Computer Integrated Manufacture of Complex Dies for Drawing Non-circular Wires

by

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Sheffield City Polytechnic

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Abstract

This research is based on the idea of machining complex wire drawing die configurations that require drastically different shapes on the top and bottom die faces, by manipulating the workpiece at a minimum of four axes.

A prototype rig motivated by four stepper motors and controlled by a micro-computer has been designed and manufactured for the fulfilment of this idea.

On the basis of experimental evidence, it is apparent that the idea is applicable in the WEDM process. Several die shapes were successfully produced. Distortion occurred at the top surface of some of the dies produced.

Experimental investigations showed that the main cause of that distortion was the backlash in the geared stepper motors.

The software, which was one of the essential factors for this work, presented, in an informative way, the required results in a tabular and graphical form on a visual display unit.

A "hard-copy" of the results was easily obtained if required.

CHAPTER 1

Introduction

1.1 Wire Drawing

The wire drawing process consists essentially of pulling a length of metal wire through a die of similar or different cross section but of smaller size.

Generally, the cross section is the same through the die, but gradually tapering to give good flow of the metal wire. A large proportion of wire produced is of circular cross section and the manufacture of these dies causes no real problems. Some special wires, however, have a non-circular section. (See Figure 1.) The manufacture of these dies can be difficult and often manual skills are employed in their production.

Wire drawing dies are subjected to severe wear, compressive forces, thermal stresses, and chemical reaction.[1, 2]

Selection of the die material is therefore important, and depends primarily upon the metal wire material, the size and the shape of the wire to be drawn, the quantity of wires required, and the cost of the die material. Therefore, the machining methods to produce these dies can be classified into two categories:-

1.1.1 Conventional Die Machining

Manual machining such as drilling, sawing, milling and filing are now generally used for repair work. The most important process is the combination of a photoelectric drawing reader with an engraving or duplicate milling machine, where dies of different sizes can be machined directly from a drawing with this process. The scale of drawing can be adjusted and the tolerances on the drawing are transferred on a much reduced scale to the die.[14, 20]

Another method of conventional die machining is producing the die from the metal powders such as iron, tin, nickel, copper, aluminium, titanium, and refractory metal such as tungsten, molybdenum etc. The process can be explained in three main steps; these steps are mixing, compacting, and sintering.

In the mixing step the elemental metal such as tungsten carbide is mixed with another powder such as cobalt to produce a homogeneous mix of ingredients (i.e. tungsten carbide 94%, and cobalt 6%). Then we come to the second step, which is compacting. In it, a controlled amount of mixed powder is compacted or pressed into a mould, and due to the high pressure the loose powder consolidates and densifies into the shape of the mould cavity. The product at this step has sufficient strength for process handling. The third step is sintering where the compacted die is heated in a furnace to a high temperature, but below its melting point. However, the die at the end of the third step can be used, but for special surface finish requirements the die may need to go into a polishing process.

1.1.2 Unconventional Die Machining

The ideal die material requires both the hardness of diamond and the fracture resistance of hard metals. Cemented Tungsten Carbide and Syndite (polycrystalline diamond) are some of the materials which approach this ideal.

Machining such hard materials can be done by using Laser or Electric Discharge Machining. Holes produced by laser generally have some taper because the beam is focused in one plane, and laser-generated holes are not as precise in geometry (diameter, smoothness, surface finish) as EDMed holes. One possible alternative is to laser-cut a rough die profile by varying the angle of die tilt, rotation speed, focal point, pulse frequency, and then finish the die profile to close tolerance with a short, finishing EDM cut.[3, 4, 5, 6, 7, 10]

This type of die is extensively used in the wire industry, especially for cold drawing small-diameter round wire, regardless of workpiece material and production requirements.

1.2 Electrical Discharge Machining

Electrical Discharge Machining (EDM), sometimes referred to as spark machining, is a non-traditional method of removing metal by a series of rapidly recurring electrical discharges between an electrode (the cutting tool) and the workpiece in the presence of a dielectric fluid. Minute particles of metal or chips, generally in the form of hollow spheres, are removed by melting and vaporization, and are washed from the gap by the dielectric fluid which is continuously flushed between the tool and workpiece.[8, 12]

The workpiece, which constitutes one of the electrodes between which the spark occurs, must be of electrically conductive material. The other electrode (tool), which also must be made of electrically conductive material, is located in close proximity to, but not in contact with, the workpiece during cutting.[11, 12, 14]

EDM can be classified into Die Sinking EDM, and Wire EDM,[13] and is extensively used for precision machining in die making and has also come to be used for machining prototypes, see Figs. 2a & 2b.

In recent Die Sinking EDM machines, the following improvements have been made possible by numerical control throughout the machine.

.(i) A planetary motion is induced between the electrodes and the workpiece to increase accuracy and removal rate.

.(ii) Machining to a complicated shape is possible by expressing it as an assembly of simple shapes and using an NC automatic tool changer with a large number of programmed simple-shape electrodes.

.(iii) Appropriate steels with small area can be machined to a mirror finish.

The advent of Wire EDM has given the field of diemaking its greatest impetus since the development of EDM die sinking. The reason is that the wire acts as a super-precision saw that is capable of cutting prehardened steels to finished die dimensions. Sectionalizing, the traditional approach to precision die design, is completely eliminated. It also eliminated the time-consuming work of die fitup, which is also the greatest test of vanishing diemaker skills.[18]

1.2.1 Physical Basis of the EDM Process

The spark erosion mechanism is attributed to the electrical breakdown of the dielectric in the inter-electrode gap, caused by the application of voltage pulses, see Fig. 3. The breakdown arises from acceleration towards the Anode of both the electrons emitted from the

Cathode by the applied field and the stray electrons present in the dielectric in the gap. These electrons collide with neutral atoms of the dielectric, thereby creating positive ions and further electrons, which in turn are accelerated towards respectively the Cathode and Anode. If the multiplication of electrons by this process is sufficiently high, an avalanche of electrons and positive ions occurs. These eventually reach the electrodes and a current flows. The entire breakdown process is a localized event, occurring in a channel of radius approximately 10 μm(12) When the electrons and positive ions reach the cathode and anode, they give up their kinetic energy in the form of heat. A large level of heat flux can be attained, so that even with sparks of very short duration (of the order of μsec) the temperature of the electrodes can be raised locally to more than their normal boiling point. Owing to the evaporation of the dielectric, the pressure in the plasma channel rises rapidly to values as high as 20 atm.(14)

Such great pressures prevent the evaporation of the superheated metal. However, at the end of the voltage pulse, when the voltage is removed the pressure also drops suddenly and the superheated metal evaporates explosively. Metal is thus removed from the electrodes.

1.3 Computer Integrated Manufacturing (CIM)

Computer Integrated Manufacturing is a strong technological resource emerging today which has the capability of providing major advances in manufacturing productivity and quality. It is a term which represents the full range of the capability potential which the digital computer holds for manufacturing. That potential is of three types.[16]

(i) The computer has unique potential in providing manufacturing with two powerful capabilities, namely:-

(a) automation, and

(b) optimization.

(ii) The computer is capable of performing the above not only for hard components of manufacturing (the manufacturing machinery and equipment), but also for the soft components of manufacturing (the information flow, the databases, etc.).

(iii) The computer is capable of performing the above not only for the various bits and pieces of manufacturing activity but also for the entire system of manufacturing. The computer therefore has the potential to integrate an entire system, producing what may be called a Computer Integrated Manufacturing System.

Recent developments in EDM power supplies have been concentrated on controlling the transistor circuits. All spark parameters, as well as machine tool functions, can now be controlled by a micro-computer. Control by micro-computers has provided another increase in cutting efficiency. Cutting conditions are monitored and then instantly changed by the computer, as required, for peak cutting efficiency.[14, 15, 16, 17]

1.4 Commercially Available EDM/CIM

To date, full development and implementation of Computer Integrated Manufacturing has not yet been realized anywhere in the world. Thus, no significant performance data yet exist which can document the full benefits of such integration. However, if we look at the current status of the CIM system development, we find one area where integration has advanced further than in any other. This is the shop-floor segment of the system, in the form of Flexible Manufacturing Systems (FMS). With the implementation of flexible manufacturing systems already advancing quite rapidly in Japan, efforts are now being directed towards developing capability for these systems to run unattended at night. One of the first systems to accomplish at least partial realization of this capability was developed by Toshiba Tungaloy Co., Ltd., and located at their Kawasaki plant. It was put into service in August 1980 and produces milling-cutter and single-point cutting-tool bodies. The system consists of one NC lathe, one vertical machining centre, three 5-axes horizontal machining centres, and one multispindle NC grinder, and it operates under hierarchical computer control.[17]

Recently, Japan has launched a machine in electric Discharge Machining called *Japax CNC Wire-EDM*, one of the larger machines in the LXR series, accommodating workpieces weighing up to 598.75 Kg (1320 lbs) and measuring up to 101.6 cm x 60.96 cm x 30.48 cm (40 in x 24 in x 12 in). Cutting speed is 122.58 cm^2/hr (19 sq. in/hr) in hardened tool steel. The non-capacitance power supply is said to offer fine surface finishes at high cutting rate.[19]

Probably the most highly articulated travelling wire EDM available today is the Charmilles Robofil, which offers up to six numerically controlled axes of motion.

The machine features a dual column bridge-type design with a head travelling left and right in the X-axis. Rigidly attached at the rear of the head is an L-shaped arm that reaches under the worktable and carries the lower wire guide. Over this, the table travels in-out in the Y-axis. Thus, the X and Y axes essentially define the basic motion of the work relative to the wire electrode and specifically with respect to the lower wire guide. Sliding vertically on the head is the 125 mm Z-axis, on which are mounted 40 mm horizontal U and V axes - parallel to X and Y, respectively - which position the upper wire guide with respect to the lower one. Thus, the Z-axis determines vertical distance between lower and upper wire guides; U and V determine horizontal displacement of the guides, or tilt of the wire. The sixth CNC axis is an optional rotary table, or indexer, mounted in a vertical plane to rotate the workpiece about a horizontal axis (B) parallel to the Y-axis. In the works at Charmilles, a new version of this optional attachment can be either set up vertically as a B-axis or laid flat on the table to rotate the work in C about a vertical axis.(8)

1.5 Scope of Present Work

Although computer controlled EDM machines are available commercially, they are very expensive and are therefore difficult to justify. Post fitting existing conventional EDM machines with a computer controlled rig is a less costly alternative.

The main aim of the present study is to design and interface such a rig which may be simply mounted onto a wire EDM machine's table. The rig should allow the machining of complex wire drawing die configurations that require drastically different shapes at the top and bottom die faces. Initial studies have shown that a minimum of four axes are required to define adequately a complex die shape (eg. square to round), and it has been decided to utilise a four axes rig in this case. The four axes of the rig are to be independently controlled by a micro-computer. The principal objectives of the study are:-

(a) To design and build a model to validate the four axes movement;

(b) To design and build a prototype four axes rig capable of being mounted onto an existing EDM machine.

(c) To interface the rig to the micro-computer.

(d) To develop software to generate complex die shapes from the four axes rig.

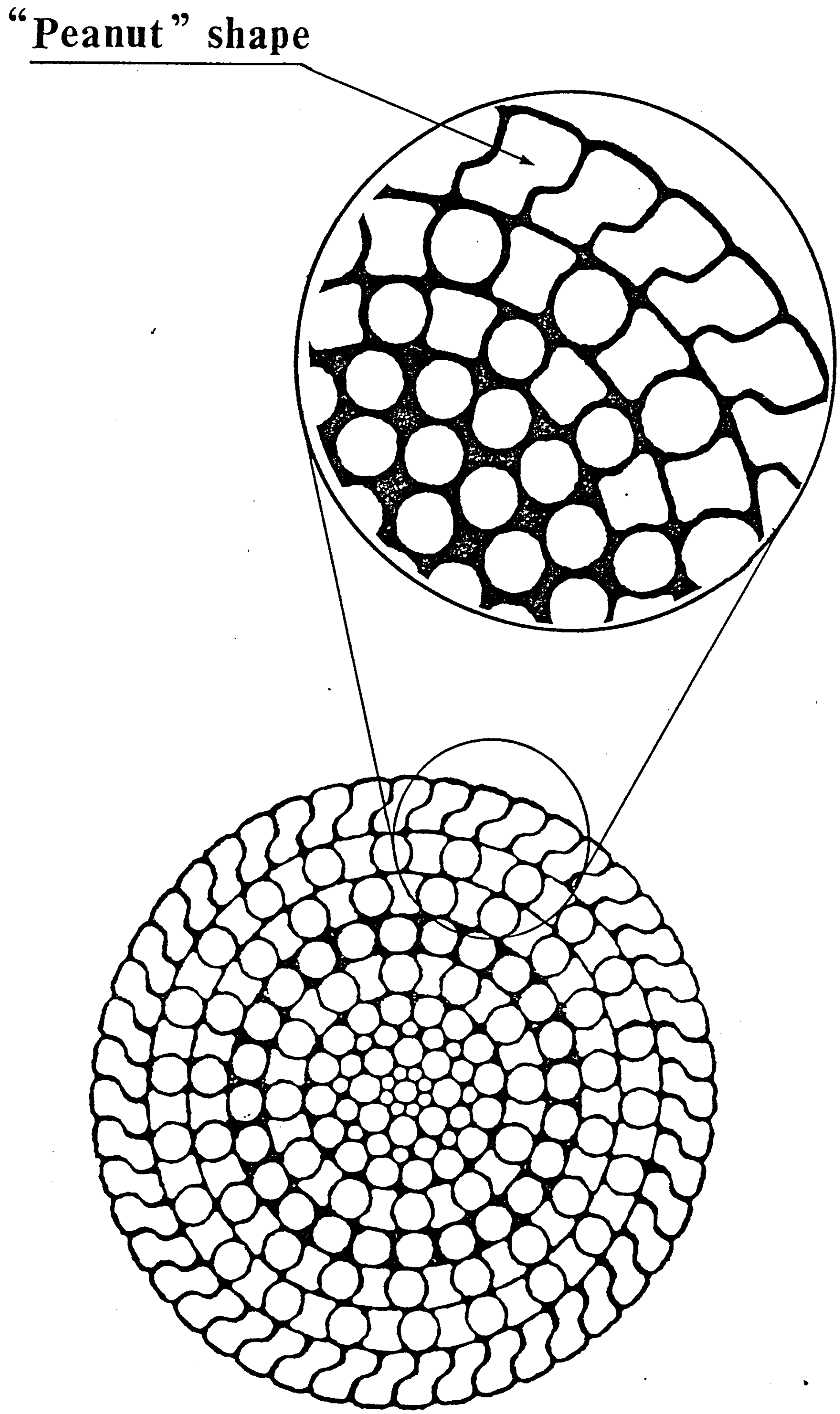


Fig. 1 A cross-section of a wire-rope showing the peanut shape.

A. WORKPIECE.
B. DIE.
C. ELECTRODE.
D. DIELECTRIC.
E. ELECTRODE MOVEMENT.

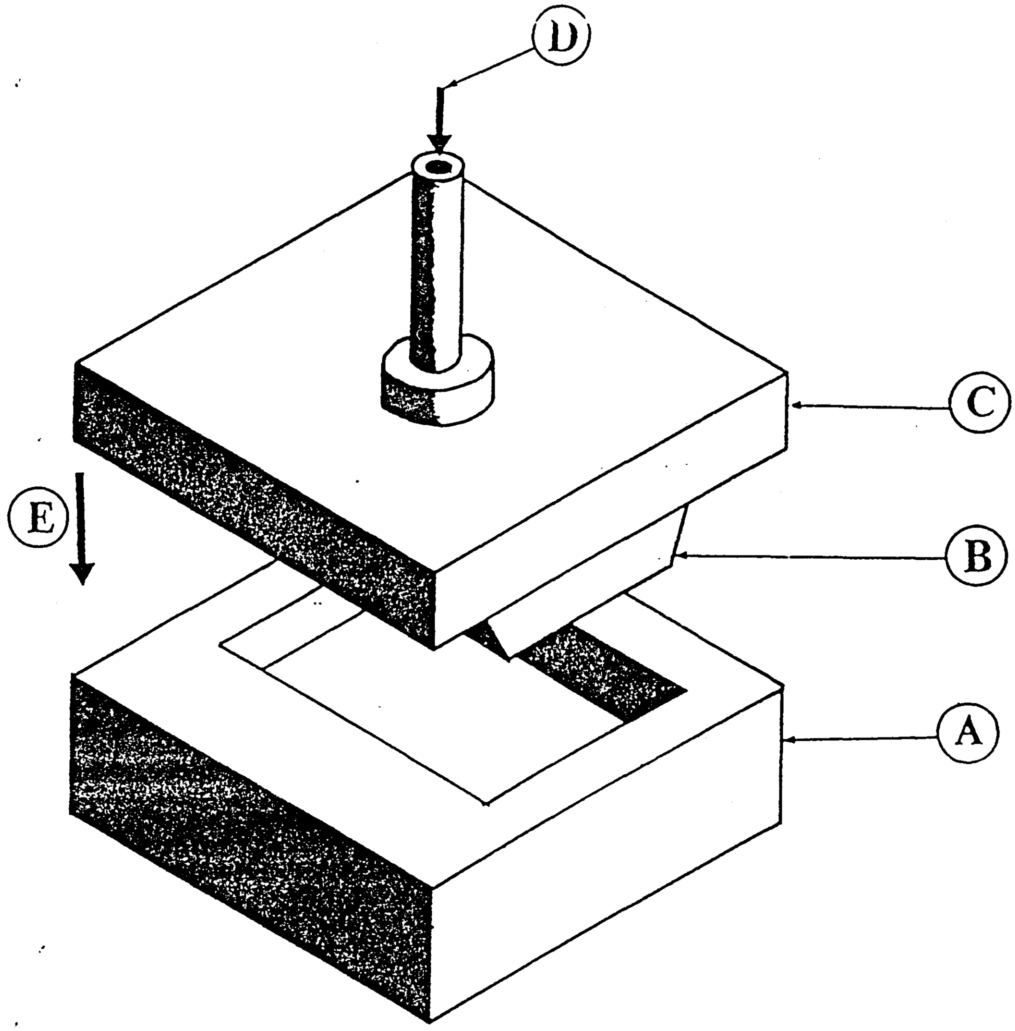


Fig. 2a EDM DIE SINKING.

A.workpiece.
B.width of cut.
C.wire.
D.nozzle.
E.dielectric jet.
F.wire movement.
G.table movement.

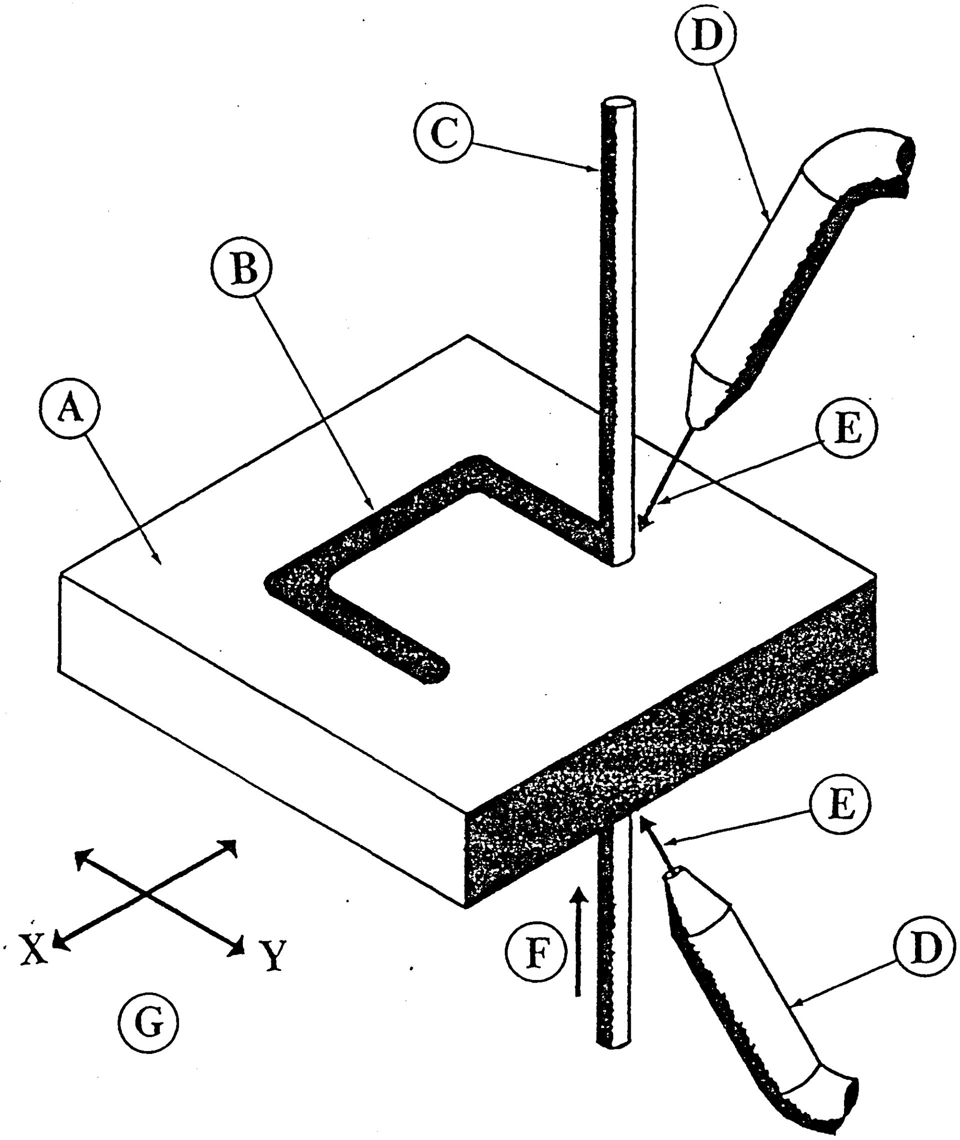


Fig.2b WIRE EDM.

⊕ POSITIVE ION.

● NEUTRAL ATOM.

- ELECTRON.

→ -------- MOVEMENT.

Ⓐ HIGH TEMP. REGION.

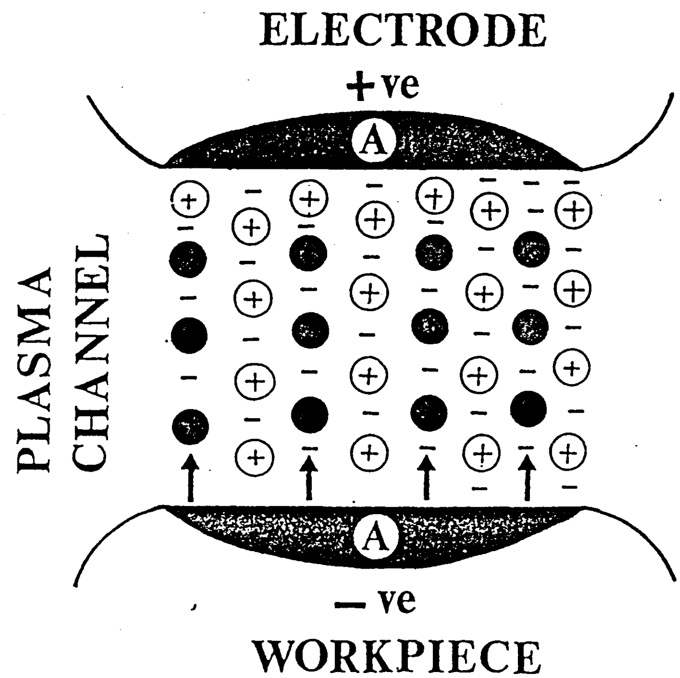


Fig. 3 ARCING PROCESS DURING EDM.

CHAPTER 2

Hardware Design and Manufacture

2.1 Introduction

This chapter is concerned mainly with the design and manufacture of a four axes rig for the manipulation of the workpiece while the WEDM process is taking place. This manipulation should be in such a way that at the end of the process, the desired die cavity should exist, regardless of the difference in shape between the top and the bottom surfaces of the die. The four axes rig was based on the design of a four axes wooden model, as shown in Fig. 4a, which was manufactured to test the hypothesis that four axes would be sufficient to achieve the desired manipulation. With the aid of computer software, which will be explained in the next chapter, the top and the bottom surfaces of the die were drawn and removed from two opposite sides of a cardboard box. This was then placed at the workpiece designated mounting location to represent the required die. A metal rod erected at the centre of the wooden model's base illustrated the validity of the idea that four axes were sufficient for the generation of any three dimensional cavity. The rod was shown to remain in contact with the boundaries of the two profiled surfaces within the 'cardboard die' while the model was motivated according to the point's coordinates representing the two surfaces.

The current prototype rig is motivated by four stepper motors, each connected to one of four translator cards interfaced with a micro-computer through an input/output digital control card.

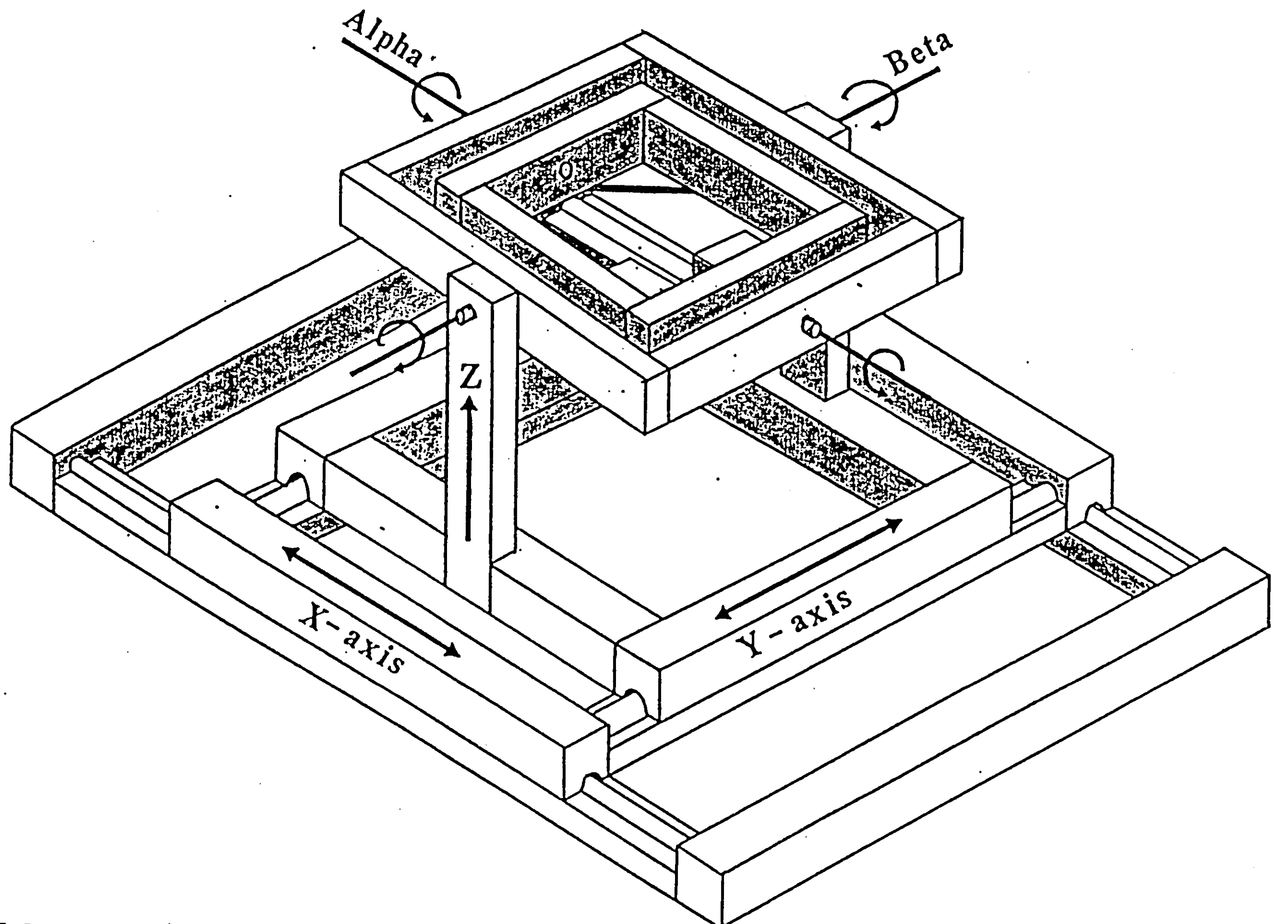


Fig. 4a A FOUR AXES WOODEN RIG.

2.2 Rig Structure

The rig consists of five main parts, namely, the base, the X-axis manoeuvring part, the Y-axis manoeuvring part, the rotated part around X-axis and the rotated part around Y-axis. Fig. 4b shows a diagramatic representation of the rig.

2.2.1 The base, which is as shown in Fig. 5, has two functions. Firstly, it hosts the two shafts onto which the X-axis manoeuvring part slides by means of a stepper motor mounted on the base. Secondly, the whole rig can be clamped on the table of the wire EDM machine at its base sides.

2.2.2 The X-axis manoeuvring part, which is as shown in Fig. 6, hosts four linear ball bearings in addition to a stepper motor assigned to motivate the Y-axis manoeuvring part, which slides on two round shafts as shown in the figure.

2.2.3 The Y-axis manoeuvring part, which is as shown in Fig. 7, hosts four linear ball bearings and one stepper motor, which rotates the upper part of the rig around the X-axis.

2.2.4 The rotated parts around the X and Y axes are all shown in Fig. 8. This diagram essentially illustrates a workpiece mounting platform which is gimbal mounted. The rotated part around the Y-axis, gives a space of 50 mm x 50 mm side length for the workpiece to be mounted.

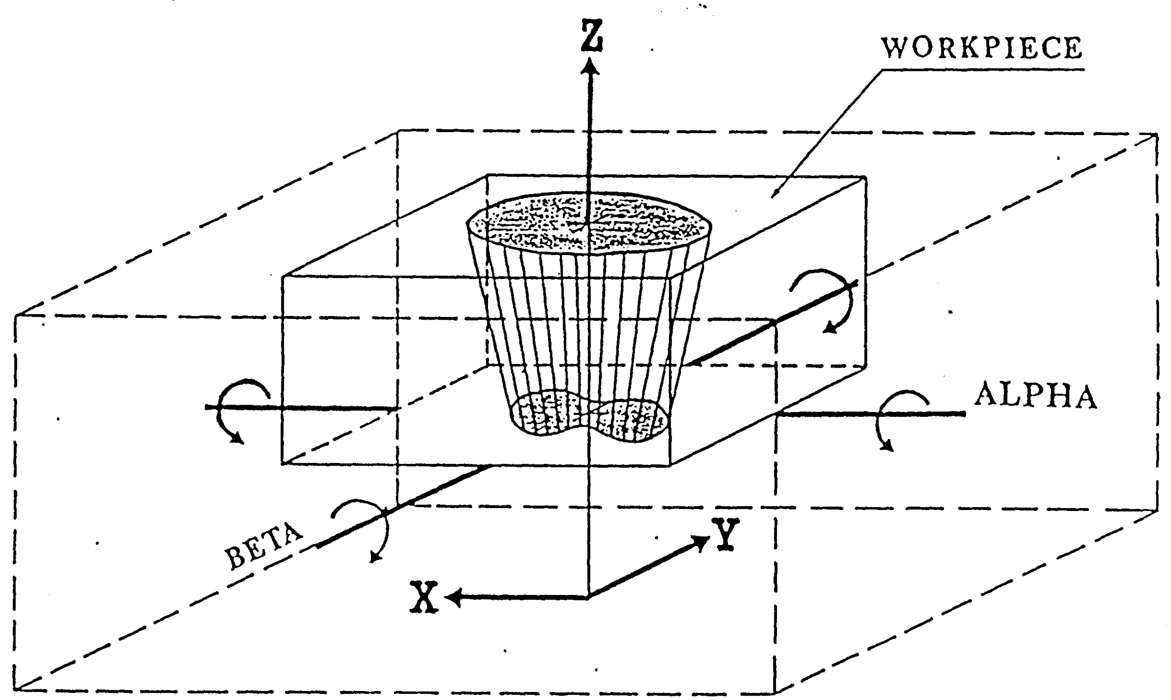


Fig.4b DIAGRAMATIC REPRESENTATION OF THE RIG.

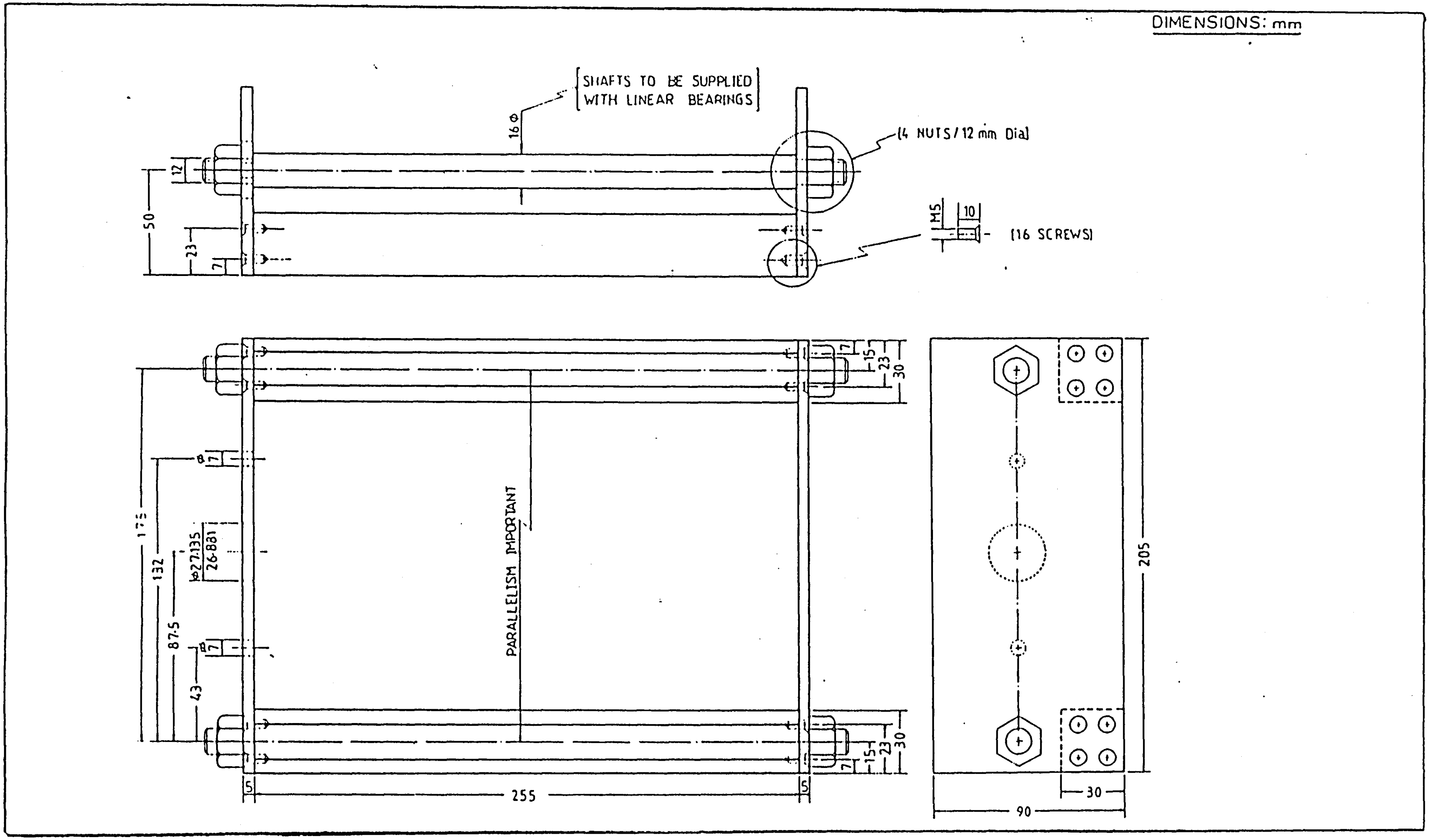


Fig.5 THE BASE.

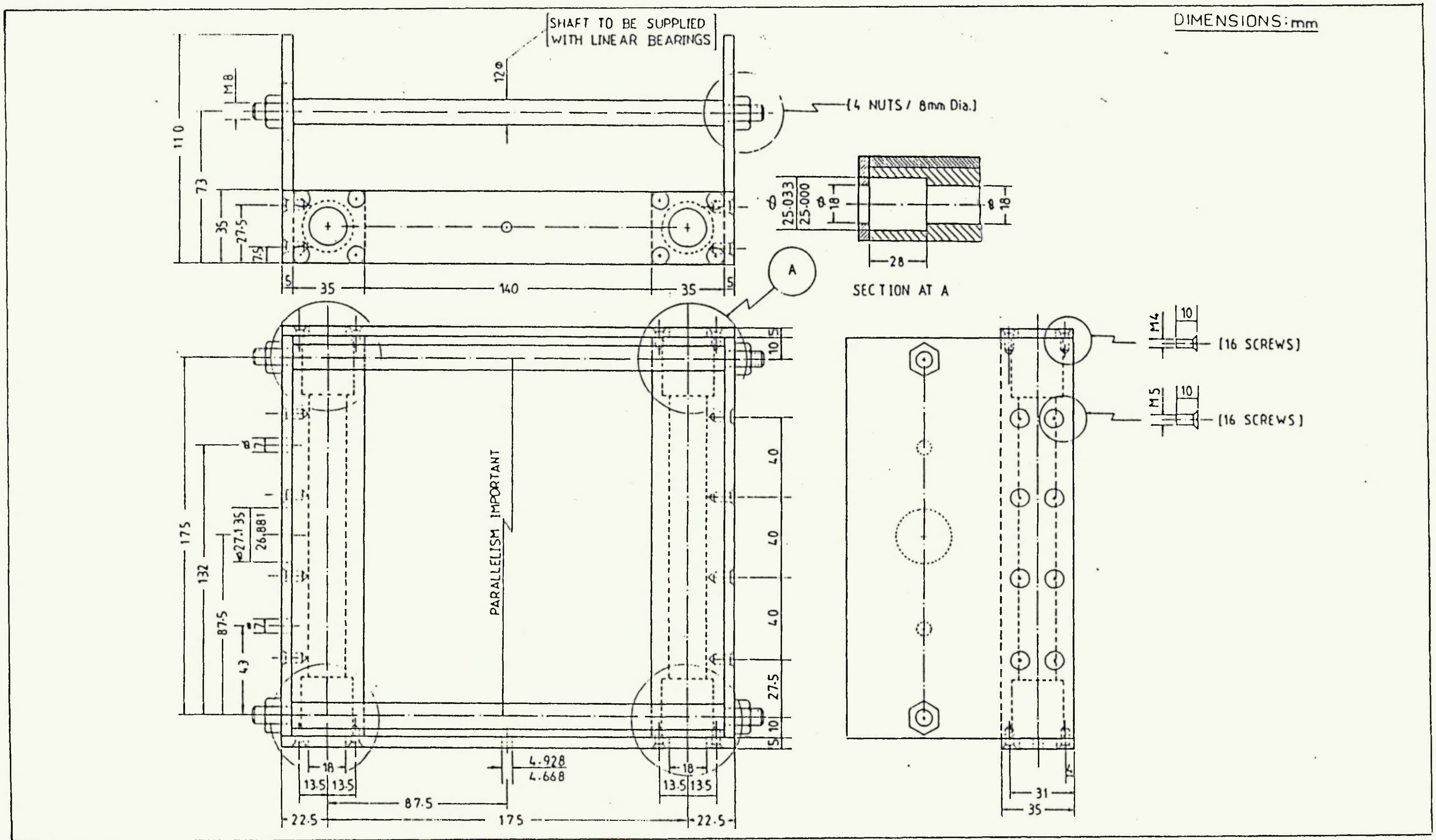


Fig. 6 The X-axis manoeuvring part.

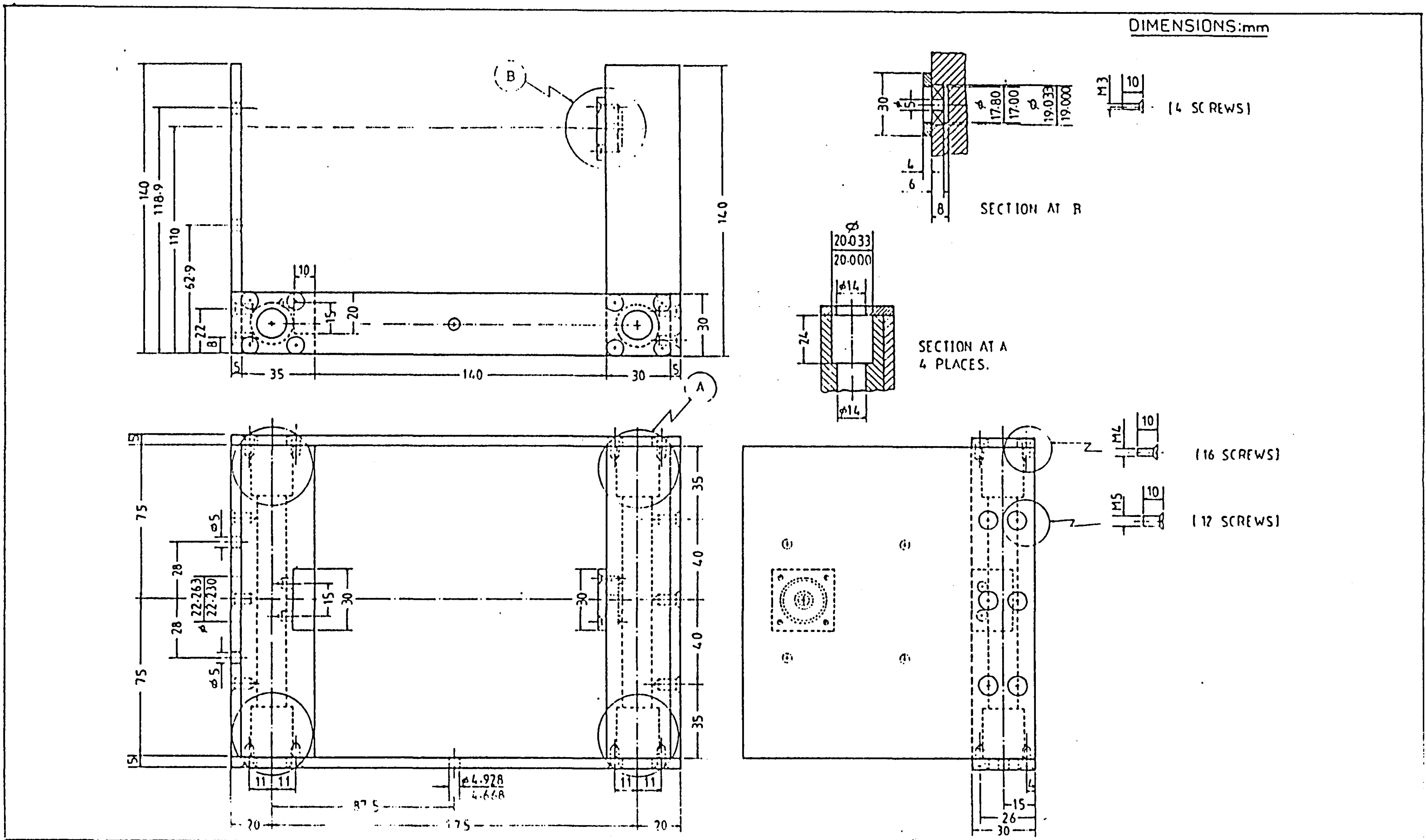


Fig.7 The Y-axis manoeuvring part.

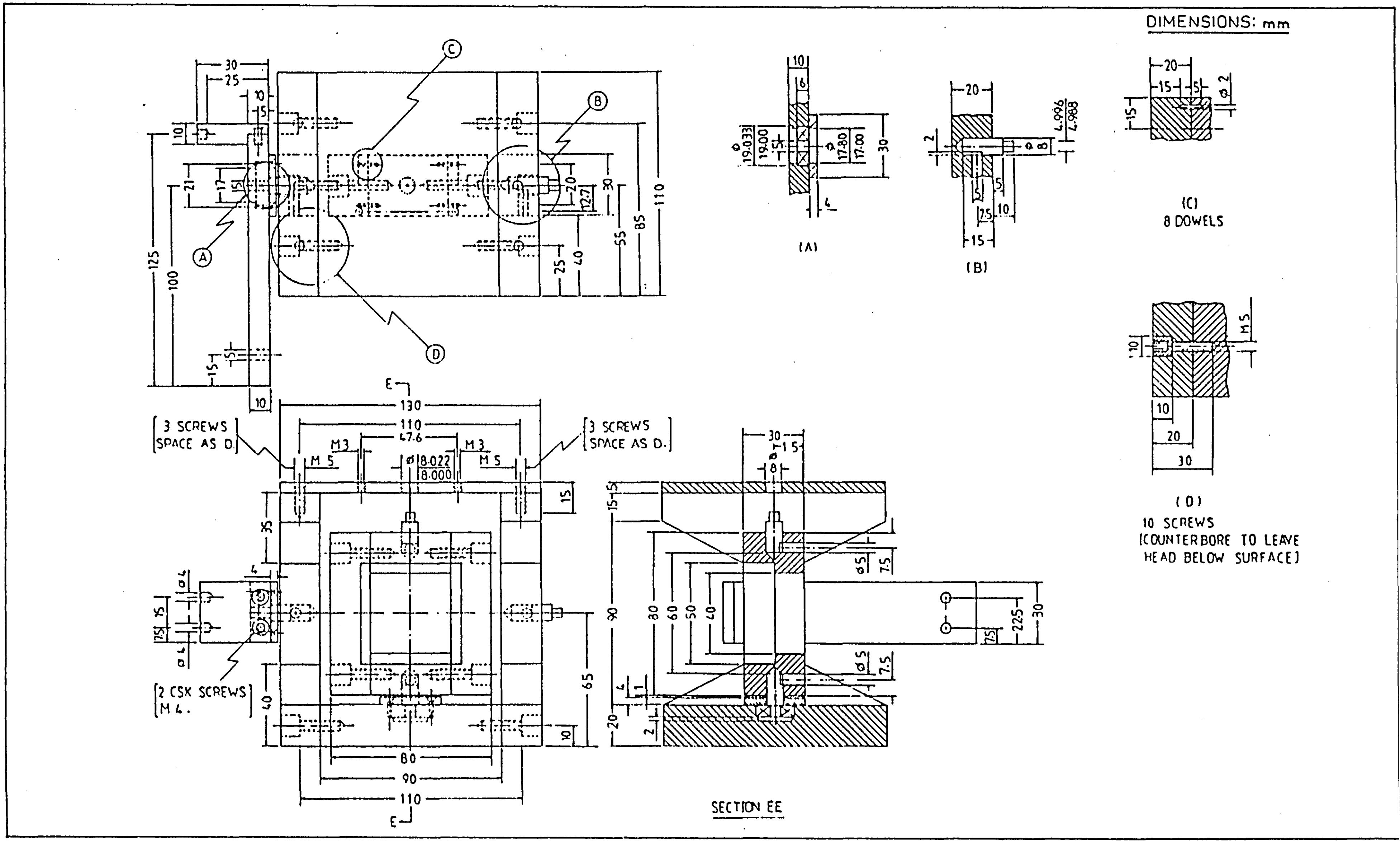
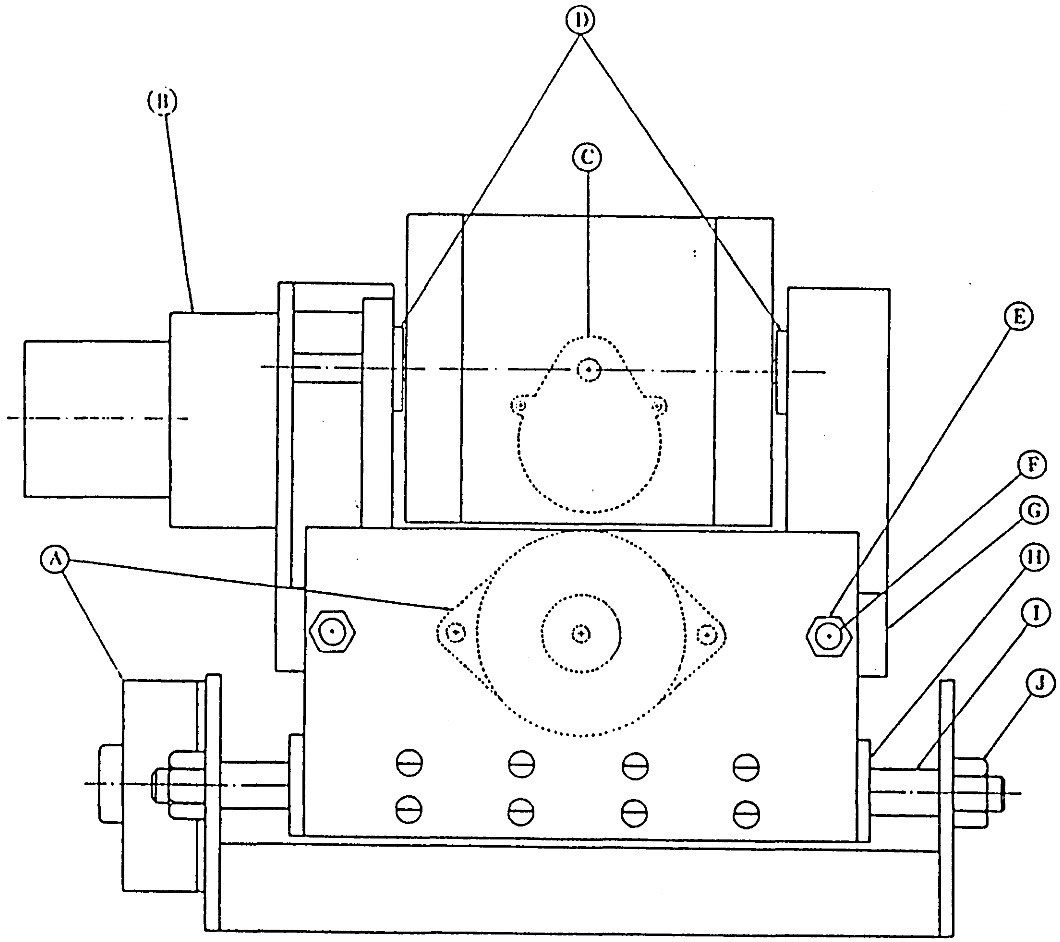


Fig.8 The rotated parts around X and Y axes.



PARTS LIST

SYMBOL	No. of Items	DESCRIPTION
A	2	Digital Linear Actuators L92400 Series (Mc Lennan Supply) Translator EM 162.
B	1	Geared Stepper Motor 1·8 degree stepper motor (HR 23) S30 Series gearhead (Ratio 20:1).
C	1	Geared Stepper Motor 7·5 degree stepper motor (ID 32) P5 Series gearhead (Ratio 20:1).
D	3	RHP single row radial ball bearing Inner dia. 5 mm Outer dia. 19mm Depth 6 mm.
E	4	Nuts (8 mm).
F	2	Stainless Steel Shaft (STAR) Dia. 12mm for a length of 210 mm & threaded ends at 15 mm.
G	4	Segmental Ball Bushings (STAR) Inner dia. 12 mm Outer dia. 20 mm Depth 24 mm.
H	4	Segmental Ball Bushings Inner dia. 16 mm Outer dia. 25 mm Depth 28 mm
I	2	Stainless Steel Shaft Dia. 16 mm for a length of 255 mm & threaded ends at 20 mm.
J	4	Nuts (12 mm).
...	...	Rig's Material is ALUMINIUM.

Fig. 9 THE RIG.

2.3 The Secret of the Four Axes Rig

The secret that a four axes rig is sufficient for the production of a die cavity regardless of the difference in shape between the top and the bottom surfaces of the die, is that if the bottom surface of the workpiece is placed at the line of rotation of the rotated parts around the X and Y axes, there will be no effect of rotation upon the bottom surface, but the rotation will affect the top surface only. Because of that, the generation of the bottom surface of the die will be due solely to the motivation of the X and Y manoeuvring parts, while the generation of the top surface of the die will be due to the motivation of the rotating parts around X and Y axes, superimposed on the linear X and Y movements.

2.4 Stepper Motors

There are three types of stepper motors which have been used to motivate the four axes rig, namely, 1.8 degree stepper motor, 7.5 degree stepper motor, and a digital linear actuator. The 1.8 degree and the 7.5 degree stepper motors are gearboxed with a gear ratio of 20:1. The digital linear actuator is a stepper motor that has been modified to incorporate an internally threaded rotor fitted with a leadscrew shaft. This type of stepper motor has a linear travel of 0.0254 mm per full step and a maximum travel of 76.2 mm. It gives up to 11.8 Kg linear force, and needs 24 Vdc to run it.

<u>Brightness Control</u> <u>Contrast Control</u>

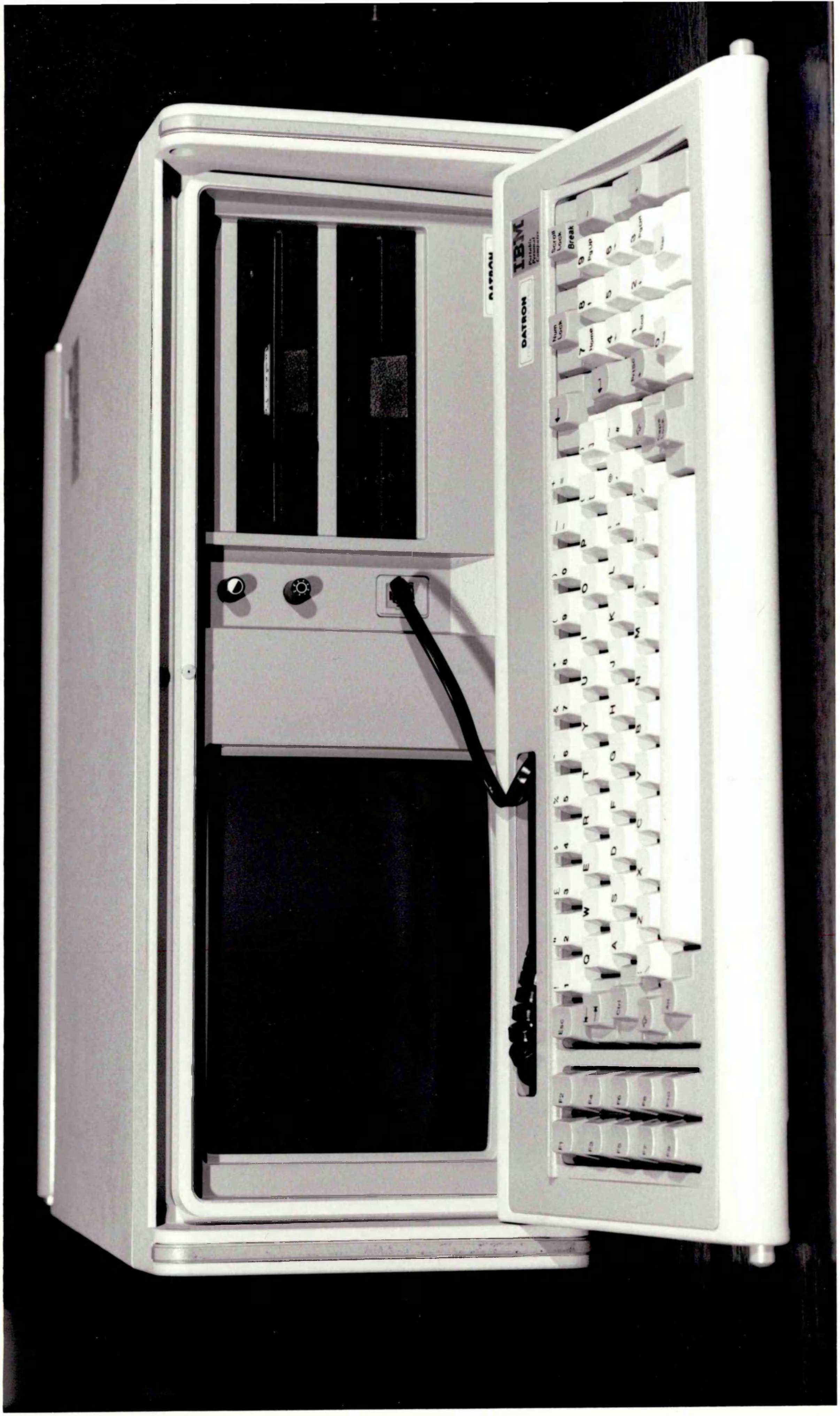
Diskette Drive 1

Visual Display Unit

Diskette Drive 2

KEYBOARD

<u>PLATE 1</u>


IBM
DATRON

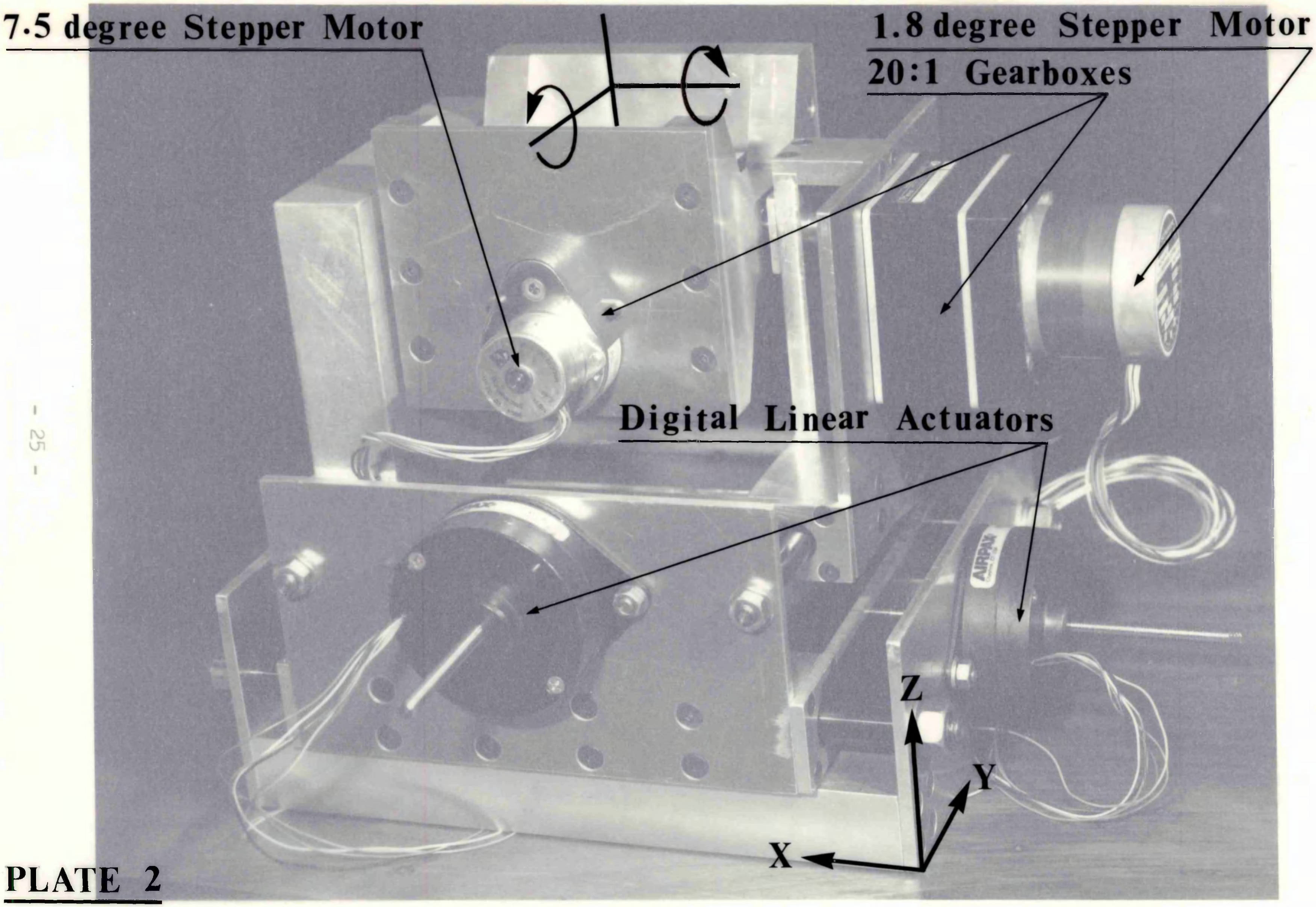

7·5 degree Stepper Motor
1.8 degree Stepper Motor
20:1 Gearboxes
Digital Linear Actuators
Z
Y
X

PLATE 2

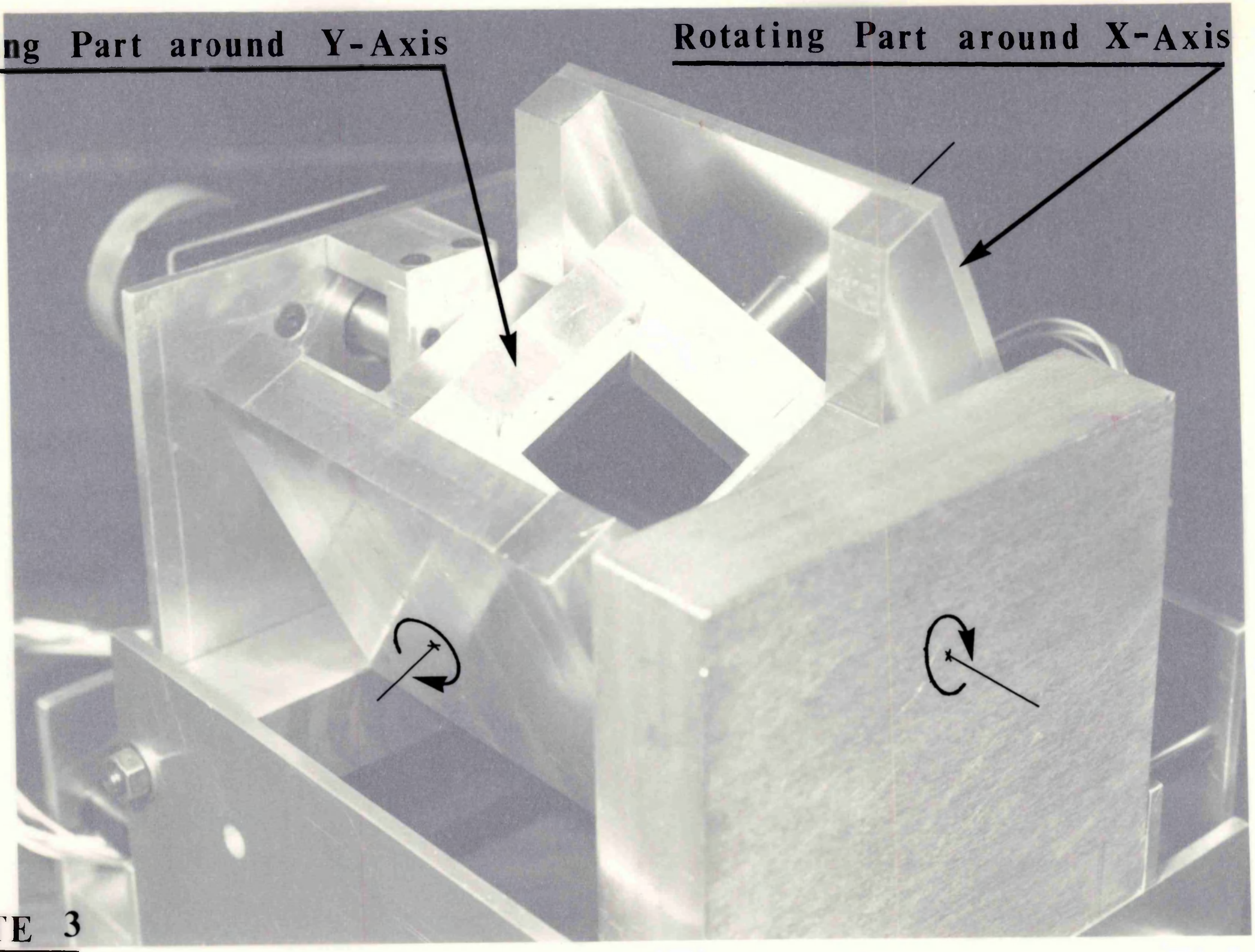


PLATE 3

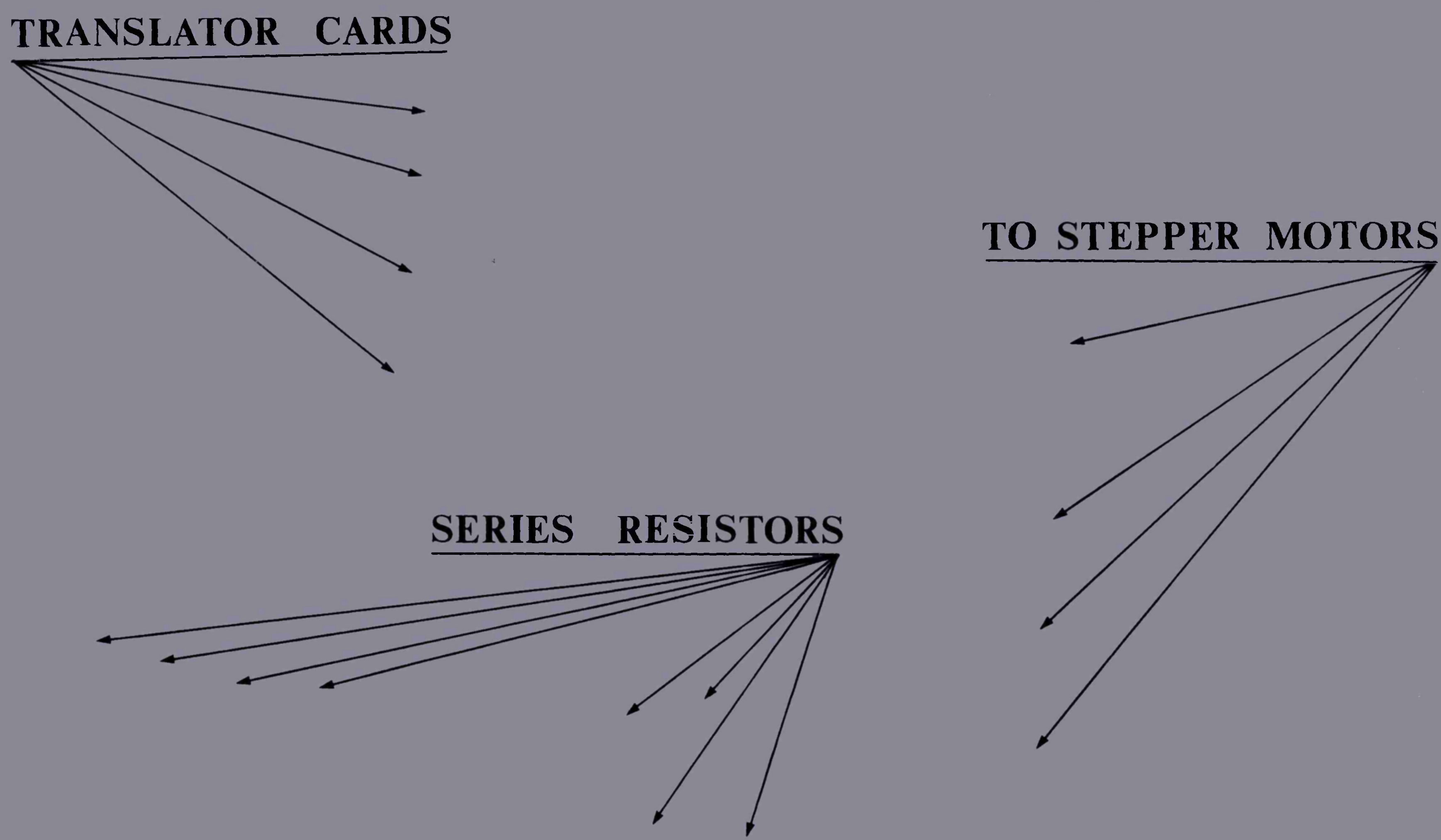
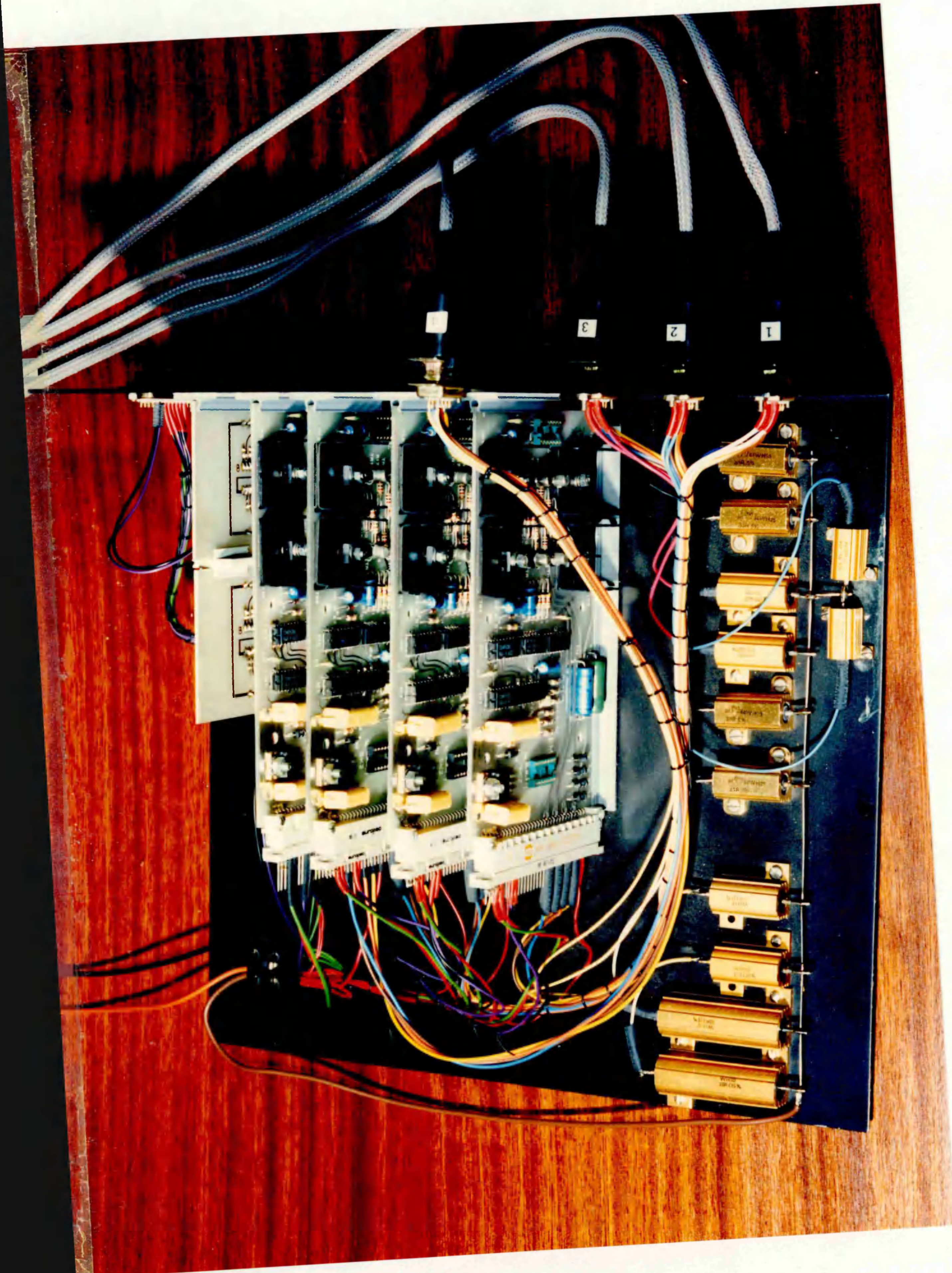


PLATE 4

PLATE 4


3
2
1

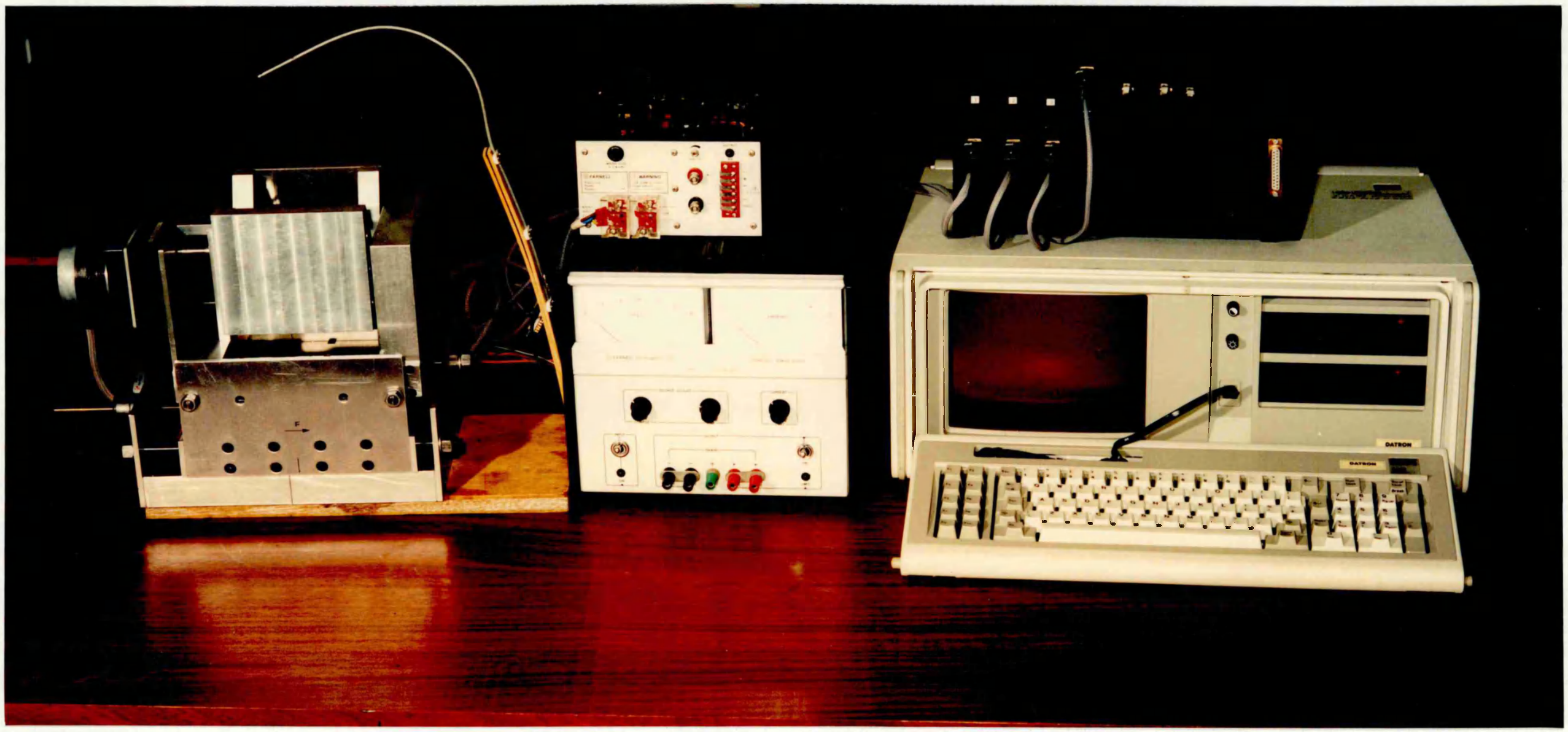


PLATE 5 (from left to right); the 4-axes rig, the hot wire, the power supplies, the translator cards unit, and the micro-computer.

CHAPTER 3

Software Development

3.1 Introduction

The control of the stepper motors which motivate the rig, or to be specific, which manipulate the mounted workpiece, needs to be precise; therefore, the software should be capable of governing each stepper motor independently. It should be noted that to obtain the required die cavity, it is necessary to drive the four stepper motors in such a way as to avoid the occurrence of overcuts while generating the top and the bottom surfaces of the die.

The computer language of this software is Advanced Basic, and it has been used for the following reasons:

i) the EDM process is slow, and because of the similarity in the time required for this cutting process and the execution time of the software, the Basic language looks suitable for the fulfilment of this task;

ii) the interfacing card, which has been employed for the communication between the computer and the stepper motors, needs to be programmed in Basic;

iii) it is an easy language to learn, and allows the possibility of obtaining a graphical hardcopy of any desired die section.

An IBM personal computer has been used to run this software, for two reasons. Firstly, using a personal computer is good for privacy in work. Secondly, there were only two systems in the department to choose from, Apple IIc or IBM Pc. I have chosen the IBM Pc because of its superiority and popularity.

The general structure of the software depends upon the built-in or feed-in data for the top and the bottom surfaces of the die. From this data the die profile can be formed, and the X and the Y coordinates of any intermediate section can be found.

3.2 Profile Generation

The main concept of the previously mentioned software is to deal with X and Y coordinates of a known number of points representing two parallel surfaces at a known distance from each other (Z-coordinate). From these points the die profile can be generated, the computer programme assigning the first group of points to represent the top surface of the die, and the second group of points, equal in number to the first group, to represent the bottom surface of the die. Then, by connecting each point from the top surface to the corresponding point on the bottom surface, the die profile can be generated. Practically, the required die profile can be produced by two concurrent steps. One of the steps is the generation of the bottom surface, which can be done by manipulating the mounted workpiece in the X and Y directions, while the second step is to generate the top surface by manipulating the workpiece according to the angles occurring in space between the top and the bottom surfaces of the die.

These angles can be calculated as follows:

$$\boxed{\beta} = \tan^{-1}\left(\frac{X_b - X_t}{Z_b - Z_t}\right)$$

$$\boxed{\alpha} = \tan^{-1}\left(\frac{Y_b - Y_t}{Z_b - Z_t}\right)$$

where X_b & Y_b : are the X & Y coordinates for the bottom surface.

and X_t & Y_t : are the X & Y coordinates for the top surface.

3.2.1 Die Cross Sectional Area Calculation

The reason for calculating the cross sectional area of the die can be stated in two points. The first point is to confirm the accuracy in the calculation of the X and Y coordinates of any intermediate section. For instance, by assuming that the chosen section was at the top surface of the die, the computed area should be equal to the actual area of that surface, and as a result, the equations for the calculation of the X and Y coordinates of any intermediate section verified. The second point is that by knowing the area of any section and the top surface area of the die (inlet), the reduction ratio can be calculated. It is very important for the wire drawing dies to be manufactured according to the recommended reduction ratios, which results in longer die life, and a good quality product.

There are two methods of calculating the area of any shape if the equation of the line representing that shape is unknown, these being the grid and sectors methods.

3.2.1.1 Grid Method

Described as drawing a grid inside the shape, then by counting the grid's units and knowing the area of one unit, the area of the shape can be found.

Disadvantages of this method:-

1. The accuracy of the determined area of the shape depends upon how small are the grid's units, because, as shown in Fig. 10, at the boundary of the shape there will be some points of the grid's units that cannot be counted and will result in an error in the total area of the shape.

2. Counting the grid units is time consuming and the user is liable to miss counting some units.

3. The user needs to redraw the grid if the shape is changed.

4. It is not easily used in a computer programme.

3.2.1.2 Sector Method

Where the resultant distance between the centre of the shape and every point on the boundary of the shape, as shown in Fig. 11a, can be calculated by using the following equation:

$$R = \sqrt{X^2 + Y^2} \qquad - (1)$$

Refer to statement 2650 (Appendix I)

Then the angles generated between these resultant distances can be found by using the equation:

$$\theta = \tan^{-1}\left(\frac{Y}{X}\right) \qquad - (2)$$

Refer to statement 2690 (Appendix I)

From equations (1) and (2) the area of each sector can be obtained by using the equation:

$$\text{Area of sector} = \frac{R^2\theta}{2} \qquad - (3)$$

Refer to statement 2750 (Appendix I)

Equation (3) is true if θ is in radians, but if θ is in degrees then the next equation should be used:

$$\text{Area of sector} = \frac{\pi R^2 \theta^{\circ}}{360}$$

By summing up the areas, the total area of the shape is obtained.

3.2.2 Error Elimination

The sector method is liable of errors in the calculation of the area, if the shape is complex, where some of the out of boundary area is included as a part of the shape, see Fig. 11b, 11c. To eliminate this error, a sub-programme, which controls the area calculation path once this error occurs, has been used. When the generated angle between the resultant distances becomes less than the previous angle, that is an indication of the inclusion of an out of boundary area, and at this stage the current area will be counted as an error. At this stage, the computer will make the previous angle a datum for subsequent angles. Once it arrives at an angle equal to or greater than the datum angle, that is an indication of passing the error zone, and the computer will return to the main programme. At the end of this stage the error areas will be subtracted from the total area of the shape and the net area remains.

3.2.3 Finding X and Y coordinates for any intermediate section

If it is assumed that the top and bottom surfaces of the die are circles as shown in Fig. 12, then by introducing a section along the die in the Z-direction such as section A-A, it can be found that by drawing a vertical line parallel to Z-axis, there will be two generated triangles, see Fig. 13 (shadow triangles).

From geometry,

$$\frac{X_2 - X_1}{Z_2 - Z_1} = \frac{X_s - X_1}{Z_s - Z_1} \qquad - (4)$$

$$\frac{Y_2 - Y_1}{Z_2 - Z_1} = \frac{Y_s - Y_1}{Z_s - Z_1} \qquad - (5)$$

where X_1 & Y_1 : are the X & Y coordinates for the bottom surface.

and X_2 & Y_2 : are the X & Y coordinates for the top surface.

From equations (4) and (5) the following may be obtained:

$$X_s = X_1 + \frac{(Z_s - Z_1)(X_2 - X_1)}{(Z_2 - Z_1)} \qquad - (6)$$

Refer to statement 1050 (Appendix I)

$$Y_s = Y_1 + \frac{(Z_s - Z_1)(Y_2 - Y_1)}{(Z_2 - Z_1)} \qquad - (7)$$

where X_s & Y_s : are the X & Y coordinates for any intermediate section.

3.3 Simulation of the Drive System

The process should start from the centre of the workpiece, where the first two profile angles namely, α and β, are generated respectively, then the X and Y coordinates of the first point at the bottom surface are generated.

The next step is to generate the second values of the α and β angles, but for the generation of the X and Y coordinates of the second point at the bottom surface, the present absolute value of the X-coordinate should be compared with the previous absolute value of the X-coordinate for the same surface. If the present value is greater than or equal to the previous value then the Y-coordinate of the present point should be generated first, then the X-coordinate follows. But if the previous condition is not true then the X-coordinate should be generated first. This procedure should be followed for the rest of points representing the bottom surface.

The motion of the rig is such that pulses are firstly generated to motivate the α axis until it reaches its next coordinate point. The angle β is then similarly generated. Finally, the linear motions, X and Y are completed individually, their order dependant upon the actual geometry of the desired part as stated above. Thus, the motion is achieved by independent movement of the four axes.

The generation of the α and β angles has been assigned to a 7.5 & 1.8 degrees geared stepper motors respectively, with a gear ratio of 20:1. The two linear actuators are assigned for the generation of the X and Y coordinates, with a linear travel of 0.0254mm per full step.

An input/output control card has been interfaced with the computer to execute the X and Y coordinates and the α and β angles through an addressed port, as shown in Fig. 14. See Fig. A7 flowchart for the description of the drive simulation.

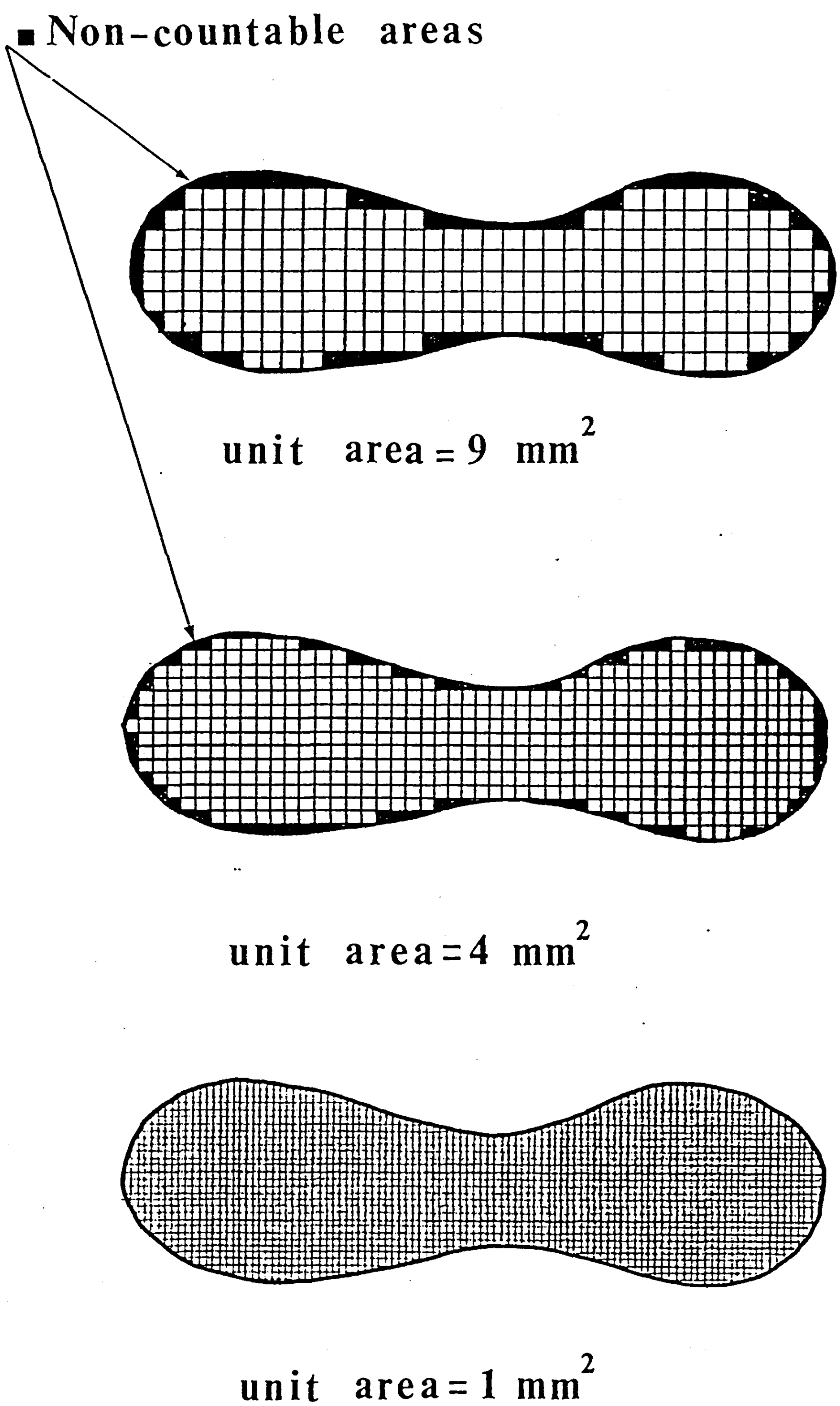
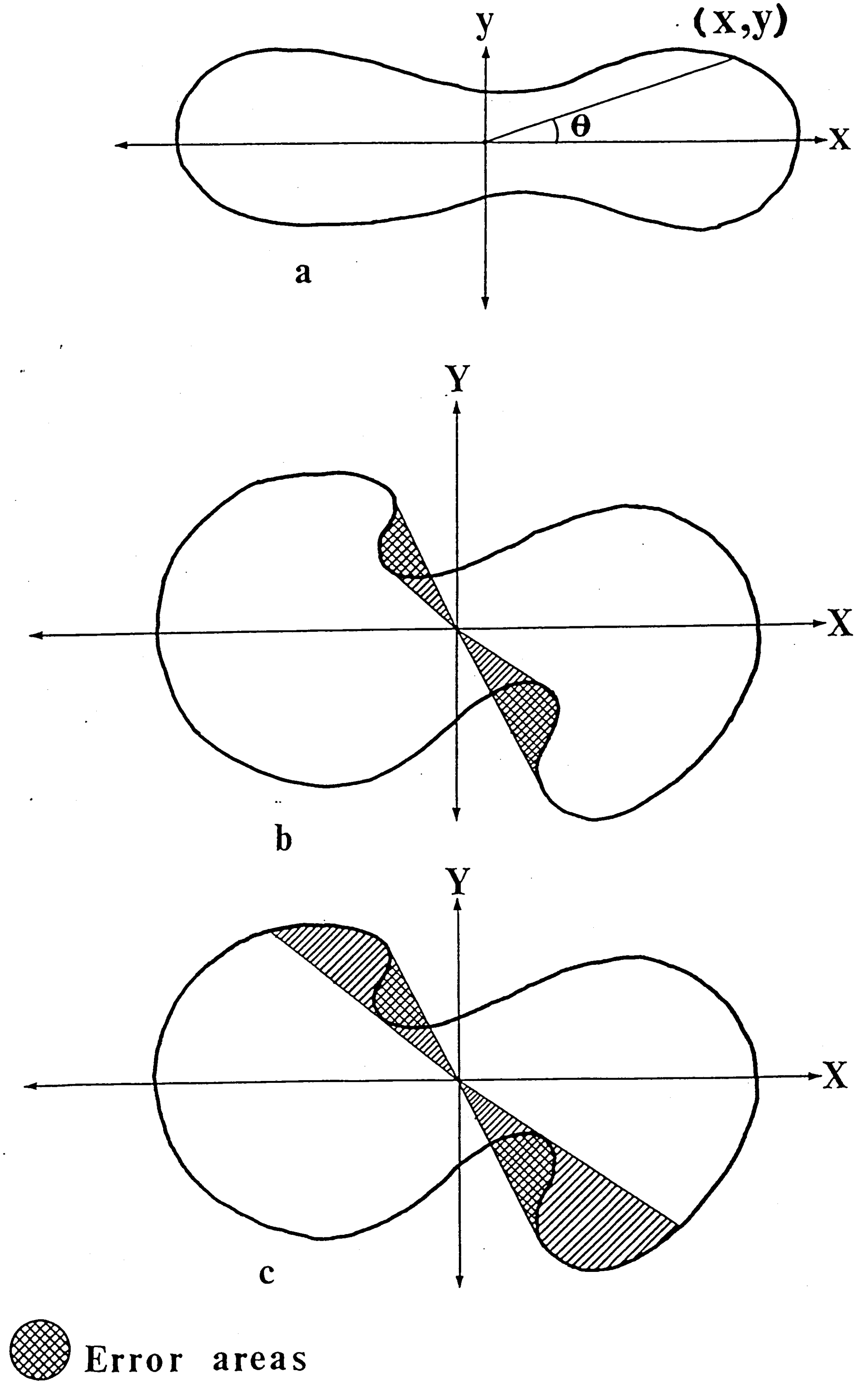


Fig.10 THE GRID METHOD.



Error areas

Fig.11 THE SECTOR METHOD.

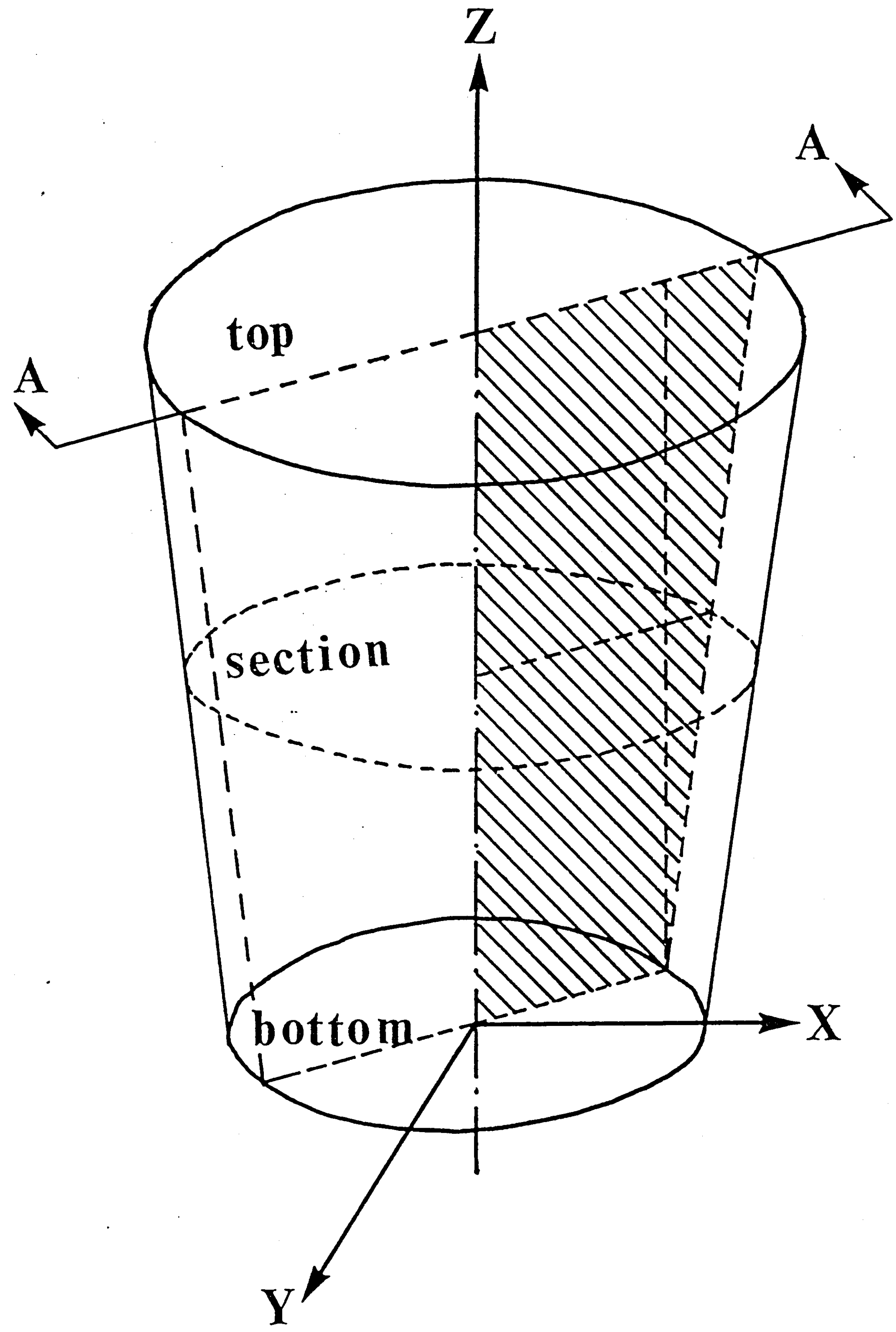
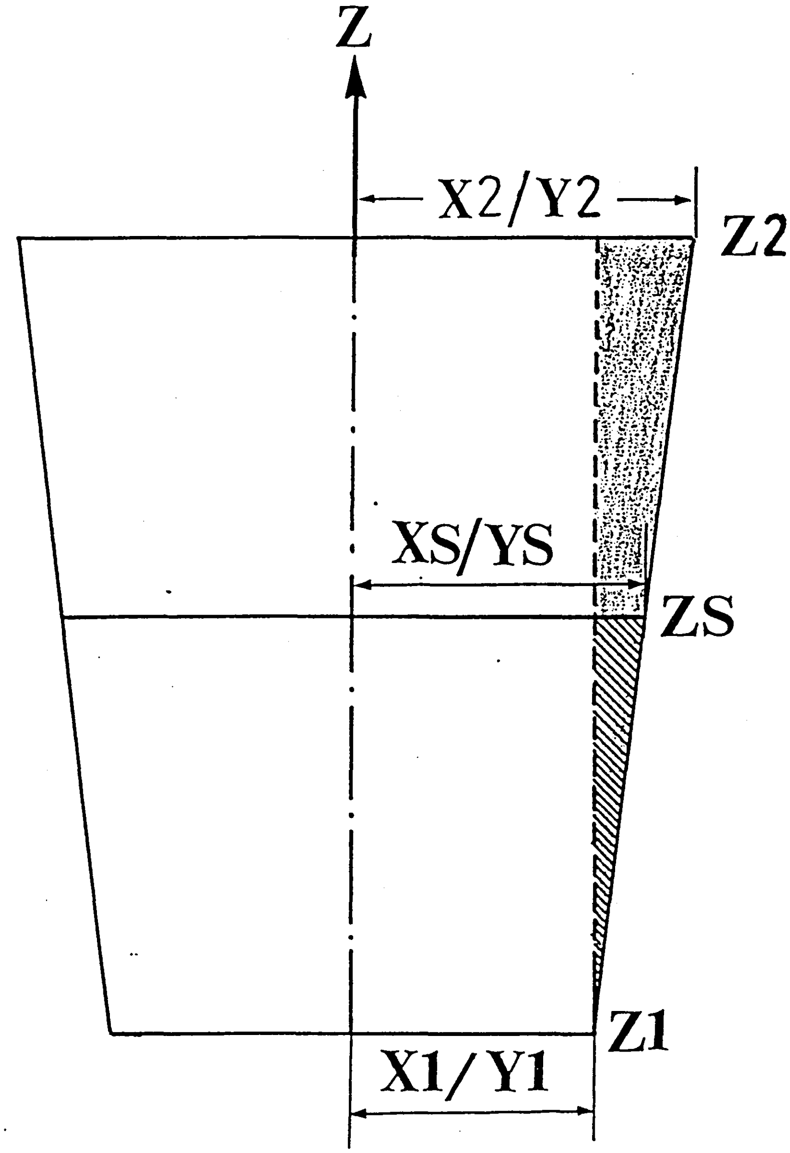


Fig. 12 Die profile.



$$\frac{(X2-X1)}{(Z2-Z1)} = \frac{(XS-X1)}{(ZS-Z1)}$$

$$\frac{(Y2-Y1)}{(Z2-Z1)} = \frac{(YS-Y1)}{(ZS\quad Z1)}$$

Fig. 13 Section AA.

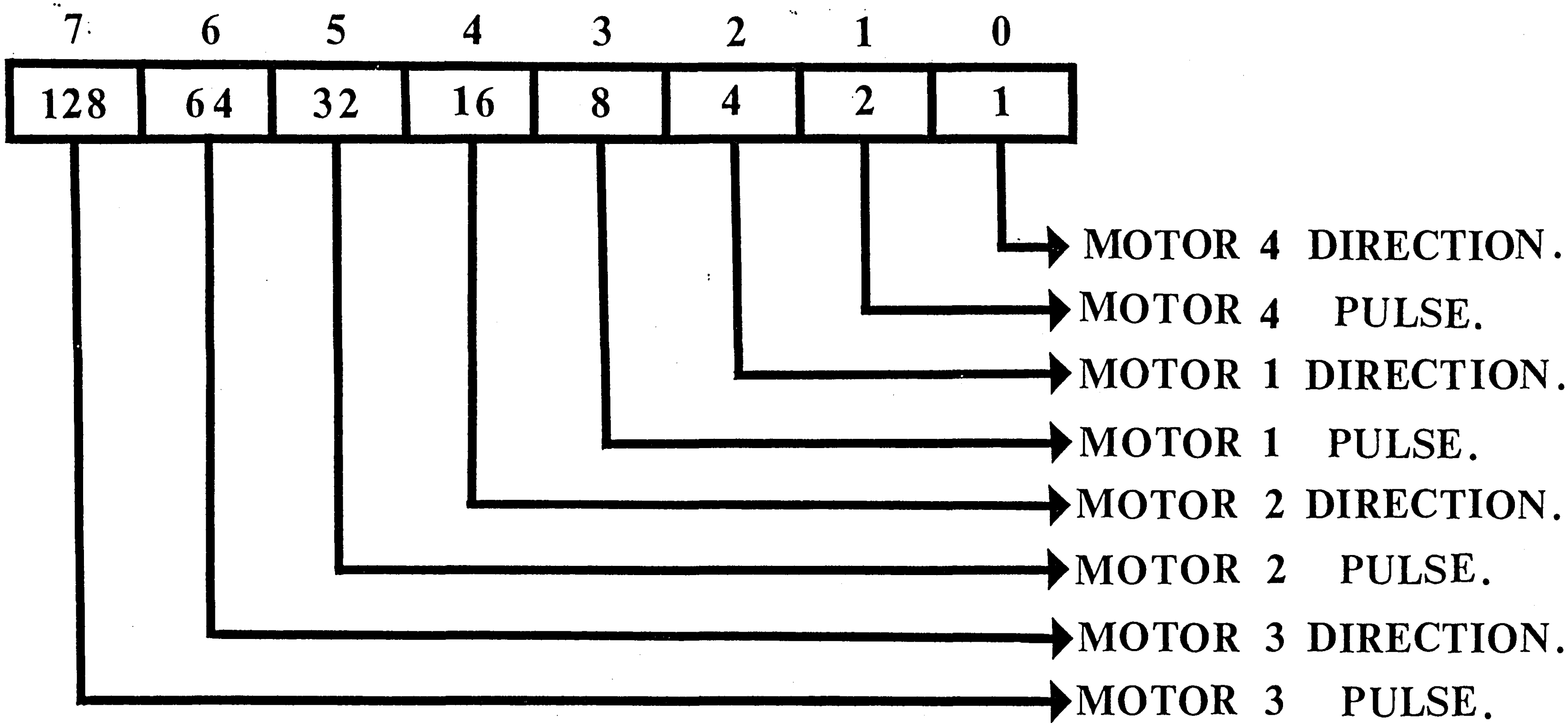


Fig. 14 Port address for the 8255 input / output control card.

Chapter 4

Interfacing

The successful implementation of a micro-computer in a control application requires that the means be found to link the process to the micro-computer.

The process in this case is the manipulation of the four axes rig, designed to produce wire drawing dies of complex shape.

The four stepper motors required to motivate the rig are all four-phase, and essentially digital, with one angular step for each input pulse supplied by power transistors switched by the computer.

There are three main drive elements which influence the overall system performance. The first element is the controller which generates the pulses. The second element is the translator which directs the pulses to the phase windings, and the third element is the power supplies which feed the actual phase currents in accordance with logic level signals from the translator. To achieve faster current rise, the stepper motor is connected to a high-voltage supply and a series resistance, as illustrated in Fig. 15.

Three types of stepper motor have been used to motivate the four axes rig. The first type is a 7.5 degree gearboxed stepper motor with a gear ratio of 20:1, which results in a 70 Ncm torque and a 0.375 degree per step at the output shaft. This type has been connected with two 88 ohms series resistors. The second type is a 1.8 degree gearboxed stepper motor with the same gear ratio as the first type, but the resolution at the output is a 300 Ncm torque and a 0.09 degree per step at the output shaft. This motor has been connected with two 20 ohms series resistors. The third type is a linear actuator with a 11.8 Kg linear force and a travel distance of 0.0254 mm/step, and connected with two 25 ohms series resistors. Two of these are used. Each stepper motor is linked with an EM162 translator card, which as mentioned before directs the incoming pulses toward the stepper motor, as shown in Fig. 16. The four translator cards are connected to the micro-computer via an 8255 input/output interface card which contains 48 input/output lines, as shown in Fig. 17.

Chapter 3 described the software used to drive the stepper motors and chapter 2 detailed the design of the rig itself. Details of the stepper motors are given in Appendix III.

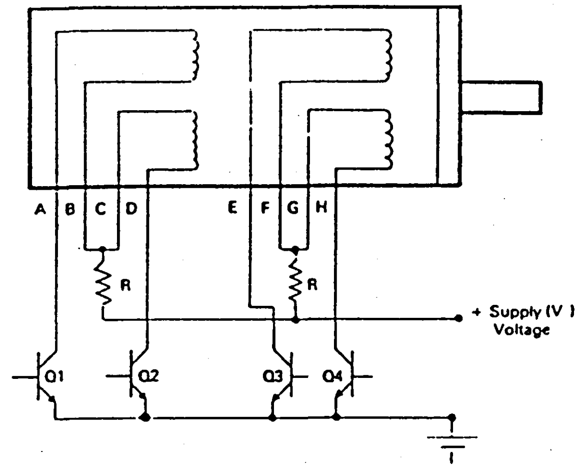


Fig.15 A schematic drawing for a 4-phase stepper motor and two series resistors.

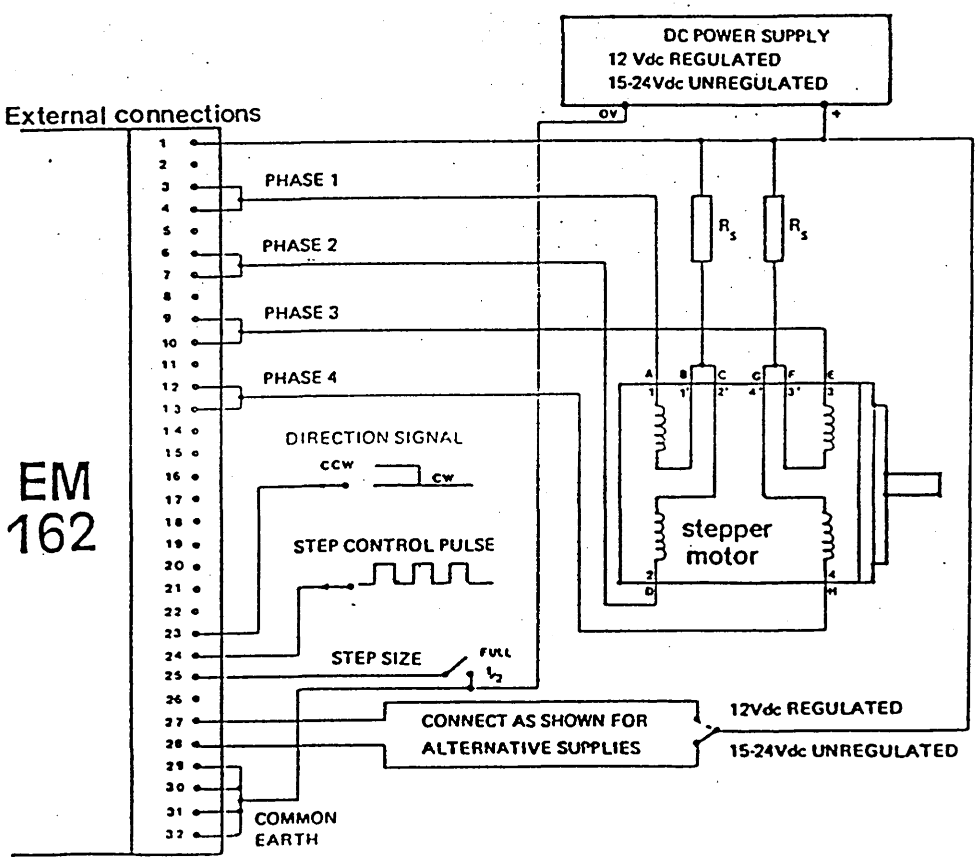


Fig. 16 A typical drawing for connecting a stepper motor with a translator card.

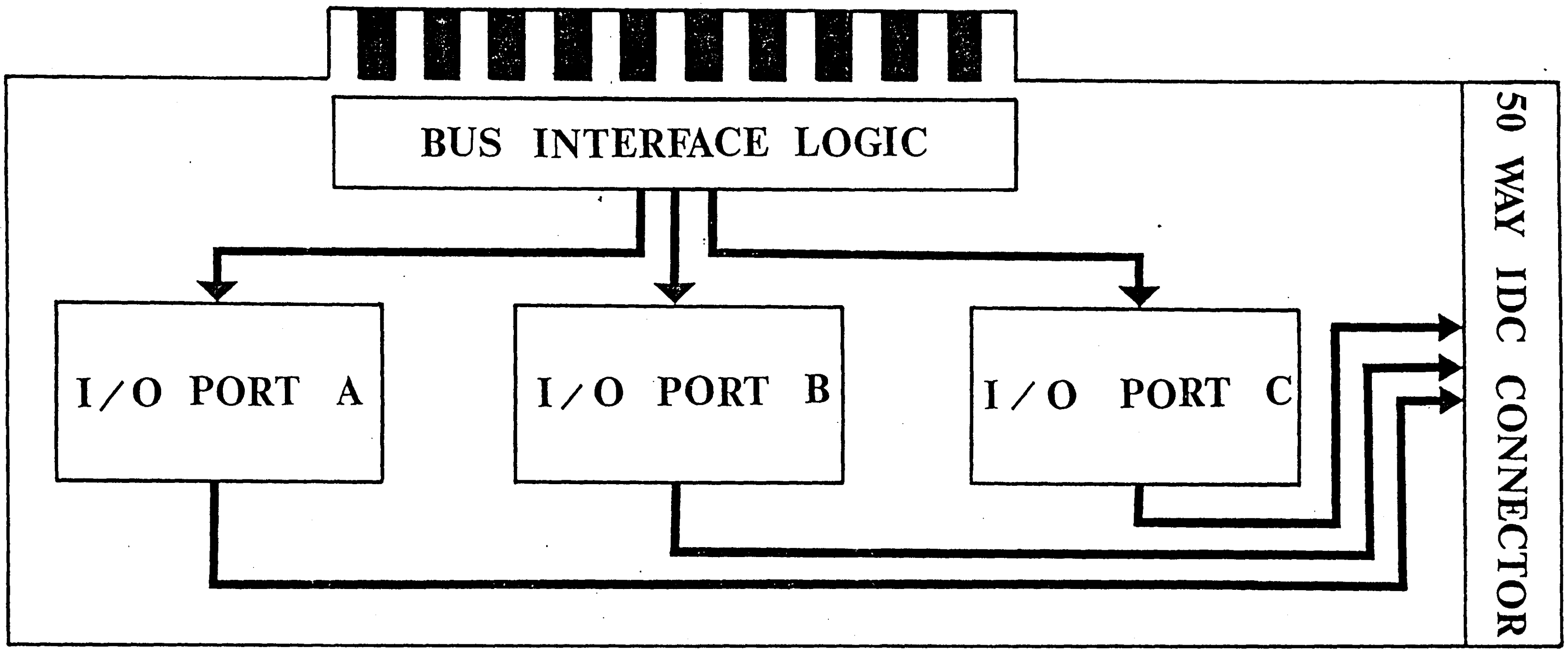


Fig. 17 The 8255 input/output control card.

Chapter 5

Test Results

To simulate the EDM process a hot wire cutting a foam material has been used instead of WEDM with a metal workpiece.

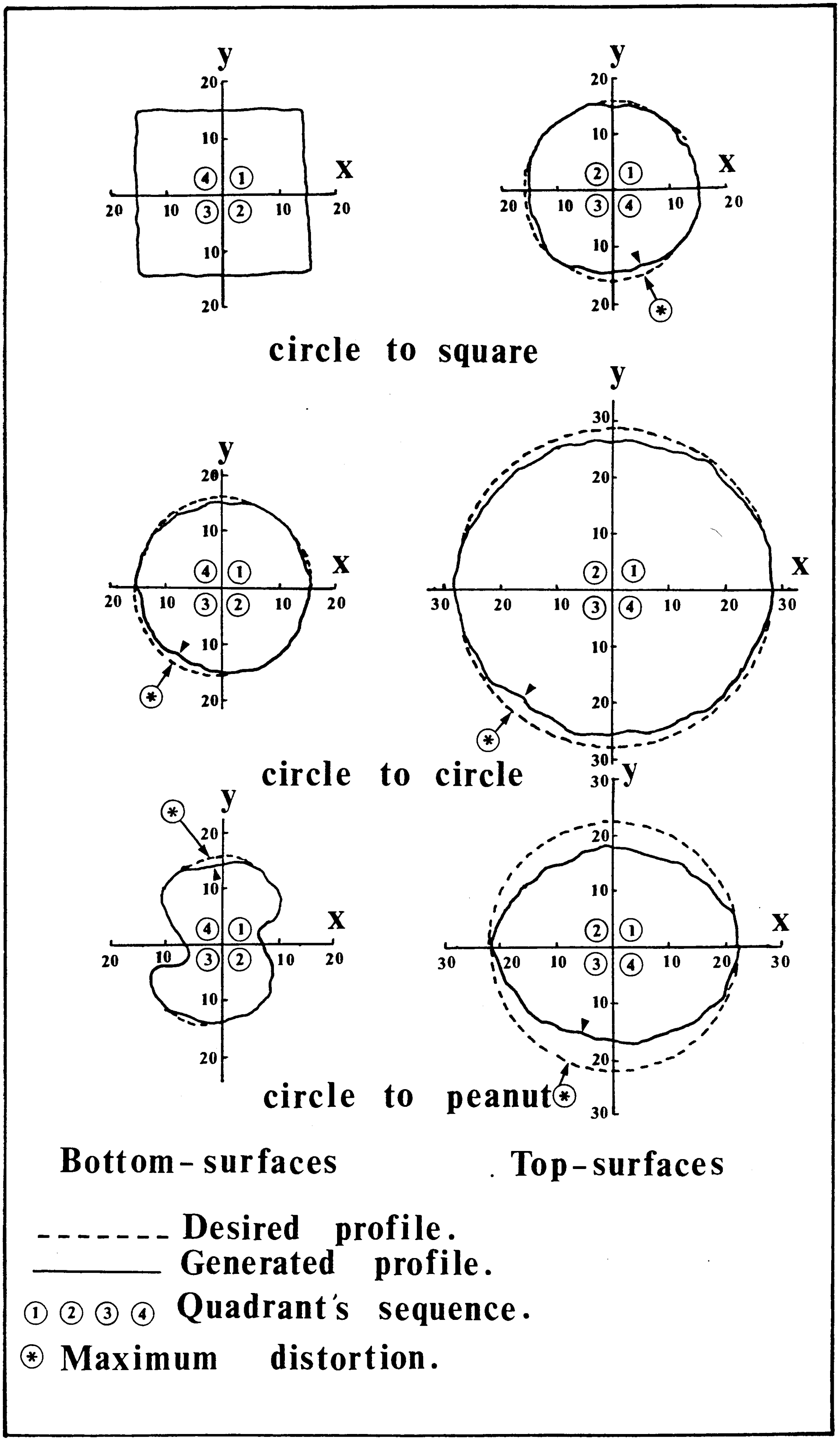
5.1 Test Procedure

Before test runs could be conducted, a 50mm cube of foam material was cut and then drilled centrally so that a hot wire could be threaded through the workpiece. Having done this, the programme was started and all the required data were fed-in through the computer's keyboard. The power supplies for both of stepper motors and the hot wire were switched-on. The computer presented, firstly, the values of all of the components of the sector area's equation which were mentioned in chapter 3, section 3.2.1.2, and then presented the total area of the top and the bottom surfaces in a tabular form. Secondly, it presented the X and Y coordinates and the total areas for up to five intermediate sections, where the locations (Z-coordinates) of these intermediate sections had been left to the user's choice. Thirdly, the computer presented the two angles, α and β, generated in space between the top and the bottom surfaces of the die. Fourthly, the user had the choice of either commanding the computer to generate the die cavity within the foam cube mounted onto the rig, or to show a graphical representation of that die on a visual display unit. When the generation of the die cavity was chosen, the computer went through a rig calibration routine to bring the hot wire to the centre of the workpiece, after which the die cavity was automatically produced. Four main elements governed the die cavity process. Two of them were the X and Y coordinates of the bottom surface, and the other two were the two space angles α and β. While the two linear actuators were assigned for the generation of the first two elements, the 7.5 degree and 1.8 degree geared stepper motors were responsible for the generation of the last two elements.

The generation of the die cavity started with the generation of the first two angles, α and β, that existed between the top and the bottom surfaces at the first point on each surface. The X and Y coordinates of the first point from the bottom surface were then generated. At this stage came the effect of the X-coordinate's value from the bottom surface upon the generation sequence of the rest of the points representing the bottom surface. If the value of the present X-coordinate was greater than or equal to the previous value, the Y-coordinate was generated first followed by the generation of the X-coordinate; otherwise, the X-coordinate was generated first, followed by the generation of the Y-coordinate.

The previous sequence was followed for all of the points defining the top and bottom surfaces and resulted in the die cavity being formed.

The top and the bottom surfaces of the die were represented by fifty-five points each. Four types of die cavities have been produced, a circle to square, a circle to circle, a circle to "peanut", and a square to "peanut".

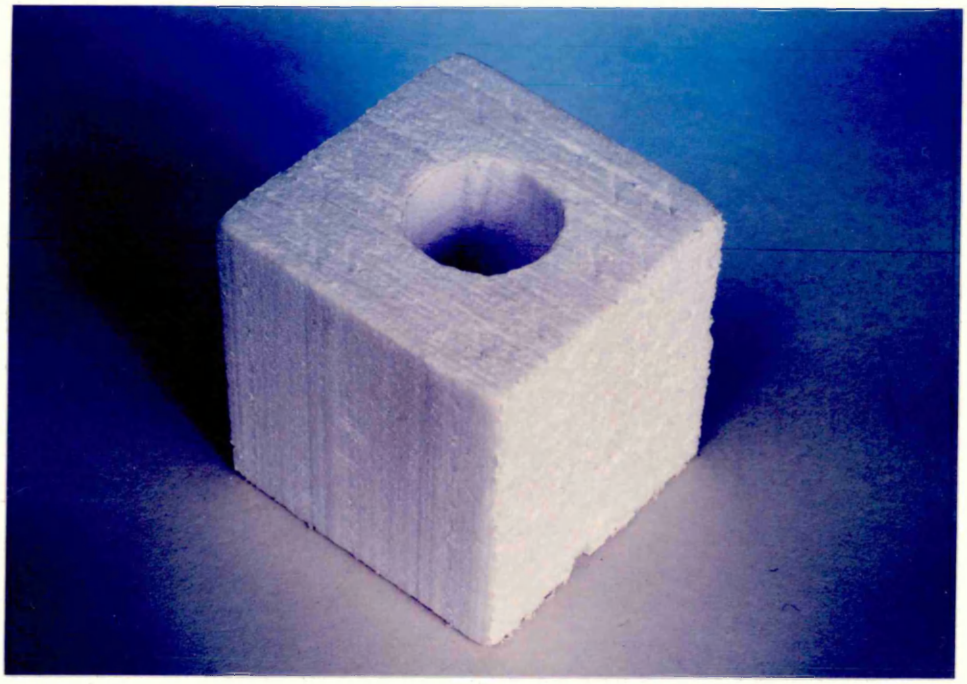

circle to square
circle to circle
circle to peanut
Bottom-surfaces
Top-surfaces
Desired profile.
Generated profile.
① ② ③ ④ Quadrant's sequence.
⊛ Maximum distortion.

Die shape	Desired profile				Generated profile				Maximum distortion			
	Top		Bottom		Top		Bottom		X-coordinate		Y-coordinate	
	X	Y	X	Y	X	Y	X	Y	Top	Bottom	Top	Bottom
circle to square	6	15	15	15	5	13·5	15	15	−1	0	−1.5	0
circle to circle	18	22	9	13	16	19	8	12	−2	−1	−3	−1
circle to peanut	8	21	2·5	15·5	6	15	1·5	14	−2	−1	−6	−1·5

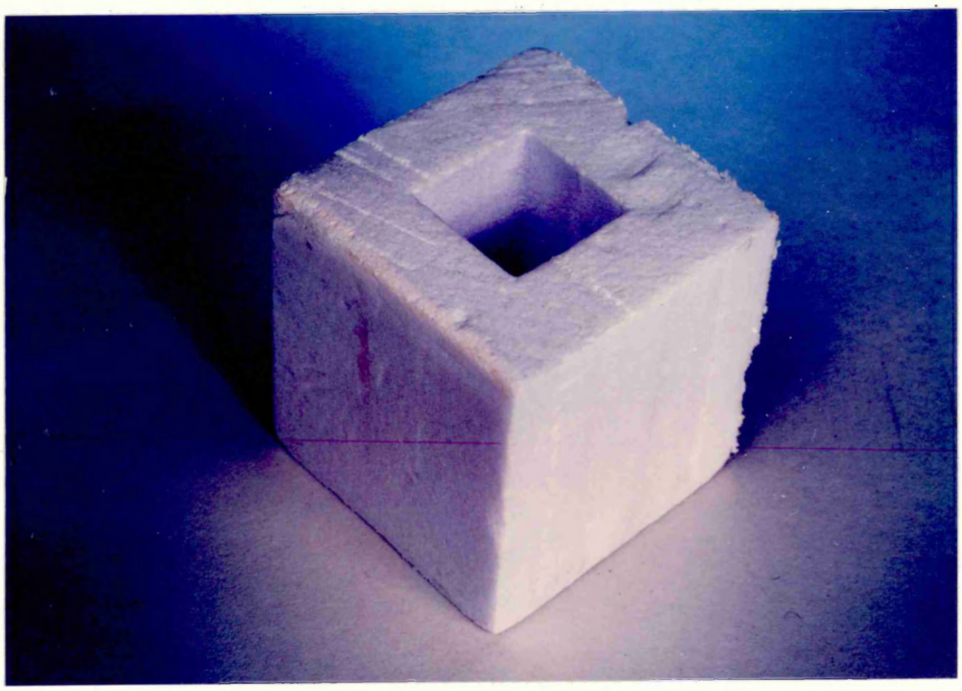
All units in mm

5.3 Other Problems

The stepper motors became hot when held in a standstill start, this being due to the EMI62 translator cards not having the function of disenabling the stepper motors during this state. Therefore, the power supply for the stepper motors needed to be switched off immediately at the end of the cutting process of each die to let them cool before commencing the cutting of the next die.

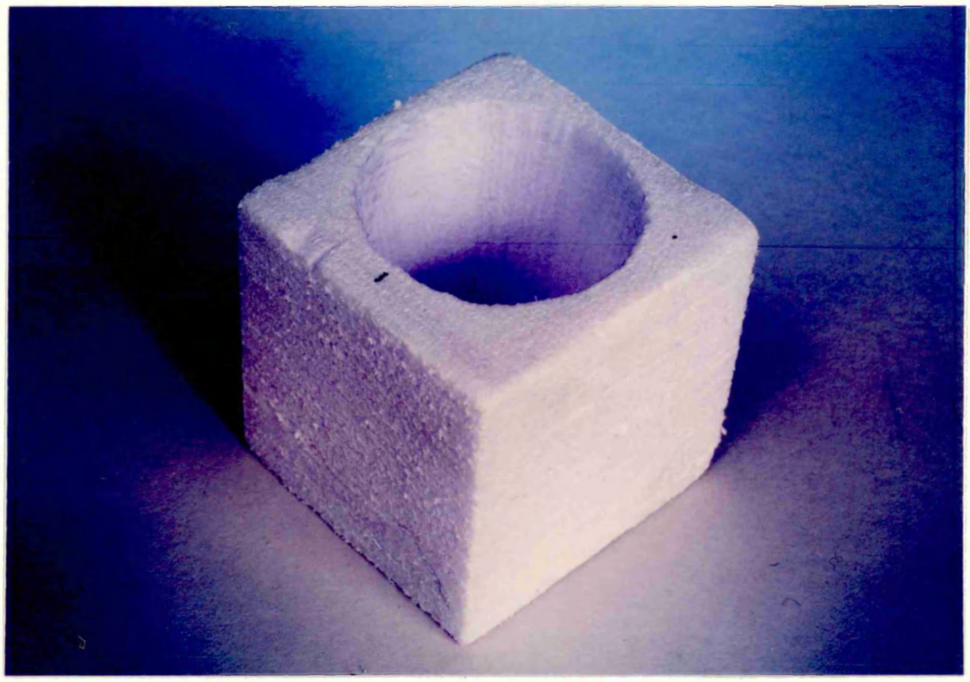


TOP SURFACE

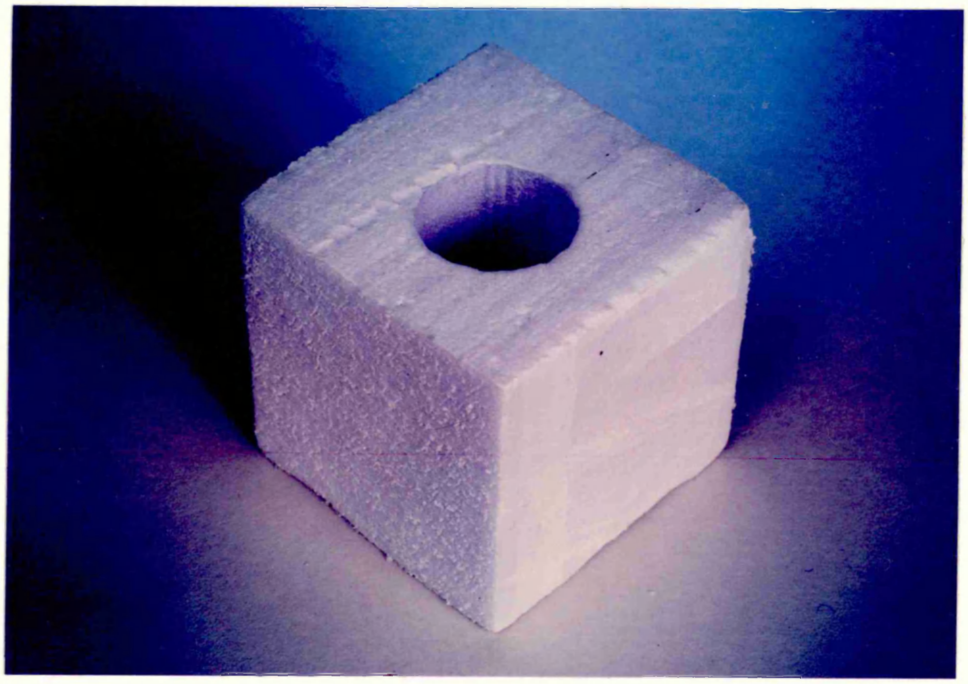


BOTTOM SURFACE

PLATE 6 CIRCLE TO SQUARE

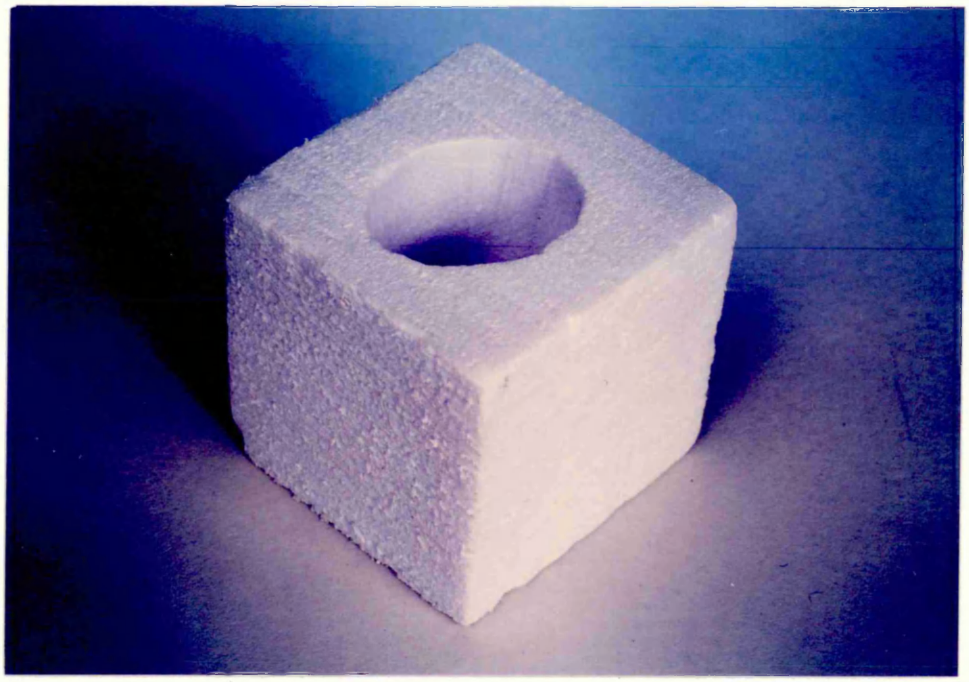


TOP SURFACE

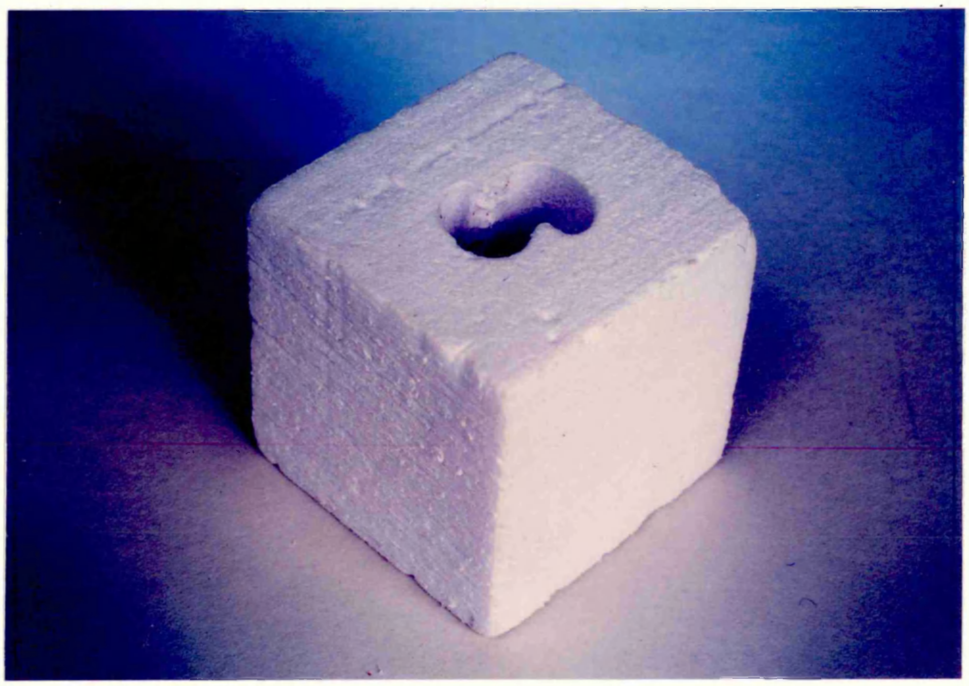


BOTTOM SURFACE

PLATE 7 CIRCLE TO CIRCLE

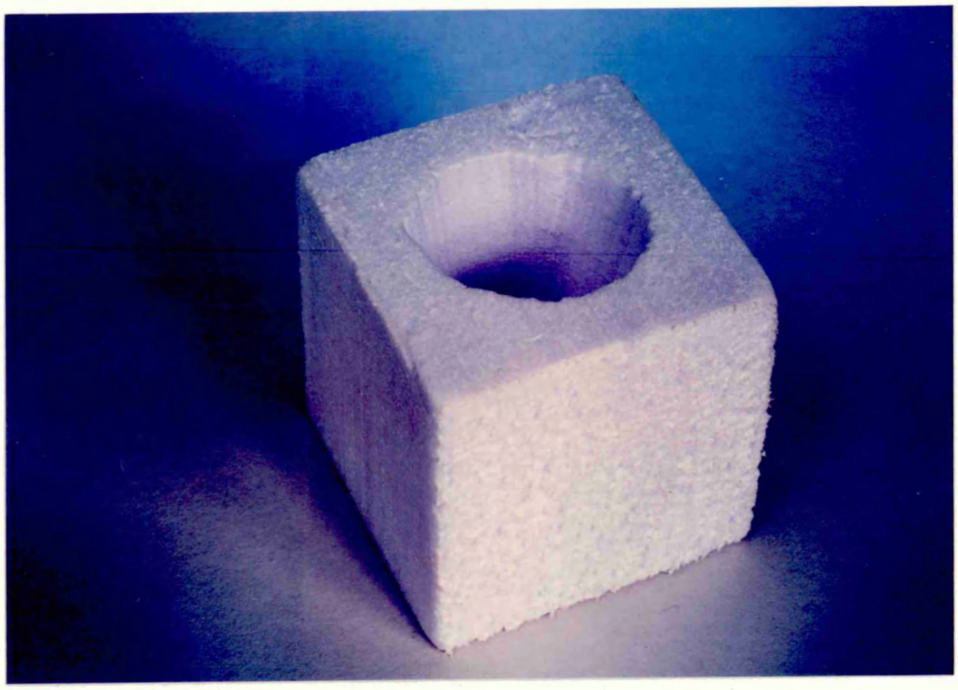


TOP SURFACE

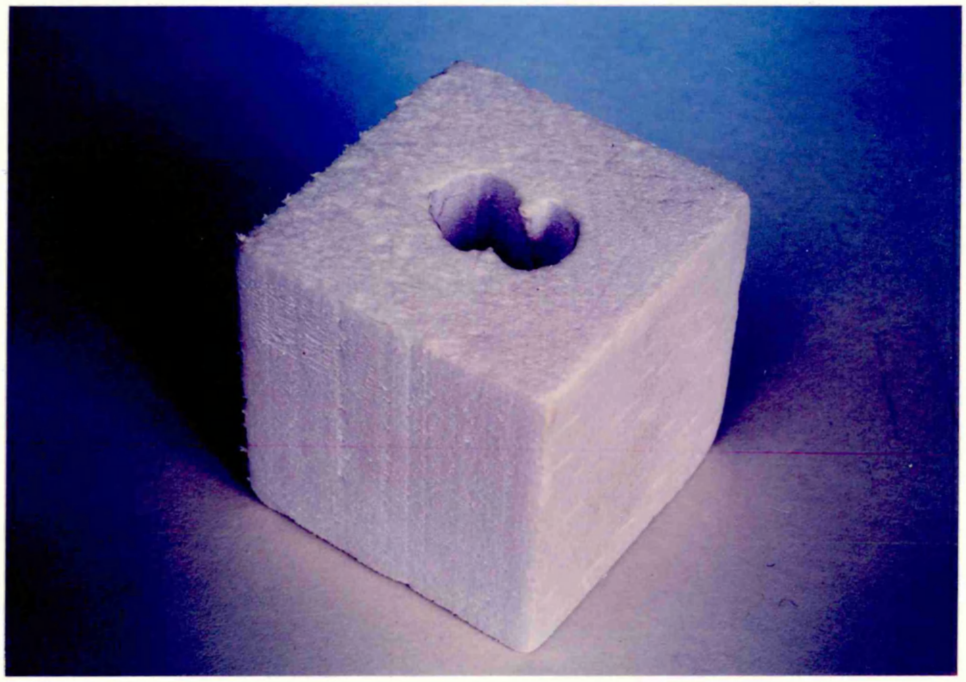


BOTTOM SURFACE

PLATE 8 CIRCLE TO PEANUT
110 - POINTS



TOP SURFACE



BOTTOM SURFACE

PLATE 9 CIRCLE TO PEANUT
55 - POINTS

Chapter 6

Discussion

6.1 The Four Axes Rig

Initial feasibility studies suggested that four axes would be sufficient to achieve the necessary manipulation of the die blank around the wire of a WEDM machine. Most commercial machines use five or more axes. Although a suitable machine may be purchased commercially, the cost is prohibitive and, therefore, one of the aims of this research was to design, to minimum cost, a rig suitable for simple attachment to an existing WEDM machine.

The resulting rig is of straightforward design with two linear translational axes and two rotary axes. The motions are powered by simple linear and rotary geared stepper motors respectively.

Since cost was of prime concern, a micro-computer was chosen to control the hardware. The IBM pc was used in this case, but any micro-computer with suitable interfacing would suffice.

6.2 Choice of Computer

Recent developments in EDM power supplies have been concentrated on controlling the transistor circuits. All spark parameters, as well as machine tool functions, can now be controlled by a micro-computer. The advantages of using a micro-computer can be briefly stated as follows:-

i) to minimize the cost of control; most of the commercially available micro-computers are cheaper than a purpose-built control system,

ii) the compactness of the micro-computer eases the mobility and the space problems of the system,

iii) the initial and running costs of a micro-computer are less than those of a mini or main-frame,

iv) micro-computers are dedicated to a task, whereas larger computers are multitasking and often slower because of time sharing.

6.3 The Software

The machining time of the WEDM process plays a very important role in the choice of the software language. It has been found that the WEDM machining time is comparative to the execution time of a programme written in the BASIC language. Therefore, this software has been written in IBM Advanced Basic. The interface card used can be easily programmed using this language.

The software structure consists of four main parts. The first part is the calculation of the cross-sectional area of the top and the bottom surfaces of the die by using the sector method as described in Chapter 3. The second part is the calculation of the X and Y coordinates of up to five intermediate sections in addition to the calculation of their cross-sectional areas. The third part is the graphical drawings of the top, the bottom, and the five intermediate sections. The fourth part is the generation of the die cavity.

The first part can be used as a confirmation facility for the accuracy of the second part. For example, if one of the intermediate sections was chosen at the location of the top surface, the area of that section should be equal to the area of the top surface and the coordinates calculated should also correspond to those initially input as the top surface.

One of the problems in using the "sector method" to calculate the area of a section is that of including "out of boundary" portions of a sector in the summation; see Figs 11b and 11c. This has been overcome in this software by implementing a sub-programme, which controls the area calculation path once this error occurs. When the generated angle between the resultant distances becomes less than the previous angle, that is an indication of the inclusion of an out of boundary area, and at this stage the current area will be counted as an error. At this stage, the computer will make the previous angle a datum for subsequent angles. Once it arrives at an angle equal to or greater than the datum angle, this is an indication of passing the error zone, and the computer will return to the main programme. At the end of this stage the error areas will be subtracted from the total area of the shape and the net area remains.

Appendix II shows in a tabular form the components of equation 3 which find the sector's areas for each surface, the total giving the area of that surface.

The possibility of calculating the X and Y coordinates for up to five intermediate sections gives the user the chance to see the changes through which the top surface of the die goes, to become the bottom surface at the other end of the die.

The two space angles, α and β, which are the most essential factors for the generation of the top surface, are also calculated.

6.4 The Stepper Motors

The implementation of the two linear actuators mentioned in Chapter 2 was governed by two main factors, namely: the weight of the rig's moving parts and the maximum travel distance in the translational axes. The other two stepper motors have been chosen according to their rotor's inertias in comparison with the generated inertias from the rig's rotating parts. (The inertia of the part to be moved should be no greater than five times the rotor inertia.) Although the motors became hot with extended use, as mentioned in Chapter 5, the two linear actuators functioned perfectly. The two geared stepper motors were disappointing due to the backlash in their gearboxes.

The translator cards currently being used do not have the facility to dis-enable the power supply to the motors. This gives a permanent holding torque which is useful for heavily loaded applications. This permanent holding torque means that current is always passing through the motors and, therefore, they become hot. For this application, holding torque is not required since the forces are low. The problem of excessive heat build-up can be overcome by using the EM163 translator cards which have a dis-enable facility instead of the installed translator cards.

6.5 Results from the Tests

The prototype rig is not suitable for attachment to a WEDM machine, since the motors are not of the sealed variety. To simulate the production of complex wire drawing dies, a hot wire cutting a foam material was used in place of the WEDM and tool material respectively.

Four main die shapes were produced, circle to square, circle to circle, circle to "peanut", and square to "peanut". Each shape was represented by fifty-five points, with the possibility of increasing the diameter of the circular surface up to 40 mm.

For the first and the third die shapes the circle was losing its curvature in the second and the fourth quadrants, while the bottom surfaces were perfect. The second die shape (circle to circle) was perfect at both surfaces. The top surface of the fourth die shape was distorted also, while the bottom surface was perfect. The tolerances in the produced die shapes were affected by the overcut zone around the hot wire, which was governed by two factors, namely: the cross-section of the wire, and the current passing through that wire.

The problem of the top surface distortion due to gearbox backlash can be solved in either of two ways; installing backlash free stepper motors instead of the current motors, or by using an Intelligent Data Buffer unit which may be programmed to compensate for mechanical system backlash.

6.6 Further Work

It has been mentioned in the previous section that the present rig is a prototype design. It is not suitable for the real WEDM process since the workpiece should be immersed in the dielectric fluid to generate a suitable environment for the spark in the gap between the workpiece and the cutting wire. Therefore, the stepper motors should be sealed, keeping in mind the problem of cooling the motors themselves.

The rig's parts should be made from a rust-proof material, and all of its bearings need to be protected from the suspended minute particles of metal in the dielectric fluid, by means of fitting a brush or rubber sealings.

One of the problems with the current software is that the centre "home" position is not returned to at the end of the cut. This means that before further dies can be produced, the rig must be centred manually. A simple modification to the software should remedy this.

The software uses data written into the programme itself to generate the desired die shape, or the coordinates may be keyed in manually if desired. If manually keyed in, the data is lost when the computer is switched off. Improvements in this area could be gained by using a digitizer pad to generate the data and subsequently spooling it to disc for future use.

The rig at present operates with stepper motors fed with pulses from the computer. No feedback is used to validate correct positioning of the die whilst it is being produced. Any "lost" pulses would result in an inaccurate die profile. To overcome this, feedback sensors need to be implemented on all four axes of the rig. The simplest type of feedback system would be a digital encoder disc, fitted to the output shaft of the stepper motor. Comparison between input pulses to the motor and output from the encoder would ensure that correct positioning could be maintained.

Chapter 7

Conclusions

The present research involved a feasibility study and the building of a prototype rig for the computer controlled manufacture of complex wire drawing dies. Certain disadvantages in the hardware became apparent during the test, notably the backlash in two geared stepper motors and the heat build-up in all of the motors. The experimental work has shown the existence of the distortion of the top surface may be successfully avoided. Attempts were made to improve the dies produced. These were not successful, and modifications to some of the hardware and software used in this work should give improved results.

It must be noted that the complex dies produced validated that the four axes were sufficient to achieve the necessary manipulation of the die blank around the wire of a WEDM machine, but it is felt that further development is required before it could be used to advantage in full scale production.

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Appendix I

Software

There are five subprogrammes branching from the main programme which is capable of calculating the area of the top, bottom, and up to five intermediate sections, in addition to the calculation of the X and Y coordinates of the previous intermediate sections. It can represent graphically the previously mentioned cross sections of the complex die shape. Finally, it can generate the die profile represented the previous surfaces with the aid of a four axes rig.

The first subprogramme is for the calculation of the surface area of each surface and intermediate section. The second subprogramme is for the elimination of the area error, mentioned in section 3.2.2. The third subprogramme is for the motivation of the stepper motors. The fourth and the fifth subprogrammes are for the execution of the X and Y coordinates of the bottom surface of the die to avoid the occurrence of overcuts while generating the die profile.

```
10 DEF SEG=&HB800
20 KEY OFF:SCREEN 0,1:COLOR 3,0,0:WIDTH 40:CLS:LOCATE 5,17:PRINT "IBM"
30 LOCATE 7,12,0:PRINT "PERSONAL COMPUTER"
40 COLOR 7,0:LOCATE 10,9,0:PRINT CHR$(213)+STRING$(21,205)+CHR$(184)
50 LOCATE 11,9,0:PRINT CHR$(179)+"      DIE PROFILE      "+CHR$(179)
60 LOCATE 12,9,0:PRINT CHR$(179)+STRING$(21,32)+CHR$(179)
70 LOCATE 13,9,0:PRINT CHR$(179)+"      WRITTEN BY:      "+CHR$(179)
80 LOCATE 14,9,0:PRINT CHR$(212)+STRING$(21,205)+CHR$(190)
90 COLOR 13,0:LOCATE 17,10,0:PRINT "ENG. S.M.R. ALDOUSARI"
100 COLOR 10,0:LOCATE 20,8,0:PRINT "Sheffield City Polytechnic"
110 COLOR 11,0:LOCATE 22,7,0:PRINT "       ( APRIL - 1985 )      "
120 COLOR 28,0:LOCATE 24,7,0:PRINT "press space bar to continue"
130 GOSUB 2980
140 CLS:COLOR 7,0:WIDTH 80
150 PRINT "THIS PROGRAM WILL DO THE FOLLOWINGS :-"
160 PRINT
170 PRINT "( 1 ) CALCULATES THE TOP SURFACE AREA OF A WIRE DRAWING DIE."
180 PRINT
190 PRINT "( 2 ) CALCULATES THE BOTTOM SURFACE AREA FOR THE SAME DIE."
200 PRINT
210 PRINT "( 3 ) CALCULATES X & Y COORDINATES AND THE AREA OF UPTO 5-SECTIONS"
220 PRINT "       BETWEEN TOP AND BOTTOM SURFACES."
230 PRINT
240 PRINT "( 4 ) DRAW GRAPHICALLY TOP, BOTTOM, AND SECTIONS SURFACES."
250 PRINT
260 PRINT "( 5 ) DRAW EACH SURFACE AND SECTION SEPARATELY."
270 PRINT
280 PRINT "( 6 ) DEMONSTRATES FIVE DIFFERENT TOP AND BOTTOM SURFACES."
290 PRINT
300 PRINT "( 7 ) DRIVE THE RIG TO GENERATE THE DIE CAVITY."
310 KEY OFF:SCREEN 0,1:COLOR 11,0,0:WIDTH 80
320 LOCATE 20,21,0:PRINT "PRESS SPACE BAR TO START THE PROGRAM"
330 GOSUB 2980
340 DIM X(10,100),Y(10,100),THETA(10,100),R(10,100),AREA(10,100),RAREA(10,100)
350 DIM DTHETA(10,100),Z(10),ALFA(100),BETA(100)
360 DIM XP(100),YP(100),ZP(100),RP(100),RM(100),EAREA(10,100),N(100)
370 CLS:WIDTH 40:COLOR 10,0:LOCATE 10,9,0:PRINT "WOULD YOU LIKE TO TYPE"
380 LOCATE 12,9,0:PRINT "( X AND Y ) COORDINATES"
390 LOCATE 14,9,0:PRINT "THROUGH THE KEYBOARD ";
400 INPUT A$
410 IF A$ = "N" OR A$ = "n" THEN GOTO 630
420 IF A$ = "Y" OR A$ = "y" THEN GOTO 440
430 GOTO 370
440 CLS:LOCATE 13,13,0:PRINT "HOW MANY POINTS ";
450 INPUT N
460 CLS:WIDTH 80:SCREEN 0,0,0
470 FOR J = 1 TO 2
480 PRINT
490 PRINT "type in Z-COORDINATE for surface No."J"";
500 INPUT Z(J)
510 IF J = 2 AND Z(2) < Z(1) THEN CLS:LOCATE 2,12:PRINT "SORRY..Z-COORDINATE FOR
 SURFACE 2 SHOULD BE GREATER THAN "Z(1)"":GOTO 480
520 FOR I = 1 TO N
530 PRINT
540 PRINT "TYPE ( X"I" ) FOR SURFACE No."J"";
550 INPUT X(J,I)
560 PRINT
570 PRINT "TYPE ( Y"I" ) FOR SURFACE No."J"";
580 INPUT Y(J,I)
590 NEXT I
600 CLS
610 NEXT J
620 GOTO 820
630 CLS:WIDTH 80
640 LOCATE 4,26,0:PRINT "******************************"
650 LOCATE 5,24,0:PRINT "*** DEMONESTRATION PROGRAMMES ***"
660 LOCATE 6,26,0:PRINT "******************************"
670 LOCATE 9,6,0:PRINT " 1. TOP SURFACE IS A CIRCLE AND BOTTOM SURFACE IS A SQUA
RE."
680 LOCATE 11,6,0:PRINT " 2. TOP SURFACE IS A CIRCLE AND BOTTOM SURFACE IS A CIR
CLE."
690 LOCATE 13,6,0:PRINT " 3. TOP SURFACE IS A CIRCLE AND BOTTOM SURFACE IS A COM
PLEX SHAPE."
700 LOCATE 15,6,0:PRINT " 4. TOP SURFACE IS A SQUARE AND BOTTOM SURFACE IS A COM
PLEX SHAPE."
710 LOCATE 21,6,0:INPUT " CHOOSE ONE OF THE ABOVE DEMONSTRATION PROGRAMMES.";D
```

```
720 ON D GOTO 730,750,770,790
730 IF D = 1 THEN RUN "demo1"
740 GOTO 710
750 IF D = 2 THEN RUN "demo2"
760 GOTO 710
770 IF D = 3 THEN RUN "demo3"
780 GOTO 710
790 IF D = 4 THEN RUN "demo4"
800 GOTO 710
810 CLS:WIDTH 80:SCREEN 0,0,0:GOTO 820
820 FOR J = 1 TO 2
830 PRINT "-----------------------------------------------------------------
----------"
840 PRINT ": S.No.:";TAB(11);" X"J" ";TAB(19);":";TAB(22);" Y"J" ";TAB(31);":";T
AB(36);" R"J" ";TAB(47);":";TAB(51);"THETA"J"";TAB(63);":";TAB(69);"AREA";TAB(79
);":"
850 PRINT "-----------------------------------------------------------------
----------"
860 GOSUB 2630
870 FOR I = 1 TO N
880 PRINT ":";TAB(2);""I"";TAB(8);":";TAB(9);X(J,I);TAB(19);":";TAB(21);Y(J,I);T
AB(31);":";TAB(33);R(J,I);TAB(47);":";TAB(49);THETA(J,I);TAB(63);":";TAB(65);ARE
A(J,I);TAB(79);":"
890 PRINT "-----------------------------------------------------------------
----------"
900 NEXT I
910 GOSUB 2560
920 NEXT J
930 PRINT
940 INPUT "CHOOSE NUMBER OF SECTIONS (MAX. 5 SECTIONS)";S
950 IF S > 5 THEN PRINT "SORRY...NUMBER OF SECTIONS SHOULD NOT EXCEED 5":GOTO 94
0
960 FOR J = 3 TO S+2
970 PRINT "TYPE Z-COORDINATE AT SECTION No."J-2"";
980 INPUT Z(J)
990 IF Z(J) < Z(1) OR Z(J) > Z(2) THEN GOTO 1010
1000 GOTO 1030
1010 PRINT "SORRY THIS VALUE IS OUT OF THE RANGE ("Z(1)"-"Z(2)") TRY AGAIN";
1020 GOTO 980
1030 FOR I = 1 TO N
1040 X(J,I) = X(1,I) + (Z(J) - Z(1)) * (X(2,I) - X(1,I)) / (Z(2) - Z(1))
1050 Y(J,I) = Y(1,I) + (Z(J) - Z(1)) * (Y(2,I) - Y(1,I)) / (Z(2) - Z(1))
1060 NEXT I
1070 GOSUB 2630
1080 PRINT "-----------------------------------------------------------------
-----------"
1090 PRINT ": S.No.:";TAB(11);" X"J" ";TAB(19);":";TAB(22);" Y"J" ";TAB(31);":";
TAB(36);" R"J" ";TAB(47);":";TAB(51);"THETA"J"";TAB(63);":";TAB(69);"AREA";TAB(7
9);":"
1100 PRINT "-----------------------------------------------------------------
-----------"
1110 FOR I = 1 TO N
1120 PRINT ":";TAB(2);""I"";TAB(8);":";TAB(9);X(J,I);TAB(19);":";TAB(21);Y(J,I);
TAB(31);":";TAB(33);R(J,I);TAB(47);":";TAB(49);THETA(J,I);TAB(63);":";TAB(65);AR
EA(J,I);TAB(79);":"
1130 PRINT "-----------------------------------------------------------------
-----------"
1140 NEXT I
1150 GOSUB 2560
1160 NEXT J
1170 PRINT
1180 PRINT "-----------------------------------------------------------------
-----------"
1190 PRINT ":";TAB(2);"S.No";TAB(8);":";TAB(10);"ALFA = ATN (XF - XI) / (ZF - ZI
)";TAB(44);":";TAB(46);"BETA = ATN (YF - YI) / (ZF - ZI)";TAB(79);":"
1200 PRINT "-----------------------------------------------------------------
-----------"
1210 FOR I = 1 TO N
1220 ALFA(I) = ATN ((X(2,I) - X(1,I)) / (Z(2) - Z(1))) * 180 / 3.1416
1230 BETA(I) = ATN ((Y(2,I) - Y(1,I)) / (Z(2) - Z(1))) * 180 / 3.1416
1240 PRINT ":";TAB(2);""I"";TAB(8);":";TAB(15);ALFA(I);TAB(44);":";TAB(50);BETA(
I);TAB(79);":"
1250 PRINT "-----------------------------------------------------------------
-----------"
1260 NEXT I
1270 PRINT
1280 INPUT "WOULD YOU LIKE TO SEE A SIMULATION OF THE DRIVE SYSTEM";S$
```

```
1290 IF S$ = "Y" OR S$ = "y" THEN GOTO 1320
1300 IF S$ = "N" OR S$ = "n" THEN GOTO 2070
1310 GOTO 1280
1320 KEY OFF:SCREEN 0,1:COLOR 3,0,0:WIDTH 40:CLS:LOCATE 12,4,0:PRINT "SIMULATION
 OF THE DRIVE SYSTEM"
1330 COLOR 28,0:LOCATE 24,7,0:PRINT "PRESS SPACE BAR TO CONTINUE"
1340 GOSUB 2980
1350 COLOR 3,0,0:CLS:LOCATE 12,12,0:PRINT "IS THE RIG READY ";
1360 INPUT R$:IF R$ = "Y" OR R$ = "y" THEN 1400
1370 IF R$ = "N" OR R$ = "n" THEN 1390
1380 GOTO 1350
1390 CLS:GOSUB 3010
1400 CLS:SCREEN 0,1:COLOR 7,0:WIDTH 80
1410 STEPS = ABS(ALFA(1))/ .375
1420 IF ALFA(1) < 0 THEN D = 2:D(2) = 2:LOCATE 20,35:PRINT "ANTI-CLOCK":GOTO 144
0
1430 IF ALFA(1) >= 0 THEN D = 2:D(2) = 1:LOCATE 20,35:PRINT "CLOCK"
1440 GOSUB 3380
1450 FOR I = 1 TO STEPS
1460 OUT PORT,BASE + PULSE
1470 OUT PORT,BASE
1480 LOCATE 13,30:PRINT "ALFA ANGLE = "I""
1490 NEXT I
1500 CLS:STEPS = ABS(BETA(1))/ 9.000001E-02
1510 IF BETA(1) < 0 THEN D = 1:D(1) = 1:LOCATE 20,35:PRINT "ANTI-CLOCK":GOTO 153
0
1520 IF BETA(1) >= 0 THEN D = 1:D(1) = 2:LOCATE 20,35:PRINT "CLOCK"
1530 GOSUB 3380
1540 FOR I = 1 TO STEPS
1550 OUT PORT,BASE + PULSE
1560 OUT PORT,BASE
1570 LOCATE 13,30:PRINT "BETA ANGLE = "I""
1580 NEXT I
1590 CLS:STEPS = ABS(X(2,1)) * 10 / .0254
1600 IF X(2,1) < 0 THEN D = 4:D(4) = 2:LOCATE 20,35:PRINT "REVERSE":GOTO 1620
1610 IF X(2,1) >= 0 THEN D = 4:D(4) = 1:LOCATE 20,35:PRINT "FORWARD"
1620 GOSUB 3380
1630 FOR I = 1 TO STEPS
1640 OUT PORT,BASE + PULSE
1650 OUT PORT,BASE
1660 LOCATE 13,30:PRINT "X 1 COORDINATE = "I""
1670 NEXT I
1680 CLS:STEPS = ABS(Y(2,1)) * 10 / .0254
1690 IF Y(2,1) < 0 THEN D = 3:D(3) = 1:LOCATE 20,35:PRINT "FORWARD":GOTO 1710
1700 IF Y(2,1) >= 0 THEN D = 3:D(3) = 2:LOCATE 20,35:PRINT "REVERSE"
1710 GOSUB 3380
1720 FOR I = 1 TO STEPS
1730 OUT PORT,BASE + PULSE
1740 OUT PORT,BASE
1750 LOCATE 13,30:PRINT "Y 1 COORDINATE = "I""
1760 NEXT I
1770 FOR I = 2 TO N
1780 CLS:ANGLE = ALFA(I) - ALFA(I-1)
1790 STEPS = ABS(ANGLE) / .375
1800 IF ANGLE < 0 THEN D = 2:D(2) = 2:LOCATE 20,35:PRINT "ANTI-CLOCK":GOTO 1820
1810 IF ANGLE >= 0 THEN D = 2:D(2) = 1:LOCATE 20,35:PRINT "CLOCK"
1820 GOSUB 3380
1830 FOR J = 1 TO STEPS
1840 OUT PORT,BASE + PULSE
1850 OUT PORT,BASE
1860 LOCATE 13,30:PRINT "ALFA ANGLE = "J""
1870 FOR K = 1 TO 50:NEXT
1880 NEXT J
1890 CLS:ANGLE = BETA(I) - BETA(I-1)
1900 STEPS = ABS(ANGLE) / 9.000001E-02
1910 IF ANGLE < 0 THEN D = 1:D(1) = 1:LOCATE 20,35:PRINT "ANTI-CLOCK":GOTO 1930
1920 IF ANGLE >= 0 THEN D = 1:D(1) = 2:LOCATE 20,35:PRINT "CLOCK"
1930 GOSUB 3380
1940 FOR J = 1 TO STEPS
1950 OUT PORT,BASE + PULSE
1960 OUT PORT,BASE
1970 LOCATE 13,30:PRINT "BETA ANGLE = "J""
1980 FOR K = 1 TO 50:NEXT
1990 NEXT J
2000 IF ABS(X(2,I)) > = ABS(X(2,I-1)) THEN GOTO 2040
2010 GOSUB 3600
2020 GOSUB 3490
```

```
2030 GOTO 2060
2040 GOSUB 3490
2050 GOSUB 3600
2060 NEXT I
2070 CLS:WIDTH 40:LOCATE 12,12,0:PRINT "GRAPHICAL DRAWINGS"
2080 COLOR 28,0:LOCATE 24,7,0:PRINT "PRESS SPACE BAR TO CONTINUE"
2090 GOSUB 2980
2100 CLS:WIDTH 80:COLOR 10,0:LOCATE 13,7:INPUT "TYPE THE MAGNIFICATION FOR GRAPH
ICAL DRAWINGS (MAX. 50) ";G
2110 IF G < 10 OR G > 50 THEN PRINT "SORRY...THIS VALUE IS OUT OF THE SCALE":GOT
O 2100
2120 CLS:SCREEN 1,0
2130 FOR J = 1 TO S+2
2140 FOR I = 1 TO N - 1
2150 LINE (160 + X(J,I) * G,100 +Y(J,I) * G) - (160 + X(J,I+1) * G,100 + Y(J,I+1
) * G),2
2160 NEXT I
2170 LINE (160 + X(J,N) * G,100 + Y(J,N) * G) - (160 + X(J,1) * G,100 + Y(J,1) *
 G),2
2180 NEXT J
2190 LOCATE 24,7,0:PRINT "PRESS SPACE BAR TO CONTINUE"
2200 GOSUB 2980
2210 FOR J = 1 TO S + 2
2220 CLS:SCREEN 1,0
2230 FOR I = 1 TO N - 1
2240 LINE (160 + X(J,I) * G,100 +Y(J,I) * G) - (160 + X(J,I+1) * G,100 + Y(J,I+1
) * G),2
2250 NEXT I
2260 LINE (160 + X(J,N) * G,100 + Y(J,N) * G) - (160 + X(J,1) * G,100 + Y(J,1) *
 G),2
2270 LOCATE 22,13,0:PRINT"SURFACE AT Z =";Z(J)
2280 LOCATE 24,7,0:PRINT "PRESS SPACE BAR TO CONTINUE"
2290 GOSUB 2980
2300 NEXT J
2310 CLS:SCREEN 0,1:WIDTH 80
2320 WIDTH 40:LOCATE 13,9,0:PRINT "WOULD YOU LIKE TO DO"
2330 LOCATE 15,9,0:PRINT "ANOTHER SET OF SECTIONS ";
2340 INPUT RS$
2350 IF RS$ = "Y" OR RS$ = "y" THEN GOTO 2450
2360 IF RS$ = "N" OR RS$ = "n" THEN GOTO 2380
2370 GOTO 2320
2380 CLS:LOCATE 13,9,0:PRINT "WOULD YOU LIKE TO REDRAW"
2390 LOCATE 15,9,0:PRINT "THE PREVIOUS SECTIONS AGAIN ";
2400 INPUT RS$
2410 IF RS$ = "Y" OR RS$ = "y" THEN GOTO 2470
2420 IF RS$ = "N" OR RS$ = "n" THEN GOTO 2490
2430 GOTO 2380
2440 GOTO 2540
2450 CLS:WIDTH 80
2460 GOTO 940
2470 CLS:WIDTH 80
2480 GOTO 2100
2490 CLS:LOCATE 13,9,0:PRINT "WOULD YOU LIKE TO QUIT ";
2500 INPUT RS$
2510 IF RS$ = "Y" OR RS$ = "y" THEN GOTO 2540
2520 IF RS$ = "N" OR RS$ = "n" THEN RUN "main.bas"
2530 GOTO 2490
2540 CLS:COLOR 28,0:LOCATE 13,12,0:PRINT "END OF PROGRAMME"
2550 END
2560 RAREA(J,0) = 0
2570 FOR I = 1 TO N
2580 RAREA(J,I) = AREA(J,I) - EAREA(J,I)
2590 RAREA(J,I) = RAREA(J,I-1) + RAREA(J,I)
2600 NEXT I
2610 PRINT "THE TOTAL AREA OF THIS SURFACE =";RAREA(J,N)
2620 RETURN
2630 THETA(J,0) = 0
2640 FOR I = 1 TO N
2650 R(J,I) = SQR (X(J,I) ^2 + Y(J,I) ^2)
2660 IF X(J,I) < 0 THEN GOTO 2710
2670 IF X(J,I) > 0 AND Y(J,I) < 0 THEN GOTO 2730
2680 IF I = N THEN GOTO 2730
2690 THETA(J,I) = ATN (Y(J,I) / X(J,I))
2700 GOTO 2740
2710 THETA(J,I) = 3.14159 + ATN (Y(J,I) / X(J,I))
2720 GOTO 2740
2730 THETA(J,I) = 2 * 3.14159 + ATN (Y(J,I) / X(J,I))
```

```
2740 DTHETA(J,I) = THETA(J,I) - THETA(J,I-1)
2750 AREA(J,I) = R(J,I)^2 * DTHETA(J,I) / 2
2760 IF THETA(J,I) < THETA(J,I-1) THEN GOTO 2780
2770 GOTO 2790
2780 GOSUB 2800
2790 NEXT I
2800 FOR K = I TO N
2810 R(J,K) = SQR (X(J,K) ^2 + Y(J,K) ^2)
2820 IF X(J,K) < 0 THEN GOTO 2860
2830 IF Y(J,K) < 0 THEN GOTO 2910
2840 THETA(J,K) = ATN (Y(J,K) / X(J,K)) + 2 * 3.14159
2850 GOTO 2940
2860 IF Y(J,K) < 0 THEN GOTO 2890
2870 THETA(J,K) = 3.14159 - ATN (Y(J,K) / ABS(X(J,K)))
2880 GOTO 2940
2890 THETA(J,K) = 3.14159 + ATN (Y(J,K) / X(J,K))
2900 GOTO 2940
2910 THETA(J,K) = 2 * 3.14159 - ATN (ABS(Y(J,K)) / X(J,K))
2920 DTHETA(J,K) = THETA(J,K) - THETA(J,K-1)
2930 EAREA(J,K) = R(J,K) ^2 * DTHETA(J,K) / 2
2940 IF THETA(J,K) >= THETA(J,I) THEN 2970
2950 PRINT EAREA(J,K)
2960 NEXT K
2970 RETURN
2980 V$ = INKEY$
2990 IF V$ <> " " THEN GOTO 2980
3000 RETURN
3010 LOCATE 12,12,0:PRINT "RIG CALIBRATION"
3020 COLOR 28,0:LOCATE 24,7,0:PRINT "Press space bar to continue"
3030 GOSUB 2980
3040 CLS:SCREEN 0,1:COLOR 7,0:WIDTH 80:FLAG = 0
3050 LOCATE 13,7:INPUT "PRESS 1 FOR MOTOR 1, 2 FOR MOTOR 2, 3 FOR MOTOR 3, 4 FOR
 MOTOR 4 ";M
3060 IF M = 1 THEN D = 1:GOTO 3110
3070 IF M = 2 THEN D = 2:GOTO 3110
3080 IF M = 3 THEN D = 3:GOTO 3110
3090 IF M = 4 THEN D = 4:GOTO 3110
3100 CLS:GOTO 3050
3110 CLS:N = M:LOCATE 13,13:PRINT "Press F for FORWARD / R for REVERSE, for MOTO
R "M"";
3120 INPUT A$
3130 IF A$ = "F" OR A$ = "f" THEN D(N) = 1:GOTO 3160
3140 IF A$ = "R" OR A$ = "r" THEN D(N) = 2:GOTO 3160
3150 GOTO 3110
3160 CLS:LOCATE 13,25:PRINT "Use < and > keys to CHANGE SPEED"
3170 LOCATE 15,32:PRINT "Press S key to STOP"
3180 PORT = &H1B0:CONTROL = &H1B3
3190 OUT CONTROL,&H80
3200 SPEED = 500
3210 GOSUB 3400
3220 A$ = INKEY$
3230 IF A$ = "S" OR A$ = "s" THEN LOCATE 24,37:PRINT "MOTOR "M" IS STOP":GOTO 32
50
3240 GOTO 3280
3250 LOCATE 25,30:PRINT "Press space bar to restart"
3260 GOSUB 2980
3270 GOTO 3350
3280 IF A$ = "<" OR A$ = "," THEN SPEED = SPEED + 100:LOCATE 24,7:PRINT "SPEED D
ECREASES"
3290 IF A$ = ">" OR A$ = "." THEN SPEED = SPEED - 100:LOCATE 24,60:PRINT "SPEED
INCREASES"
3300 IF SPEED <= 0 THEN SPEED = 1
3310 OUT PORT,BASE + PULSE
3320 FOR I = 1 TO SPEED:NEXT
3330 OUT PORT,BASE
3340 GOTO 3220
3350 CLS:LOCATE 13,25:INPUT "WOULD YOU LIKE TO DO ANOTHER MOTOR ";Q$
3360 IF Q$ = "Y" OR Q$ = "y" THEN GOTO 3050
3370 IF Q$ = "N" OR Q$ = "n" THEN RETURN
3380 PORT = &H1B0:CONTROL = &H1B3
3390 OUT CONTROL,&H80
3400 IF D = 1 AND D(1) = 1 THEN BASE = 4:PULSE = 8:RETURN
3410 IF D = 1 AND D(1) = 2 THEN BASE = 0:PULSE = 8:RETURN
3420 IF D = 2 AND D(2) = 1 THEN BASE = 16:PULSE = 32:RETURN
3430 IF D = 2 AND D(2) = 2 THEN BASE = 0:PULSE = 32:RETURN
3440 IF D = 3 AND D(3) = 1 THEN BASE = 64:PULSE = 128:RETURN
3450 IF D = 3 AND D(3) = 2 THEN BASE = 0:PULSE = 128:RETURN
```

```
3460 IF D = 4 AND D(4) = 1 THEN BASE = 1:PULSE = 2:RETURN
3470 IF D = 4 AND D(4) = 2 THEN BASE = 0:PULSE = 2:RETURN
3480 RETURN
3490 CLS:DISTANCE = Y(2,I) - Y(2,I-1)
3500 STEPS = ABS(DISTANCE) * 10 / .0254
3510 IF DISTANCE < 0 THEN D = 3:D(3) = 1:LOCATE 20,35:PRINT "FORWARD":GOTO 3530
3520 IF DISTANCE >= 0 THEN D = 3:D(3) = 2:LOCATE 20,35:PRINT "REVERSE"
3530 GOSUB 3380
3540 FOR J = 1 TO STEPS
3550 OUT PORT,BASE + PULSE
3560 OUT PORT,BASE
3570 LOCATE 13,30:PRINT "Y"I" COORDINATE = "J""
3580 NEXT J
3590 RETURN
3600 CLS:DISTANCE = X(2,I) - X(2,I-1)
3610 STEPS = ABS(DISTANCE) * 10 / .0254
3620 IF DISTANCE < 0 THEN D = 4:D(4) = 2:LOCATE 20,35:PRINT "REVERSE":GOTO 3640
3630 IF DISTANCE >= 0 THEN D = 4:D(4) = 1:LOCATE 20,35:PRINT "FORWARD"
3640 GOSUB 3380
3650 FOR J = 1 TO STEPS
3660 OUT PORT,BASE + PULSE
3670 OUT PORT,BASE
3680 LOCATE 13,30:PRINT "X"I" COORDINATE = "J""
3690 NEXT J
3700 RETURN
Ok
```

FIG. A1 flowchart for MAIN program

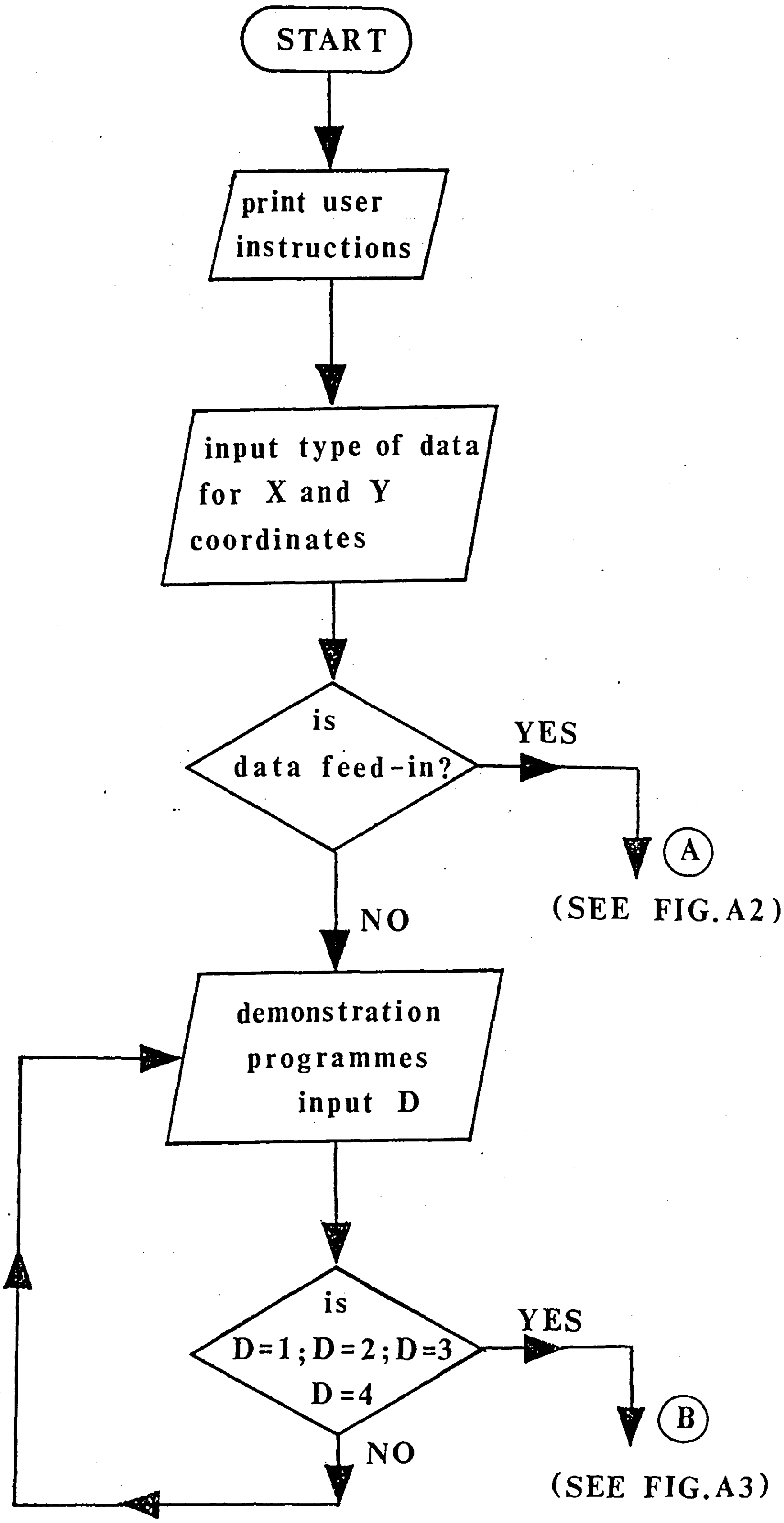
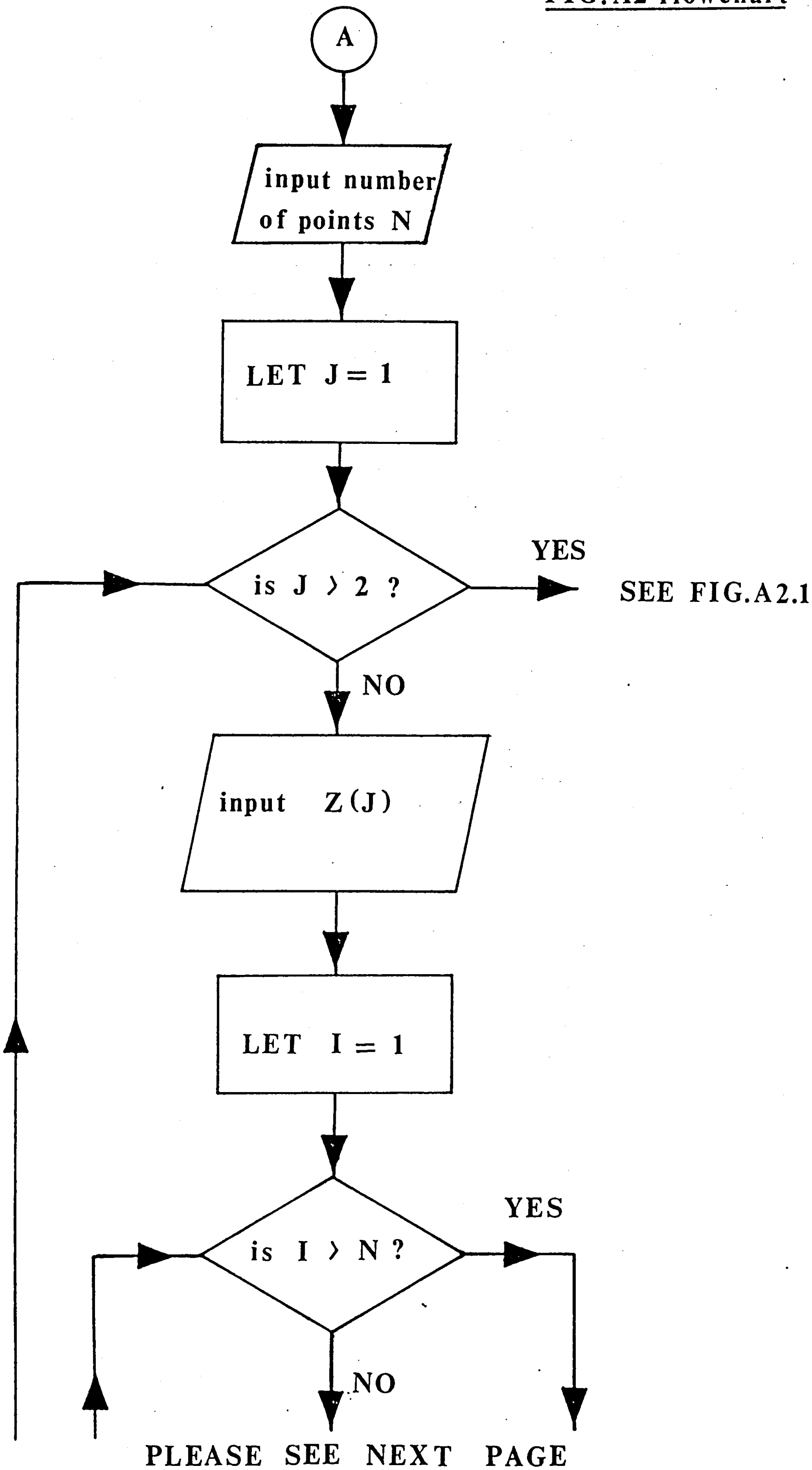


FIG.A2 flowchart



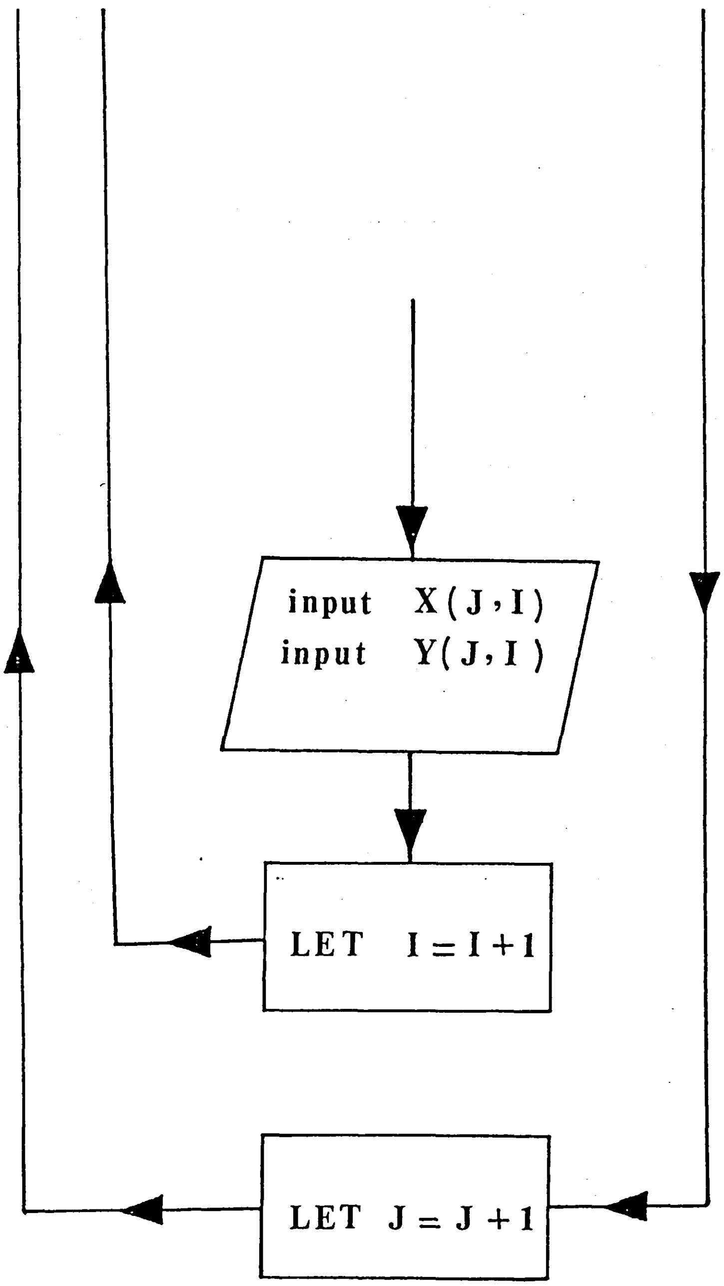


FIG. A2 CONTINUED

FIG.A2.1 flowchart

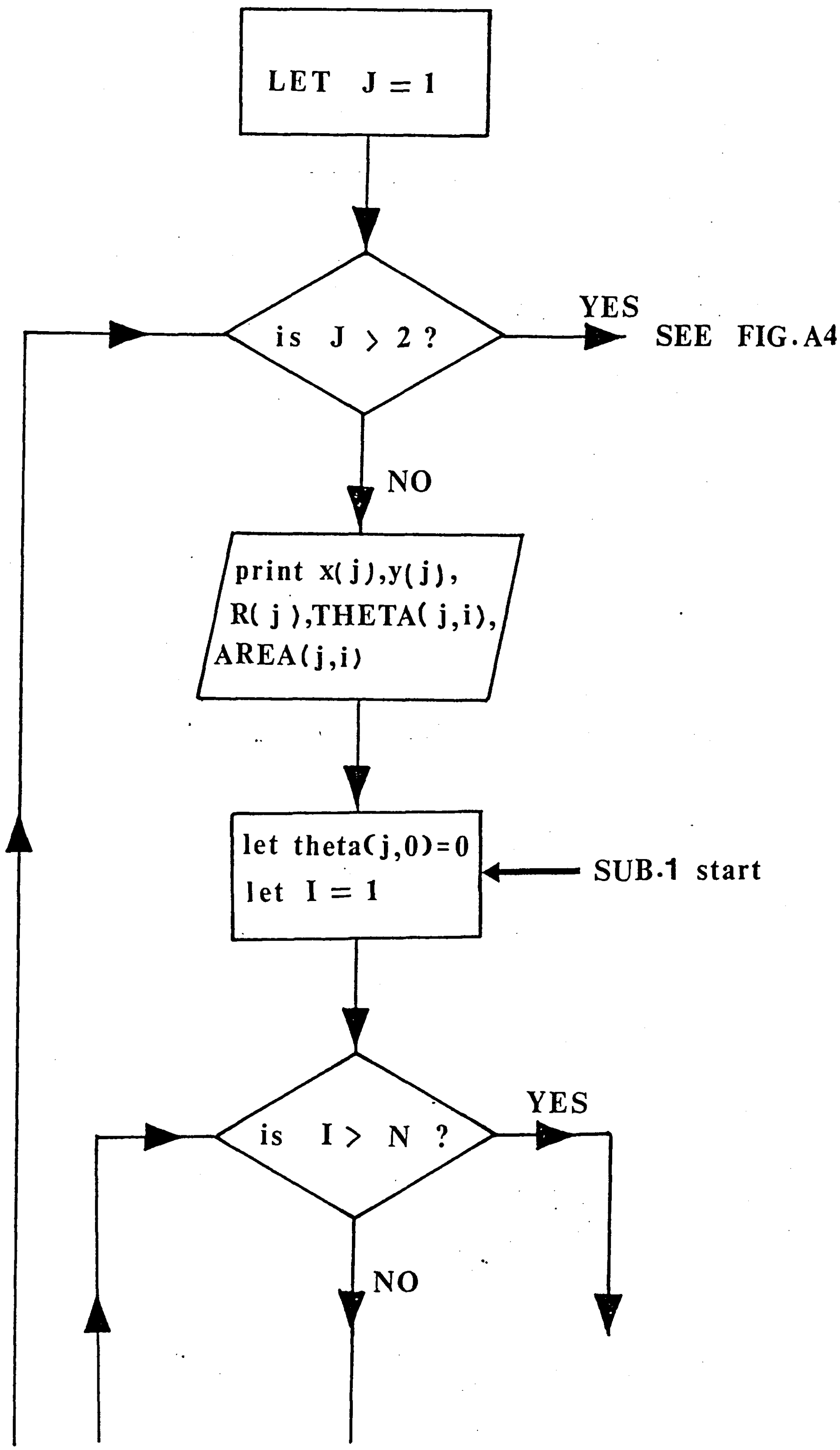
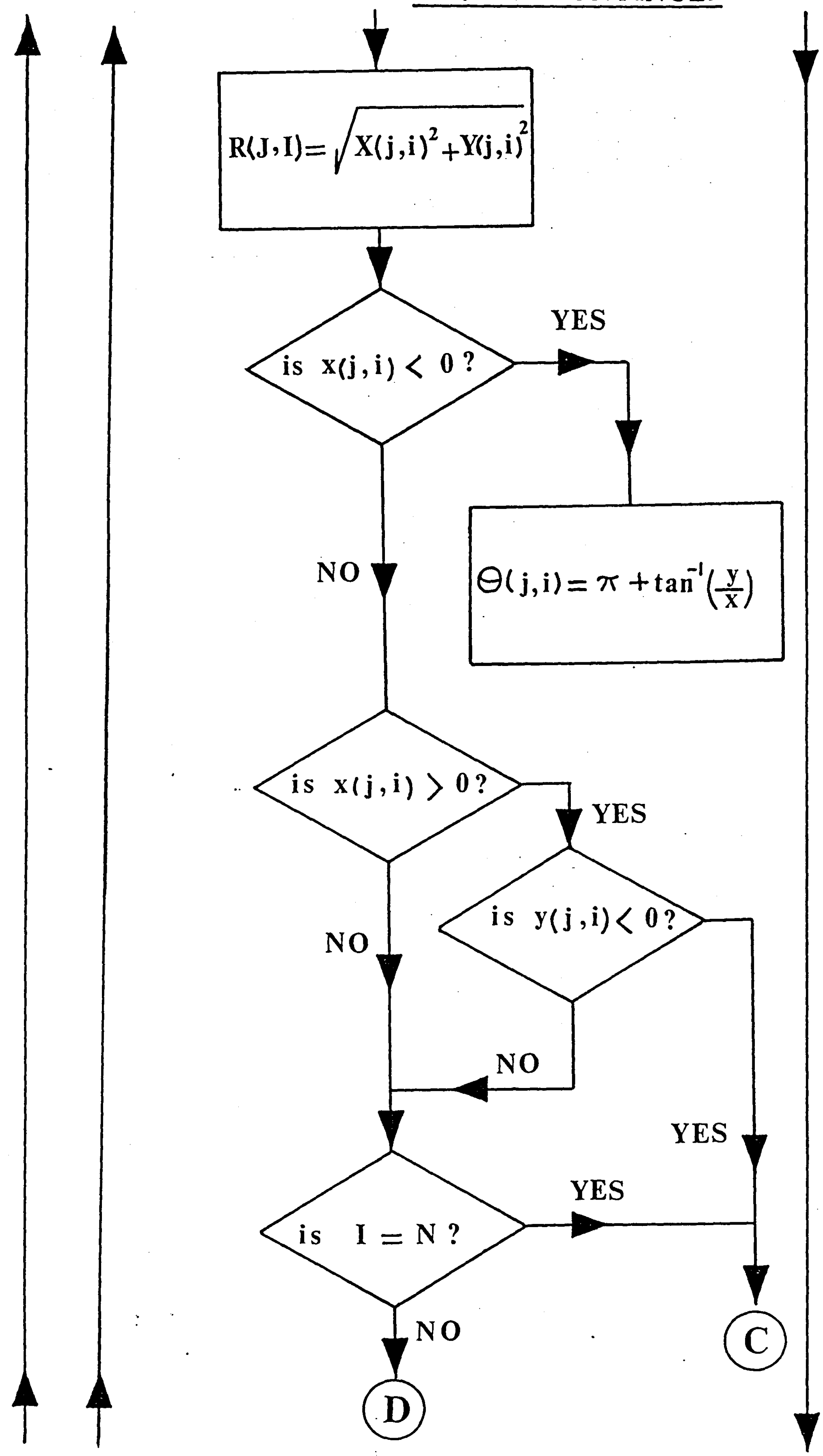
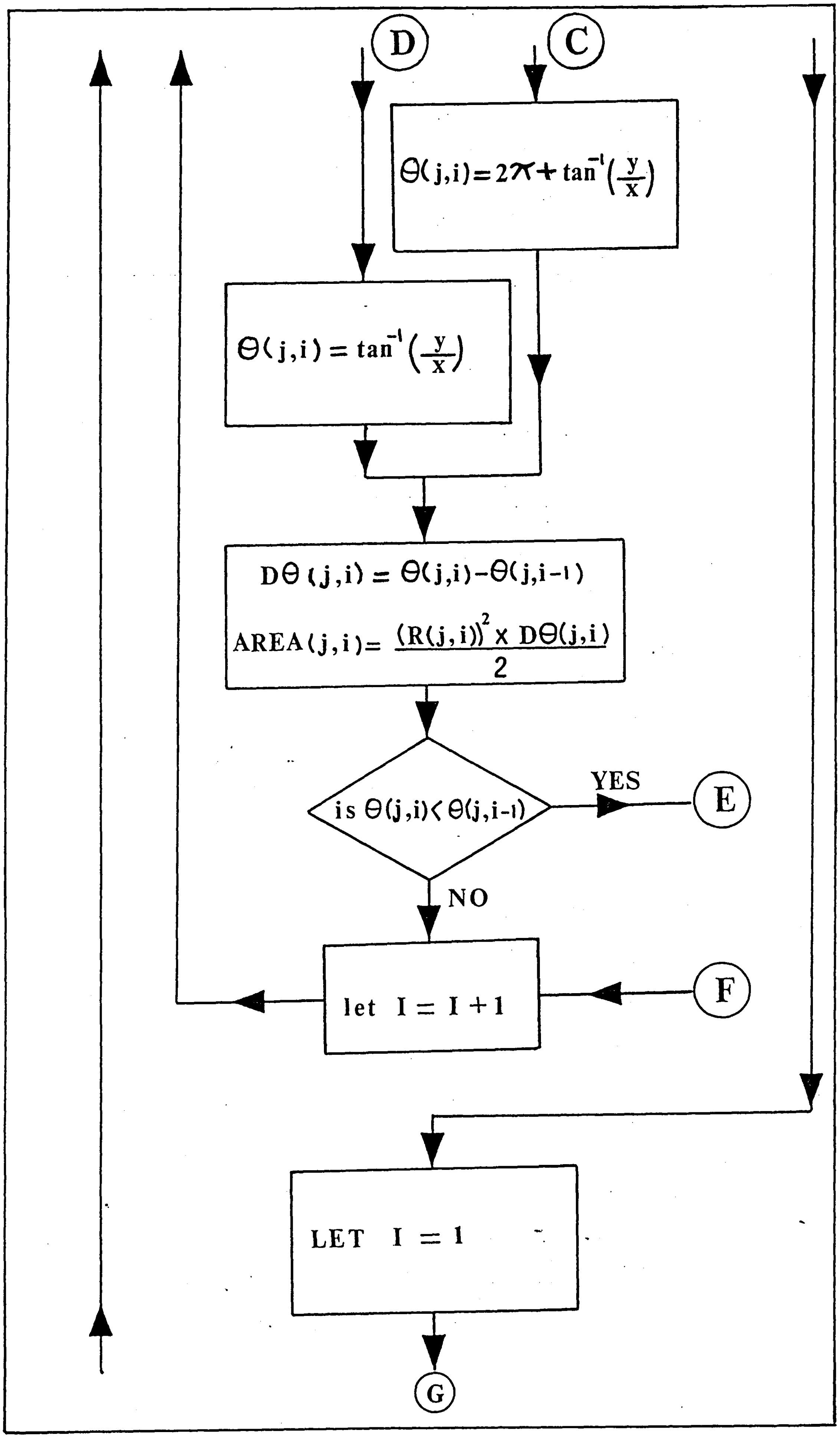
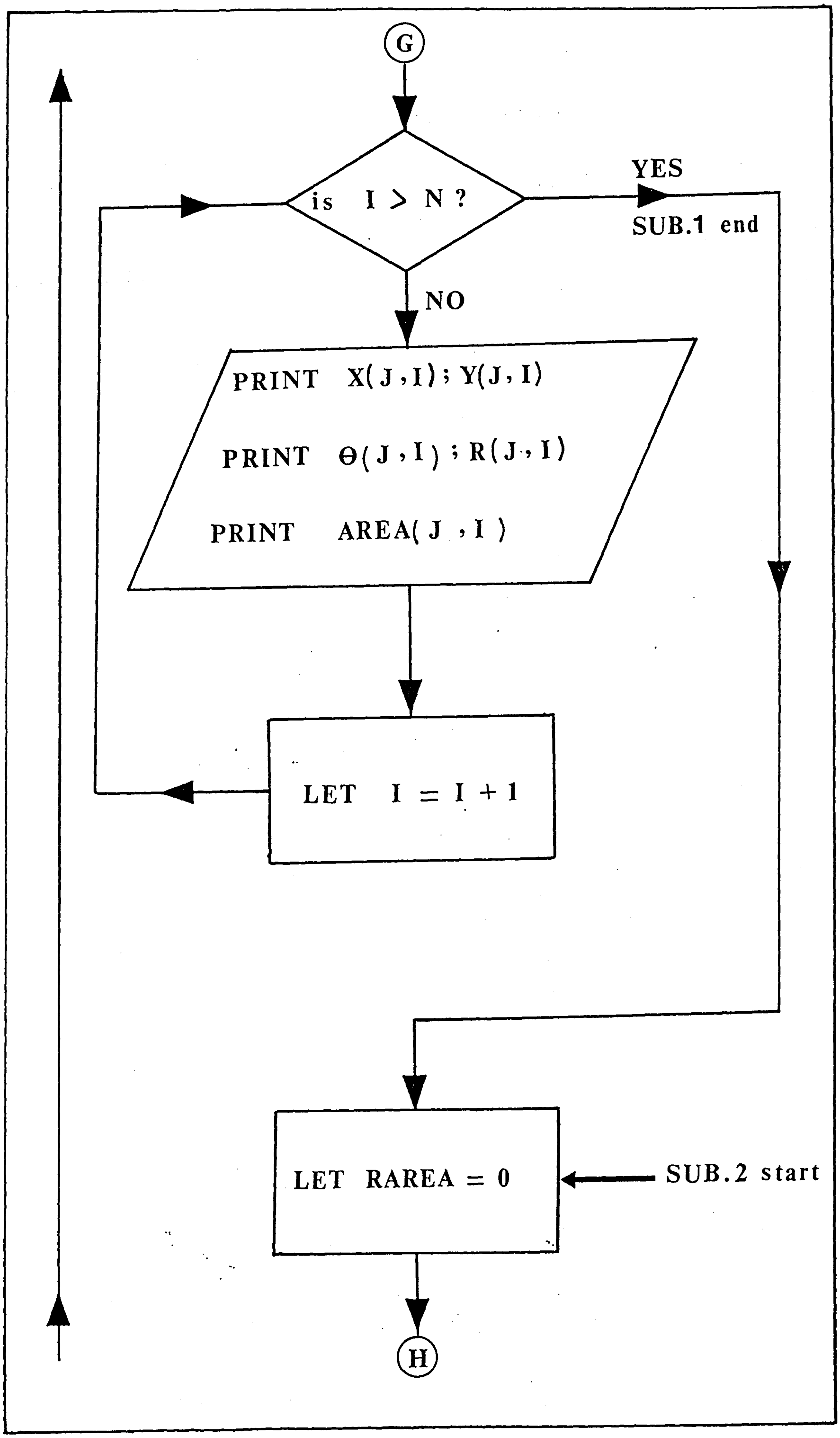


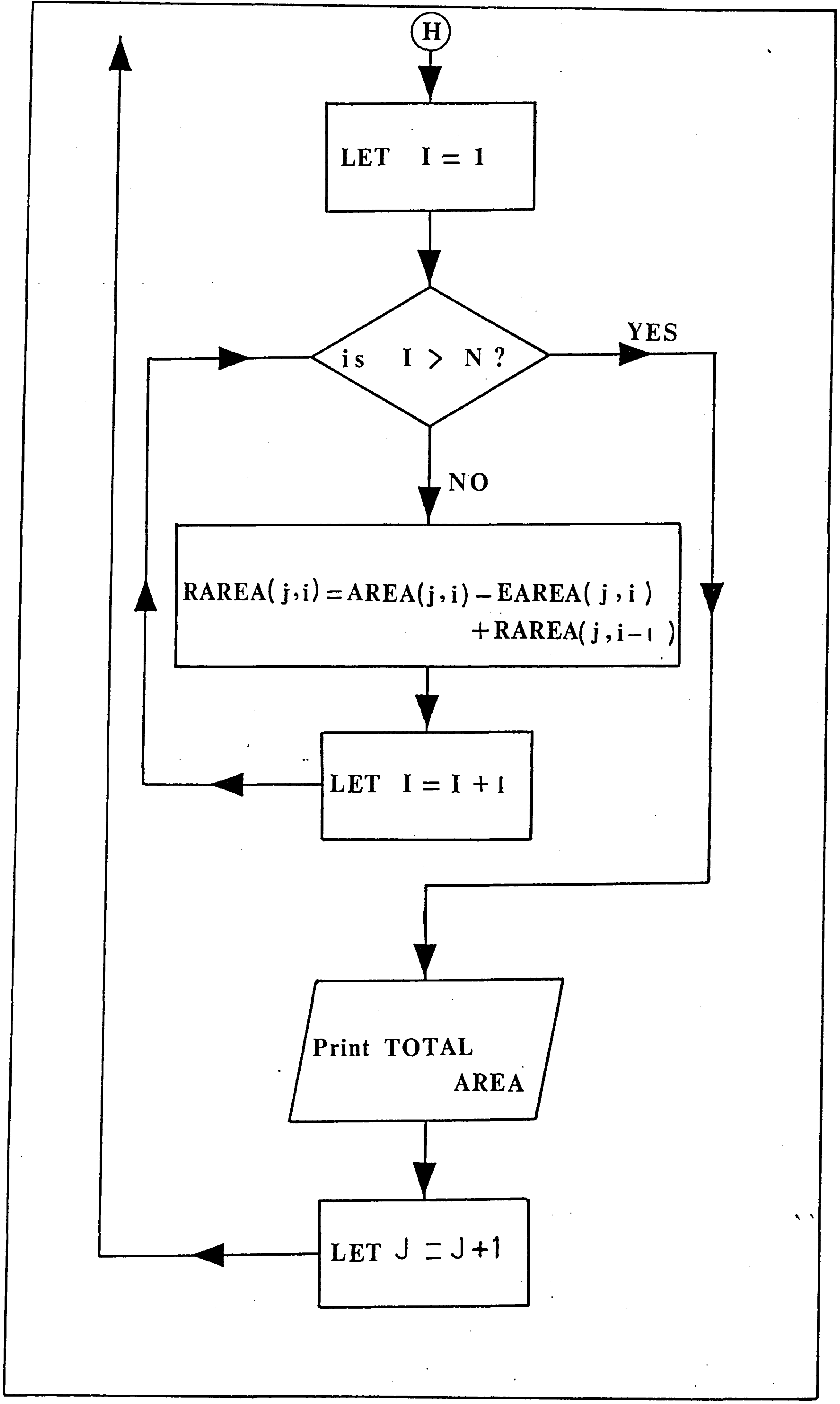
FIG. A2.1 CONTINUED

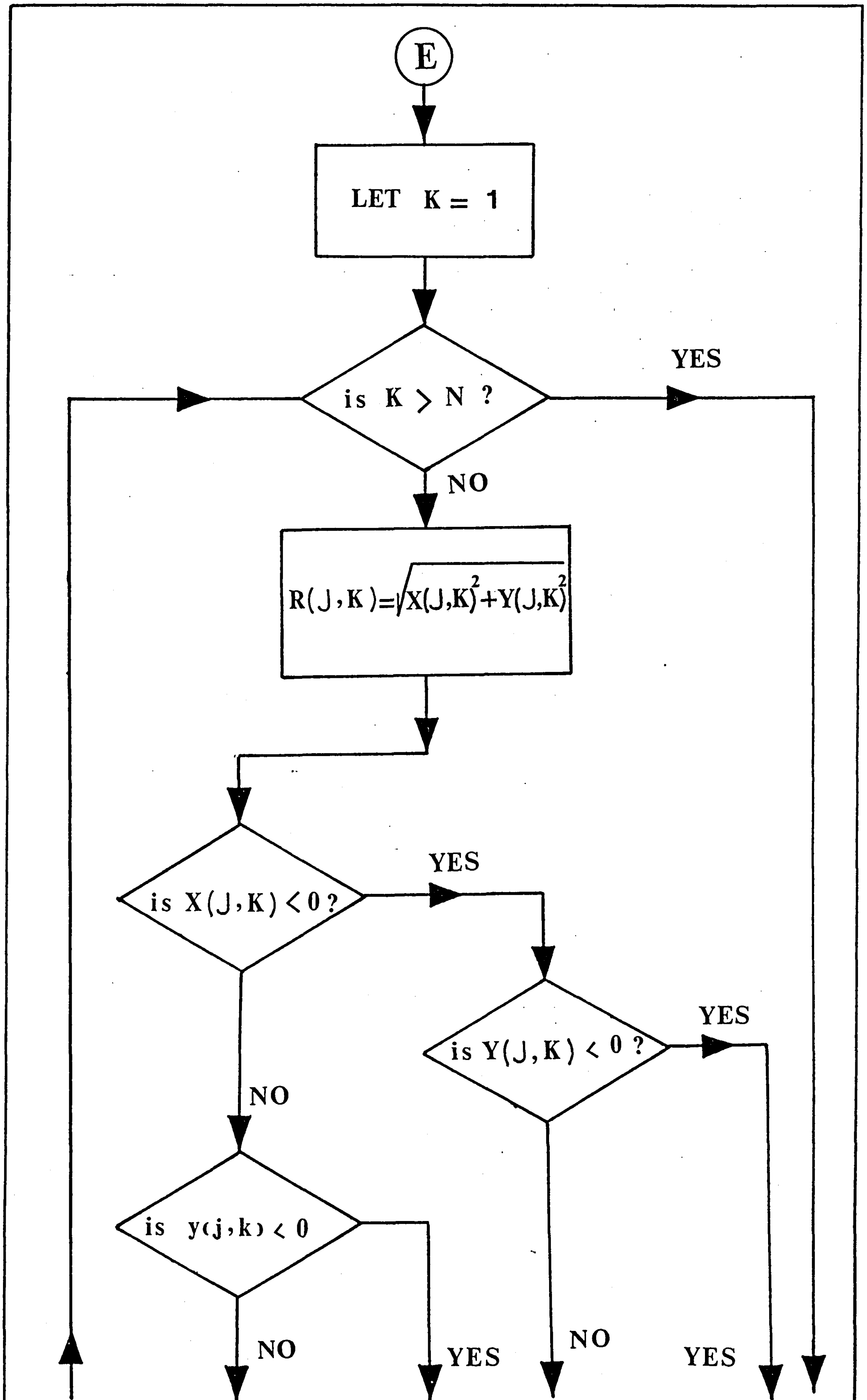


PLEASE SEE NEXT PAGE


D
C
Θ(j,i) = 2π + tan⁻¹(y/x)
Θ(j,i) = tan⁻¹(y/x)
DΘ(j,i) = Θ(j,i) − Θ(j,i−1)
AREA(j,i) = (R(j,i))² x DΘ(j,i) / 2
is Θ(j,i) < Θ(j,i−1)
YES
E
NO
let I = I + 1
F
LET I = 1
G


G
is I > N ?
YES
SUB.1 end
NO
PRINT X(J,I); Y(J,I)
PRINT Θ(J,I); R(J,I)
PRINT AREA(J,I)
LET I = I + 1
LET RAREA = 0
SUB.2 start
H


H
LET I = 1
is I > N ?
YES
NO
RAREA(j,i) = AREA(j,i) – EAREA(j,i)
+RAREA(j,i–1)
LET I = I + 1
Print TOTAL AREA
LET J = J+1



Please see next page

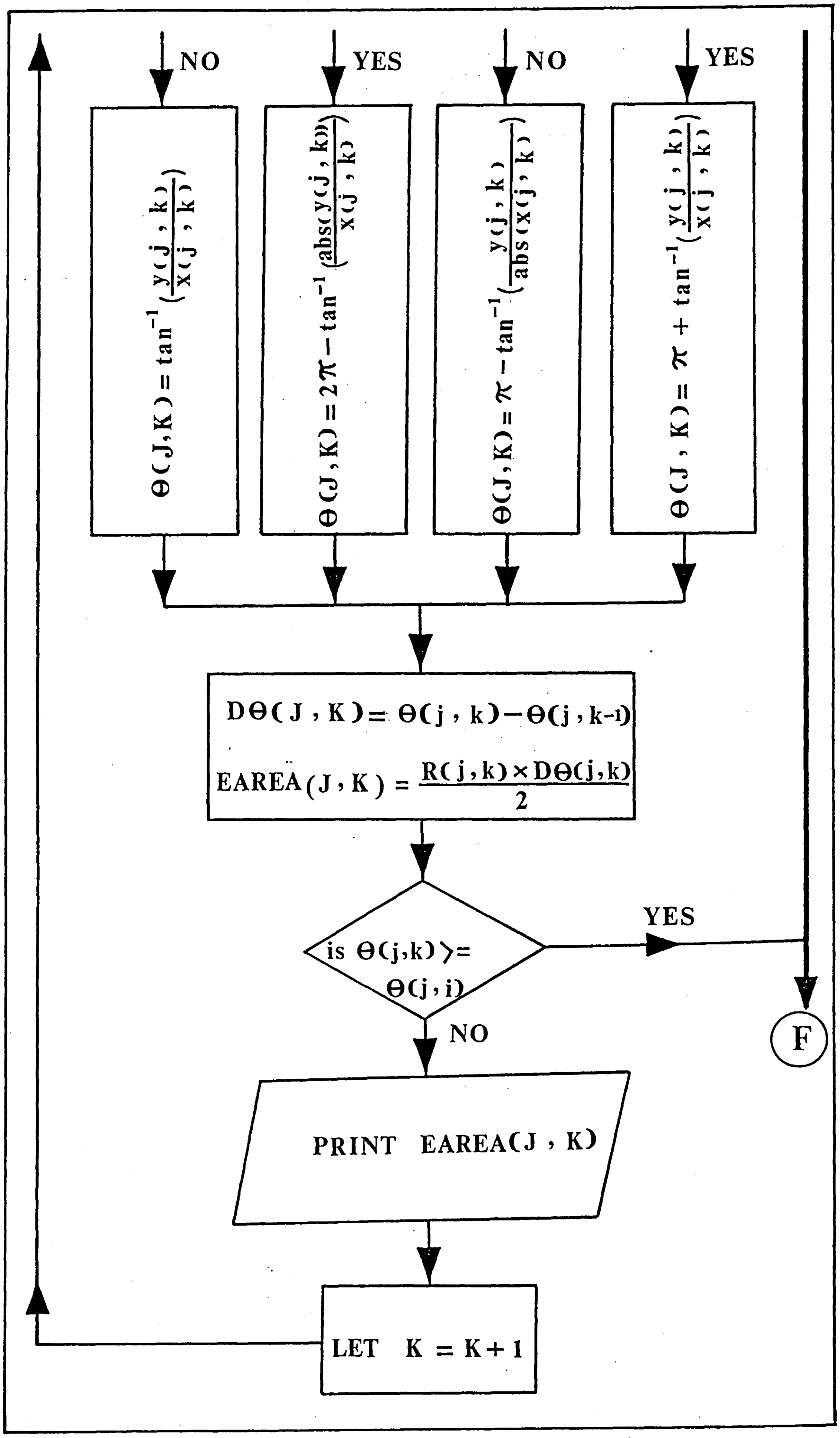

NO
YES
NO
YES
Θ(J,K) = tan⁻¹(y(j,k)/x(j,k))
Θ(J,K) = 2π − tan⁻¹(abs(y(j,k))/x(j,k))
Θ(J,K) = π − tan⁻¹(y(j,k)/abs(x(j,k)))
Θ(J,K) = π + tan⁻¹(y(j,k)/x(j,k))
DΘ(J,K) = Θ(j,k) − Θ(j,k-1)
EAREA(J,K) = R(j,k) × DΘ(j,k) / 2
is Θ(j,k) >= Θ(j,i)
YES
NO
F
PRINT EAREA(J,K)
LET K = K+1

FIG. A3 flowchart

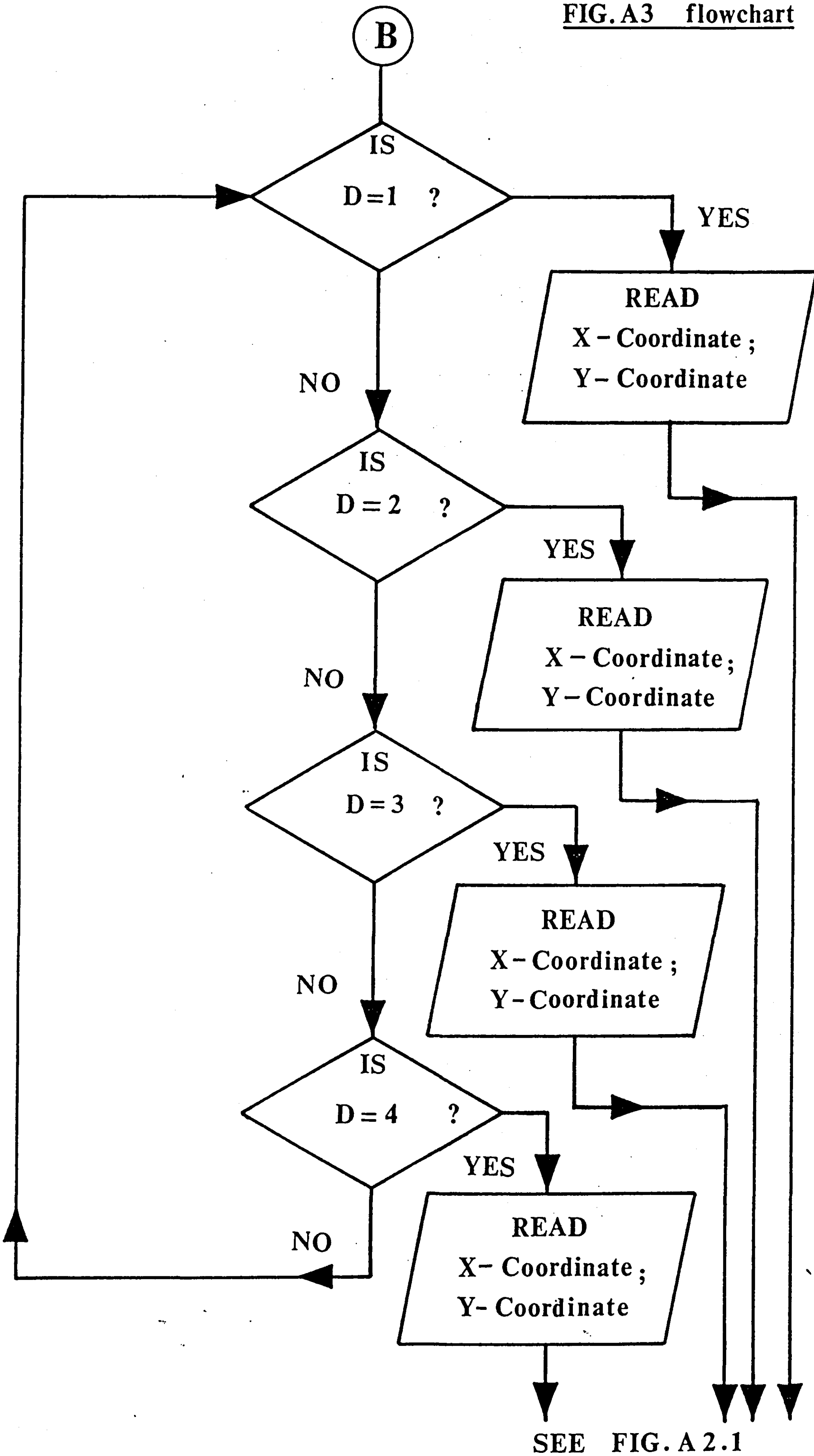
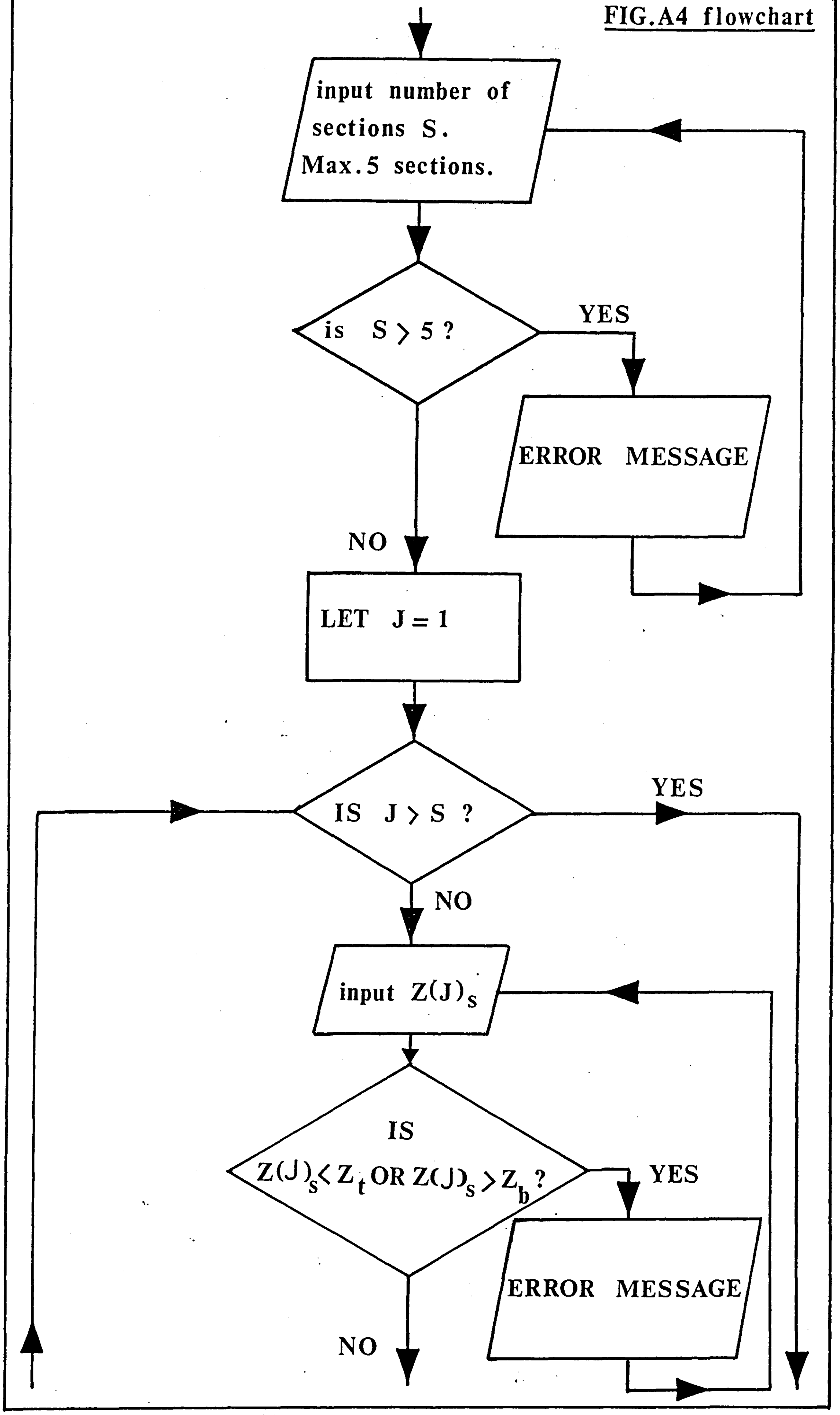


FIG.A4 flowchart



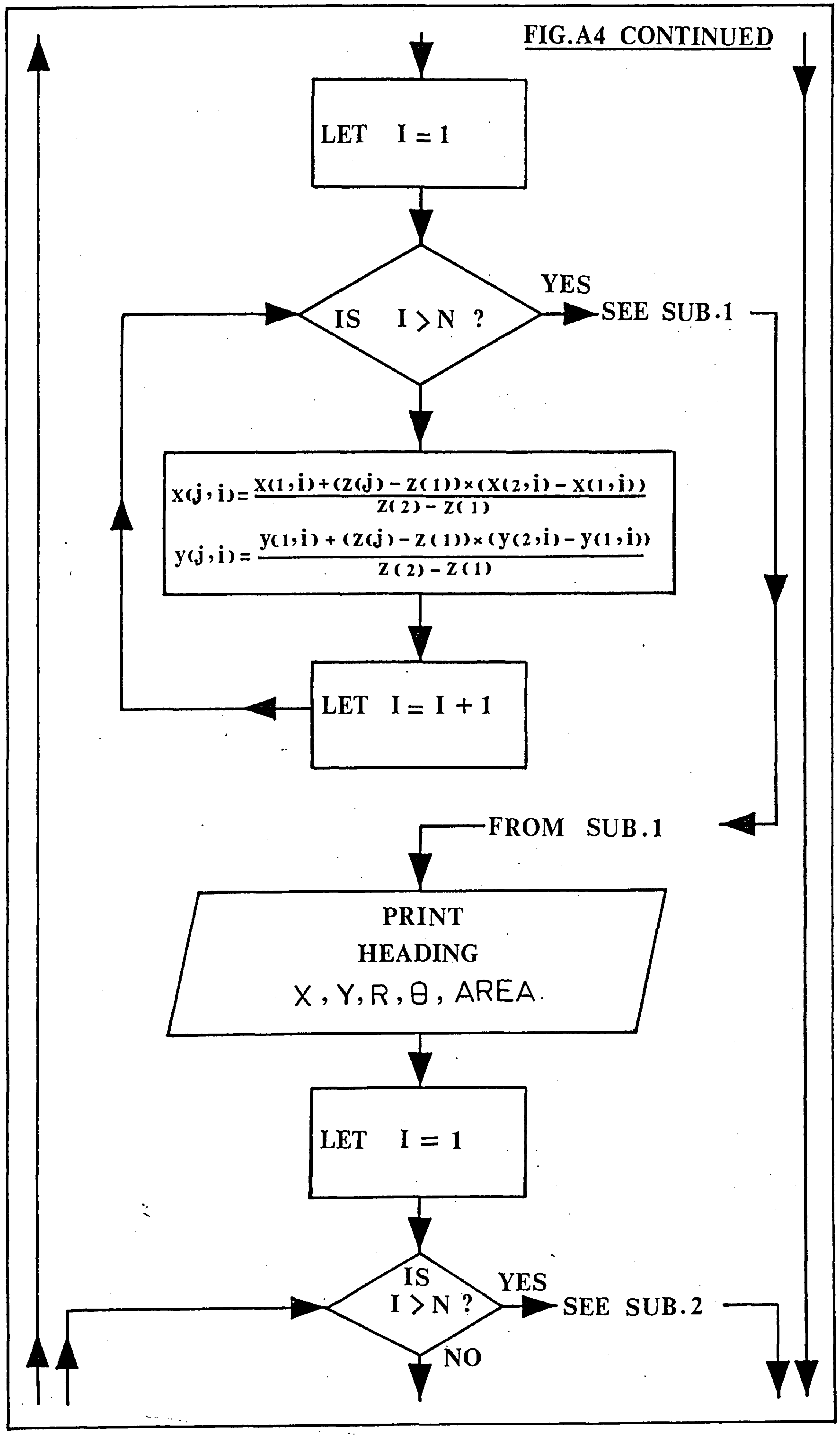
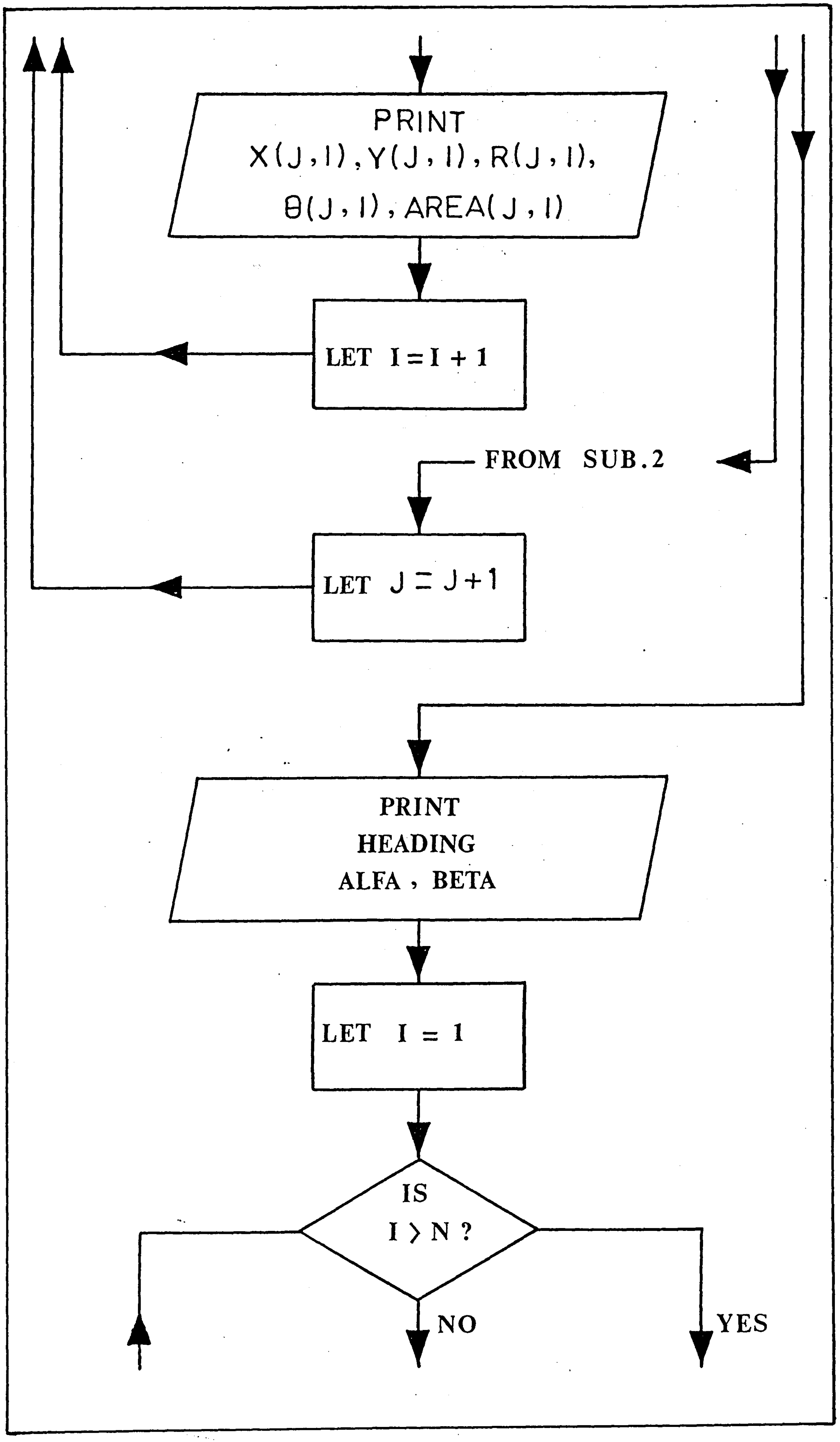


FIG.A4 CONTINUED
LET I = 1
IS I > N ?
YES
SEE SUB.1
x(j,i) = (x(1,i) + (z(j) − z(1)) × (x(2,i) − x(1,i))) / (z(2) − z(1))
y(j,i) = (y(1,i) + (z(j) − z(1)) × (y(2,i) − y(1,i))) / (z(2) − z(1))
LET I = I + 1
FROM SUB.1
PRINT
HEADING
X, Y, R, θ, AREA
LET I = 1
IS
I > N ?
YES
SEE SUB.2
NO


PRINT
X(J,I),Y(J,I),R(J,I),
θ(J,I),AREA(J,I)
LET I=I+1
FROM SUB.2
LET J=J+1
PRINT
HEADING
ALFA , BETA
LET I = 1
IS
I > N ?
NO
YES

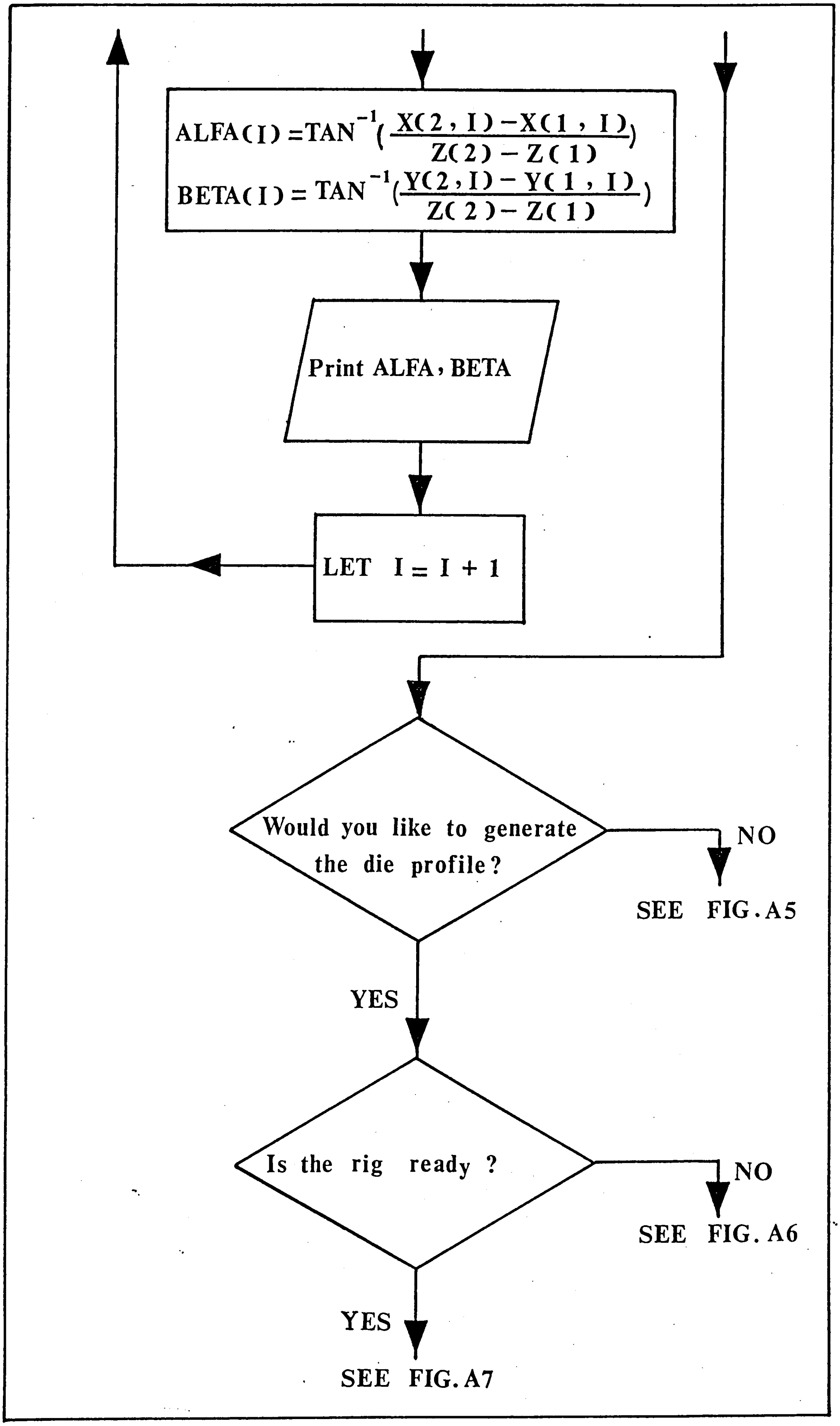
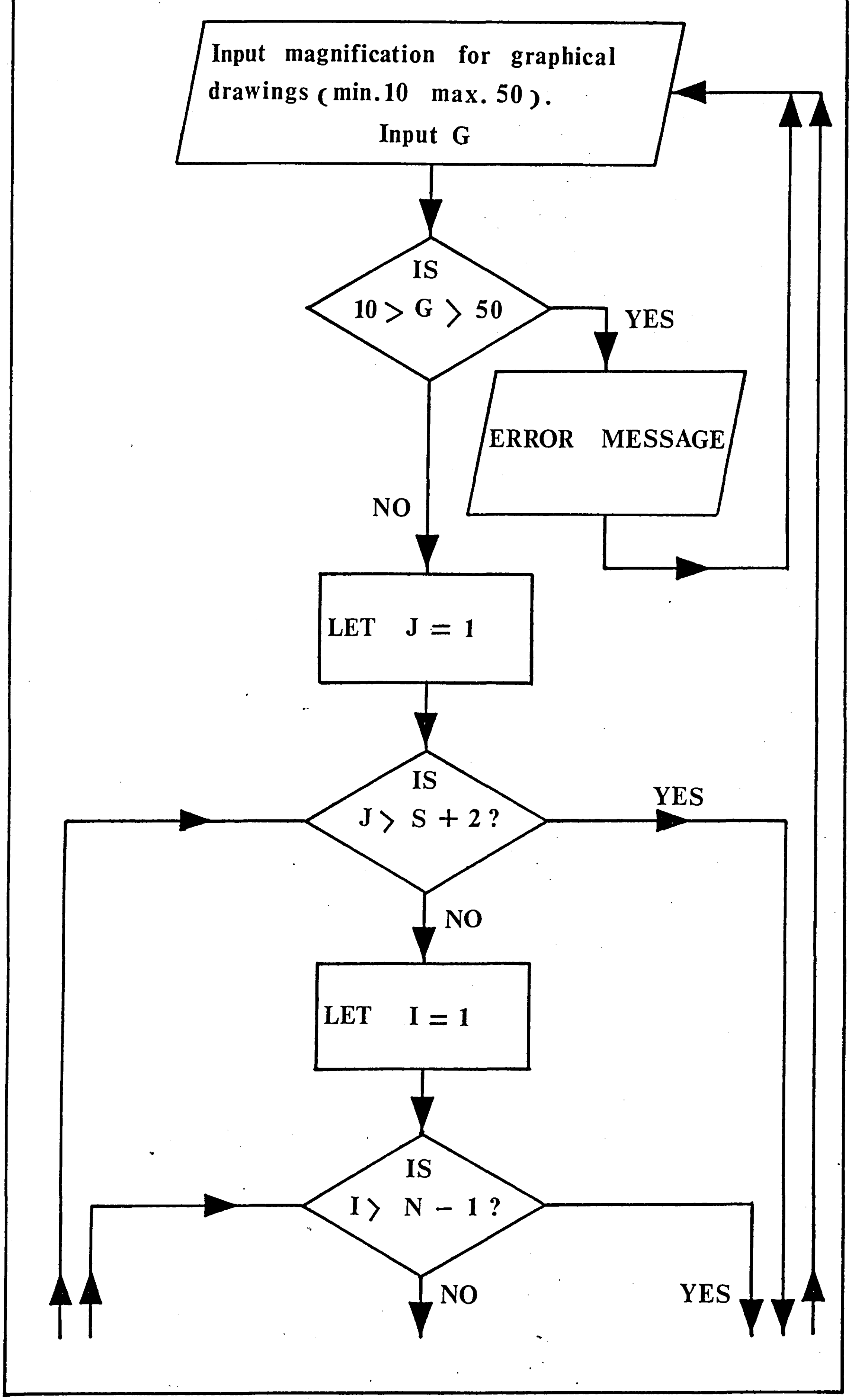

ALFA(I) =TAN^{-1}(X(2,I)−X(1,I) / Z(2)−Z(1))
BETA(I) = TAN^{-1}(Y(2,I)−Y(1,I) / Z(2)−Z(1))
Print ALFA, BETA
LET I = I + 1
Would you like to generate the die profile?
NO
SEE FIG.A5
YES
Is the rig ready ?
NO
SEE FIG. A6
YES
SEE FIG. A7

FIG.A5 flowchart



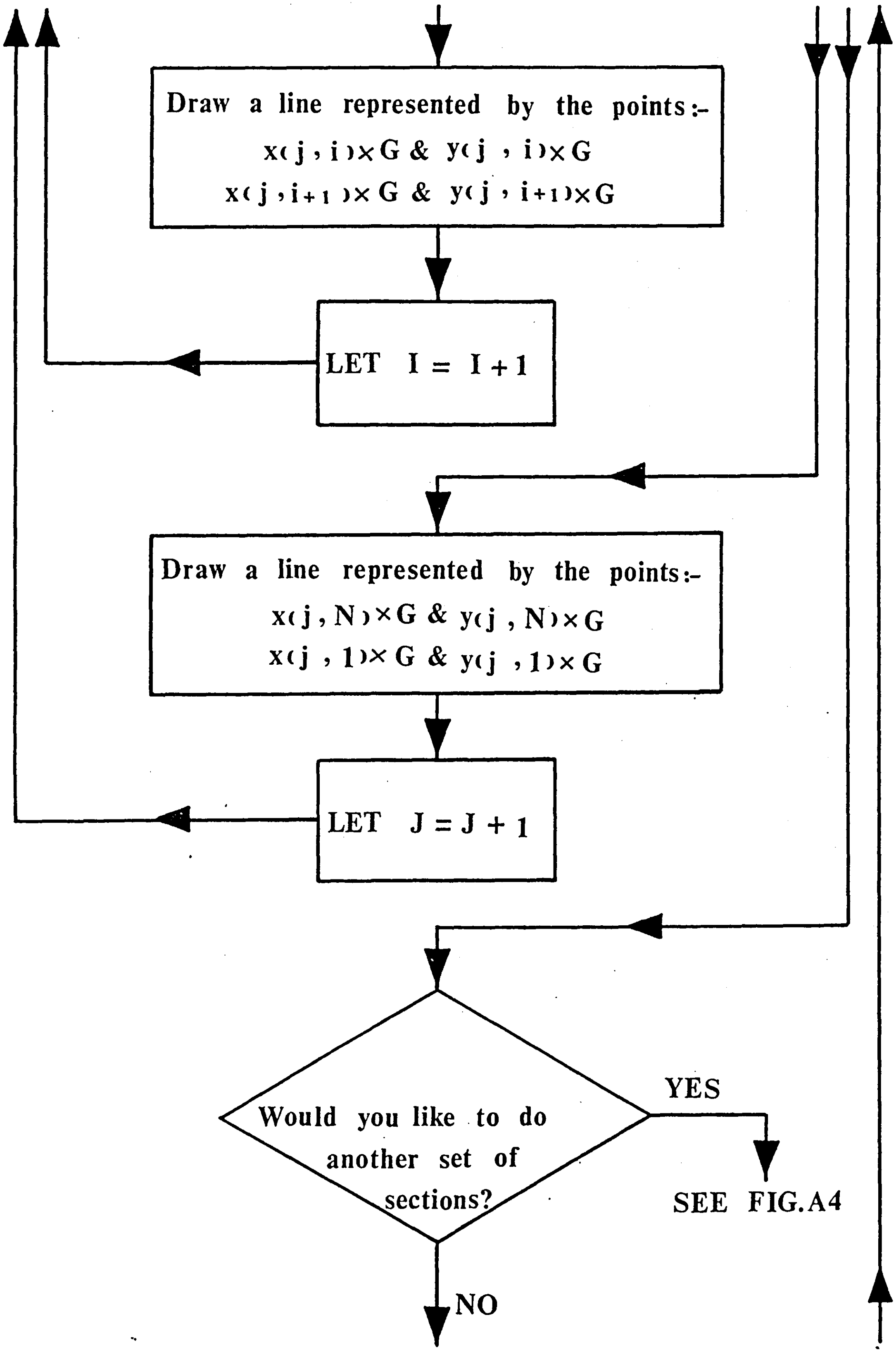


FIG.A5 CONTINUED

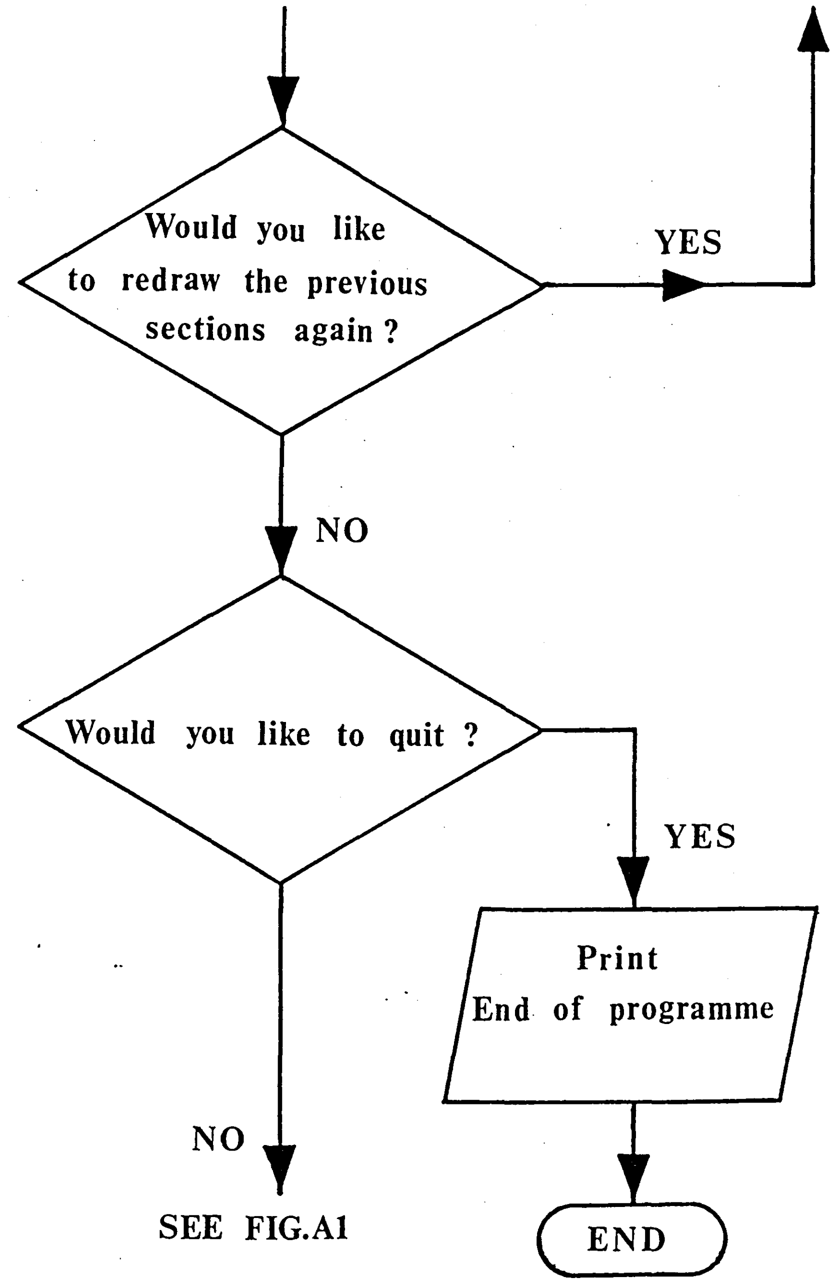

Would you like to redraw the previous sections again ?
YES
NO
Would you like to quit ?
YES
Print
End of programme
NO
SEE FIG.A1
END

FIG.A6 flowchart

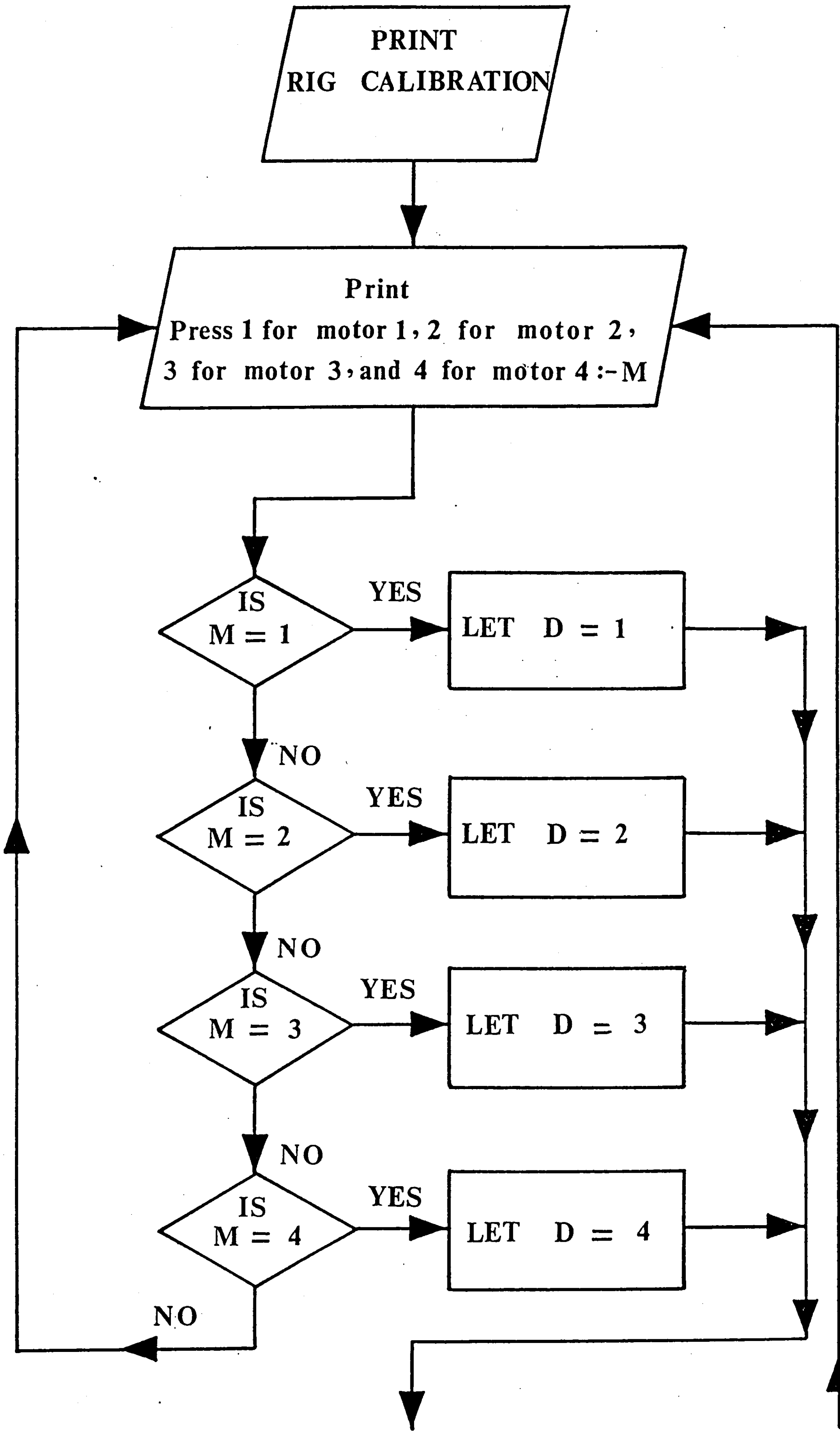
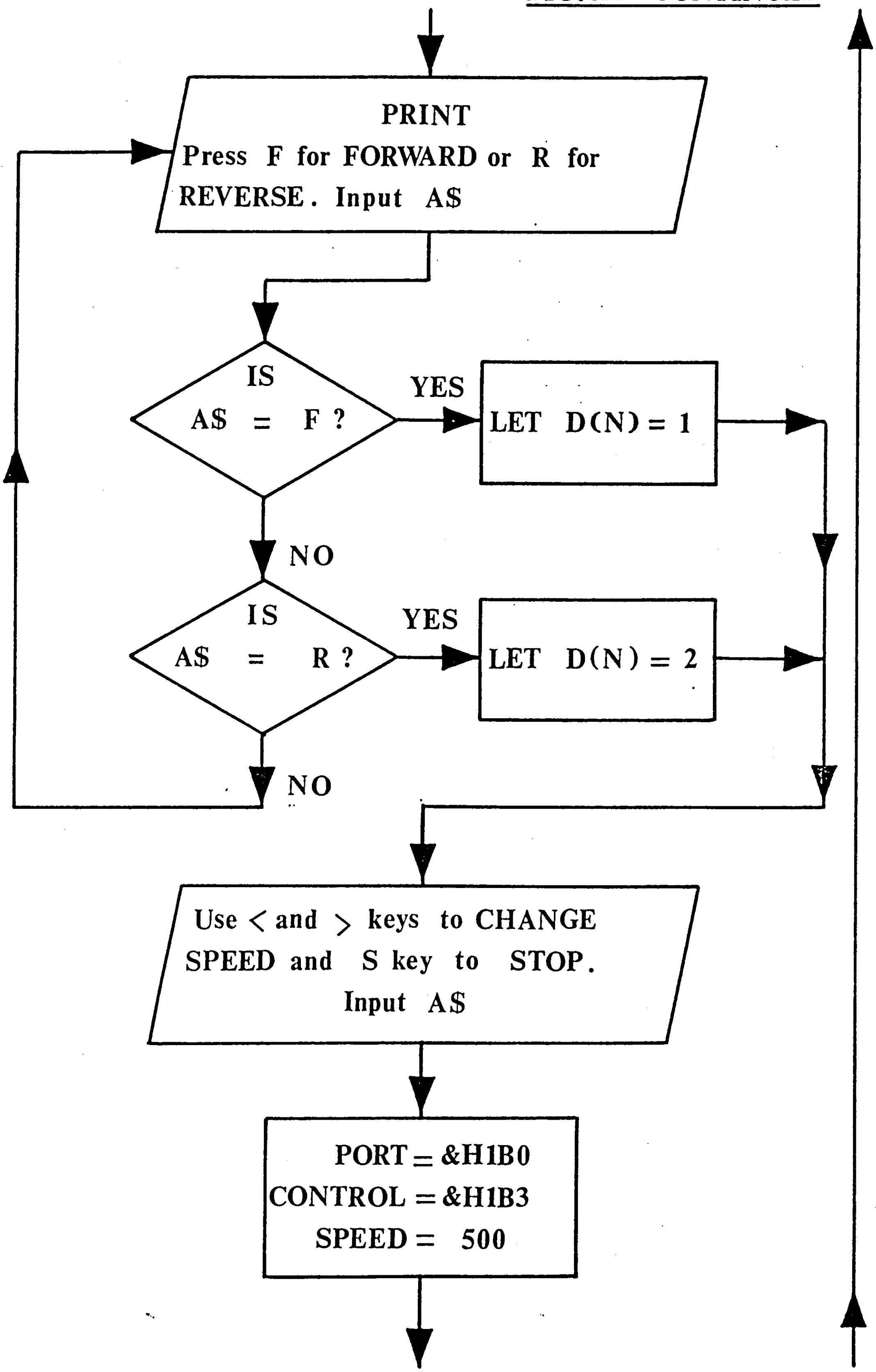
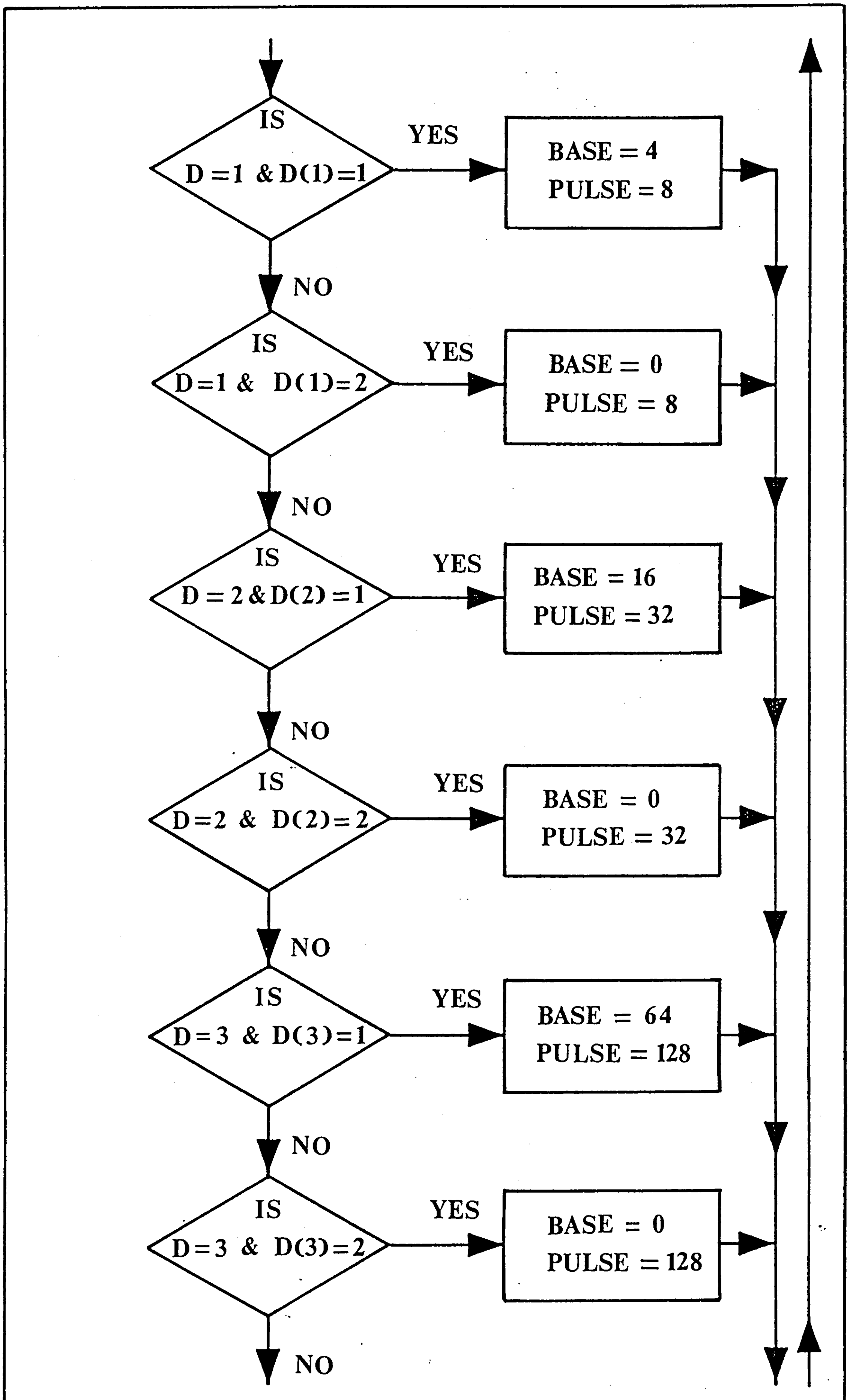
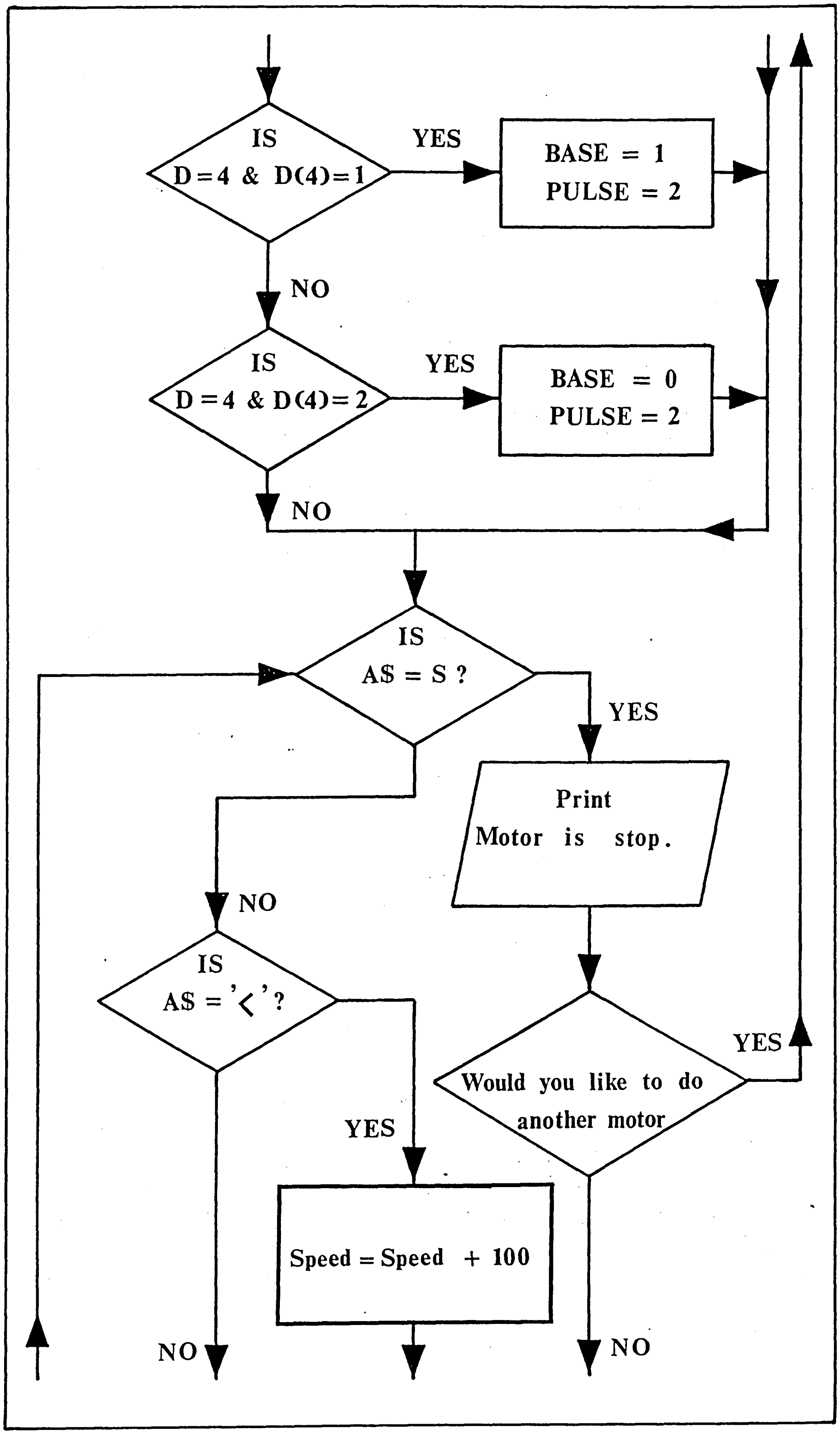


FIG. A6 CONTINUED





SEE NEXT PAGE


IS
D=4 & D(4)=1
YES
BASE = 1
PULSE = 2
NO
IS
D=4 & D(4)=2
YES
BASE = 0
PULSE = 2
NO
IS
A$ = S ?
YES
Print
Motor is stop.
NO
IS
A$ = '<' ?
YES
Would you like to do
another motor
YES
Speed = Speed + 100
NO
NO

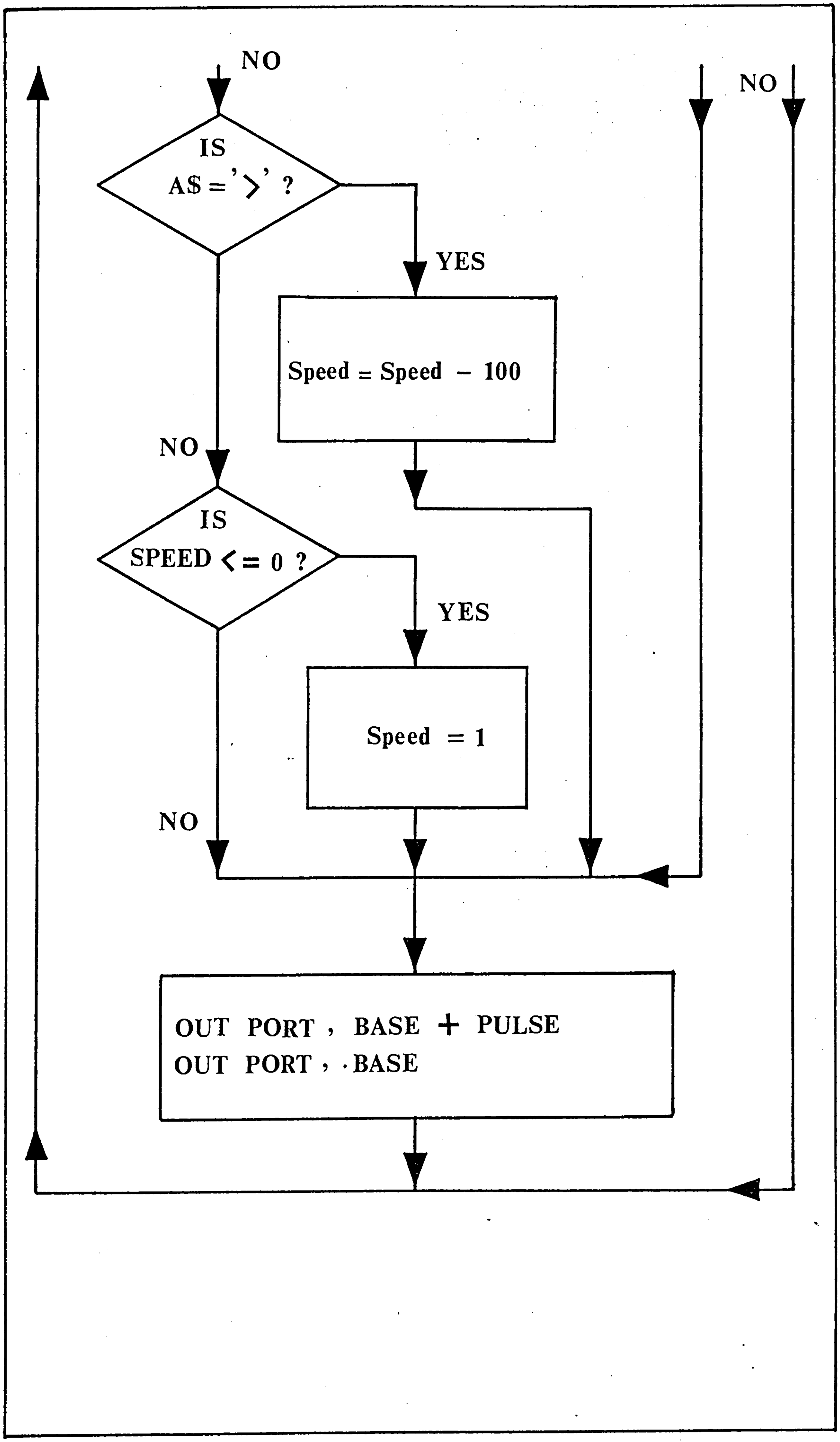
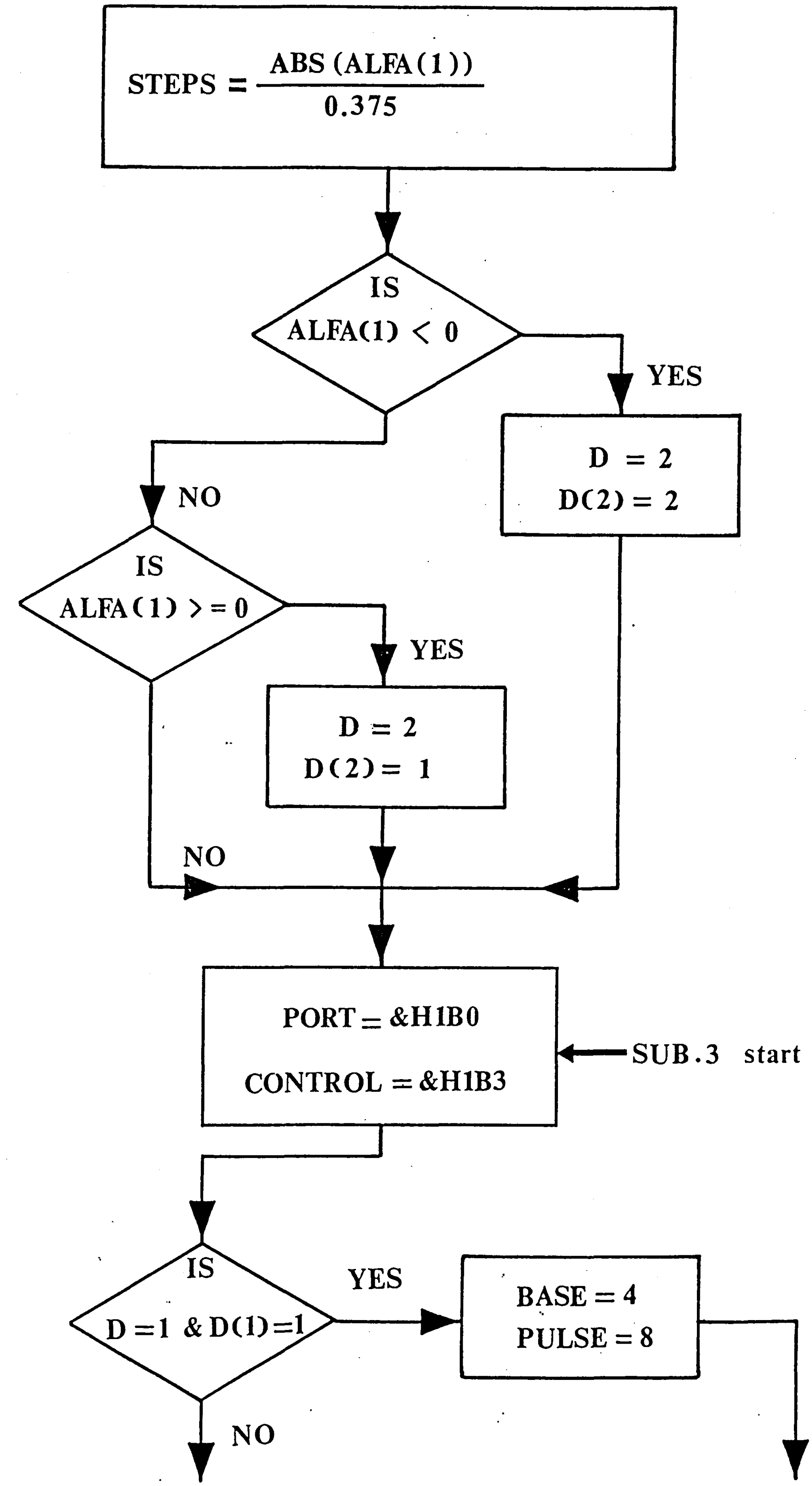
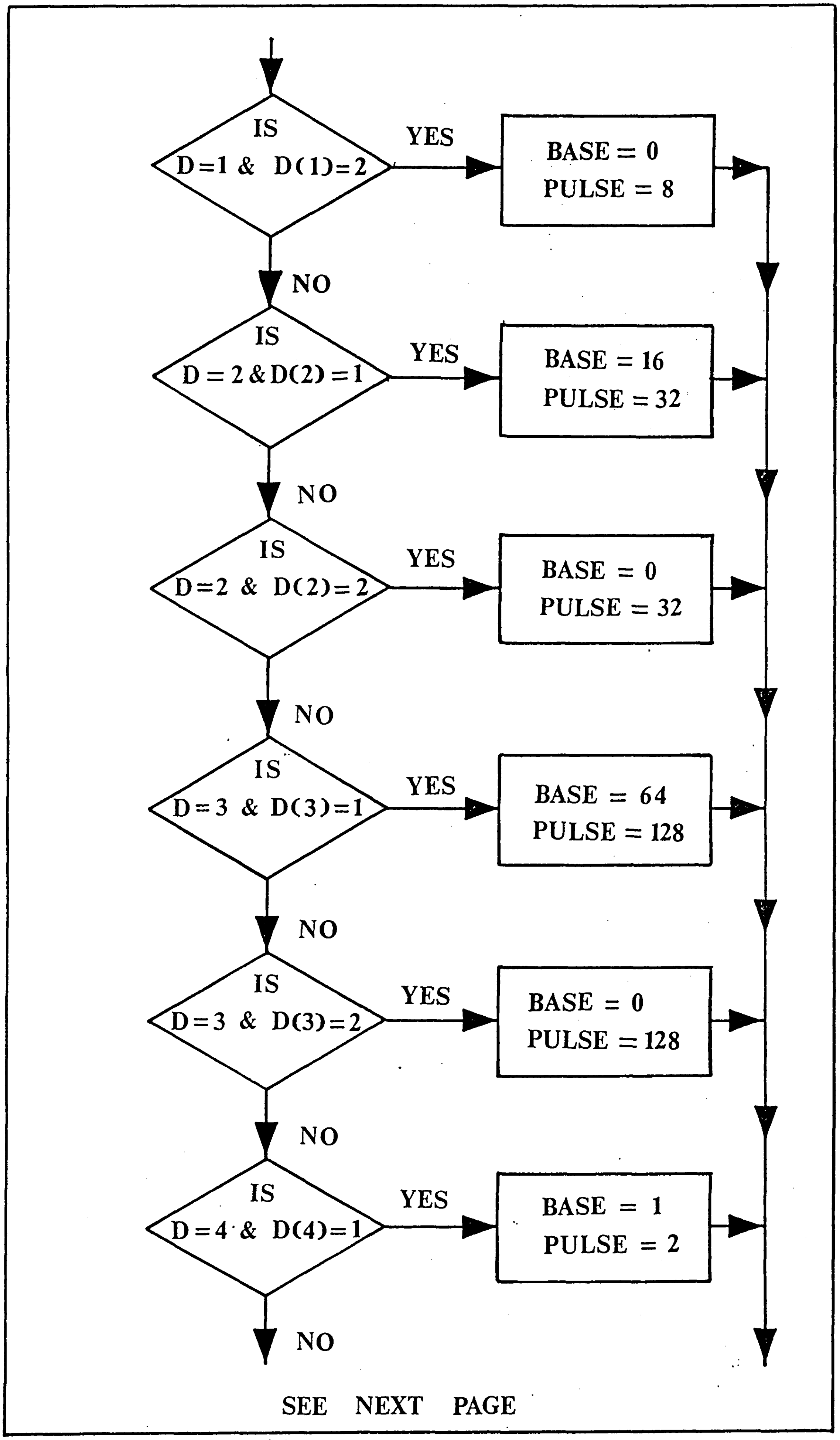
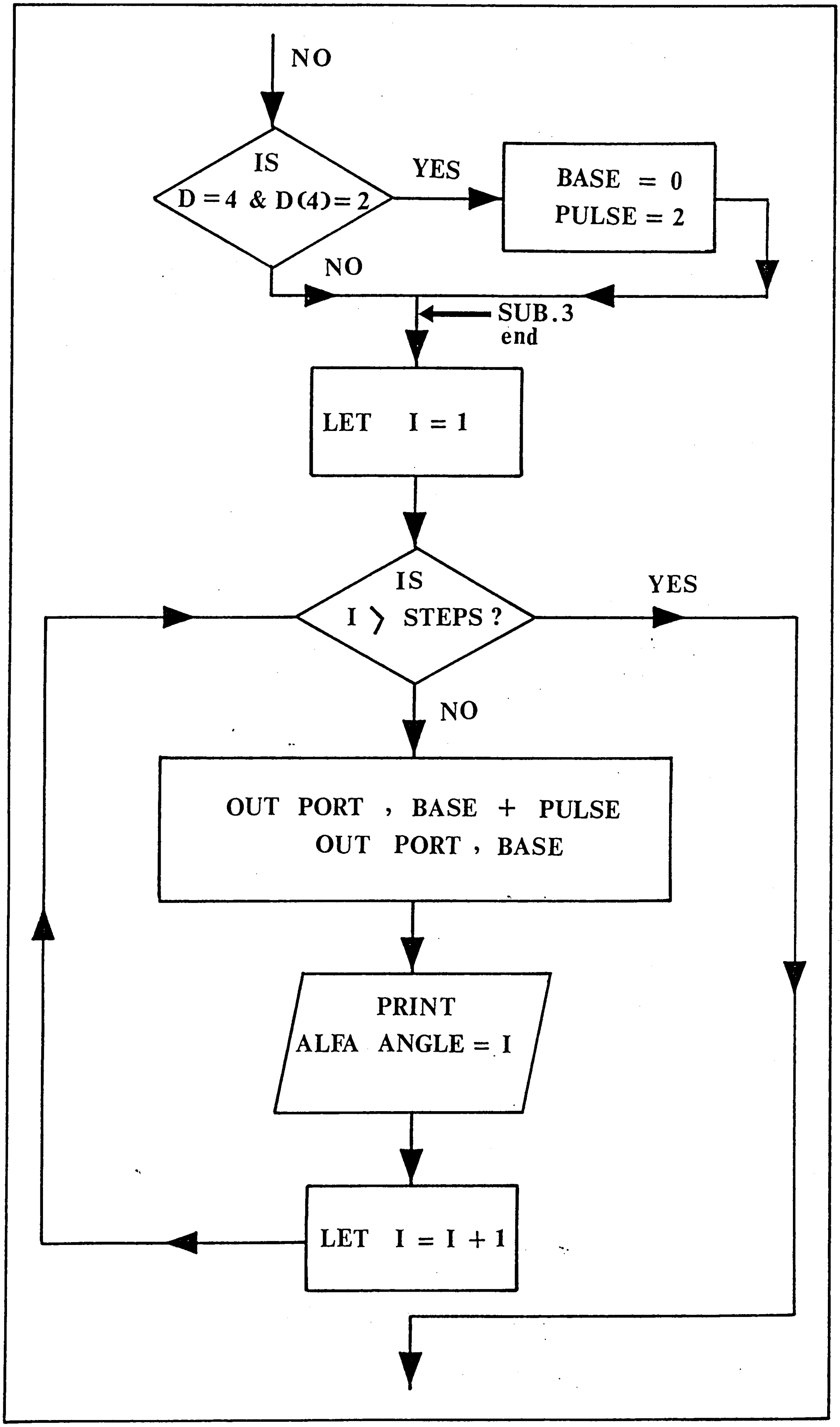
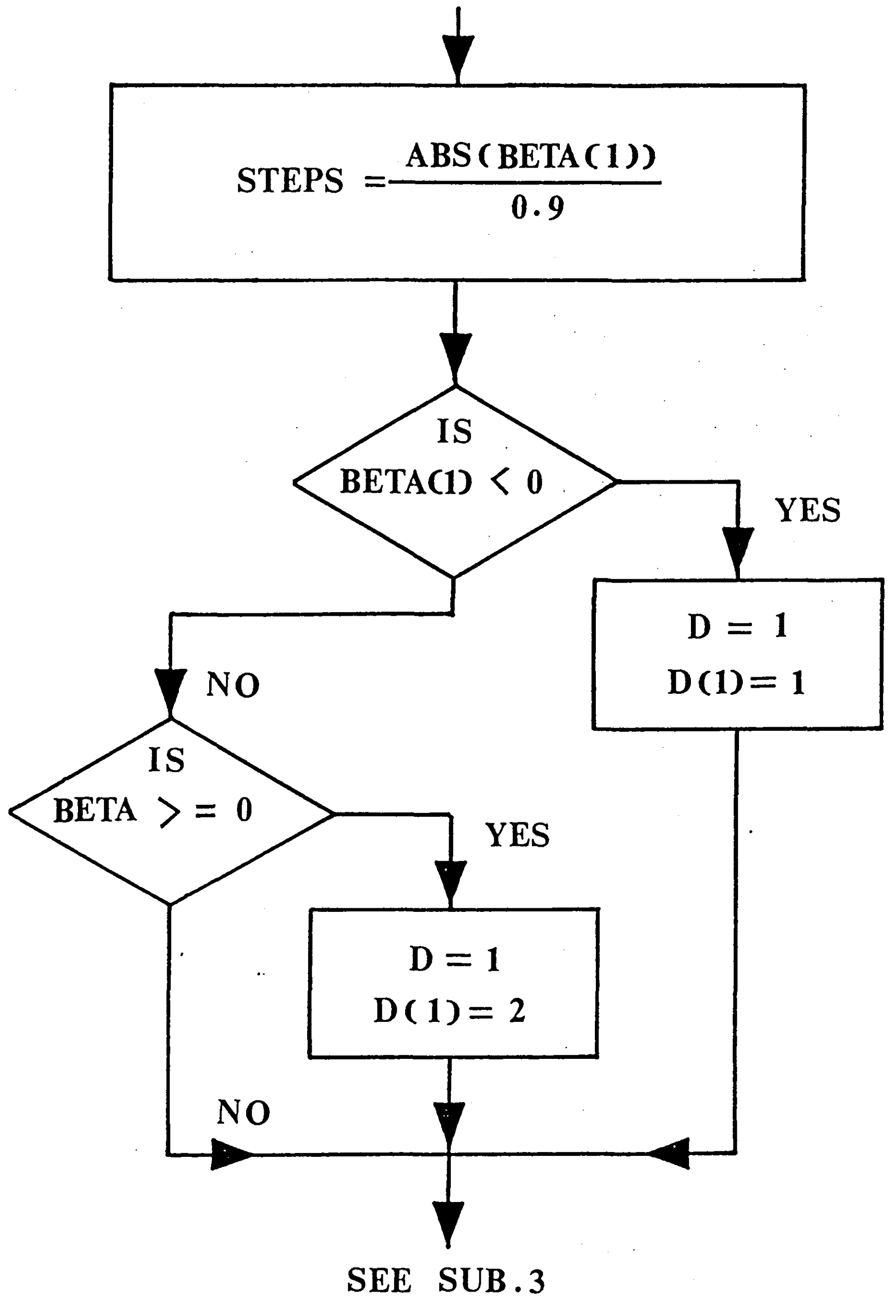

NO
IS
A$ = '>' ?
YES
Speed = Speed - 100
NO
IS
SPEED <= 0 ?
YES
Speed = 1
NO
NO
OUT PORT , BASE + PULSE
OUT PORT , BASE

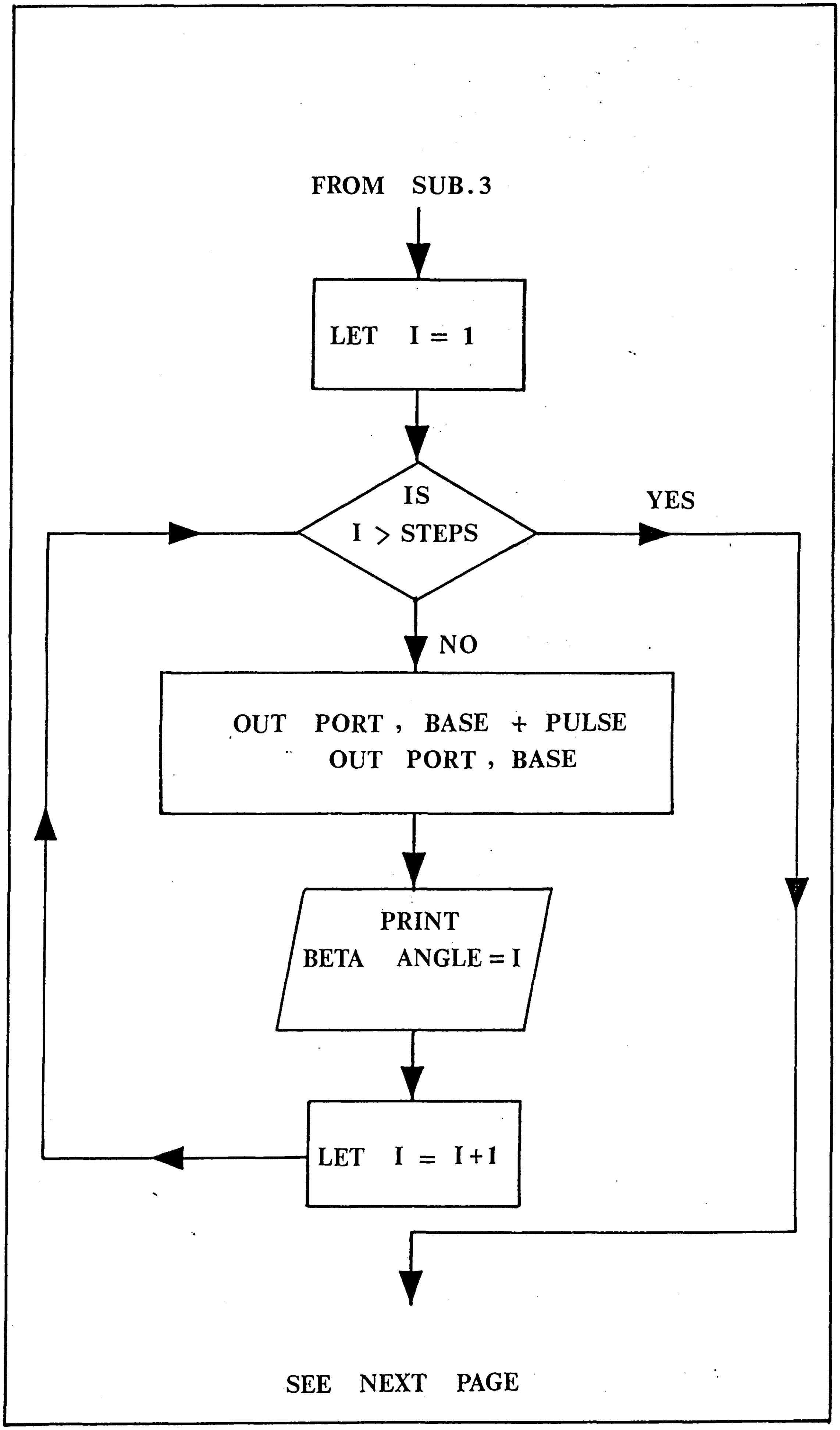
FIG. A7 flowchart

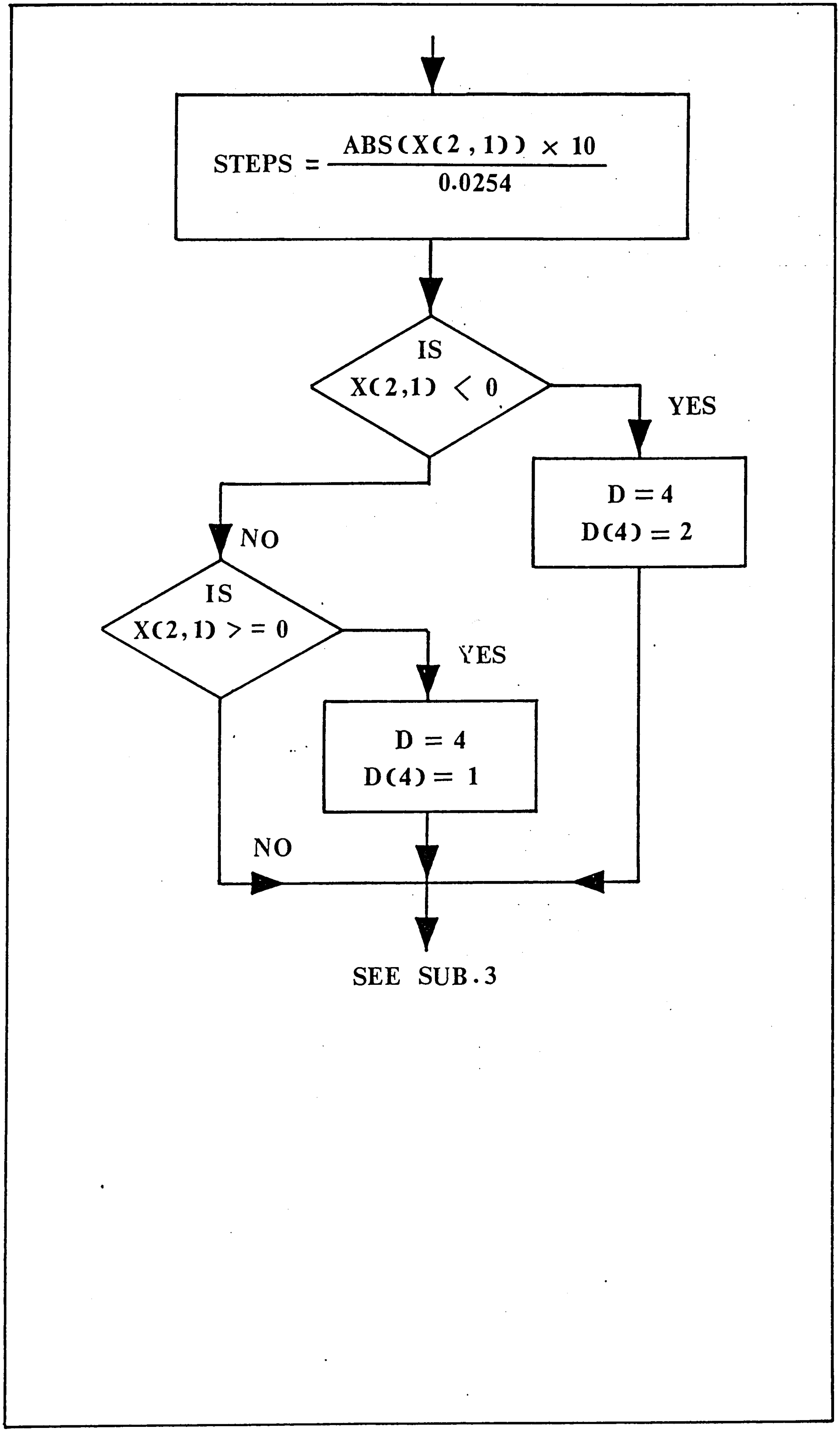


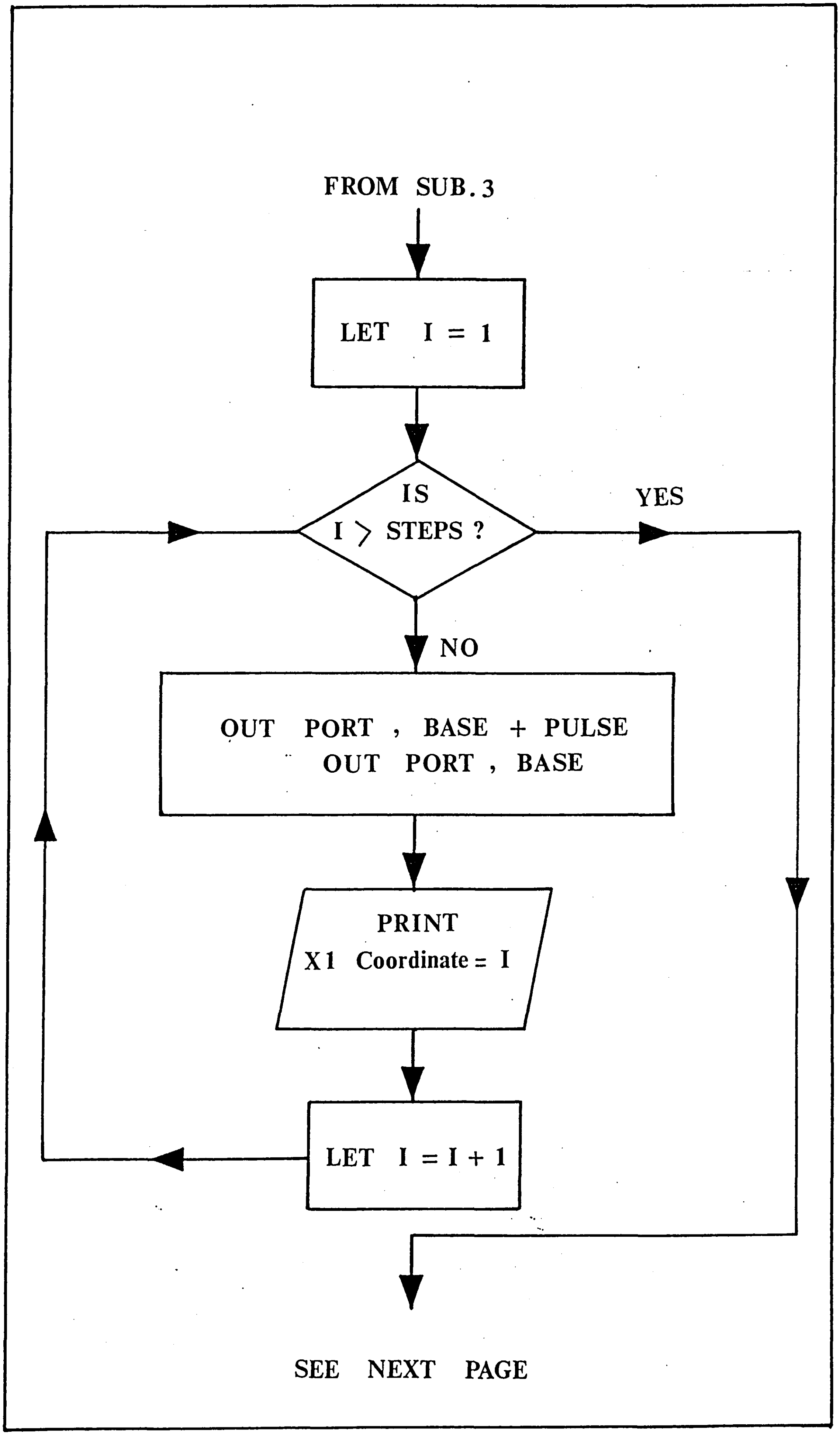

IS
D=1 & D(1)=2
YES
BASE = 0
PULSE = 8
NO
IS
D = 2 & D(2) = 1
YES
BASE = 16
PULSE = 32
NO
IS
D=2 & D(2)=2
YES
BASE = 0
PULSE = 32
NO
IS
D=3 & D(3)=1
YES
BASE = 64
PULSE = 128
NO
IS
D=3 & D(3)=2
YES
BASE = 0
PULSE = 128
NO
IS
D=4 & D(4)=1
YES
BASE = 1
PULSE = 2
NO
SEE NEXT PAGE

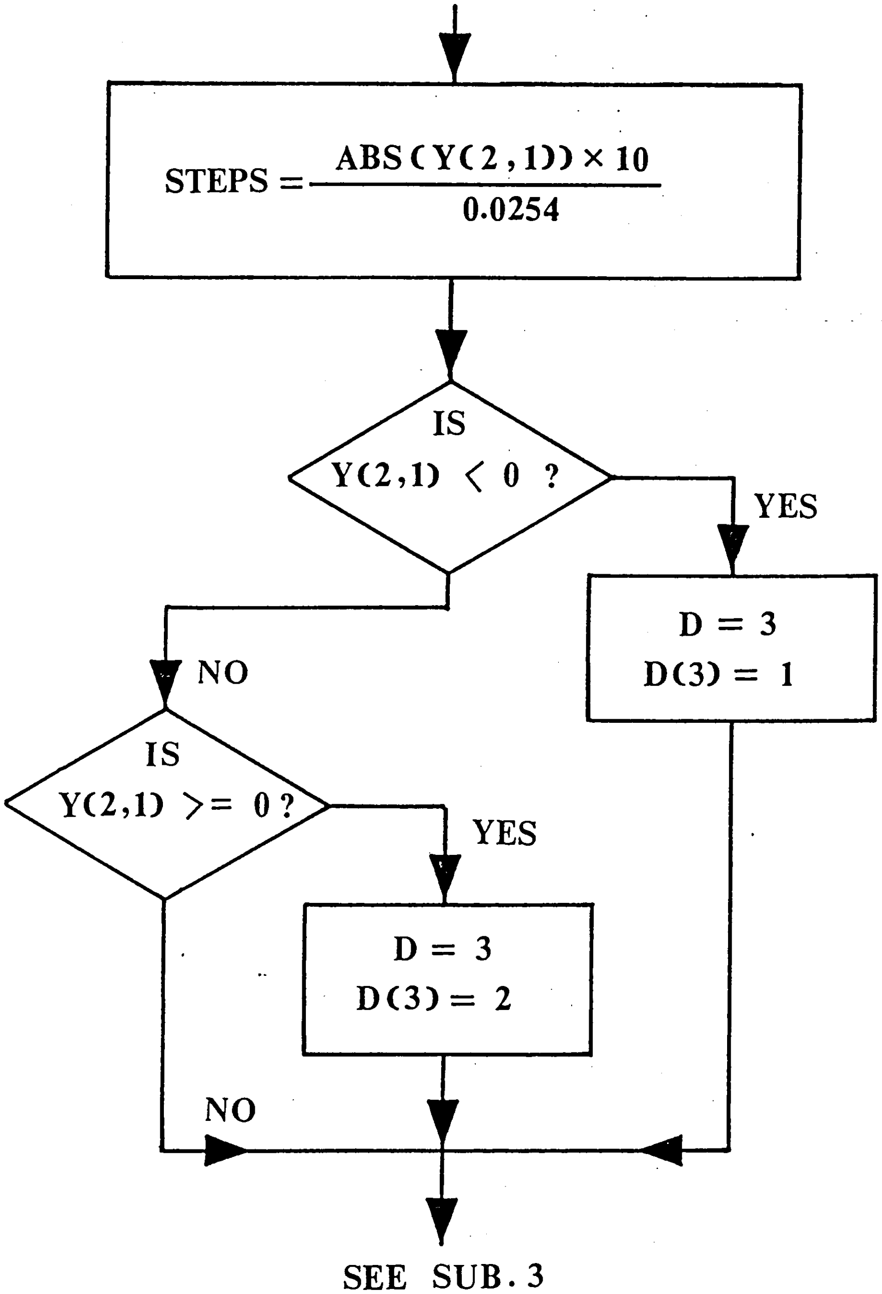

NO
IS
D = 4 & D(4) = 2
YES
BASE = 0
PULSE = 2
NO
SUB.3
end
LET I = 1
IS
I 〉 STEPS ?
YES
NO
OUT PORT , BASE + PULSE
OUT PORT , BASE
PRINT
ALFA ANGLE = I
LET I = I + 1


STEPS = ABS(BETA(1)) / 0.9
IS BETA(1) < 0
YES
D = 1
D(1) = 1
NO
IS BETA >= 0
YES
D = 1
D(1) = 2
NO
SEE SUB.3

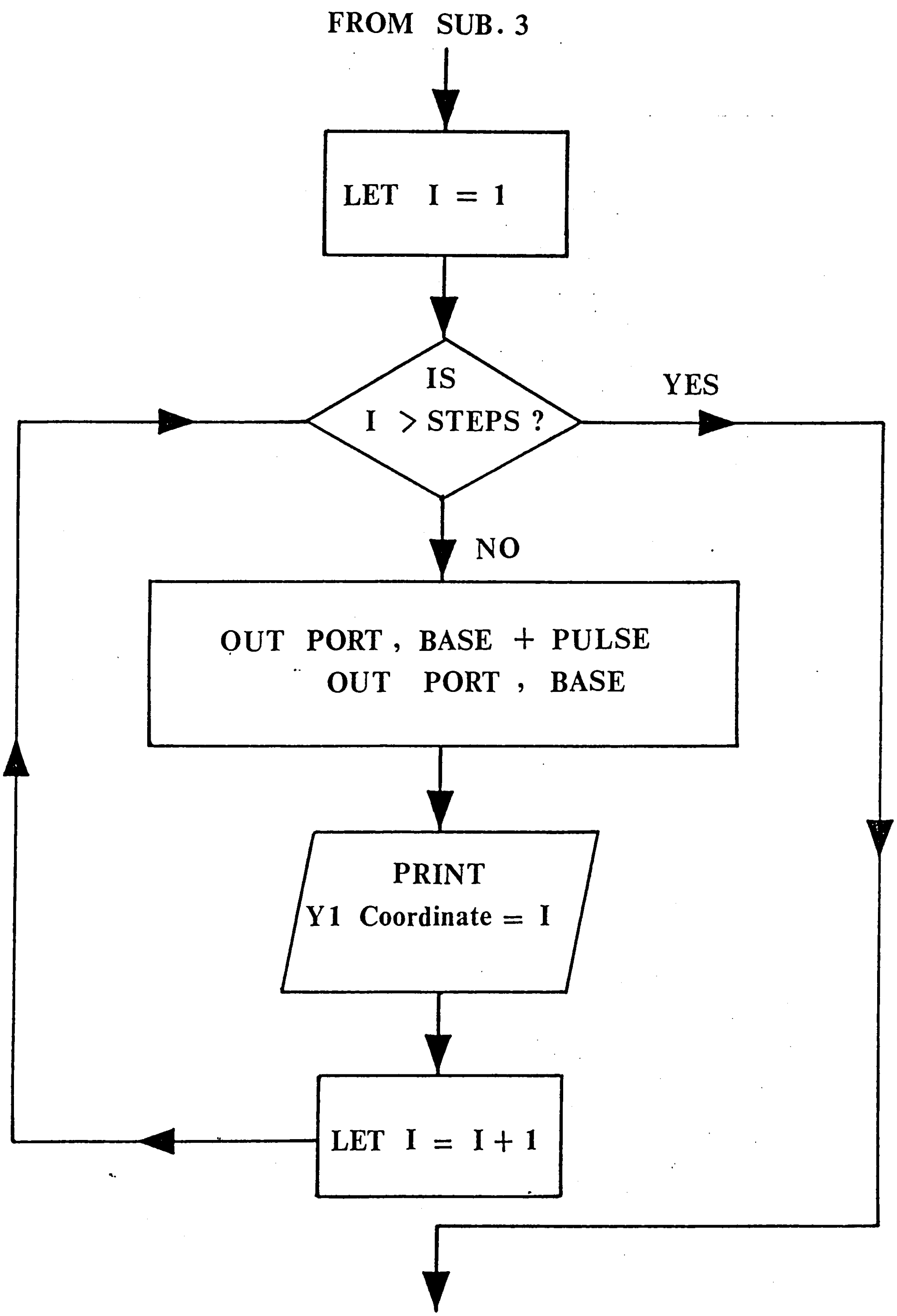

FROM SUB.3
LET I = 1
IS
I > STEPS
YES
NO
OUT PORT , BASE + PULSE
OUT PORT , BASE
PRINT
BETA ANGLE = I
LET I = I+1
SEE NEXT PAGE


STEPS = ABS(X(2,1)) × 10 / 0.0254
IS X(2,1) < 0
YES
D = 4
D(4) = 2
NO
IS X(2,1) >= 0
YES
D = 4
D(4) = 1
NO
SEE SUB.3

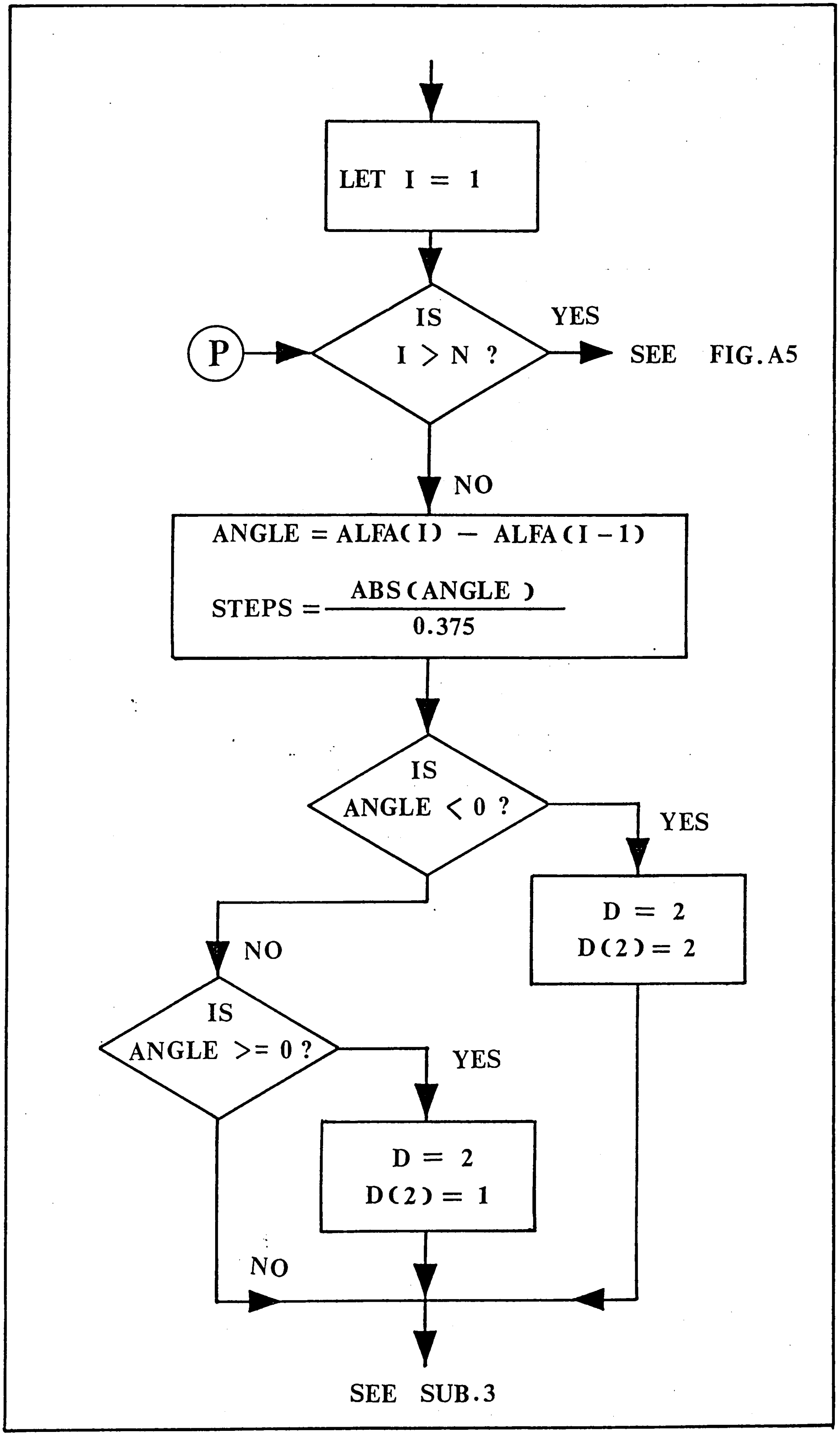

FROM SUB.3
LET I = 1
IS
I > STEPS ?
YES
NO
OUT PORT , BASE + PULSE
OUT PORT , BASE
PRINT
X1 Coordinate = I
LET I = I + 1
SEE NEXT PAGE

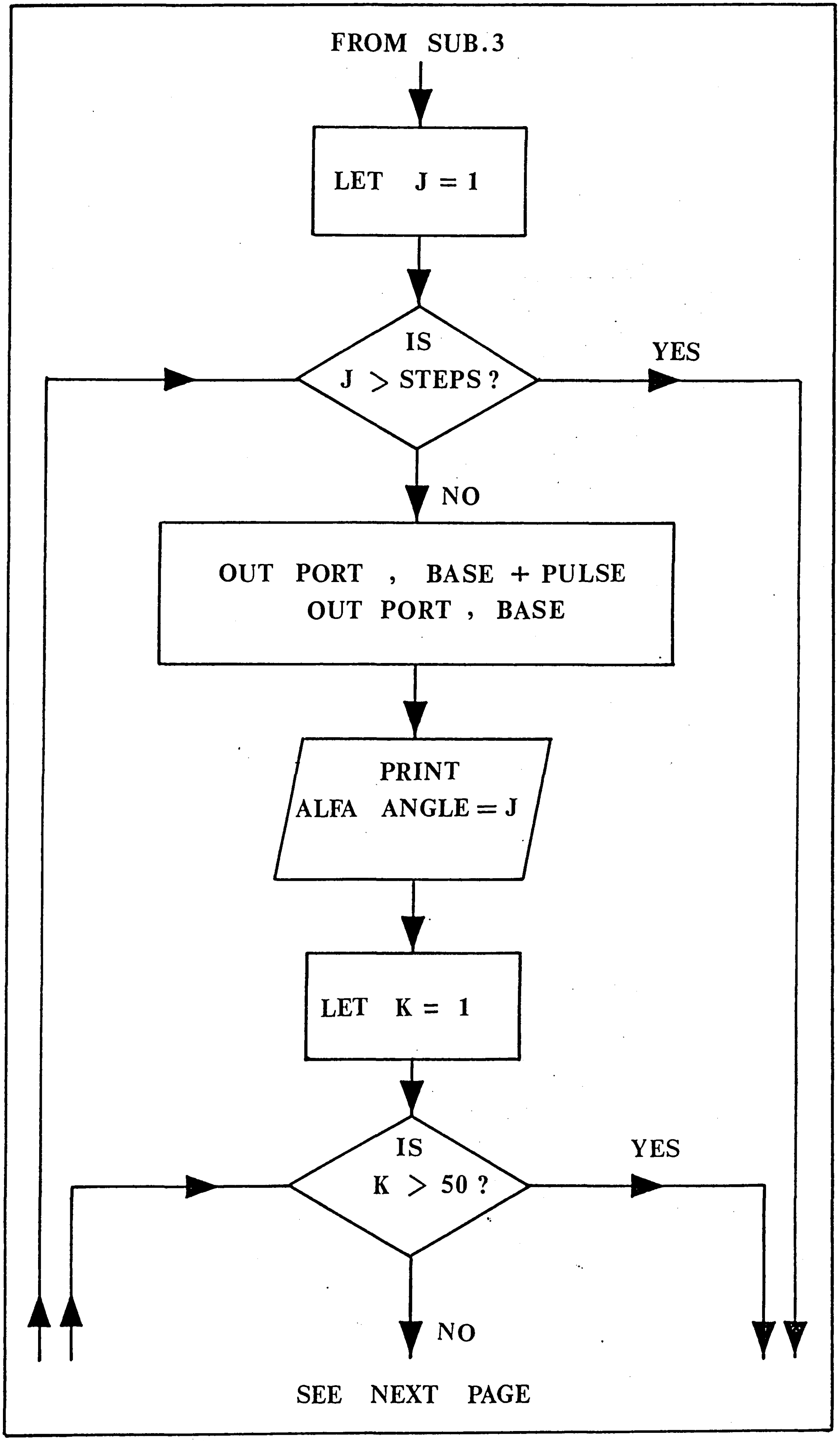


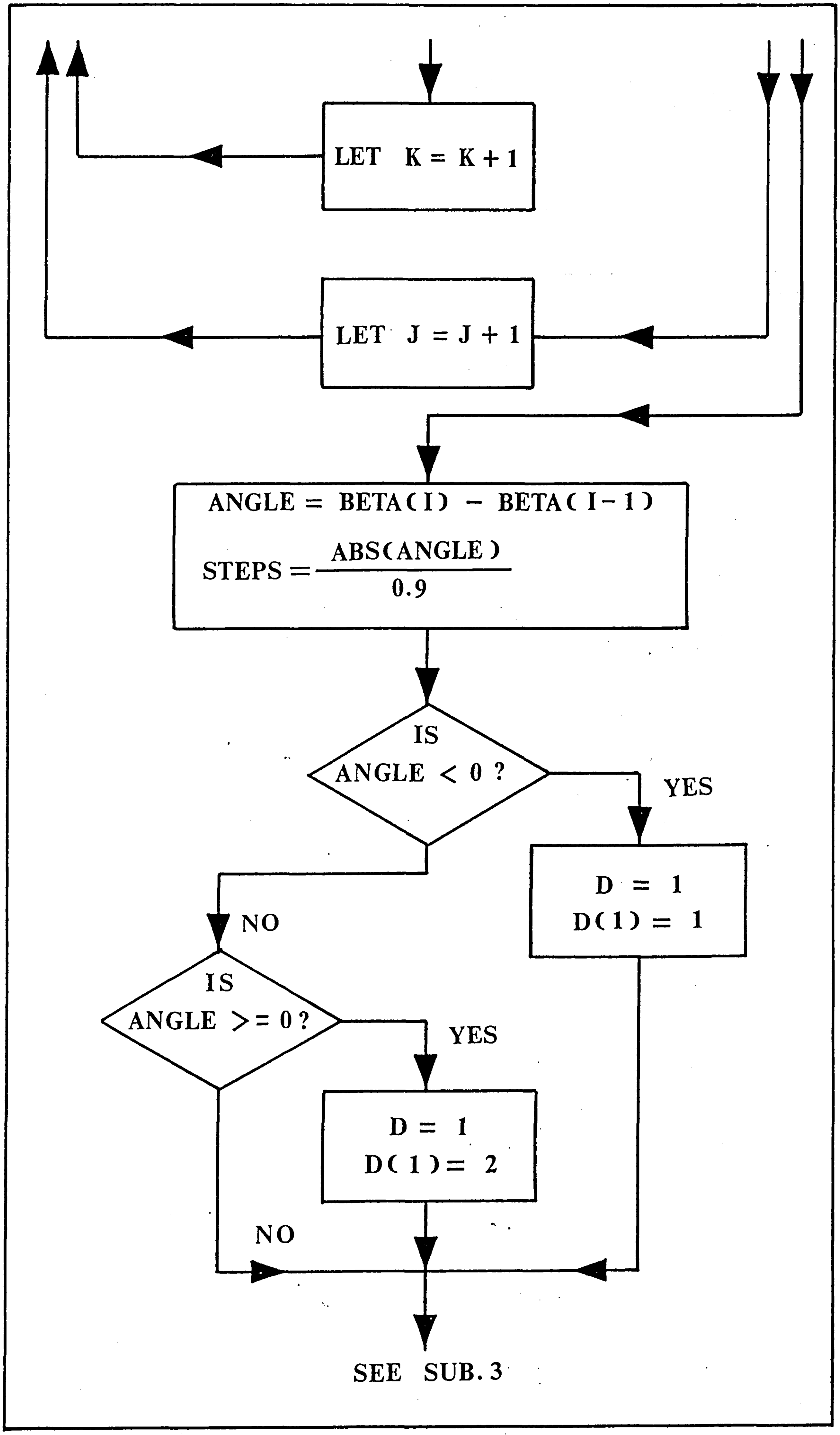
STEPS = ABS (Y(2 , 1)) × 10 / 0.0254
IS
Y(2,1) < 0 ?
YES
D = 3
D(3) = 1
NO
IS
Y(2,1) >= 0 ?
YES
D = 3
D(3) = 2
NO
SEE SUB. 3

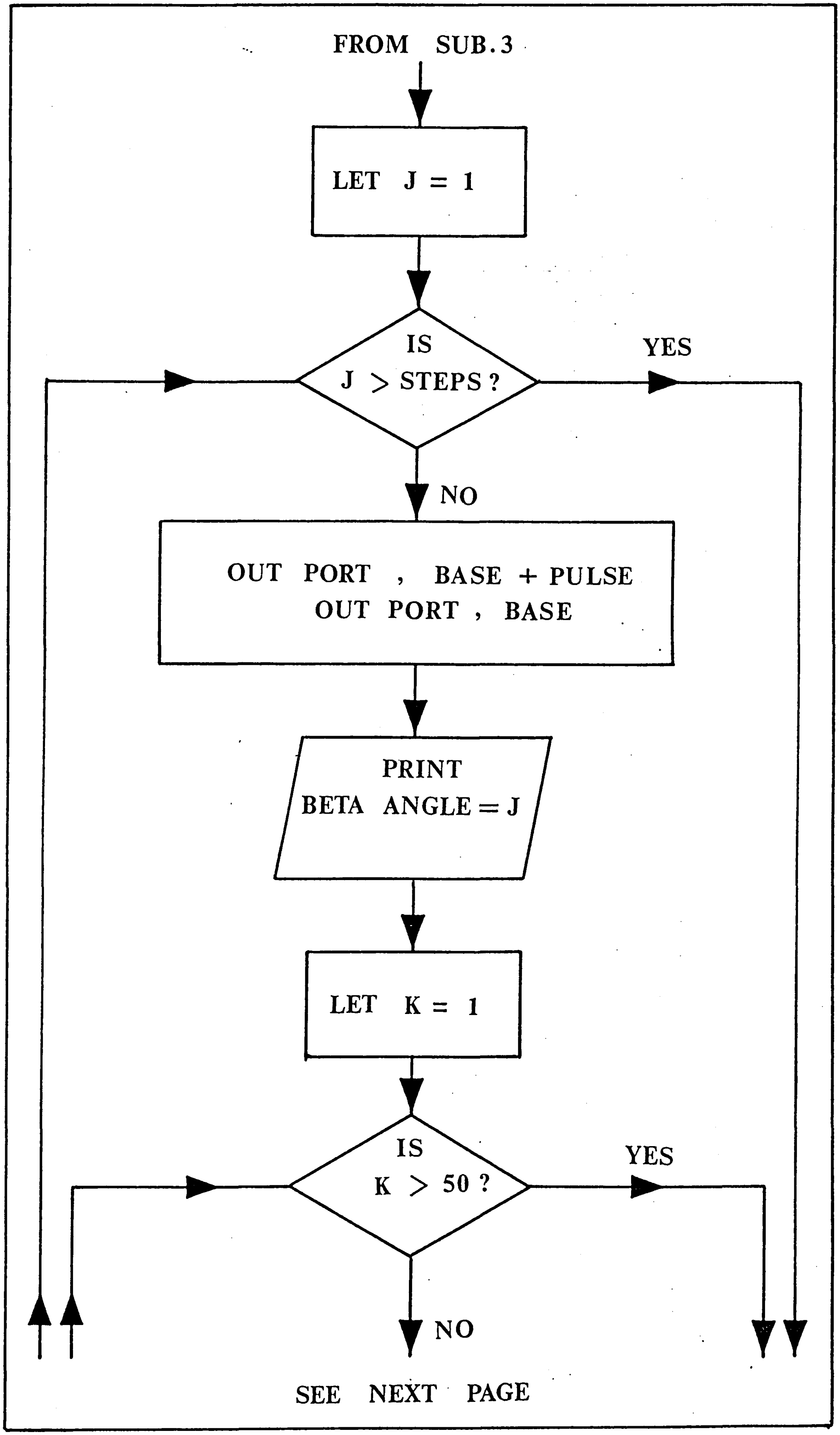


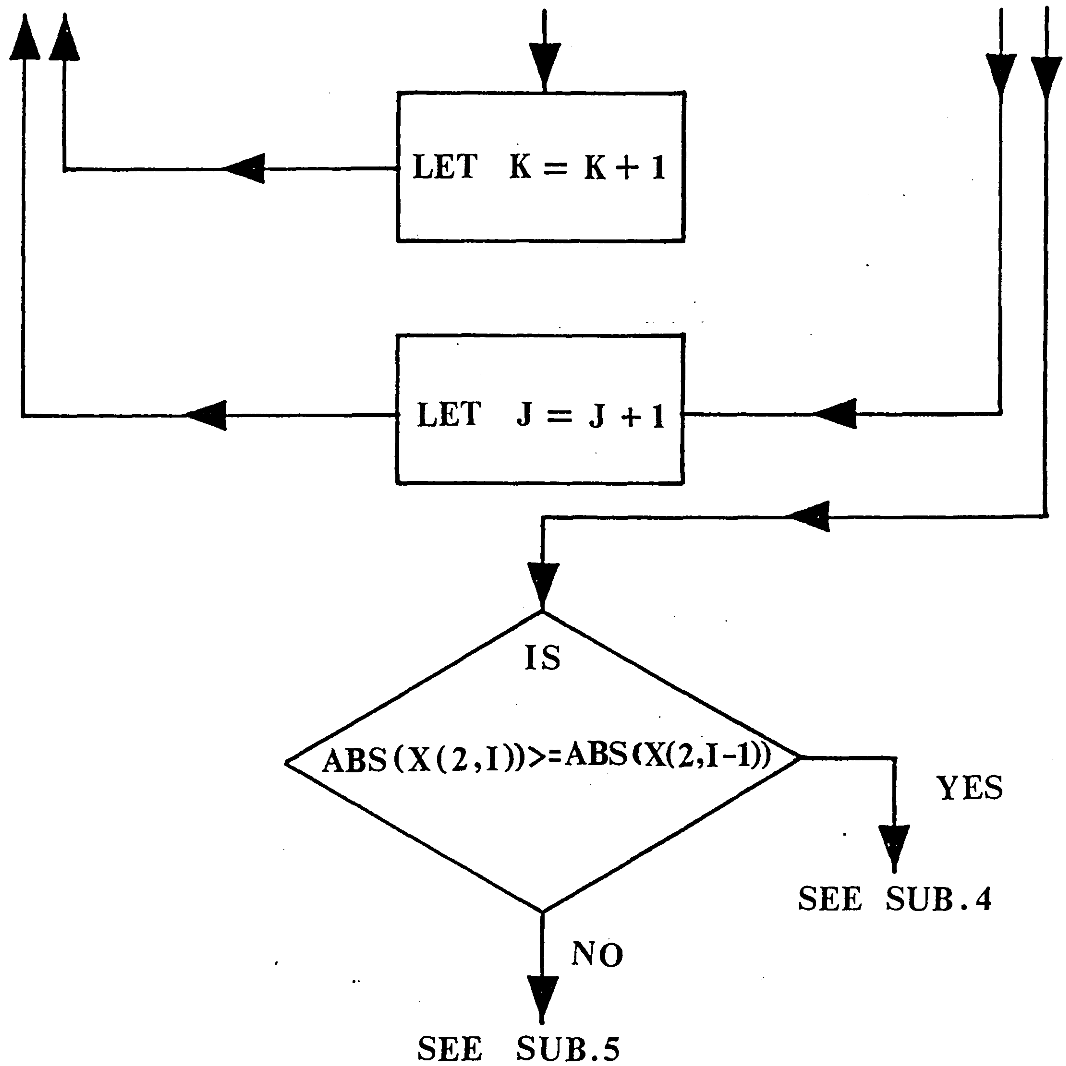
SEE NEXT PAGE

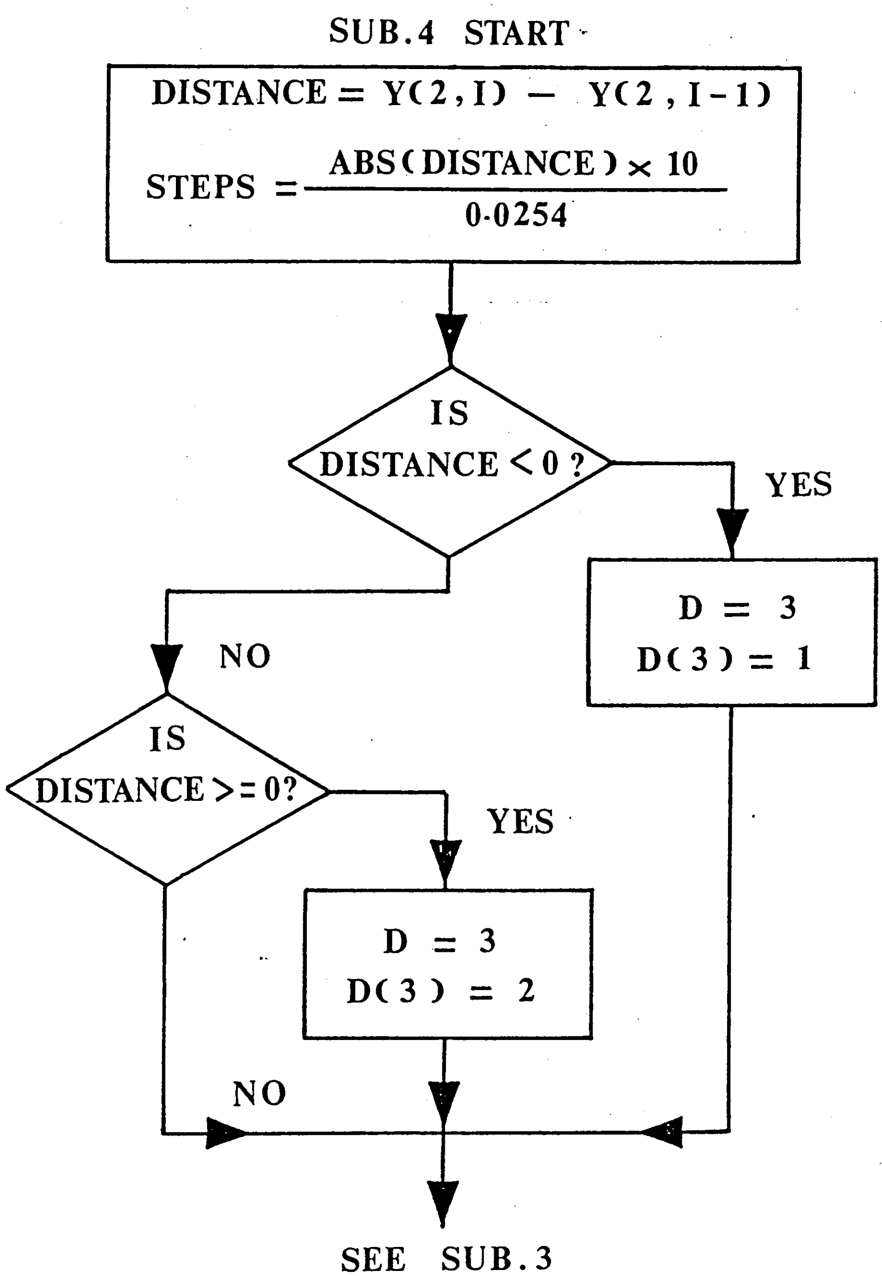

LET I = 1
IS
I > N ?
YES
SEE FIG.A5
P
NO
ANGLE = ALFA(I) — ALFA(I-1)
STEPS = ABS(ANGLE) / 0.375
IS
ANGLE < 0 ?
YES
D = 2
D(2) = 2
NO
IS
ANGLE >= 0 ?
YES
D = 2
D(2) = 1
NO
SEE SUB.3

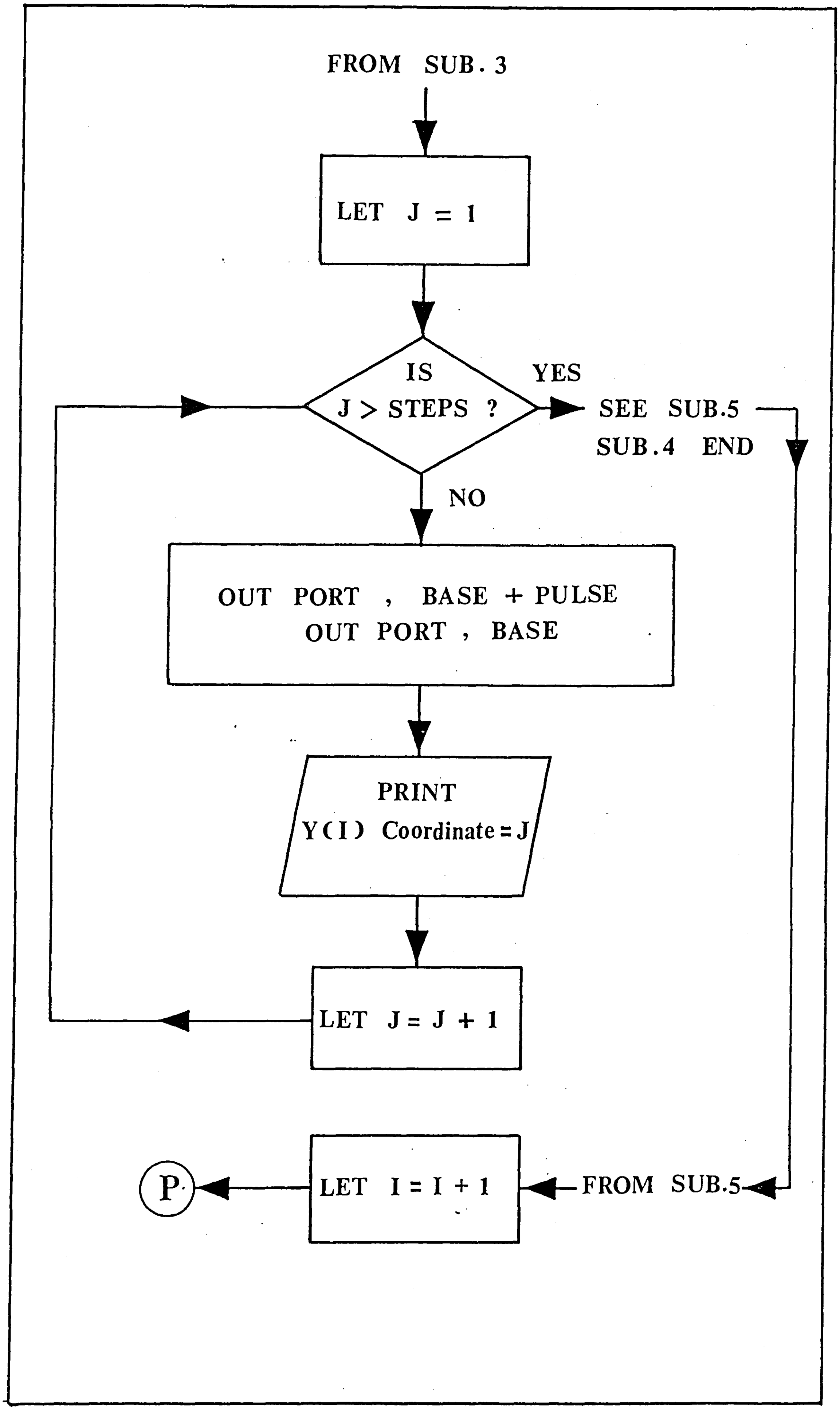

FROM SUB.3
LET J = 1
IS
J > STEPS ?
YES
NO
OUT PORT , BASE + PULSE
OUT PORT , BASE
PRINT
ALFA ANGLE = J
LET K = 1
IS
K > 50 ?
YES
NO
SEE NEXT PAGE

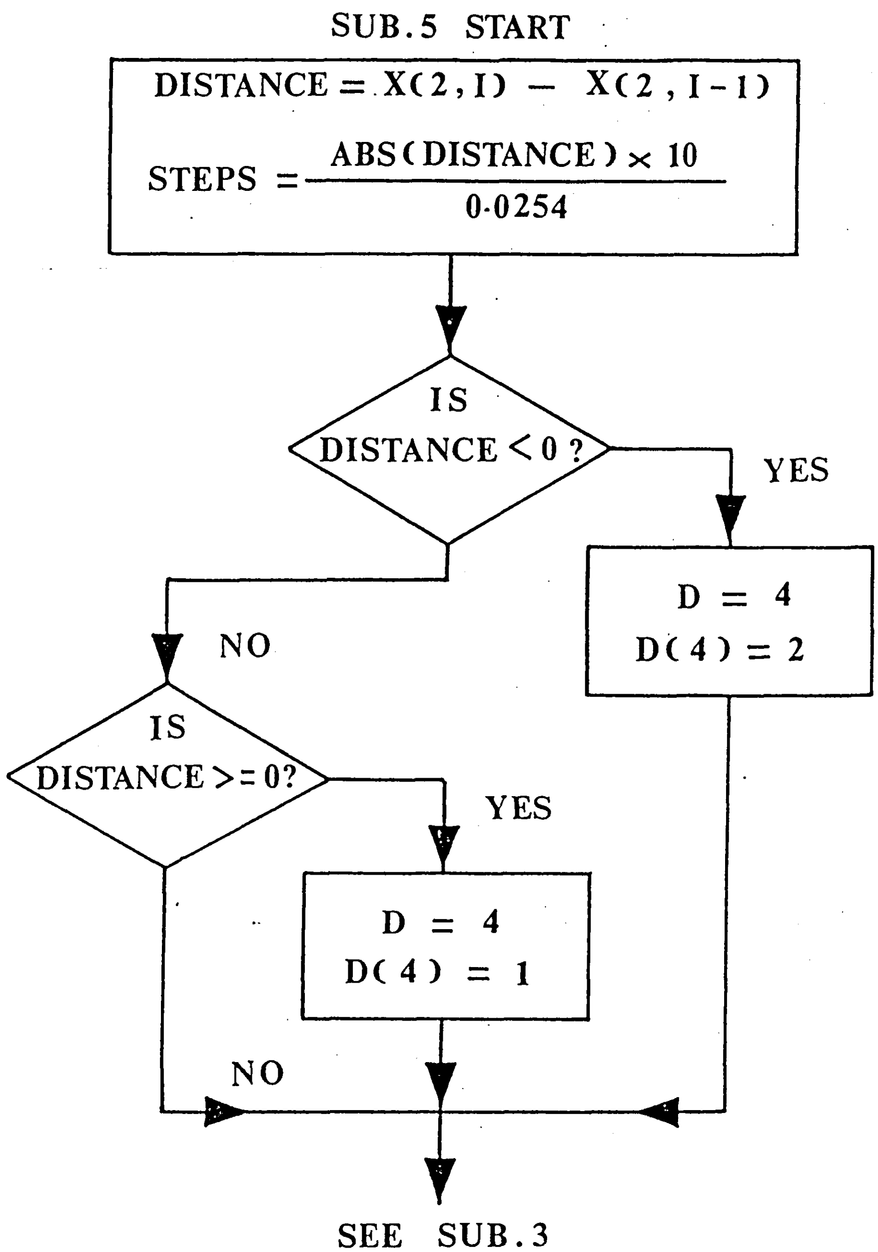

LET K = K + 1
LET J = J + 1
ANGLE = BETA(I) − BETA(I − 1)
STEPS = ABS(ANGLE) / 0.9
IS ANGLE < 0 ?
YES
D = 1
D(1) = 1
NO
IS ANGLE >= 0 ?
YES
D = 1
D(1) = 2
NO
SEE SUB. 3

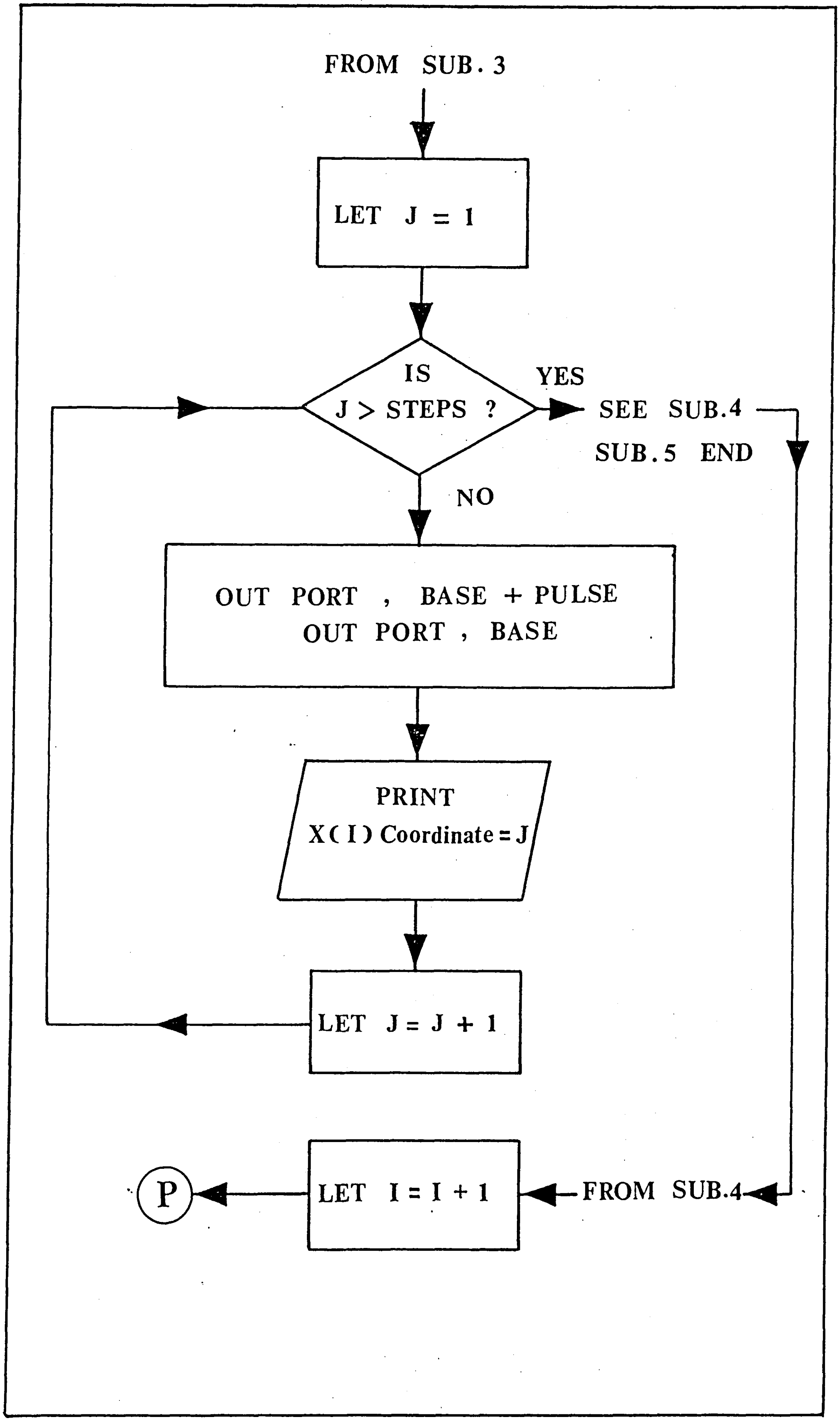

FROM SUB.3
LET J = 1
IS
J > STEPS ?
YES
NO
OUT PORT , BASE + PULSE
OUT PORT , BASE
PRINT
BETA ANGLE = J
LET K = 1
IS
K > 50 ?
YES
NO
SEE NEXT PAGE


LET K = K + 1
LET J = J + 1
IS
ABS(X(2,I))>=ABS(X(2,I-1))
YES
SEE SUB.4
NO
SEE SUB.5


SUB.4 START
DISTANCE = Y(2,I) − Y(2,I−1)
STEPS = ABS(DISTANCE) × 10 / 0·0254
IS DISTANCE < 0 ?
YES
D = 3
D(3) = 1
NO
IS DISTANCE >= 0?
YES
D = 3
D(3) = 2
NO
SEE SUB.3


FROM SUB. 3
LET J = 1
IS
J > STEPS ?
YES
SEE SUB.5
SUB.4 END
NO
OUT PORT , BASE + PULSE
OUT PORT , BASE
PRINT
Y(I) Coordinate = J
LET J = J + 1
P
LET I = I + 1
FROM SUB.5


SUB.5 START
DISTANCE = X(2,I) – X(2,I-1)
STEPS = ABS(DISTANCE) × 10 / 0·0254
IS DISTANCE < 0 ?
YES
D = 4
D(4) = 2
NO
IS DISTANCE >= 0?
YES
D = 4
D(4) = 1
NO
SEE SUB.3


FROM SUB. 3
LET J = 1
IS
J > STEPS ?
YES
SEE SUB.4
SUB. 5 END
NO
OUT PORT , BASE + PULSE
OUT PORT , BASE
PRINT
X(I) Coordinate = J
LET J = J + 1
P
LET I = I + 1
FROM SUB.4

Appendix II

Computer Generated Data

This Appendix contains the following:-

1) The X and Y coordinates of up to fifty-five points representing the top, the bottom, and up to five intermediate sections respectively. Plus the sector area and the angle θ generated between each two successive points. The programme has been left unitless to give the user the freedom to include any type of units.

2) The total cross-sectional area of each surface.

3) The angles α and β which are generated in space between the top and the bottom surfaces for up to fifty-five points.

4) The graphical drawings of the superimposed top, bottom, and five intermediate sections.

5) The graphical drawings of each surface separately.

The above has been done for the four different dies, which are the circle to square, the circle to circle, the circle to "peanut", and the square to "peanut" respectively.

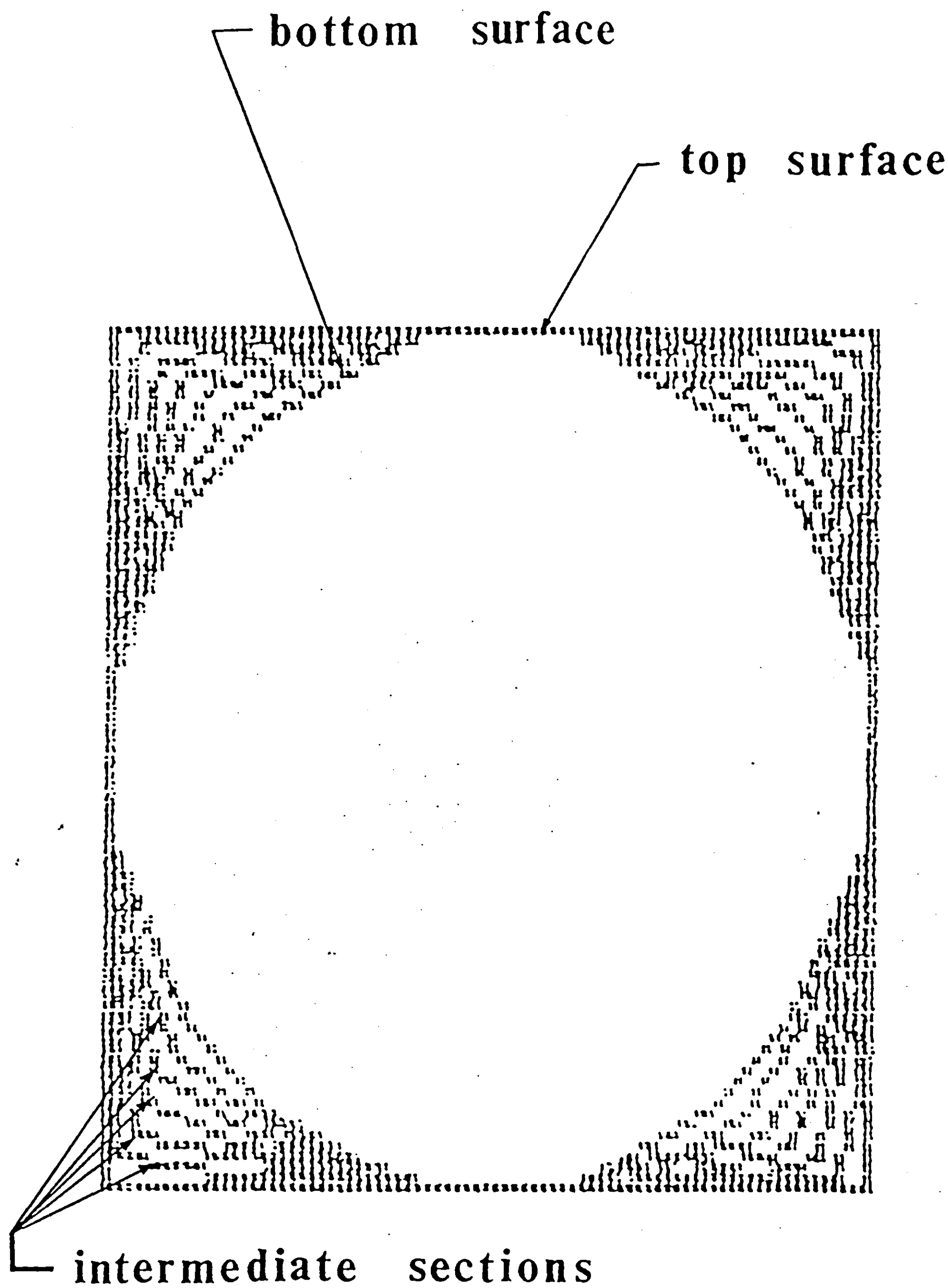
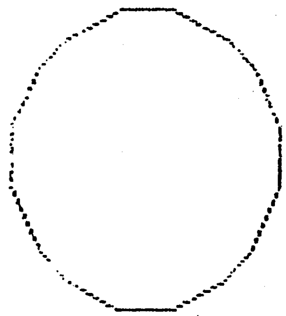
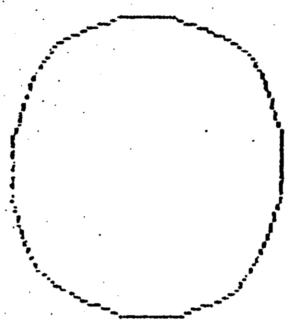


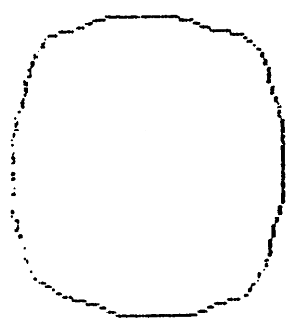
Fig.A8 A typical printout from the graphical drawing for top, bottom, and 5- intermediate sections.



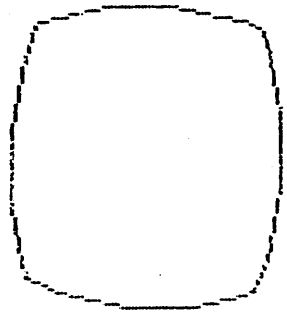
SURFACE AT Z = 0



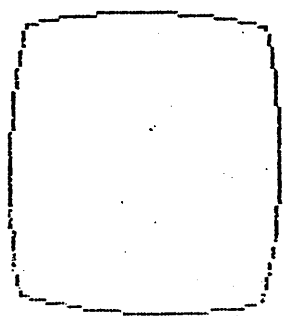
SURFACE AT Z = 1



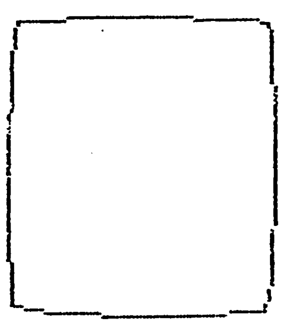
SURFACE AT Z = 2



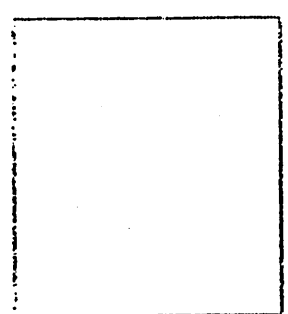
SURFACE AT Z = 3



SURFACE AT Z = 4



SURFACE AT Z = 5



SURFACE AT Z = 6

```
UP
RUN
CIRCLE AND SQUARE
PRESS SPACE BAR TO CONTINUE
Type in Z-COORDINATE for surface No. 1 ? 0
WHAT IS THE RADIUS OF THE CIRCLE ...(MAX. 2 cm)? 1
Type in Z-COORDINATE for surface No. 2 ? 6
```

S.No.	X 1	Y 1	R 1	THETA 1	AREA
1	1	0	1	0	0
2	1	.1	1.004988	9.966866E-02	5.033267E-02
3	1	.2	1.019804	.1973956	5.081799E-02
4	.95	.3	.9962429	.3058789	5.383485E-02
5	.9	.4	.9848857	.4182244	5.448754E-02
6	.85	.5	.9861542	.5317241	5.518922E-02
7	.8	.6	1	.6435011	5.588854E-02
8	.7	.7	.9899494	.7853983	.0695296
9	.6	.8	1	.9272952	7.094848E-02
10	.5	.85	.9861542	1.039072	5.435161E-02
11	.4	.9	.9848857	1.152572	5.504738E-02
12	.3	.95	.9962429	1.264918	5.575143E-02
13	.2	1	1.019804	1.373401	5.641132E-02
14	.1	1	1.004988	1.471128	.0493521
15	-.1	1	1.004988	1.670462	.100664
16	-.2	1	1.019804	1.768189	5.081801E-02
17	-.3	.95	.9962429	1.876673	5.383484E-02
18	-.4	.9	.9848857	1.989018	5.448754E-02
19	-.5	.85	.9861542	2.102518	5.518927E-02
20	-.6	.8	1	2.214295	5.588854E-02
21	-.7	.7	.9899494	2.356192	6.952951E-02
22	-.8	.6	1	2.498089	.0709486
23	-.85	.5	.9861542	2.609866	5.435161E-02
24	-.9	.4	.9848857	2.723366	5.504732E-02
25	-.95	.3	.9962429	2.835711	5.575143E-02
26	-1	.2	1.019804	2.944195	5.641132E-02
27	-1	.1	1.004988	3.041922	4.935204E-02
28	-1	0	1	3.14159	4.983437E-02
29	-1	-.1	1.004988	3.241259	5.033271E-02
30	-1	-.2	1.019804	3.338986	5.081795E-02
31	-.95	-.3	.9962429	3.447469	5.383484E-02
32	-.9	-.4	.9848857	3.559815	5.448754E-02
33	-.85	-.5	.9861542	3.673314	5.518921E-02
34	-.8	-.6	1	3.785091	5.588854E-02
35	-.7	-.7	.9899494	3.926988	6.952963E-02

36	-.6	-.8	1	4.068885	7.094848E-02
37	-.5	-.85	.9861542	4.180662	5.435149E-02
38	-.4	-.9	.9848857	4.294163	5.504755E-02
39	-.3	-.95	.9962429	4.406508	5.575131E-02
40	-.2	-1	1.019804	4.514991	5.641132E-02
41	-.1	-1	1.004988	4.612718	4.935204E-02
42	.1	-1	1.004988	4.812053	.1006642
43	.2	-1	1.019804	4.90978	5.081795E-02
44	.3	-.95	.9962429	5.018263	5.383484E-02
45	.4	-.9	.9848857	5.130608	5.448742E-02
46	.5	-.85	.9861542	5.244108	5.518944E-02
47	.6	-.8	1	5.355885	5.588842E-02
48	.7	-.7	.9899494	5.497782	.0695294
49	.8	-.6	1	5.639679	.0709486
50	.85	-.5	.9861542	5.751457	5.435172E-02
51	.9	-.4	.9848857	5.864956	5.504732E-02
52	.95	-.3	.9962429	5.977301	5.575131E-02
53	1	-.2	1.019804	6.085785	5.641157E-02
54	1	-.1	1.004988	6.183512	4.935204E-02
55	1	0	1	6.28318	4.983425E-02

THE TOTAL AREA OF THIS SURFACE = 3.128102

S.No.	X 2	Y 2	R 2	THETA 2	AREA
1	1	0	1	0	0
2	1	.1	1.004988	9.966866E-02	5.033267E-02
3	1	.2	1.019804	.1973956	5.081799E-02
4	1	.4	1.077033	.3805064	.1062043
5	1	.5	1.118034	.4636476	5.196326E-02
6	1	.7	1.220656	.610726	.1095734
7	1	.8	1.280625	.674741	5.249233E-02
8	1	.9	1.345362	.7328151	5.255708E-02
9	1	1	1.414214	.7853983	5.258316E-02
10	.9	1	1.345362	.8379813	4.758765E-02
11	.8	1	1.280625	.8960554	4.762078E-02
12	.6	1	1.16619	1.030377	9.133862E-02
13	.5	1	1.118034	1.107149	4.798241E-02
14	.3	1	1.044031	1.27934	9.384398E-02
15	.2	1	1.019804	1.373401	4.891185E-02
16	-.1	1	1.004988	1.670462	.1500161
17	-.2	1	1.019804	1.768189	5.081801E-02
18	-.4	1	1.077033	1.9513	.1062043
19	-.5	1	1.118034	2.034442	5.196333E-02
20	-.7	1	1.220656	2.18152	.1095733
21	-.8	1	1.280625	2.245535	5.249223E-02
22	-1	1	1.414214	2.356192	.1106572
23	-1	.9	1.345362	2.408775	4.758781E-02
24	-1	.8	1.280625	2.466849	4.762068E-02
25	-1	.6	1.16619	2.601171	9.133859E-02
26	-1	.5	1.118034	2.677943	4.798249E-02
27	-1	.3	1.044031	2.850134	9.384405E-02
28	-1	.2	1.019804	2.944195	4.891179E-02
29	-1	0	1	3.14159	9.869778E-02
30	-1	-.1	1.004988	3.241259	5.033271E-02
31	-1	-.3	1.044031	3.433047	.1045244
32	-1	-.4	1.077033	3.522097	5.164889E-02
33	-1	-.6	1.16619	3.68201	.1087409
34	-1	-.7	1.220656	3.752316	.0523782
35	-1	-.9	1.345362	3.874405	.1104907
36	-1	-1	1.414214	3.926988	5.258322E-02
37	-.8	-1	1.280625	4.037645	9.073873E-02
38	-.7	-1	1.220656	4.101661	4.769147E-02

39	-.5	-1	1.118034	4.248739	9.192378E-02
40	-.4	-1	1.077033	4.33188	4.822197E-02
41	-.2	-1	1.019804	4.514991	9.521757E-02
42	-.1	-1	1.004988	4.612718	4.935204E-02
43	.2	-1	1.019804	4.90978	.1544722
44	.3	-1	1.044031	5.003841	5.126319E-02
45	.5	-1	1.118034	5.176032	.1076195
46	.6	-1	1.16619	5.252804	5.220478E-02
47	.9	-1	1.345362	5.445199	.1741181
48	1	-1	1.414214	5.497782	5.258274E-02
49	1	-.9	1.345362	5.550365	4.758781E-02
50	1	-.8	1.280625	5.60844	4.762107E-02
51	1	-.6	1.16619	5.742761	9.133842E-02
52	1	-.5	1.118034	5.819533	4.798234E-02
53	1	-.3	1.044031	5.991724	9.384418E-02
54	1	-.2	1.019804	6.085785	4.891192E-02
55	1	0	1	6.28318	9.869766E-02

THE TOTAL AREA OF THIS SURFACE = 4.033605

CHOOSE NUMBER OF SECTIONS (MAX. 5 SECTIONS)? 5
TYPE Z-COORDINATE AT SECTION No. 1 ? 1

S.No.	X 3	Y 3	R 3	THETA 3	AREA
1	1	0	1	0	0
2	1	.1	1.004988	9.966866E-02	5.033267E-02
3	1	.2	1.019804	.1973956	5.081799E-02
4	.9583333	.3166667	1.009297	.3191396	6.200915E-02
5	.9166666	.4166667	1.00692	.4266275	5.449039E-02
6	.875	.5333333	1.024729	.5473929	.063406
7	.8333334	.6333333	1.046688	.6498704	5.613493E-02
8	.75	.7333334	1.048941	.7741626	.068378
9	.6666667	.8333334	1.067187	.8960554	6.941115E-02
10	.5666667	.875	1.042466	.9960968	.0543593
11	.4666667	.9166666	1.028618	1.099903	.0549161
12	.35	.9583333	1.020246	1.22063	6.283263E-02
13	.25	1	1.030776	1.325818	5.588113E-02
14	.1333333	1	1.00885	1.438245	5.721291E-02
15	-.05	1	1.001249	1.620752	9.148179E-02
16	-.1833333	1	1.016667	1.752114	6.788835E-02
17	-.2833333	.9583333	.9993401	1.858257	5.300165E-02
18	-.4	.9166666	1.000139	1.98225	6.201373E-02
19	-.5	.875	1.007782	2.08994	5.468626E-02
20	-.6166667	.8333334	1.036688	2.207864	6.336788E-02
21	-.7166666	.75	1.037358	2.333469	6.758215E-02
22	-.8333334	.6666667	1.067187	2.466849	7.595301E-02
23	-.875	.5666667	1.042466	2.566891	5.435917E-02
24	-.9166666	.4666667	1.028618	2.670696	5.491613E-02
25	-.9583333	.35	1.020246	2.791423	6.283256E-02
26	-1	.25	1.030776	2.896612	.0558812
27	-1	.1333333	1.00885	3.009039	5.721285E-02
28	-1	3.333334E-02	1.000555	3.108269	4.967051E-02
29	-1	-8.333334E-02	1.003466	3.224732	5.863549E-02
30	-1	-.1833333	1.016667	3.32291	5.073913E-02
31	-.9583333	-.3	1.004193	3.44497	6.154297E-02
32	-.9166666	-.4	1.000139	3.553047	5.405317E-02
33	-.875	-.5166667	1.016154	3.674977	6.295104E-02
34	-.8333334	-.6166667	1.036688	3.77866	5.571521E-02
35	-.75	-.7333334	1.048941	3.915753	7.541996E-02
36	-.6666667	-.8333334	1.067187	4.037645	6.941098E-02

37	-.55	-.875	1.033501	4.151223	6.065768E-02
38	-.45	-.9166666	1.021165	4.256038	5.464913E-02
39	-.3333334	-.9583333	1.01465	4.37765	6.260041E-02
40	-.2333333	-1	1.026861	4.483155	5.562458E-02
41	-.1166667	-1	1.006783	4.596245	.0573149
42	6.666666E-02	-1	1.00222	4.778952	9.175968E-02
43	.2	-1	1.019804	4.90978	6.803026E-02
44	.3	-.9583333	1.004193	5.015764	5.343738E-02
45	.4166667	-.9166666	1.00692	5.139012	.0624797
46	.5166667	-.875	1.016154	5.245772	5.511858E-02
47	.6500001	-.8333334	1.056856	5.37481	.0720646
48	.75	-.75	1.06066	5.497782	6.917148E-02
49	.8333334	-.6500001	1.056856	5.620754	6.867645E-02
50	.875	-.55	1.033501	5.722017	5.408081E-02
51	.9166666	-.4333334	1.013931	5.841588	6.146292E-02
52	.9583333	-.3333334	1.01465	5.948444	5.500455E-02
53	1	-.2166667	1.023203	6.069812	.063533
54	1	-.1166667	1.006783	6.167039	4.927499E-02
55	1	0	1	6.28318	.0580709

THE TOTAL AREA OF THIS SURFACE = 3.29251

TYPE Z-COORDINATE AT SECTION No. 2 ? 2

S.No.	X 4	Y 4	R 4	THETA 4	AREA
1	1	0	1	0	0
2	1	.1	1.004988	9.966866E-02	5.033267E-02
3	1	.2	1.019804	.1973956	5.081799E-02
4	.9666666	.3333334	1.022524	.3320595	7.039931E-02
5	.9333333	.4333334	1.029023	.4346702	5.432667E-02
6	.9000001	.5666667	1.063537	.5619216	.0719677
7	.8666667	.6666667	1.093415	.6556957	5.605611E-02
8	.8	.7666666	1.108051	.7641248	.0665634
9	.7333334	.8666667	1.135293	.8685394	6.728949E-02
10	.6333333	.9000001	1.100505	.9575891	.0539245
11	.5333334	.9333333	1.074968	1.05165	5.434647E-02
12	.4	.9666666	1.046157	1.178456	.069391
13	.3	1	1.044031	1.27934	5.498144E-02
14	.1666667	1	1.013794	1.405648	6.490838E-02
15	0	1	1	1.570796	8.257431E-02
16	-.1666667	1	1.013794	1.735942	8.486668E-02
17	-.2666667	.9666666	1.002774	1.839961	.0522984
18	-.4	.9333333	1.015436	1.975686	6.997343E-02
19	-.5	.9000001	1.029563	2.077892	5.416955E-02
20	-.6333333	.8666667	1.073416	2.201873	7.142671E-02
21	-.7333334	.8	1.085255	2.312741	6.528892E-02
22	-.8666667	.7333334	1.135293	2.439333	8.158163E-02
23	-.9000001	.6333333	1.100505	2.528383	5.392446E-02
24	-.9333333	.5333334	1.074968	2.622444	5.434644E-02
25	-.9666666	.4	1.046157	2.74925	6.939106E-02
26	-1	.3	1.044031	2.850134	.0549815
27	-1	.1666667	1.013794	2.976442	6.490825E-02
28	-1	6.666667E-02	1.00222	3.075022	4.950937E-02
29	-1	-6.666666E-02	1.00222	3.208158	.066864
30	-1	-.1666667	1.013794	3.306739	5.065947E-02
31	-.9666666	-.3	1.012148	3.44251	6.954518E-02
32	-.9333333	-.4	1.015436	3.546482	5.360308E-02
33	-.9000001	-.5333334	1.046157	3.676545	7.117353E-02
34	-.8666667	-.6333333	1.073416	3.77267	5.537835E-02
35	-.8	-.7666666	1.108051	3.905715	8.167511E-02
36	-.7333334	-.8666667	1.135293	4.01013	6.728934E-02

37	-.6	-.9000001	1.081665	4.124384	6.683888E-02
38	-.5	-.9333333	1.058825	4.220577	.0539217
39	-.3666667	-.9666666	1.033871	4.349842	6.908485E-02
40	-.2666667	-1	1.034945	4.451784	5.459564E-02
41	-.1333333	-1	1.00885	4.579835	6.516364E-02
42	3.333333E-02	-1	1.000555	4.745705	.083027
43	.2	-1	1.019804	4.90978	8.531894E-02
44	.3	-.9666666	1.012148	5.013304	5.302764E-02
45	.4333334	-.9333333	1.029023	5.147054	7.081318E-02
46	.5333334	-.9000001	1.046157	5.247339	5.487822E-02
47	.7	-.8666667	1.114052	5.391798	.0896444
48	.8	-.8	1.131371	5.497782	6.782989E-02
49	.8666667	-.7	1.114052	5.603767	6.576939E-02
50	.9000001	-.6	1.081665	5.695178	5.347551E-02
51	.9333333	-.4666667	1.043498	5.819533	.0677043
52	.9666666	-.3666667	1.033871	5.920636	5.403435E-02
53	1	-.2333333	1.026061	6.053949	7.028516E-02
54	1	-.1333333	1.00885	6.150629	4.919946E-02
55	1	0	1	6.28318	6.627584E-02

THE TOTAL AREA OF THIS SURFACE = 3.451622

TYPE Z-COORDINATE AT SECTION No. 3 ? 3

S.No.	X 5	Y 5	R 5	THETA 5	AREA
1	1	0	1	0	0
2	1	.1	1.004988	9.966866E-02	5.033267E-02
3	1	.2	1.019804	.1973956	5.081799E-02
4	.975	.35	1.035918	.3446473	7.900978E-02
5	.95	.45	1.05119	.4423742	5.399412E-02
6	.925	.6	1.102554	.5754247	8.086973E-02
7	.9	.7000001	1.140175	.6610433	5.565205E-02
8	.85	.8	1.167262	.7551044	6.407915E-02
9	.8	.9	1.20416	.844154	6.456099E-02
10	.7	.925	1.160011	.9229849	5.303842E-02
11	.6	.95	1.12361	1.00748	5.333763E-02
12	.45	.975	1.073837	1.138389	7.547693E-02
13	.35	1	1.059481	1.234122	5.373011E-02
14	.2	1	1.019804	1.373401	.0724252
15	5.000001E-02	1	1.001249	1.520838	7.390292E-02
16	-.15	1	1.011187	1.719684	.1016598
17	-.25	.975	1.006541	1.821796	.0517265
18	-.4	.95	1.030776	1.969316	7.836991E-02
19	-.5	.925	1.051487	2.066346	5.363895E-02
20	-.65	.9	1.11018	2.196279	8.007143E-02
21	-.75	.85	1.133578	2.293773	6.264013E-02
22	-.9	.8	1.20416	2.414948	8.785157E-02
23	-.925	.7	1.160011	2.493779	5.303846E-02
24	-.95	.6	1.12361	2.578274	5.333752E-02
25	-.975	.45	1.073837	2.709182	7.547693E-02
26	-1	.35	1.059481	2.804915	5.373011E-02
27	-1	.2	1.019804	2.944195	7.242527E-02
28	-1	.1	1.004988	3.041922	4.935204E-02
29	-1	-.05	1.001249	3.191549	7.500065E-02
30	-1	-.15	1.011187	3.29048	5.057876E-02
31	-.975	-.3	1.02011	3.440089	7.784336E-02
32	-.95	-.4	1.030776	3.540113	5.313749E-02
33	-.925	-.55	1.076162	3.678026	7.986023E-02
34	-.9	-.65	1.11018	3.767075	.0548768
35	-.85	-.8	1.167262	3.896695	8.830319E-02
36	-.8	-.9	1.20416	3.985744	6.456095E-02
37	-.65	-.925	1.130542	4.099849	7.292007E-02

38	-.55	-.95	1.097725	4.187591	5.286446E-02
39	-.4	-.975	1.053862	4.32307	7.523317E-02
40	-.3	-1	1.044031	4.42093	5.333389E-02
41	-.15	-1	1.011187	4.563497	7.288722E-02
42	0	-1	1	4.712384	-3.067147
43	.2	-1	1.019804	4.90978	.1026458
44	.3	-.975	1.02011	5.010883	5.260532E-02
45	.45	-.95	1.05119	5.154758	7.949102E-02
46	.55	-.925	1.076162	5.24882	5.446741E-02
47	.75	-.9	1.171537	5.407122	.1086353
48	.85	-.85	1.202082	5.497782	6.550158E-02
49	.9	-.75	1.171537	5.588442	6.221548E-02
50	.925	-.65	1.130542	5.670643	5.253158E-02
51	.95	-.5	1.073546	5.798702	7.379421E-02
52	.975	-.4	1.053862	5.893864	5.284434E-02
53	1	-.25	1.030776	6.038202	7.667938E-02
54	1	-.15	1.011187	6.13429	4.912545E-02
55	1	0	1	6.28318	7.444501E-02

THE TOTAL AREA OF THIS SURFACE = .389338

TYPE Z-COORDINATE AT SECTION No. 4 ? 4

S.No.	X 6	Y 6	R 6	THETA 6	AREA
1	1	0	1	0	0
2	1	.1	1.004988	9.966866E-02	5.033267E-02
3	1	.2	1.019804	.1973956	5.081799E-02
4	.9833334	.3666667	1.049471	.356912	8.784479E-02
5	.9666666	.4666667	1.073416	.4497597	5.349058E-02
6	.95	.6333333	1.141758	.5880026	9.010754E-02
7	.9333333	.7333334	1.186966	.6659693	5.492315E-02
8	.9	.8333333	1.226558	.7469556	6.091971E-02
9	.8666667	.9333333	1.273665	.8224183	6.120868E 02
10	.7666666	.95	1.220769	.8917911	5.169236E-02
11	.6666667	.9666666	1.174261	.967047	5.188474E-02
12	.5	.9833334	1.103152	1.100392	8.113681E-02
13	.4	1	1.077033	1.19029	5.214076E-02
14	.2333334	1	1.026861	1.341564	7.975525E-02
15	.1	1	1.004988	1.471128	6.542947E-02
16	-.1333333	1	1.00885	1.703345	.1181729
17	-.2333334	.9833334	1.010638	1.803773	.0512879
18	-.4	.9666666	1.046157	1.963134	8.720581E-02
19	-.5	.95	1.073546	2.055272	5.309434E-02
20	-.6666667	.9333333	1.146977	2.191044	8.930764E-02
21	-.7666666	.9	1.182277	2.276362	5.962819E-02
22	-.9333333	.8666667	1.273665	2.393212	9.477843E-02
23	-.95	.7666666	1.220769	2.462585	5.169227E-02
24	-.9666666	.6666667	1.174261	2.537841	5.188491E-02
25	-.9833334	.5	1.103152	2.671186	8.113681E-02
26	-1	.4	1.077033	2.761084	5.214062E-02
27	-1	.2333334	1.026861	2.912358	7.975538E-02
28	-1	.1333333	1.00885	3.009039	4.919946E-02
29	-1	-3.333333E-02	1.000555	3.174911	8.302843E-02
30	-1	-.1333333	1.00885	3.274142	5.049732E-02
31	-.9833334	-.3	1.028078	3.437705	8.643889E-02
32	-.9666666	-.4	1.046157	3.53393	5.265647E-02
33	-.95	-.5666667	1.10617	3.679426	.0890149
34	-.9333333	-.6666667	1.146977	3.76184	5.421004E-02
35	-.9	-.8333333	1.226558	3.888546	9.531116E-02
36	-.8666667	-.9333333	1.273665	3.964008	6.120853E-02
37	-.7	-.95	1.180042	4.07736	7.892086E-02

38	-.6	-.9666666	1.137737	4.156893	5.147559E-02
39	-.4333334	-.9833334	1.07458	4.297312	8.107246E-02
40	-.3333334	-1	1.054093	4.390636	5.184678E-02
41	-.1666667	-1	1.013794	4.547238	8.047597E-02
42	-3.333334E-02	-1	1.000555	4.679066	6.598715E-02
43	.2	-1	1.019804	4.90978	.1199712
44	.3	-.9833334	1.028078	5.008499	5.217057E-02
45	.4666667	-.9666666	1.073416	5.162144	8.851633E-02
46	.5666667	-.95	1.10617	5.25022	5.388517E-02
47	.8	-.9333333	1.229273	5.42101	.1290419
48	.9	-.9	1.272792	5.497782	.0621851
49	.9333333	-.8	1.229273	5.574554	5.800567E-02
50	.95	-.7	1.180042	5.648154	5.124353E-02
51	.9666666	-.5333334	1.104033	5.779014	7.975239E-02
52	.9833334	-.4333334	1.07458	5.868106	5.143785E-02
53	1	-.2666667	1.034945	6.022578	8.272854E-02
54	1	-.1666667	1.013794	6.118032	4.905261E-02
55	1	0	1	6.28318	8.257437E-02

THE TOTAL AREA OF THIS SURFACE = 3.753679

TYPE 2-COORDINATE AT SECTION No. 5 ? 5

S.No.	X 7	Y 7	R 7	THETA 7	AREA
1	1	0	1	0	0
2	1	.1	1.004988	9.966866E-02	5.033267E-02
3	1	.2	1.019804	.1973956	5.081799E-02
4	.9916667	.3833333	1.063178	.3688621	9.690832E-02
5	.9833334	.4833334	1.095699	.456845	5.281421E-02
6	.975	.6666666	1.181131	.5997438	9.967682E-02
7	.9666667	.7666666	1.233784	.6705216	.0538698
8	.95	.8666667	1.285928	.7395588	5.708035E-02
9	.9333333	.9666667	1.34371	.8029403	5.721941E-02
10	.8333333	.975	1.282603	.8635796	4.987794E-02
11	.7333334	.9833334	1.226671	.9300126	4.998162E-02
12	.55	.9916667	1.133977	1.064412	8.641205E-02
13	.45	1	1.096586	1.147942	5.022288E-02
14	.2666667	1	1.034945	1.310194	8.689475E-02
15	.15	1	1.011187	1.421907	.057113
16	-.1166667	1	1.006783	1.686935	.1343181
17	-.2166667	.9916667	1.01506	1.785901	5.098436E-02
18	-.4	.9833334	1.061576	1.957131	9.648339E-02
19	-.5	.975	1.09573	2.044645	5.253585E-02
20	-.6833333	.9666667	1.183803	2.186134	9.914008E-02
21	-.7833334	.95	1.231305	2.260333	.0562473
22	-.9666667	.9333333	1.34371	2.373734	.1023761
23	-.975	.8333333	1.282603	2.434374	4.987799E-02
24	-.9833334	.7333334	1.226671	2.500806	4.998157E-02
25	-.9916667	.55	1.133977	2.635205	8.641198E-02
26	-1	.45	1.096586	2.718736	5.022295E-02
27	-1	.2666667	1.034945	2.880988	8.689468E-02
28	-1	.1666667	1.013794	2.976442	4.905261E-02
29	-1	-1.666667E-02	1.000139	3.158255	9.093222E-02
30	-1	-.1166667	1.006783	3.257732	5.041516E-02
31	-.9916667	-.3	1.036052	3.435358	9.533232E-02
32	-.9833334	-.4	1.061576	3.527928	5.216026E-02
33	-.975	-.5833334	1.136179	3.680752	9.864071E-02
34	-.9666667	-.6833333	1.183803	3.75693	5.337739E-02
35	-.95	-.8666667	1.285928	3.881149	.1027051
36	-.9333333	-.9666667	1.34371	3.944531	5.721957E-02
37	-.75	-.975	1.230092	4.056691	8.485621E-02

38	-.65	-.9833334	1.178747	4.128306	4.975235E-02
39	-.4666667	-.9916667	1.095984	4.272544	8.662821E-02
40	-.3666667	-1	1.065103	4.360942	.0501413
41	-.1833333	-1	1.016667	4.531067	8.792154E-02
42	-6.666667E-02	-1	1.00222	4.645818	5.763068E-02
43	.2	-1	1.019804	4.90978	.1372599
44	.3	-.9916667	1.036052	5.006152	5.172331E-02
45	.4833334	-.9833334	1.095699	5.169229	9.789142E-02
46	.5833334	-.975	1.136179	5.251546	5.313123E-02
47	.8499999	-.9666667	1.287224	5.43365	.1508686
48	.95	-.95	1.343503	5.497782	5.787889E-02
49	.9666667	-.8499999	1.287224	5.561915	5.313216E-02
50	.975	-.75	1.230092	5.627485	4.960807E-02
51	.9833334	-.5666668	1.134925	5.760391	8.559544E-02
52	.9916667	-.4666667	1.095984	5.843338	4.981673E-02
53	1	-.2833334	1.039364	6.007083	8.844526E-02
54	1	-.1833333	1.016667	6.101861	4.898158E-02
55	1	0	1	6.28318	9.065986E-02

THE TOTAL AREA OF THIS SURFACE = 3.896454

S.No	ALFA = ATN (XF - XI) / (ZF - ZI)	BETA = ATN (YF - YI) / (ZF - ZI)
1	0	0
2	0	0
3	0	0
4	.4774528	.9548389
5	.9548393	.9548389
6	1.432093	1.909148
7	1.909148	1.909148
8	2.862399	1.909148
9	3.814066	1.909148
10	3.814066	1.432093
11	3.814066	.9548393
12	2.862399	.4774528
13	2.862399	0
14	1.909148	0
15	2.862399	0
16	.9548391	0
17	.9548391	.4774528
18	0	.9548393
19	0	1.432093
20	-.9548386	1.909148
21	-.9548393	2.862399
22	-1.909148	3.814066
23	-1.432093	3.814066
24	-.9548393	3.814066
25	-.4774528	2.862399
26	0	2.862399
27	0	1.909148
28	0	1.909148
29	0	.9548391
30	0	.9548391
31	-.4774528	0
32	-.9548393	0
33	-1.432093	-.9548393
34	-1.909148	-.9548386
35	-2.862399	-1.909148
36	-3.814066	-1.909148
37	-2.862399	-1.432093
38	-2.862399	-.9548393

39	-1.909148	-.4774528
40	-1.909148	0
41	-.9548391	0
42	-1.909148	0
43	0	0
44	0	-.4774528
45	.9548389	-.9548393
46	.9548393	1.432093
47	2.862398	-1.909148
48	2.862399	-2.862399
49	1.909148	-2.862398
50	1.432093	-2.862399
51	.9548393	-1.909148
52	.4774528	-1.909148
53	0	-.9548391
54	0	-.9548391
55	0	0

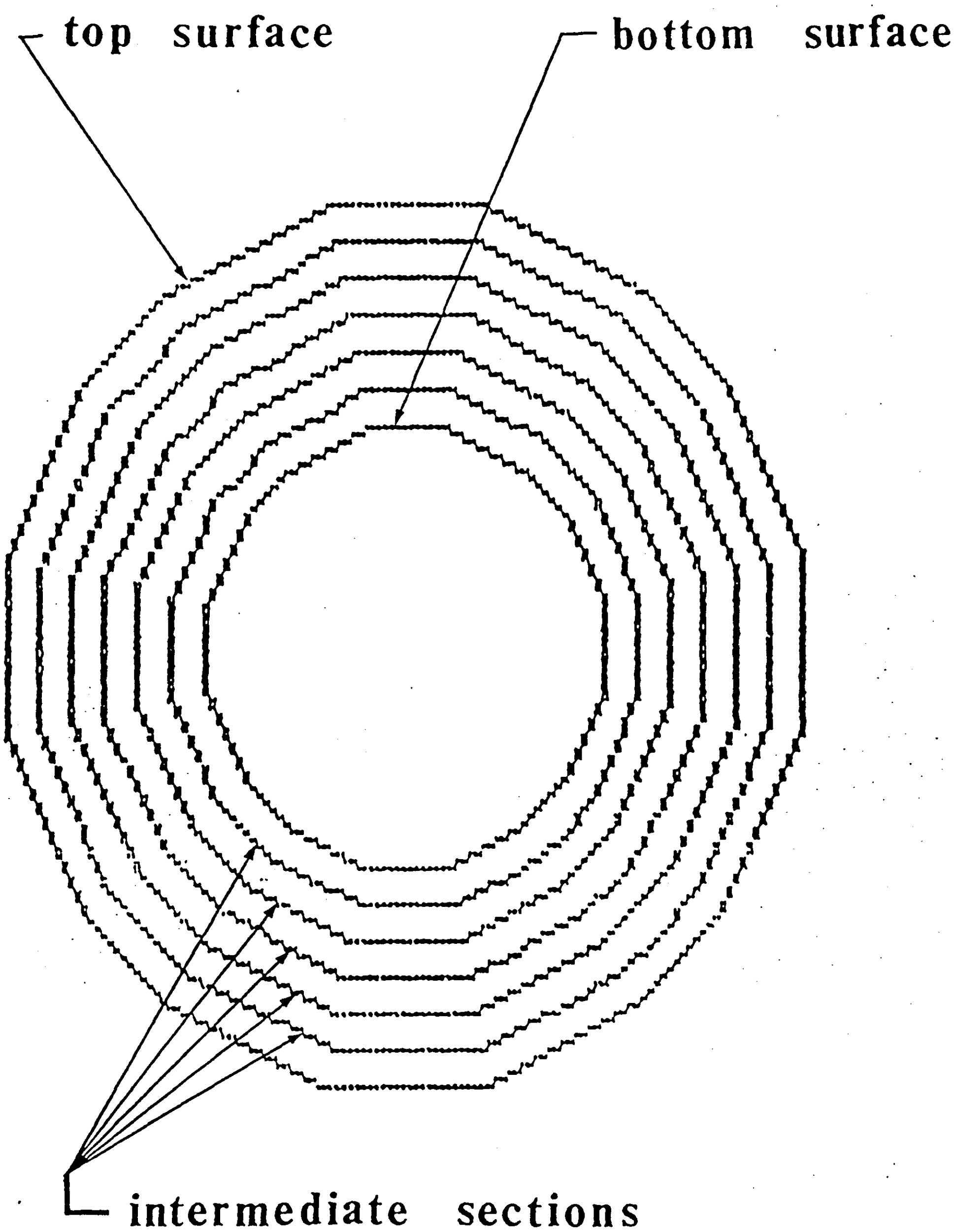
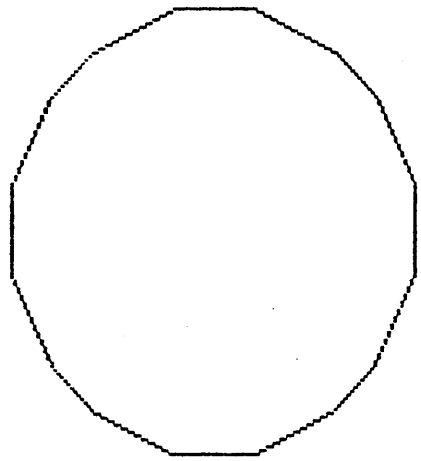
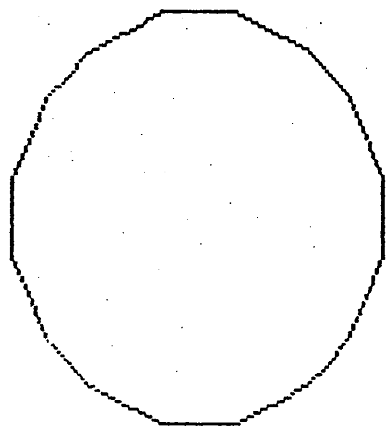


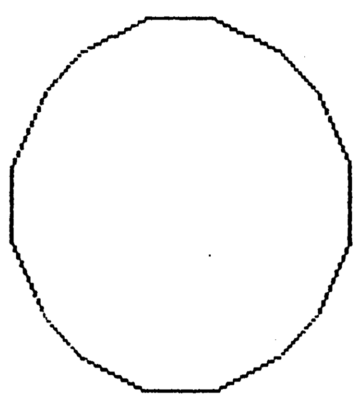
Fig. A9 A typical printout from the graphical drawing for top, bottom, and 5- intermediate sections.



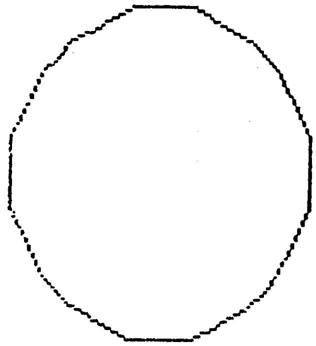
SURFACE AT Z = 0



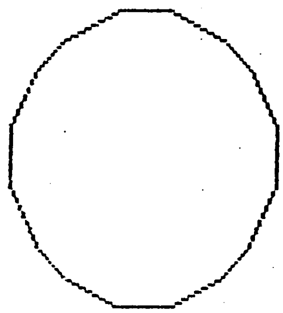
SURFACE AT Z = 1



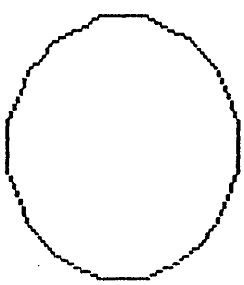
SURFACE AT Z = 2



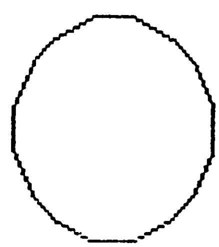
SURFACE AT Z = 3



SURFACE AT Z = 4



SURFACE AT Z = 5



SURFACE AT Z = 6

Type in Z-COORDINATE for surface No. 1 ? 0
WHAT IS THE RADIUS OF CIRCLE No. 1 .(MAX. 2 cm)? 2
Type in Z-COORDINATE for surface No. 2 ? 6
WHAT IS THE RADIUS OF CIRCLE No. 2 .(MAX. 2 cm)? 1

S.No.	X 1	Y 1	R 1	THETA 1	AREA
1	2	0	2	0	0
2	2	.2	2.009975	9.966866E-02	.2013307
3	2	.4	2.039608	.1973956	.203272
4	1.9	.6	1.992486	.3058789	.2153394
5	1.8	.8	1.969771	.4182244	.2179502
6	1.7	1	1.972308	.5317241	.2207569
7	1.6	1.2	2	.6435011	.2235541
8	1.4	1.4	1.979899	.7853983	.2781184
9	1.2	1.6	2	.9272952	.2837939
10	1	1.7	1.972308	1.039072	.2174064
11	.8	1.8	1.969771	1.152572	.2201895
12	.6	1.9	1.992486	1.264918	.2230057
13	.4	2	2.039608	1.373401	.2256453
14	.2	2	2.009975	1.471128	.1974084
15	-.2	2	2.009975	1.670462	.4026559
16	-.4	2	2.039608	1.768189	.203272
17	-.6	1.9	1.992486	1.876673	.2153394
18	-.8	1.8	1.969771	1.989018	.2179502
19	-1	1.7	1.972308	2.102518	.2207571
20	-1.2	1.6	2	2.214295	.2235541
21	-1.4	1.4	1.979899	2.356192	.2781181
22	-1.6	1.2	2	2.498089	.2837944
23	-1.7	1	1.972308	2.609866	.2174064
24	-1.8	.8	1.969771	2.723366	.2201893
25	-1.9	.6	1.992486	2.835711	.2230057
26	-2	.4	2.039608	2.944195	.2256453
27	-2	.2	2.009975	3.041922	.1974082
28	-2	0	2	3.14159	.1993375
29	-2	-.2	2.009975	3.241259	.2013308
30	-2	-.4	2.039608	3.338986	.2032718
31	-1.9	-.6	1.992486	3.447469	.2153394
32	-1.8	-.8	1.969771	3.559815	.2179502
33	-1.7	-1	1.972308	3.673314	.2207568
34	-1.6	-1.2	2	3.785091	.2235541
35	-1.4	-1.4	1.979899	3.926988	.2781105
36	-1.2	-1.6	2	4.068885	.2837939

37	-1	-1.7	1.972308	4.180662	.217406
38	-.8	-1.8	1.969771	4.294163	.2201902
39	-.6	-1.9	1.992486	4.406508	.2230052
40	-.4	-2	2.039608	4.514991	.2256453
41	-.2	-2	2.009975	4.612718	.1974082
42	.2	-2	2.009975	4.812053	.4026569
43	.4	-2	2.039608	4.90978	.2032718
44	.6	-1.9	1.992486	5.018263	.2153394
45	.8	-1.8	1.969771	5.130608	.2179477
46	1	-1.7	1.972308	5.244108	.2207578
47	1.2	-1.6	2	5.355885	.2235537
48	1.4	-1.4	1.979899	5.497782	.2781176
49	1.6	-1.2	2	5.639679	.2837944
50	1.7	-1	1.972308	5.751457	.2174069
51	1.8	-.8	1.969771	5.864956	.2201893
52	1.9	-.6	1.992486	5.977301	.2230052
53	2	-.4	2.039608	6.085785	.2256463
54	2	-.2	2.009975	6.183512	.1974082
55	2	0	2	6.28318	.199337

THE TOTAL AREA OF THIS SURFACE = 12.51241

S.No.	X 2	Y 2	R 2	THETA 2	AREA
1	1	0	1	0	0
2	1	.1	1.004988	9.966866E-02	5.033267E-02
3	1	.2	1.019804	.1973956	5.081799E-02
4	.95	.3	.9962429	.3058789	5.383485E-02
5	.9	.4	.9848857	.4182244	5.448754E-02
6	.85	.5	.9861542	.5317241	5.518922E-02
7	.8	.6	1	.6435011	5.588854E-02
8	.7	.7	.9899494	.7853983	.0695296
9	.6	.8	1	.9272952	7.094848E-02
10	.5	.85	.9861542	1.039072	5.435161E-02
11	.4	.9	.9848857	1.152572	5.504738E-02
12	.3	.95	.9962429	1.264918	5.575143E-02
13	.2	1	1.019804	1.373401	5.641132E-02
14	.1	1	1.004988	1.471128	.0493521
15	-.1	1	1.004988	1.670462	.100664
16	-.2	1	1.019804	1.768189	5.081801E-02
17	-.3	.95	.9962429	1.876673	5.383484E-02
18	-.4	.9	.9848857	1.989018	5.448754E-02
19	-.5	.85	.9861542	2.102518	5.518927E-02
20	-.6	.8	1	2.214295	5.588854E-02
21	-.7	.7	.9899494	2.356192	6.952951E-02
22	-.8	.6	1	2.498089	.0709486
23	-.85	.5	.9861542	2.609866	5.435161E-02
24	-.9	.4	.9848857	2.723366	5.504732E-02
25	-.95	.3	.9962429	2.835711	5.575143E-02
26	-1	.2	1.019804	2.944195	5.641132E-02
27	-1	.1	1.004988	3.041922	4.935204E-02
28	-1	0	1	3.14159	4.983437E-02
29	-1	-.1	1.004988	3.241259	5.033271E-02
30	-1	-.2	1.019804	3.338986	5.081795E-02
31	-.95	-.3	.9962429	3.447469	5.383484E-02
32	-.9	-.4	.9848857	3.559815	5.448754E-02
33	-.85	-.5	.9861542	3.673314	5.518921E-02
34	-.8	-.6	1	3.785091	5.588854E-02
35	-.7	-.7	.9899494	3.926988	6.952963E-02
36	-.6	-.8	1	4.068885	7.094848E-02
37	-.5	-.85	.9861542	4.180662	5.435149E-02
38	-.4	-.9	.9848857	4.294163	5.504755E-02

39	-.3	-.95	.9962429	4.406508	5.575131E-02
40	-.2	-1	1.019804	4.514991	5.641132E-02
41	-.1	-1	1.004988	4.612718	4.935204E-02
42	.1	-1	1.004988	4.812053	.1006642
43	.2	-1	1.019804	4.90978	5.081795E-02
44	.3	-.95	.9962429	5.018263	5.383484E-02
45	.4	-.9	.9848857	5.130608	5.448742E-02
46	.5	-.85	.9861542	5.244108	5.518944E-02
47	.6	-.8	1	5.355885	5.588842E-02
48	.7	-.7	.9899494	5.497762	.0695294
49	.8	-.6	1	5.639679	.0709486
50	.85	-.5	.9861542	5.751457	5.435172E-02
51	.9	-.4	.9848857	5.864956	5.504732E-02
52	.95	-.3	.9962429	5.977301	5.575131E-02
53	1	-.2	1.019804	6.085785	5.641157E-02
54	1	-.1	1.004988	6.183512	4.935204E-02
55	1	0	1	6.28318	4.983425E-02

THE TOTAL AREA OF THIS SURFACE = 3.128102

CHOOSE NUMBER OF SECTIONS (MAX. 5 SECTIONS)? 5
TYPE Z-COORDINATE AT SECTION No. 1 ? 1

S.No.	X 3	Y 3	R 3	THETA 3	AREA
1	1.833333	0	1.833333	0	0
2	1.833333	.1833333	1.842477	9.966866E-02	.1691737
3	1.833333	.3666667	1.869641	.1973956	.1708049
4	1.741667	.55	1.826445	.3058789	.1809449
5	1.65	.7333334	1.805624	.4182243	.1831387
6	1.558333	.9166667	1.807949	.5317241	.1854971
7	1.466667	1.1	1.833333	.6435011	.1870476
8	1.283333	1.283333	1.814907	.7853983	.2336967
9	1.1	1.466667	1.833333	.9272952	.2384658
10	.9166667	1.558333	1.807949	1.039072	.1826817
11	.7333334	1.65	1.805624	1.152572	.1850204
12	.55	1.741667	1.826445	1.264918	.1873868
13	.3666667	1.833333	1.869641	1.373401	.1896048
14	.1833333	1.833333	1.842477	1.471128	.1658779
15	-.1833333	1.833333	1.842477	1.670462	.3383429
16	-.3666667	1.833333	1.869641	1.768189	.170805
17	-.55	1.741667	1.826445	1.876673	.1809449
18	-.7333334	1.65	1.805624	1.989018	.1831387
19	-.9166667	1.558333	1.807949	2.102518	.1854972
20	-1.1	1.466667	1.833333	2.214295	.1878476
21	-1.283333	1.283333	1.814907	2.356192	.2336964
22	-1.466667	1.1	1.833333	2.498089	.2384661
23	-1.558333	.9166667	1.807949	2.609866	.1826818
24	-1.65	.7333334	1.805624	2.723366	.1850202
25	-1.741667	.55	1.826445	2.835711	.1873868
26	-1.833333	.3666667	1.869641	2.944195	.1896048
27	-1.833333	.1833333	1.842477	3.041922	.1658777
28	-1.833333	0	1.833333	3.14159	.1674988
29	-1.833333	-.1833333	1.842477	3.241259	.1691738
30	-1.833333	-.3666667	1.869641	3.338986	.1708048
31	-1.741667	-.55	1.826445	3.447469	.1809449
32	-1.65	-.7333334	1.805624	3.559815	.1831387
33	-1.558333	-.9166667	1.807949	3.673314	.185497
34	-1.466667	-1.1	1.833333	3.785091	.1878476
35	-1.283333	-1.283333	1.814907	3.926988	.2336968
36	-1.1	-1.466667	1.833333	4.068885	.2384657
37	-.9166667	-1.558333	1.807949	4.180662	.1826814

38	-.7333334	-1.65	1.805624	4.294163	.185021
39	-.55	-1.741667	1.826445	4.406508	.1873864
40	-.3666667	-1.833333	1.869641	4.514991	.1896048
41	-.1833333	-1.833333	1.842477	4.612718	.1658777
42	.1833333	-1.833333	1.842477	4.812053	.3383437
43	.3666667	-1.833333	1.869641	4.90978	.1708048
44	.55	-1.741667	1.826445	5.018263	.1809449
45	.7333334	-1.65	1.805624	5.130608	.1831383
46	.9166667	-1.558333	1.807949	5.244108	.1854978
47	1.1	-1.466667	1.833333	5.355885	.1878472
48	1.283333	-1.283333	1.814907	5.497782	.233696
49	1.466667	-1.1	1.833333	5.639679	.2384661
50	1.558333	-.9166667	1.807949	5.751457	.1826822
51	1.65	-.7333334	1.805624	5.864956	.1850202
52	1.741667	-.55	1.826445	5.977302	.1873872
53	1.833333	-.3666667	1.869641	6.085785	.1896048
54	1.833333	-.1833333	1.842477	6.183512	.1658777
55	1.833333	0	1.833333	6.28318	.1674984

THE TOTAL AREA OF THIS SURFACE = 10.5139

TYPE Z-COORDINATE AT SECTION No. 2 ? 2

S.No.	X 4	Y 4	R 4	THETA 4	AREA
1	1.666667	0	1.666667	0	0
2	1.666667	.1666667	1.674979	9.966867E-02	.139013
3	1.666667	.3333334	1.699673	.1973956	.1411611
4	1.583333	.5	1.660405	.3058789	.1495413
5	1.5	.6666667	1.641476	.4182243	.1513543
6	1.416667	.8333333	1.64359	.5317241	.1533034
7	1.333333	1	1.666667	.6435011	.155246
8	1.166667	1.166667	1.649916	.7853983	.1931378
9	1	1.333333	1.666667	.9272952	.1970792
10	.8333333	1.416667	1.64359	1.039072	.1509766
11	.6666667	1.5	1.641476	1.152572	.1529094
12	.5	1.583333	1.660405	1.264918	.1548651
13	.3333334	1.666667	1.699673	1.373401	.1566981
14	.1666667	1.666667	1.674979	1.471128	.1370892
15	-.1666667	1.666667	1.674979	1.670462	.2796222
16	-.3333334	1.666667	1.699673	1.768189	.1411611
17	-.5	1.583333	1.660405	1.876673	.1495412
18	-.6666667	1.5	1.641476	1.989018	.1513543
19	-.8333333	1.416667	1.64359	2.102518	.1533035
20	-1	1.333333	1.666667	2.214295	.155246
21	-1.166667	1.166667	1.649916	2.356192	.1931375
22	-1.333333	1	1.666667	2.498089	.1970795
23	-1.416667	.8333333	1.64359	2.609866	.1509767
24	-1.5	.6666667	1.641476	2.723366	.1529092
25	-1.583333	.5	1.660405	2.835711	.1548651
26	-1.666667	.3333334	1.699673	2.944195	.1566981
27	-1.666667	.1666667	1.674979	3.041922	.137089
28	-1.666667	0	1.666667	3.14159	.1384288
29	-1.666667	-.1666667	1.674979	3.241259	.1398131
30	-1.666667	-.3333334	1.699673	3.338986	.141161
31	-1.583333	-.5	1.660405	3.447469	.1495412
32	-1.5	-.6666667	1.641476	3.559815	.1513543
33	-1.416667	-.8333333	1.64359	3.673314	.1533033
34	-1.333333	-1	1.666667	3.785091	.155246
35	-1.166667	-1.166667	1.647916	3.926988	.1931378
36	-1	-1.333333	1.666667	4.068885	.1970791
37	-.8333333	-1.416667	1.64359	4.180662	.1509763

38	-.6666667	-1.5	1.641476	4.294163	.1529099
39	-.5	-1.583333	1.660405	4.406508	.1548647
40	-.3333334	-1.666667	1.699673	4.514991	.1566981
41	-.1666667	-1.666667	1.674979	4.612718	.137089
42	.1666667	-1.666667	1.674979	4.812053	.2796228
43	.3333334	-1.666667	1.699673	4.90978	.141161
44	.5	-1.583333	1.660405	5.018263	.1495412
45	.6666667	-1.5	1.641476	5.130608	.151354
46	.8333333	-1.416667	1.64359	5.244108	.153304
47	1	-1.333333	1.666667	5.355885	.1552456
48	1.166667	-1.166667	1.649916	5.497782	.1931372
49	1.333333	-1	1.666667	5.639679	.1970795
50	1.416667	-.8333333	1.64359	5.751457	.150977
51	1.5	-.6666667	1.641476	5.864956	.1529092
52	1.583333	-.5	1.660405	5.977301	.1548647
53	1.666667	-.3333334	1.699673	6.085785	.1566981
54	1.666667	-.1666667	1.674979	6.183512	.1370897
55	1.666667	0	1.666667	6.28318	.1384285

THE TOTAL AREA OF THIS SURFACE = 8.689172

TYPE Z-COORDINATE AT SECTION No. 3 ? 3

S.No.	X 5	Y 5	R 5	THETA 5	AREA
1	1.5	0	1.5	0	0
2	1.5	.15	1.507481	9.966866E-02	.1132485
3	1.5	.3	1.529706	.1973956	.1143405
4	1.425	.45	1.494364	.3058789	.1211284
5	1.35	.6	1.477329	.4182243	.1225969
6	1.275	.75	1.479231	.5317241	.1241758
7	1.2	.9000001	1.5	.6435011	.1257491
8	1.05	1.05	1.484924	.7853983	.1564416
9	.9000001	1.2	1.5	.9272952	.1596341
10	.75	1.275	1.479231	1.039072	.122291
11	.6	1.35	1.477329	1.152572	.1238566
12	.45	1.425	1.494364	1.264918	.1254407
13	.3	1.5	1.529706	1.373401	.1269255
14	.15	1.5	1.507481	1.471128	.1110422
15	-.15	1.5	1.507481	1.670462	.226494
16	-.3	1.5	1.529706	1.768189	.1143405
17	-.45	1.425	1.494364	1.876673	.1211284
18	-.6	1.35	1.477329	1.989018	.122597
19	-.75	1.275	1.479231	2.102518	.1241758
20	-.9000001	1.2	1.5	2.214295	.1257492
21	-1.05	1.05	1.484924	2.356192	.1564414
22	-1.2	.9000001	1.5	2.498089	.1596344
23	-1.275	.75	1.479231	2.609866	.1222911
24	-1.35	.6	1.477329	2.723366	.1238565
25	-1.425	.45	1.494364	2.835711	.1254407
26	-1.5	.3	1.529706	2.944195	.1269255
27	-1.5	.15	1.507481	3.041922	.1110421
28	-1.5	0	1.5	3.14159	.1121273
29	-1.5	-.15	1.507481	3.241259	.1132486
30	-1.5	-.3	1.529706	3.338986	.1143404
31	-1.425	-.45	1.494364	3.447469	.1211284
32	-1.35	-.6	1.477329	3.559815	.122597
33	-1.275	-.75	1.479231	3.673314	.1241757
34	-1.2	-.9000001	1.5	3.785091	.1257492
35	-1.05	-1.05	1.484924	3.926988	.1564416
36	-.9000001	-1.2	1.5	4.068885	.1596341
37	-.75	-1.275	1.479231	4.180662	.1222908

38	-.6	-1.35	1.477329	4.294163	.123857
39	-.45	-1.425	1.494364	4.406508	.1254405
40	-.3	-1.5	1.529706	4.514991	.1269255
41	-.15	-1.5	1.507481	4.612718	.1110421
42	.15	-1.5	1.507481	4.812053	.2264945
43	.3	-1.5	1.529706	4.90978	.1143404
44	.45	-1.425	1.494364	5.018263	.1211234
45	.6	-1.35	1.477329	5.130608	.1225967
46	.75	-1.275	1.479231	5.244108	.1241762
47	.9000001	-1.2	1.5	5.355885	.1257489
48	1.05	-1.05	1.484924	5.497782	.1564411
49	1.2	-.9000001	1.5	5.639679	.1596344
50	1.275	-.75	1.479231	5.751457	.1222913
51	1.35	-.6	1.477329	5.864956	.1238565
52	1.425	-.45	1.494364	5.977301	.1254405
53	1.5	-.3	1.529706	6.085785	.126926
54	1.5	-.15	1.507481	6.183512	.1110421
55	1.5	0	1.5	6.28318	.1121271

THE TOTAL AREA OF THIS SURFACE = 7.038227

TYPE Z-COORDINATE AT SECTION No. 4 ? 4

S.No.	X 6	Y 6	R 6	THETA 6	AREA
1	1.333333	0	1.333333	0	0
2	1.333333	.1333333	1.339983	9.966866E-02	8.948029E-02
3	1.333333	.2666667	1.359739	.1973956	9.034308E-02
4	1.266667	.4	1.328324	.3058789	9.570641E-02
5	1.2	.5333333	1.313181	.4182243	9.686667E-02
6	1.133334	.6666666	1.314872	.531724	.0981142
7	1.066667	.8000001	1.333333	.6435013	9.935754E-02
8	.9333332	.9333332	1.319933	.7853983	.1236081
9	.8000001	1.066667	1.333333	.9272951	.1261306
10	.6666666	1.133334	1.314872	1.039072	9.662523E-02
11	.5333333	1.2	1.313181	1.152572	9.786201E-02
12	.4	1.266667	1.328324	1.264918	9.911354E-02
13	.2666667	1.333333	1.359739	1.373401	.1002868
14	.1333333	1.333333	1.339983	1.471128	8.773707E-02
15	-.1333333	1.333333	1.339983	1.670462	.1789582
16	-.2666667	1.333333	1.359739	1.768189	9.034312E-02
17	-.4	1.266667	1.328324	1.876673	9.570638E-02
18	-.5333333	1.2	1.313181	1.989018	9.686664E-02
19	-.6666666	1.133334	1.314872	2.102518	9.811415E-02
20	-.8000001	1.066667	1.333333	2.214295	9.935759E-02
21	-.9333332	.9333332	1.319933	2.356192	.123608
22	-1.066667	.8000001	1.333333	2.498089	.1261306
23	-1.133334	.6666666	1.314872	2.609866	9.662528E-02
24	-1.2	.5333333	1.313181	2.723366	9.786191E-02
25	-1.266667	.4	1.328324	2.835711	9.911364E-02
26	-1.333333	.2666667	1.359739	2.944195	.1002868
27	-1.333333	.1333333	1.339983	3.041922	8.773696E-02
28	-1.333333	0	1.333333	3.14159	8.859442E-02
29	-1.333333	-.1333333	1.339983	3.241259	8.948037E-02
30	-1.333333	-.2666667	1.359739	3.338986	9.034301E-02
31	-1.266667	-.4	1.328324	3.447469	9.570638E-02
32	-1.2	-.5333333	1.313181	3.559815	9.686675E-02
33	-1.133334	-.6666666	1.314872	3.673314	9.811415E-02
34	-1.066667	-.8000001	1.333333	3.785092	9.935759E-02
35	-.9333332	-.9333332	1.319933	3.926988	.123608
36	-.8000001	-1.066667	1.333333	4.068885	.1261306
37	-.6666666	-1.133334	1.314872	4.180663	9.662528E-02

38	-.5333333	-1.2	1.313181	4.294163	9.786191E-02
39	-.4	-1.266667	1.328324	4.406508	9.911344E-02
40	-.2666667	-1.333333	1.359739	4.514991	.1002868
41	-.1332333	-1.333333	1.339983	4.612718	8.773696E-02
42	.1333333	-1.333333	1.339983	4.812053	.1787586
43	.2666667	-1.333333	1.359739	4.90978	9.034301E-02
44	.4	-1.266667	1.328324	5.018263	9.570638E-02
45	.5333333	-1.2	1.313131	5.130608	9.686654E-02
46	.6666666	-1.133334	1.314872	5.244108	9.811415E-02
47	.8000001	-1.066667	1.333333	5.355885	9.935759E-02
48	.9333332	-.9333332	1.319933	5.497782	.1236078
49	1.066667	-.8000001	1.333333	5.639679	.1261308
50	1.133334	-.6666666	1.314872	5.751457	9.662528E-02
51	1.2	-.5333333	1.313181	5.864956	9.786191E-02
52	1.266667	-.4	1.328324	5.977301	9.911344E-02
53	1.333333	-.2666667	1.359739	6.085785	.1002872
54	1.333333	-.1333333	1.339983	6.183512	8.773696E-02
55	1.333333	0	1.333333	6.28318	8.859421E-02

THE TOTAL AREA OF THIS SURFACE = 5.561071

TYPE Z-COORDINATE AT SECTION No. 5 ? 5

S.No.	X 7	Y 7	R 7	THETA 7	AREA
1	1.166667	0	1.166667	0	0
2	1.166667	.1166667	1.172486	9.966865E-02	6.850837E-02
3	1.166667	.2333333	1.189771	.1973956	6.916893E-02
4	1.108333	.35	1.162283	.3058789	7.327524E-02
5	1.05	.4666667	1.149033	.4182244	.0741636
6	.9916668	.5833334	1.150513	.5317241	7.511866E-02
7	.9333333	.7000001	1.166667	.6435012	7.607056E-02
8	.8166667	.8166667	1.154941	.7853983	9.463747E-02
9	.7000001	.9333333	1.166667	.9272952	9.656878E-02
10	.5833334	.9916668	1.150513	1.039072	7.397857E-02
11	.4666667	1.05	1.149033	1.152572	.0749256
12	.35	1.108333	1.162283	1.264918	.0758839
13	.2333333	1.166667	1.189771	1.373401	7.678209E-02
14	.1166667	1.166667	1.172486	1.471128	6.717371E-02
15	-.1166667	1.166667	1.172486	1.670462	.1370149
16	-.2333333	1.166667	1.189771	1.768189	6.916896E-02
17	-.35	1.108333	1.162283	1.876673	7.327521E-02
18	-.4666667	1.05	1.149033	1.989018	.0741636
19	-.5833334	.9916668	1.150513	2.102518	7.511871E-02
20	-.7000001	.9333333	1.166667	2.214295	7.607052E-02
21	-.8166667	.8166667	1.154941	2.356192	9.463739E-02
22	-.9333333	.7000001	1.166667	2.498089	9.656878E-02
23	-.9916668	.5833334	1.150513	2.609866	7.397873E-02
24	-1.05	.4666667	1.149033	2.723366	7.492551E-02
25	-1.108333	.35	1.162283	2.835711	.0758839
26	-1.166667	.2333333	1.189771	2.944195	7.678209E-02
27	-1.166667	.1166667	1.172486	3.041922	6.717363E-02
28	-1.166667	0	1.166667	3.14159	6.783013E-02
29	-1.166667	-.1166667	1.172486	3.241259	6.850843E-02
30	-1.166667	-.2333333	1.189771	3.338986	6.916888E-02
31	-1.108333	-.35	1.162283	3.447469	7.327521E-02
32	-1.05	-.4666667	1.149033	3.559815	.0741636
33	-.9916668	-.5833334	1.150513	3.673314	7.511863E-02
34	-.9333333	-.7000001	1.166667	3.785092	7.607068E-02
35	-.8166667	-.8166667	1.154941	3.926988	9.463739E-02
36	-.7000001	-.7333333	1.166667	4.068885	9.656878E-02
37	-.5833334	-.9916668	1.150513	4.180662	.0739784

38	-.4666667	-1.05	1.149033	4.294163	7.492583E-02
39	-.35	-1.108333	1.162283	4.406508	7.588373E-02
40	-.2333333	-1.166667	1.189771	4.514991	7.678209E-02
41	-.1166667	-1.166667	1.172486	4.612718	6.717363E-02
42	.1166667	-1.166667	1.172486	4.812053	.1370152
43	.2333333	-1.166667	1.189771	4.90978	6.916888E-02
44	.35	-1.108333	1.162283	5.018263	7.327521E-02
45	.4666667	-1.05	1.149033	5.130608	7.416344E-02
46	.5833334	-.9916668	1.150513	5.244108	7.511895E-02
47	.7000001	-.9333333	1.166667	5.355885	7.607036E-02
48	.8166667	-.8166667	1.154941	5.497782	9.463723E-02
49	.9333333	-.7000001	1.166667	5.639679	9.656894E-02
50	.9916668	-.5833334	1.150513	5.751457	7.397873E-02
51	1.05	-.4666667	1.149033	5.864956	7.492551E-02
52	1.108333	-.35	1.162283	5.977301	7.588373E-02
53	1.166667	-.2333333	1.189771	6.085785	7.678243E-02
54	1.166667	-.1166667	1.172486	6.183512	6.717363E-02
55	1.166667	0	1.166667	6.28318	6.782996E-02

THE TOTAL AREA OF THIS SURFACE = 4.257694

S.No	ALFA = ATN (XF - XI) / (ZF - ZI)	BETA = ATN (YF - YI) / (ZF - ZI)
1	-9.4623	0
2	-9.4623	-.9548391
3	-9.4623	-1.909148
4	-8.997122	-2.862399
5	-8.530746	-3.814066
6	-8.063228	-4.763631
7	-7.594626	-5.710581
8	-6.654411	-6.654411
9	-5.710581	-7.594626
10	-4.763631	-8.063228
11	-3.814066	-8.530746
12	-2.862399	-8.997122
13	-1.909148	-9.4623
14	-.9548391	-9.4623
15	.9548391	-9.4623
16	1.909148	-9.4623
17	2.862399	-8.997122
18	3.814066	-8.530746
19	4.763631	-8.063228
20	5.710581	-7.594626
21	6.654411	-6.654411
22	7.594626	-5.710581
23	8.063228	-4.763631
24	8.530746	-3.814066
25	8.997122	-2.862399
26	9.4623	-1.909148
27	9.4623	-.9548391
28	9.4623	0
29	9.4623	.9548391
30	9.4623	1.909148
31	8.997122	2.862399
32	8.530746	3.814066
33	8.063228	4.763631
34	7.594626	5.710581
35	6.654411	6.654411
36	5.710581	7.594626
37	4.763631	8.063228
38	3.814066	8.530746

39	2.862399	8.997122
40	1.909148	9.4623
41	.9548391	9.4623
42	-.9548391	9.4623
43	-1.909148	9.4623
44	-2.862399	8.997122
45	-3.814066	8.530746
46	-4.763631	8.063228
47	-5.710581	7.594626
48	-6.654411	6.654411
49	-7.594626	5.710581
50	-8.063228	4.763631
51	-8.530746	3.814066
52	-8.997122	2.862399
53	-9.4623	1.909148
54	-9.4623	.9548391
55	-9.4623	0

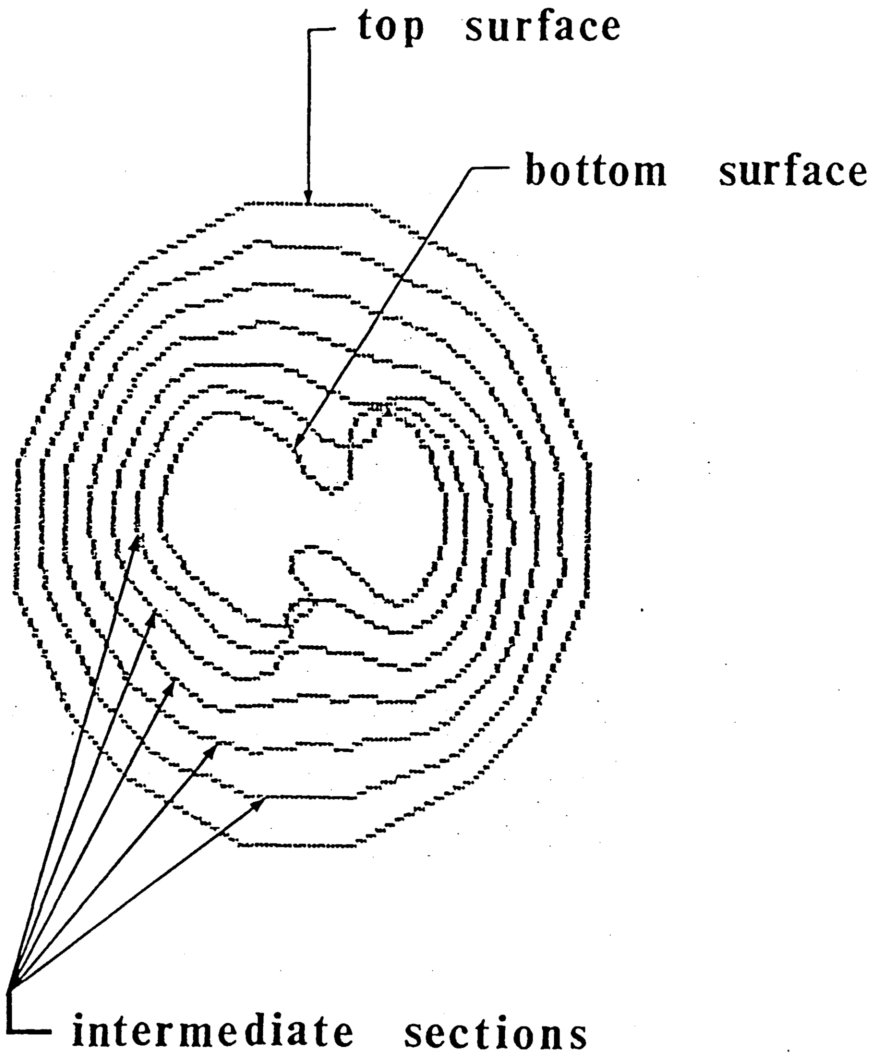
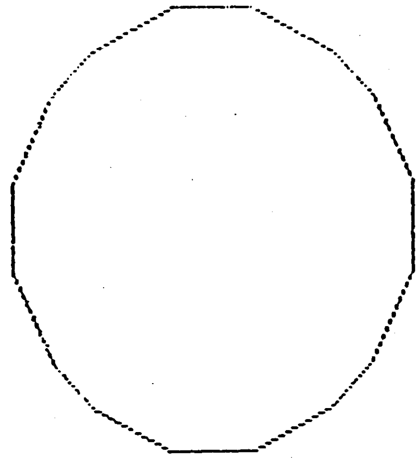
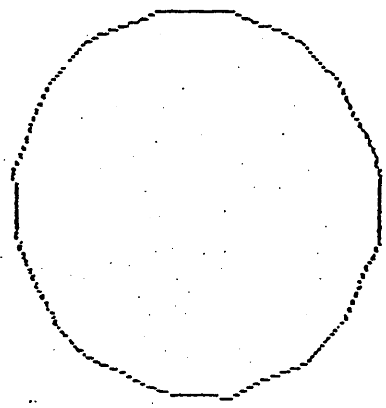


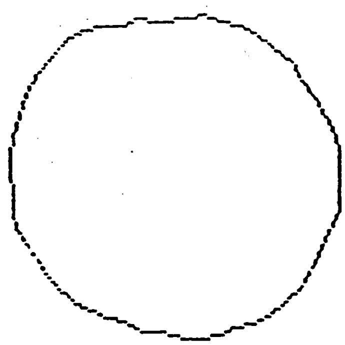
Fig.A10 A typical printout from the graphical drawing for top, bottom, and 5- intermediate sections.



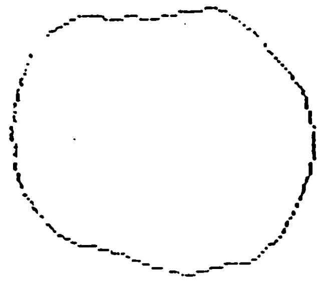
SURFACE AT Z = 0



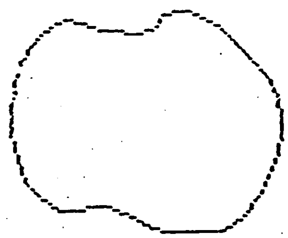
SURFACE AT Z = 1



SURFACE AT Z = 2

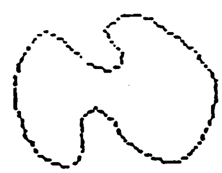


SURFACE AT Z = 3



SURFACE AT Z = 4

SURFACE AT Z = 5



SURFACE AT Z = 6

CIRCLE AND COMPLEX SHAPE
PRESS SPACE BAR TO CONTINUE
Type in Z-COORDINATE for surface No. 1 ? 0
WHAT IS THE THE RADIUS OF THE CIRCLE...(MAX. 2 cm)? 2
Type in Z-COORDINATE for surface No. 2 ? 6

S.No.	X 1	Y 1	R 1	THETA 1	AREA
1	2	0	2	0	0
2	2	.2	2.009975	9.966866E-02	.2013307
3	2	.4	2.039608	.1973956	.203272
4	1.9	.6	1.992486	.3058789	.2153394
5	1.8	.8	1.969771	.4182244	.2179502
6	1.7	1	1.972308	.5317241	.2207569
7	1.6	1.2	2	.6435011	.2235541
8	1.4	1.4	1.979899	.7853983	.2781184
9	1.2	1.6	2	.9272952	.2837939
10	1	1.7	1.972308	1.039072	.2174064
11	.8	1.8	1.969771	1.152572	.2201895
12	.6	1.9	1.992486	1.264918	.2230057
13	.4	2	2.039608	1.373401	.2256453
14	.2	2	2.009975	1.471128	.1974084
15	-.2	2	2.009975	1.670462	.4026559
16	-.4	2	2.039608	1.768189	.203272
17	-.6	1.9	1.992486	1.876673	.2153394
18	-.8	1.8	1.969771	1.989018	.2179502
19	-1	1.7	1.972308	2.102518	.2207571
20	-1.2	1.6	2	2.214295	.2235541
21	-1.4	1.4	1.979899	2.356192	.2781181
22	-1.6	1.2	2	2.498089	.2837944
23	-1.7	1	1.972308	2.609866	.2174064
24	-1.8	.8	1.969771	2.723366	.2201893
25	-1.9	.6	1.992486	2.835711	.2230057
26	-2	.4	2.039608	2.944195	.2256453
27	-2	.2	2.009975	3.041922	.1974082
28	-2	0	2	3.14159	.1993375
29	-2	-.2	2.009975	3.241259	.2013308
30	-2	-.4	2.039608	3.338986	.2032718
31	-1.9	-.6	1.992486	3.447469	.2153394
32	-1.8	-.8	1.969771	3.559815	.2179502
33	-1.7	-1	1.972308	3.673314	.2207568
34	-1.6	-1.2	2	3.785091	.2235541
35	-1.4	-1.4	1.979899	3.926988	.2781185
36	-1.2	-1.6	2	4.068885	.2837939

37	-1	-1.7	1.972308	4.180662	.217406
38	-.8	-1.8	1.969771	4.294163	.2201902
39	-.6	-1.9	1.992486	4.406508	.2230052
40	-.4	-2	2.039608	4.514991	.2256453
41	-.2	-2	2.009975	4.612718	.1974082
42	.2	-2	2.009975	4.812053	.4026569
43	.4	-2	2.039608	4.90978	.2032718
44	.6	-1.9	1.992486	5.018263	.2153394
45	.8	-1.8	1.969771	5.130608	.2179497
46	1	-1.7	1.972308	5.244108	.2207578
47	1.2	-1.6	2	5.355885	.2235537
48	1.4	-1.4	1.979899	5.497782	.2781176
49	1.6	-1.2	2	5.639679	.2837944
50	1.7	-1	1.972308	5.751457	.2174069
51	1.8	-.8	1.969771	5.864956	.2201893
52	1.9	-.6	1.992486	5.977301	.2230052
53	2	-.4	2.039608	6.085785	.2256463
54	2	-.2	2.009975	6.183512	.1974082
55	2	0	2	6.28318	.199337

THE TOTAL AREA OF THIS SURFACE = 12.51241

S.No.	X 2	Y 2	R 2	THETA 2	AREA
1	1	0	1	0	0
2	1	.1	1.004988	9.966866E-02	5.033267E-02
3	.95	.3	.9962429	.3058789	.1023318
4	.9	.4	.9848857	.4182244	5.448754E-02
5	.85	.5	.9861542	.5317241	5.518922E-02
6	.8	.55	.9708244	.6022874	3.325296E-02
7	.7	.65	.9552486	.7483781	6.665387E-02
8	.6	.7	.9219544	.8621701	4.836163E-02
9	.5	.7	.8602326	.9505469	.0326994
10	.4	.65	.7632169	1.019141	1.997817E-02
11	.25	.6	.65	1.176005	3.313748E-02
12	.2	.55	.585235	1.222025	7.880951E-03
13	.1	.5	.509902	1.373401	.0196788
14	.05	.45	.4527692	1.460139	8.890679E-03
15	-.05	.3	.3041381	1.735942	.0127559
16	-.1	.25	.2692582	1.9513	7.806719E-03
17	-.2	.2	.2828427	2.356192	1.619567E-02
18	-.3	.25	.3905125	2.446852	6.912814E-03
19	-.35	.3	.4609773	2.432964	-1.475588E-03
20	-.35	.4	.5315073	2.289624	-2.024679E-02
21	-.35	.5	.6103278	2.18152	-2.013437E-02
22	-.35	.6	.6946222	2.098868	-.0199397
23	-.4	.7	.8062258	2.08994	-2.901697E-03
24	-.5	.72	.8765843	2.177781	3.374871E-02
25	-.6	.7	.9219544	2.27942	4.319639E-02
26	-.7	.65	.9552486	2.393212	5.191768E-02
27	-.8	.6	1	2.498089	.0524385
28	-.85	.5	.9861542	2.609866	5.435161E-02
29	-.9	.45	1.006231	2.677943	3.446367E-02
30	-.95	.3	.9962429	2.835711	7.829272E-02
31	-1	.2	1.019804	2.944195	5.641132E-02
32	-1	0	1	3.14159	9.869778E-02
33	-.98	-.2	1.0002	3.342907	.1006988
34	-.85	-.4	.9394148	3.581433	.1052494
35	-.8	-.45	.917878	3.65398	3.056031E-02
36	-.7	-.5	.8602326	3.76184	3.990824E-02
37	-.6	-.48	.768375	3.816331	1.608583E-02
38	-.5	-.4	.6403125	3.816331	4.887581E-08

39	-.3	-.25	.3905125	3.836329	1.524799E-03
40	-.2	-.18	.2690725	3.874406	1.378383E-03
41	-.05	-.15	.1581139	4.390636	6.452882E-03
42	.05	-.2	.2061553	4.957363	1.204294E-02
43	.05	-.3	.3041381	4.877533	-3.692146E-03
44	-.05	-.4	.4031129	4.588032	-2.352193E-02
45	-.1	-.5	.509902	4.514991	-9.495324E-03
46	.05	-.62	.6220129	4.792855	5.375279E-02
47	.1	-.65	.6576473	4.865033	1.560857E-02
48	.2	-.65	.6800735	5.010883	3.372774E-02
49	.35	-.6	.6946222	5.240459	5.538513E-02
50	.5	-.5	.7071068	5.497782	6.433081E-02
51	.65	-.4	.7632169	5.731526	6.807784E-02
52	.8	-.3	.8544004	5.92441	7.040265E-02
53	.88	-.2	.9024411	6.059704	.0550919
54	.95	-.1	.9552486	6.178303	5.411098E-02
55	1	0	1	6.28318	.0524385

THE TOTAL AREA OF THIS SURFACE = 1.819178

CHOOSE NUMBER OF SECTIONS (MAX. 5 SECTIONS)? 5
TYPE Z-COORDINATE AT SECTION No. 1 ? 1

S.No.	X 3	Y 3	R 3	THETA 3	AREA
1	1.833333	0	1.833333	0	0
2	1.833333	.1833333	1.842477	9.966866E-02	.1691737
3	1.825	.3833333	1.864824	.2070359	.1866885
4	1.733333	.5666667	1.823611	.3159703	.1811336
5	1.641667	.75	1.804874	.4285381	.1833487
6	1.55	.925	1.805028	.5380441	.1783922
7	1.45	1.108333	1.825076	.6526333	.1908427
8	1.266667	1.283333	1.803161	.791934	.2264604
9	1.083333	1.45	1.810003	.9291369	.2247459
10	.9	1.525	1.77077	1.037641	.1701136
11	.7083334	1.6	1.749782	1.154023	.1781655
12	.5333334	1.675	1.757859	1.262538	.1676602
13	.35	1.75	1.784657	1.373401	.1765487
14	.175	1.741667	1.750437	1.470654	.1489933
15	-.175	1.716667	1.725564	1.672385	.3003333
16	-.35	1.708333	1.743819	1.772875	.1527914
17	-.5333334	1.616667	1.702368	1.889448	.1689177
18	-.7166667	1.541667	1.700102	2.00594	.1683512
19	-.8916666	1.466667	1.716444	2.117042	.163662
20	-1.058333	1.4	1.755013	2.218094	.1556237
21	-1.225	1.25	1.750179	2.346091	.1960364
22	-1.391667	1.1	1.773904	2.472719	.1992312
23	-1.483333	.95	1.76147	2.571958	.1539592
24	-1.583333	.7866667	1.76799	2.680472	.1695957
25	-1.683333	.6166667	1.792732	2.790436	.1767066
26	-1.783333	.4416667	1.837212	2.898812	.1829022
27	-1.8	.2666667	1.819646	2.994512	.1584371
28	-1.808333	8.333334E-02	1.810252	3.09554	.165535
29	-1.816667	-9.166668E-02	1.818978	3.192006	.1595881
30	-1.825	-.2833333	1.846863	3.295612	.1766941
31	-1.75	-.4666667	1.811154	3.402193	.1748076
32	-1.666667	-.6666667	1.795055	3.522097	.1931787
33	-1.58	-.8666667	1.802085	3.643299	.1968028
34	-1.475	-1.066667	1.820276	3.767694	.2060852
35	-1.3	-1.241667	1.797703	3.904042	.22032
36	-1.116667	-1.416667	1.803854	4.04486	.2291044

37	-.9333333	-1.496667	1.763837	4.154789	.1710007
38	-.75	-1.566667	1.736935	4.265905	.1676146
39	-.55	-1.625	1.715554	4.386028	.1767691
40	-.3666667	-1.696667	1.735835	4.49955	.1710279
41	-.175	-1.691667	1.700694	4.609305	.1587256
42	.175	-1.7	1.708984	4.814964	.3003263
43	.3416667	-1.716667	1.750337	4.908846	.1438124
44	.4916667	-1.65	1.721696	5.001987	.1380454
45	.65	-1.583333	1.711562	5.101932	.1463918
46	.8416667	-1.52	1.73747	5.218085	.1753219
47	1.016667	-1.441667	1.76409	5.326593	.1688394
48	1.2	-1.275	1.750893	5.467489	.2159662
49	1.391667	-1.1	1.773904	5.614309	.2310028
50	1.5	-.9166667	1.757919	5.734631	.1859138
51	1.608333	-.7333334	1.76763	5.855382	.1886447
52	1.716667	-.55	1.802622	5.973125	.1912997
53	1.813333	-.3666667	1.850033	6.083665	.1891674
54	1.825	-.1833333	1.834185	6.18306	.1671946
55	1.833333	0	1.833333	6.28318	.1682581

THE TOTAL AREA OF THIS SURFACE = 9.906251

TYPE Z-COORDINATE AT SECTION No. 2 ? 2

S.No.	X 4	Y 4	R 4	THETA 4	AREA
1	1.666667	0	1.666667	0	0
2	1.666667	.1666667	1.674979	9.966867E-02	.139813
3	1.65	.3666667	1.69025	.218669	.1699886
4	1.566667	.5333334	1.654959	.3281199	.1498871
5	1.483333	.7	1.640207	.4409243	.1517374
6	1.4	.85	1.637834	.545655	.1404702
7	1.3	1.016667	1.650337	.6637005	.1607549
8	1.133333	1.166667	1.626516	.79989	.1801484
9	.9666667	1.3	1.620014	.9314104	.1725841
10	.8	1.35	1.569236	1.035841	.1285804
11	.6166667	1.4	1.529797	1.155891	.1404744
12	.4666667	1.45	1.523246	1.259426	.1201156
13	.3	1.5	1.529706	1.373401	.1333504
14	.15	1.483333	1.490898	1.470015	.1073764
15	-.15	1.433333	1.441161	1.675065	.2129388
16	-.3	1.416667	1.448083	1.779476	.1094711
17	-.4666667	1.333333	1.412641	1.907469	.1277087
18	-.6333333	1.283333	1.431103	2.029233	.1246901
19	-.7833334	1.233333	1.461069	2.136648	.1146508
20	-.9166668	1.2	1.510059	2.223125	9.859529E-02
21	-1.05	1.1	1.520691	2.33294	.126974
22	-1.183333	1	1.549283	2.439965	.1284445
23	-1.266667	.9	1.553848	2.523835	.1012494
24	-1.366667	.7733333	1.570294	2.626657	.1267708
25	-1.466667	.6333333	1.597568	2.733959	.1369292
26	-1.566667	.4833333	1.639529	2.842344	.1456726
27	-1.6	.3333334	1.634353	2.936195	.125343
28	-1.616667	.1666667	1.625235	3.03886	.13559
29	-1.633333	1.666665E-02	1.633418	3.131386	.1234322
30	-1.65	-.1666667	1.658396	3.242259	.1524651
31	-1.6	-.3333334	1.634353	3.346986	.1398685
32	-1.533333	-.5333333	1.623439	3.476327	.1704432
33	-1.46	-.7333334	1.633823	3.607063	.1744914
34	-1.35	-.9333334	1.641223	3.746493	.1877848
35	-1.2	-1.083333	1.616667	3.875938	.1691598
36	-1.033333	-1.233333	1.609003	4.014996	.1800027
37	-.8666667	-1.293333	1.556863	4.122009	.1296905

38	-.7	-1.333333	1.505914	4.22894	.1212476
39	.5	1.35	1.439618	4.357681	.1334081
40	-.3333334	-1.393333	1.432651	4.477566	.1230313
41	-.15	-1.383333	1.391442	4.604375	.1227583
42	.15	-1.4	1.408013	4.81912	.2128656
43	.2833333	-1.433333	1.461069	4.907542	9.437903E-02
44	.3833333	-1.4	1.451532	4.979643	7.595601E-02
45	.5	-1.366667	1.455259	5.063112	.0883843
46	.6833333	-1.34	1.504176	5.18396	.1367122
47	.8333334	-1.283333	1.53016	5.288303	.1221531
48	1	-1.15	1.523975	5.428128	.1623716
49	1.183333	-1	1.549283	5.581555	.1841344
50	1.3	-.8333333	1.544165	5.71314	.1568787
51	1.416667	-.6666667	1.565691	5.843338	.1595824
52	1.533333	-.5	1.612796	5.967966	.1620857
53	1.626667	-.3333334	1.660469	6.081061	.15591
54	1.65	-.1666667	1.658396	6.182512	.1395091
55	1.666667	0	1.666667	6.28318	.1398179

THE TOTAL AREA OF THIS SURFACE = 7.628833

TYPE Z-COORDINATE AT SECTION No. 3 ? 3

S.No.	X 5	Y 5	R 5	THETA 5	AREA
1	1.5	0	1.5	0	0
2	1.5	.15	1.507481	9.966866E-02	.1132485
3	1.475	.35	1.515957	.2329793	.1531822
4	1.4	.5	1.486607	.343024	.1215994
5	1.325	.65	1.475847	.4560721	.1231164
6	1.25	.7750001	1.470757	.5549957	.1069922
7	1.15	.925	1.475847	.6773865	.1332912
8	1	1.05	1.45	.8097836	.1391825
9	.85	1.15	1.430035	.9342881	.1273059
10	.7	1.175	1.367708	1.033512	9.280502E-02
11	.525	1.2	1.309819	1.158386	.1071188
12	.4	1.225	1.288652	1.255181	8.036988E-02
13	.25	1.25	1.274755	1.373401	9.605382E-02
14	.125	1.225	1.231361	1.469108	7.255766E-02
15	-.125	1.15	1.156773	1.679064	.1404742
16	-.25	1.125	1.152443	1.789463	7.331137E-02
17	-.4	1.05	1.12361	1.934773	9.172694E-02
18	-.55	1.025	1.163239	2.06328	8.694296E-02
19	-.675	1	1.206493	2.164544	7.370103E-02
20	-.775	1	1.265158	2.230104	5.246877E-02
21	-.875	.9500001	1.291559	2.315119	7.090828E-02
22	-.975	.9000001	1.326886	2.396171	7.135051E-02
23	-1.05	.85	1.350926	2.461069	5.921965E-02
24	-1.15	.76	1.378441	2.557612	9.172029E-02
25	-1.25	.65	1.4089	2.662071	.1036758
26	-1.35	.525	1.448491	2.770699	.1139576
27	-1.4	.4	1.456022	2.863291	9.814726E-02
28	-1.425	.25	1.446764	2.967919	.1095001
29	-1.45	.125	1.455378	3.055596	9.285543E-02
30	-1.475	-4.999998E-02	1.475847	3.175475	.1305563
31	-1.45	-.2	1.463728	3.278656	.1105325
32	-1.4	-.4	1.456022	3.41989	.1497074
33	-1.34	-.6	1.468196	3.562581	.1537922
34	-1.225	-.8000001	1.463088	3.720114	.1686103
35	-1.1	-.9249999	1.437228	3.840783	.1246278
36	-.9500001	-1.05	1.41598	3.976947	.1365043
37	-.8	-1.09	1.352073	4.07924	9.350114E-02

38	-.65	-1.1	1.277693	4.178679	8.116678E-02
39	-.45	-1.075	1.165386	4.315945	9.321262E-02
40	-.3	-1.09	1.130531	4.443807	.0817102
41	-.125	-1.075	1.082243	4.596627	8.949529E-02
42	.125	-1.1	1.10708	4.825535	.1402775
43	.225	-1.15	1.171804	4.905596	.0549665
44	.275	-1.15	1.182423	4.947107	2.901882E-02
45	.35	-1.15	1.202082	5.007825	4.386914E-02
46	.525	-1.16	1.273274	5.137387	.1050241
47	.6500001	-1.125	1.299279	5.236304	8.349215E-02
48	.8	-1.025	1.30024	5.375114	.1173379
49	.975	-.9000001	1.326886	5.537761	.1431804
50	1.1	-.75	1.331353	5.684762	.1302795
51	1.225	-.6	1.364047	5.827729	.1330046
52	1.35	-.45	1.423025	5.96143	.1353716
53	1.44	-.3	1.470918	6.077785	.1258728
54	1.475	-.15	1.482608	6.181834	.1143566
55	1.5	0	1.5	6.28318	.1140148

THE TOTAL AREA OF THIS SURFACE = 5.680268

TYPE Z-COORDINATE AT SECTION No. 4 ? 4

S.No.	X 6	Y 6	R 6	THETA 6	AREA
1	1.333333	0	1.333333	0	0
2	1.333333	.1333333	1.339983	9.966866E-02	8.948029E-02
3	1.3	.3333334	1.342055	.2510027	.1362847
4	1.233333	.4666667	1.318669	.3617293	9.627059E-02
5	1.166667	.6	1.311911	.4750107	9.748501E-02
6	1.1	.7000001	1.303841	.5667293	7.796075E-02
7	1	.8333334	1.301708	.6947383	.1084521
8	.8666667	.9333332	1.273665	.8224183	.1035627
9	.7333334	1	1.240072	.9380475	.088906
10	.6	1	1.16619	1.030377	6.278398E-02
11	.4333334	1	1.089852	1.161889	7.810331E-02
12	.3333334	1	1.054093	1.249046	.0484207
13	.2	1	1.019804	1.373401	6.466458E-02
14	.1	.9666667	.9718254	1.467715	4.453716E-02
15	-.1	.8666667	.8724169	1.68567	8.294421E-02
16	-.2	.8333334	.8569974	1.806339	4.431208E-02
17	-.3333334	.7666666	.8359957	1.980921	6.100687E-02
18	-.4666667	.7666666	.8975274	2.117583	5.504418E-02
19	-.5666668	.7666666	.9533566	2.207302	4.077254E-02
20	-.6333334	.8	1.020349	2.240433	1.724634E-02
21	-.7	.8	1.063015	2.289624	2.779291E-02
22	-.7666667	.8000001	1.108051	2.334919	2.780596E-02
23	-.8333333	.8	1.155182	2.376598	2.780909E-02
24	-.9333333	.7466667	1.19525	2.466849	6.446778E-02
25	-1.033333	.6666667	1.229724	2.568624	7.695315E-02
26	-1.133334	.5666667	1.267105	2.677943	8.775848E-02
27	-1.2	.4666667	1.287547	2.770699	7.688465E-02
28	-1.233333	.3333334	1.277585	2.877627	8.726484E-02
29	-1.266667	.2333333	1.287979	2.959422	.0678448
30	-1.3	.0666667	1.301708	3.090353	.1109278
31	-1.3	-6.666666E-02	1.301708	3.192827	8.681842E-02
32	-1.266667	-.2666667	1.294432	3.349086	.1309103
33	-1.22	-.4666667	1.306207	3.506932	.1346563
34	-1.1	-.6666667	1.286252	3.686454	.1485048
35	-1	-.7666666	1.260071	3.795673	8.670762E-02
36	-.8666667	-.8666667	1.225652	3.926988	9.863251E-02
37	-.7333334	-.8866667	1.150633	4.021358	.0624703

38	-.6	-.8666666	1.054093	4.106842	4.749139E-02
39	-.4	-.8	.8944272	4.248739	5.675869E-02
40	-.2666667	-.7866668	.8306357	4.38556	.0472003
41	-.1	-.7666666	.7731609	4.582684	5.891817E-02
42	.1	-.8000001	.8062258	4.836739	8.256774E-02
43	.1666667	-.8666667	.8825468	4.902373	2.556071E-02
44	.1666667	-.9	.915302	4.895495	-2.881075E-03
45	.2	-.9333333	.9545214	4.923477	1.274768E-02
46	.3666667	-.98	1.046348	5.070409	8.043365E-02
47	.4666667	-.9666666	1.073416	5.162144	5.284949E-02
48	.6	-.9	1.081665	5.300387	8.087197E-02
49	.7666667	-.8000001	1.108051	5.476509	.1081195
50	.9000001	-.6666666	1.12002	5.645632	.1060775
51	1.033333	-.5333333	1.162851	5.806713	.1089089
52	1.166667	-.4	1.233333	5.952883	.1111705
53	1.253333	-.2666667	1.281388	6.07354	9.905707E-02
54	1.3	-.1333333	1.30682	6.180974	9.173611E-02
55	1.333333	0	1.333333	6.28318	.0908504

THE TOTAL AREA OF THIS SURFACE = 4.063767

TYPE Z-COORDINATE AT SECTION No. 5 ? 5

S.No.	X 7	Y 7	R 7	THETA 7	AREA
1	1.166667	0	1.166667	0	0
2	1.166667	.1166667	1.172486	9.966865E-02	6.850837E-02
3	1.125	.3166667	1.168719	.274382	.1193207
4	1.066667	.4333334	1.151328	.3858827	7.390023E-02
5	1.008333	.55	1.14858	.4993467	7.484289E-02
6	.9500001	.625	1.137157	.5819051	5.337919E-02
7	.85	.7416667	1.128082	.7174401	8.623884E-02
8	.7333334	.8166667	1.097598	.8391099	7.328916E-02
9	.6166667	.85	1.050132	.943167	5.737589E-02
10	.5	.825	.964689	1.025932	.0385118
11	.3416667	.8	.8699058	1.167162	5.343692E-02
12	.2666667	.7750001	.8195952	1.2394	2.426227E-02
13	.15	.75	.7648529	1.373401	3.919526E-02
14	.075	.7083334	.712293	1.465307	2.331482E-02
15	-.075	.5833334	.588135	1.698664	4.035937E-02
16	-.15	.5416666	.5620523	1.840947	2.247383E-02
17	-.2666667	.4833334	.5520165	2.07496	3.565446E-02
18	-.3833334	.5083333	.6366689	2.216913	2.877013E-02
19	-.4583333	.5333333	.7032168	2.280706	1.577319E-02
20	-.4916668	.6	.7757166	2.257279	-7.048224E-03
21	-.525	.65	.8355387	2.250208	-2.468477E-03
22	-.5583334	.7000001	.8953972	2.244081	-2.455785E-03
23	-.6166667	.75	.9709674	2.258939	7.003675E-03
24	-.7166666	.7333334	1.025373	2.344698	4.508323E-02
25	-.8166666	.6833333	1.064842	2.444848	5.677927E-02
26	-.9166666	.6083334	1.100158	2.555689	6.707777E-02
27	-1	.5333334	1.133333	2.651633	6.161763E-02
28	-1.041667	.4166667	1.121909	2.761084	6.888197E-02
29	-1.083333	.3416667	1.135935	2.836079	4.838513E-02
30	-1.125	.1833334	1.13984	2.980047	9.352412E-02
31	-1.15	6.666666E-02	1.151931	3.083684	6.876011E-02
32	-1.133333	-.1333333	1.14115	3.258699	.1139542
33	-1.1	-.3333333	1.149396	3.435825	.1170014
34	-.975	-.5333333	1.111337	3.642134	.127403
35	-.9	-.6083333	1.08631	3.735976	5.537005E-02
36	-.7833333	-.6833333	1.039498	3.858912	6.641971E-02
37	-.6666667	-.6833333	.9546669	3.939334	.0366476

38	-.55	-.6333333	.8388153	3.997295	2.039117E-02
39	-.35	-.525	.6309715	4.124384	2.529866E-02
40	-.2333333	-.4833335	.5367083	4.262627	1.991087E-02
41	-.075	-.4583334	.4644292	4.550188	.0310126
42	.075	-.5	.5055937	4.861274	.0397607
43	.1083334	-.5833334	.5933076	4.896006	6.113134E-03
44	5.833334E-02	-.65	.6526122	4.801888	-2.004268E-02
45	5.000001E-02	-.7166666	.7184086	4.782039	-5.122097E-03
46	.2083333	-.8	.8266818	4.967142	.0632501
47	.2833334	-.8083333	.8565516	5.049518	3.021866E-02
48	.4	-.775	.8721381	5.188852	5.299036E-02
49	.5583334	-.7000001	.8953972	5.385672	7.889897E-02
50	.7000001	-.5833334	.9111959	5.588442	8.417782E-02
51	.8416666	-.4666667	.9623828	5.776923	8.728365E-02
52	.9833334	-.35	1.043765	5.941231	8.950201E-02
53	1.066667	-.2333333	1.091889	6.067823	7.546298E-02
54	1.125	-.1166667	1.131033	6.179846	7.165216E-02
55	1.166667	0	1.166667	6.28318	7.032483E-02

THE TOTAL AREA OF THIS SURFACE = 2.796792

S.No	ALFA = ATN (XF - XI) / (ZF - ZI)	BETA = ATN (YF - YI) / (ZF - ZI)
1	-9.4623	0
2	-9.4623	-.9548391
3	-9.926222	-.9548389
4	-9.4623	-1.909148
5	8.997122	-2.862399
6	8.530746	-4.289143
7	-8.530746	-5.237465
8	-7.594626	-6.654411
9	-6.654411	-8.530746
10	-5.710581	-9.926222
11	-5.237464	-11.30991
12	-3.814066	-12.68035
13	-2.862399	-14.03621
14	-1.432093	-14.4847
15	1.432093	-15.81916
16	2.862399	-16.26017
17	3.814066	-15.81916
18	4.763631	-14.4847
19	6.182916	-13.13399
20	8.063228	-11.30991
21	9.926222	-8.530746
22	11.76826	-5.710581
23	12.2251	-2.862399
24	12.22509	-.7638965
25	12.22509	.9548386
26	12.22509	2.385938
27	11.30991	3.814066
28	10.85008	4.763631
29	10.38883	6.182916
30	9.926222	6.654411
31	8.530746	7.594626
32	7.594626	7.594626
33	6.842759	7.594626
34	7.125	7.594626
35	5.71058	8.997122
36	4.763632	10.38883
37	3.814066	11.49343
38	2.862399	13.13399

39	2.862399	15.37622
40	1.909148	16.87426
41	1.432093	17.13623
42	-1.432093	16.6992
43	-3.338463	15.81916
44	-6.182917	14.03621
45	-8.530746	12.22509
46	-8.997122	10.20395
47	-10.38883	8.997122
48	-11.30991	7.125
49	-11.76826	5.710581
50	-11.30991	4.763631
51	-10.85008	3.814066
52	-10.38883	2.862399
53	-10.5735	1.909148
54	-9.926222	.9548391
55	-9.4623	0

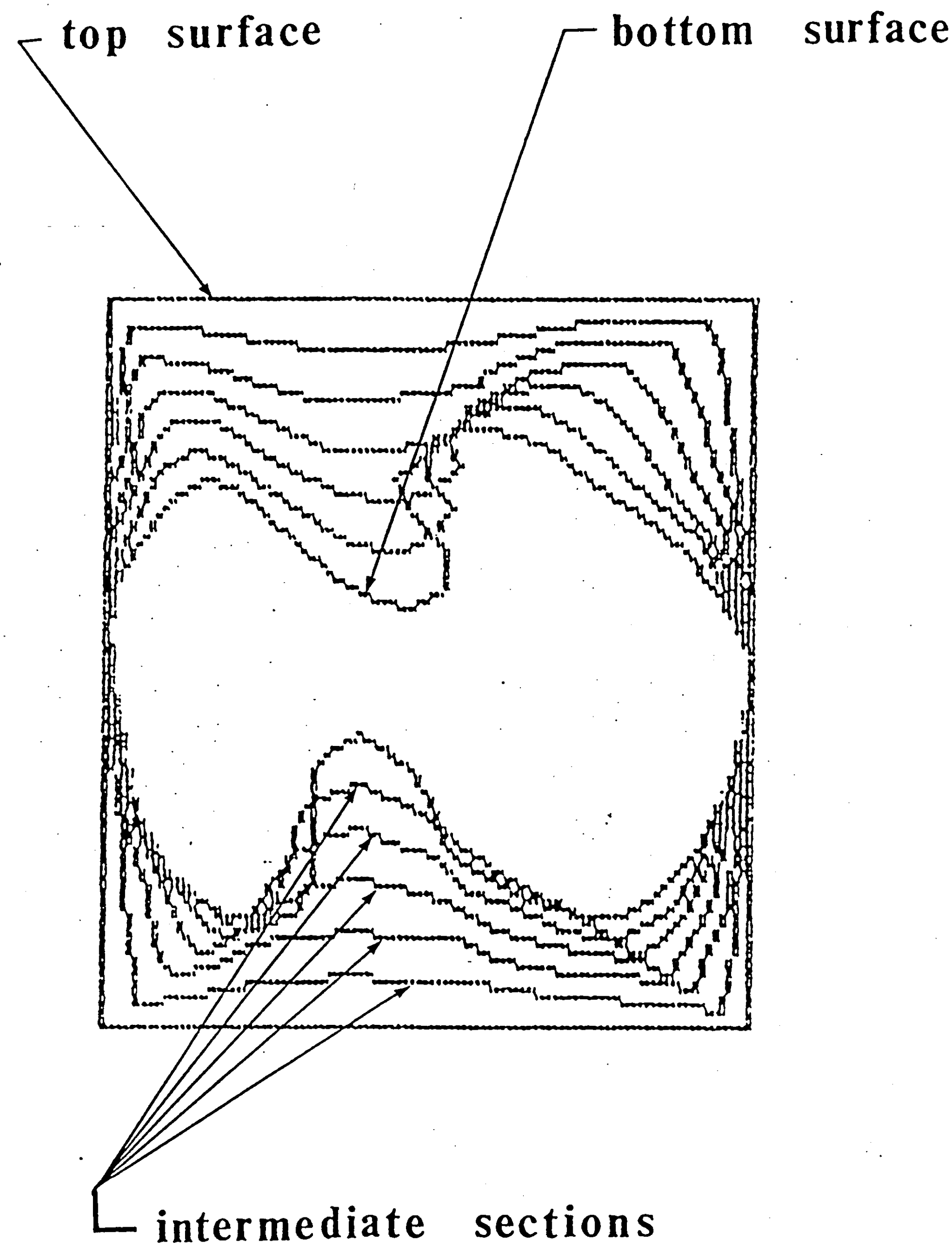
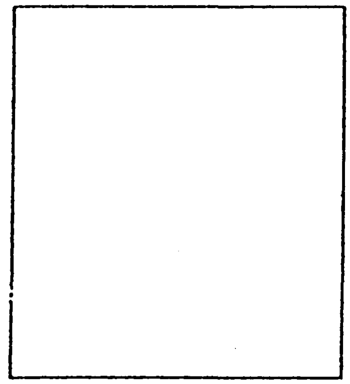
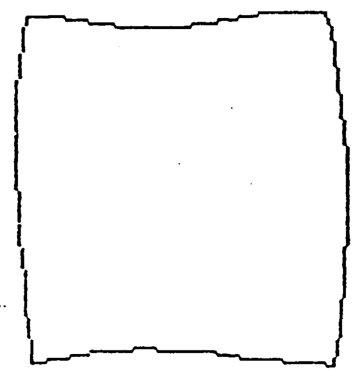


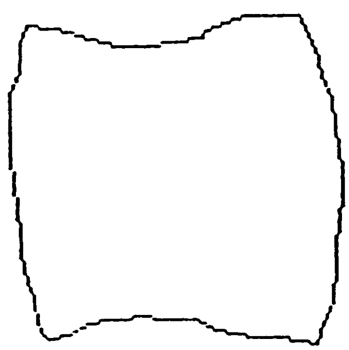
Fig. A11 A typical printout from the graphical drawing for top, bottom, and 5- intermediate sections.



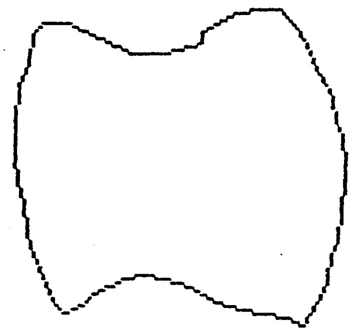
SURFACE AT Z = 0



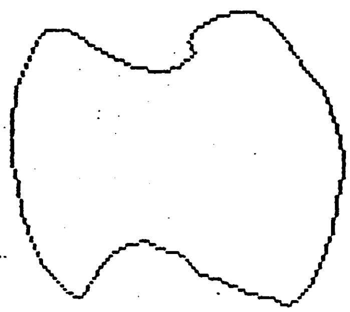
SURFACE AT Z = 1



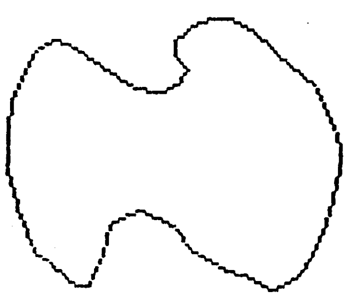
SURFACE AT Z = 2



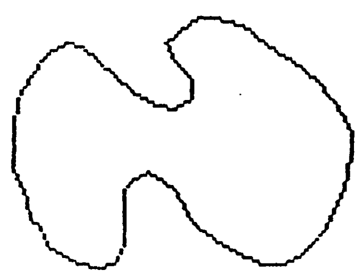
SURFACE AT Z = 3



SURFACE AT Z = 4



SURFACE AT Z = 5



SURFACE AT Z = 6

SQUARE AND COMPLEX SHAPE
PRESS SPACE BAR TO CONTINUE

Type in Z-COORDINATE for surface No. 1 ? 0

Type in Z-COORDINATE for surface No. 2 ? 6

S.No.	X 1	Y 1	R 1	THETA 1	AREA
1	1	0	1	0	0
2	1	.1	1.004988	9.966866E-02	5.033267E-02
3	1	.2	1.019804	.1973956	5.081799E-02
4	1	.4	1.077033	.3805064	.1062043
5	1	.5	1.118034	.4636476	5.196326E-02
6	1	.7	1.220656	.610726	.1095734
7	1	.8	1.280625	.674741	5.249233E-02
8	1	.9	1.345362	.7328151	5.255708E-02
9	1	1	1.414214	.7853983	5.258316E-02
10	.9	1	1.345362	.8379813	4.758765E-02
11	.8	1	1.280625	.8960554	4.762078E-02
12	.6	1	1.16619	1.030377	9.133062E-02
13	.5	1	1.118034	1.107149	4.798241E-02
14	.3	1	1.044031	1.27934	9.384398E-02
15	.2	1	1.019804	1.373401	4.891185E-02
16	-.1	1	1.004988	1.670462	.1500161
17	-.2	1	1.019804	1.768189	5.081801E-02
18	-.4	1	1.077033	1.9513	.1062043
19	-.5	1	1.118034	2.034442	5.196333E-02
20	-.7	1	1.220656	2.18152	.1095733
21	-.8	1	1.280625	2.245535	5.249223E-02
22	-1	1	1.414214	2.356192	.1106572
23	-1	.9	1.345362	2.408775	4.758781E-02
24	-1	.8	1.280625	2.466849	4.762068E-02
25	-1	.6	1.16619	2.601171	9.133859E-02
26	-1	.5	1.118034	2.677943	4.798249E-02
27	-1	.3	1.044031	2.850134	9.384405E-02
28	-1	.2	1.019804	2.944195	4.891179E-02
29	-1	0	1	3.14159	9.869778E-02
30	-1	-.1	1.004988	3.241259	5.033271E-02
31	-1	-.3	1.044031	3.433047	.1045244
32	-1	-.4	1.077033	3.522097	5.164089E-02
33	-1	-.6	1.16619	3.68201	.1087409
34	-1	-.7	1.220656	3.752316	.0523782
35	-1	-.9	1.345362	3.874405	.1104907

36	-1	-1	1.414214	3.926988	5.258322E-02
37	-.8	-1	1.280625	4.037645	9.073873E-02
38	-.7	-1	1.220656	4.101661	4.769147E-02
39	-.5	-1	1.118034	4.248739	9.192378E-02
40	-.4	-1	1.077033	4.33188	4.822197E-02
41	-.2	-1	1.019804	4.514991	9.521757E-02
42	-.1	-1	1.004988	4.612718	4.935204E-02
43	.2	-1	1.019804	4.90978	.1544722
44	.3	-1	1.044031	5.003841	5.126319E-02
45	.5	-1	1.118034	5.176032	.1076195
46	.6	-1	1.16619	5.252804	5.220478E-02
47	.9	-1	1.345362	5.445199	.1741181
48	1	-1	1.414214	5.497782	5.258274E-02
49	1	-.9	1.345362	5.550365	4.753781E-02
50	1	-.8	1.280625	5.60844	4.762107E-02
51	1	-.6	1.16619	5.742761	9.133842E-02
52	1	-.5	1.118034	5.819533	4.798234E-02
53	1	-.3	1.044031	5.991724	9.384418E-02
54	1	-.2	1.019804	6.085785	4.891192E-02
55	1	0	1	6.28318	9.869766E-02

THE TOTAL AREA OF THIS SURFACE = 4.033605

S.No.	X 2	Y 2	R 2	THETA 2	AREA
1	1	0	1	0	0
2	1	.1	1.004988	9.966866E-02	5.033267E-02
3	.95	.3	.9962429	.3058789	.1023318
4	.9	.4	.9848857	.4182244	5.448754E-02
5	.85	.5	.9861542	.5317241	5.518922E-02
6	.8	.55	.9708244	.6022874	3.325296E-02
7	.7	.65	.9552486	.7483781	6.665387E-02
8	.6	.7	.9219544	.8621701	4.836163E-02
9	.5	.7	.8602326	.9505469	.0326974
10	.4	.65	.7632169	1.019141	1.997817E-02
11	.25	.6	.65	1.176005	3.313748E-02
12	.2	.55	.585235	1.222025	7.880951E-03
13	.1	.5	.509902	1.373401	.0196788
14	.05	.45	.4527692	1.460139	8.890679E-03
15	-.05	.3	.3041381	1.735942	.0127559
16	-.1	.25	.2692582	1.9513	7.806719E-03
17	-.2	.2	.2828427	2.356192	1.619567E-02
18	-.3	.25	.3905125	2.446852	6.912814E-03
19	-.35	.3	.4609773	2.432964	-1.475538E-03
20	-.35	.4	.5315073	2.289624	-2.024679E-02
21	-.35	.5	.6103278	2.18152	-2.013437E-02
22	-.35	.6	.6946222	2.098868	-.0199397
23	-.4	.7	.8062258	2.08994	-2.901697E-03
24	-.5	.72	.8765843	2.177781	3.374871E-02
25	-.6	.7	.9219544	2.27942	4.319639E-02
26	-.7	.65	.9552486	2.393212	5.191768E-02
27	-.8	.6	1	2.478089	.0524385
28	-.85	.5	.9861542	2.609866	5.435161E-02
29	-.9	.45	1.006231	2.677943	3.446367E-02
30	-.95	.3	.9962429	2.835711	7.829272E-02
31	-1	.2	1.019804	2.944195	5.641132E-02
32	-1	0	1	3.14159	9.869778E-02
33	-.98	-.2	1.0002	3.342907	.1006988
34	-.85	-.4	.9394148	3.581433	.1052494
35	-.8	-.45	.917878	3.65398	3.056031E-02
36	-.7	-.5	.8602326	3.76184	3.990824E-02
37	-.6	-.48	.768375	3.816331	1.608583E-02
38	-.5	-.4	.6403125	3.816331	4.887581E-08

39	-.3	-.25	.3905125	3.836329	1.524799E-03
40	-.2	-.18	.2690725	3.874406	1.378383E-03
41	-.05	-.15	.1581139	4.390636	6.452882E-03
42	.05	-.2	.2061553	4.957363	1.204294E-02
43	.05	-.3	.3041381	4.877533	-3.692146E-03
44	-.05	-.4	.4031129	4.588032	-2.352193E-02
45	-.1	-.5	.509902	4.514991	-9.495324E-03
46	.05	-.62	.6220129	4.792855	5.375279E-03
47	.1	-.65	.6576473	4.865033	1.560857E-02
48	.2	-.65	.6800735	5.010883	3.372774E-02
49	.35	-.6	.6946222	5.240459	5.538513E-02
50	.5	-.5	.7071068	5.497782	6.433081E-02
51	.65	-.4	.7632169	5.731526	6.807784E-02
52	.8	-.3	.8544004	5.92441	7.040265E-02
53	.88	-.2	.9024411	6.059704	.0550919
54	.95	-.1	.9552486	6.178303	5.411098E-02
55	1	0	1	6.28318	.0524385

THE TOTAL AREA OF THIS SURFACE = 1.819178

CHOOSE NUMBER OF SECTIONS (MAX. 5 SECTIONS)? 5
TYPE Z-COORDINATE AT SECTION No. 1 ? 1

S.No.	X 3	Y 3	R 3	THETA 3	AREA
1	1	0	1	0	0
2	1	.1	1.004988	9.966866E-02	5.033267E-02
3	.9916667	.2166667	1.01506	.2151071	5.947083E-02
4	.9833334	.4	1.061576	.3863372	9.648342E-02
5	.975	.5	1.09573	.4738513	5.253581E-02
6	.9666667	.675	1.179012	.6095679	9.432772E-02
7	.95	.775	1.22602	.6842948	5.616196E-02
8	.9333333	.8666667	1.273665	.7483781	5.197061E-02
9	.9166667	.95	1.320143	.8032535	.0478178
10	.8166667	.9416667	1.246467	.8563688	.0412622
11	.7083334	.9333333	1.171686	.9216054	4.477993E-02
12	.5333334	.925	1.067741	1.047778	7.192284E-02
13	.4333334	.9166667	1.013931	1.129204	4.185518E-02
14	.2583334	.9083333	.9443546	1.293709	7.335313E-02
15	.1583333	.8233333	.8974114	1.393435	4.015691E-02
16	-.1	.875	.8806957	1.684586	.1129121
17	-.2	.8666667	.8894443	1.797593	4.470048E-02
18	-.3833333	.875	.9552849	1.983704	8.491959E-02
19	-.475	.8833333	1.002947	2.064172	4.047183E-02
20	-.6416666	.9	1.105322	2.190167	7.696598E-02
21	-.725	.9166667	1.168719	2.239967	3.401109E-02
22	-.8916666	.9333333	1.290806	2.333365	7.780903E-02
23	-.9	.8666667	1.249444	2.375058	3.254349E-02
24	-.9166667	.7866667	1.207941	2.432365	4.180931E-02
25	-.9333333	.6166667	1.118655	2.55772	7.843363E-02
26	-.95	.525	1.085415	2.636729	4.654127E-02
27	-.9666667	.35	1.028078	2.794204	8.322141E-02
28	-.975	.25	1.006541	2.890587	4.882407E-02
29	-.9833334	.075	.9861894	3.065467	8.504102E-02
30	-.9916667	-3.333333E-02	.9922268	3.175191	5.401266E-02
31	-1	-.2166667	1.023203	3.354959	9.410349E-02
32	-1	-.3333334	1.054093	3.463341	6.021223E-02
33	-.9966667	-.5333334	1.130393	3.632935	.1083529
34	-.975	-.65	1.171804	3.729593	.0663616
35	-.9666667	-.825	1.270854	3.848083	9.568458E-02
36	-.95	-.9166667	1.320143	3.909133	5.319866E-02

38	-.6666666	-.9	1.12002	4.074838	3.811542E-02
39	-.4666667	-.875	.9916667	4.22243	.072571
40	-.3666667	-.8633334	.9379706	4.310761	3.885663E-02
41	-.175	-.8583334	.8759914	4.51126	.0769274
42	-.075	-.8666667	.8699058	4.626064	4.343809E-02
43	.175	-.8833333	.9005014	4.907965	.1142973
44	.2416667	-.9	.9318813	4.974715	2.898276E-02
45	.4	-.9166667	1.000139	5.123841	7.458374E-02
46	.5083333	-.9366667	1.065714	5.209609	4.870578E-02
47	.7666666	-.9416667	1.214296	5.395699	.1371961
48	.8666667	-.9416667	1.279784	5.456332	4.965316E-02
49	.8916666	-.8499999	1.231897	5.521701	4.960146E-02
50	.9166667	-.75	1.184389	5.597451	5.313012E-02
51	.9416667	-.5666667	1.099021	5.741461	8.697078E-02
52	.9666667	-.4666667	1.073416	5.833421	5.297943E-02
53	.98	-.2833333	1.020136	6.001739	8.758226E-02
54	.9916667	-.1833333	1.008471	6.100371	5.015498E-02
55	1	0	1	6.28318	9.140491E-02

THE TOTAL AREA OF THIS SURFACE = 3.512328

TYPE Z-COORDINATE AT SECTION No. 2 ? 2

S.No.	X 4	Y 4	R 4	THETA 4	AREA
1	1	0	1	0	0
2	1	.1	1.004988	9.966866E-02	5.033267E-02
3	.9833334	.2333333	1.010638	.2329793	6.808098E-02
4	.9666666	.4	1.046157	.3923402	8.720582E-02
5	.95	.5	1.073546	.484478	5.309441E-02
6	.9333333	.65	1.13737	.608325	8.010495E-02
7	.9	.75	1.171537	.6947383	.0593011
8	.8666667	.8333333	1.202313	.7657929	5.135667E-02
9	.8333333	.9	1.226558	.8238408	4.366472E-02
10	.7333334	.8833333	1.148066	.8779168	3.563764E-02
11	.6166667	.8666667	1.063668	.9523684	4.211684E-02
12	.4666667	.85	.9696792	1.068706	5.469492E-02
13	.3666667	.8333333	.9104334	1.15629	3.629841E-02
14	.2166667	.8166667	.8449194	1.311465	5.528889E-02
15	.1166667	.7666666	.7754927	1.419781	3.257015E-02
16	-.1	.75	.7566373	1.703345	.0811703
17	-.2	.7333334	.760117	1.837046	3.862459E-02
18	-.3666667	.75	.834832	2.025513	6.567566E-02
19	-.45	.7666666	.8889756	2.101567	3.005193E-02
20	-.5833333	.8	.9900898	2.200828	4.865135E-02
21	-.65	.8333333	1.056856	2.23322	1.809031E-02
22	-.7833334	.8666667	1.168213	2.30573	4.947785E-02
23	-.8	.8333333	1.155132	2.335787	2.005451E-02
24	-.8333333	.7733333	1.136877	2.393519	3.730721E-02
25	-.8666667	.6333333	1.073416	2.510511	6.740026E-02
26	-.9	.55	1.054751	2.593041	4.590732E-02
27	-.9333333	.4	1.015436	2.736699	7.406352E-02
28	-.95	.3	.9962429	2.835711	4.913512E-02
29	-.9666666	.15	.9782354	2.987646	7.269627E-02
30	-.9833334	3.333334E-02	.9838982	3.107705	5.811202E-02
31	-1	-.1333333	1.00885	3.274142	8.469789E-02
32	-1	-.2666667	1.034945	3.402193	6.857845E-02
33	-.9933333	-.4666667	1.097492	3.580786	.107557
34	-.95	-.6	1.12361	3.704907	.0783509
35	-.9333333	-.75	1.197335	3.818505	.0814281
36	-.9	-.8333333	1.226553	3.888546	5.268618E-02
37	-.7333334	-.8266666	1.105059	3.986746	5.995894E-02

38	-.6333333	-.8	1.020349	4.042748	2.915185E-02
39	-.4333334	-.75	.8661858	4.188467	5.466507E-02
40	-.3333334	-.7266667	.7994721	4.282309	2.998968E-02
41	-.15	-.7166667	.7321961	4.506063	5.997849E-02
42	-.05	-.7333334	.7350359	4.64431	3.734603E-02
43	.15	-.7666666	.7812028	4.905596	.0797283
44	.1833333	-.8	.8207381	4.937661	.0107998
45	.3	-.8333333	.8856887	5.05794	4.717603E-02
46	.4166667	-.8733333	.9676374	5.157544	4.663078E-02
47	.6333333	-.8833333	1.086917	5.334416	.1044775
48	.7333334	-.8833333	1.148066	5.405264	4.669048E-02
49	.7633334	-.8	1.119648	5.487256	5.139344E-02
50	.8333333	-.7	1.088322	5.584521	5.760209E-02
51	.8833333	-.5333334	1.031854	5.739991	8.276637E-02
52	.9333333	-.4333334	1.029023	5.84851	5.745483E-02
53	.96	-.2666667	.9963489	6.012234	8.126505E-02
54	.9833334	-.1666667	.9973576	6.115284	5.125341E-02
55	1	0	1	6.28318	8.394814E-02

THE TOTAL AREA OF THIS SURFACE = 3.051844

TYPE Z-COORDINATE AT SECTION No. 3 ? 3

S.No.	X 5	Y 5	R 5	THETA 5	AREA
1	1	0	1	0	0
2	1	.1	1.004988	9.966866E-02	5.033267E-02
3	.975	.25	1.006541	.2510027	7.666015E-02
4	.95	.4	1.030776	.3985224	7.836788E-02
5	.925	.5	1.051487	.4955517	5.363095E-02
6	.9	.625	1.09573	.6069877	6.689646E-02
7	.85	.725	1.117195	.7061991	6.191407E-02
8	.8	.8	1.131371	.7853981	.0506874
9	.75	.85	1.133578	.847817	4.010413E-02
10	.65	.825	1.050298	.9034902	3.070727E-02
11	.525	.8	.9568829	.9900401	3.962359E-02
12	.4	.7750001	.8721382	1.094329	3.966234E-02
13	.3	.75	.8077748	1.19029	3.130731E-02
14	.175	.725	.7458217	1.333948	.0399548
15	.075	.65	.6543126	1.45592	2.610965E-02
16	-.1	.625	.6329495	1.729449	5.479134E-02
17	-.2	.6	.6324555	1.892544	3.261905E-02
18	-.35	.625	.7163275	2.081282	4.842306E-02
19	-.425	.65	.7766112	2.149868	2.068293E-02
20	-.525	.7	.875	2.214295	2.466342E-02
21	-.575	.75	.9450529	2.224877	4.725298E-03
22	-.675	.8	1.046721	2.271648	2.562215E-02
23	-.7	.8	1.063015	2.289624	.0101562
24	-.75	.76	1.067755	2.349569	3.417178E-02
25	-.8	.65	1.030776	2.459274	5.828039E-02
26	-.85	.575	1.026219	2.546831	.0461044
27	-.9	.45	1.006231	2.677943	6.637526E-02
28	-.925	.35	.9890021	2.779861	.0498445
29	-.95	.225	.9762812	2.909033	6.155868E-02
30	-.975	.1	.9801148	3.039384	.0626088
31	-1	-5.000001E-02	1.001249	3.191549	7.627281E-02
32	-1	-.2	1.019804	3.338986	7.666729E-02
33	-.99	-.4	1.067755	3.525575	.1063651
34	-.925	-.55	1.076162	3.678026	8.827853E-02
35	-.9	-.675	1.125	3.785091	.0677525
36	-.85	-.75	1.133578	3.86457	5.106479E-02
37	-.7000001	-.74	1.018627	3.954759	4.679029E-02

38	-.6	-.7	.9219544	4.00376	2.082562E-02
39	-.4	-.625	.7420411	4.143073	3.835454E-02
40	-.3	-.5900001	.6618913	4.241983	.0216661
41	-.125	-.575	.5884301	4.498326	4.437943E-02
42	-.025	-.6	.6005206	4.670744	3.108914E-02
43	.125	-.65	.6619101	4.902373	5.074109E-02
44	.125	-.7	.7110732	4.889093	-3.357329E-03
45	.2	-.75	.7762088	4.972986	.025273
46	.325	-.81	.8727686	5.093954	4.607213E-02
47	.5	-.825	.964689	5.257248	7.598265E-02
48	.6	-.825	1.02011	5.341181	4.367107E-02
49	.675	-.75	1.009022	5.445199	5.295201E-02
50	.75	-.65	.9924716	5.56909	6.101602E-02
51	.825	-.5	.964689	5.738317	7.874349E-02
52	.9	-.4	.9848857	5.864956	6.142009E-02
53	.94	-.25	.9726768	6.02324	7.487634E-02
54	.975	-.15	.986471	6.130531	5.220366E-02
55	1	0	1	6.28318	.0763247

THE TOTAL AREA OF THIS SURFACE = 2.655379

TYPE Z-COORDINATE AT SECTION No. 4 ? 4

S.No.	X 6	Y 6	R 6	THETA 6	AREA
1	1	0	1	0	0
2	1	.1	1.004988	9.966866E-02	5.033267E-02
3	.9666666	.2666667	1.002774	.2691676	8.522026E-02
4	.9333333	.4	1.015436	.4048918	6.997339E-02
5	.9000001	.5	1.029563	.5070985	5.416952E-02
6	.8666667	.6	1.054093	.6055447	5.469237E-02
7	.8	.7	1.063015	.71883	6.400619E-02
8	.7333334	.7666666	1.060922	.8076168	4.996723E-02
9	.6666666	.8	1.041367	.8760581	.0371104
10	.5666667	.7666666	.9533566	.9342881	2.646232E-02
11	.4333334	.7333334	.8517954	1.037088	3.729356E-02
12	.3333334	.7000001	.7753136	1.126377	2.683633E-02
13	.2333333	.6666666	.7063206	1.234122	2.687623E-02
14	.1333333	.6333333	.6472162	1.3633	2.705572E-02
15	3.333333E-02	.5333333	.534374	1.508378	2.071384E-02
16	-.1	.5	.509902	1.768189	3.377553E-02
17	-.2	.4666667	.5077182	1.975686	2.674397E-02
18	-.3333334	.5	.6009252	2.158796	3.306166E-02
19	-.4	.5333333	.6666666	2.214295	1.233302E-02
20	-.4666667	.6	.760117	2.231837	5.067656E-03
21	-.5	.6666666	.8333333	2.214295	-6.090932E-03
22	-.5666668	.7333334	.9267626	2.228683	6.178677E-03
23	-.6	.7666666	.9735386	2.23484	2.917922E-03
24	-.6666666	.7466667	1.000977	2.299648	3.246755E-02
25	-.7333334	.6666667	.9910712	2.403775	5.113778E-02
26	-.8	.6	1	2.498089	4.715705E-02
27	-.8666667	.5	1.000555	2.618312	6.017819E-02
28	-.9000001	.4	.9848858	2.723366	5.095115E-02
29	-.9333333	.3	.9803627.	2.830592	5.152811E-02
30	-.9666666	.1666667	.9809292	2.970855	6.748201E-02
31	-1	3.333333E-02	1.000555	3.108269	6.878357E-02
32	-1	-.1333333	1.00885	3.274142	8.441059E-02
33	-.9866667	-.3333334	1.041452	3.467389	.1048003
34	-.9000001	-.5	1.029563	3.648689	9.608869E-02
35	-.8666667	-.6	1.054093	3.747135	.0546923
36	-.8	-.6666666	1.041367	3.836328	4.836274E-02

37	-.6666667	-.6533333	.9334285	3.916888	3.509519E-02
38	-.5666667	-.6	.8252946	3.955552	1.316744E-02
39	-.3666667	-.5	.6200358	4.079638	2.385198E-02
40	-.2666667	-.4533333	.5259489	4.180662	1.397283E-02
41	-.1	-.4333334	.4447222	4.485588	3.015374E-02
42	0	-.4666667	.4666667	4.712384	-.6594729
43	.1	-.5333333	.5426273	4.897732	2.728735E-02
44	6.666666E-02	-.6	.6036924	4.823041	-1.361033E-02
45	9.999999E-02	-.6666666	.6741249	4.861274	8.687342E-03
46	.2333334	-.7466667	.7822759	5.015269	4.711906E-02
47	.3666667	-.7666666	.8498366	5.158489	5.171849E-02
48	.4666667	-.7666666	.8975274	5.259173	4.055296E-02
49	.5666668	-.7	.9006171	5.392905	5.423609E-02
50	.6666666	-.6	.8969083	5.550365	.0633338
51	.7666666	-.4666667	.8975274	5.736392	7.492737E-02
52	.8666667	-.3666667	.9410397	5.88294	6.488812E-02
53	.92	-.2333334	.9491282	6.034795	6.839886E-02
54	.9666666	-.1333333	.9758188	6.146114	5.300047E-02
55	1	0	1	6.28318	6.853318E-02

THE TOTAL AREA OF THIS SURFACE = 1.617493

TYPE Z-COORDINATE AT SECTION No. 5 ? 5

S.No.	X 7	Y 7	R 7	THETA 7	AREA
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3	.9583333	.2833334	.9993401	.2874633	.0937734
4	.9166666	.4	1.000139	.4114563	6.201371E-02
5	.875	.5	1.007782	.5191461	5.468624E-02
6	.8333334	.575	1.012457	.603983	4.348186E-02
7	.75	.675	1.009022	.732815	6.558356E-02
8	.6666667	.7333334	.9910712	.8329814	.0491928
9	.5833334	.75	.9501462	.9097531	3.465394E-02
10	.4833334	.7083333	.8575239	.9720124	2.289111E-02
11	.3416667	.6666667	.7491199	1.097199	3.512608E-02
12	.2666667	.625	.6795117	1.167515	1.623371E-02
13	.1666667	.5833334	.6066759	1.292497	2.300014E-02
14	9.166668E-02	.5416666	.5493683	1.403154	1.669848E-02
15	-8.333326E-03	.4166667	.41675	1.590791	1.629447E-02
16	-.1	.375	.3881044	1.831396	1.812057E-02
17	-.2	.3333333	.3887301	2.111213	2.114174E-02
18	-.3166667	.375	.4908185	2.272054	1.937347E-02
19	-.375	.4166667	.5605677	2.303609	4.957888E-03
20	-.4083333	.5	.645551	2.255615	-.0100004
21	-.425	.5833334	.721736	2.200439	-1.437067E-02
22	-.4583333	.6666667	.8090203	2.173081	-8.953036E-03
23	-.5	.7333334	.8875685	2.169213	-1.523791E-03
24	-.5833334	.7333334	.9370462	2.242757	3.228798E-02
25	-.6666667	.6833333	.9546669	2.343847	4.606613E-02
26	-.75	.625	.9762812	2.446852	4.908828E-02
27	-.8333334	.55	.9984711	2.558217	5.551253E-02
28	-.875	.45	.9839334	2.66658	.0524542
29	-.9166666	.375	.9904053	2.753271	4.251814E-02
30	-.9583333	.2333334	.9863301	2.902759	7.271424E-02
31	-1	.1166667	1.006783	3.025449	6.217983E-02
32	-1	-6.666666E-02	1.00222	3.208158	9.176088E-02
33	-.9833334	-.2666667	1.01885	3.406407	.1028968
34	-.875	-.45	.9839334	3.616601	.1017467
35	-.8333334	-.525	.9849211	3.703777	4.228344E-02
36	-.75	-.5833334	.9501462	3.802633	4.462271E-02

37	-.6333333	-.5666668	.8498366	3.87149	2.486493E-02
38	-.5333333	-.5	.7310571	3.894742	6.213326E-03
39	-.3333334	-.375	.5017331	3.985744	.0114543
40	-.2333333	-.3166667	.3933475	4.07736	7.08749E-03
41	-.075	-.2916667	.3011552	4.460696	1.738325E-02
42	.025	-.3333333	.3342695	4.787244	1.824358E-02
43	.075	-.4166667	.4233629	4.890477	9.251529E-03
44	8.333326E-03	-.5	.5000695	4.729049	-.0201841
45	0	-.5833334	.5833334	4.712384	-1.071849
46	.1416667	-.6833333	.6978638	4.916806	4.977807E-02
47	.2333334	-.7083333	.7457751	5.030601	3.164549E-02
48	.3333333	-.7083333	.7828456	5.152227	.0372689
49	.4583333	-.6500001	.7953423	5.326544	5.513377E-02
50	.5833334	-.55	.8017342	5.527186	6.448415E-02
51	.7083333	-.4333334	.8303697	5.734155	7.135426E-02
52	.8333334	-.3333334	.8975275	5.902674	6.787553E-02
53	.9	-.2166667	.9257129	6.046935	6.181199E-02
54	.9583333	-.1166667	.9654087	6.162037	5.363825E-02
55	1	0	1	6.28318	6.057167E-02

THE TOTAL AREA OF THIS SURFACE = .9878866

S.No	ALFA = ATN (XF - XI) / (ZF - ZI)	BETA = ATN (YF - YI) / (ZF - ZI)
1	0	0
2	0	0
3	-.4774528	.9548391
4	-.9548393	0
5	-1.432093	0
6	-1.909148	-1.432093
7	-2.862399	-1.432093
8	-3.814066	-1.909148
9	-4.763631	-2.862399
10	-4.763631	-3.338463
11	-5.237464	-3.814066
12	-3.814066	-4.289143
13	-3.814066	-4.763631
14	-2.385939	-5.237464
15	-2.385939	-6.654411
16	0	-7.125
17	0	-7.594626
18	.9548389	-7.125
19	1.432093	-6.654411
20	3.338463	-5.710581
21	4.289144	-4.763631
22	6.182916	-3.814066
23	5.710581	-1.909148
24	4.763631	-.7638965
25	3.814066	.9548386
26	2.862399	1.432093
27	1.909148	2.862399
28	1.432093	2.862399
29	.9548393	4.289143
30	.4774528	3.814066
31	0	4.763631
32	0	3.814066
33	.1909846	3.814066
34	1.432093	2.862399
35	1.909148	4.289143
36	2.862399	4.763631
37	1.909148	4.953246
38	1.909148	5.710581

39	1.909148	7.125
40	1.909148	7.782193
41	1.432093	8.063228
42	1.432093	7.594626
43	-1.432093	6.654411
44	-3.338463	5.710581
45	-5.710581	4.763631
46	-5.237464	3.623884
47	-7.594626	3.338463
48	-7.594626	3.338463
49	-6.182916	2.862398
50	-4.763631	2.862399
51	-3.338463	1.909148
52	-1.909148	1.909148
53	-1.14576	.9548391
54	-.4774528	.9548391
55	0	0

Appendix III

Stepper Motors

III.1 Basic forms

Fig A12 shows a prototype permanent magnet motor; (a) has a 2-pole rotor magnet within a 4-pole stator with windings (phases) marked A, B, C. and D. Excitation applied to A and C develops the magnetic polarities indicated for step 1 in (b) and the rotor sets itself vertically. If A and C are switched off and B and D are excited as in step 2, an alignment torque is developed on the rotor to turn its axis to the horizontal by 90°, and so on. The stator currents with uniform pulse frequency and equal on/off periods are shown in (c). The stepping angle can be made 45° by energizing successive phases simultaneously as in (d).

III.1.2 Variable reluctance

Fig A13 shows a 6-pole prototype (three-phase because opposite poles are normally excited together) which has its rotor structurally polarized but unexcited. The rotor angle must differ from that of the stator, the difference determining the step angle.

On step 1, with A and D energized, two opposite rotor poles are aligned. On step 2, with A and D switched off, and with B and E energized the rotor moves to a minimum reluctance position with its other two poles in alignment.

The step angle is the difference between the change 60° in the stator magnetomotive force (m.m.f) axis and the angle 90° between successive rotor poles.

Hence step angle = 60° - 90° = -30°

The rotor is moving in a direction opposite to that of the stator m.m.f.

Figs A14-A16 show details of stepper motors used in the present research.

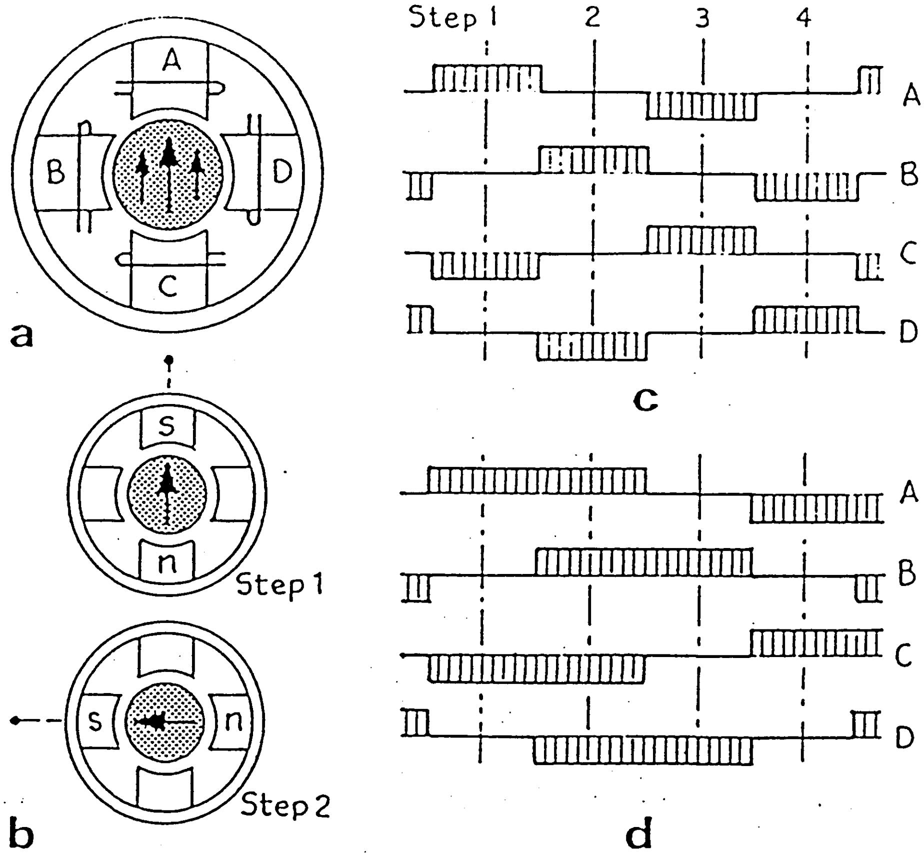


Fig.A12 Permanent-magnet stepper motor

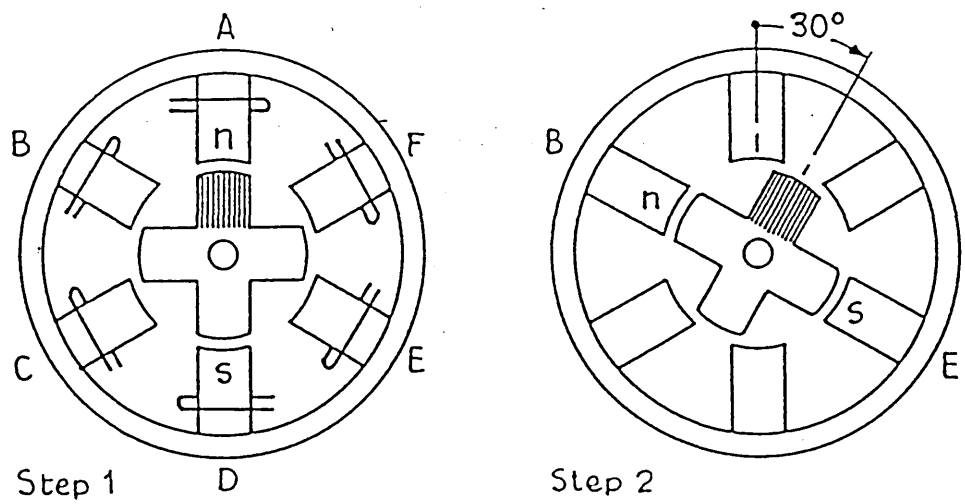


Fig.A13 Variable-reluctance stepper motor

DIMENSIONS mm.

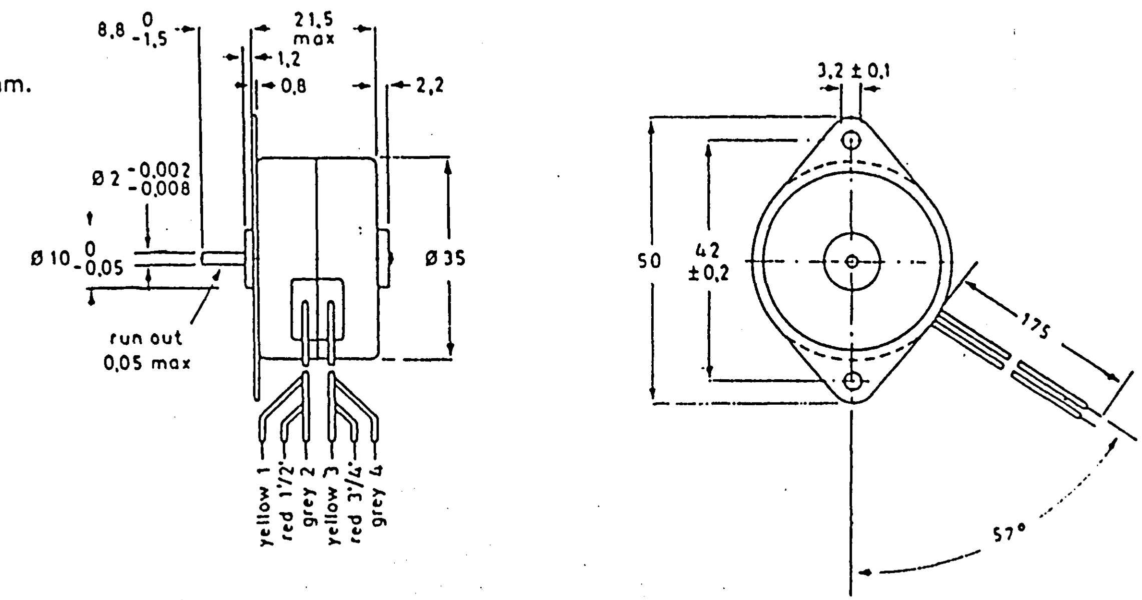


Fig. A14 a 7·5 degree stepper motor

DIMENSIONS mm.

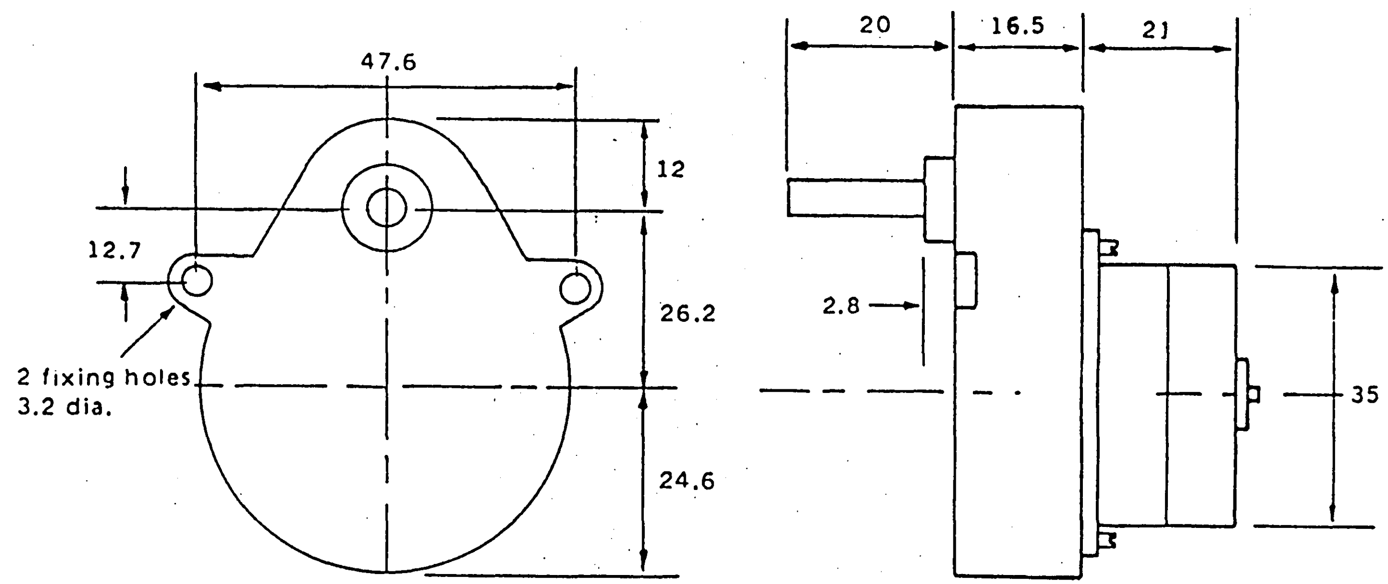


Fig. A14b 7·5 degree geared stepper motor

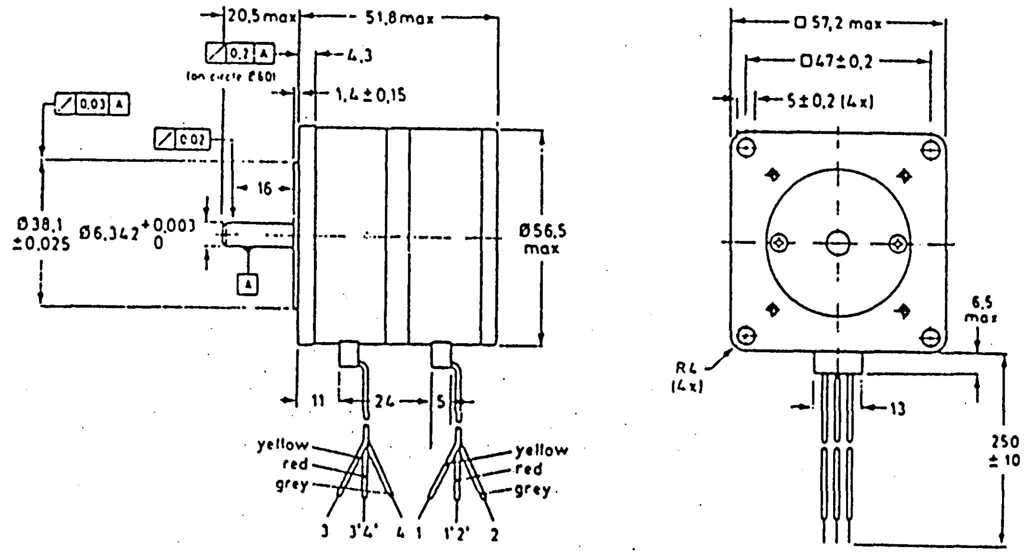


Fig. A15a 1·8 degree stepper motor

DIMENSIONS mm.

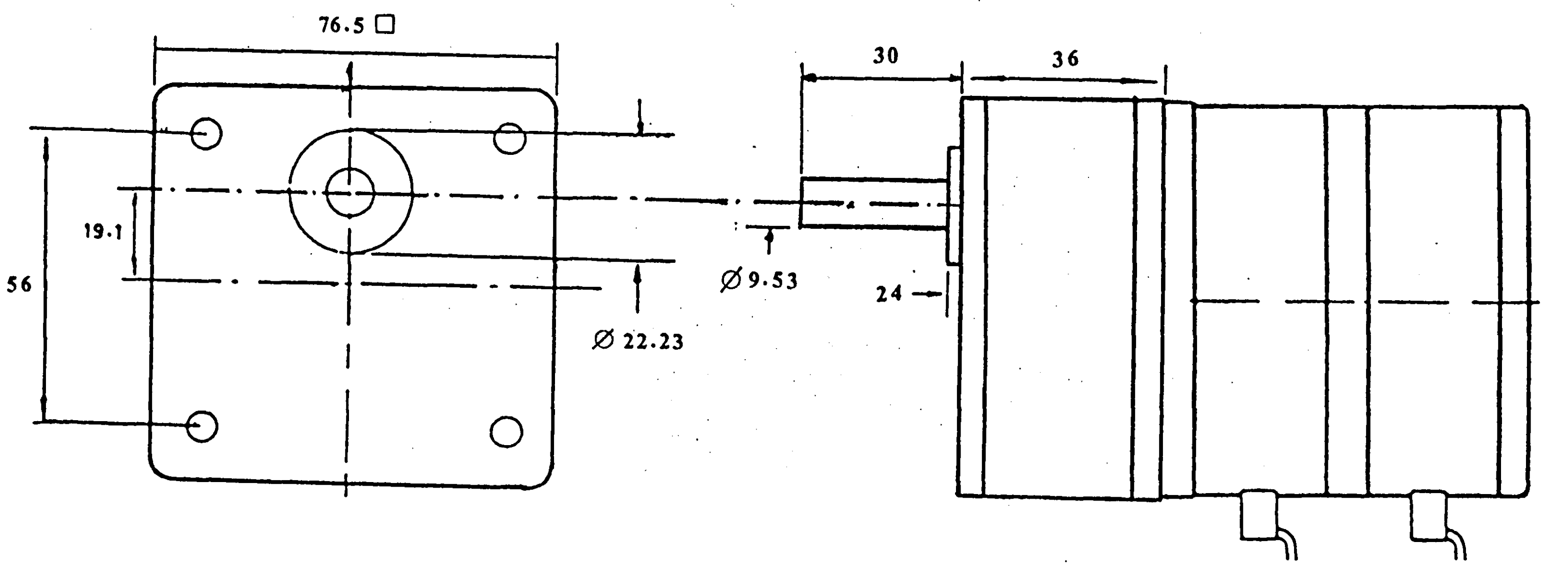


Fig. A15b 1·8 degree geared stepper motor

4 phase stepper motors specifications

TYPE		Holding Torque	Step Angle	Step Angle Tolerance	Rotor Inertia	Current per phase	Resistance per phase	Inductance per phase	Mass
		(Ncm)	(degrees)	+ / –	(gcm^2)	(Amps)	(Ohms)	(mH)	(gms)
ID32	101	1.0	7.5	9%	2.6	0.22	21	30	80
	FD6002	37.4	1.8	5%	117	1.0	5.0	10	560

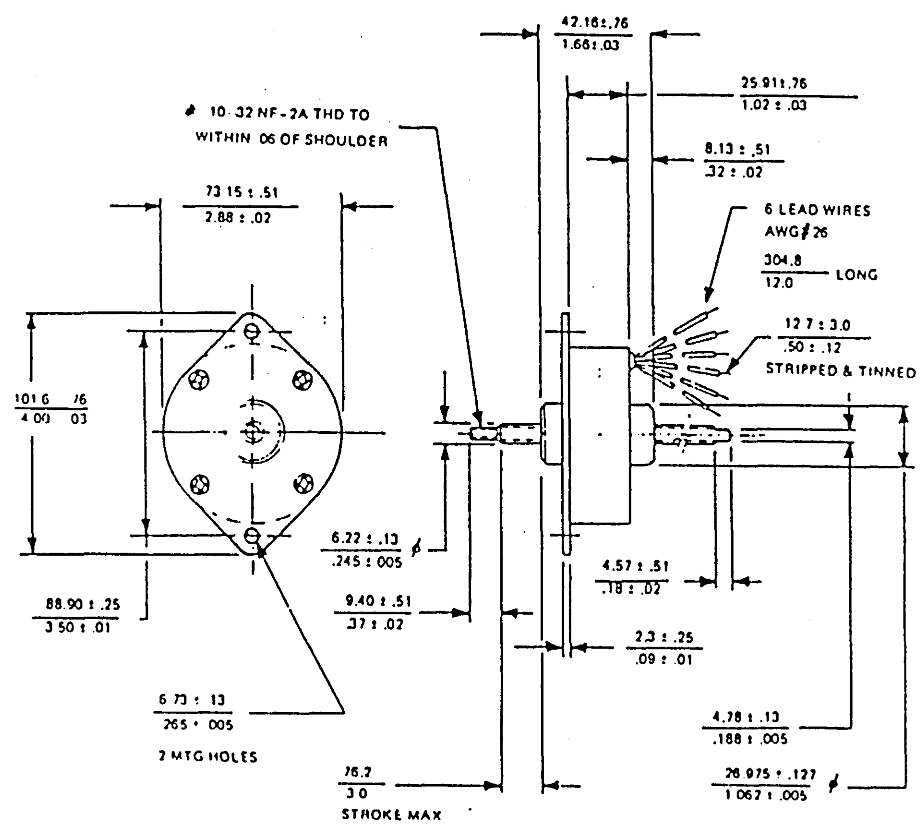
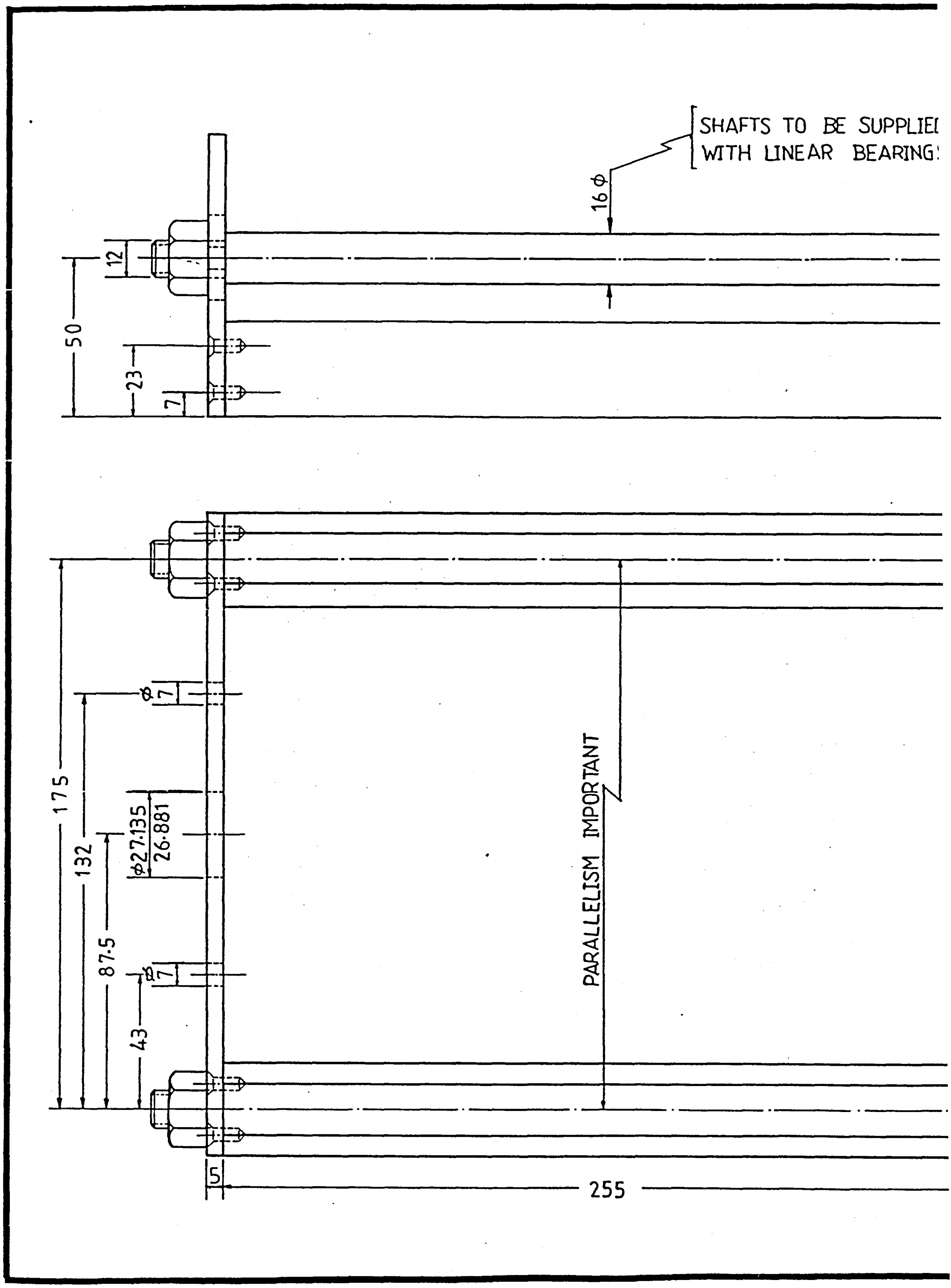


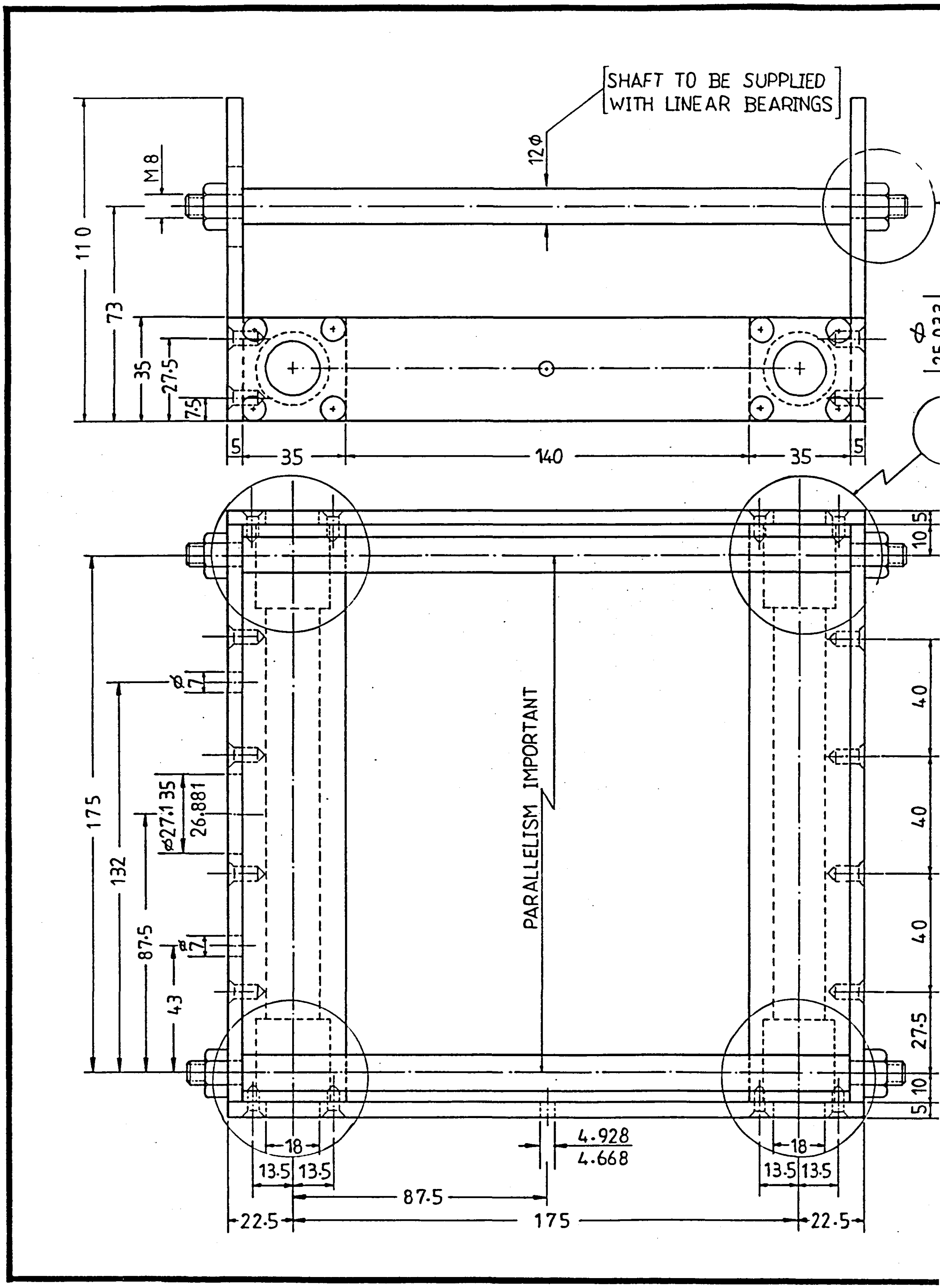
Fig. A16 digital linear actuator

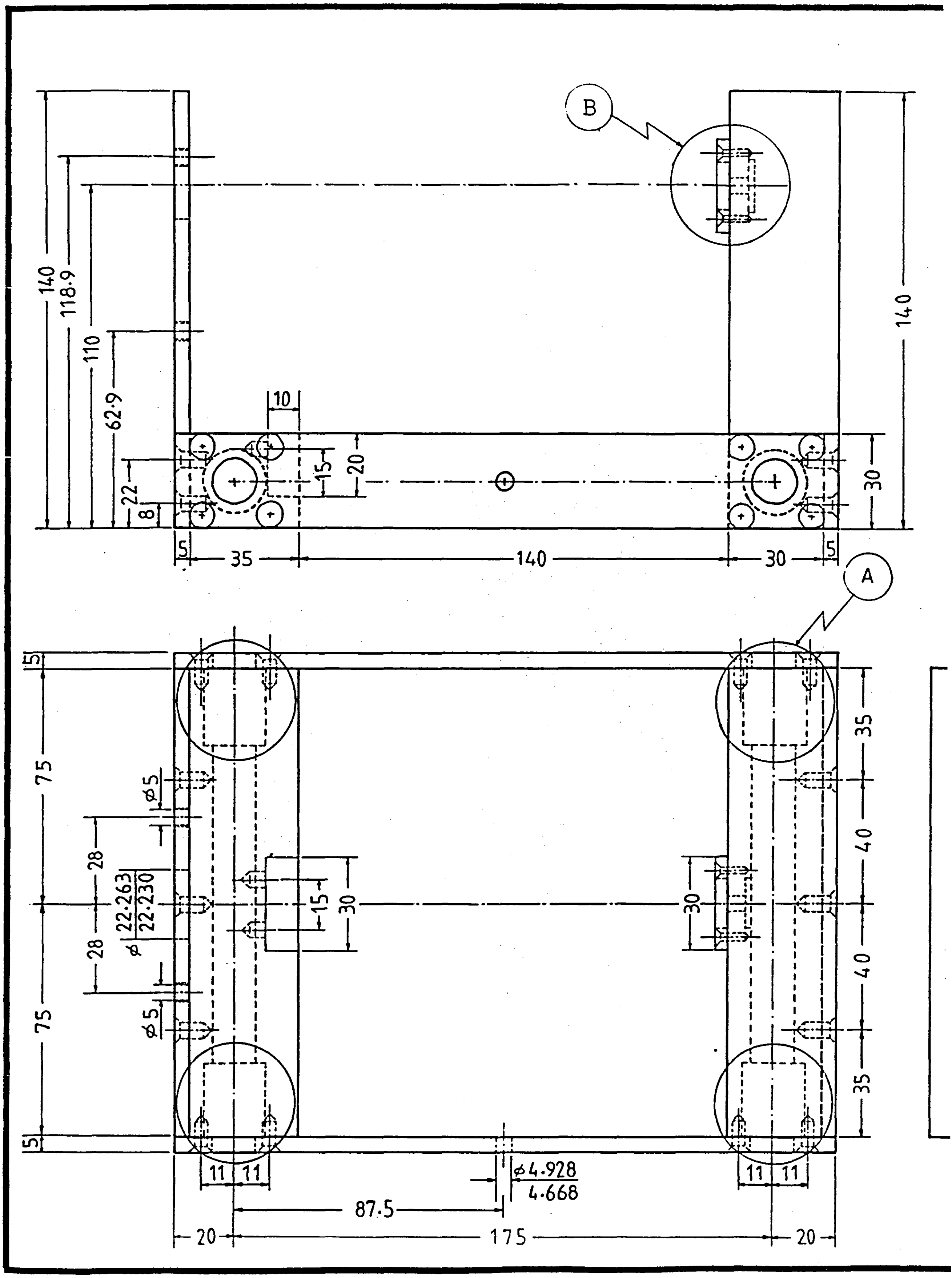
digital linear actuators specifications

		L92411-P2
Maximum Linear Force	kg	11.8
Linear travel per full step	ins (mm)	0.001 (0.0254)
Minimum Holding torque (de-energised)	kg	11.8
Maximum Travel	mm	76.2
Bearing Construction		Radial Ball
Maximum Pull-in rate (full step)	steps/s	350
Maximum Pull-out rate (full step)	steps/s	1000
Unit weight	gms	455
Resistance per phase	Ohms	25
Current per phase	Amps	0.485
Inductance per phase	mH	25
Insulation resistance	MOhms	20
Operating temperature range	deg. C	–40 to +85
Storage temperature range	deg. C	–40 to +100
Supply voltage	Vdc	24
Used with Series Resistors,	Ohms	25
Drive Mode		2
TRANSLATOR RECOMMENDED	TYPE	EM 162

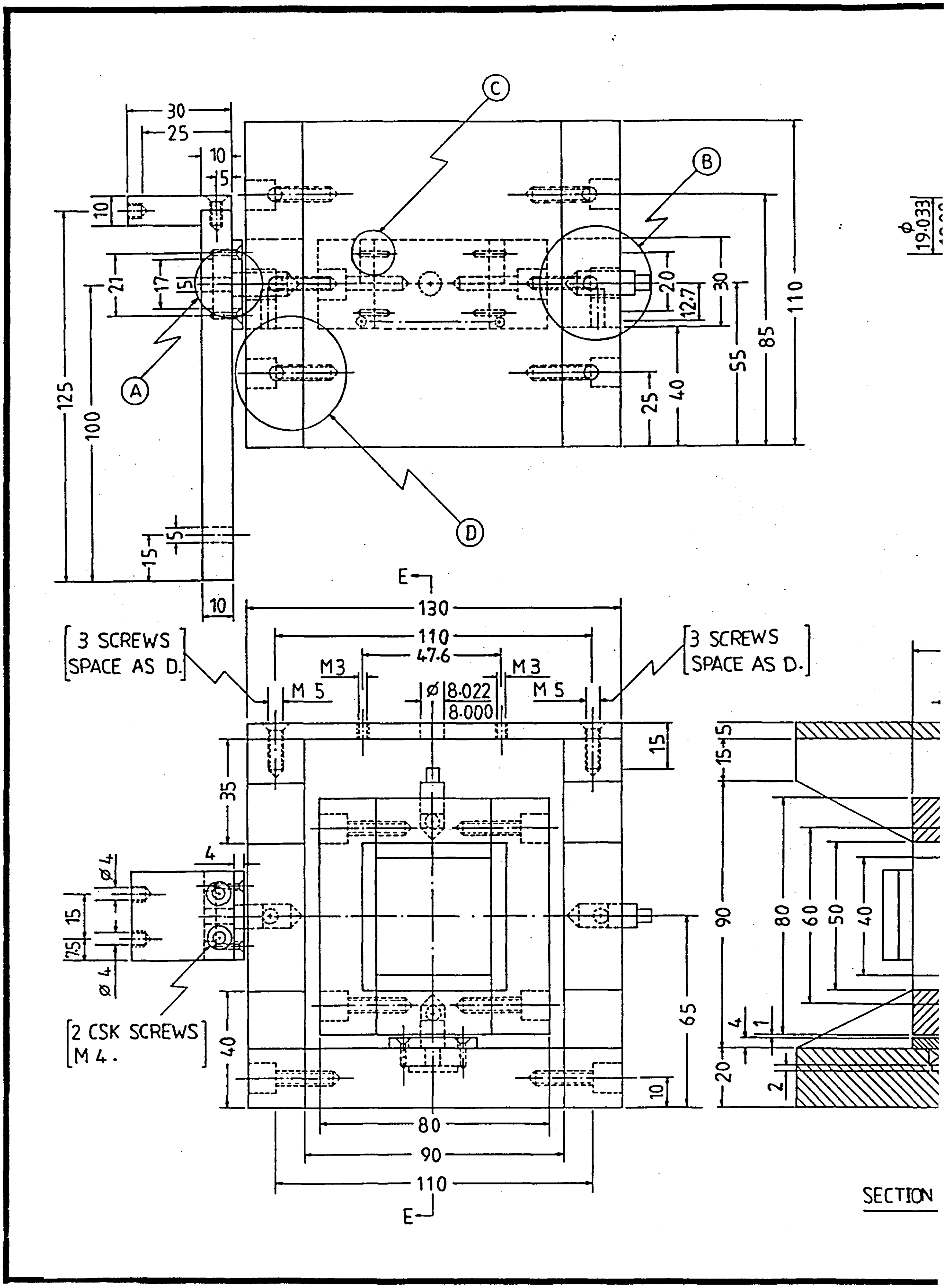


SHAFTS TO BE SUPPLIE[
WITH LINEAR BEARING[
16 ϕ
12
50
23
7
ϕ 7
175
132
ϕ27.135
26.881
87.5
ϕ 7
43
PARALLELISM IMPORTANT
5
255

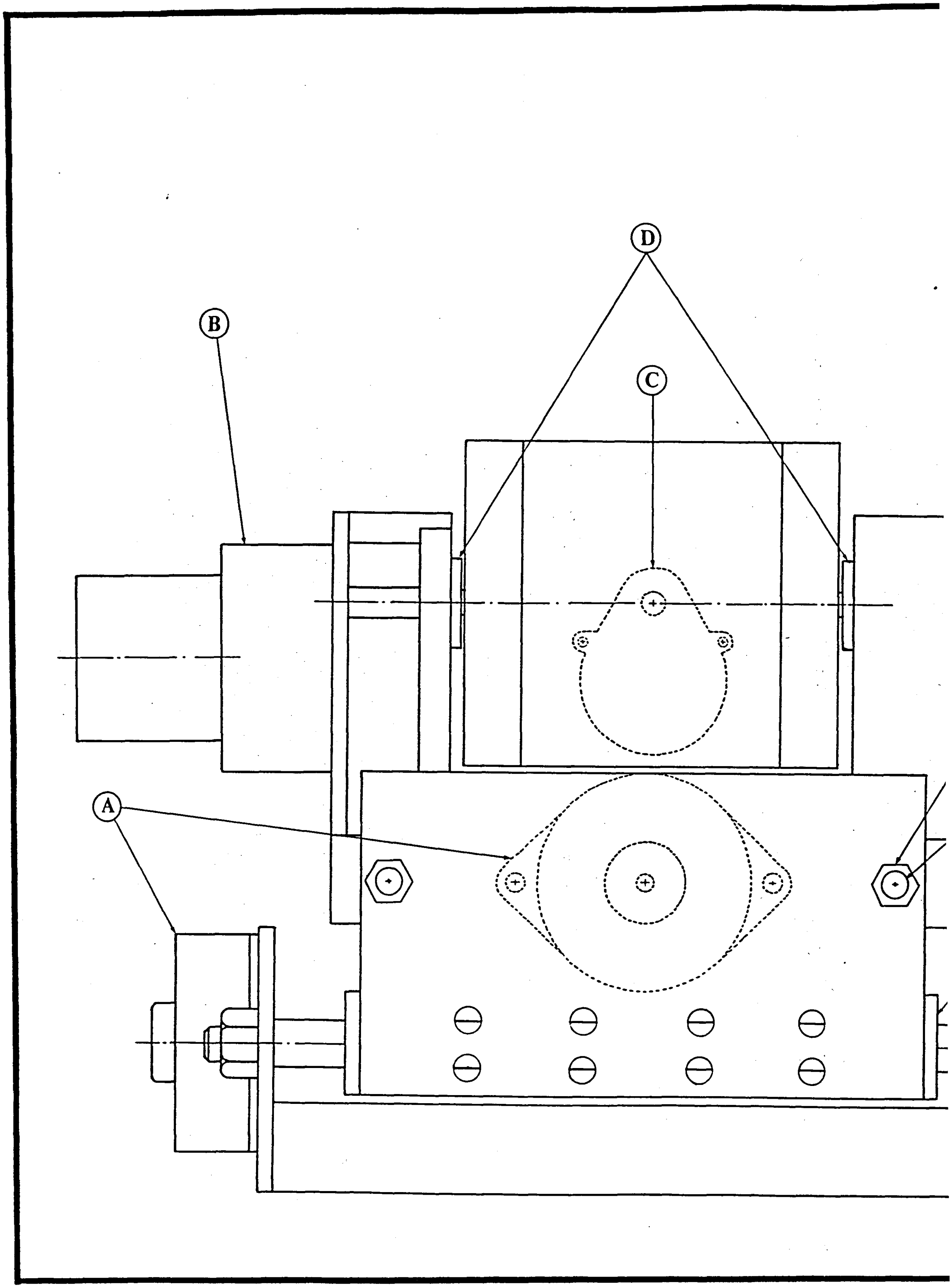

SHAFT TO BE SUPPLIED
WITH LINEAR BEARINGS
12ϕ
M8
110
73
35
27.5
7.5
5
35
140
35
5
PARALLELISM IMPORTANT
175
132
87.5
43
ϕ7
ϕ7
ϕ27.135
26.881
4.928
4.668
18
13.5
13.5
87.5
22.5
175
22.5
10.5
40
40
40
27.5
10
5



A
B
140
118·9
110
62·9
22
8
10
15
20
30
5
35
140
30
5
75
ø5
28
ø 22·263 / 22·230
28
ø5
75
5
15
30
30
35
40
40
35
11
11
11
11
ø4·928 / 4·668
87·5
20
175
20



A
B
C
D
3 SCREWS SPACE AS D.
3 SCREWS SPACE AS D.
2 CSK SCREWS M 4.
M3
M 5
M3
M 5
ø 8.022 / 8.000
ø 4
ø 4
ϕ 19.033
E
E
SECTION


D
B
C
A