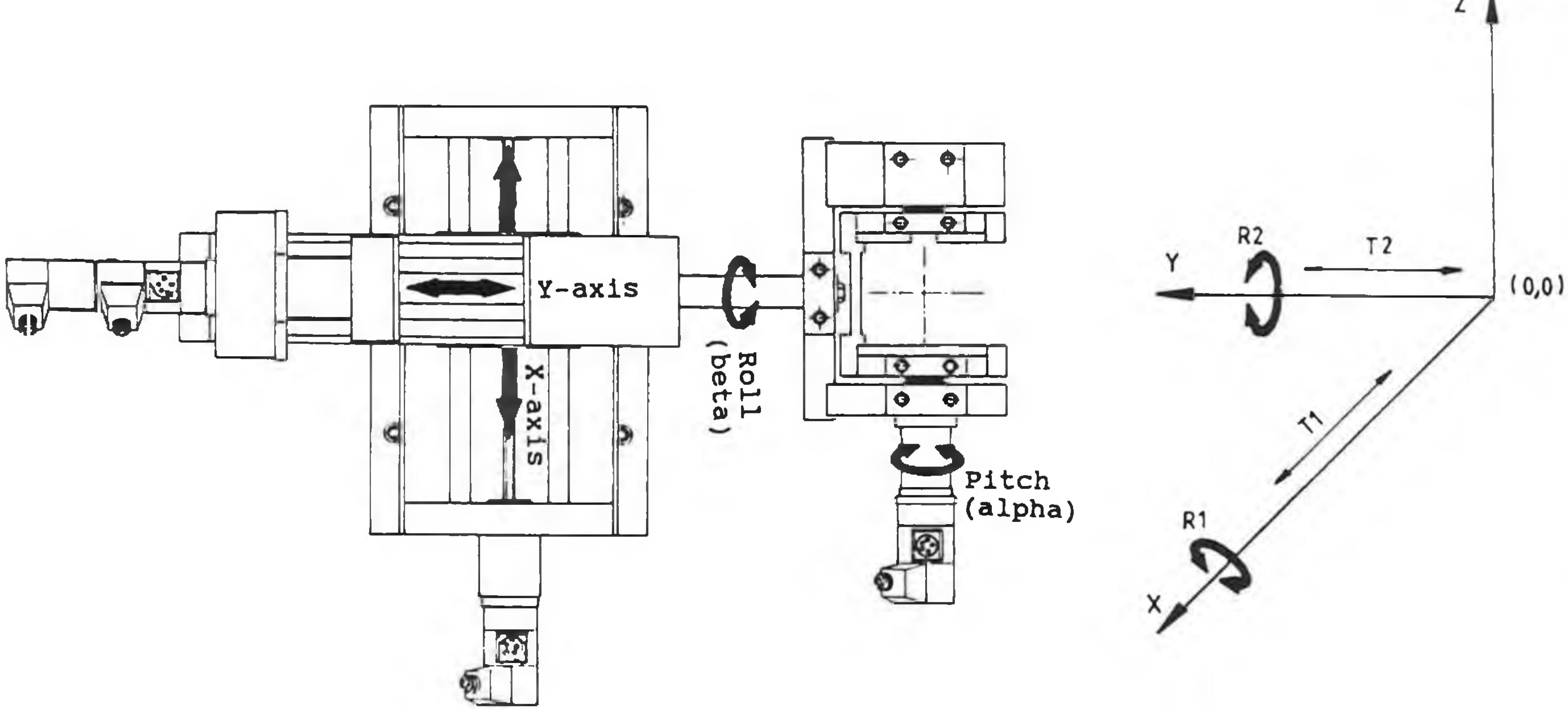


FIGURE 1.3 <u>Shows a plan view of the robotic manipulator, which represents four degrees of freedomn, two translation (T1 and T2) and two rotary motions (R1 and R2).</u>

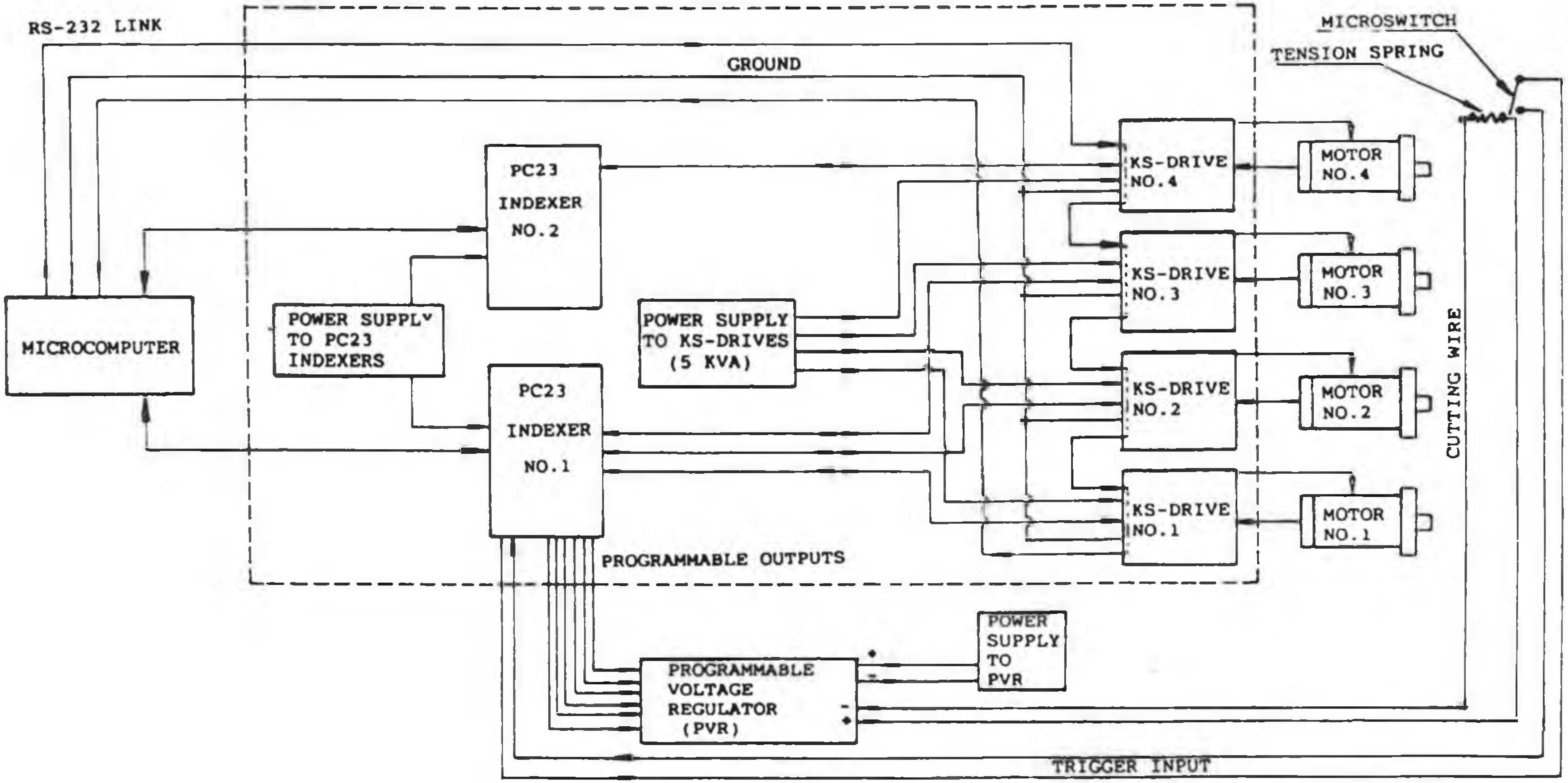


FIGURE 1.4 **Shows a full interfacing system diagram.**

1.2 Wire Electric Discharge Machining (WEDM)

In the Wire Electric Discharge Machining (WEDM) process metal is eroded away by electric discharges between the workpiece and a thin wire electrode, with no tool workpiece contact and without the application of mechanical forces[2]. The wire electrode runs through the workpiece like band saw blade, except the wire is used only once[3,4], and is surrounded by a stream of usually de-ionised water which serves as a conductor for the current as well as a coolant and a means of removing the machined metallic particles[5]. The wire is continuously renewed in order to compensate the diminution in the wire diameter by the spark erosion process[6]. The cutting wire is capable of cutting pre-hardened steel to finished die dimensions[7]. Figure 1.2 shows a schematic diagram of the equipment for electro discharge machining using a moving wire electrode.

In the WEDM process a wire having a diameter of between 0.03 and 0.3 mm is normally used, with 12 intermediate diameters[2]. EDM eliminates most of the hard tooling that would be required for conventional machining, therefore, it has low tooling costs. The wire erosion process provides an important advantage in that punches, dies,and strippers can be cut from hardened steel blanks in single block and operation[8,9].

In WEDM, the distance from the wire to the workpiece is usually around 0.025 mm. In this tiny space, metal is being eroded by rather violent but extremely localized and momentary action[3]. The criteria for quality are the surface roughness and tolerance. Shape accuracy in WEDM in a working environment, with temperature variations of about 3 degrees celsius, can be about 4 micrometers[10].

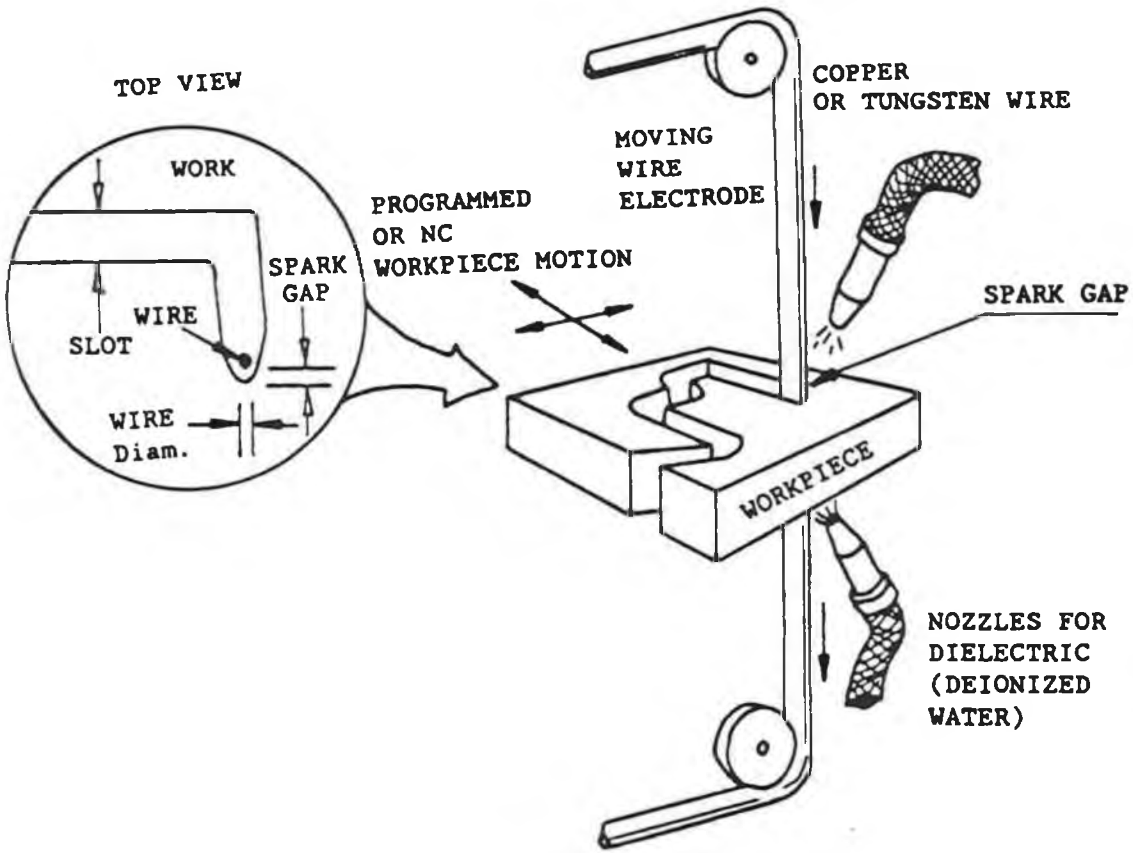


FIGURE 1.5 **A schematic diagram of Electro-Discharge Machining (EDM) using the moving wire electrode.**

1.3 Integration of CAD and CAM

1.3.1 Computer Aided Design

Computer aided design involves any type of design activity which makes use of the computer to develop, analyze, or modify an engineering design. The evolution of computer-aided design has been largely related to the developments in computer graphics. Of course, CAD encompasses much more than computer graphics. However, interactive computer graphics forms the essential technological foundation for computer aided design[11]. Modern CAD systems are based on interactive computer graphics. Interactive computer graphics denotes a user-oriented system in which the computer is employed to create, transform, and display data in the form of pictures or symbols. The user in the computer graphics design system is the designer, who communicates data and commands to the computer through any of several input devices. The computer communicates with the user via a cathode ray tube (CRT). The designer creates an image on the CRT screen by entering commands to call the desired software subroutines stored in the computer. In most systems, the image is constructed out of basic geometric elements-points, lines, circles, and so on. It can be modified according to the commands of the designer --- enlarged, reduced in size, moved to another location on the screen, rotated, and other transformations. Through these various manipulations, the required details of the image are formulated.

The typical computer aided design system is a combination of hardware and software. The hardware includes a central processing unit, one or more workstations (including the graphics display terminals), and peripheral devices such as printers, plotters, and drafting equipment. The software consists of the computer programs needed to implement graphics processing on the system. The software would also typically include additional specialized application programs to accomplish the particular engineering function required by the user company[11].

It is important to note the fact that the interactive computer graphics is one component of a computer-aided design system and the other major component is the human designer. Interactive computer graphics is a tool used by the designer to solve a design problem which in effect, magnifies the power of the designer.

There are several fundamental reasons for implementing a computer-aided design system:

1. To increase the productivity of the designer: This is accomplished by helping the designer to visualize the product and

its component sub-assemblies and parts; and by reducing the time required in synthesizing, analyzing, and documenting the design. This productivity improvement translates not only into lower design cost but also into shorter project completion times.

2. To improve the quality of design: A CAD system permits a more thorough engineering analysis and a larger number of design alternatives can be investigated. Design errors are also reduced through the greater accuracy provided by the system. These factors lead to a better design.

3. To improve communications: Use of a CAD system provides better engineering drawings, more standardization in the drawings, better documentation of the design, fewer drawing errors, and greater legibility.

4. To create a data base for manufacturing: In the process of creating the documentation for the product design (geometries and dimensions of the product and its components, material specifications for components, bill of materials, etc.), much of the required data base to manufacture the product is also created.

1.3.2 Computer Aided Manufacturing

The most readily understood form of CAM is the stand-alone CNC (Computer Numerical Control) machine tool, closely followed by DNC (Direct Numerical Control) operation. The definition of CAM , however, should be understood in a wider context. Non-metal-cutting production processes (welding, presswork, etc.) and related activities such as Computer Aided NC Part Programming, Computer Aided Inspection, testing and assembly techniques, together with automated materials handling, should be included[12].

Historically, numerical control in engineering is the beginning of CAM[13]. It is NC development that makes it possible for the computer to be involved in the manufacturing process. The basic technique for a NC machine used in production was for a set of instructions, a part program, to be written in one of a number of specialized languages developed for the purpose. The program was then fed into the control unit of a NC machine which 'read' it, section by section, and moved a cutting tool accordingly.

However, without a bridge linking CAD to CAM, or NC, the usefulness of CAM or NC in practical engineering was very limited[13].

1.3.3 Integration of CAD and CAM

Engineering design has been influenced heavily by the CAD technology and tools available to designers. Similarly, manufacturing has undergone major changes with the introduction of numerically controlled (NC) and computer numerically controlled (CNC) machine tools. These replace conventional machines, thus offering increased flexibility, superior accuracy, and shorter production cycles. Machining of complex surfaces with conventional machining is neither economical nor accurate. These surfaces are found in a wide range of components including those for aircrafts, automobiles construction and agricultural equipment, machine tools themselves, appliances and instrument cases.

In the conventional manufacturing cycle practised for so many years in industry, engineering drawings were prepared by design draughtsmen and then used by manufacturing engineers to develop the process plan (i.e. the route sheets). The activities involved in designing the product were separated from the activities associated with process planning. Essentially, a two-step procedure was employed. This was both time consuming and involved duplication of effort by design and manufacturing personnel. In an integrated CAD/CAM system, a link is

established between product design and manufacturing.
The potential benefits of integrating engineering and manufacturing are well recognized. More specifically, full integration of CAD and CAM is an important aspect of factory automation or computer integrated manufacturing system (CIMS)[14].

Historically, CAD/CAM Integration began with the development of the NC technology. NC machine tools have been improving steadily in both areas of hardware control and software developments. NC part programming and interactive computer graphics have contributed heavily to these developments. The integration of CAD/CAM places increasing emphasis on tools and paths for NC machines. It is interesting to note how independent developments (CAD and CAM) which began at completely opposite ends of the CAD/CAM spectrum during the evolution of CAD/CAM systems have gradually approached each other.

A large volume of work has been done in the area of CAD/CAM integration during the last twenty years. Most CAD systems are similar in their facilities but the differences appear when integrating them with other systems such as CAM. The main efforts have been concentrated on computer aided manufacturing and the different ways of making use of the CAD in order to simulate the manufacturing processes and to develop the suitable code to control the machines.

For example, an integrated system called KNOTS [15] has been developed for generating optimized numerical control commands to instruct NC machine system to produce complex splining geometry.

SPAM [16] is a software package developed at Instituto di Ingegnria Meccanica of Firenze University for application on standard microcomputers. It is devoted to provide a set of facilities for NC machine tools.

Paull Gitto [17] discussed interfacing Direct Numerical control (DNC) with CAD/CAM system. In [18] a postprocessor has been developed to convert the Automatic programming Tool (APT) language into G-Code language. This software might be used with other graphic packages to develop an integrated CAD/CAM system.

Similar progress has been done in integrating the graphic packages with manufacturing packages [19 - 23]. So it was possible, for example, to produce the tool path of CNC machines using CAD facilities and save them in the CAD database to be used later by postprocessors to produce the G-Code for a particular CNC machine. The General Electric Aircraft Engine Group's Evendale, Ohio DNC system services 100 NC machines. The DNC system is only one step in their total CAM project [24].

The application of mini-computers to a numerical control system to perform numerical control, servo control and adaptive control for metal cutting process also has been studied [26]. CN3D-LURPA is a machining software for forging dies, from a part definition drawing, it is possible to machine by aided programming a 3D part with complex topology [27].

FIGURE 1.6 shows how the CAD/CAM data base is related to design and manufacturing in a typical production-oriented company.

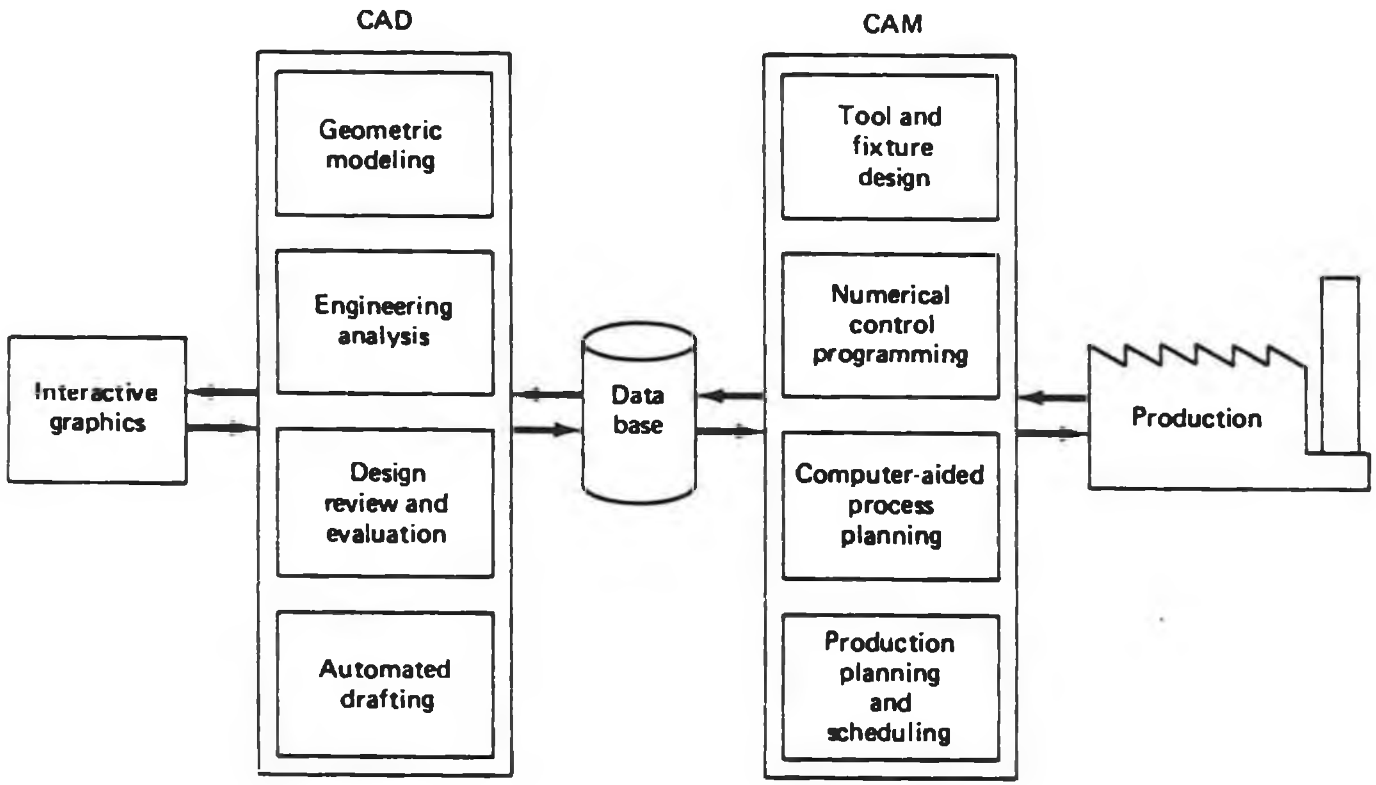


FIGURE 1.6 Desirable relationship of CAD/CAM data base to CAD and CAM.

4 Plan and Aim of the present work

The title of this present research project is "Integration of CAD and CAM for Manufacturing of Complex Shaped Components Using a Robotic Manipulator". Based on the background of previous related research, the following tasks are put forward to be solved:

1. To create a 3D model drawing for wire electric discharge machining, both efficiently and accurately, with the help of AUTOCAD R11 instead of BASIC.

2. To make sure that the graphic files of 3D model drawings created can be easily transferred and processed later by other software automatically towards the direction of integrating CAD with CAM.

3. To build up a bridge between CAD and CAM, that is to say, between a drawing file in AUTOCAD and the control programme for the manipulator control system, which is a key problem in the integration of CAD and CAM.

4. To develop a universal control programme which is suitable for the machining of any kind of complex shaped model in WEDM.

5. To improve the WEDM machining accuracy by means of the integration of CAD and CAM.

THE OBJECTIVES OF THE PRESENT PROJECT ARE:

1. To find a way to create 3D model drawings for WEDM towards the direction of integration of CAD and CAM.

2. To build up a bridge between CAD and CAM - to transfer a graphic drawing file in AUTOCAD to a non-graphic file and create a standard database by extracting related information from the non-graphic drawing file.

3. To develop a universal control program which is suitable for the machining of any kind of complex shaped model in WEDM.

4. To find a way to improve the WEDM machining accuracy by means of the integration of CAD and CAM.

5. To simulate WEDM tests using model materials and the above machining facility.

Chapter 2

TECHNIQUE FOR CREATING 3D DRAWINGS

2.1 Introduction for 3D-CAD for WEDM

2.2 Geometry Features

2.3 Machining Features

2.4 Technique for creating 3D drawing for WEDM

2.5 Conclusion

2.1 Introduction for 3D-CAD for WED

3D-CAD here refers to the use of AutoCAD to create three-dimensional drawings mainly for WEDM. AutoCAD is a general purpose Computer Aided Design (CAD) program which one can use to prepare a variety of two-dimensional drawing and three-dimensional models.

3D-CAD of complex shaped components for WEDM is a very significant part in the integration of CAD/CAM for manufacturing of complex shaped components. Some very useful dies, such as extrusion dies for producing unusual gears , section metal materials or plastic parts of complex shapes, could be created more easily and accurately based on the 3D-CAD. This is not only because using AutoCAD to create three-dimensional drawings is faster and more accurate than traditional methods of creating 3D drawings but also because an AutoCAD drawing file is a database containing the precise locations, sizes and attributes of the objects which can be extracted and analyzed to generate numerical control data for production applications[29]. Moreover, the 3D-CAD of complex shaped components for WEDM is also the basic problem to solve in following integrated CAD-CAM in WEDM.

Considerable research on 3D-CAD of complex shaped components have been done using AutoCAD Release 11 [28]. This has been installed and configured on a workstation to integrate CAD and

CAM for the WEDM process. The features and principles of 3D-CAD of complex shaped components for WEDM are described in the following sections.

2.2 Geometry features

The geometries of 3D complex shaped components for Wire Electric Discharge Machining have some common features which must be known before creating a proper 3D drawing for WEDM.

Firstly, the top surface and the bottom surface of a complex shaped component for WEDM must be flat and parallel with each other. Secondly, the profile on the top surface or on the bottom surface of the component must be taken from only one closed line, otherwise, it is impossible to realise that 3D drawing in reality for WEDM.

Figures 2.1-2.6 show different profile lines on the surfaces of some components. The profile lines on the bottom surfaces in Figs.2.5 and 2.6 are not valid since these are not formed from one closed line. Though the profile lines in Figs.2.1-2.4 look complex, they consist of only one closed line, as such they are valid. Corresponding 3D drawing of the Figs.2.1, 2.2 and 2.4 can be seen in Figs.2.7, 2.8 and 2.19 respectively.

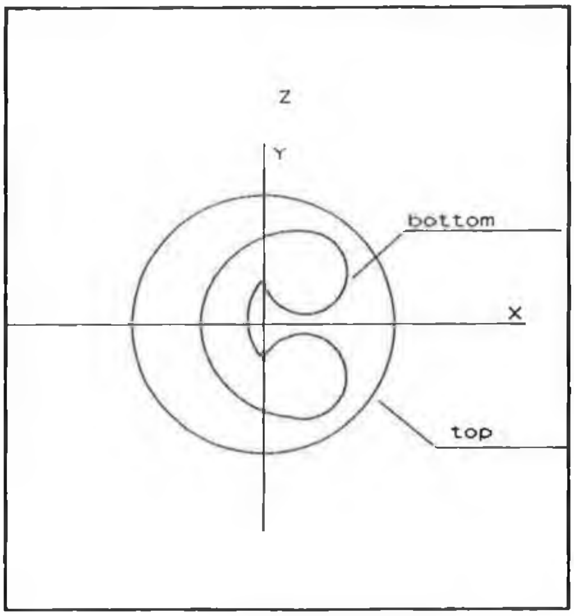


Fig. 2.1

A 3D model's plan view

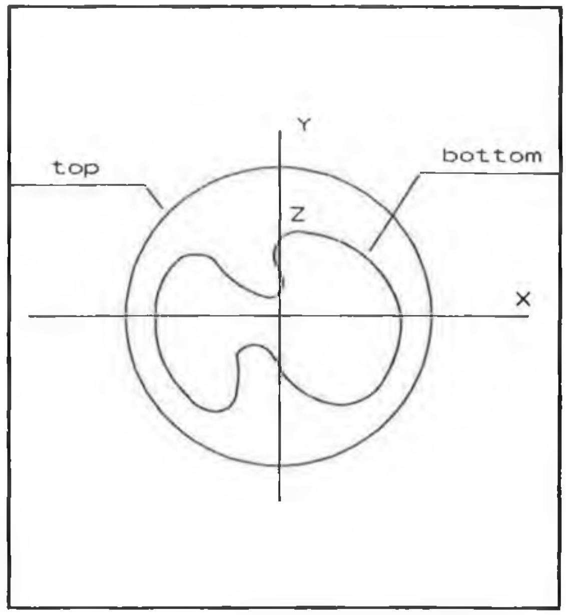


Fig. 2.2

A 3D model's plan view

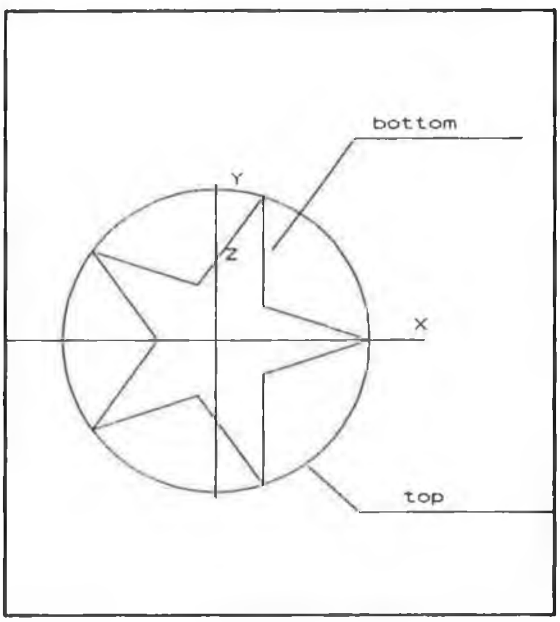


Fig. 2.3

A 3D model's plan view

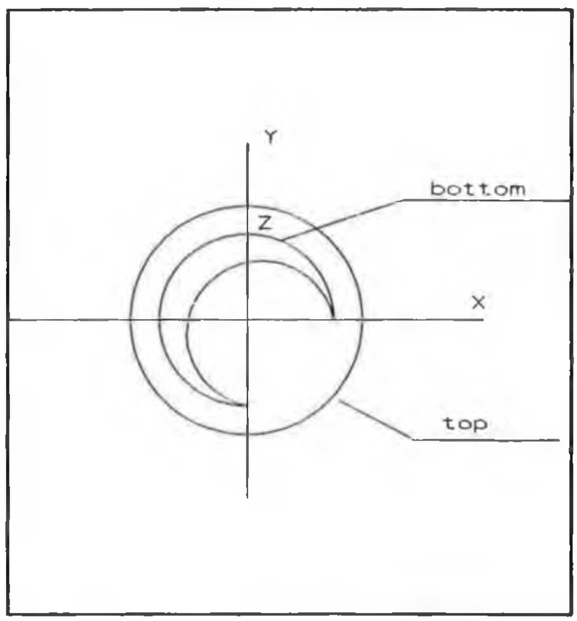


Fig. 2.4

A 3D model's plan view

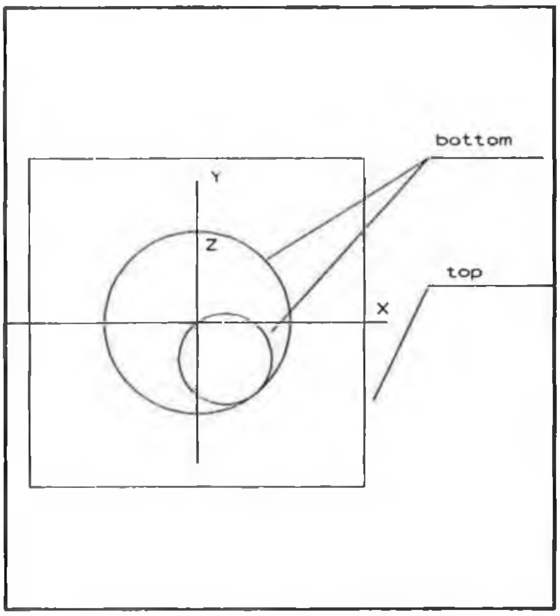


Fig. 2.5

A 3D model's plan view

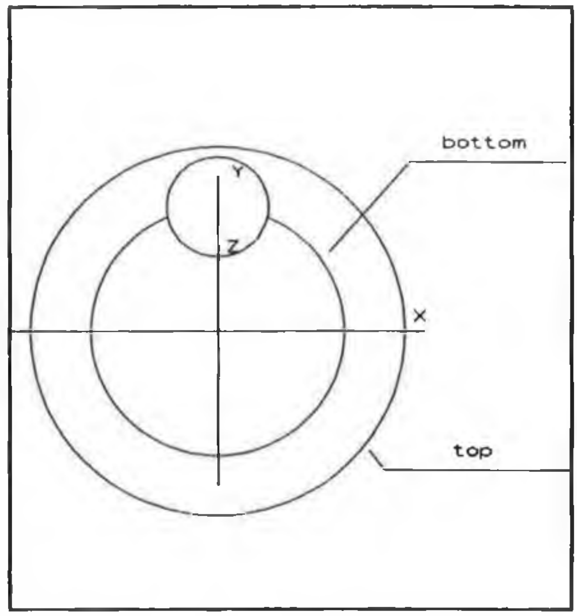


Fig. 2.6

A 3D model's plan view

Thirdly, the distance between the top surface and the bottom surface is limited in a component for manufacturing reasons. In the case of our research , the maximum thickness of any complex shaped component to be drawn in 3D for WEDM is set to 50 mm.

Finally, when designing an extrusion die, attention must be paid so that an area of any section of a 3D model parallel to x-y plane must be larger (or smaller) than or equal to the area of any other corresponding sections above (or below) it. In other words, if the model drawing were

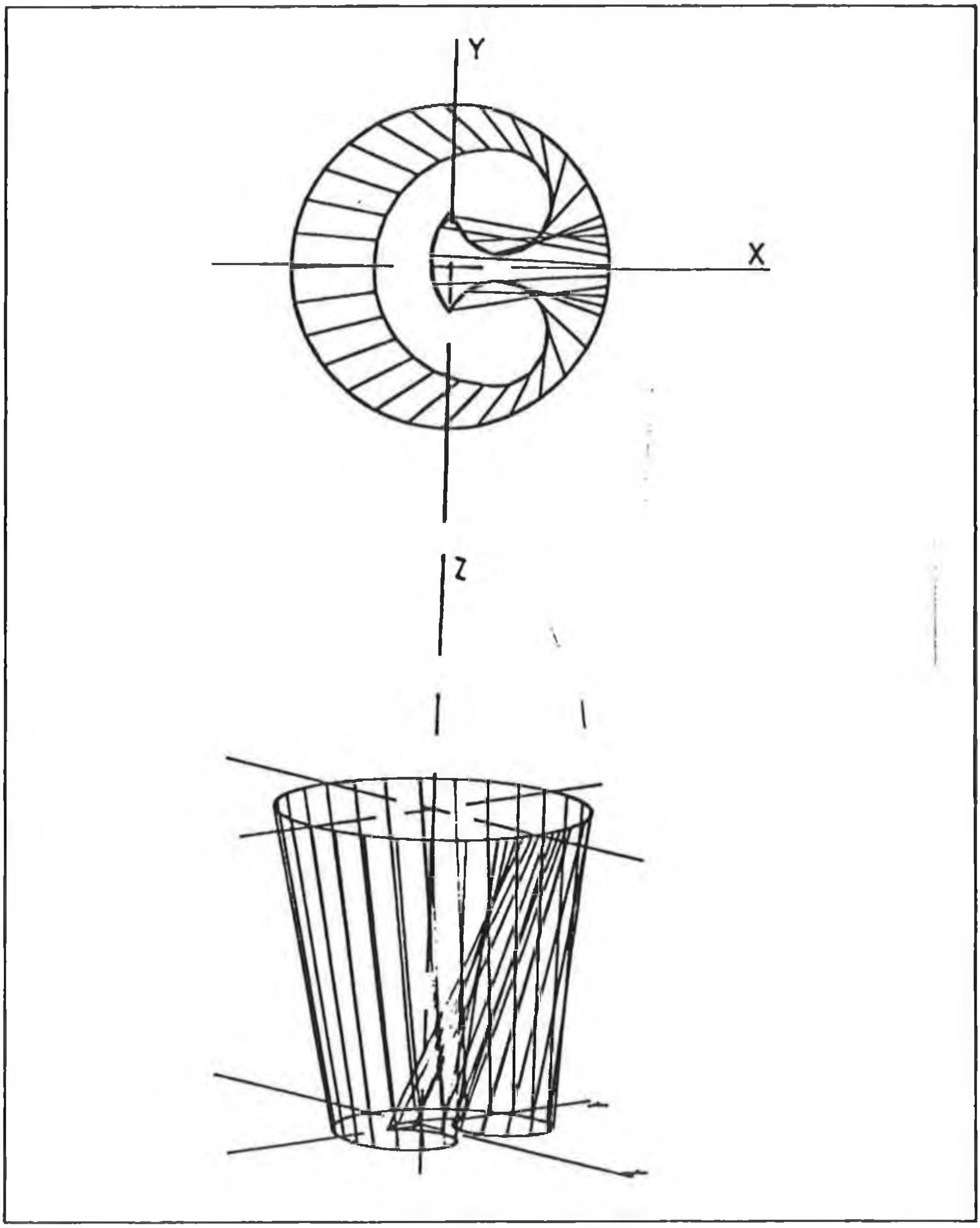


Fig. 2.7 A complex shaped 3D model drawing.

cut in two along z axis in any direction, the section profile obtained should only look like a trapezoid. The principle used to ensure this is to prevent the splines of the model from crossing each other in any situation.

Otherwise the die drawn would be of no practical use as an extrusion die, but it could be drawn and generated as an object of art. See the solidified picture Fig. 2.7 . Because the area of one middle section is smaller than that of the top section and also smaller than that of the bottom section, this model cavity can not be used as an extrusion die.

Even for the same sizes and profiles on the top and bottom surfaces of two model, different arrangements of the splines may bring about different results.

For example, the models in Figs. 2.8, 2.12 and 2.13 can be taken as extrusion die models, but the models in Figs. 2.9 and 2.10 can only be taken as a pure model because of the crossing splines at points A and B.

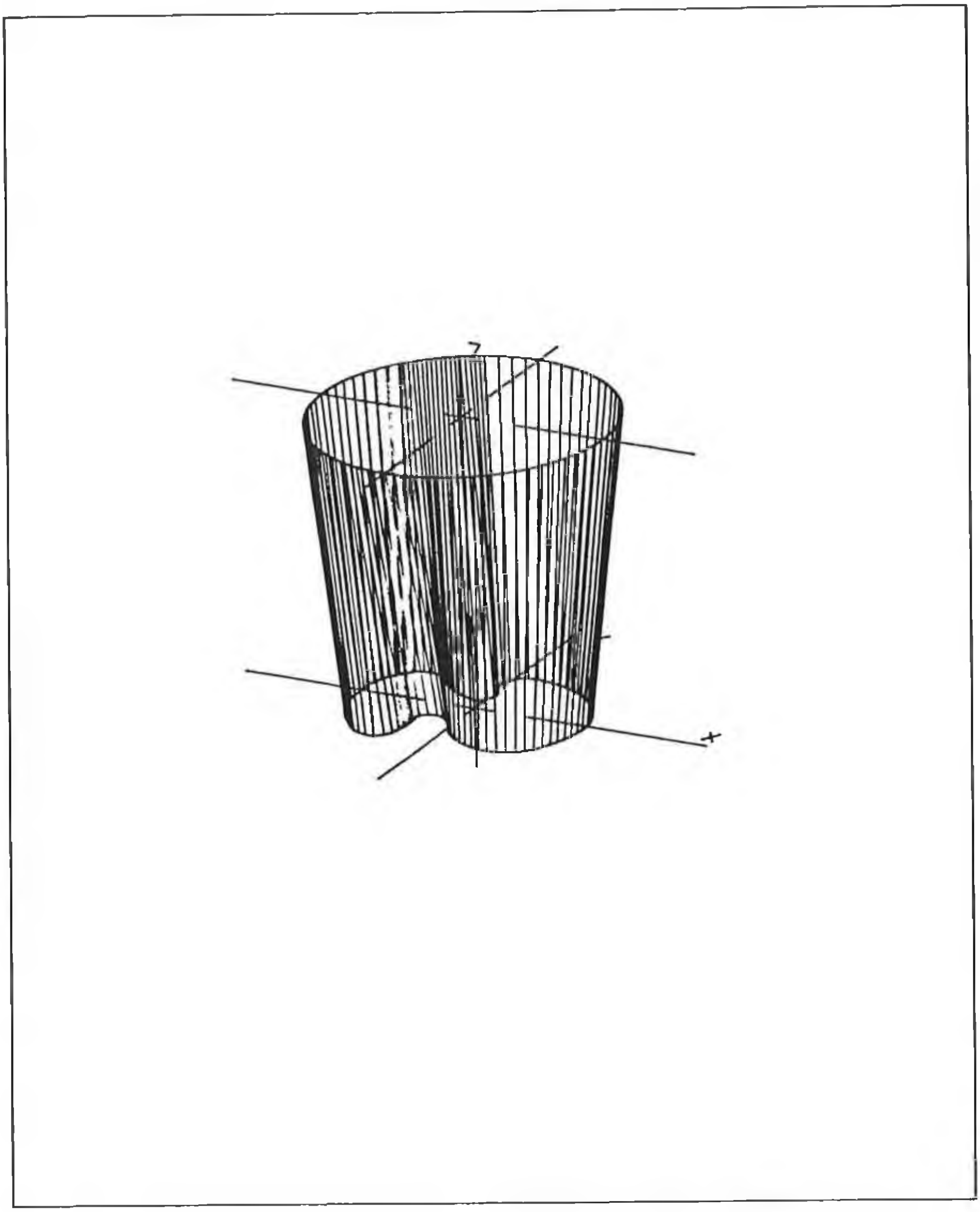


Fig. 2.8

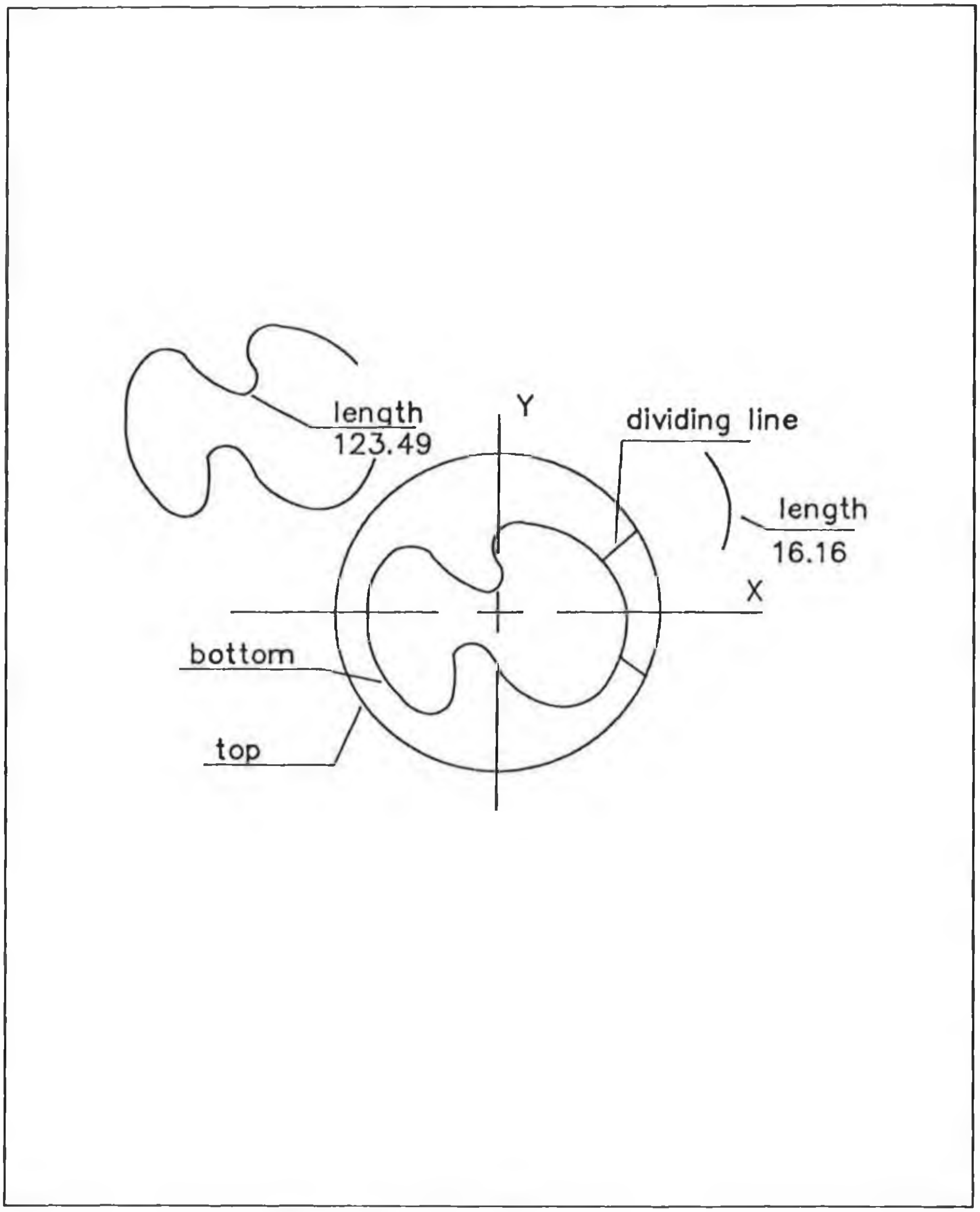


Fig. 2.9

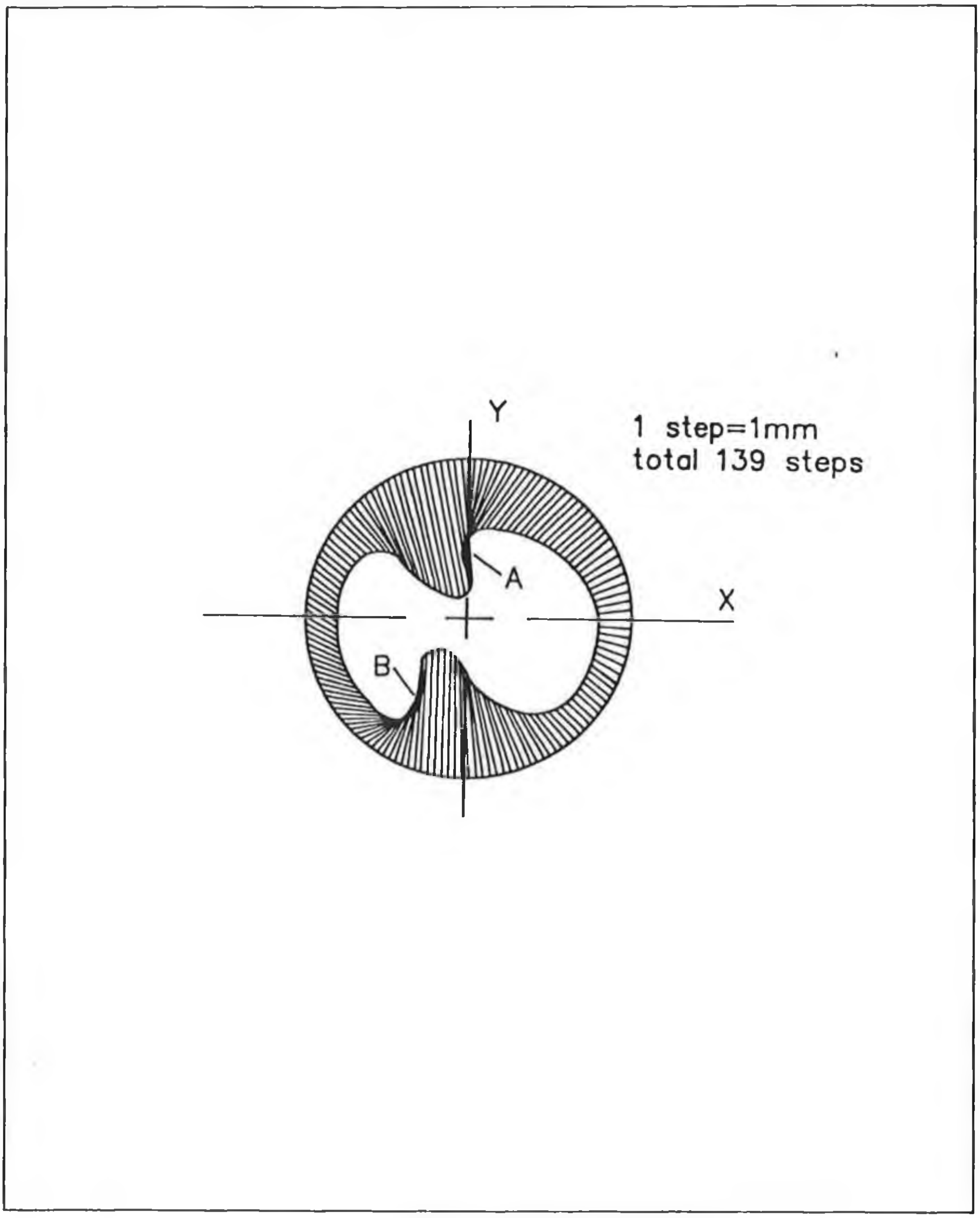


Fig. 2.10

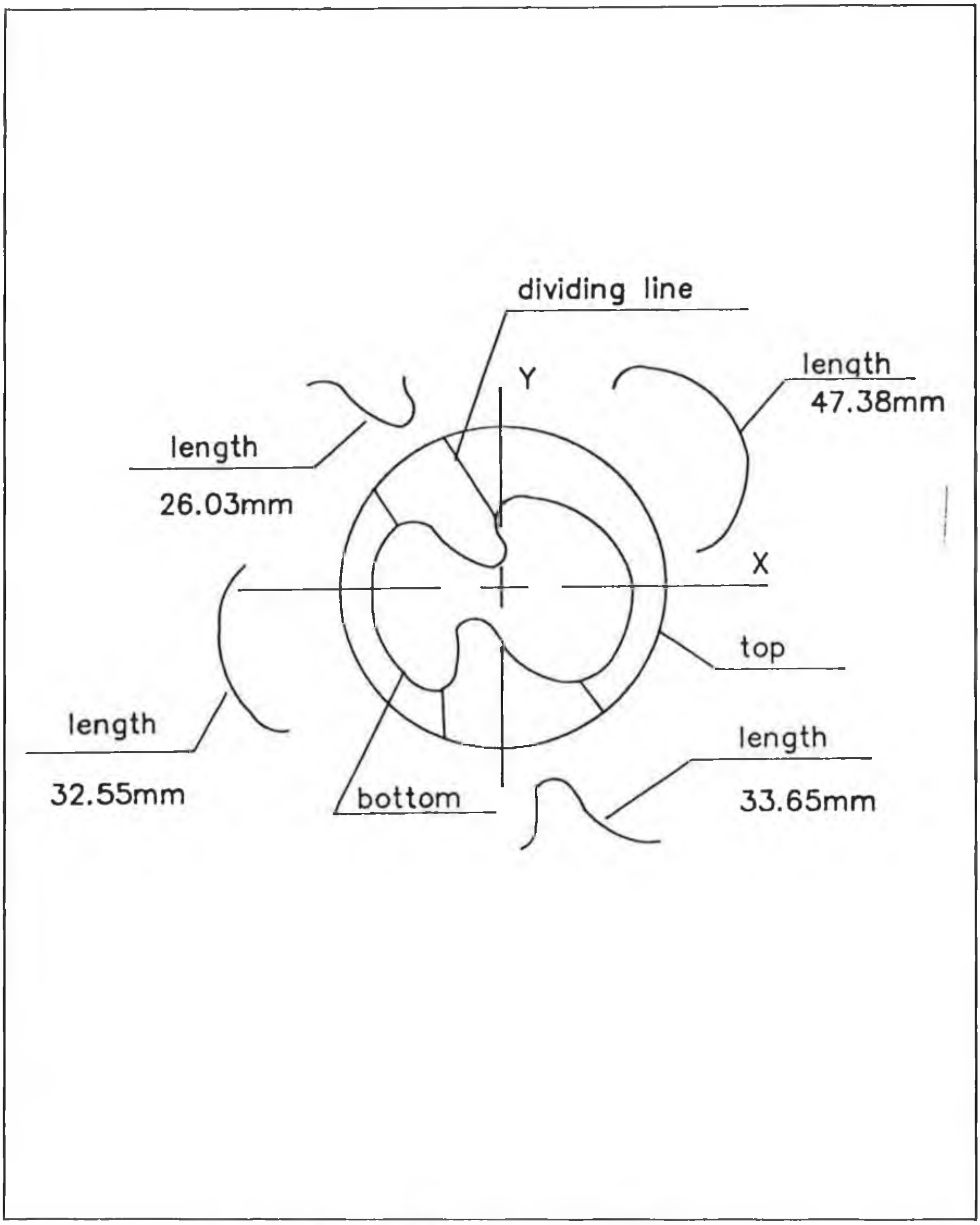

dividing line
Y
length
47.38mm
length
26.03mm
X
top
length
32.55mm
length
33.65mm
bottom

Fig. 2.11

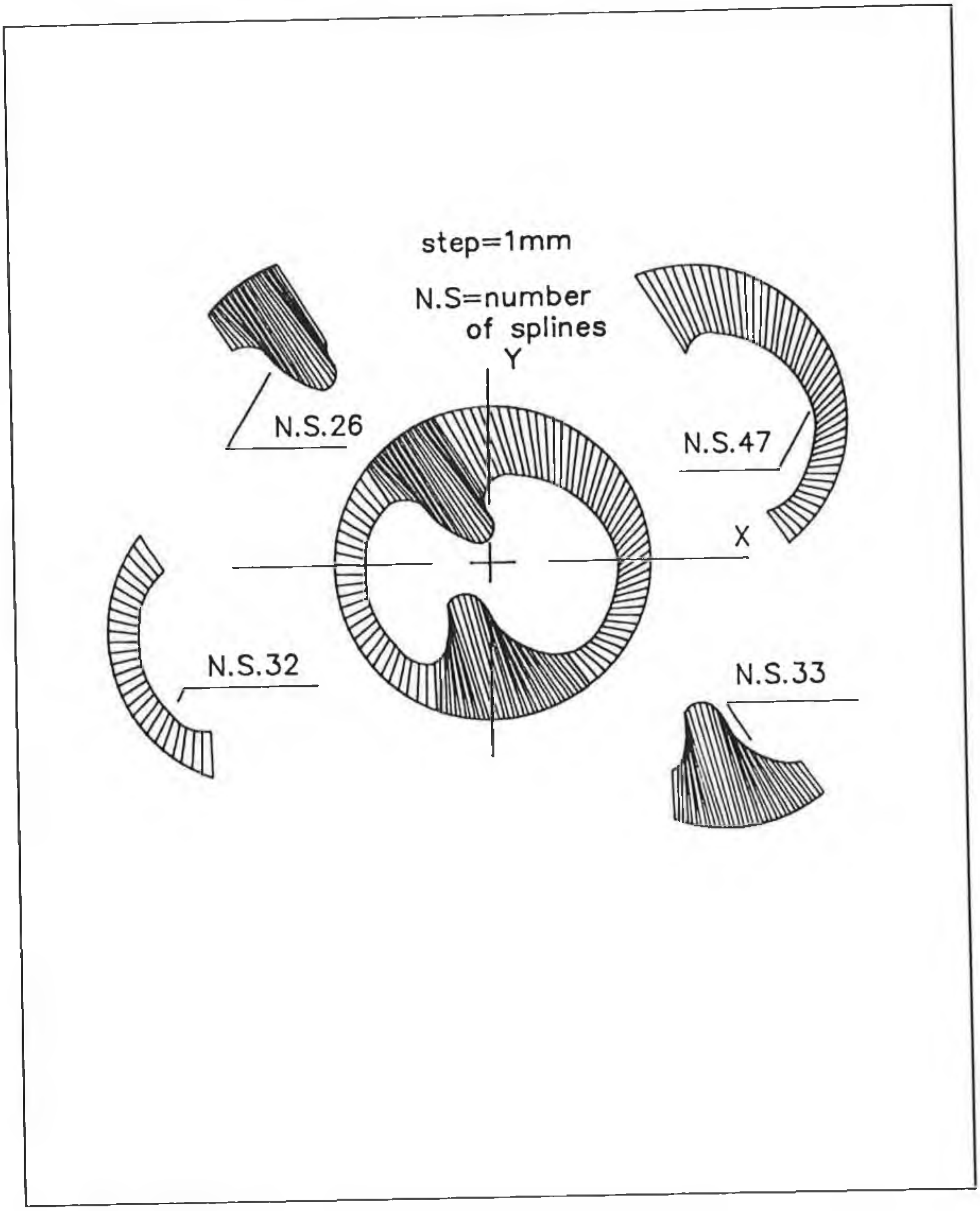


Fig. 2.12

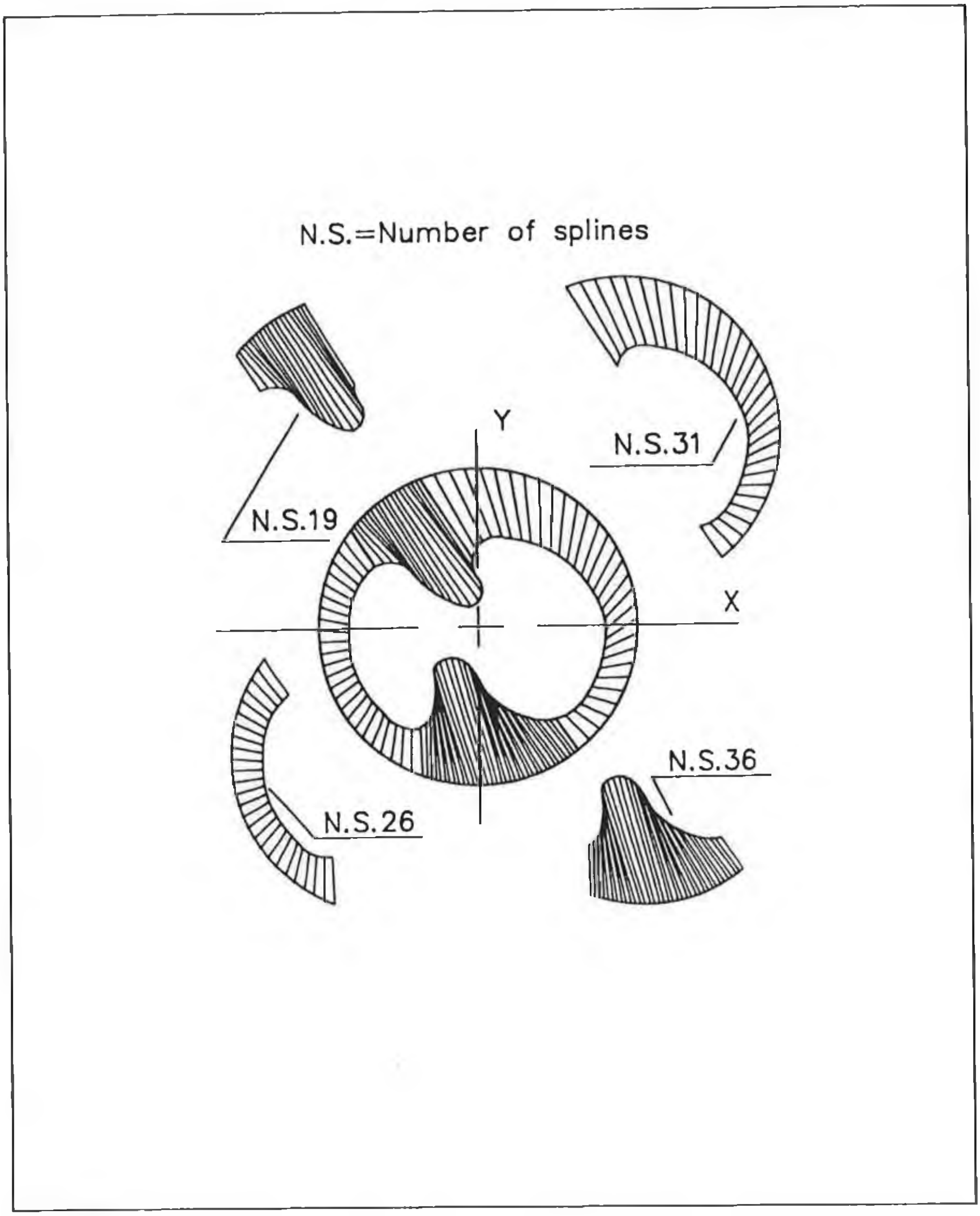


Fig. 2.13

2.3 Machining features

Wire Electric Discharge Machining itself has some features which must be also understood before creating a 3D drawing for WEDM. Because the purpose of this project is to integrate CAD-CAM for generating desired complex shaped 3D model dies in WEDM, it is better to combine the machining features while creating the 3D drawings for WEDM.

3D die cavities or models are generated by two concurrent steps in WEDM. Firstly, the generation of the bottom shape is obtained by manipulating the workpiece in x and y directions. Secondly, the generation of the top surface is obtained by rotating the workpiece around the x and y axes to align the cutting wire with the corresponding splines between the top and bottom surfaces according to the corresponding angles alpha and beta.

The process is then repeated to cover all the splines in order to generate the whole 3D shape in the model material.

The trace passed by the cutting wire of WEDM is just like the surface mesh drawn to form the 3D die cavities or models in creating the drawing which is a very important machining feature of WEDM.

Therefore, it can be imagined that the ruled surface mesh generated by AutoCAD to form the 3D model drawing is an imitation of the trace of the cutting wire in WEDM. In this way the arrangement of the directions and the numbers of the 3D model splines as the trace of the straight cutting wire could conveniently be determined and set as desired during the process of creating the 3D drawing's ruled surface mesh.

The machining accuracy of the 3D model obtained depends on the distance between two splines next to each other. The smaller the distance, the better is the accuracy. As a machining feature, each part of the shaped profile on the end faces of the 3D model is divided equally by the same number of the splines. However the distances between these same two splines at the top and bottom surfaces may be different due to the different shape profiles on each end face of the model.

The principle of determining the required number of the splines in order to get the desired accuracy model should be based on the accuracy requirement of an outlet of the model die or an outlet shape profile of the model, not that of an intake. This is another important aspect to take into account when creating any 3D model drawing for WEDM. See Figs. 2.11 to 2.13.

2.4 Technique for creating 3D drawing for WEDM

When creating any 3D shape drawing for the purpose of integration of CAD/CAM for WEDM the following steps need to be taken.

1st step: Set up a 3D coordinate system and a new corresponding origin, see Fig. 2.15. A principal rule that needs to be kept in mind is to set the origin the same as that of the **WORLD COORDINATES SYSTEM** by first initialising LIMITS, then choosing **ZOOM ALL** from the menu bar in AUTOCAD. During this process **USER'S COORDINATES SYSTEM** may often need to be referred to during the creation of the drawing.

2nd step: Choose **SETTING** from menu bar, then choose **PLAN VIEW** from its pull-down menu in order to create a profile on one of the model ends easily.

3rd step: Choose **SETTING** from menu bar, then choose **LAYER CONTROL** to pick a colour and a type of the line you like.

4th step: Create 2D drawing on the plan view. Say, it is the bottom surface, choose **DRAW** from menu bar. Almost any thing can be selected and drawn using the functions provided in its pull down menu. The arc's function and a group of coordinates can very easily be used to create a complex bottom shape same as in Fig.2.9 or Fig.2.11. See Table 2.4.1 for the group of coordinates.

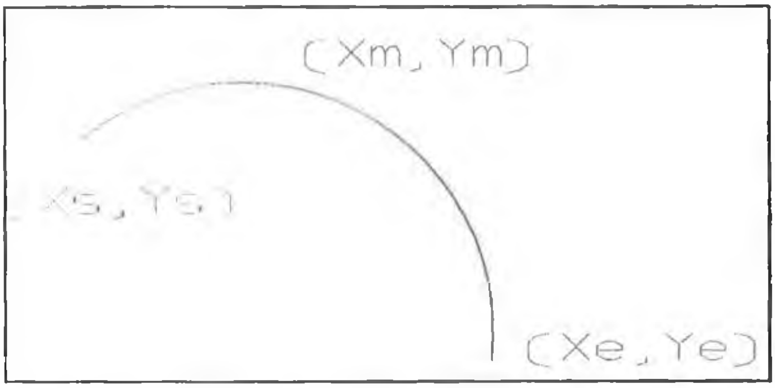


Fig. 2.14 An arc formed by 3 given points.

5th step: Moving the **UCS icon** to top surface. Any shape can be drawn according to the geometry features for WEDM. Given a diameter and a centre, you can create a circle on the top face using circle function. See Fig. 2.11.

6th step: Divide the profile lines at both the top and bottom end faces into two or more parts, then use the **RULED SURFACE** function to mesh them into solid model. But before that, it must first be established that the profile line is divided in such a way that the splines of the mesh do not cross each other in any situation. Secondly, the step distance between two splines next to each other must be determined according to the machining accuracy required. In other words, the number of splines of each parts must be determined first. The length of its profile segment can be measured with AUTOCAD to decide how many splines it needs according to the step distance required with the function **SURFTABLE 1**. See Figs. 2.8-2.12.

7th step: Choose **RULESURF** from pull-down menu to form the surface meshes of the 3D drawing one by one. Choose **DISPLAY** from menu bar, then **VPONIT 3D** to check the model created, improve it then save it and that is all.

8th step: Objects can be made larger or smaller in **AUTO CAD** R11. The same scale factor is applied to X , Y and Z dimensions, so **SCALE** cannot turn circles into ellipses. This is the prompt sequence:

Command: SCALE

Select objects: Do so.

Base point: Point.

Scale factor:

If one responds to the last prompt with a number, this is taken as a relative scale factor by which all dimensions of the selected objects are to be multiplied. To enlarge an object, enter a scale factor greater than 1. To shrink an object , use a scale factor between 0 and 1. In this case the base point is suggested to be selected as the origin of the coordinates system.

When creating a drawing, the principles mentioned in chapter 2 must be observed. It is advisable to put the top surface, bottom surface, side's mesh and coordinates system on different layers in order to easily separate and process them for the purpose of integration of CAD-CAM.

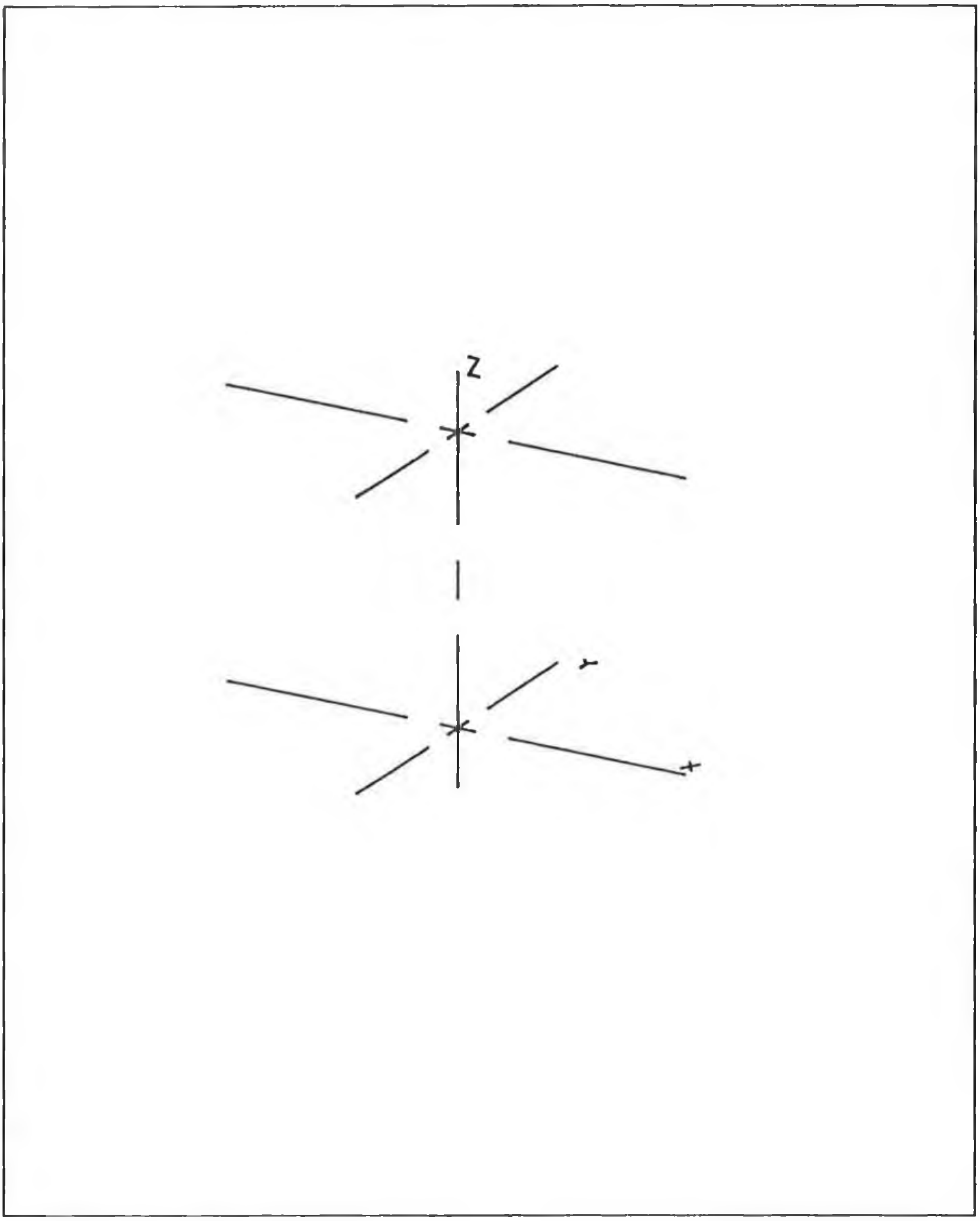


Fig. 2.15 A 3D coordinate system.

TABLE 2.4.1

Xs	Ys	Xm	Ym	Xe	Ye
20.00	0	17.06	6.78	12.84	10.92
12.84	10.92	8.16	13.2	4.52	13.92
4.52	13.92	1.48	13.58	-0.62	11.58
-0.62	11.58	-0.54	8.54	0	7.66
0	7.66	5.56	6.68	0.56	5.00
0.56	5.00	-0.86	3.32	-1.4	3.12
-1.4	3.12	-3.32	3.608	-4.52	4.174
-4.52	4.174	-8.646	7.006	-10.8	9.56
-10.8	9.56	-13.92	10.3	-16.0	9.738
-16.0	9.738	-19.56	4.33	-20.0	0.0
-20.0	0.0	-18.52	-8.30	-17.96	-9.36
-17.96	-9.36	-16.62	-11.4	-15.0	-13.21
-15.0	-13.21	-12.844	-15.264	-10.44	-16.00
-10.44	-16.00	-7.62	-14.56	-6.956	-12.52
-6.956	-12.52	-6.66	-8.968	-6.956	-6.608
-6.956	-6.608	-5.00	-5.00	-1.392	-6.26
-1.392	-6.26	0	-8.28	0.68	-9.738

Xs	Ys	Xm	Ym	Xe	Ye
0.68	-9.738	4.92	-13.26	8.348	-14.608
8.348	-14.608	13.876	-13.96	16.696	-11.478
16.696	-11.478	19.52	-4.82	20.0	0.0

For general purpose drawing skill, see Auto CAD manual.

The following are some 3D drawing examples for WEDM to show how to create them and also to show some features they have. Among them:

Fig.2.16
The 3D model drawing consists of a square shape on the top and a circle shape on the bottom. It's side surface is formed by a ruled surface mesh which also is an imitation of the trace of the cutting wire in WEDM.

Fig.2.8 to Fig.2.13
These figures show clearly the process to create a complicated 3D drawing of a component having a complex shape on bottom and a square shape on top, which is to be produced using a WEDM process.

Fig. 2.17

The bottom shape is complex while the top shape is a square.

Fig. 2.7.

This is a typical 3D model which can only be taken as a drawing model but not an extrusion die model, because the mesh splines cross each other at some points.

Fig. 2.18

The bottom shape is a circle while the top is a 2 shape.

Fig.2.19

The bottom shape is a crescent while the top is a circle.

Fig.2.20 to 2.22

This is an Arc gear extrusion die showing how to create it.

Fig. 2.23 and Fig. 2.24

This is a non-circular pitch gear extrusion die with non-evolute teeth showing how to create it.

These 3D drawings of extrusion die might be very valuable in practical production because it may be a wholly new way to produce gears with different tooth shapes or non-circular pitches.

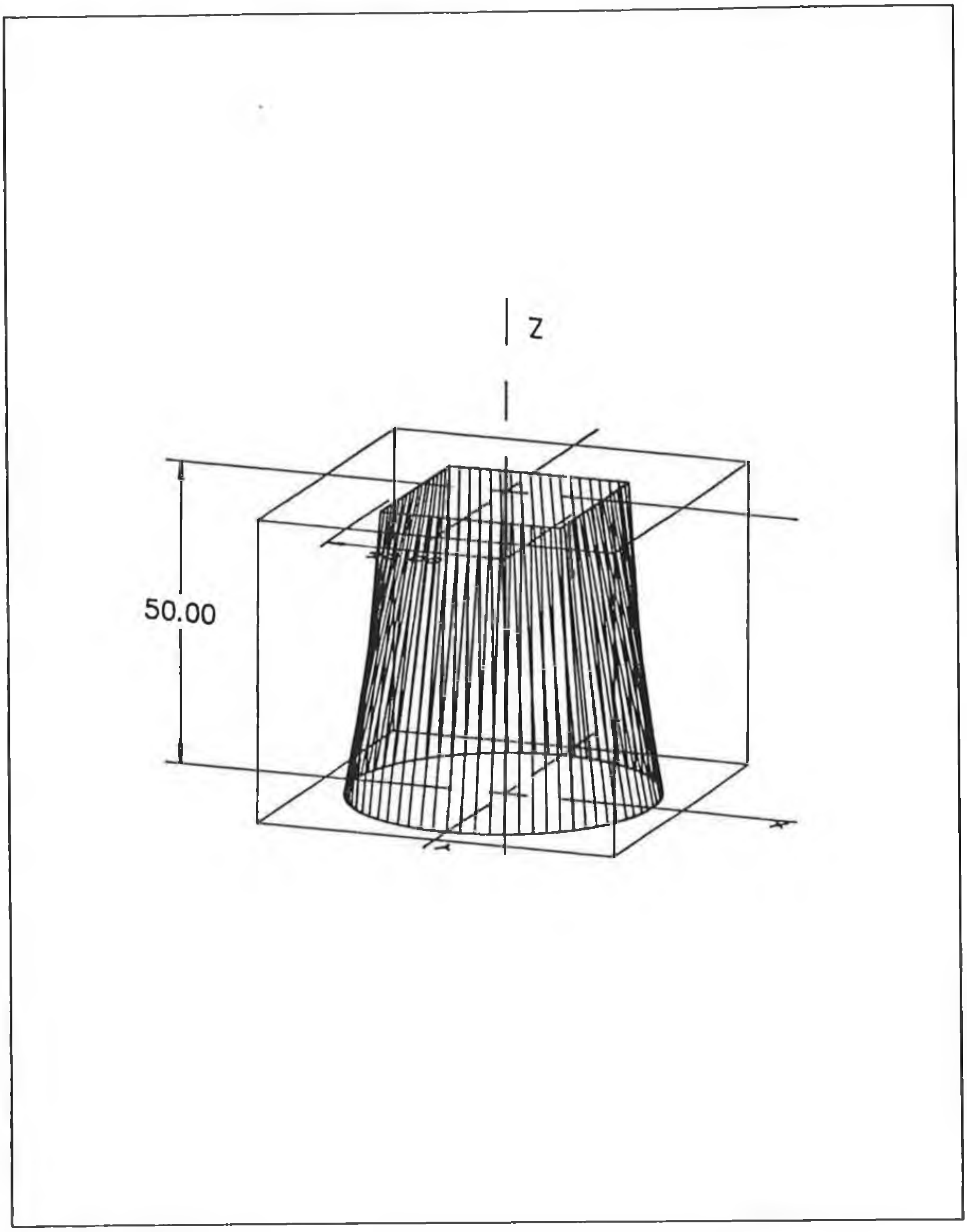


FIG. 2.16

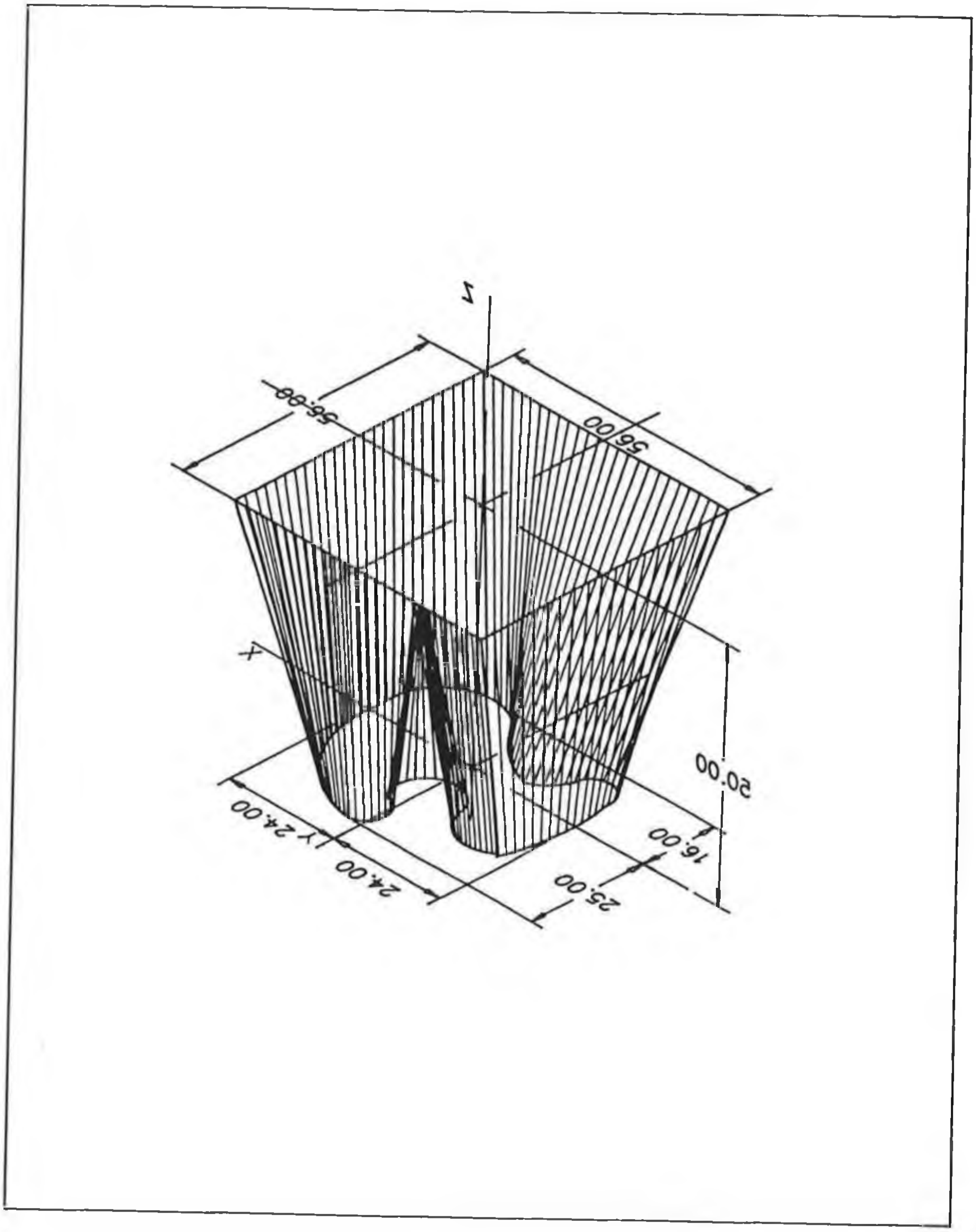


FIG. 2.17

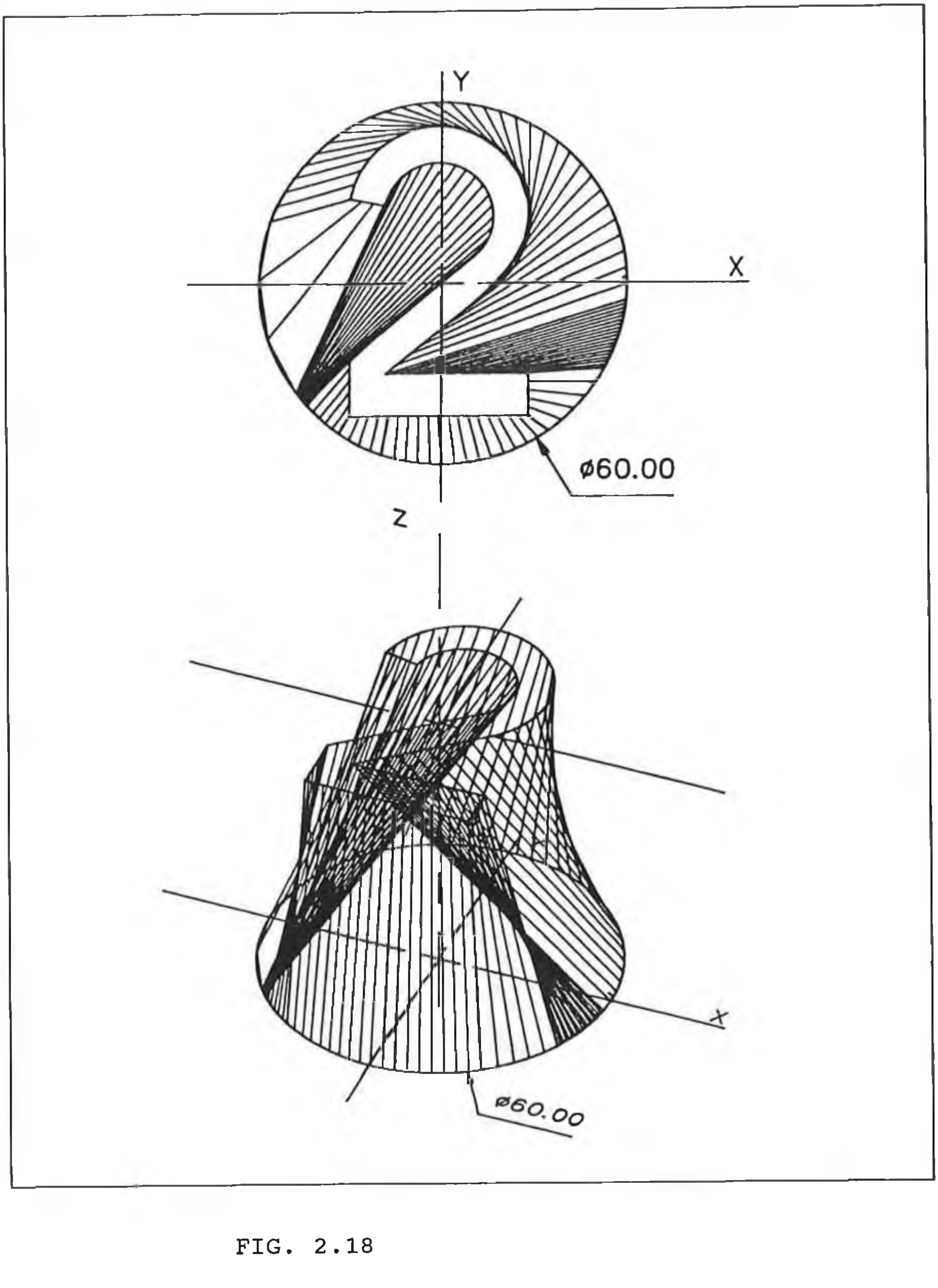


FIG. 2.18

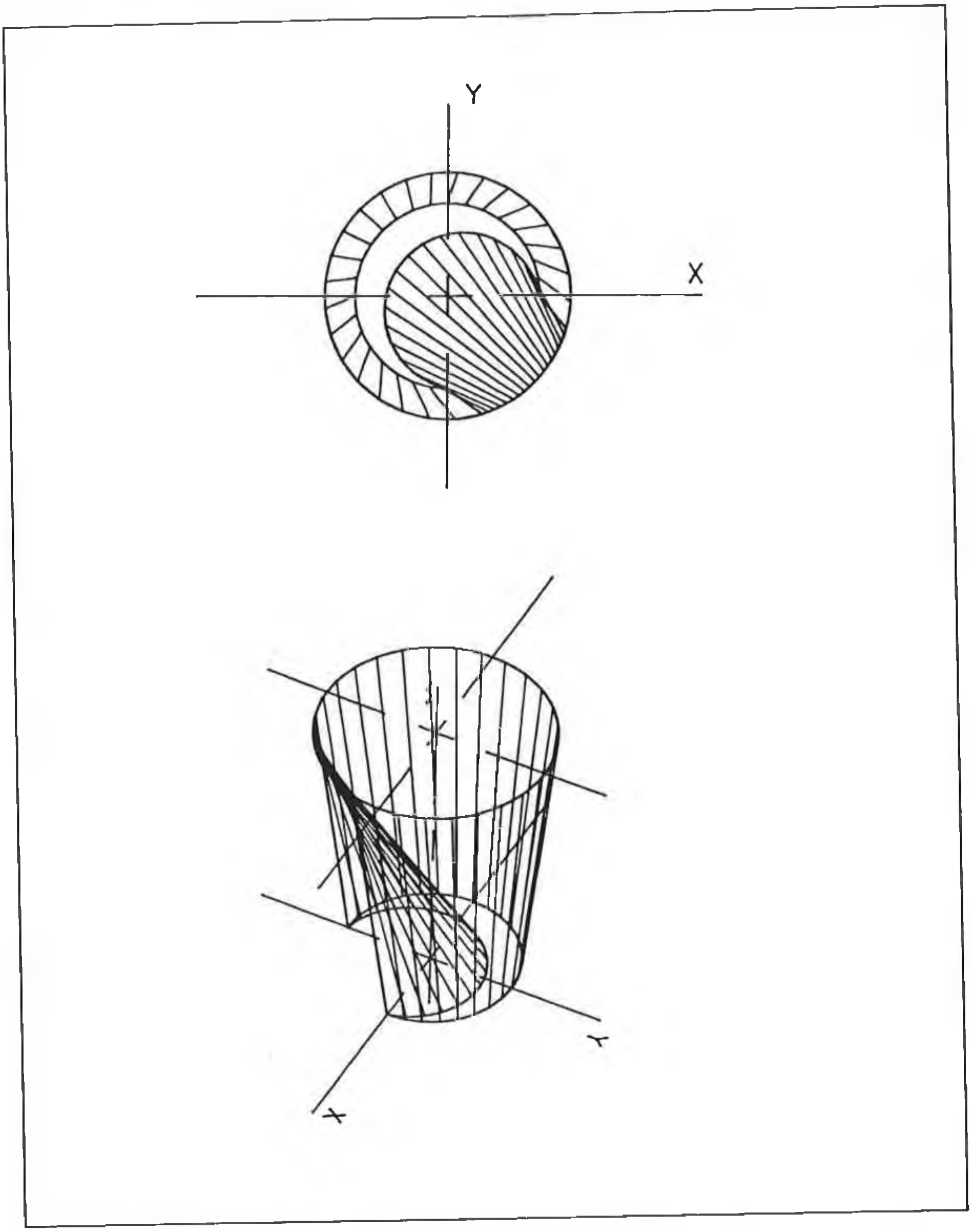


FIG. 2.19

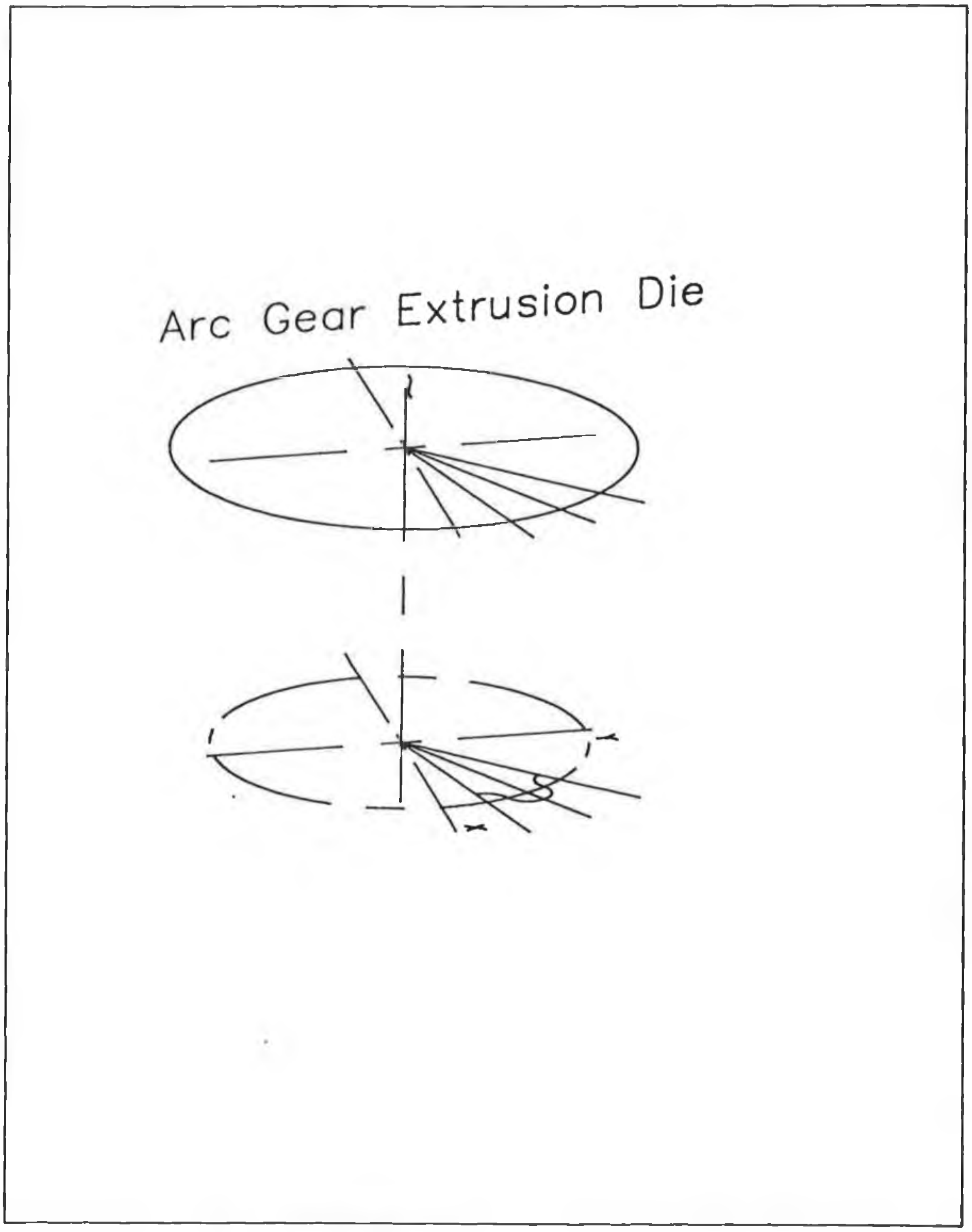


FIG. 2.20

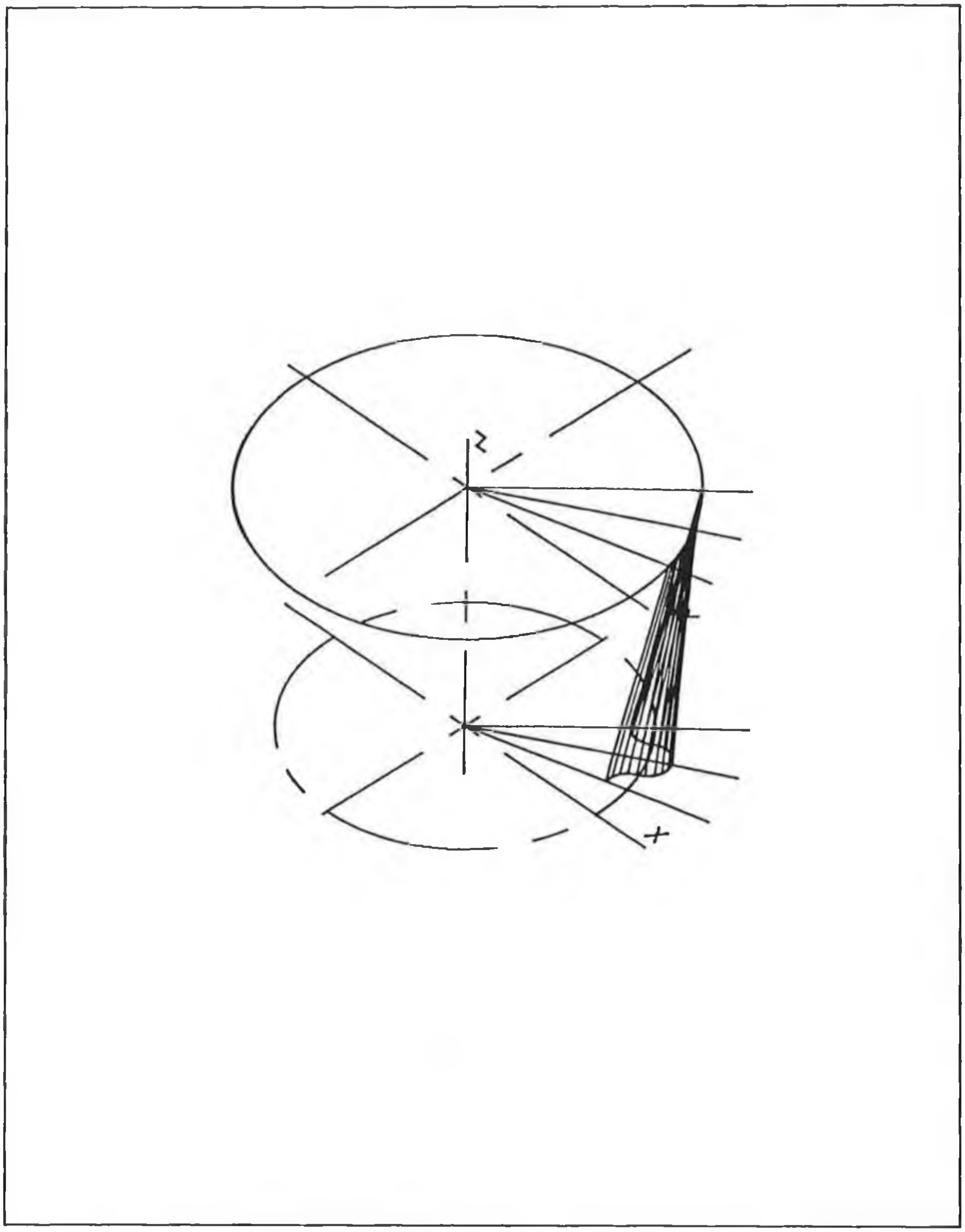


FIG. 2.21

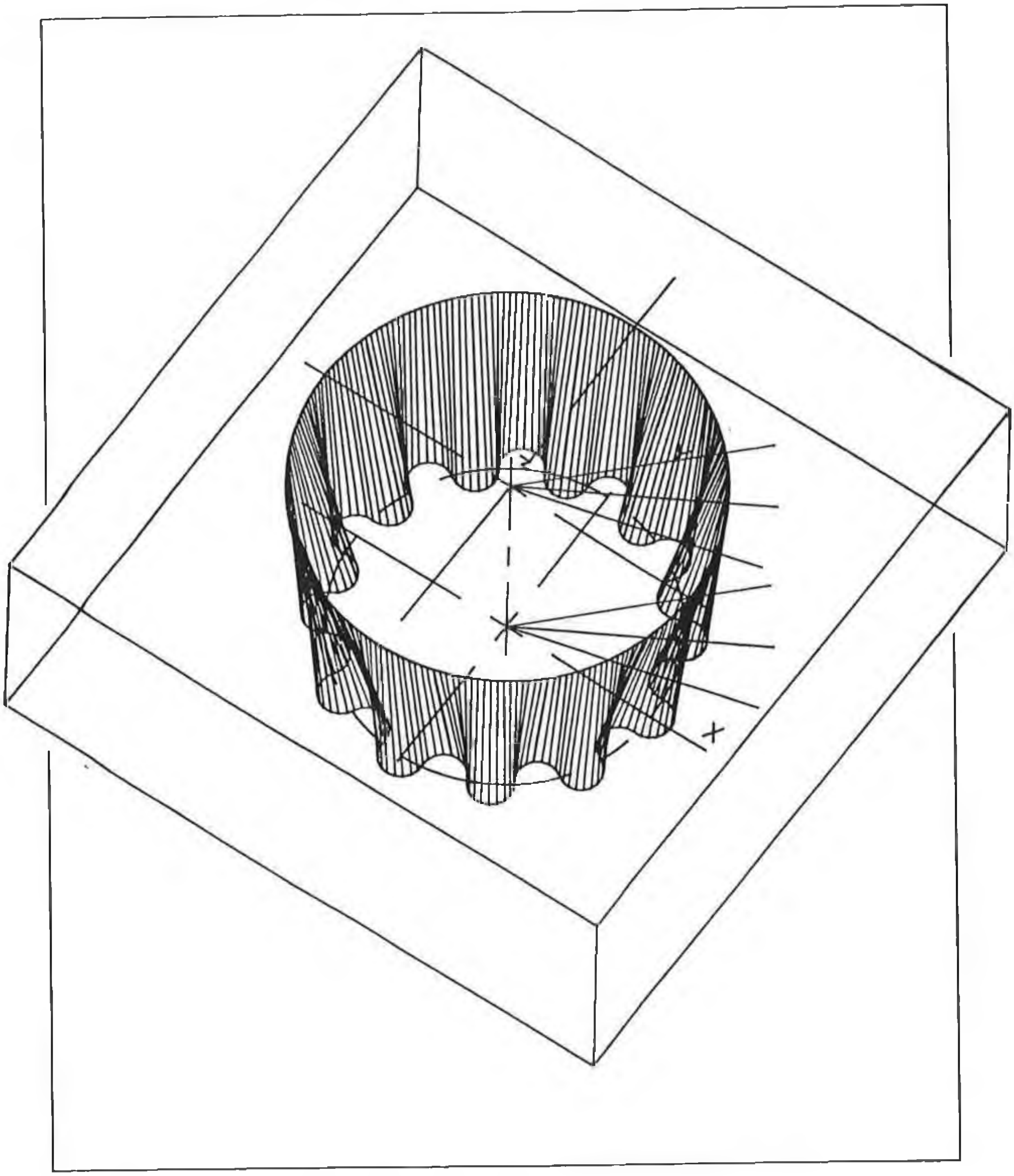


FIG. 2.22

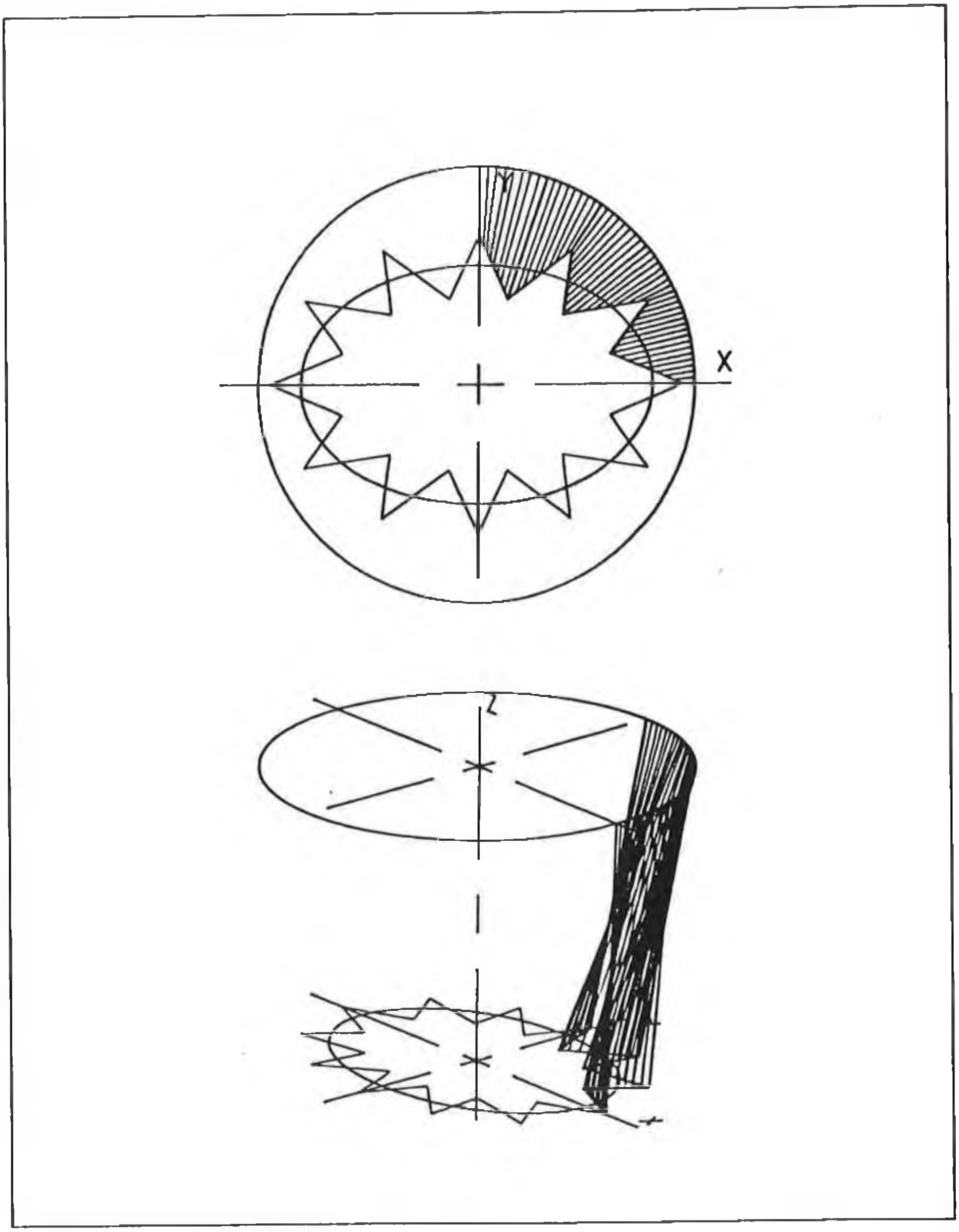


FIG. 2.23

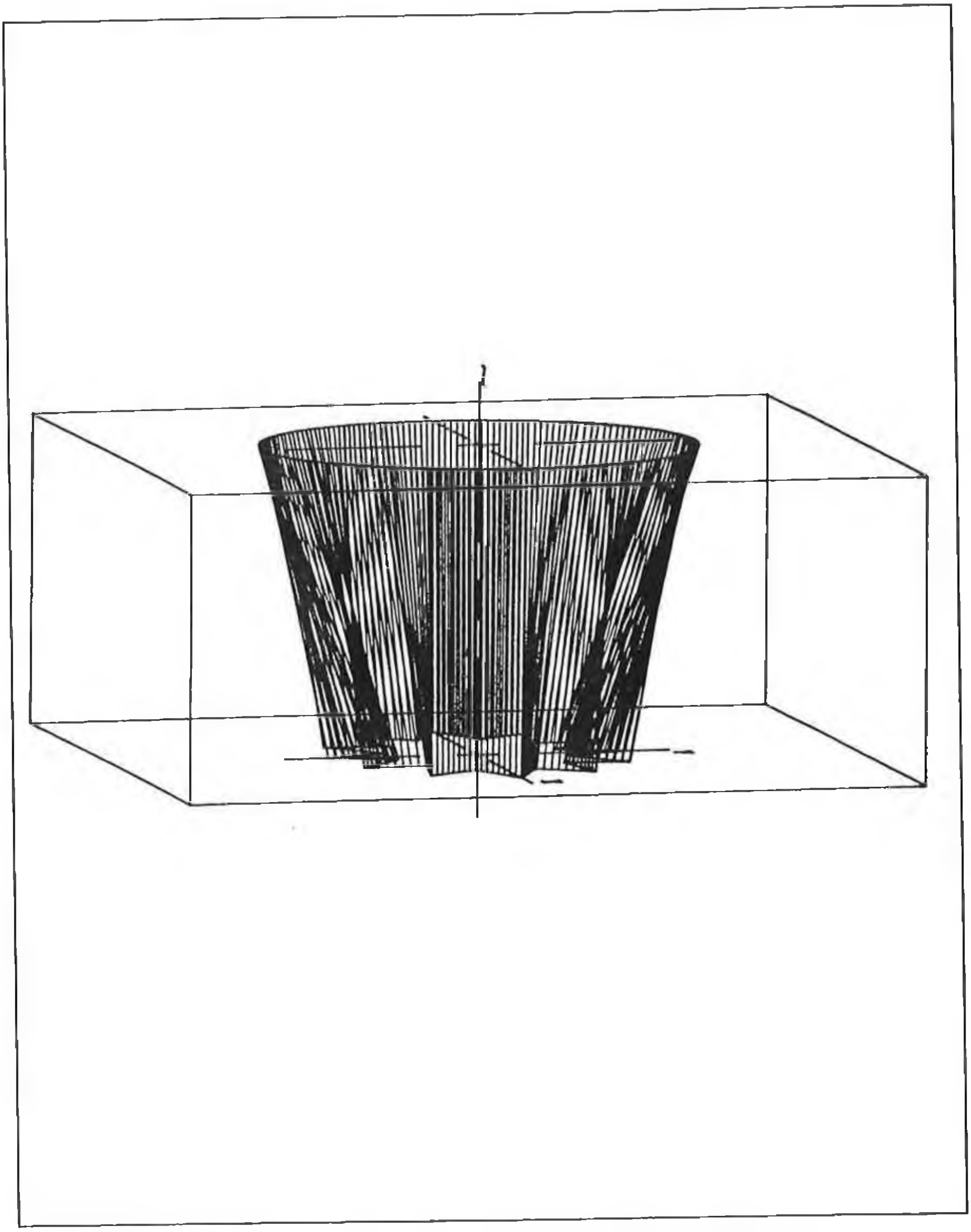


FIG. 2.24

2.5 conclusion

Not all drawings created using AutoCAD benefit the integration of CAD-CAM for WEDM. Only the 3D model drawing files for WEDM created in the way mentioned in this chapter could be useful in the future towards the integration of CAD-CAM, because it ensures that those drawing files created could be easily transferred and processed no matter how complicated they are.

(1) The ruled surface mesh can be taken as the imitation of the trace of WEDM , (2) the machining accuracy of WEDM could be improved by choosing proper step length or distance between two splines next to each other on the drawing, (3) the principle of arranging the spline meshes in 3D drawing for WEDM has been described and (4) the special procedure to create 3 dimensional drawing for subsequent process for integration of CAD/CAM has also been summarized here. These are all the new results of this research.

The creation of 3D drawing and their linking with the integrated CAD-CAM is the feature of this thesis.

Chapter 3

TRANSFERRING AND EXTRACTING

3.1 Introduction

3.2 IGES Transferring

3.3 DXF Transferring

3.4 Comparison

3.5 DXF Interface Programme

3.6 Examples

3.7 Conclusion

3.1 Introduction

The research project presented here is about the integration of CAD/CAM for manufacturing of complex shaped components using a robotic manipulator. So after a 3D drawing is completed using AUTOCAD, it must be possible for it to be extracted and transferred to other software systems for further analysis and processing in a subsequent stage of an integrated CAD-CAM system.

However, this kind of drawing file is a graphic file stored in a form which is very difficult to interpret or alter later.

There are two steps to solve this problem, firstly, AUTOCAD itself provides two ways to transfer graphic drawing files to non-graphic file using either DXF or IGES form in ASCII text format. This is a very important step towards solving the problem because it can be read later, but is not sufficient enough.

The drawing file created in DXF or IGES form is comprehensive, for example, in DXF.file even a blank drawing contains a large amount of data about everything contained within the prototype drawing. As a result, the DXF.file or IGES.file can appear fearsomely complicated and difficult to be used by other software.

The second step is to decide how best to extract selected data from a DXF.file or IGES.file in order to create a standard database which acts as a bridge that connects CAD with CAM. This is a key task of this project.

A extracting programme, which is an interface programme, has been developed successfully as will be shown in this chapter.

3.2 IGES Transferring

IGES means Initial Graphics Exchange Specification which is a public domain data specification intended as an international standard for the exchange of information between computer aided design systems.

It is relatively easy to instruct AUTOCAD to transfer a drawing graphic file to a IGES format file. By means of the drawing editor's IGESOUT command, one can transfer a graphic file such as in Fig. 3.1 which is a simplified drawing example in order to explain how to transfer a graphic file in AUTOCAD to non-graphic IGES file and to demonstrate what a IGES format file looks like.

The AUTOCAD system transfers the whole contents to the non-graphic file once the command "igesout" is chosen in AUTOCAD RII irrespective of whether the whole contents in a drawing file or only part of the ENTITIES in the drawing file is of interest.

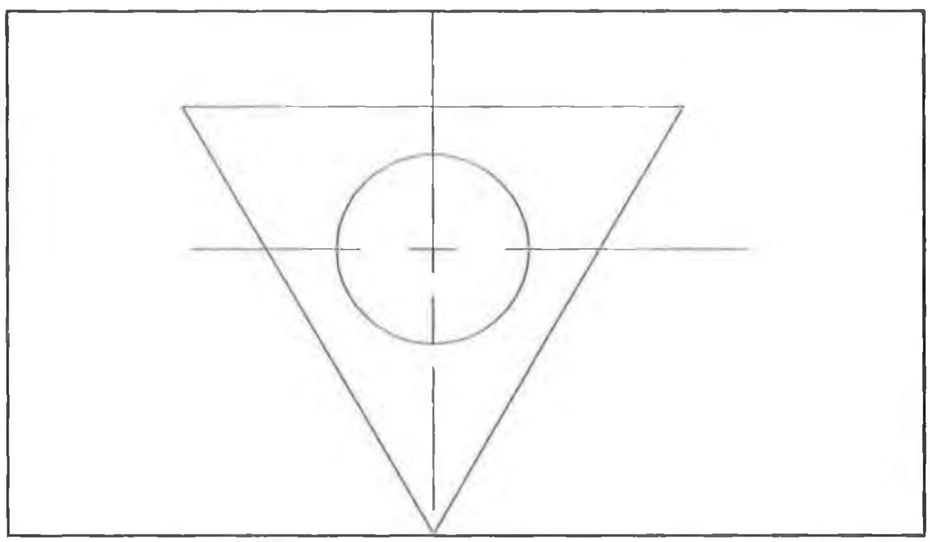


Fig.3.1 A simple drawing example for transferring.

```
IGES file generated from an AutoCAD drawing by the IGES                 S00000
translator from Autodesk, Inc., translator version IGESOUT-3.04.        S00000
,,4HCPT1,8HCPT3.IGS,15HAutoCAD-R11i c2,12HIGESOUT-3.04,32,38,6,99,15,4HCG00000
PT1,1.0,1,4HINCH,32767,3.2767D1,13H940223.124946,2.55D-7,255.0,9HFaek diG00000
ko,10H DCU-Mech.,6,0;                                                   G00000
     110       1       1       1                                 00000000D00000
     110                       1                                         D00000
     110       2       1       1                                 00000000D00000
     110                       1                                         D00000
     110       3       1       1                                 00000000D00000
     110                       1                                         D00000
     110       4       1       1                                 00000000D00000
     110                       1                                         D00000
     110       5       1       1                                 00000000D00000
     110                       1                                         D00000
     110       6       1       1                                 00000000D00000
     110                       1                                         D00000
     100       7       1       1                       0         00000000D00000
     100                       1                                         D00000
     124       8       1                                         00000000D00000
     124                       1       0                                 D00000
     110       9       1       1                                 00010000D00000
     110                       1                                         D00000
     110      10       1       1                                 00010000D00000
     110                       1                                         D00000
     110      11       1       1                                 00010000D00000
     110                       1                                         D00000
     102      12       1       1                       0         00000001D00000
     102                       1                                         D00000
     404      13       1                                         00000000D00000
     404                       1                                         D00000
110,140.0,155.0,0.0,175.0,155.0,0.0;                                    1P00000
110,185.0,155.0,0.0,195.0,155.0,0.0;                                    3P00000
110,205.0,155.0,0.0,255.0,155.0,0.0;                                    5P00000
110,190.0,205.0,0.0,190.0,150.0,0.0;                                    7P00000
110,190.0,145.0,0.0,190.0,135.0,0.0;                                    9P00000
110,190.0,130.0,0.0,190.0,100.0,0.0;                                   11P00000
100,0.0,190.0,155.0,210.0,155.0,210.0,155.0;                           13P00000
124,1.0,0.0,0.0,0.0,0.0,-1.0,0.0,0.0,0.0,0.0,-1.0,0.0;                 15P00000
110,1.3803847577293D2,185.0,0.0,190.0,95.0,0.0;                        17P00000
110,190.0,95.0,0.0,2.4196152422707D2,1.85D2,0.0;                       19P00000
110,2.4196152422707D2,1.85D2,0.0,1.3803847577293D2,185.0,0.0;          21P00000
102,3,17,19,21;                                                        23P00000
404,0,0;                                                               25P00000
S0000002G0000003D0000026P0000013                                        T00000
```

This is a IEGS file transferred from Fig. 3.1.

3.3 DXF transferring

DXF is an abbreviation for Drawing Interchange File. In a similar way as in IEGS transferring, a DXF file can be made from the current drawing by simply typing command "dxfout" or choosing it from a menu bar, the file will automatically be given a .DXF extension. Before transferring, a prompt will be displayed on the screen like this:

"Enter decimal places of accuracy(0-16)/Entities/Binary"

This sets the number of decimal places of the coordinates of any points specified in the file. If ENTITIES is selected, one would be prompted to select the required entities from the drawing; only those selected will be transferred to the DXF file. The BINARY option allows the extraction of the same data in the same format but it is saved in binary not ASCII text format. This gives a more accurate and compact file but is much more difficult to read and edit.

The following is a DXF. file example transferred from the same drawing graphic file as Fig. 3.1 mentioned in section 3.2 IGES transferring which is named as c:\acad11\dwgs\cpt3.dxf.

```
~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
  0
SECTION
  2
ENTITIES
  0
POLYLINE
  8
0
 66
      1
 10
0.0
 20
0.0
 30
0.0
 70
      1
  0
VERTEX
  8
0
 10
138.04
 20
185.0
 30
0.0
  0
VERTEX
  8
0
 10
190.0
 20
95.0
 30
0.0
  0
VERTEX
  8
0
 10
241.96
 20
185.0
 30
0.0
```

```
  0
SEQEND
  8
0
  0
CIRCLE
  8
0
 10
190.0
 20
155.0
 30
0.0
 40
20.0
  0
ENDSEC
  0
EOF
------------------------------
```

However the following points must be kept in mind before transferring, firstly, Only 'ENTITIES' should be chosen from the prompt.

Secondly, the ruled surface mesh created should be picked up only in a sequential way, otherwise the data file created could be too difficult to analyze and process later for integrated CAD-CAM. Choosing only the meshes to obtain a no-graphic file is the important feature in this research.

Thirdly, decimal places of accuracy according to the requirement of machining accuracy must be entered and finally, It is essential that all drawings exist in the WORLD COORDINATES SYSTEM rather than USER'S COORDINATES SYSTEM. Furthermore the origin of the drawing coordinates system must be compatible with that of the WORLD COORDINATES SYSTEM so that the data in DXF. file could easily be processed in the future.

3.4 comparison

Both the IGES and DXF file format can be used to transfer a graphic drawing file in AUTOCAD to a non-graphic file.

IGES files have some of the characteristics of AUTOCAD DXF. that make them suitable for data transfer, such as device independence, system independence and a degree of version independence .

Once the command"IGESout" is chosen, it automatically transfers the whole contents on the graphic drawing file to a IGES file. IGES has no direct equivalent to AUTOCAD which means this transferring process has some limitations so that the more complex the drawing in AUTOCAD, the more likely that information will have to be approximated resulting in some problems of data loss to some degree.

For the AUTOCAD user, DXF avoids most problems of data loss and with DXF, before transferring, one has some choice such as

"ACCURACY", "ENTITIES" and "BINARY" which is really a great advantage over the IGES. Because a complex drawing often consists of a lot of contents or entities, the useful data which are needed in most cases are composed of only some related Entities and not the whole contents of the 3D drawing.

So in this project DXF was adopted to transfer the graphic drawing file to a non-graphic drawing file.

Now it can be seen that the data in the DXF. file is presented in a rigid format and although it looks complicated it does provide the possibility to process it or extract data from it. This helps towards the aim of the project, the integration of CAD and CAM for WEDM.

3.5 DXF Interface program

Writing a program that communicates with AUTOCAD via the DXF mechanism to create a standard database often appears far more difficult than it really is. The DXF file contains a seemingly overwhelming amount of information and on examining a DXF file manually it may lead to the conclusion that the task is enormous.

However, the DXF file had been designed to be easily processed by programming, but not manually. The format was constructed with the deliberate intention of making it easy to ignore information not required while easily reading the information which is needed.

Some identifying codes used within the DXF file are given below:

Code	Function
o	The start of an entity
1	The primary text value for an entity
2	A name; attribute tag etc.
3-4	Other textual name values
5	Entity handles as hexadecimal strings
6	Line type name
7	Text style name
8	Layer name
9	Variable name identifier
10	Primary X coordinate
11-18	Other X coordinates
20	Primary y coordinate
21-28	Other y coordinates
30	Primary Z coordinate
31-37	Other Z coordinates
38	The entities elevation if non-zero

39	The entities thickness if non-zero
40-48	Numeral floating point
49	Repeated value
50-58	Angles
62	Colour number
66	"Entities follow"flag
70-78	Integer values
210,220,230	X,Y and Z components of extrusion direction
999	Comments
1000	ASCII string up to 255 bytes long

The following is a DXF interface program developed in BASIC to create a standard database by extracting data from any DXF file mentioned above.

```
' Filename: EXTRACTING.BAS
' Author:   Liu Ruishan
' Dublin City University
' Extracting a Standard Database "3D-MODEL.DAT" from 3D Model
  Drawing Files
' -------------------------------------------------------------
```

```
'
' This program is specially designed to extract a standard
database from 3D model drawing files in a form of DRAWING
INTERCHANGE FILES (DXF) so that a CNC machine or a computer
controlled manipulator in wire electric discharge machining can
produce some complex shaped 3D model accurately and efficiently
by reading these databases.
'
    CLS
    PRINT "TYPE [3D-MODEL] for example for the following new
     database file"
    LINE INPUT "standard database file name:"; D$
    OPEN "O", #2,   D$ + ".DAT"
    CLOSE #2
    DIM XB(250), YB(250), ZB(250), XT(250), YT(250), ZT(250)
      REM
    REM EXTRACT VERTEX FROM DXF FILE
    REM
    G1% = 0
    PRINT "Type [C:\ACAD11\DWGS\LIU\ABS1] for example for
      following prompt. " LINE INPUT "DXF FILE NAME: "; a$
    OPEN "i", 1, a$ + ".dxf"
    REM
    REM Ignore until section start encountered
    REM
```

```
    PRINT "-------------------------------------------------------"
    PRINT
" SERIAL"; TAB(12); "XB"; TAB(20); "YB"; TAB(29); "ZB";
         TAB(37); "XT"; TAB(45); "YT"; TAB(54); "ZT"
     PRINT
  " NUMBER"; TAB(12); "MM"; TAB(20); "MM"; TAB(29);
       "MM"; TAB(37); "MM"; TAB(45); "MM"; TAB(54); "MM"
    PRINT "-------------------------------------------------
 10 GOSUB 60
    IF G% <> 0 THEN 10
    IF S$ <> "SECTION" THEN 10
    GOSUB 60
    REM
    REM Skip unless ENTITIES section
    REM
    IF S$ <> "ENTITIES" THEN 10
    REM
    REM Scan until end of section, processing Vertexes
    REM
20 GOSUB 60
30 IF G% = 0 AND S$ = "ENDSEC" THEN 80
    IF G% = 0 AND S$ = "VERTEX" THEN GOSUB 40: GOTO 30
    GOTO 20
40 REM
    REM Accumulate VERTEX entity groups
```

```
      REM
      I = 0: J = 0
 50 GOSUB 60
      IF G% = 10 THEN GOSUB 90
      IF G% = 0 AND S$ = "SEQEND" THEN ZT(J) = 0: K = K + 1:
      GOSUB 100: RETURN
      GOTO 50
 60 REM
      REM Read group code and following value
      REM FOR X coordinates,read Y and possible z also
      REM
      IF G1% < 0 THEN G% = -G1%: G1% = 0 ELSE INPUT #1, G%
      IF G% < 10 OR G% = 999 THEN LINE INPUT #1, S$: RETURN
      IF G% >= 38 AND G% <= 49 THEN INPUT #1, V: RETURN
      IF G% >= 50 AND G% <= 59 THEN INPUT #1, a: RETURN
      IF G% >= 60 AND G% <= 69 THEN INPUT #1, P%: RETURN
      IF G% >= 70 AND G% <= 79 THEN INPUT #1, F%: RETURN
      IF G% >= 210 AND G% <= 219 THEN 70
      IF G% >= 1000 THEN LINE INPUT #1, T$: RETURN
      IF G% >= 20 THEN PRINT "INVALID GROUP CODE"; G%: STOP
 70 INPUT #1, X
      INPUT #1, G1%
      IF G1% <> (G% + 10) THEN PRINT "Invalid y  code"; G1%: STOP
     INPUT #1, Y
      INPUT #1, G1%
```

```
    IF G1% <> (G% + 20) THEN G1% = -G1% ELSE INPUT #1, Z
    RETURN
80 CLOSE 1
    END
90 IF Z = 0! THEN XB(I) = X: YB(I) = Y: ZB(I) = Z ELSE XT(J) = X:
YT(J) = Y: ZT(J) = Z      IF Z = 0 THEN I = I + 1 ELSE J = J + 1
    RETURN
100 IF K = 1 THEN I = 0: J = 0 ELSE I = 1: J = 1
110 IF ZT(J) = 0 THEN GOSUB 120: GOTO 30
    PRINT USING "  ###    "; I;
    PRINT USING "####.###";
                XB(I); YB(I); ZB(I); XT(J); YT(J); ZT(J)
    OPEN "A", #2, "3D-MODEL.DAT"
    PRINT #2, USING "####.###,";
                XB(I); YB(I); ZB(I); XT(J); YT(J); ZT(J)
      CLOSE #2
    I = I + 1: J = J + 1: GOTO 110
    RETURN
120 PRINT "--------------------------------------------------"
  RETURN
""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""""
```

Corresponding flow diagrams are shown in the following pages.

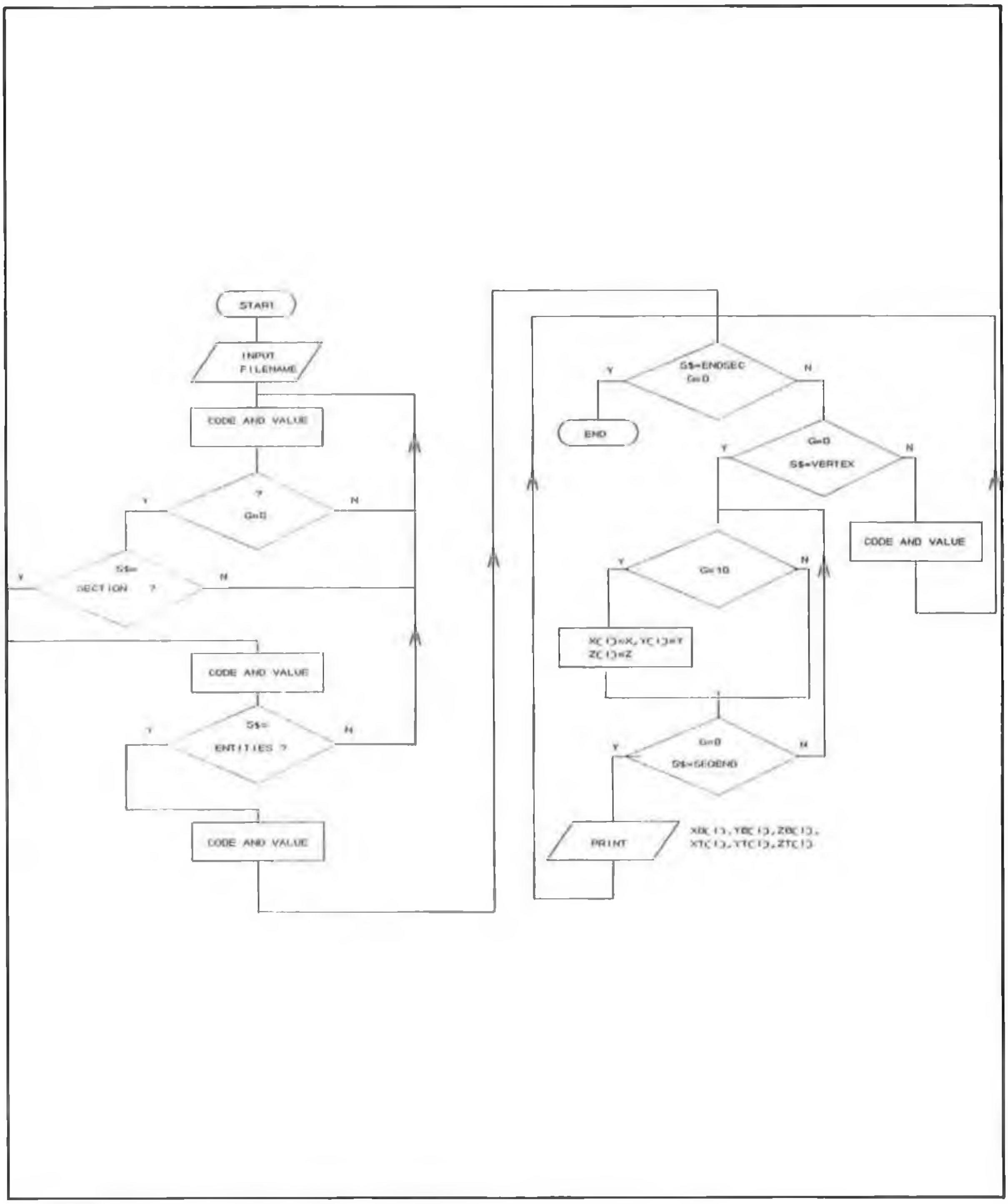


Fig. 3.2 Flow diagram of extracting programme

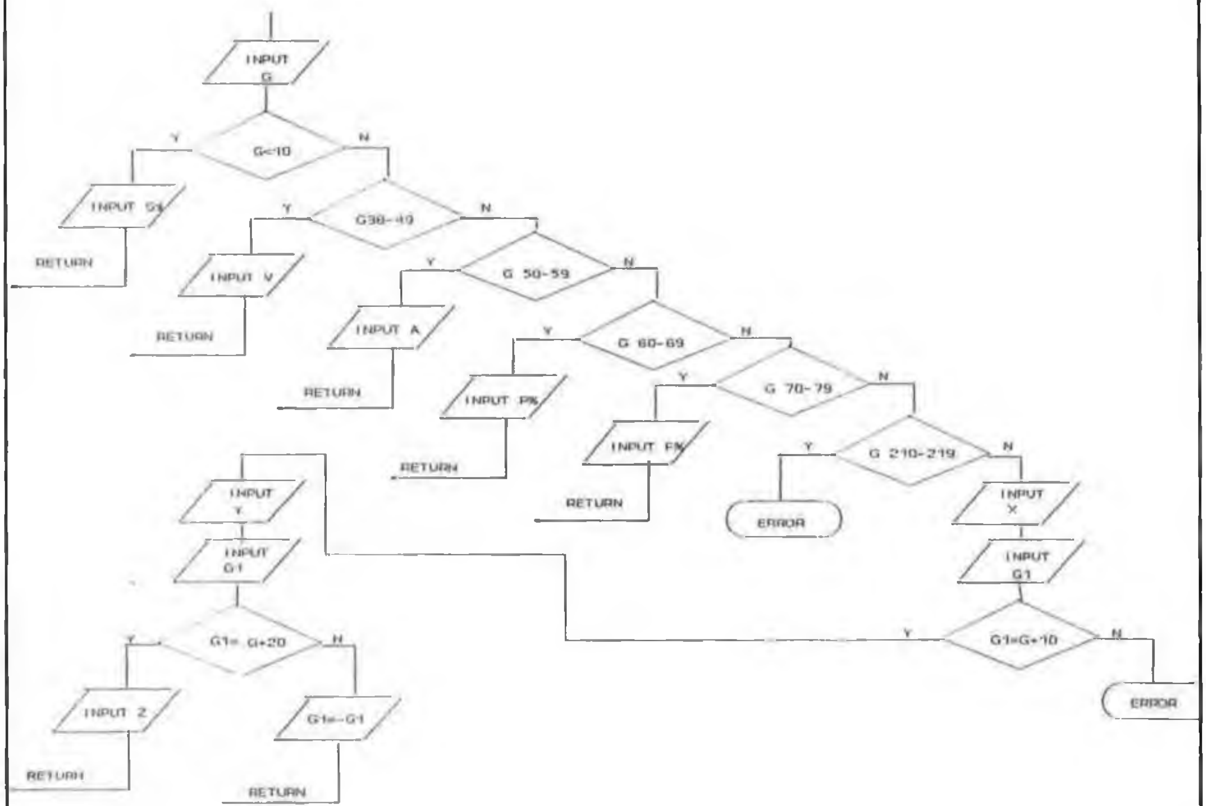


Fig. 3.3 Flow diagram of extracting programme

3.6 Example

Here is a database created by the above interface program extracting from a 3 dimensional drawing file same as in Fig.2.13 and Fig. 2.8 in AUTOCAD named, "C:\ACAD11\DWGS\LIU\ABS1.DXF".

DATABASE OF ABS1

No.	XB MM	YB MM	ZB MM	XT MM	YT MM	ZT MM
0	11.930,	-14.670,	0.000,	15.490,	-19.620,	50.000,
1	13.430,	-14.180,	0.000,	17.270,	-18.070,	50.000,
2	14.800,	-13.400,	0.000,	18.900,	-16.370,	50.000,
3	15.980,	-12.360,	0.000,	20.360,	-14.510,	50.000,
4	16.940,	-11.100,	0.000,	21.630,	-12.530,	50.000,
5	17.720,	-9.730,	0.000,	22.720,	-10.430,	50.000,
6	18.400,	-8.310,	0.000,	23.600,	-8.250,	50.000,
7	18.960,	-6.830,	0.000,	24.270,	-5.980,	50.000,
8	19.400,	-5.310,	0.000,	24.730,	-3.670,	50.000,
9	19.730,	-3.770,	0.000,	24.970,	-1.320,	50.000,
10	19.930,	-2.200,	0.000,	24.980,	1.040,	50.000,
11	20.000,	-0.630,	0.000,	24.770,	3.390,	50.000,
12	19.790,	0.930,	0.000,	24.340,	5.710,	50.000,
13	19.330,	2.440,	0.000,	23.690,	7.980,	50.000,
14	18.740,	3.900,	0.000,	22.840,	10.170,	50.000,
15	18.010,	5.310,	0.000,	21.780,	12.280,	50.000,
16	17.160,	6.640,	0.000,	20.520,	14.280,	50.000,
17	16.190,	7.890,	0.000,	19.080,	16.150,	50.000,
18	15.120,	9.040,	0.000,	17.480,	17.880,	50.000,
19	13.940,	10.090,	0.000,	15.710,	19.440,	50.000,
20	12.670,	11.030,	0.000,	13.810,	20.840,	50.000,
21	11.320,	11.850,	0.000,	11.780,	22.050,	50.000,
22	9.910,	12.550,	0.000,	9.650,	23.060,	50.000,
23	8.430,	13.110,	0.000,	7.440,	23.870,	50.000,
24	6.910,	13.540,	0.000,	5.150,	24.460,	50.000,
25	5.360,	13.830,	0.000,	2.820,	24.840,	50.000,
26	3.810,	14.110,	0.000,	0.470,	25.000,	50.000,
27	2.240,	14.060,	0.000,	-1.890,	24.930,	50.000,
28	0.810,	13.410,	0.000,	-4.230,	24.640,	50.000,
29	-0.270,	12.280,	0.000,	-6.530,	24.130,	50.000,
30	-0.830,	10.810,	0.000,	-8.780,	23.410,	50.000,
1	-0.810,	9.370,	0.000,	-9.480,	23.130,	50.000,

2	-0.270,	8.030,	0.000,	-10.180,	22.840,	50.000,
3	0.510,	6.820,	0.000,	-10.860,	22.520,	50.000,
4	0.650,	5.400,	0.000,	-11.540,	22.180,	50.000,
5	0.080,	4.090,	0.000,	-12.200,	21.820,	50.000,
6	-1.060,	3.230,	0.000,	-12.850,	21.440,	50.000,
7	-2.470,	3.330,	0.000,	-13.500,	21.040,	50.000,
8	-3.830,	3.820,	0.000,	-14.120,	20.630,	50.000,
9	-5.120,	4.470,	0.000,	-14.740,	20.190,	50.000,
10	-6.370,	5.200,	0.000,	-15.340,	19.740,	50.000,
11	-7.540,	6.040,	0.000,	-15.930,	19.260,	50.000,
12	-8.640,	6.990,	0.000,	-16.510,	18.770,	50.000,
13	-9.630,	8.040,	0.000,	-17.070,	18.270,	50.000,
14	-10.530,	9.170,	0.000,	-17.610,	17.740,	50.000,
15	-11.680,	9.980,	0.000,	-18.140,	17.200,	50.000,
16	-13.080,	10.290,	0.000,	-18.650,	16.650,	50.000,
17	-14.530,	10.230,	0.000,	-19.150,	16.080,	50.000,
18	-15.900,	9.790,	0.000,	-19.620,	15.490,	50.000,

1	-16.870,	8.930,	0.000,	-20.730,	13.970,	50.000,
2	-17.720,	7.940,	0.000,	-21.720,	12.380,	50.000,
3	-18.440,	6.860,	0.000,	-22.590,	10.710,	50.000,
4	-19.050,	5.700,	0.000,	-23.330,	8.980,	50.000,
5	-19.510,	4.490,	0.000,	-23.940,	7.200,	50.000,
6	-19.830,	3.230,	0.000,	-24.410,	5.380,	50.000,
7	-20.010,	1.940,	0.000,	-24.750,	3.530,	50.000,
8	-20.040,	0.640,	0.000,	-24.940,	1.660,	50.000,
9	-20.050,	-0.660,	0.000,	-25.000,	-0.220,	50.000,
10	-20.060,	-1.960,	0.000,	-24.910,	-2.090,	50.000,
11	-19.970,	-3.260,	0.000,	-24.680,	-3.960,	50.000,
12	-19.770,	-4.550,	0.000,	-24.320,	-5.800,	50.000,
13	-19.470,	-5.810,	0.000,	-23.810,	-7.610,	50.000,
14	-19.060,	-7.050,	0.000,	-23.170,	-9.380,	50.000,
15	-18.550,	-8.240,	0.000,	-22.400,	-11.100,	50.000,
16	-17.940,	-9.400,	0.000,	-21.510,	-12.750,	50.000,
17	-17.260,	-10.510,	0.000,	-20.490,	-14.330,	50.000,
18	-16.500,	-11.560,	0.000,	-19.350,	-15.830,	50.000,
19	-15.650,	-12.550,	0.000,	-18.110,	-17.240,	50.000,
20	-14.790,	-13.520,	0.000,	-16.760,	-18.550,	50.000,
21	-13.920,	-14.490,	0.000,	-15.320,	-19.760,	50.000,
22	-12.870,	-15.250,	0.000,	-13.790,	-20.850,	50.000,
23	-11.680,	-15.760,	0.000,	-12.190,	-21.830,	50.000,
24	-10.400,	-16.000,	0.000,	-10.510,	-22.680,	50.000,
25	-9.100,	-15.970,	0.000,	-8.780,	-23.410,	50.000,

1	-8.280,	-15.250,	0.000,	-8.090,	-23.660,	50.000,
2	-7.620,	-14.560,	0.000,	-7.390,	-23.880,	50.000,
3	-7.170,	-13.710,	0.000,	-6.690,	-24.090,	50.000,
4	-6.970,	-12.780,	0.000,	-5.980,	-24.280,	50.000,
5	-6.830,	-11.830,	0.000,	-5.260,	-24.440,	50.000,

6	-6.710,	-10.870,	0.000,	-4.540,	-24.580,	50.000,
7	-6.650,	-9.910,	0.000,	-3.820,	-24.710,	50.000,
8	-6.660,	-8.950,	0.000,	-3.090,	-24.810,	50.000,
9	-6.730,	-7.990,	0.000,	-2.360,	-24.890,	50.000,
10	-6.870,	-7.040,	0.000,	-1.630,	-24.950,	50.000,
11	-6.680,	-6.170,	0.000,	-0.900,	-24.980,	50.000,
12	-6.000,	-5.500,	0.000,	-0.170,	-25.000,	50.000,
13	-5.150,	-5.050,	0.000,	0.570,	-24.990,	50.000,
14	-4.210,	-4.870,	0.000,	1.300,	-24.970,	50.000,
15	-3.260,	-4.970,	0.000,	2.030,	-24.920,	50.000,
16	-2.370,	-5.340,	0.000,	2.760,	-24.850,	50.000,
17	-1.640,	-5.950,	0.000,	3.490,	-24.760,	50.000,
18	-1.040,	-6.700,	0.000,	4.220,	-24.640,	50.000,
19	-0.480,	-7.490,	0.000,	4.940,	-24.510,	50.000,
20	0.020,	-8.310,	0.000,	5.650,	-24.350,	50.000,
21	0.450,	-9.170,	0.000,	6.370,	-24.180,	50.000,
22	0.910,	-10.000,	0.000,	7.070,	-23.980,	50.000,
23	1.560,	-10.710,	0.000,	7.770,	-23.760,	50.000,
24	2.260,	-11.370,	0.000,	8.470,	-23.520,	50.000,
25	2.990,	-11.990,	0.000,	9.150,	-23.260,	50.000,
26	3.770,	-12.560,	0.000,	9.830,	-22.990,	50.000,
27	4.580,	-13.070,	0.000,	10.500,	-22.690,	50.000,
28	5.430,	-13.530,	0.000,	11.160,	-22.370,	50.000,
29	6.300,	-13.930,	0.000,	11.810,	-22.030,	50.000,
30	7.200,	-14.270,	0.000,	12.460,	-21.680,	50.000,
31	8.120,	-14.550,	0.000,	13.090,	-21.300,	50.000,
32	9.060,	-14.750,	0.000,	13.710,	-20.910,	50.000,
33	10.020,	-14.840,	0.000,	14.310,	-20.500,	50.000,
34	10.980,	-14.810,	0.000,	14.910,	-20.070,	50.000,
35	11.930,	-14.670,	0.000,	15.490,	-19.620,	50.000,

Note: " C:\ACAD11\DWGS\LIU\ABS1.DXF " file for Fig.2.13 is listed in APPENDIX 1.

The following is another database example named "3D- GEAR.DAT" extracted from a gear.dxf file of Figure 2.22 which is a more complex shaped 3 dimensional model.

DATABASE OF 3D-GEAR

No.	XB MM	YB MM	ZB MM	XT MM	YT MM	ZT MM
0	25.190,	6.750,	0.000,	35.740,	9.580,	50.000,
1	25.070,	8.110,	0.000,	35.450,	10.610,	50.000,
2	25.420,	9.420,	0.000,	35.120,	11.640,	50.000,
3	26.200,	10.540,	0.000,	34.770,	12.650,	50.000,
4	27.320,	11.320,	0.000,	34.390,	13.660,	50.000,
5	28.500,	11.990,	0.000,	33.970,	14.650,	50.000,
6	29.380,	13.040,	0.000,	33.530,	15.640,	50.000,
7	29.850,	14.320,	0.000,	33.060,	16.610,	50.000,
8	29.850,	15.680,	0.000,	32.570,	17.560,	50.000,
9	29.380,	16.960,	0.000,	32.040,	18.500,	50.000,
10	28.500,	18.010,	0.000,	31.490,	19.420,	50.000,
11	27.320,	18.690,	0.000,	30.910,	20.330,	50.000,
12	25.980,	18.920,	0.000,	30.310,	21.220,	50.000,
13	24.640,	18.690,	0.000,	29.680,	22.090,	50.000,
14	23.460,	18.000,	0.000,	29.020,	22.950,	50.000,
15	22.230,	17.420,	0.000,	28.340,	23.780,	50.000,
16	20.870,	17.300,	0.000,	27.640,	24.600,	50.000,
17	19.550,	17.660,	0.000,	26.910,	25.390,	50.000,
18	18.440,	18.440,	0.000,	26.160,	26.160,	50.000,
1	17.660,	19.550,	0.000,	25.390,	26.910,	50.000,
2	17.300,	20.870,	0.000,	24.600,	27.640,	50.000,
3	17.420,	22.230,	0.000,	23.780,	28.340,	50.000,
4	18.000,	23.460,	0.000,	22.950,	29.020,	50.000,
5	18.690,	24.640,	0.000,	22.090,	29.680,	50.000,
6	18.920,	25.980,	0.000,	21.220,	30.310,	50.000,
7	18.690,	27.320,	0.000,	20.330,	30.910,	50.000,
8	18.010,	28.500,	0.000,	19.420,	31.490,	50.000,
9	16.960,	29.380,	0.000,	18.500,	32.040,	50.000,
10	15.680,	29.850,	0.000,	17.560,	32.570,	50.000,
11	14.320,	29.850,	0.000,	16.610,	33.060,	50.000,
12	13.040,	29.380,	0.000,	15.640,	33.530,	50.000,
13	11.990,	28.500,	0.000,	14.650,	33.970,	50.000,
14	11.320,	27.320,	0.000,	13.660,	34.390,	50.000,
15	10.540,	26.200,	0.000,	12.650,	34.770,	50.000,

16	9.420,	25.420,	0.000,	11.640,	35.120,	50.000,
17	8.110,	25.070,	0.000,	10.610,	35.450,	50.000,
18	6.750,	25.190,	0.000,	9.580,	35.740,	50.000,

1	5.510,	25.760,	0.000,	8.530,	36.000,	50.000,
2	4.550,	26.730,	0.000,	7.480,	36.240,	50.000,
3	3.970,	27.960,	0.000,	6.420,	36.440,	50.000,
4	3.860,	29.320,	0.000,	5.360,	36.610,	50.000,
5	3.860,	30.680,	0.000,	4.300,	36.750,	50.000,
6	3.400,	31.960,	0.000,	3.220,	36.860,	50.000,
7	2.520,	33.010,	0.000,	2.150,	36.940,	50.000,
8	1.340,	33.690,	0.000,	1.080,	36.980,	50.000,
9	0.000,	33.920,	0.000,	0.000,	37.000,	50.000,
10	-1.340,	33.690,	0.000,	-1.080,	36.980,	50.000,
11	-2.520,	33.010,	0.000,	-2.150,	36.940,	50.000,
12	-3.400,	31.960,	0.000,	-3.220,	36.860,	50.000,
13	-3.860,	30.680,	0.000,	-4.300,	36.750,	50.000,
14	-3.860,	29.320,	0.000,	-5.360,	36.610,	50.000,
15	-3.970,	27.960,	0.000,	-6.420,	36.440,	50.000,
16	-4.550,	26.730,	0.000,	-7.480,	36.240,	50.000,
17	-5.510,	25.760,	0.000,	-8.530,	36.000,	50.000,
18	-6.750,	25.190,	0.000,	-9.580,	35.740,	50.000,

1	-8.110,	25.070,	0.000,	-10.610,	35.450,	50.000,
2	-9.420,	25.420,	0.000,	-11.640,	35.120,	50.000,
3	-10.540,	26.200,	0.000,	-12.650,	34.770,	50.000,
4	-11.320,	27.320,	0.000,	-13.660,	34.390,	50.000,
5	-11.990,	28.500,	0.000,	-14.650,	33.970,	50.000,
6	-13.040,	29.380,	0.000,	-15.640,	33.530,	50.000,
7	-14.320,	29.850,	0.000,	-16.610,	33.060,	50.000,
8	-15.680,	29.850,	0.000,	-17.560,	32.570,	50.000,
9	-16.960,	29.380,	0.000,	-18.500,	32.040,	50.000,
10	-18.010,	28.500,	0.000,	-19.420,	31.490,	50.000,
11	-18.690,	27.320,	0.000,	-20.330,	30.910,	50.000,
12	-18.920,	25.980,	0.000,	-21.220,	30.310,	50.000,
13	-18.690,	24.640,	0.000,	-22.090,	29.680,	50.000,
14	-18.000,	23.460,	0.000,	-22.950,	29.020,	50.000,
15	-17.420,	22.230,	0.000,	-23.780,	28.340,	50.000,
16	-17.300,	20.870,	0.000,	-24.600,	27.640,	50.000,
17	-17.660,	19.550,	0.000,	-25.390,	26.910,	50.000,
18	-18.440,	18.440,	0.000,	-26.160,	26.160,	50.000,

1	-19.550,	17.660,	0.000,	-26.910,	25.390,	50.000,
2	-20.870,	17.300,	0.000,	-27.640,	24.600,	50.000,
3	-22.230,	17.420,	0.000,	-28.340,	23.780,	50.000,
4	-23.460,	18.000,	0.000,	-29.020,	22.950,	50.000,
5	-24.640,	18.690,	0.000,	-29.680,	22.090,	50.000,
6	-25.980,	18.920,	0.000,	-30.310,	21.220,	50.000,
7	-27.320,	18.690,	0.000,	-30.910,	20.330,	50.000,

8	-28.500,	18.010,	0.000,	-31.490,	19.420,	50.000,
9	-29.380,	16.960,	0.000,	-32.040,	18.500,	50.000,
10	-29.850,	15.680,	0.000,	-32.570,	17.560,	50.000,
11	-29.850,	14.320,	0.000,	-33.060,	16.610,	50.000,
12	-29.380,	13.040,	0.000,	-33.530,	15.640,	50.000,
13	-28.500,	11.990,	0.000,	-33.970,	14.650,	50.000,
14	-27.320,	11.320,	0.000,	-34.390,	13.660,	50.000,
15	-26.200,	10.540,	0.000,	-34.770,	12.650,	50.000,
16	-25.420,	9.420,	0.000,	-35.120,	11.640,	50.000,
17	-25.070,	8.110,	0.000,	-35.450,	10.610,	50.000,
18	-25.190,	6.750,	0.000,	-35.740,	9.580,	50.000,

1	-25.760,	5.510,	0.000,	-36.000,	8.530,	50.000,
2	-26.730,	4.550,	0.000,	-36.240,	7.480,	50.000,
3	-27.960,	3.970,	0.000,	-36.440,	6.420,	50.000,
4	-29.320,	3.860,	0.000,	-36.610,	5.360,	50.000,
5	-30.680,	3.860,	0.000,	-36.750,	4.300,	50.000,
6	-31.960,	3.400,	0.000,	-36.860,	3.220,	50.000,
7	-33.010,	2.520,	0.000,	-36.940,	2.150,	50.000,
8	-33.690,	1.340,	0.000,	-36.980,	1.080,	50.000,
9	-33.920,	0.000,	0.000,	-37.000,	0.000,	50.000,
10	-33.690,	-1.340,	0.000,	-36.980,	-1.080,	50.000,
11	-33.010,	-2.520,	0.000,	-36.940,	-2.150,	50.000,
12	-31.960,	-3.400,	0.000,	-36.860,	-3.220,	50.000,
13	-30.680,	-3.860,	0.000,	-36.750,	-4.300,	50.000,
14	-29.320,	-3.860,	0.000,	-36.610,	-5.360,	50.000,
15	-27.960,	-3.970,	0.000,	-36.440,	-6.420,	50.000,
16	-26.730,	-4.550,	0.000,	-36.240,	-7.480,	50.000,
17	-25.760,	-5.510,	0.000,	-36.000,	-8.530,	50.000,
18	-25.190,	-6.750,	0.000,	-35.740,	-9.580,	50.000,

1	-25.070,	-8.110,	0.000,	-35.450,	-10.610,	50.000,
2	-25.420,	-9.420,	0.000,	-35.120,	-11.640,	50.000,
3	-26.200,	-10.540,	0.000,	-34.770,	-12.650,	50.000,
4	-27.320,	-11.320,	0.000,	-34.390,	-13.660,	50.000,
5	-28.500,	-11.990,	0.000,	-33.970,	-14.650,	50.000,
6	-29.380,	-13.040,	0.000,	-33.530,	-15.640,	50.000,
7	-29.850,	-14.320,	0.000,	-33.060,	-16.610,	50.000,
8	-29.850,	-15.680,	0.000,	-32.570,	-17.560,	50.000,
9	-29.380,	-16.960,	0.000,	-32.040,	-18.500,	50.000,
10	-28.500,	-18.010,	0.000,	-31.490,	-19.420,	50.000,
11	-27.320,	-18.690,	0.000,	-30.910,	-20.330,	50.000,
12	-25.980,	-18.920,	0.000,	-30.310,	-21.220,	50.000,
13	-24.640,	-18.690,	0.000,	-29.680,	-22.090,	50.000,
14	-23.460,	-18.000,	0.000,	-29.020,	-22.950,	50.000,
15	-22.230,	-17.420,	0.000,	-28.340,	-23.780,	50.000,
16	-20.870,	-17.300,	0.000,	-27.640,	-24.600,	50.000,
17	-19.550,	-17.660,	0.000,	-26.910,	-25.390,	50.000,

```
18 -18.440, -18.440,   0.000, -26.160, -26.160,  50.000,
-----------------------------------------------------------
1   -17.660, -19.550,   0.000, -25.390, -26.910,  50.000,
2   -17.300, -20.870,   0.000, -24.600, -27.640,  50.000,
3   -17.420, -22.230,   0.000, -23.780, -28.340,  50.000,
4   -18.000, -23.460,   0.000, -22.950, -29.020,  50.000,
5   -18.690, -24.640,   0.000, -22.090, -29.680,  50.000,
6   -18.920, -25.980,   0.000, -21.220, -30.310,  50.000,
7   -18.690, -27.320,   0.000, -20.330, -30.910,  50.000,
8   -18.010, -28.500,   0.000, -19.420, -31.490,  50.000,
9   -16.960, -29.380,   0.000, -18.500, -32.040,  50.000,
10 -15.680, -29.850,   0.000, -17.560, -32.570,  50.000,
11 -14.320, -29.850,   0.000, -16.610, -33.060,  50.000,
12 -13.040, -29.380,   0.000, -15.640, -33.530,  50.000,
13 -11.990, -28.500,   0.000, -14.650, -33.970,  50.000,
14 -11.320, -27.320,   0.000, -13.660, -34.390,  50.000,
15 -10.540, -26.200,   0.000, -12.650, -34.770,  50.000,
16   -9.420, -25.420,   0.000, -11.640, -35.120,  50.000,
17   -8.110, -25.070,   0.000, -10.610, -35.450,  50.000,
18   -6.750, -25.190,   0.000,  -9.580, -35.740,  50.000,
----------------------------------------------------------
1    -5.510, -25.760,   0.000,  -8.530, -36.000,  50.000,
2    -4.550, -26.730,   0.000,  -7.480, -36.240,  50.000,
3    -3.970, -27.960,   0.000,  -6.420, -36.440,  50.000,
4    -3.860, -29.320,   0.000,  -5.360, -36.610,  50.000,
5    -3.860, -30.680,   0.000,  -4.300, -36.750,  50.000,
6    -3.400, -31.960,   0.000,  -3.220, -36.860,  50.000,
7    -2.520, -33.010,   0.000,  -2.150, -36.940,  50.000,
8    -1.340, -33.690,   0.000,  -1.080, -36.980,  50.000,
9     0.000, -33.920,   0.000,   0.000, -37.000,  50.000,
10    1.340, -33.690,   0.000,   1.080, -36.980,  50.000,
11    2.520, -33.010,   0.000,   2.150, -36.940,  50.000,
12    3.400, -31.960,   0.000,   3.220, -36.860,  50.000,
13    3.860, -30.680,   0.000,   4.300, -36.750,  50.000,
14    3.860, -29.320,   0.000,   5.360, -36.610,  50.000,
15    3.970, -27.960,   0.000,   6.420, -36.440,  50.000,
16    4.550, -26.730,   0.000,   7.480, -36.240,  50.000,
17    5.510, -25.760,   0.000,   8.530, -36.000,  50.000,
18    6.750, -25.190,   0.000,   9.580, -35.740,  50.000,
  --------------------------------------------------------
1     8.110, -25.070,   0.000,  10.610, -35.450,  50.000,
2     9.420, -25.420,   0.000,  11.640, -35.120,  50.000,
3    10.540, -26.200,   0.000,  12.650, -34.770,  50.000,
4    11.320, -27.320,   0.000,  13.660, -34.390,  50.000,
5    11.990, -28.500,   0.000,  14.650, -33.970,  50.000,
6    13.040, -29.380,   0.000,  15.640, -33.530,  50.000,
7    14.320, -29.850,   0.000,  16.610, -33.060,  50.000,
8    15.680, -29.850,   0.000,  17.560, -32.570,  50.000,
9    16.960, -29.380,   0.000,  18.500, -32.040,  50.000,
```

10	18.010,	-28.500,	0.000,	19.420,	-31.490,	50.000,
11	18.690,	-27.320,	0.000,	20.330,	-30.910,	50.000,
12	18.920,	-25.980,	0.000,	21.220,	-30.310,	50.000,
13	18.690,	-24.640,	0.000,	22.090,	-29.680,	50.000,
14	18.000,	-23.460,	0.000,	22.950,	-29.020,	50.000,
15	17.420,	-22.230,	0.000,	23.780,	-28.340,	50.000,
16	17.300,	-20.870,	0.000,	24.600,	-27.640,	50.000,
17	17.660,	-19.550,	0.000,	25.390,	-26.910,	50.000,
18	18.440,	-18.440,	0.000,	26.160,	-26.160,	50.000,

1	19.550,	-17.660,	0.000,	26.910,	-25.390,	50.000,
2	20.870,	-17.300,	0.000,	27.640,	-24.600,	50.000,
3	22.230,	-17.420,	0.000,	28.340,	-23.780,	50.000,
4	23.460,	-18.000,	0.000,	29.020,	-22.950,	50.000,
5	24.640,	-18.690,	0.000,	29.680,	-22.090,	50.000,
6	25.980,	-18.920,	0.000,	30.310,	-21.220,	50.000,
7	27.320,	-18.690,	0.000,	30.910,	-20.330,	50.000,
8	28.500,	-18.010,	0.000,	31.490,	-19.420,	50.000,
9	29.380,	-16.960,	0.000,	32.040,	-18.500,	50.000,
10	29.850,	-15.680,	0.000,	32.570,	-17.560,	50.000,
11	29.850,	-14.320,	0.000,	33.060,	-16.610,	50.000,
12	29.380,	-13.040,	0.000,	33.530,	-15.640,	50.000,
13	28.500,	-11.990,	0.000,	33.970,	-14.650,	50.000,
14	27.320,	-11.320,	0.000,	34.390,	-13.660,	50.000,
15	26.200,	-10.540,	0.000,	34.770,	-12.650,	50.000,
16	25.420,	-9.420,	0.000,	35.120,	-11.640,	50.000,
17	25.070,	-8.110,	0.000,	35.450,	-10.610,	50.000,
18	25.190,	-6.750,	0.000,	35.740,	-9.580,	50.000,

1	25.760,	-5.510,	0.000,	36.000,	-8.530,	50.000,
2	26.730,	-4.550,	0.000,	36.240,	-7.480,	50.000,
3	27.960,	-3.970,	0.000,	36.440,	-6.420,	50.000,
4	29.320,	-3.860,	0.000,	36.610,	-5.360,	50.000,
5	30.680,	-3.860,	0.000,	36.750,	-4.300,	50.000,
6	31.960,	-3.400,	0.000,	36.860,	-3.220,	50.000,
7	33.010,	-2.520,	0.000,	36.940,	-2.150,	50.000,
8	33.690,	-1.340,	0.000,	36.980,	-1.080,	50.000,
9	33.920,	0.000,	0.000,	37.000,	0.000,	50.000,
10	33.690,	1.340,	0.000,	36.980,	1.080,	50.000,
11	33.010,	2.520,	0.000,	36.940,	2.150,	50.000,
12	31.960,	3.400,	0.000,	36.860,	3.220,	50.000,
13	30.680,	3.860,	0.000,	36.750,	4.300,	50.000,
14	29.320,	3.860,	0.000,	36.610,	5.360,	50.000,
15	27.960,	3.970,	0.000,	36.440,	6.420,	50.000,
16	26.730,	4.550,	0.000,	36.240,	7.480,	50.000,
17	25.760,	5.510,	0.000,	36.000,	8.530,	50.000,
18	25.190,	6.750,	0.000,	35.740,	9.580,	50.000,

===

Now it can be seen that all data in this database extracted from a drawing file in DXF format should be very easy to be used by another program as part of integration of CAD and CAM system. Because it is a kind of neutral database, any software can easily have access to it whenever it is necessary.

The data base (from c:\acad11\dwgs\liu\abs2.dxf) below is obtained after scaling down the Figure 2.13 to half its size, similarly, one also can get the database of a larger size of the Figure 2.13 easily, comparing this database with the previous database of the Figure 2.13.

DATABASE OF ABS2

No.	XB mm	YB mm	ZB mm	XT mm	YT mm	ZT mm
0	5.960,	-7.330,	0.000,	7.750,	-9.810,	25.000,
1	6.710,	-7.090,	0.000,	8.640,	-9.040,	25.000,
2	7.400,	-6.700,	0.000,	9.450,	-8.180,	25.000,
3	7.990,	-6.180,	0.000,	10.180,	-7.260,	25.000,
4	8.470,	-5.550,	0.000,	10.820,	-6.260,	25.000,
5	8.860,	-4.870,	0.000,	11.360,	-5.220,	25.000,
6	9.200,	-4.150,	0.000,	11.800,	-4.120,	25.000,
7	9.480,	-3.420,	0.000,	12.140,	-2.990,	25.000,
8	9.700,	-2.660,	0.000,	12.360,	-1.830,	25.000,
9	9.860,	-1.880,	0.000,	12.480,	-0.660,	25.000,
10	9.960,	-1.100,	0.000,	12.490,	0.520,	25.000,
11	10.000,	-0.310,	0.000,	12.380,	1.690,	25.000,
12	9.900,	0.470,	0.000,	12.170,	2.850,	25.000,
13	9.670,	1.220,	0.000,	11.850,	3.990,	25.000,
14	9.370,	1.950,	0.000,	11.420,	5.090,	25.000,

```
15    9.010,    2.650,   0.000,  10.890,   6.140,  25.000,
16    8.580,    3.320,   0.000,  10.260,   7.140,  25.000,
17    8.100,    3.940,   0.000,   9.540,   8.080,  25.000,
18    7.560,    4.520,   0.000,   8.740,   8.940,  25.000,
19    6.970,    5.050,   0.000,   7.860,   9.720,  25.000,
20    6.340,    5.520,   0.000,   6.910,  10.420,  25.000,
21    5.660,    5.930,   0.000,   5.890,  11.020,  25.000,
22    4.950,    6.270,   0.000,   4.830,  11.530,  25.000,
23    4.220,    6.560,   0.000,   3.720,  11.930,  25.000,
24    3.460,    6.770,   0.000,   2.580,  12.230,  25.000,
25    2.680,    6.910,   0.000,   1.410,  12.420,  25.000,
26    1.900,    7.050,   0.000,   0.240,  12.500,  25.000,
27    1.120,    7.030,   0.000,  -0.940,  12.460,  25.000,
28    0.400,    6.710,   0.000,  -2.110,  12.320,  25.000,
29   -0.140,    6.140,   0.000,  -3.270,  12.070,  25.000,
30   -0.420,    5.410,   0.000,  -4.390,  11.700,  25.000,
------------------------------------------------------------
1    -0.400,    4.680,   0.000,  -4.740,  11.570,  25.000,
2    -0.130,    4.020,   0.000,  -5.090,  11.420,  25.000,
3     0.250,    3.410,   0.000,  -5.430,  11.260,  25.000,
4     0.330,    2.700,   0.000,  -5.770,  11.090,  25.000,
5     0.040,    2.040,   0.000,  -6.100,  10.910,  25.000,
6    -0.530,    1.620,   0.000,  -6.430,  10.720,  25.000,
7    -1.230,    1.670,   0.000,  -6.750,  10.520,  25.000,
8    -1.910,    1.910,   0.000,  -7.060,  10.310,  25.000,
9    -2.560,    2.240,   0.000,  -7.370,  10.100,  25.000,
10   -3.180,    2.600,   0.000,  -7.670,   9.870,  25.000,
11   -3.770,    3.020,   0.000,  -7.970,   9.630,  25.000,
12   -4.320,    3.500,   0.000,  -8.250,   9.390,  25.000,
13   -4.820,    4.020,   0.000,  -8.530,   9.130,  25.000,
14   -5.260,    4.590,   0.000,  -8.810,   8.870,  25.000,
15   -5.840,    4.990,   0.000,  -9.070,   8.600,  25.000,
16   -6.540,    5.150,   0.000,  -9.330,   8.320,  25.000,
17   -7.260,    5.110,   0.000,  -9.570,   8.040,  25.000,
18   -7.950,    4.890,   0.000,  -9.810,   7.750,  25.000,
------------------------------------------------------------
1    -8.430,    4.460,   0.000, -10.370,   6.990,  25.000,
2    -8.860,    3.970,   0.000, -10.860,   6.190,  25.000,
3    -9.220,    3.430,   0.000, -11.300,   5.350,  25.000,
4    -9.520,    2.850,   0.000, -11.670,   4.490,  25.000,
5    -9.760,    2.240,   0.000, -11.970,   3.600,  25.000,
6    -9.920,    1.610,   0.000, -12.210,   2.690,  25.000,
7   -10.010,    0.970,   0.000, -12.370,   1.770,  25.000,
8   -10.020,    0.320,   0.000, -12.470,   0.830,  25.000,
9   -10.020,   -0.330,   0.000, -12.500,  -0.110,  25.000,
10  -10.030,   -0.980,   0.000, -12.460,  -1.050,  25.000,
11   -9.990,   -1.630,   0.000, -12.340,  -1.980,  25.000,
12   -9.890,   -2.270,   0.000, -12.160,  -2.900,  25.000,
13   -9.730,   -2.910,   0.000, -11.910,  -3.810,  25.000,
```

14	-9.530,	-3.520,	0.000,	-11.590,	-4.690,	25.000,
15	-9.270,	-4.120,	0.000,	-11.200,	-5.550,	25.000,
16	-8.970,	-4.700,	0.000,	-10.750,	-6.370,	25.000,
17	-8.630,	-5.250,	0.000,	-10.240,	-7.160,	25.000,
18	-8.250,	-5.780,	0.000,	-9.680,	-7.910,	25.000,
19	-7.820,	-6.270,	0.000,	-9.050,	-8.620,	25.000,
20	-7.400,	-6.760,	0.000,	-8.380,	-9.270,	25.000,
21	-6.960,	-7.240,	0.000,	-7.660,	-9.880,	25.000,
22	-6.430,	-7.620,	0.000,	-6.900,	-10.430,	25.000,
23	-5.840,	-7.880,	0.000,	-6.090,	-10.910,	25.000,
24	-5.200,	-8.000,	0.000,	-5.260,	-11.340,	25.000,
25	-4.550,	-7.980,	0.000,	-4.390,	-11.700,	25.000,

1	-4.140,	-7.630,	0.000,	-4.040,	-11.830,	25.000,
2	-3.810,	-7.280,	0.000,	-3.690,	-11.940,	25.000,
3	-3.580,	-6.860,	0.000,	-3.340,	-12.040,	25.000,
4	-3.480,	-6.390,	0.000,	-2.990,	-12.140,	25.000,
5	-3.410,	-5.910,	0.000,	-2.630,	-12.220,	25.000,
6	-3.350,	-5.440,	0.000,	-2.270,	-12.290,	25.000,
7	-3.330,	-4.960,	0.000,	-1.910,	-12.350,	25.000,
8	-3.330,	-4.480,	0.000,	-1.550,	-12.400,	25.000,
9	-3.370,	-4.000,	0.000,	-1.180,	-12.440,	25.000,
10	-3.440,	-3.520,	0.000,	-0.820,	-12.470,	25.000,
11	-3.340,	-3.080,	0.000,	-0.450,	-12.490,	25.000,
12	-3.000,	-2.750,	0.000,	-0.080,	-12.500,	25.000,
13	-2.580,	-2.520,	0.000,	0.280,	-12.500,	25.000,
14	-2.100,	-2.430,	0.000,	0.650,	-12.480,	25.000,
15	-1.630,	-2.480,	0.000,	1.020,	-12.460,	25.000,
16	-1.190,	-2.670,	0.000,	1.380,	-12.420,	25.000,
17	-0.820,	-2.980,	0.000,	1.750,	-12.380,	25.000,
18	-0.520,	-3.350,	0.000,	2.110,	-12.320,	25.000,
19	-0.240,	-3.740,	0.000,	2.470,	-12.250,	25.000,
20	0.010,	-4.150,	0.000,	2.830,	-12.180,	25.000,
21	0.220,	-4.580,	0.000,	3.180,	-12.090,	25.000,
22	0.460,	-5.000,	0.000,	3.540,	-11.990,	25.000,
23	0.780,	-5.350,	0.000,	3.890,	-11.880,	25.000,
24	1.130,	-5.690,	0.000,	4.230,	-11.760,	25.000,
25	1.500,	-5.990,	0.000,	4.580,	-11.630,	25.000,
26	1.890,	-6.280,	0.000,	4.920,	-11.490,	25.000,
27	2.290,	-6.530,	0.000,	5.250,	-11.340,	25.000,
28	2.710,	-6.760,	0.000,	5.580,	-11.180,	25.000,
29	3.150,	-6.960,	0.000,	5.910,	-11.020,	25.000,
30	3.600,	-7.130,	0.000,	6.230,	-10.840,	25.000,
31	4.060,	-7.270,	0.000,	6.540,	-10.650,	25.000,
32	4.530,	-7.380,	0.000,	6.850,	-10.450,	25.000,
33	5.010,	-7.420,	0.000,	7.160,	-10.250,	25.000,
34	5.490,	-7.410,	0.000,	7.450,	-10.030,	25.000,
35	5.960,	-7.330,	0.000,	7.750,	-9.810,	25.000,

3.7 Conclusion

Now it can be seen that the DXF interface program developed here is very successful in extracting and transferring 3 dimensional drawing files in DXF format to a standard neutral database which acts like a bridge between CAD and CAM systems. It is this bridge standard neutral database that makes it possible to realise the integration of the CAD/CAM and WEDM in this project.

Of course, nowadays there are a lot of books and software about the integration of CAD/CAM available on the market. However, most of them are just about some general introduction of CAD/CAM systems and the purpose of some material is to market their software for integration of CAD/CAM.

On the other hand, even though some software packages are available, such as NCP SYSTEM PACKAGE (NCP SYSTEM means NC programmer system by NC Microproducts Inc. that offers a set of programs that work in conjunction with a computer aided design program to generate numerical control code for NC or CNC machine tools)[33], it could be found that no one software package about integration of CAD/CAM was designed specially for a given project, especially for 3D complex shaped model machining on WEDM. In most cases, even if one decides to apply those software to his project such as a CNC milling machine or a CNC lathe, it is necessary to do a lot of work first to make the software suit the project, like pre-processing and post-processing as well as using some necessary support programs for specialized operations.

So the DXF interface program developed successfully here is a considerable breakthrough in this area of research towards the integration of CAD/CAM for WEDM. Compared to other software for the integration of CAD/CAM, it can be seen later that using this DXF interface program it is simpler, more efficient and less costly to realise the integration of CAD/CAM.

Moreover, the DXF interface program developed here can not only be applied to this WEDM research but can also be applied to other projects related to the integration of CAD/CAM. For example the integration of CAD/CAM on a CNC milling machine or on a CNC lathe to generate some complex shaped parts.

The following Fig. 3.4 is a complex shaped part which can be taken either as a spinning object to be turned on a NC lathe or as an object to be milled on a NC milling machine.

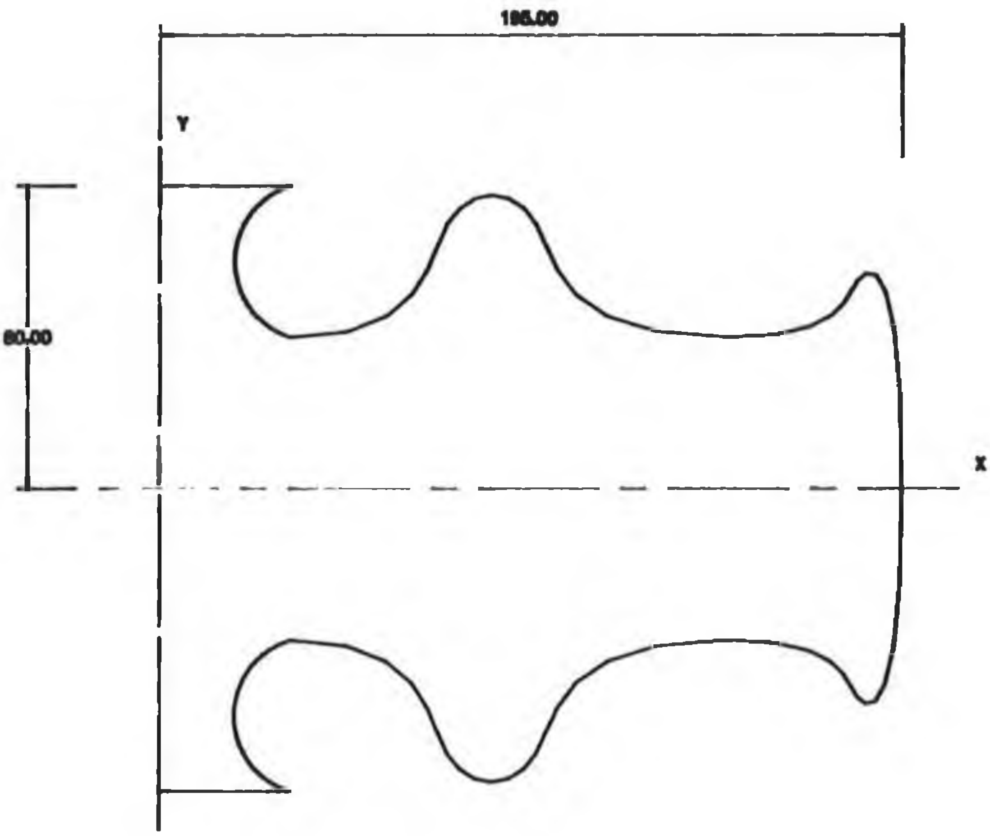


Fig. 3.4 A complex shapped part for turning or milling.

In either case, the drawing created with AUTOCAD needs to be transferred to a kind of neutral database to link the CAD with NC program that controls a machine in order to get an integrated effect.

With the help of the DXF interface program developed here, it is very easy to obtain the desired database mentioned above from the sample drawing shown in Fig.3.4.

In the following database, coordinates XB,YB can be directly accessed by the related control program. Other coordinate values can be taken as a sort of virtual values as CNC lathe only need to know two coordinate values XB, YB without having concerned with the other values.

However, all values of coordinates XB,YB,ZB,XT,YT and ZT are very useful for a CNC milling machine as the CNC milling machine not only requires the data like XB,YB describing the plan view, but also requires the data on the depth on its point so as to create complex shaped parts.

Database generated from drawing Fig. 3.4

XB MM	YB MM	ZB MM	XT MM	YT MM	ZT MM
195.000,	0.000,	0.000,	195.000,	0.000,	20.000,
194.870,	5.670,	0.000,	194.870,	5.670,	20.000,
194.740,	11.330,	0.000,	194.740,	11.330,	20.000,
194.610,	17.000,	0.000,	194.610,	17.000,	20.000,
194.490,	22.660,	0.000,	194.490,	22.660,	20.000,
194.150,	28.320,	0.000,	194.150,	28.320,	20.000,
193.640,	33.960,	0.000,	193.640,	33.960,	20.000,
193.140,	39.610,	0.000,	193.140,	39.610,	20.000,
192.230,	45.190,	0.000,	192.230,	45.190,	20.000,
191.030,	50.730,	0.000,	191.030,	50.730,	20.000,
188.600,	55.810,	0.000,	188.600,	55.810,	20.000,
183.910,	55.130,	0.000,	183.910,	55.130,	20.000,
180.900,	50.340,	0.000,	180.900,	50.340,	20.000,
177.190,	46.100,	0.000,	177.190,	46.100,	20.000,
172.280,	43.320,	0.000,	172.280,	43.320,	20.000,
166.870,	41.750,	0.000,	166.870,	41.750,	20.000,
161.310,	40.680,	0.000,	161.310,	40.680,	20.000,
155.660,	40.340,	0.000,	155.660,	40.340,	20.000,
150.000,	40.000,	0.000,	150.000,	40.000,	20.000,

```
141.770,  40.660,   0.000, 141.770,  40.660,  20.000,
133.540,  41.320,   0.000, 133.540,  41.320,  20.000,
125.550,  43.230,   0.000, 125.550,  43.230,  20.000,
117.740,  45.820,   0.000, 117.740,  45.820,  20.000,
110.950,  50.520,   0.000, 110.950,  50.520,  20.000,
105.680,  56.800,   0.000, 105.680,  56.800,  20.000,
101.920,  64.130,   0.000, 101.920,  64.130,  20.000,
 98.060,  71.380,   0.000,  98.060,  71.380,  20.000,
 91.850,  76.650,   0.000,  91.850,  76.650,  20.000,
 83.750,  76.780,   0.000,  83.750,  76.780,  20.000,
 77.330,  71.860,   0.000,  77.330,  71.860,  20.000,
 73.380,  64.660,   0.000,  73.380,  64.660,  20.000,
 70.030,  57.130,   0.000,  70.030,  57.130,  20.000,
 65.360,  50.380,   0.000,  65.360,  50.380,  20.000,
 58.980,  45.210,   0.000,  58.980,  45.210,  20.000,
 51.310,  42.140,   0.000,  51.310,  42.140,  20.000,
 43.210,  40.850,   0.000,  43.210,  40.850,  20.000,
 35.000,  40.000,   0.000,  35.000,  40.000,  20.000,
 32.210,  41.040,   0.000,  32.210,  41.040,  20.000,
 29.590,  42.460,   0.000,  29.590,  42.460,  20.000,
 27.210,  44.240,   0.000,  27.210,  44.240,  20.000,
 25.100,  46.340,   0.000,  25.100,  46.340,  20.000,
 23.320,  48.720,   0.000,  23.320,  48.720,  20.000,
 21.890,  51.330,   0.000,  21.890,  51.330,  20.000,
 20.850,  54.120,   0.000,  20.850,  54.120,  20.000,
```

20.210,	57.030,	0.000,	20.210,	57.030,	20.000,
20.000,	60.000,	0.000,	20.000,	60.000,	20.000,
20.210,	62.970,	0.000,	20.210,	62.970,	20.000,
20.850,	65.880,	0.000,	20.850,	65.880,	20.000,
21.890,	68.670,	0.000,	21.890,	68.670,	20.000,
23.320,	71.280,	0.000,	23.320,	71.280,	20.000,
25.100,	73.660,	0.000,	25.100,	73.660,	20.000,
27.210,	75.760,	0.000,	27.210,	75.760,	20.000,
29.590,	77.540,	0.000,	29.590,	77.540,	20.000,
32.210,	78.960,	0.000,	32.210,	78.960,	20.000,
35.000,	80.000,	0.000,	35.000,	80.000,	20.000,
33.060,	80.000,	0.000,	33.060,	80.000,	20.000,
31.110,	80.000,	0.000,	31.110,	80.000,	20.000,
29.170,	80.000,	0.000,	29.170,	80.000,	20.000,
27.220,	80.000,	0.000,	27.220,	80.000,	20.000,
25.280,	80.000,	0.000,	25.280,	80.000,	20.000,
23.330,	80.000,	0.000,	23.330,	80.000,	20.000,
21.390,	80.000,	0.000,	21.390,	80.000,	20.000,
19.440,	80.000,	0.000,	19.440,	80.000,	20.000,
17.500,	80.000,	0.000,	17.500,	80.000,	20.000,
15.560,	80.000,	0.000,	15.560,	80.000,	20.000,
13.610,	80.000,	0.000,	13.610,	80.000,	20.000,
11.670,	80.000,	0.000,	11.670,	80.000,	20.000,
9.720,	80.000,	0.000,	9.720,	80.000,	20.000,
7.780,	80.000,	0.000,	7.780,	80.000,	20.000,

5.830,	80.000,	0.000,	5.830,	80.000,	20.000,
3.890,	80.000,	0.000,	3.890,	80.000,	20.000,
1.940,	80.000,	0.000,	1.940,	80.000,	20.000,
0.000,	80.000,	0.000,	0.000,	80.000,	20.000,

==

Chapter 4

THE MOTION CONTROL

4.1 An overview of the motion control

4.1.1 The hardware for the motion control

4.1.2 The software for the motion control

4.2 Transformation of co-ordinates

4.3 Features of the control program

4.4 Test Procedure

4.5 conclusion

4.1 An overview of the motion control

4.1.1 The hardware for the motion control

It can be seen from Figs.1.1-1.4 that the machine in this case is actually a four axes manipulator controlled by a computer, each axis is driven by a corresponding AC brushless motor. Between the AC brushless motors and the computer are the interface hardware ------ KS Brushless Servo Motor Indexer Drives or Compumotor KS Indexer/Drive made by Parker Hannifin Corporation, USA.

The KS Drive adds a complete indexer with an industry standard RS-232C interface. It is easily controlled from a computer, terminal, and most programmable contllers. The indexng language is based on Copumotor's popular Model 2100 indexer, and the KS is capable of storing and executing complex motion programs from its own non-volatile memory (EEPROM).

The Compumotor KS Indexer/Drive is a powerful, " all in one" motion control device. It provides the user with the indexer and the drive in one package.

The additional facilities of the PC23 indexer like trigger inputs and programmable outputs had been utilized by designing a programmable voltage regulator (PVR) circuit, which controls the voltage in the cutting wire.(Fig.4.1)

THE INDEXER:

Each of the prototype indexers which have been used in this research can control three axes independently and simultaneously. It is designed to be connected to an IBM micro-computer (PC). The PC23 indexer uses a 16 bit processor to manage the control of three motor axes. Two PC23 indexers and four KS-drives were used to generate some complex shaped model.

The PC23 indexer receives acceleration, velocity, position and direction information from the micro-computer based software. The on-board micro-processor uses this information to generate motion profile command signals for the KS - drives.

The KS - drive accepts these digital "step" pulses from the indexer, at controlled rates up to 5000,000 steps per second, and the internal drive logic and power amplifiers set and maintains the output current levels to the AC servomotor windings[31].

The PC23 indexer consists of two parts, the main circuit board and the adaptor box. The main circuit board is incorporated inside the micro-computer and is connected to the adaptor box.

The adaptor box is outside the computer and has all the connections to the KS - drives and other devices.

The two PC23 indexers are set at two different addresses (not sharing with any other peripheral); one is set at 300 hex and the other at 310 hex in the I/O BUS of the computer (IBM compatible) with 20 MB hard disk, a floppy drive and a 640 KB RAM. A PC23 system diagram is shown in Figure 4.2.

All applications of an indexer axes involve either movement of a motor to a precise position (number of steps) or movement of the motor at a prescribed velocity (revolutions/second).

The model for motion control adopted here is an absolute normal model because it is suitable for the simulated WEDM process.

For example, if we want to move motor one with an acceleration of 0.1 rev./ squared sec. and a velocity of 0.2 rev./sec. through a distance of 10 mm in the CW(clockwise) direction and if the indexer is set at 5000 steps/rev., and the KS-Drive is also set at the same resolution, the mode selected is absolute then the number of motor steps is calculated as follows:

10mm(linear distance)*5000(steps/rev.)/2mm(pitch of lead screw)=25,000 motor steps.

Then the command to indexer will be :

1MN 1MPA 1A0.1 1V0.2 1D-25000 1G

MN = normal mode.

MPA = absolute normal mode.

A = acceleration.

V = velocity.

D = distance.

G = "go" an execution command to initiate a motor motion.

THE KS-DRIVE:

The KS-Drive is a complete brushless servo positioning system. It consists of a brushless servomotor, a brushless feedback and microprocessor based closed loop drive amplifier.

The KS-drive accepts digital STEP and DIRECTION inputs to control position and velocity. The on-board micro-processor monitors both the pulse inputs from the indexer and the resolver feedback from the motor shaft and then determines the proper current levels to apply to the motor. The resolver feedback used on KS-drive can be programmed between 1000 to 16,384 steps/revolution by using CMR command through the RS-232 interface and is saved in EEPROM memory.

The KS-drive can be divided into two major parts, the digital controller board and the analog amplifier board. The controller board sends two digitized waveforms from its digital analog converters to the analog amplifier board. The analog amplifier board generates its own third phase command and measures the actual current to determine the correct voltage pulse width to apply to the motor's windings. A block diagram of the KS drive is shown in Figure 4.3.

The controller commands a " desired current" in the motor windings. The position of the motor shaft is sensed by the controller via the resolver attached to the motor. The positional information is used by the controller to generate a "desired current" command to the amplifier.

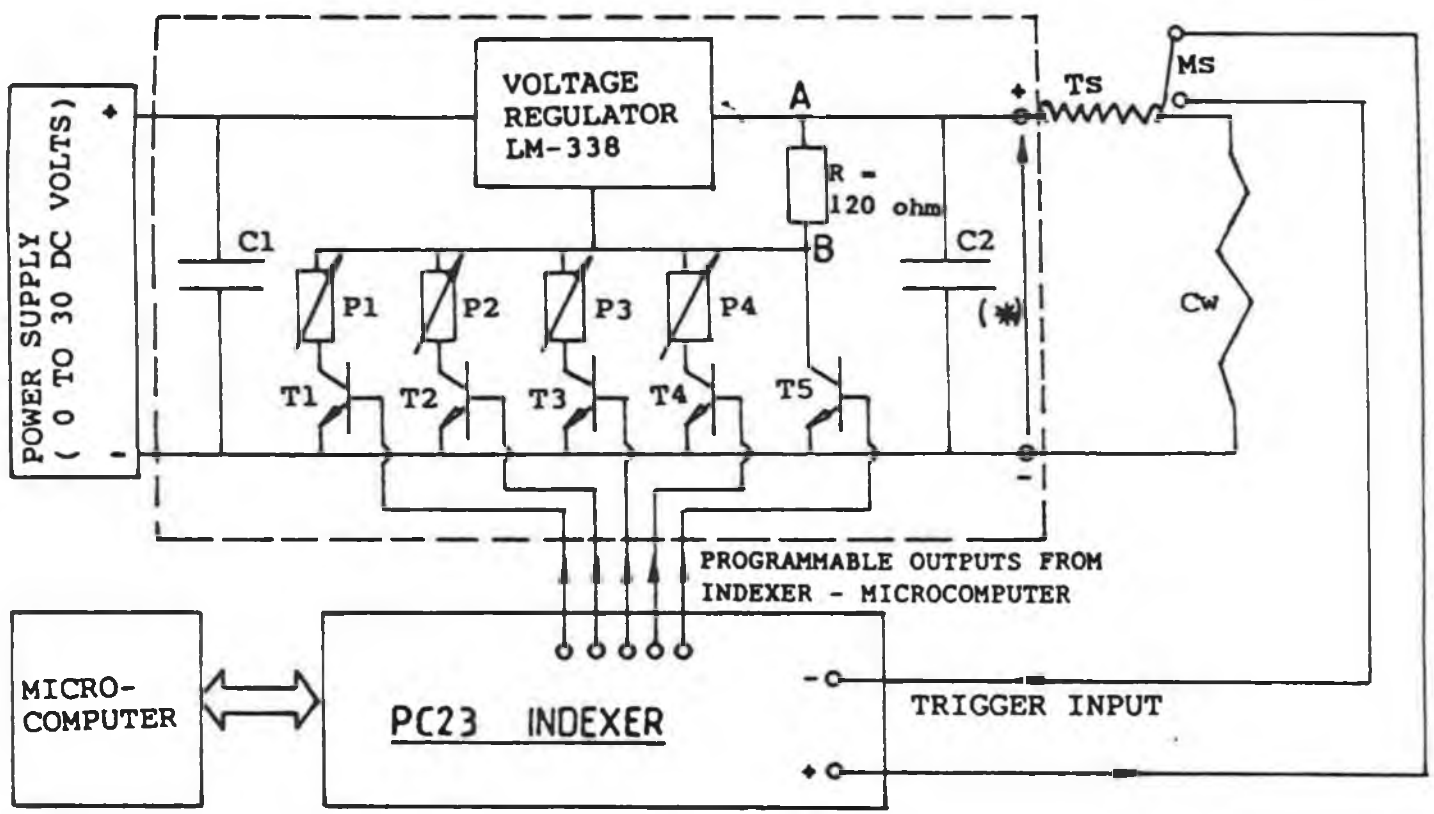
A important aspect of the servo system is that all of the position compensation can be handled by the digital controller board. The recursive equation is an approximation of an analog, continuous-time PID network, which is used quite often for the purpose of stabilizing conventional servo systems.
The following outline describes how the PID and V (Proportional, Integral, Derivative and Velocity) gain affect the system response. Figure 4.1.4 is a PID loop block diagram of the KS-drive.

Proportional gain: This affects the systems stiffness and accuracy. High proportional gain will cause resolver feedback signals to be amplified, and the system will start oscillating. In this case, it should be kept below that oscillating value.

Integral gain: This allows the systems to compensate for positional errors in static position by slowing down the electronic response time, so that it more closely resembles the response of the mechanical components.

Derivative gain: This adds damping effects to the system, in the case where the system is oscillating which may occur at the end of a move or during a change in velocity. By increasing the derivative gain the ringing will be reduced.

Velocity gain: This is used to affect the overall responsiveness of the system. If the system is overshooting badly or there is excessive ringing such that the derivative term is not able to adequately compensate, then velocity gain should be kept low or can be increased if the system is sluggish.



(✱)= TOTAL PROGRAMMABLE OUTPUT VOLTAGE (1.25 TO 30 VOLTS)

C1 = 1 µF C2 = 0.1 µF Ms= MICROSWITCH

Cw = CUTTING WIRE Ts = TENSION SPRING Pi= POTENTIOMETERS

Ti = 2N222 2A (NPN) 50 K. Ohm. 10%

Figure 4.1 _ Shows a circuit diagram of the Programmable Voltage Regulator (PVR) circuit.

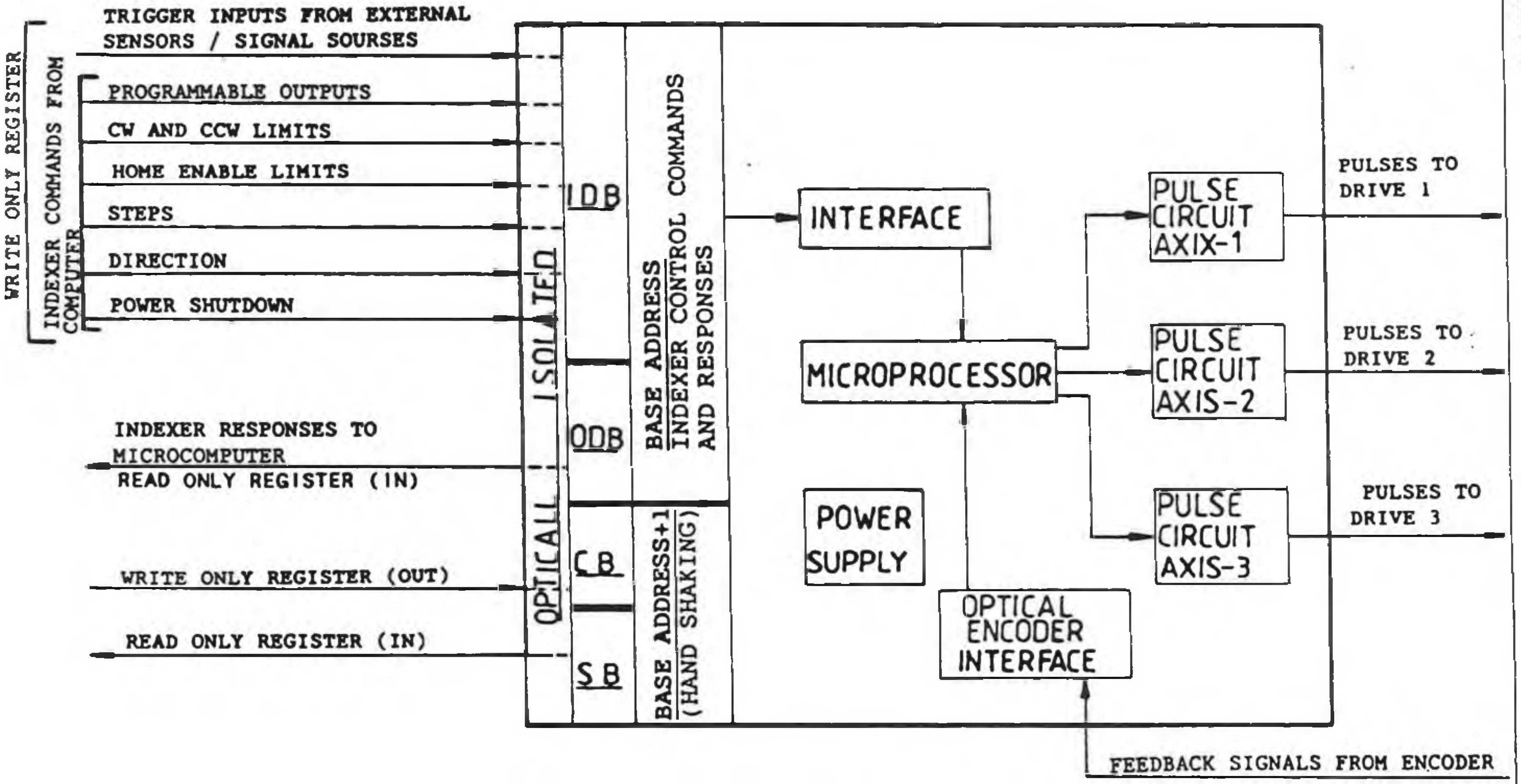


Fig.4.2 **An indexer system diagram.**

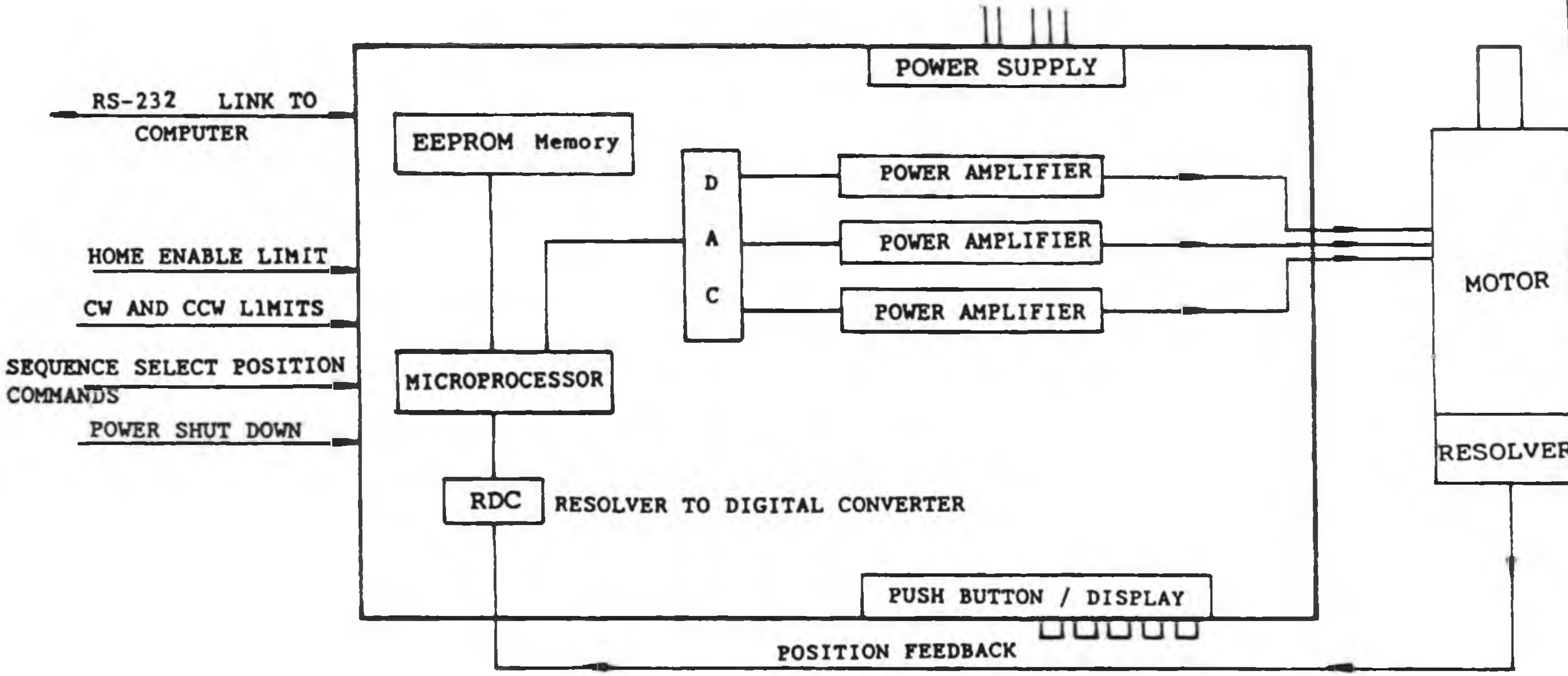
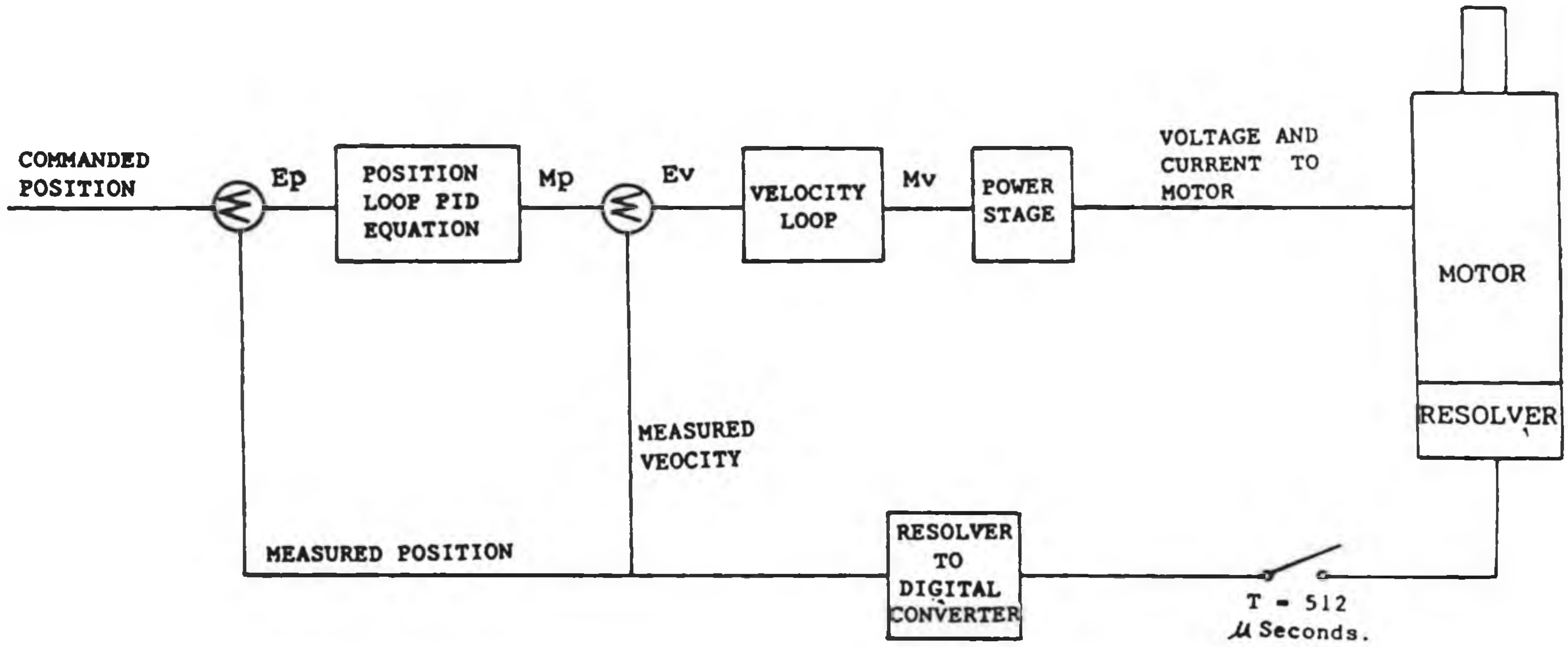


Fig. 4.3 **A digital servo system of the KS-drive.**



Ep = SYSTEM POSITION ERROR. Mp = SYSTEM POSITION CORRECTION FACTOR. (COMMANDED VELOCITY)

Ev = SYSTEM VELOCITY ERROR. Mv = SYSTEM VELOCITY CORRECTION FACTOR.

Fig.4.4 PID loop block diagram of the KS-DRIVE.

4.1.2 The software for the motion control

The motion control is carried out by a general control program which interfaces the CAD database and WEDM machining control system which have been listed in APPENDIX 2. It covers the following main tasks sequentially during its running :

{1}. Reading data from the standard database.

{2}. Calculating for transformation of coordinates and checking movement limitation.

{3}. Changing absolute distance to motor steps .

{4}. Calculating machining area and time and constructing the commands for the motor motion control.

{5}. Reading indexer commands to and writing indexer commands from the Input/Output bus of the computer through part of the program for PC23 INDEXER.

Programming the PC23 indexer is independent of the programming language. This part of the control program is for reading data from the Output Data Buffer (ODB) and writing indexer commands to the Input Data Buffer (IDB) at the base address of the indexer.

The programming structure of the PC23 indexer consists of 3 main parts:

(1) Resetting PC23 indexer.

(2) Sending a command character to PC23 indexer (output driver subroutine).

(3) Receiving a character from the indexer (input driver subroutine).

The distance parameter is defined in terms of motor steps. The linear and rotary distance in millimetres and degrees must be translated into motor steps; the acceleration and velocity are defined in revolutions/squared sec. and revolutions/sec. respectively.

It was decided to start machining from the centre of the workpiece for all the 3D shapes and each point to be machined for both end surfaces is referenced to the absolute zero point (centre of the workpiece).

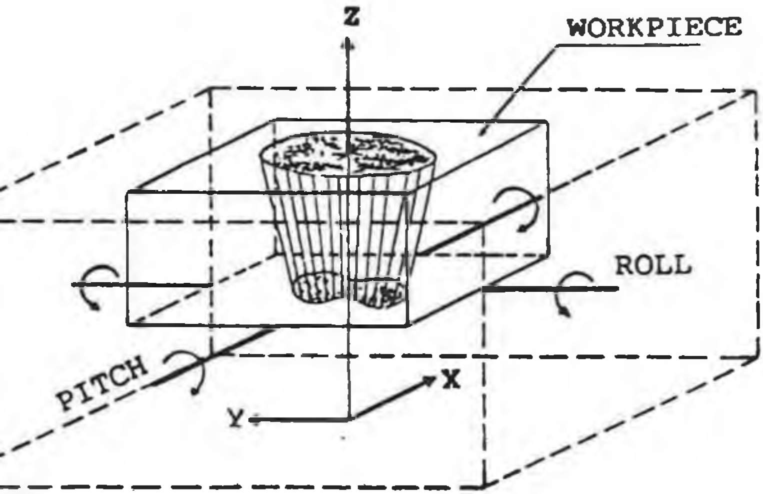
The point is that the WEDM machining system is a four axes movement system which includes two linear axes and two rotary axes and in this case all 4 motors should work in a synchronized way. Halting execution of the commands until all axes are ready to move at almost the same time is the way adopted in this control program in order to obtain synchronization.

Basically the original control program is successful. The general control program developed is just an improvement on the original one. The main differences are (1) recalculating the transformation of coordinates and correcting one transformation formula, (2) making the control program suitable to machining almost any model for WEDM and (3) ruling out the planning of a practice path for the workpiece to be manipulated for the cutting wire in the control program because the path planning for die generation is designed better in CAD stage.

4.2 Transformation of coordinates

If the cutting wire in WEDM could move freely in space, it would not be necessary to transform the relative coordinates since the data in the standard database which describe the die model geometry provides enough details for the cutting wire to move directly according to them in order to generate a desired die (See a database example in Chapter 3.5).

Fig.4.5



Shows a diagramatic representation of the manipulator.

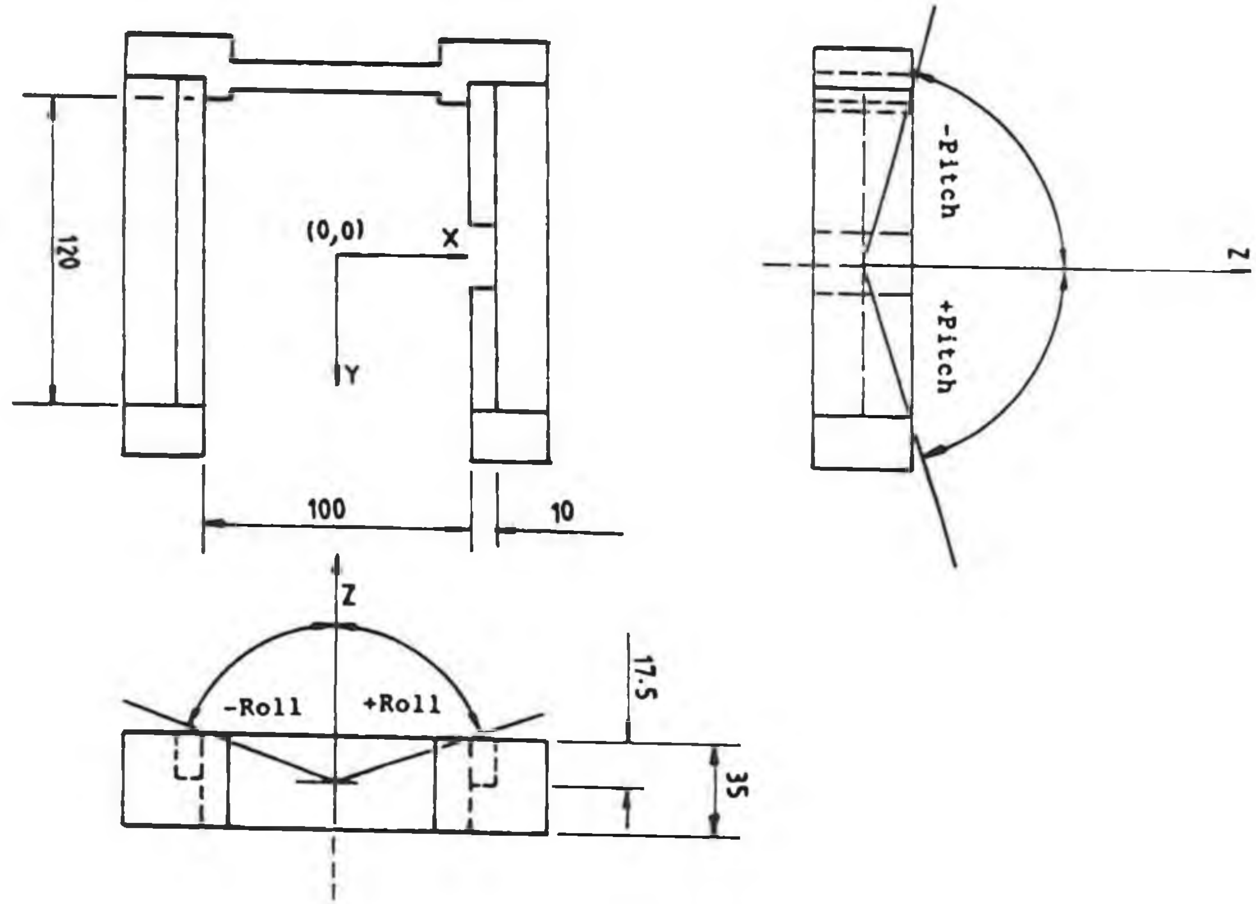


Fig.4.6 Shows the workpiece gimbaling part of the manipulator, which shows the angular cutting facility around X and Y-axes (Pitch and Roll)

Unfortunately the cutting wire is fixed in this case and can not move freely, so the only way to obtain the desired die cavity is to make the workpiece move in either a linear or a rotary way relative to the cutting wire. In this situation, the base of the workpiece is kept along the plane containing the lines of rotation around X and Y axes (See Fig. 1.1, Figs.4.5 and 4.6) and, the workpiece is moved in such a way that each point on the bottom is obtained by manipulating the workpiece in X and Y directions and each corresponding point on the top surface for each spline is obtained by rotating workpiece around the X and Y axes.

Regarding the die geometry itself, once the coordinates (XB,YB,and ZB) of the bottom point of each spline and corresponding top coordinates (XT,YT and ZT or alpha-1 and beta-1) are known, it is described clearly.

$$\alpha 1=\tan^{-1}\left(\frac{YT-YB}{ZT}\right)\ldots\ldots\ldots(4.2\text{-}1)$$

$$\beta 1=\tan^{-1}\left(\frac{XT-XB}{ZT}\right)\ldots\ldots\ldots.(4.2\text{-}2)$$

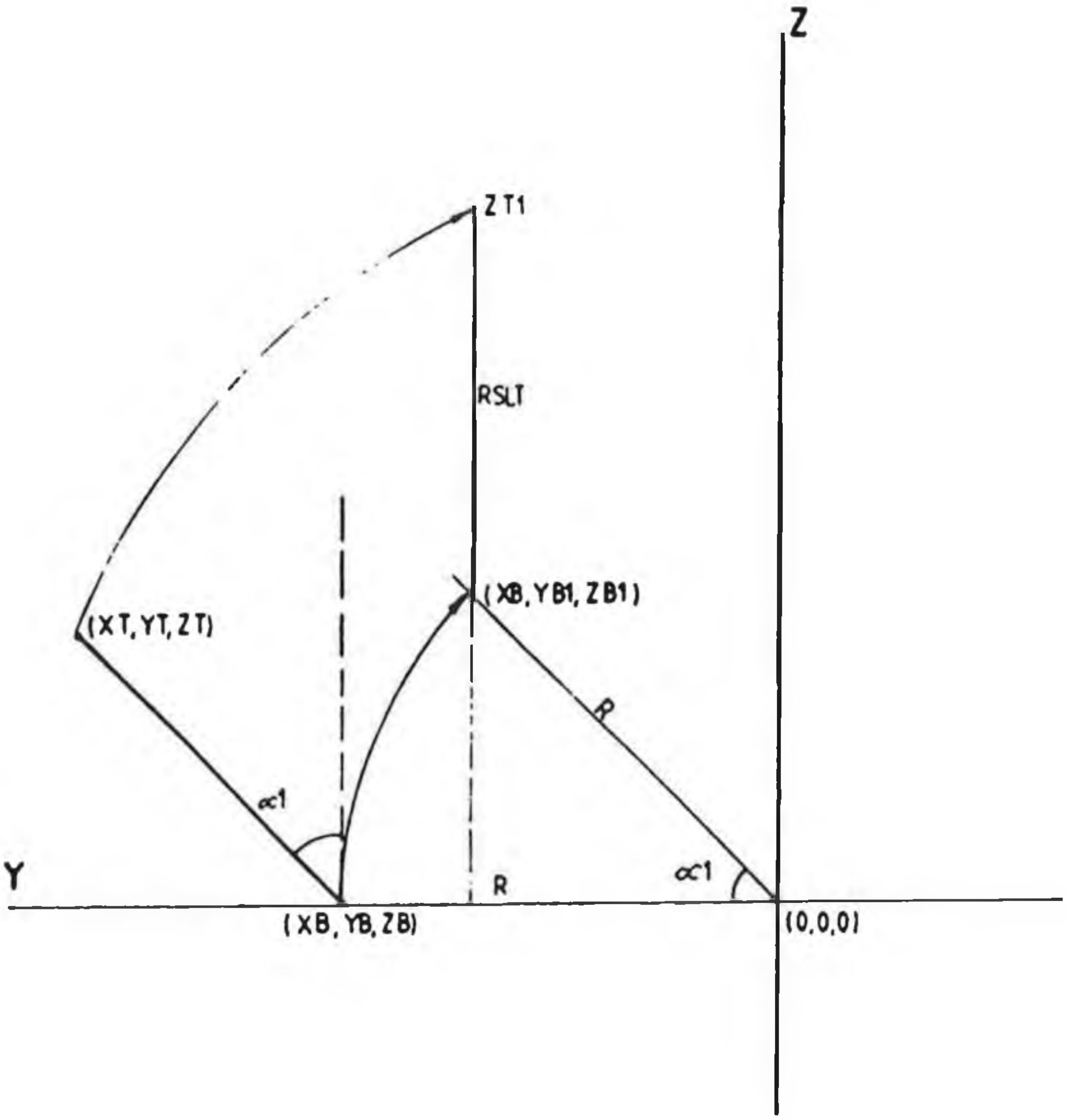


Fig.4.7 Shows the transformation of the Y-coordinates for the bottom surface due to angle alpha in Y-Z plane

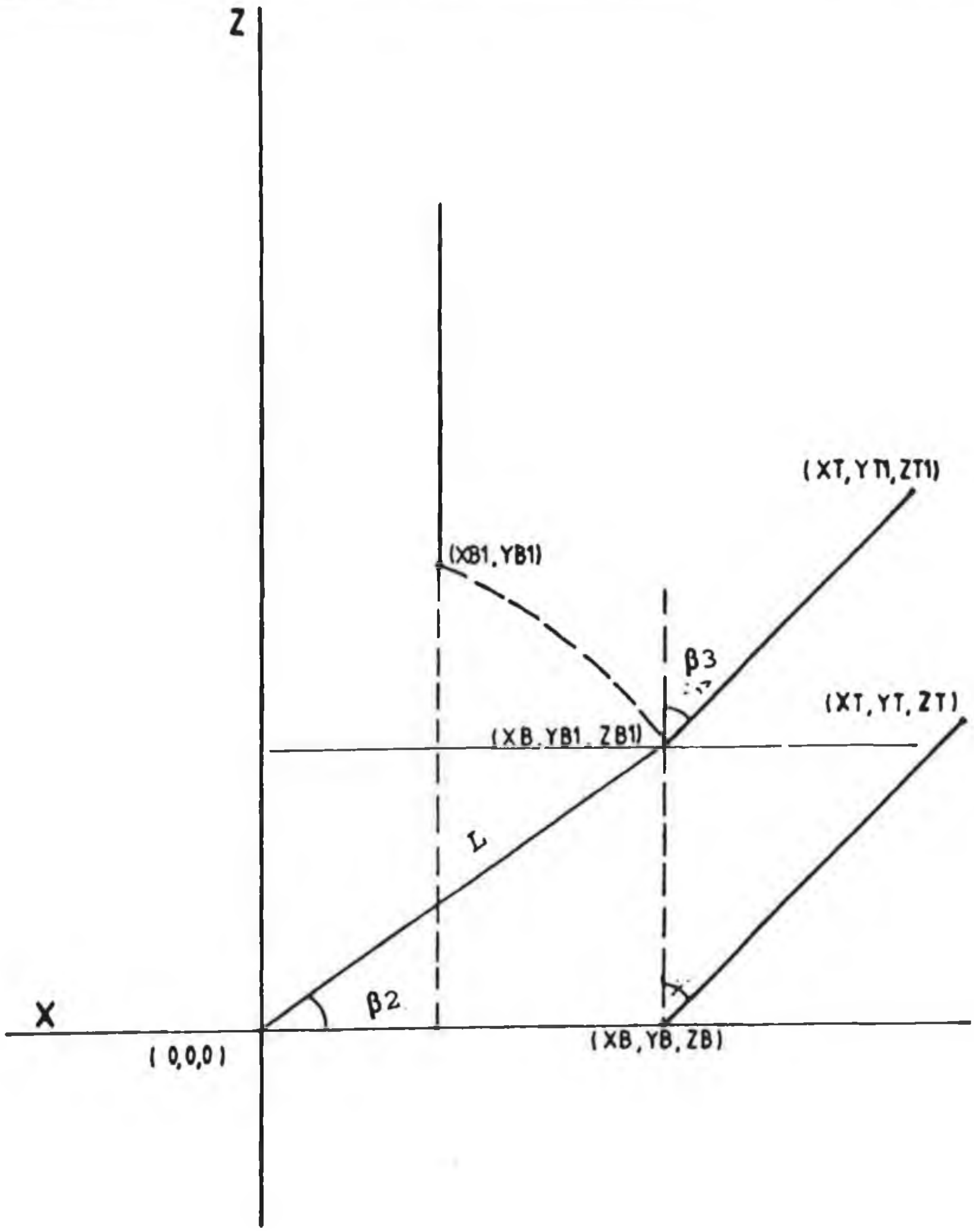


Fig.4.8 Shows the transformation of the X-coordinates for the bottom surface due to angle beta in X-Z plane

To generate a die in the WEDM, however, only knowing these data is not enough. Due to rotation of any angle, all coordinates for the top and bottom surfaces will change. To compensate for the errors occurring in angular and linear displacements, all new rotated coordinates and angles need to be recalculated.

So actually in order to generate a desired die, the data which the control system needs to know are XB1,YB1,ZB1,ALPHA-1,BETA-2 and BETA-3 of each spline for the die geometry.

Fig. 4.7 shows the Y-Z plane of the rotating coordinates for a single rotating point by the angle alpha.

The Y coordinate YB for the bottom surface changes its position to YB1 after rotating coordinates to alpha-1 angle.

$$YB1=YB*\cos(\alpha 1)\text{..........}(4.2\text{-}3)$$

$$ZB1=ZB*\cos(\alpha 1)\text{..........}(4.2\text{-}4)$$

Now the length of a line in Y-Z plane between the top and bottom surface is equal to

$$RSLT=\sqrt{(YT-YB)^2+ZT^2} \quad \text{.......(4.2-5)}$$

$$ZT1=ZB1+RSLT \quad \text{............(4.2-6)}$$

Fig.4.8 shows the same coordinates of the single point after rotation by alpha1 from x-z plane. Therefore,

$$\beta 2=\tan^{-1}\frac{ZB1}{XB} \quad \text{..........(4.2-7)}$$

$$\beta 3=\tan^{-1}\left(\frac{XT-XB}{ZT1-ZB1}\right) \quad \text{.......(4.2-8)}$$

$$XB=L*\cos(\beta 2) \quad \text{............(4.2-9)}$$

$$L=\frac{XB}{\cos(\beta 2)} \quad \text{...........(4.2-10)}$$

$$XB1=L*\cos(\beta 2+\beta 3) \quad \text{.......(4.2-11)}$$

$$XB1=XB*\frac{\cos(\beta 2+\beta 3)}{\cos(\beta 2)} \quad \ldots\ldots\ldots (4.2\text{-}12)$$

4.3 Features of the control program

The main feature of this general control program is that it is suitable for generating almost any model for WEDM. Each time one runs this control program, it will prompt with the following message on the screen.

```
!~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~!
!       PLEASE   WAIT                                    !
!       LOADING DATA                                     !
!       ENTER A DATABASE FILE NAME                       !
!       FOR EXAMPLE, " C:\3D-MODEL.DAT "                  !
!       DATABASE FILE NAME:                              !
!~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~!
```

Then one can enter a database file name of any 3D model drawing for WEDM which is intended. It is not limited to the number of the 3D model kinds that it can generate no matter how complex shape it is. But in the related previous research only 12 kinds of models were able to be created.

After entering a database file name, the control program begins to process the data obtained and send commands to the WEDM control system for the machine to carry out.

Another main feature is that one can adjust the voltage level in the cutting wire during the control program running and manipulator working, in other words, one can adjust the voltage on line accordingly. The following message is displayed on the screen during machining.

```
TOTAL MACHINING TIME FOR THIS DIE PROFILE IS : 11 MINUTES AND 30.21 SECONDS
REST OF THE PROFILE NEEDS MACHINING TIME OF : 9 MINUTES AND 46.67 SECONDS.
TIME FOR THIS SEGMENT TO BE MANUFACTURED IS : 0 MINUTES AND 11.85 SECONDS.
          TOTAL MACHINING  AREA OF THE DIE IS : 9202.837mm.Sqr
          PRESENT WORKPIECE FEEDRATE IS :  800 mm. Sqr./min.
          THE VOLTAGE IN THE CUTTING WIRE IS APRX. 6 VOLTS.

             NOW POINT NUMBER 3 IS BEING MANUFACTURED.


             PRESS 'R' IF WISH TO CHANGE VOLTAGE IN THE
             CUTTING WIRE OR TO TEST RETRACING FACILITY


        COMMANDS SENT TO THE PC23 INDEXERS FOR POINT  3  ARE

      1VS.1143 1V.1143 1D71656 1I 2VS.208 2V.208 2D25672 2IS 2I
      3VS.0071 3V.0071 3D-2587 3I 3VS.0051 3V.0051 3D127 3I
```

VS = Sets instantaneous velocity.

V = Maintains the same velocity of 'VS' for each new move.

D = Sets distance in motor steps.

I = Pre-calculates the move profile.

Following is a menu displayed on the screen while the voltage in the cutting wire needs to be changed.

```
NOW YOU CAN SELECT NEW VOLTAGE FROM FOLLOWING OPTIONS
   ************************************************
   * VOLTAGE 1.........................1.25 VOLTS *
   * VOLTAGE 2.........................6    VOLTS *
   * VOLTAGE 3.........................5.5  VOLTS *
   * VOLTAGE 4.........................5    VOLTS *
   * VOLTAGE 5.........................4.5  VOLTS *
   *************************************************
     SELECT VOLTAGE BY PRESSING KEYS 1-5 KEY
```

4.4 Test procedure

Before any test is carried out, the polystyrene pieces of 120 x 120 mm of different thicknesses (ZT) should be ready and a small size hole is drilled centrally in all the workpiece so that the cutting wire could be inserted through at an initial machining position.

The polystyrene used to carry out the tests, bought from the Dow Chemical company limited, has a density of 34 kg/sq. m, compressive strength of 300 KN/sq.m and thermal conductivity of 0.025 W/mk.

For 3D die generation, the manipulator was first adjusted to the zero position of linear movement (middle of X and Y total linear travels). Secondly the rotary frames should be kept parallel with reference to the main base plate of the manipulator. Thirdly the wire cutting unit is moved manually to the rotary frames, making sure that the cutting wire is positioned as near as possible at the centre of the frames , in other words , the junction of the X and Y axes.

Then pass the wire through the centre hole of the workpiece. The tension in the wire needs to be checked beforehand, so that the cutting wire could maintain its vertical position. A micro-switch can be used to stop machining thereby protecting the wire and die being machined once any increase in the wire tension occurs.

Now one can begin to test by running the general control program and supplying the power sequentially. At the same time the computer will prompt for the workpiece feed rate to be input, and during the operation one can press "R" to pause the process for the adjusting voltage on line.

The following is the result processed by the general control program during the operation on the WEDM:

SEGMENT NUMBER	ALFA (Degr-ees)	BETA (Degr-ees)	MACHINING AREA (mm Sq.)	MACHINING TIME (Seconds)	TOTAL M.AREA mm Sq.	TOTAL M.TIME (Sec.)
1	-5.6538	4.0528	1097.65	82.3242	1097.656	82.3242
2	-4.4486	4.3785	98.4570	7.38427	1196.113	89.7085
3	-3.3993	4.6795	98.2917	7.37187	1294.405	97.0803
4	-2.4622	5.0017	98.4367	7.38275	1392.842	104.463
5	-1.6382	5.3564	98.4085	7.38064	1491.25	111.843
6	-.80208	5.7100	98.5628	7.39221	1589.813	119.236
7	6.8755	5.9374	98.1333	7.36000	1687.947	126.596
8	.97393	6.0612	98.7304	7.40478	1786.677	134.000
9	1.8786	6.0815	98.4439	7.38329	1885.121	141.384
10	2.8052	5.9756	98.4295	7.38222	1983.551	148.766
11	3.7075	5.7553	98.5677	7.39257	2082.118	156.158
12	4.5966	5.4321	98.2731	7.37048	2180.391	163.529
13	5.4608	5.1761	98.3395	7.37546	2278.731	170.904
14	6.3225	4.9534	98.4935	7.38701	2377.224	178.291
15	7.1475	4.6514	98.0969	7.35726	2475.321	185.649
16	7.9358	4.2708	98.7264	7.40448	2574.048	193.053
17	8.6875	3.8005	98.5556	7.39167	2672.603	200.445
18	9.3805	3.2638	98.5601	7.39200	2771.163	207.837
19	10.026	2.6611	98.1813	7.36360	2869.345	215.200
20	10.591	1.9929	98.4717	7.38538	2967.817	222.586
21	11.100	1.2816	98.5028	7.38771	3066.319	229.974
22	11.530	.51646	98.5696	7.39272	3164.889	237.366
23	11.870	-.29156	98.2881	7.37161	3263.177	244.738
24	12.144	-1.1089	98.4041	7.38031	3361.581	252.118
25	12.319	-1.9695	98.6108	7.39581	3460.192	259.514
26	12.418	-2.8401	98.4419	7.38314	3558.634	266.897
27	12.287	-3.7343	98.2631	7.36774	3656.897	274.267
28	12.265	-4.6146	98.2958	7.37216	3755.193	281.639
29	12.658	-5.6169	98.2174	7.36630	3853.411	289.005
30	13.333	-6.9458	97.9742	7.34807	3951.385	296.353
31	14.144	-8.7648	98.3861	7.37896	4049.771	303.732
32	15.386	-9.4911	54.8515	4.11386	4104.623	307.846
33	16.499	-10.760	55.0602	4.12951	4159.683	311.976
34	17.432	-12.240	54.7787	4.10840	4214.462	316.084
35	18.551	-13.014	54.6787	4.10090	4269.14	320.185
36	19.524	-13.033	54.5108	4.08831	4323.651	324.273
37	20.011	-12.492	54.5233	4.08925	4378.175	328.363
38	19.504	-11.746	54.4189	4.08142	4432.594	332.444
39	18.582	-11.038	54.7221	4.10415	4487.316	336.548
40	17.453	-10.400	55.1192	4.13394	4542.435	340.682
41	16.214	-9.7740	54.9387	4.12040	4597.374	344.803

42	14.810	-9.2145	55.0226	4.12669	4652.396	348.929
43	13.257	-8.7102	55.3180	4.14885	4707.714	353.078
44	11.563	-8.2941	54.8463	4.11347	4762.56	357.192
45	9.7259	-7.9451	55.0312	4.12734	4817.592	361.319
46	8.2167	-7.2870	54.0815	4.05611	4871.673	365.375
47	7.2490	-6.3061	54.5994	4.09495	4926.273	369.470
48	6.6732	-5.2435	55.2365	4.14274	4981.509	373.613
49	6.5036	-4.2276	54.8311	4.11233	5036.34	377.725
50	5.7559	-4.3923	79.4623	5.95967	5115.802	383.685
51	5.0745	-4.5560	79.4463	5.95848	5195.249	389.643
52	4.4030	-4.7307	79.5257	5.96442	5274.775	395.608
53	3.7532	-4.8821	79.8058	5.98543	5354.58	401.593
54	3.1023	-5.0558	79.4027	5.95520	5433.983	407.548
55	2.4622	-5.2288	79.4926	5.96195	5513.476	413.510
56	1.8213	-5.4127	79.5870	5.96902	5593.063	419.479
57	1.1686	-5.5959	79.4993	5.96245	5672.562	425.442
58	.50418	-5.6536	79.5248	5.96436	5752.087	431.406
59	-.14896	-5.5403	79.3050	5.94788	5831.392	437.354
60	-.80208	-5.3808	79.6800	5.97600	5911.073	443.330
61	-1.4320	-5.1979	79.5074	5.96306	5990.58	449.293
62	-2.0617	-4.9576	79.3925	5.95443	6069.972	455.248
63	-2.6680	-4.6940	79.7044	5.97783	6149.677	461.225
64	-3.2737	-4.3959	79.4792	5.96094	6229.157	467.186
65	-3.8330	-4.0748	79.6334	5.97250	6308.79	473.159
66	-4.3689	-3.6854	79.5592	5.96694	6388.349	479.126
67	-4.8812	-3.2505	79.5056	5.96292	6467.855	485.089
68	-5.3586	-2.8043	79.5630	5.96722	6547.418	491.056
69	-5.7446	-2.2449	79.4364	5.95773	6626.854	497.014
70	-6.0167	-1.5950	79.5968	5.96976	6706.451	502.983
71	-6.3904	-1.0475	79.3687	5.95265	6785.82	508.936
72	-6.9218	-.58013	79.2738	5.94553	6865.094	514.882
73	-7.6096	-.12494	79.6274	5.97205	6944.721	520.854
74	-8.4635	.36269	79.4514	5.95885	7024.173	526.813
75	-9.5477	.21470	45.6267	3.42217	7067.801	530.235
76	-10.556	.25909	42.2146	3.1661	7112.016	533.401
77	-11.728	.53854	42.3147	3.17360	7154.331	536.574
78	-12.952	1.1054	42.1561	3.16171	7196.457	539.736
79	-14.154	1.7439	42.4455	3.18341	7238.933	542.919
80	-15.335	2.3967	42.5239	3.18929	7281.457	546.109
81	-16.488	3.1065	42.3376	3.17534	7323.795	549.284
82	-17.599	3.8934	42.4217	3.18163	7366.217	552.466
83	-18.675	4.7331	42.4229	3.18172	7408.639	555.647
84	-19.707	5.6346	42.3180	3.17385	7450.957	558.821
85	-20.616	6.1752	40.5280	3.03960	7491.485	561.861
86	-21.305	6.1997	42.1223	3.15917	7533.608	565.020
87	-21.742	6.0655	42.5459	3.19094	7576.154	568.211
88	-21.900	5.8380	42.1838	3.16378	7618.337	571.375
89	-21.752	5.6122	42.1739	3.16304	7660.511	574.538
90	-21.315	5.4598	42.4298	3.18224	7702.941	577.720

91	-20.616	5.4852	42.1710	3.16282	7745.112	580.883
92	-19.737	5.6549	42.5066	3.18799	7787.618	584.071
93	-18.798	5.8590	42.4997	3.18748	7830.118	587.258
94	-17.786	6.1197	42.2055	3.16541	7872.324	590.424
95	-16.709	6.4697	42.5326	3.18994	7914.857	593.614
96	-15.620	6.7664	41.9239	3.14429	7956.781	596.758
97	-14.627	6.8526	42.4089	3.18067	7999.19	599.939
98	-13.658	6.8816	42.5520	3.19140	8041.742	603.130
99	-12.702	6.8532	42.1442	3.16081	8083.886	606.291
100	-11.782	6.7662	42.4429	3.18322	8126.329	609.474
101	-10.890	6.6318	42.2820	3.17115	8168.611	612.645
102	-10.026	6.4385	42.4993	3.18744	8211.111	615.833
103	-9.2019	6.2083	42.2775	3.17081	8253.388	619.004
104	-8.4298	5.9410	42.5080	3.18810	8295.896	622.192
105	-7.6884	5.6258	42.4349	3.18261	8338.33	625.374
106	-7.0234	5.2735	42.3375	3.17531	8380.668	628.55
107	-6.4583	4.8729	42.2728	3.17046	8422.941	631.720
108	-6.0054	4.4696	42.4660	3.18495	8465.406	634.905
109	-5.6538	4.0528	42.3589	3.17692	8507.766	638.082
110	0	0	1097.65	82.3242	9605.422	720.406

TOTAL AREA OF 9605.422 mm. Sqr. NEEDS MACHINING TIME OF
12 MINUTES AND .4064 SECONDS AT THE FEED RATE OF 800 mm Sqr./Min.

4.5 *Conclusion*

Broadly speaking, the motion control in this case was successful, especially after improvement on the previous, the control program became simpler in structure, easier to use and more flexible to suit larger numbers of different complex shaped models.

The major problems encountered during the motion control are as follows:

LACK OF MEMORY: As we know, the machine is to generate the desired model step by step; and the greater the number of steps adopted for a specified model, the more accurate the shape will be. However, the number of steps to be adopted is limited in this case because more steps means more memory required in computer which some times leads the computer often display " out of memory" and can not continue to work. The maximum number of steps which can be assigned is 125 in this research. Lack of sufficient memory during running the control program is also contributed to by the (1) BASIC language itself which was used to develop this software and (2) computer itself with insufficient memory.

SYNCHRONIZATION: Synchronization of the PC23 indexers is another problem, which is still unsolved. Synchronization of three motor axes on one indexer is done by using global command "G123", which initiates all three motor axes motion approximately within 150 micro seconds of one another. As in the present research, two PC23 indexers were used, this time delay of initiating all the motor axes on both indexers could cause some inaccuracy in the profile being generated.

The main method used to obtain synchronization of all four axes in the project was to halt execution of commands, until all axes were ready to move in a synchronized way, which makes the machine motion look like an on - off and on - off, a discontinuous rather than a continuous motion.

Chapter 5

RESULTS AND DISCUSSIONS

5.1 Introduction

5.2 Results

5.3 Discussions

5.3.1 Overview

5.3.2 Data exchange between CAD/CAM

5.3.3 From graphic file to no-graphic file

5.3.4 Use of ruled surface

5.3.5 The factors affectting the machining accuracy

5.1 Introduction

All the research done here is an extension of a previous research project titled as "Effectiveness of Computer Controlled Robotic Precision Manipulator"[1], The experimental and hardware conditions are almost same as the original ones.

The main study undertaken here includes (1) summing up the technique for creating 3D model drawing for the Wire Electric Discharge Machining, (2) finding a way to bridge the gap between CAD and CAM for the WEDM, that is to say, transferring the complex 3D graphic drawing in AUTOCAD R11 to a non-graphic file in a proper way and then developing an interface program to establish a standard database via the non-graphic file in AUTO CAD for general use, (3) improving the control program so that it can be more universal, (4) undertaking experiments to verify the results of above research. The final aim is to realize the integration of CAD and CAM under the experimental conditions.

It must be mentioned that the manipulator described here is not suitable for carrying out tests on a real WEDM machine, since the workpiece needs to be immersed into a dielectric fluid. The simulated WEDM process was carried out by using a hot wire and a model material in place of the WEDM machine and tool steel material respectively.

Some die models with different complex 3D shapes have been generated.

The following pages show some photographs of die models and their cores produced during the experimental WEDM process.

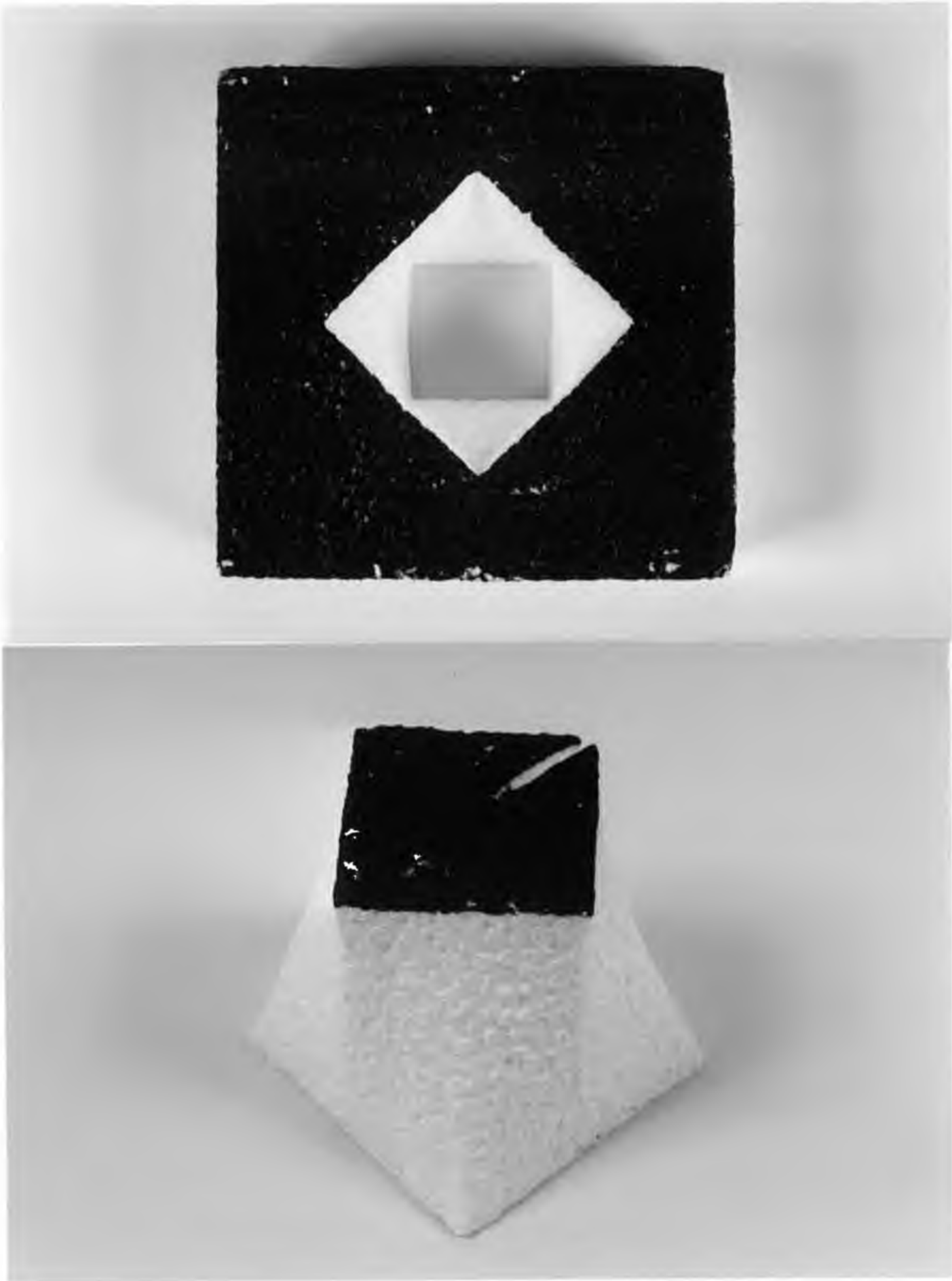


PLATE 1. Die Model and Its Core

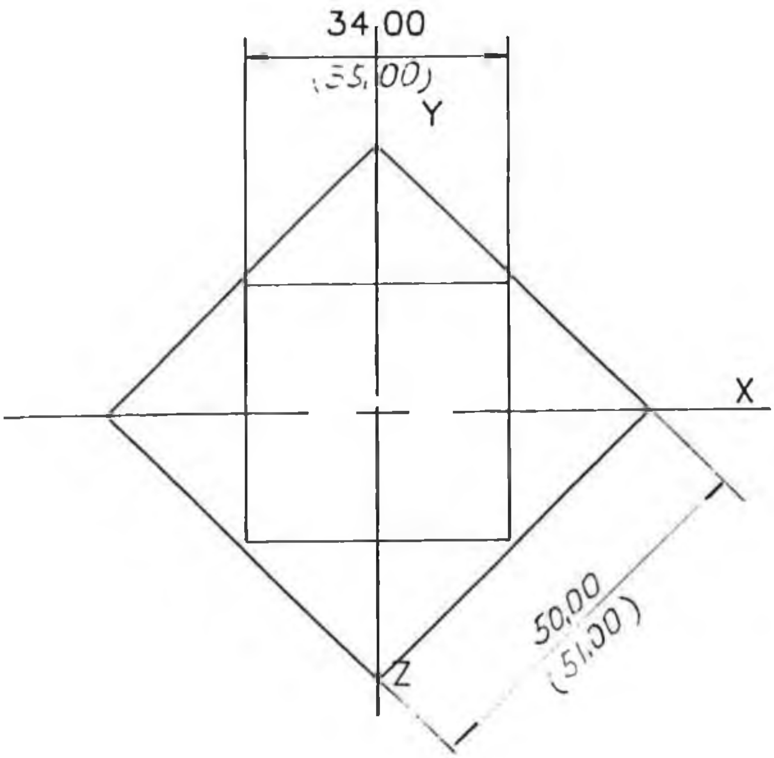


Fig. 5.1

In Fig.5.1 the numbers show the dimensions designed and the numbers in brackets show the dimensions actually produced. The difference between the dimensions is due to the spark gap and the diameter of the cutting wire in WEDM process.

DATA FOR PLATE 1

Diameter of cutting wire = 0.58 mm

Voltage supplied to cutting wire = 4.20 V

Current through the cutting wire = 1.6 A

Workpiece feedrate (sq. mm/min) = 800

Workpiece thickness = 50 mm

Scale = 1:1

PLATE 2. Die Model and Its Core

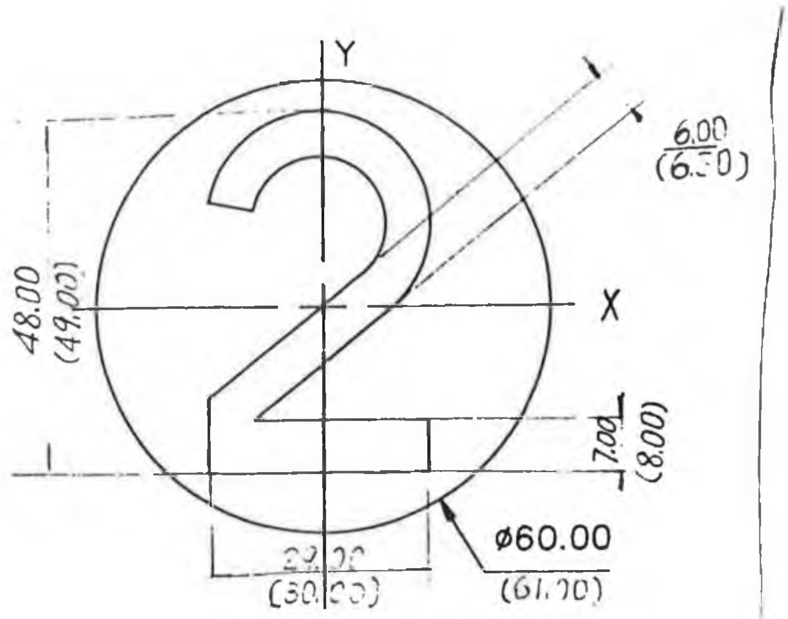


Fig. 5.2

In Fig.5.2 the numbers show the dimensions designed and the numbers in brackets show the dimensions actually produced. The difference between the dimensions is due to the spark gap and the diameter of the cutting wire in WEDM process.

DATA FOR PLATE 2

Diameter of cutting wire = 0.58 mm

Voltage supplied to cutting wire = 4.20 V

Current through the cutting wire = 1.6 A

Workpiece feedrate (sq. mm/min) = 800

Workpiece thickness = 50 mm

Scale = 1:1

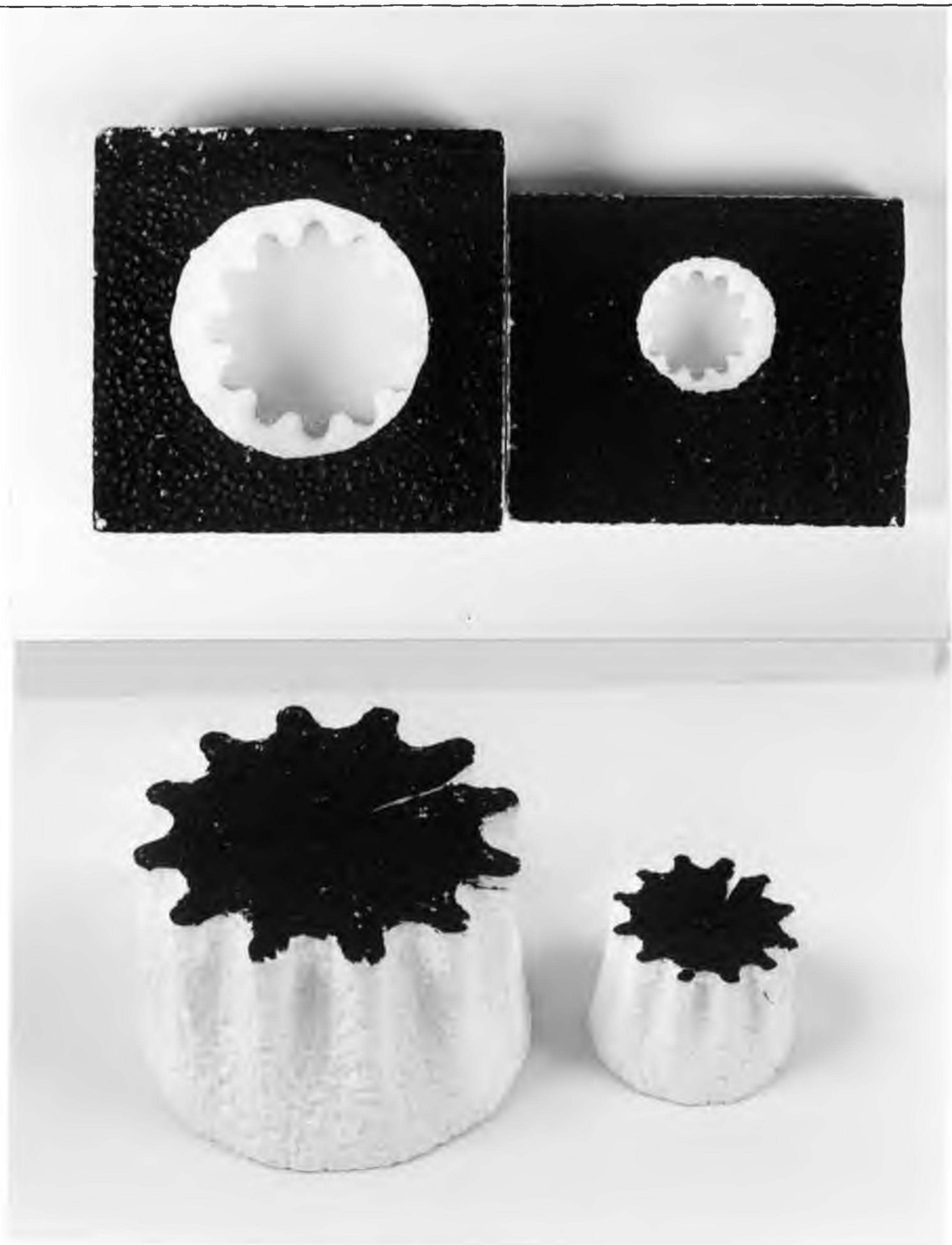


PLATE 3. Die Model and Its Core

DATA FOR PLATE 2

(1) Lager Die Model

Diameter of cutting wire = 0.58 mm

Voltage supplied to cutting wire = 4.20 V

Current through the cutting wire = 1.6 A

Workpiece feedrate (sq. mm/min) = 800

Workpiece thickness = 50 mm

Scale = 1:1

(2) Small Die Model

Diameter of cutting wire = 0.25 mm

Voltage supplied to cutting wire = 4.50 V

Current through the cutting wire = 0.92 A

Workpiece feedrate (sq. mm/min) = 800

Workpiece thickness = 25 mm

Scale = 2:1

PLATE 4. Die Model and Its Core

PLATE 5. Die Model and Its Core

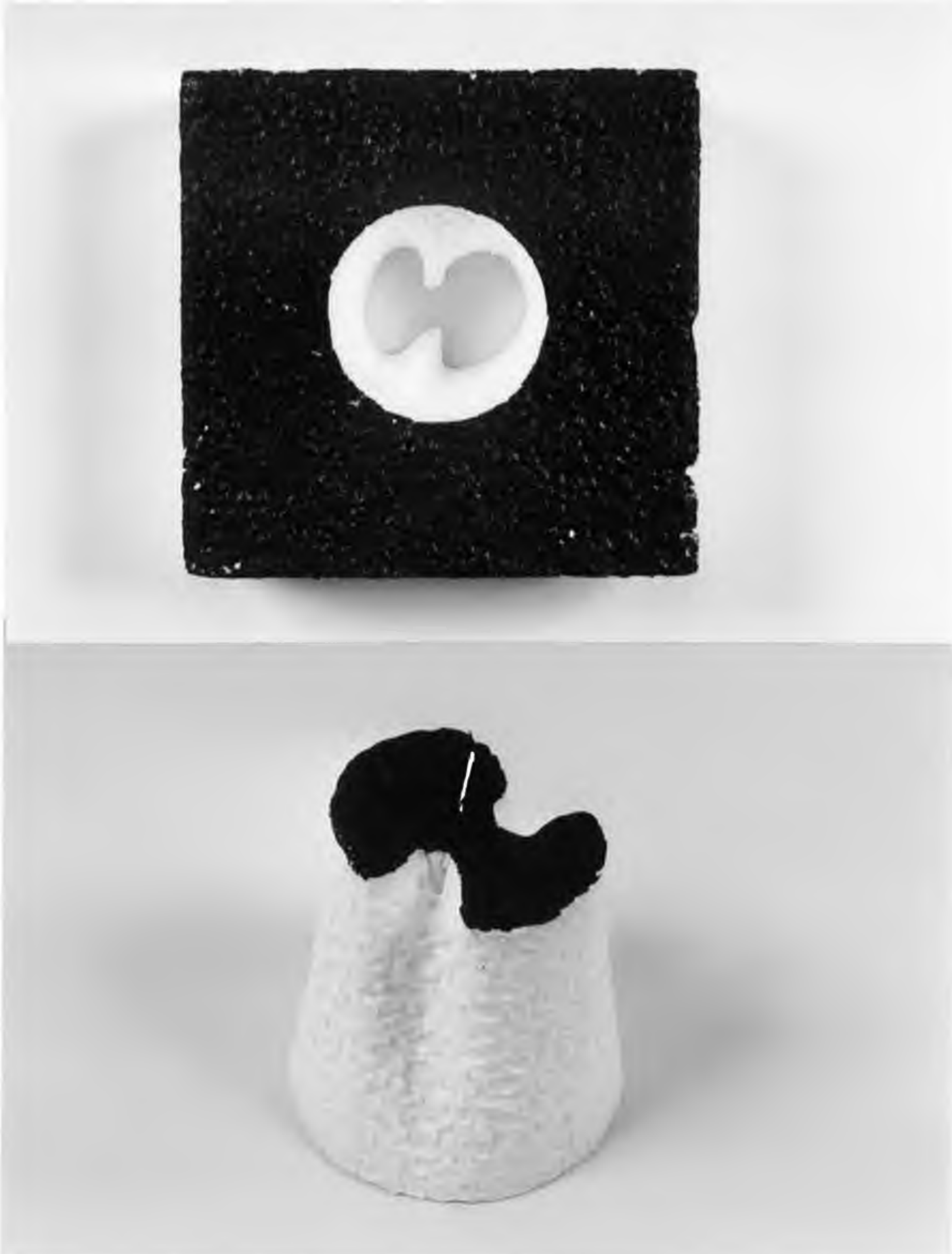


PLATE 6. Die Model and Its Core

PLATE 7. Die Model and Its Core

PLATE 8. Die Model and Its Core

PLATE 9. Die Model and Its Core

5.2 Results

Firstly, the technique for creating a complex 3D shaped drawing for the WEDM has been developed as described. The method developed to create the 3D model drawing is combined with considerations of its machining features. This is very useful because the same drawing created in a different way may not be suitable for the integration of CAD and CAM.

The ruled surface used to imitate the path of the cutting wire is a special feature in this case. For a die with a fixed top shape (Inlet) and a fixed bottom shape (Outlet), many different ruled surfaces could be designed to form many different 3D models according to the technique described in CHAPTER 2. These can then be compared with each other and finally one can be chosen which is the most suitable for the desired die by the WEDM.

According to the required machining accuracy for a die , any step length can be set as required as long as the memory of the computer is sufficiently large. In the previous related research[1], the subdivision on each model can only be divided into four fixed different numbers 100, 80, 60 and 40.

Also with the AUTOCAD RII, all 3D drawing can be created conveniently on the computer screen with their real dimensions rather than using a specified unit dimension as in the previous research.

Additionally, a larger or smaller size of a die model can easily be obtained using the SCALE command within the AUTOCAD.

Secondly, bridging the gap between CAD and CAM appears to be very important in any project related to integration of CAD and CAM because in most cases, software of CAD and CAM are developed in different environments and they also run in different environments. Additionally, published materials on the practical technique and theory for it are few. Even though some software for the integration of CAD and CAM has been developed throughout the world, this software is very expensive to buy. Furthermore a lot of work is required for per-processing and postprocessing in order to apply them to a specific project.

In this work this problem is solved in two ways, (1) Transferring the graphic drawings in AUTOCAD to non-graphic files. (By comparing IGES transferring with DXF transferring, DXF transferring method was adopted in this research to transfer graphic drawings to non-graphic files with AUTO CAD).

(2) For extracting the non-graphic files to a standard database, a DXF interface programm have been developed for this purpose.

It is specially designed to extract data from 3D die models for WEDM to establish a standard database for general use, in this way a bridge between CAD and CAM can be built.

Thirdly, the hardware and devices used previously in reference [1] have again been used in this work. The control program has however been improved relating its main structure and functions. The new general control program is now considerably simplified, it is more universal and is suitable for almost any kind of die model used in WEDM as well as being easier to operate.

Lastly, the results of the experiment undertaken in this project have proved that the technique of creating 3D drawings, the method of transferring and extracting data , DXF interface program developed and improved control program are successful. The aim of the integration of CAD and CAM for WEDM in this experimental conditions has been realized.

Now it can been seen that irrespective of how complex a shape a die has, its 3D model drawing can be more easily created and its die model can be more easily generated using the techniques developed in this project.

5.3 Discussion

5.3.1 Overview

CAD/CAM integration is a highly complex problem which includes integration of three different technical and management activities --- design, manufacturing and computing --- each of which may reside in different management components of a company.

Software related to manufacturing or motion control is written in BASIC in this case while AUTOCAD is written in C language which results in the integration of CAD/CAM often appearing fearsomely complicated.

This project actually is just a specific one of the integration of CAD/CAM, and is only related to a particular computer controlled manipulator in manufacturing and 3D complex shaped die model drawings for WEDM. In other words, this project is a much simplified one about the integration of CAD/CAM but it involves the central parts of the integration of CAD/CAM as well as CIM (computer integrated manufacturing).

5.3.2 Data exchange between CAD/CAM

In a integration of CAD/CAM, the key problem which needs to be solved is how to exchange data between CAD/CAM systems. This problem has two solutions: direct and indirect. The direct solution entails translating the modelling data stored in a product database directly from a CAD system format to a CAM system, usually in one step.

On the other hand, the indirect solution is more general and adopts the philosophy of creating a neutral database structure (also called a neutral file) which is independent of any existing or future CAD/CAM system. This structure acts as an intermediary and a focal point of communication among dissimilar database structures of CAD/CAM systems.

The structure of the neutral database must be general, governed only by the minimum required definitions of any of the modelling data types, and be independent of any vendor format. Naturally, the structure of this database is influenced by structures of existing vendor's database and can be viewed as the common denominator among them. In order to achieve such generality, efficiency and special enhancements to store and access the database suffer. Therefore the size of the neutral database is larger and its access speed is slower in comparison to counterparts created by some vendors' system.

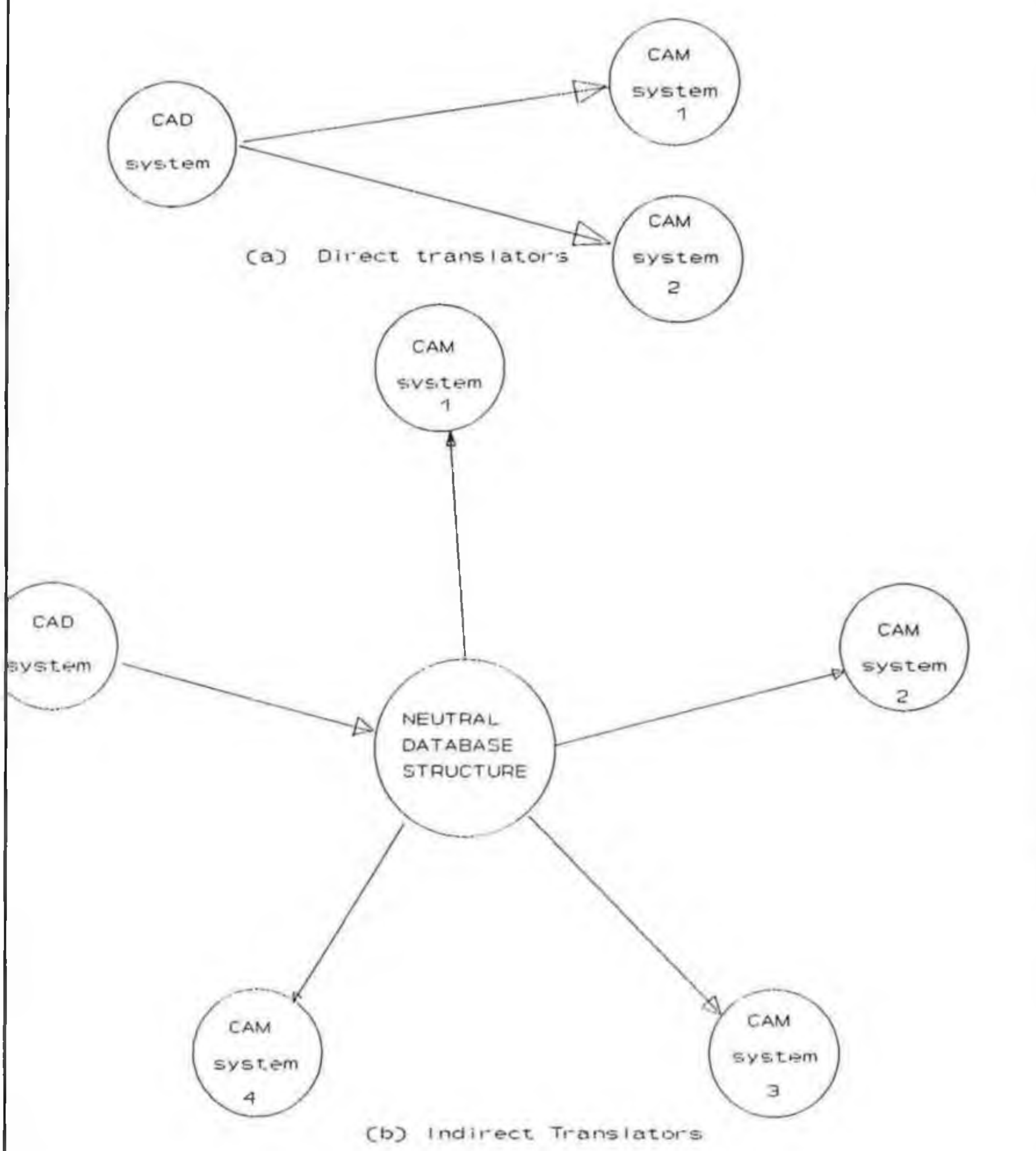


Fig. 5.3 Methods of exchanging data among dissimilar CAD/CAM systems

Indirect translator based on standard neutral file format are now the common practice while direct translators are seldom used.

In our research the former was adopted which is CAD---STANDARD DATABASE--- CAM procedure. Fig. 5.3 shows how both solutions work.

5.3.3 From graphic file to no-graphic file

To transfer graphic drawing in AUTOCAD to non-graphic file, two methods IGES and DXF formats are available. IGES files have some of the characteristics of AUTOCAD Drawing Interchange (DXF) Files, but DXF does avoid most problems of data loss compared with the IGES format. Also the data in a DXF file is presented in a rigid format with every type of entry identified by a code number, it is relatively easy to read or alternatively to use a simple computer program to check through the data and pick out only those bits which are required. So the DXF format was finally used for this purpose.

5.3.4 Use of ruled surface

The choice of the ruled surfaces to transfer graphic 3D drawing to non-graphic files is a main feature in this research.

In a graphic drawing in AUTO CAD, actually, it consists of lot of information such as HEADER, TABLES, BLOCKS and ENTITIES.

The header section contains the current values of the system variable; approximately 150 items in all covering everything from the snap setting to the current polyline width.

The tables section covers viewports, line types, layers, text styles, views, UCS's, dimstyles and data relating to currently running applications software such as AME(the advanced modelling extension).

The blocks section gives full details of all blocks in the drawing including block attributes, whether constant, variable or preset, and also full data on the entities of which the blocks are composed, e.g. lines, circles, polylines etc.

The entities section covers everything else. All entities not included in any blocks are detailed together with their coordinates in the drawing and the layer on which they appear.

Also , when relevant, data is given on the entities' thickness, linetype and colour.

But in the present case, we only need to know the relevant Entities which accurately describe the geometry in order to generate the die in WEDM. It is not advisable to transfer the whole graphic drawing to the standard database.

Also a point to bear in mind about transferring drawing to DXF file is that the entities must be chosen sequentially either clockwise or counterclockwise because it represents the order of the corresponding machining operation.

5.3.5 The factors affecting the machining accuracy

The main purpose of this research was to produce a precise die. There are several main factors influencing the precision of die production using WEDM under experimental conditions.

(1) Control system: The problem of synchronization of the PC 23 indexer is still not entirely solved. For synchronization, the three motor axes on one indexer is achieved by using a global command "G123", which initiates all three motor axes motion

approximately within 0.0015 seconds of one another. As in this research two PC23 indexers are used, the time delay of initiating all the 4 motor axes on both indexers will cause some inaccuracy in the profile to be generated.

In fact, the problem of the synchronization of 4 axes under coordinated control in engineering is very difficult to solve satisfactorily. The 4 axes coordinated control system produced by FUNAC Company in Japan could solve this problem but it is expensive.

(2) Mechanical system: The accuracy of the manipulator components produced will also affect the machining accuracy. Backlashes in either linear or rotary direction often exist in the gear box or motor, but this backlash error can be compensated to some extend by proper programming .

(3) Step length: This refers to the distance between two spline lines of the 3D model drawing mentioned in CHAPTER 2 for the cutting wire to pass. Of course, the smaller the step length, the more precise will be the die produced, but it will occupy more computer memory.

(4) Home position: As mentioned in CHAPTER 4, home position is defined as the Origin of the manipulator system coordinates, all

the data of 3D model drawing is referenced to that origin. It is required that the cutting wire should be positioned at the origin at first in order to produce an ideal die.

But it is virtually impossible to position exactly a line at the origin, so this kind of error will also influence the accuracy of the machined die.

(5) The gap produced by the cutting wire: Among all factors affecting the precision of the die produced, the gap produced by wire electric discharge is the most contributory one because the width of gap can range from 0.025 mm to 1.00 mm (see Fig.5.1 , Fig. 5.2 and Fig. 1.5).

With AUTOCAD, there is one way to compensate the error caused by the gap, The way is, first to determine exactly how wide the gap created is in the present condition, supposing that gap width is B, the designed diameter of a die outlet circle is D, it can be estimated that the diameter actually produced would be equal to D plus B rather than D.

The second is to amend the 3D drawing in AUTOCAD in the way of taking the advantage of SCALE function in AUTOCAD, because it is easy to enlarge or reduce a 3D drawing to any required size. A proper scale can be chosen to make the 3D drawing a little smaller to compensate for the gap so that the resulting dimensions of a die model wiil be as precise as required. In the above example, a scale factor S=(D-B)/D can be used to make the 3D drawing a little smaller so that diameter actually produced would be exactly D, see Figs.5.2 and 1.5. Other work get to be done is mentioned in CHAPTER 2. Of course, a lot of experiments also need to be performed in order to determine a proper scale value for that.

(6) Electric current, its voltage supplied to the cutting wire, (7) feedrate, (8) model material property, (9) diameter of the cutting wire and so on are also main factors affecting the machining accuracy.

By trial and error method, a very good precise die could finally be produced in this way.

Chapter 6

CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

6.1 Conclusions

6.2 Suggestions

6.1 Conclusion

In this research, an experimental and theoretical study towards the integration of CAD/CAM has been carried out on the existing robotic manipulator for WEDM simulation with the help of AUTOCAD R11.

The geometric features of 3D complex shaped model drawings for WEDM as well as the corresponding machining features were analyzed so that the technique of creating a 3D die model drawing for WEDM towards the integration of CAD/CAM was achieved. The method of realizing the integration of CAD/CAM has been evaluated; the standard database for 3D die model drawings can now be established by the DXF interface program developed here for general use; the motion control program was also much improved.

It was proved by the experiment that it is possible to achieve the integration of CAD/CAM to generate 3D complex shaped die accurately and efficiently using WEDM. The following can therefore be concluded:

1. The technique established for creating 3D complex shaped drawing for WEDM towards the integration of CAD/CAM is successful.

2. Transferring 3D graphic drawings to non-graphic files in DXF format is more convenient than that in the IGES format if it is to be subsequently processed by other software.

3. The generation of a ruled surface, taken as the path imitation of the cutting wire in WEDM, is an important feature of this project.

4. When transferred, it is advisable to choose sequentially the entities of the relevant ruled surface (the splines of the die).

5. The DXF interface extracting program developed here for WEDM is very successful and the form of database obtained in this way can be available for general use.

6. As one of the features of integration of CAD/CAM, setting the step length properly and making use of the offset or scale function wisely in CAD stage could greatly improve the accuracy of the die generated.

7. For integration among different systems, a neutral standard database should be established as a bridge to connect each other system as a practical method.

8. The general control program improved here is more flexible and

more easy to use than the one in reference [1].

In one words, except Item 8, all the conclusions mentioned above can be directly applied to a real CNC WEDM.

6.2 Suggestions for further work

Several aspects have been considered in the present work which relate to the effectiveness of the integration of CAD/CAM for WEDM simulation experiment. Some of these have been investigated thoroughly, but others have not been investigated due to limited time and the scope of the present work. The following are some suggestions for further work:

1. For the integration of CAD/CAM, it is better to use the updated AUTOCAD R12 for creating 3D complex shaped model drawing because AUTOCAD R11 lacks some basic functions.

2. The procedure to position the cutting wire exactly at the home position has still to be investigated.

3.The present computer connected with the manipulator needs to be replaced by one with more memory.

4. The control program developed in BASIC should be written in C language.

5. It is time now to apply the results obtained here to real WEDM.

6. Because most advanced WEDM are CNC machines, it is suggested to develop a new control program and carry out research on the integration of CAD and CAM for CNC WEDM machine.

7. Part of the results obtained here could possibly be applied to some other projects related to the integration of CAD/CAM or CIM.

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The following is A DXF file from 3D file in Fig. 2.8 or 2.13 from whice the DXF file structure and features can be seen.

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VERTEX
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SEQEND
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ENDSEC
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EOF
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APPENDIX 2

A GENERAL CONTROL PROGRAM

```
1000 '*************************************************************
1010 '************A*GENERAL*CONTROL*PROGRAM******************
1020 '*************************************************************
1030 KEY OFF:CLEAR:CLS:SCREEN 1:LOCATE 10,14:PRINT "PLEASE  WAIT"
1040 LOCATE 13,14 : PRINT "LOADING DATA"
1050 PRINT
1060 LOCATE 15,14: PRINT "For example,"
1070 PRINT
1080 LOCATE 17,14: PRINT "C:\3d-model.dat"
1090 PRINT
1100 LINE INPUT "DATABASE file name:";F$
1110 OPEN "i",#2,F$
1120 I=0
1130 DIM XB(250),YB(250),XT(250),YT(250)
1140 IF EOF(2) THEN N=I:GOTO 1180
1150 I=I+1
1160 INPUT #2,XB(I),YB(I),ZB,XT(I),YT(I),ZT,AP
1170  GOTO 1140
1180 CLOSE #2 : CLS
1190 PI = 3.141592654# : RD = 180/PI : DR = PI/180
1200 '**************************************************************
1210 DIM ALFA1(N+3),BETA1(N+3),BETA2(N+3),BETA3(N+3),BETA4(N+3)
1220 DIM XB1(N+3), YB1(N+3), ZB1(N+3), ZT1(N+3), RSLT(N+3)
1230 CLS : LOCATE 3,14 : PRINT " PLEASE WAIT "
1240 LOCATE 6,3 : PRINT "CALCULATING :-
1250 LOCATE 8,9 : PRINT "1.  PITCH AND ROLL ANGLES.
1260 LOCATE 10,9 : PRINT "2.  ROTATING CO-ORDINATES.
1270 LOCATE 12,9 : PRINT "          AND
1280 LOCATE 14,9 : PRINT "3.  CHECKING  THAT  EITHER
1290 LOCATE 16,9 : PRINT "    THESE    ANGLES    ARE
1300 LOCATE 18,9 : PRINT "    ACHEIVABLE OR NOT ...?
1310 COLOR 1,5
1320 '
1330 '***** FOLLOWING LOOP CLCULATES ALFA, BETA AND  ROTATIONAL ****
1340 '***** CO-ORDINATES, AND  CHECKS THESE  ACHEIVABLE  ANGLES ****
1350 '--------------------------------------------------------------
1360 FOR I = 1 TO N+1
1370 ALFA1(I) =   ATN( (YT(I)-YB(I)) / ZT )
1380 BETA1(I) =   ATN( (XT(I)-XB(I)) / ZT )
1390 YB1(I) = YB(I) * COS(  ABS(ALFA1(I))   )
1400 ZB1(I) = YB(I) * SIN ( ALFA1(I) )
1410 RSLT(I) = SQR( ABS( (YT(I)-YB(I))^2 + ZT^2 ) )
1420 ZT1(I) = ZB1(I) + RSLT(I)
1430 BETA2(I) = ATN( ZB1(I)/XB(I) )
1440 BETA3(I) = ATN( (XT(I)-XB(I)) / (ZT1(I)-ZB1(I)) )
1450 BETA4(I) = BETA2(I) + BETA3(I)
1460 XB1(I) = XB(I)  * COS( ABS(BETA4(I))  ) / COS( ABS(BETA2(I)))
1470 IF ZT > 72  AND (ALFA1(I)*RD) < -30 THEN BEEP : GOTO 1620
1480  'W.P. protection from being in touch with upper support bar of
```

```
1490  'W.P. protection from being in touch with upper support bar of main beam
1500 IF ZT > 50 AND (ALFA1(I)*RD) < ((6+(ATN(60/ZT)*RD))-90) THEN BEEP:GOTO
     1620
1510  'W.P. protection from being in touch with Mx10 HCSH screw.
1520 IF (YT(I)-YB(I)) < 0 AND (ALFA1(I)*RD) < ( (ABS(( ATN(17.5/(60+YB(I)))
     )*RD))-90) THEN BEEP : GOTO 1620
1530 'Protection of wire being in touch with inner frame for max .-ve Alfa
1540 IF (ALFA1(I)*RD) > (90-( ATN(17.5/(60-YB(I) )))   ) THEN BEEP : GOTO 1620
1550 'Protection of wire being in touch with inner frame for max. +ve Alfa
1560 IF (XT(I)-XB(I)) < 0 AND (BETA3(I)*RD) < -50 THEN BEEP : GOTO 1670
1570  'Protection of motor being in touch with table (Base) at Max. -ve Beta.
1580 IF (BETA3(I)*RD) > ( 90-((ATN(17.5/(50-XB(I)))) *RD)) THEN BEEP:GOTO 1670
1590  'Protection of wire being in touch with inner frame at Max. +ve Beta.
1600 NEXT I
1610 GOTO 1770
1620 CLS
1630 PRINT"SORRY ! THE PITCH MOTION IS MORE THAN IT IS OFFERED BY THE
1640 PRINT"MANIPULATOR.  IT WILL CAUSE THE  WORKPIECE EDGE OR CUTTING
1650 PRINT "WIRE TO BE IN TOUCH WITH THE STABLIZER (DRG. NO. 01B02)."
1660 PRINT : PRINT : GOTO 6740
1670 CLS
1680 PRINT "SORRY !  THE ROLL MOTION  IS MORE THAN IT IS  OFFERED BY  THE"
1690 PRINT "MANIPULATOR.  IT WILL CAUSE THE  CUTTING WIRE IN  TOUCH  WITH"
1700 PRINT "THE MANIPULATOR OR MOTOR NO. 4 IN TOUCH WITH THE TABLE (BASE)"
1710 PRINT : PRINT
1720 GOTO 3540
1730 '____________________________________________________________
1740 '**FOLLOWING LOOP CHANGE ABSOLUTE DISTANCES TO MOTOR STEPS AND*
1750 '**COMPENSATES THE BACKLESH OF 1 DEGREE IN G.BOX  WITH MOTOR 3*
1760 '------------------------------------------------------------
1770 ERASE BETA1, BETA2, BETA4, ZB1, ZT1, RSLT
1780 DIM M(N+3),M1(N+3),M2(N+3),M3(N+3),M4(N+3)
1790 CLS : SCREEN 1 : LOCATE 5,14 : PRINT " PLEASE WAIT "
1800 LOCATE 8,12 : PRINT "CHANGING ABSOLUTE"
1810 LOCATE 10,12 : PRINT "DISTANCE TO MOTOR"
1820 LOCATE 12,12 : PRINT "STEPS          AND
1830 LOCATE 14,12 : PRINT "COMPENSATES    THE
1840 LOCATE 16,12 : PRINT "BACKLESH IN G.BOX
1850 LOCATE 18,12 : PRINT "WITH MOTOR  NO. 3
1860 FOR I = 1 TO N+1
1870 M1(I) = FIX((5000/1.5) * XB1(I))
1880 M2(I) = FIX((5000/1.5) * YB1(I))
1890 M3(I) = FIX(((18 * 5000) / 360 )*(BETA3(I)*RD)):M3(I) = -M3(I)
1900 M4(I) = FIX(((100 * 5000) / 360 ) * (ALFA1(I)*RD)) : GOTO 1990
1910  IF I =  1 THEN GOTO 1980
1920  IF M(1) < 0  THEN GOTO 1970
1930  IF M(1) > 0  THEN GOTO 1950
1940  IF M(1) = 0 AND M(2) < 0 THEN GOTO 1970
1950  IF M(I) < M(I-1) THEN M3(I) = M(I)  - 250  ELSE M3(I)=M(I)
1960  GOTO 1990
1970  IF M(I) > M(I-1) THEN M3(I) = M(I)  + 250 ELSE M3(I)=M(I)
1980  IF I = 1         THEN M3(1) = M(1)
1990 NEXT I
2000 LOCATE 22,5 : GOSUB 5330
2010 CLS : SCREEN 2 : SCREEN 0,0,0
2020 INPUT "INPUT WORKPIECE FEEDRATE (Max. 800 mm. Sqr./min. =";FR
2030 CLS : SCREEN 1 : LOCATE 5,14 : PRINT " PLEASE WAIT "
2040 LOCATE 9,8 : PRINT "1. CALCULATING INSTANTANEOUS"
```

```
2050 LOCATE 10,11 : PRINT "AND  CONSTANT  VELOCITIES"
2060 LOCATE 12,19 : PRINT "AND
2070 LOCATE 14,8 : PRINT "2. CONSTRUCTING CHARACTER"
2080 LOCATE 15,8 : PRINT "   COMMANDS  USING   PC23"
2090 LOCATE 16,8 : PRINT "   INDEXER COMMANDS."
2100 LOCATE 20,4 : PRINT "THIS IS POINT NUMBER     OUT OF"
2110 LOCATE 21,4 : PRINT "TOTAL POINTS ";N+1;" ON THIS DIE." 2120 COLOR 1,5
2130 '
2140 '** FOLLOWING LINES CALCULATE MACHINING AREA, MACHINING TIME **
2150 '** AND CONSTRUCTS  THE COMMANDS FOR  MOTOR  MOTION  CONTROL **
2160 '-------------------------------------------------------------
2170 DIM RB(N+3), RT(N+3), AREA(N+3), TAREA(N+3), XA(N+3), YA(N+3)
2180 DIM ALFA(N+3), BETA(N+3), TM(N+3), MIN(N+3), SEC(N+3)
2190 DIM  CMD$(4,N+3), TIME(N+3)
2200 FOR I = 1 TO N+1
2210 RB(I) = SQR(((XB(I)-XB(I-1))^2) + ((YB(I)-YB(I-1))^2))
2220 RT(I) = SQR(((XT(I)-XT(I-1))^2) + ((YT(I)-YT(I-1))^2))
2230 AREA(I) = ( (RB(I)+RT(I))*ZT )/2
2240 TAREA(I) = TAREA(I-1) + AREA(I)
2250 XA(I) = XB1(I) - XB1(I-1)
2260 YA(I) = YB1(I) - YB1(I-1)
2270 ALFA(I) = ALFA1(I)-ALFA1(I-1)
2280 BETA(I) = BETA3(I)-BETA3(I-1)
2290 S = SQR(XA(I)^2 + YA(I)^2) : H = AREA(I)/S
2300 TM(I) = S / ( FR/(H*60) )
2310 MIN(I) = INT(TM(I)/60)
2320 SEC(I) = (((TM(I)/60)-MIN(I))*60)
2330 LOCATE 20,25 : PRINT I
2340 RTO = ABS(YA(I) / XA(I))
2350 VR = (FR/(H*60)) * (1/1.5)
2360 K = M1(I) : B = 2
2370 IF K  < 0 THEN  B = 1
2380 D$ = MID$( STR$(K),B )
2390 S$ = MID$( STR$(1),1 )
2400 VX = SQR((VR^2) / (1+RTO^2))
2410 'TX = ABS(XA(I))/(VX*1.5) : PRINT TAB(20);TX;
2420 P = VX : GOSUB 5400 : VX$ = MID$(P$,1)
2430 CMD$(1,I) = S$+"VS"+VX$+S$+"V"+VX$+S$+"D"+D$+S$+"I"
2440 K = M2(I) : B = 2
2450 IF K < 0 THEN  B = 1
2460 D$ = MID$( STR$(K),B )
2470 S$ = MID$( STR$(2),1 )
2480 VY = VX * RTO
2490 P = VY : GOSUB 5400 : VY$ = MID$(P$,1)
2500 'TY = ABS(YA(I))/(VY*1.5)  : PRINT TAB(34);TY;
2510 CMD$(2,I) = S$+"VS"+VY$+S$+"V"+VY$+S$+"D"+D$+S$+"TS"+S$+"I"
2520 K = M3(I) : B = 2
2530 IF K < 0 THEN B = 1
2540 D$ = MID$( STR$(K),B )
2550 S$ = MID$( STR$(3),1 )
2560 VB = (ABS(BETA(I))*18) / (2*PI*TM(I))
2570 P = VB : GOSUB 5400 : VB$ = MID$(P$,1)
2580 'TB = (ABS(BETA(I)*18)/(2*PI*VB)) : PRINT TAB(48);TB;
2590 CMD$(3,I) = S$+"VS"+VB$+S$+"V"+VB$+S$+"D"+D$+S$+"I"
2600 K = M4(I) : B = 2
2610 IF K < 0 THEN B = 1
2620 D$ = MID$( STR$(K),B )
2630 S$ = MID$( STR$(3),1 )
```

```
2640 VA = (ABS(ALFA(I)*100))/(2*PI*TM(I))
2650 P = VA : GOSUB 5400 : VA$ = MID$(P$,1)
2660 'TA=(ABS(ALFA(I))*100)/(2*PI*VA)  : PRINT TAB(62);TA
2670 CMD$(4,I) = S$+"VS"+VA$+S$+"V"+VA$+S$+"D"+D$+S$+"I"
2680 TIME(I) = TIME(I-1) + TM(I)
2690 NEXT I
2700 CLS : SCREEN 2 : SCREEN 0,0,0
2710 LOCATE 12,8
2720 PRINT "PRESS SPACE BAR TO DISPLAY ALFA, BETA, MACHINING TIME AND AREA"
2730 LOCATE 13,8
2740 PRINT "-------------------------------------------------------------"
2750 GOSUB 5340 : CLS
2760 PRINT "_______________________________________________________________________________
2770 PRINT "|SEGMENT|  ALFA   |  BETA   |MACHINING | MACHINING|  TOTAL   | TOTAL
2780 PRINT "|NUMBER |  (Degr- | (Degr-  |  AREA    |   TIME    | M.AREA   | M.TIME
2790 PRINT "|       |   ees)  |  ees)   |(mm Sq.)  | (Seconds)|  mm Sq.  | (Sec.)
2800 PRINT "|-------|---------|---------|----------|-----------|----------|-------
2810 FOR I =  1 TO N+1
2820 ALFA1 = ALFA1(I)*RD : BETA3 = BETA3(I)*RD
2830 ALFA$=MID$(STR$(ALFA1),1,7) : BETA$=MID$(STR$(BETA3),1,7)
2840 AREA$ = MID$(STR$(AREA(I)),1,8)  : MT$ = MID$(STR$(TM(I)),1,8)
2850 TAREA$ = MID$(STR$(TAREA(I)),1,9):TM$ = MID$(STR$(TIME(I)),1,8)
2860 PRINT "|";TAB(4);I;TAB(9);"|";TAB(10);ALFA$;TAB(18);"|";TAB(19);BETA$; 2870
PRINT TAB(27)"|";TAB(28);AREA$;TAB(38);"|";TAB(39);MT$;TAB(49);"|";
2880 PRINT TAB(50);TAREA$;TAB(59)"|";TAB(60);TM$;TAB(68);"|"
2890 NEXT I
2900 PRINT ":-----------------------------------------------------------------------------
2910 MIN = INT(TIME(I-1)/60)  : TTIM = TIME(I-1)
2920 SEC=(((TIME(I-1)/60)-MIN)*60):TAREA$=MID$(STR$(TAREA(I-1)),1,9)
2930 TIM$ = STR$(MIN)+" MINUTES AND"+MID$(STR$(SEC),1,6)+" SECONDS"
2940 PRINT TAB(7);"TOTAL AREA OF";TAREA$ ;" mm. Sqr. NEEDS MACHINING";
2950 PRINT " TIME  OF";TIM$;" AT THE FEED RATE OF ";FR; " mm Sqr./Min."
2960 PRINT : PRINT  TAB(25) : GOSUB  5330
2970 'ERASE XB1, YB1, M, RB, RT
2980 ERASE M
2990 SCREEN 0,1 : WIDTH 40
3000 CLS : LOCATE 2,13 : PRINT "PLEASE ! MAKE SURE
3010 LOCATE 5,8 : PRINT "1. THE MANIPULATOR IS IN READY POSITION.
3020 LOCATE 8,8 : PRINT "2. W.C.U.    IS    IN    RIGHT    POSITION.
3030 LOCATE 11,8 : PRINT "3. WORKPIECE    IS    PROPERLY    HOUSED.
3040 LOCATE 14,8 : PRINT "4. MICRO SWITCH IS  PROPERLY POSITIONED.
3050 LOCATE 17,8 : PRINT "5  PVR IS CONNECTED TO THE INDEXER # 1 .
3060 COLOR 23,0 : LOCATE 22,2,0
3070 PRINT "PRESS SPACE BAR TO START INITIALIZATION"
3080 GOSUB 5340  : SCREEN 1 : COLOR 1,5 :  GOSUB 5550
3090 SCREEN 2
3100 '______________________________________________________________
3110 '****  FOLLOWING LOOP  CONTROL THE MOTOR MOTION AND  CHECKS ***
3120 '****  THE TRIGGER INPUT FROM 'PVR' CIRCUIT AFTER EACH MOVE ***
3130 '--------------------------------------------------------------
3140 FOR L = 1 TO N+1
3150 ADDRESS% = ADDRESS2%
3160 CMD$ = CMD$(4,L) : GOSUB 6930
3170 ADDRESS% = ADDRESS1%
3180 CMD$ = CMD$(1,L)+CMD$(2,L)+CMD$(3,L)  : GOSUB 6930
3190 CND$ = CMD$(1,L)+CMD$(2,L) : CDN$ = CMD$(3,L)+CMD$(4,L)
3200 GOSUB 3690
3210 GOSUB 7220
```

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3220 IF ANSWER$ = "2:001000"+CHR$(13) THEN 3230 ELSE 3250
3230 TTIM = 0 : TEM = 0 : GOSUB 3770
3240 L = Z : GOTO 3150
3250 TEM = TEM + TM(L) : TMI = TTIM - TEM
3260 MIN = INT(TMI/60) : SEC = (((TMI/60)-MIN)* 60)
3270 TMS$ = STR$(MIN)+" MINUTES AND"+MID$(STR$(SEC),1,6)+" SECONDS."
3280 TME$ = STR$(MIN(L))+" MINUTES AND"+MID$(STR$(SEC(L)),1,6)+" SECONDS."
3290 LOCATE 3,47 : PRINT TMS$
3300 LOCATE 4,47 : PRINT TME$
3310 ADDRESS% = ADDRESS2% : CMD$ = "3G" : GOSUB 6930 : ADDRESS% = ADDRESS1%
3320 CMD$ = "G123"  : GOSUB 6930
3330 LOCATE 9,18:PRINT "NOW POINT NUMBER";L;"IS BEING MANUFACTURED."
3340 LOCATE 18,12
3350 PRINT "COMMANDS SENT TO THE PC23 INDEXERS FOR POINT ";L;" ARE
3360 LOCATE 20,10
3370 PRINT "                                                                     "
3380 LOCATE 21,10
3390 PRINT "                                                                     "
3400 LOCATE 20,10 : PRINT ;CND$ : LOCATE 21,10 : PRINT ;CDN$
3410 LOCATE 12,18:PRINT "PRESS 'R' IF WISH TO CHANGE VOLTAGE IN THE"
3420 LOCATE 13,18:PRINT "CUTTING WIRE OR TO TEST RETRACING FACILITY"
3430 Q$ = INKEY$
3440 IF Q$ = "R" OR Q$ = "r" THEN GOTO 3450 ELSE 3460
3450 GOSUB 3690 : GOSUB 5760
3460 NEXT L
3470 GOSUB 3690 : PRINT : PRINT : PRINT
3480 '*************************************************************
3490 LOCATE 23,26 : PRINT "PRESS SPACE BAR TO CONTINUE. "
3500 GOSUB 5340
3510 ADDRESS% = ADDRESS1%
3520 CMD$ = "O000001" : GOSUB 6930
3530 GOTO 3540
3540 CLS : SCREEN 1 : PLAY "ABABABC" : LOCATE 5,5
3550 PRINT "PLEASE ! " : LOCATE 8,10
3560 PRINT "TURN OFF THE POWER SUPPLIES"
3570 LOCATE 11,10 : PRINT "TO   ALL   THE   EQUIPMENT."
3580 LOCATE 16,23  : PRINT "THANKS"
3590 PLAY "ABABABABCDCDCDAD":FOR DL = 1 TO 1000:NEXT:CLS:LOCATE 12,3
3600 PRINT "E N D   O F   T H E   P R O G R A M":FOR DLY = 1 TO 5000
3610 NEXT DLY  : SCREEN 2 : SCREEN 0,0,0 : END
3620 '*************************************************************
3630 '*********** E N D    O F    T H E    P R O G R A M ***********
3640 '*************************************************************
3650 '
3660 '**     FOLLOWING LINES  CHECK THAT, IS THE  COMMANDED MOVE     **
3670 '**     COMPLETED OR NOT. IF YES, THEN STOP ALL  THE MOTORS     **
3680 '-------------------------------------------------------------
3690 ADDRESS% = ADDRESS1%
3700 CH = INP(ADDRESS%+1)
3710 IF (CH AND 1) + (CH AND 2) + (CH AND 4) = 7 THEN 3720 ELSE 3700
3720 CMD$ = "1S 2S 3S" : GOSUB 6930
3730 RETURN
3740 '
3750 '** THIS S-ROUTINE RETRACES W.P. TILL  Trg. INPUT IS CLEARED **
3760 '-------------------------------------------------------------
3770 GOSUB 3690 : CMD$ = CPD$ + " O0000X1" : GOSUB 6930 : CLS
3780 LOCATE 8,20 : PRINT "TRIGGER INPUT SIGNAL IS ENCOUNTERED  NOW"
3790 LOCATE 10,20:PRINT "POWER  SUPPLY  TO THE  CUTTING  WIRE  IS"
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3800 LOCATE 11,20:PRINT "STOPED AND ALL MOTOR MOTIONS ARE KILLED."
3810 PLAY "AGAGAGAGA"
3820 FOR Z = (L-1) TO 1 STEP -1
3830 RB(Z) = SQR(((XB(Z)-XB(Z-1))^2) + ((YB(Z)-YB(Z-1))^2))
3840 RT(Z) = SQR(((XT(Z)-XT(Z-1))^2) + ((YT(Z)-YT(Z-1))^2))
3850 AREA(Z) = ( (RB(Z)+RT(Z))*ZT )/2
3860 XA(Z) = XB1(Z) - XB1(Z-1)
3870 YA(Z) = YB1(Z) - YB1(Z-1)
3880 ALFA(Z) = ALFA1(Z)-ALFA1(Z-1)
3890 BETA(Z) = BETA3(Z)-BETA3(Z-1)
3900 S = SQR(XA(Z)^2 + YA(Z)^2) : H = AREA(Z)/S
3910 TM(Z) = S / ( FR/(H*60) )
3920 MIN(Z) = INT(TM(Z)/60)
3930 SEC(Z) = (((TM(Z)/60)-MIN(Z))*60)
3940 RTO = ABS(YA(Z) / XA(Z))
3950 VR = (FR/(H*60)) * (1/1.5)
3960 K = M1(Z-1) : B = 2
3970 IF K  < 0 THEN  B = 1
3980 D$ = MID$( STR$(K),B )
3990 S$ = MID$( STR$(1),1 )
4000 VX = SQR((VR^2) / (1+RTO^2))
4010 P = VX : GOSUB 5400 : VX$ = MID$(P$,1)
4020 CMD$(1,Z) = S$+"VS"+VX$+S$+"V"+VX$+S$+"D"+D$+S$+"I"
4030 K = M2(Z-1) : B = 2
4040 IF K < 0 THEN  B = 1
4050 D$ = MID$( STR$(K),B )
4060 S$ = MID$( STR$(2),1 )
4070 VY = VX * RTO
4080 P = VY : GOSUB 5400 : VY$ = MID$(P$,1)
4090 CMD$(2,Z) = S$+"VS"+VY$+S$+"V"+VY$+S$+"D"+D$+S$+"TS"+S$+"I" 4100 K = M3(Z-1)
: B = 2
4110 IF K < 0 THEN B = 1
4120 D$ = MID$( STR$(K),B )
4130 S$ = MID$( STR$(3),1 )
4140 VB = (ABS(BETA(Z))*18) / (2*PI*TM(Z))
4150 P = VB : GOSUB 5400 : VB$ = MID$(P$,1)
4160 CMD$(3,Z) = S$+"VS"+VB$+S$+"V"+VB$+S$+"D"+D$+S$+"I"
4170 K = M4(Z-1) : B = 2
4180 IF K < 0 THEN B = 1
4190 D$ = MID$( STR$(K),B )
4200 S$ = MID$( STR$(3),1 )
4210 VA = (ABS(ALFA(Z)*100))/(2*PI*TM(Z))
4220 P = VA : GOSUB 5400 : VA$ = MID$(P$,1)
4230 CMD$(4,Z) = S$+"VS"+VA$+S$+"V"+VA$+S$+"D"+D$+S$+"I"
4240 CND$=CMD$(1,Z)+CMD$(2,Z):CDN$=CMD$(3,Z)+CMD$(4,Z)
4250 ADDRESS% = ADDRESS2% : CMD$ = CMD$(4,Z)  : GOSUB 6930
4260 ADDRESS%=ADDRESS1% : CMD$=CMD$(1,Z)+CMD$(2,Z)+CMD$(3,Z)
4270 GOSUB 6930
4280 '----------------------------------------------------------
4290 TME$ = STR$(MIN(Z))+" MINUTES AND "+MID$(STR$(SEC(Z)),1,6)
4300 LOCATE 13,20
4310 PRINT "TIME REQUIRED FOR POINT NO. ";Z;" IS TO BE"
4320 LOCATE 14,20
4330 PRINT "RETRACED =";TME$;" SECONDS."
4340 LOCATE 18,13
4350 PRINT"COMMANDS SENT TO PC23 INDEXERS FOR POINT NO. ";Z;" ARE ="
4360 LOCATE 20,10
4370 PRINT "                                                        "
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4380 LOCATE 21,10
4390 PRINT "                                                              "
4400 GOSUB 3690
4410 LOCATE 20,10:PRINT ;CND$:LOCATE 21,10:PRINT ;CDN$
4420 ADDRESS% = ADDRESS2% : CMD$ = "3G" : GOSUB 6930
4430 ADDRESS% = ADDRESS1% : CMD$ = "G123":GOSUB 6930
4440 GOSUB 7220
4450 IF ANSWER$ = "2:000000" + CHR$(13) THEN 4480
4460 IF Z = 1 THEN 4480
4470 NEXT Z
4480 GOSUB 3690 : CLS
4490 PLAY "ABABC":LOCATE 10,25:PRINT "TRIGGER INPUT IS CLEARED NOW."
4500 LOCATE 14,10
4510 INPUT "INPUT NEW WORKPIECE FEEDRATE (Max. 800 mm Sq./min. =";FR
4520 CLS : SCREEN 1 : LOCATE 5,14 : PRINT " PLEASE WAIT "
4530 LOCATE 9,4 : PRINT "1. CALCULATING  NEW  INSTANTANEOUS"
4540 LOCATE 10,7 : PRINT "AND CONSTANT VELOCITIES"
4550 LOCATE 12,18 : PRINT "AND"
4560 LOCATE 14,4 : PRINT "2. CONSTRUCTING CHARACTER COMMANDS"
4570 LOCATE 15,7 : PRINT "USING PC23 INDEXER COMMANDS."
4580 LOCATE 20,3 : PRINT "THIS IS POINT NUMBER         OUT  OF"
4590 LOCATE 21,3 : PRINT "TOTAL POINTS ";N+1;" ON THIS SPUR GEAR."
4600 '_____________________________________________________________
4610 '*FOLLOWING SUBROTINE CALCULATE NEW MACHINING TIME, VELOCITIES**
4620 '*** AND CONSTRUCTS THE COMMANDS  FOR  MOTOR  MOTION CONTROL ***
4630 '-------------------------------------------------------------
4640 FOR Y = Z TO N+1
4650 LOCATE 20,25 : PRINT Y
4660 S = SQR(XA(Y)^2 +YA(Y)^2) : H = AREA(Y)/S
4670 TM(Y) = S / (FR/(H*60))
4680 MIN(Y) = INT(TM(Y)/60)
4690 SEC(Y) = (((TM(Y)/60)-MIN(Y)) *60)
4700 RTO = ABS(YA(Y) / XA(Y) )
4710 VR = (FR/(H*60)) * (1/1.5)
4720 K = M1(Y) : B = 2
4730 IF K < 0 THEN B = 1
4740 D$ = MID$( STR$(K),B)
4750 S$ = MID$( STR$(1),1)
4760 VX = SQR((VR^2) / (1+RTO^2))
4770 P = VX : GOSUB 5400 : VX$ = MID$(P$,1)
4780 CMD$(1,Y) = S$+"VS"+VX$+S$+"V"+VX$+S$+"D"+D$+S$+"I"
4790 K = M2(Y) : B = 2
4800 IF K < 0 THEN  B = 1
4810 D$ = MID$( STR$(K),B )
4820 S$ = MID$( STR$(2),1 )
4830 VY = VX * RTO
4840 P = VY : GOSUB 5400 : VY$ = MID$(P$,1)
4850 CMD$(2,Y) = S$+"VS"+VY$+S$+"V"+VY$+S$+"D"+D$+S$+"TS"+S$+"I"
4860 K = M3(Y) : B = 2
4870 IF K < 0 THEN B = 1
4880 D$ = MID$( STR$(K),B )
4890 S$ = MID$( STR$(3),1 )
4900 VB = (ABS(BETA(Y))*18) / (2*PI*TM(Y))
4910 P = VB : GOSUB 5400 : VB$ = MID$(P$,1)
4920 CMD$(3,Y) = S$+"VS"+VB$+S$+"V"+VB$+S$+"D"+D$+S$+"I"
4930 K = M4(Y) : B = 2
4940 IF K < 0 THEN B = 1
4950 D$ = MID$( STR$(K),B )
```

```
4960 S$ = MID$( STR$(3),1 )
4970 VA = (ABS(ALFA(Y)*100))/(2*PI*TM(Y))
4980 P = VA : GOSUB 5400 : VA$ = MID$(P$,1)
4990 CMD$(4,Y) = S$+"VS"+VA$+S$+"V"+VA$+S$+"D"+D$+S$+"I"
5000 TIME(Y) = TIME(Y-1) + TM(Y)
5010 NEXT Y
5020 CLS : SCREEN 2 : SCREEN 0,0,0
5030 LOCATE 12,8
5040 PRINT "PRESS SPACE BAR TO DISPLAY ALFA, BETA, MACHINING TIME AND AREA"
5050 LOCATE 13,8
5060 PRINT "------------------------------------------------------------------"
5070 GOSUB 5340 : CLS
5080 PRINT "_____________________________________________________________________________
5090 PRINT "¦SEGMENT¦  ALFA   ¦  BETA   ¦MACHINING  ¦ MACHINING¦  TOTAL   ¦ TOTAL
5100 PRINT "¦NUMBER ¦ (Degr-  ¦ (Degr-  ¦  AREA     ¦   TIME   ¦ M.AREA   ¦ M.TIME
5110 PRINT "¦       ¦  ees)   ¦  ees)   ¦(mm Sq.)   ¦ (Seconds)¦ mm Sq.   ¦ (Sec.)
5120 PRINT "¦-------¦---------¦---------¦-----------¦----------¦----------¦-------
5130 FOR I =  Z TO N+1
5140 ALFA1 = ALFA1(I)*RD : BETA3 = BETA3(I)*RD
5150 ALFA$=MID$(STR$(ALFA1),1,7) : BETA$=MID$(STR$(BETA3),1,7)
5160 AREA$ = MID$(STR$(AREA(I)),1,8)  : MT$ = MID$(STR$(TM(I)),1,8)
5170 TAREA$ = MID$(STR$(TAREA(I)),1,9): TM$ = MID$(STR$(TIME(I)),1,8)
5180 PRINT "¦";TAB(4);I;TAB(9);"¦";TAB(10);ALFA$;TAB(18);"¦";TAB(19);BETA$;
5190 PRINT TAB(27)"¦";TAB(28);AREA$;TAB(38);"¦";TAB(39);MT$;TAB(49);"¦";
5200 PRINT TAB(50);TAREA$;TAB(59)"¦";TAB(60);TM$;TAB(68);"¦"
5210 NEXT I
5220  PRINT ":----------------------------------------------------------------:
5230 MIN = INT(TIME(I-1)/60)  : TTIM = TIME(I-1)    'Total machining time
5240 SEC = (((TIME(I-1)/60)-MIN)*60) : TAREA$ = MID$(STR$(TAREA(I-1)),1,9)
5250 TIM$ = STR$(MIN)+" MINUTES AND"+MID$(STR$(SEC),1,6)+" SECONDS"
5260 PRINT TAB(7);"TOTAL AREA OF";TAREA$ ;" mm. Sqr. NEEDS MACHINING";
5270 PRINT " TIME  OF";TIM$;" AT THE FEED RATE OF ";FR; " mm Sqr./Min."
5280 PRINT : PRINT  TAB(25) : GOSUB  5330
5290 '---------------------------------------------------------------
5300 SCREEN 2 : GOSUB 5800
5310 RETURN
5320 '****************************************************************
5330 PRINT " PRESS SPACE BAR TO CONTINUE."
5340 V$ = INKEY$
5350 IF V$ <> " " THEN 5340
5360 RETURN
5370 '
5380 '**  THIS SUB-ROUTINE FINDS FOUR DIGITS AFTER DECIMAL POINT   **
5390 '---------------------------------------------------------------
5400 WH = FIX(P)
5410 P = P - WH
5420 P = FIX( P * 10000 )
5430 P = P / 10000
5440 P = P + 1
5450 P$ = MID$(STR$(P),3,6)
5460 IF WH = 0 THEN 5480
5470 P = WH + VAL(P$) : P$ = MID$(STR$(P),2,6)
5480 E$ = MID$(STR$(.001),2,5)
5490 IF VAL(P$) < VAL(E$) THEN P$ = E$
5500 RETURN
5510 '
5520 '**  THIS SUBROUTINE RESETS PC23, SETS OPERATING MODE,MOTOR   **
5530 '**  RESOLUTION AND SELECTS VOLTAGE IN THE PVR CIRCUIT.        **
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5540 '-------------------------------------------------------------
5550 VL1=1.25   :   VL2=6   :   VL3=5.5   :   VL4=5   :   VL5=4.5
5560 CLS : LOCATE 8 ,3
5570 LOCATE 8,3 :  PRINT "PLEASE ! NOW SUPPLY POWER TO
5580 LOCATE 10,12 : PRINT "PC23  ADAPTOR BOXES
5590 LOCATE 12,12 : PRINT "FOR   COMMUNICATION
5600 LOCATE 14,12 : PRINT "INITIALIZATION THEN
5610 LOCATE 20,6 : PRINT " PRESS SPACE BAR TO CONTINUE"
5620 GOSUB  5340:GOSUB 6280 : CPD$="1MR6 2MR6 3MR6 1MPA 2MPA 3MPA"
5630 CMD$ = CPD$ + " 00000X1" : ADDRESS%=ADDRESS1% : GOSUB 6930
5640 CMD$ = "3MR6 3MPA" : ADDRESS% = ADDRESS2% : GOSUB 6930
5650 CLS  : LOCATE 2,2
5660 LOCATE  5,8 : PRINT"NOW SUPPLY POWER TO --->
5670 LOCATE 8,8 :  PRINT "1. KS-DRIVE NO. 1,2,3 & 4
5680 LOCATE 10,8 : PRINT "2. PVR  CIRCUIT  UNIT AND
5690 LOCATE 12,8 : PRINT "3. CONNECT  MULTIMETER TO
5700 LOCATE 14,8 : PRINT "   SEE VOLTAGE  VARIATION
5710 LOCATE 16,8 : PRINT "   IN  THE  CUTTING WIRE.
5720 LOCATE 20,6 : PRINT "PRESS SPACE BAR TO CONTINUE"
5730 GOSUB  5340
5740 SCREEN 0,0,0 : SCREEN 2
5750 GOTO 5850
5760 CLS : LOCATE 3,21
5770 PRINT "PLEASE !  SELECT THE LOWEST  VALUE TO CHECK"
5780 LOCATE 4,24
5790 PRINT "RETRACING CAPABILITY OF THE SYSTEM."
5800 LOCATE 6,14
5810 PRINT "PREVIOUSLY VOLTAGE SUPPLIED TO WIRE WAS ";VLT;"  VOLTS."
5820 LOCATE 7,14
5830 PRINT "NOW YOU CAN SELECT NEW VOLTAGE FROM  FOLLOWING OPTIONS."
5840 GOTO 5870
5850 LOCATE 7,16
5860 PRINT "PRESENT VOLTAGE IN THE CUTTING WIRE IS =";VL1;"VOLTS."
5870 LOCATE 8,22 :PRINT STRING$(40,"*")
5880 PRINT TAB(22) "* VOLTAGE 1................";VL1;"VOLTS *"
5890 PRINT TAB(22) "* VOLTAGE 2................";VL2;"   VOLTS *"
5900 PRINT TAB(22) "* VOLTAGE 3................";VL3;" VOLTS *"
5910 PRINT TAB(22) "* VOLTAGE 4................";VL4;"   VOLTS *"
5920 PRINT TAB(22) "* VOLTAGE 5................";VL5;" VOLTS *"
5930 PRINT TAB(22) STRING$(40,"*")
5940 LOCATE 18,22 : PRINT "SELECT VOLTAGE BY PRESSING KEYS  1-5 KEY
5950 PRINT
5960 A$=INKEY$
5970 IF VAL(A$)=1 THEN CMD$=CPD$ + " 00000X1":GOTO 6030
5980 IF VAL(A$)=2 THEN CMD$=CPD$ + " 00100X0":GOTO 6030
5990 IF VAL(A$)=3 THEN CMD$=CPD$ + " 01000X0":GOTO 6030
6000 IF VAL(A$)=4 THEN CMD$=CPD$ + " 00001X0":GOTO 6030
6010 IF VAL(A$)=5 THEN CMD$=CPD$ + " 00010X0":GOTO 6030
6020 GOTO 5960
6030 ADDRESS% = ADDRESS1% : GOSUB 6930 : CLS
6040 IF VAL(A$) = 1 THEN VLT = VL1
6050 IF VAL(A$) = 2 THEN VLT = VL2
6060 IF VAL(A$) = 3 THEN VLT = VL3
6070 IF VAL(A$) = 4 THEN VLT = VL4
6080 IF VAL(A$) = 5 THEN VLT = VL5
6090 CLS : SCREEN 2 : LOCATE 2,2
6100 PRINT "TOTAL MACHINING TIME FOR THIS DIE PROFILE IS =";TIM$
6110 LOCATE 3,2
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6120 PRINT "REST OF THE PROFILE NEEDS MACHINING TIME OF =";
6130 LOCATE 4,2
6140 PRINT "TIME FOR THIS SEGMENT TO BE MANUFACTURED IS ="
6150 LOCATE 5,14
6160 PRINT "TOTAL MACHINING  AREA OF THE DIE IS =";TAREA$;"mm.Sqr"
6170 LOCATE 6,14
6180 PRINT "PRESENT WORKPIECE FEEDRATE IS = ";FR;"mm. Sqr./min."
6190 LOCATE 7,14
6200 PRINT "THE VOLTAGE IN THE CUTTING WIRE IS APRX.";VLT;"VOLTS."
6210 PRINT : PRINT : PRINT
6220 RETURN
6230 '
6240 '____________________________________________________________
6250 '************************************************************
6260 '* THIS SUB-ROUTINE SETS VARIABLES, & RESET BOTH THE INDEXERS*
6270 '************************************************************
6280 ADDRESS1% =&H300  'Base address of PC23 indexer one (deci 768)
6290 ADDRESS2% =&H310  'Base address of PC23 indexer two (deci 784)
6300 INTRCLR =&H20     'This variable is for clearing Control Bit 5
6310 '                          (to signal "Restart Watchdog Timer")
6320 RESTART =&H40     'This variable is for clearing Control Bit 6
6330 '                          (to signal "Restart Watchdog Timer")
6340 CONTROL =&H60    'This is the normal state of the Control Byte
6350 '                                  (only Bits 5 and 6 are high)
6360 READY   =&H17     'This is the normal state of the Status Byte
6370 '                                   (bit 0, 1, 2 and 4 are set)
6380 HALT  =&H64        'This variable is for setting Control Bit 2
6390 '                 (to signal the "Watchdog Timer" to time out)
6400 CMDRDY  =&H70 'THIS VARIABLE IS A MASK FOR SETTING CONTROL BIT
6410 '          4 (to signal "Command Byte Ready in the IDB or not)
6420 RECEIVED=&HE0 'This variable is a mask for setting Control Bit
6430 '               7  (to signal "Message Received from the ODB")
6440 ODBREADY =8  'This variable is a mask for testing Status Bit 3
6450 '            (is a response waiting in the Output Data Buffer?)
6460 IDBREADY =&H10 'This variable is a mask for testing Status Bit
6470 '        4 (is the Input Data Buffer ready for a command byte)
6480 FAIL =&H20   'This variable is a mask for testing Status Bit 5
6490 '               (has the PC23 suffered a processing  failure?)
6500 MASK =&H7F    'This variable is a mask for the Status byte MSB
6510 '----------------------------------------------------------
6520 '************************************************************
6530 '*    "RESET SUBROUTINE" FOR BOTH PC23 INDEXER BOARDS        *
6540 '************************************************************
6550 'The following  subroutine  allows  the  "Watchdog Timer"  to
6560 'time  out,  and Resets  both the  PC23s.  Then the  timer  is
6570 'restarted. A "GOSUB 10220" instruction will reset both PC23s.
6580 '
6590 BYTE1=0 : BYTE2=0 : TIMEOUT=1000         'Set timeout duration
6600   OUT ADDRESS1%+1,( HALT )'Control Bit 2 of PC23 No. 1 is high
6610   OUT ADDRESS2%+1,( HALT )'Control Bit 2 of PC23 No. 2 is high
6620 WHILE (BYTE1 AND BYTE2  AND FAIL)=0 AND TIMEOUT>0'Fail/timeout
6630   BYTE1=INP( ADDRESS1%+1 )      'Read Status Byte of PC23 No. 1
6640   BYTE2=INP( ADDRESS2%+1 )      'Read Status Byte of PC23 No. 2
6650 TIMEOUT = TIMEOUT - 1 : WEND      'Repeat until timeout or fail
6660 IF TIMEOUT <= 0 THEN GOTO 6680
6670 GOTO 6690
6680 PRINT "Invalid response from either of the addresses."  :  END
6690 BYTE1=0 : BYTE2=0  : TIMEOUT=1000       'Set time out duration
```

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6700  OUT ADDRESS1%+1,(RESTART)'Control Bit 2 of PC23 No. 1 is high
6710  OUT ADDRESS2%+1,(RESTART)'Control Bit 2 of PC23 No. 2 is high
6720 WHILE (BYTE1 AND BYTE2 AND MASK) <> READY AND TIMEOUT > 0
6730  BYTE1=INP( ADDRESS1%+1 )      'Read Status Byte of PC23 No. 1
6740  BYTE2=INP( ADDRESS2%+1 )      'Read Status Byte of PC23 No. 2
6750 TIMEOUT = TIMEOUT - 1 : WEND           'Repeat until recovery
6760  OUT ADDRESS1%+1,(CONTROL)  'Restore Control byte of PC23 No.1
6770  OUT ADDRESS1%+1,(INTRCLR)  'Restore Control byte of PC23 No.1
6780  OUT ADDRESS2%+1,(CONTROL)  'Restore Control byte of PC23 No.2
6790  OUT ADDRESS2%+1,(INTRCLR)  'Restore Control byte of PC23 No.2
6800 IF TIMEOUT <= 0 THEN GOTO 6820
6810 GOTO 6830
6820 PRINT "Timeout recovering from reset!" : BEEP : END
6830 FOR I=1 TO 200 : NEXT
6840 RETURN
6850 '-------------------------------------------------------------
6860 '*************************************************************
6870 '*                      "OUTPUT DRIVER"                      *
6880 '*************************************************************
6890 '  The following is a handshake subroutine allowing data to be
6900 ' transferred from the IBM BUS to either of the PC23 indexers.
6910 ' Command  string data is sent to the PC23s one character at a
6920 ' time.
6930 FOR I = 1 TO LEN( CMD$ )
6940    CHAR$ = MID$( CMD$, I, 1 )    'Fetch command characters and
6950    GOSUB 7000                       'Send them one at a time.
6960 NEXT I
6970   CHAR$ = CHR$(13):GOSUB 7000  'Follow with a carriage return
6980 RETURN
6990 '
7000 BYTE = 0:TIMEOUT = 1000                    'Set timeout duration
7010 WHILE (BYTE AND IDBREADY)=0 AND TIMEOUT > 0  'Ready or timeout
7020    BYTE = INP( ADDRESS%+1 )                  'Read Status Byte
7030 TIMEOUT = TIMEOUT - 1 : WEND                           'Repeat
7040 IF TIMEOUT <= 0 THEN PRINT "Timeout during write!": BEEP : END
7050  OUT ADDRESS%, ASC(CHAR$)              'Write command character
7060  OUT ADDRESS%+1, (CMDRDY)           'Signal charater is waiting
7070 BYTE = 255:TIMEOUT = 1000                 'Set timeout duration.
7080 WHILE (BYTE AND IDBREADY)>0 AND TIMEOUT > 0   'Busy or timeout
7090    BYTE = INP( ADDRESS%+1 )                  'Read Status Byte
7100 TIMEOUT = TIMEOUT - 1:WEND                             'Repeat
7110   OUT ADDRESS%+1, ( CONTROL )
7120 IF TIMEOUT <= 0 THEN PRINT "Timeout after write!" : BEEP : END
7130 RETURN
7140 '-------------------------------------------------------------
7150 '*************************************************************
7160 '*                      "INPUT DRIVER"                       *
7170 '*************************************************************
7180 '  The following is a handshake subroutine allowing data to be
7190 '  transfered from either of the PC23 indexers to the IBM BUS.
7200 '  This data is sent one character at a time.
7210 '
7220 ANSWER$=""                            'Initialize response string
7230 BYTE = 0:TIMEOUT = 5                    'Initialize variables
7240 WHILE (BYTE AND ODBREADY)= 0 AND TIMEOUT > 0 'Ready or timeout
7250   BYTE = INP( ADDRESS%+1 )                   'Read Status Byte
7260   TIMEOUT = TIMEOUT - 1:WEND                           'Repeat
7270 IF TIMEOUT <= 0 THEN RETURN              'Give up if no message
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7280 ANSWER = INP( ADDRESS% )                      'Read 1 response byte
7290 OUT ADDRESS%+1,(RECEIVED)                 'Signal character received
7300 BYTE = 255:TIMEOUT = 1000                     'Initialize variables
7310 WHILE (BYTE AND ODBREADY)> 0 AND TIMEOUT > 0  'Busy or timeout
7320   BYTE = INP( ADDRESS%+1 )                         'Read Status Byte
7330   TIMEOUT = TIMEOUT - 1 : WEND                               'Repeat
7340 IF TIMEOUT <= 0 THEN PRINT "Timeout after read!"  : BEEP : END
7350 OUT ADDRESS%+1, ( CONTROL )                  'Restore control byte
7360 CHAR$ = CHR$( ANSWER )                      'Convert code to char.
7370 ANSWER$ = ANSWER$ + CHAR$                      'Add char to answer
7380 IF CHAR$ = CHR$(13) THEN RETURN ELSE 7230
7390 '_____________________________________________________________________
```