INTEGRATED COMPUTER AIDED DESIGN SIMULATION AND MANUFACTURE

BY

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DECLARATION

I hereby declare that all the work reported in this thesis was carried out by me at Dublin City University during the period of December 1987 to September 1989.

To the best of my knowledge, The results presented in this thesis originated from the present study, except where references have been made. No part of this thesis has been submitted for a degree at any other institution.

Signature of Candidate

FAEK DIKO

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ABSTRACT

INTEGRATED COMPUTER AIDED DESIGN SIMULATION AND MANUFACTURE

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Computer Aided Design (CAD) and Computer Aided Manufacture (CAM) have been investigated and developed since twenty years as standalone systems. A large number of very powerful but independent packages have been developed for Computer Aided Design,Aanlysis and Manufacture. However, in most cases these packages have poor facility for communicating with other packages.

Recently attempts have been made to develop integrated CAD/CAM systems and many software companies are actively engaged in this field of engineering.

In the present work an integrated system for Computer Aided Design, Analysis and Manufacture has been developed incorporating AutoCAD Draughting package, Finite Element Analysis software and NC machining software. In this system, the draughting and NC machining software are resident in a PC and the Finite Element and Mesh Generation programs are resident in the mainframe computer. Appropriate softwares have also been developed for effective communication between different packages of this integrated system. The difficulties experienced in making the system work and the way these facilities were solved are described in this thesis with special reference to communication software.

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CHAPTER ONE

1- INTRODUCTION

The term CAD/CAM stands for Computer Aided Design and Computer Aided Manufacturing,and is intended to relate to a closely integrated system of producing components from the design stage through to manufacture using computer assistance.In practice it is only larger installations that achieve this goal.It is more common to find that CAD systems (based on computer aided draughting principles) ,and CAM systems (based on stand-alone CNC machines) ,operate in comparative isolation.

True CAD/CAM systems provide the all important link that converts information generated by the CAD system into a form that can be readily utilized by the manufacturing systems of the organizations.

1-1- COMPUTER AIDED DESIGN

CAD systems require large amounts of computing power For this reason they are usually based around mini-computer or large capacity micro-computer Peripheral devices such as printer,plotter,disc storage devices,etc.are also required.This may be shared by a number of users.CAD software is usually expensive.

It is common to talk of a CAD workstation at which the designer interacts with the system A typical workstation comprises a high resolution graphics screen and some means of inputting informations. Input devices include keyboards,graphics/menu,tablets,light pens, joysticks and hand held mice.

On larger systems it is common to have an additional VDU (Visual Display Unit) screen on which commands,menus and other textual information appear, all graphics being plotted on a dedicated graphics VDU

The designer who uses a CAD system now spends most of the working day sitting at the computerized workstation and concentrating on information displayed on VDU devices

Many of the above input devices have been designed to ease the strain of interacting with computerized systems.This and other ergonomic considerations,such as lighting and posture,should be considered as important as in the planning of a CAD installation. CAD software is usually supplied as different packages that can be used for different aspects of the design process A CAD system is likely to consist of more than one package.It is essential that all packages within the system are compatible so that data can be transferred between them The most common packages include

- **Design analysis packages**

  This is specialist software that performs complex mathematical analysis on designs originated by the designer Stress analysis on large structures is a typical example.Such packages have the advantage that designs can be optimized for maximum performance in a very short time Using such a package means that better quality products with fewer errors can be produced quickly and accurately.

- Surface and solid modelling packages

This software allows the creation of 3-Dimentional models of objects to be constructed quickly on graphic screen Design concepts can be visualized from all angles,in true perspective,and in some cases in colour. Surface modelling generally produces wire-frame representations,whilst solid modelling produces a solid representation which can be sectioned as required. Modifications to the design can be carried out swiftly allowing various alternatives to be explored.Customer's requirement can be matched quickly and accurately and design time is considerably shortened

- Simulation packages

This software usually models the operation of dynamic systems. For example,mechanical systems such as car suspension performance,or organizational systems such as complete factory layouts simulating different components routing through the system,may be simulated.Performance characteristics and design variables may be used to contract physical set-ups.

- 2-D draughting Packages

These are by far the most common packages in use They allow detail drawings and designs to be contracted quickly and easily on the graphics screen.Complete working drawings can then be generated from the stored information.They also offer the following facilities·

- Move,draw and delete lines
- Points,circles,arcs,etc in a variety of line types
- Ability to store and retrieve information to/from backing store.

Common facilities of such systems also include the following

- Rotate all or part of the design through any angle
- Scale parts of the design up or down.
- Translate parts of the design to different positions

- Replicate the same feature at different places
- Pan across a large design using the screen as a window.
- Zoom-into or away from design features

Many packages also offer automatic dimensioning and cross-hatching facilities as well as the ability to apply layering Layering involves producing different parts of the design on different screen and storing them separately.The designer can then recall any screen combination and superimpose different layers on top of each other This allow an uncluttered build-up of drawings to be accomplished. Standard parts or symbols may also be defined and stored in a symbol library They may then be recalled and positioned on the drawing at any desired position

The data generated by the software is held on disc or tape as computer file.If this data can be accessed by other software within the manufacturing system,it can then form the basis of a manufacturing data base that can support post-design activities

1-2- COMPUTER AIDED MANUFACTURING

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

CAM software is perhaps just as important.Much CAM software makes use of data generated at the CAD stage BY interrogating the appropriate computer files,CAM software can provide.

a) A list of materials and parts which can be used for Materials Requirements Planning (MRP),stock control and estimating.

b) Post-processed output of component design data into CNC, part program language,suitable for transmission via DNC.

c) production planning data concerning machining time,operation sequences,and tooling requirement which can assist process and production planning.

Much of the above CAM software is itself now being packaged into a separate category know as Computer Aided Production Management (CAPM) The aim of CAPM is to monitor and control the production management elements of materials control,work-in-process and accounting. It can be seen that a manufacturing installation make use of CAD/CAM and FMS (Flexible Manufacturing System)

1-3- BACKGROUND LITERATURE

A large number of works have been done in CADCAM systems during the last twenty years. Most of these works have been done in the development of integrated CADCAM systems Most CAD system ara similar in their facilities but the differences appear when integrating them with other systems such as CAM. The main efforts have been concentrated on the computer aided manufacturing and the different ways of making use of the CAD in order to simulate the manufacturing processes and then develop the suitable code to control the machines.

For example an integrated system called KNOTS [1] has been developed for generating optimized numerical control commands the instruct NC machine system to produce complex splining geometry

SPAM [2] is a software package under development at Instituto di Ingegnria Meccanica of Firenze University for application on standard microcomputers It is devoted to provide a set of facilities for NC machine tools.

Furthermore, efforts have been devoted on individual aspects of the CADCAM system. The company which has been using a Finite Element Analysis and gets CAD system,for example, might think of integrateing the analysis package with the CAD package and also with other new packages. ADINA [3] is a Finite Element Package which has performed a higher degree of automation in mesh generation and refinning the mesh and the feedback of the mesh before and after deformation. All these facilities have been done using CAD system.

Also the DRAFT-MESH [4] is a computer aided and finite element mesh generation package. This package consists of a draughting routine for planar or axially symmetric models, with the option to interactively generate a data file The file can then be used with an existing finite element mesh generation program to enable the user to view incremental and history mesh. Graphics were used to both draughting and to interface with GRID4,the mesh generation program,wherever possible. This was done because in many ways it is easier to work with picture than to work with the numbers which represents these pictures. Reference [18] also discuss the automation of mesh generation for structural analysis.

Paull Gitto in [7] discussed interfacing Direct Numerical Control (DNC) with CADCAM system. IN [19] a postprocessor has been developed to convert the Automatic Programming Tool (APT) language into G-Code language. So this software might be used with other graphic packkages to develop an integrated CADCAM system Some studies were about using personal computers for manufacturing engineer [20] or using PCs as support computers for mainframe computers [21]. For example at General Electric Aircraft Engin Div.,24 PC-Based VersaCAD systems from T&W systems Inc.[22], and at Boeing 5400 of these devices most of them used for engineering work such as preliminary parts design and coare Finite Element modeling. Nearly all Boeing PCs are connected to large computers , and most are being tied together through networks that enable users in different cities to exchange numerical data and text [22]

Similar progress has been done in integrating the graphic packages with manufacturing packages [8],[9] [10],[11],[12]. So it was possible for example to produce the tool path of CNC machines using CAD facilities and save them in the CAD data base to be used later by postprocessors to produce the G-code for a particular machine-controller combination The General Electric Aircraft Engine Group's Evendale, Ohio DNC system services 100 nc machines The DNC system is only one step in their total CAM project [23] Another CADCAM system which offer mainly numerical control via computer graphics in General Motors Institute U S.A. using a work station based on PDP-11/70 computer with 384KB [24].

Another area has been studied is the application of mini-computer to a numerical cotrol system to perform numerical control, servo control and adaptive control for metal cutting process [25]. CN3D-LURPA is a machining software for forging dies. From a part definition drawing , it is possible to machine by aided programming a 3D part with complex topology [26].

1-4- SCOPE OF PRESENT WORK AND ITS AIM

CAD has became a standard tool in engineering design and analysis.At the design stage it is normal practice to develop a draught and carry out an elastic Finite Element Analysis (FEA) to assess the stress integrity of engineering components These results are usually presented as stress contours

Currently many software packages are used during the phases of the design and development process.Most of the tools are stand alone analyis or test modules that are optimized to perform specific functions.

The main objective of this project is to achieve a CAD/CAM system which is an integration of CAD and CAM techniques into a single complete process.This will mean,for example,that a component can be drawn on a VDU screen and the graphics data then transferred via coded electrical signals along a cable link to manufacturing system, where the component would be automatically produced on a CNC-machine This work has been done using a combination of PC and Mainframe facilities using three main packages, finite element analysis in main frame, AutoCAD and NC programmer for milling machine in PC Also part of the work was to modify the postprocessor of the NC programmer in order to generate the part program for a particular machine-controller combination To achieve this aim several communication packages have been developed to provide suitable linkage between the main packages and accurate data transfer.

This theises divided into six chapter, the first chapter is the introduction contains the definition of CADCAM, the previous work and scope of the present work. Chapter two is about the development of a software for designing power transsmision shafts using the conventional methods in designing. Chapter three explains the packages used in this project and the development of communication software for integrating the CADCAM system. Chapter four gives a view about NC,CNC Machine Tools and part programming Chapter five is about computer aided manufacturing and the explaination of the package which has been used Chapter six is the last one, it contains a full example of machining a component using the NC programmer package. Finally ,the appendix which contains all the programs and the postprocessor which have been developed in this project

CHAPTER TWO

SIMPLE ILLUSTRATION OF CAD

2-1 DEVELOPING A SIMPLE COMPUTER SOFTWARE BASED ON CONVENTIONAL DESIGN METHODS.

This program is developed using BASIC language to design simply supported shafts which are affected by the torque produced by an power source, such as an electric motor,and transverse load acting on the shaft should be noted that this program does not have the capability of designing shafts under very complex loading.

The aim of this program was to provide an illustration only and not to develop a complete program to cover all conditions.That would be out of the scope of this thesis It would also be inappropriate to develop an analysis program for several types of conditions based on the conventional methods of analysis.

Now a days, many designers are using different methods for analysing engineering components.One example is the Finite Element Method and this method has been chosen for use in this project. The main aims of this study are

- Getting extensive practice and training in programming methods, using data files and connecting programs together.

- To understand the differences between the conventional methods of analysis and the new methods which offer accuracy and reduction time consumption

2-2 DATA INPUT

The first stage of any interactive computer program is to interrogate the program user until all the required data has been received. In the program discussed here the user has to input the data gradually according to the options of the program depending on different conditions of load application

Initially the program has two options for simply supported shafts. The first one has two supports at its ends. The second option also has two supports. However, one of them is at the end of the shaft which is connected with power supply, and the second support can be anywhere along the shaft.

So,at the beginning of the program the user has to input the power value (P) which must be transmitted,the length of the shaft,and the speed of rotation (N). Also there are several alternatives for loading and support locations.For example,the user may have a concentrated load,distributed load,pure bending moment or forces which act parallel to the shaft.The last type of load produces two load conditions,pure bending moment and pure extension or compresion load

This master program consist of five programs They are

1 Input program
2 Design specification program.
3. Material selecting program.
4. Standard components program.
5. Calculation program.

These programs are given in **Appendix [A]**.

In order that these programs may be extended in future which may cause them to become too large, especially those parts which deal with material selection,standad components and design specifications,it was necessary to break the program into sections and save each one separately.

Essentially each section becomes a separate program and it is given a name when it is saved.Then the execution is begun by bringing the first program into the main memory and running it At the end of this program,a special statement is executed to fetch the second program after erasing the first one to be executed,and so on until the last program is executed. This process is called chaining,and the statement which is used is

CHAIN "program name"

One problem with "CHAIN" statement is that all data used or produced by the first program will be erased after fetching the second program.To solve this problem a data file containing all of the data was created.This data file must be opened at the end of the first program just before the CHAIN statement,and all the necessary data should be saved on it.The same file also must be reopened at the beginning of the second program and the data should be read and saved in the main memory to be used in the second program.

2-3 THE INPUT PROGRAM

The input program starts with the main symbols which are used in all the programs and the units which are used.Then the auxliary symbols appear. Next, the program will interrogate the user until all the required data have been received.After that the input program will connect Design Specification Program.

2-4 DESIGN SPECIFICATION PROGRAM

This program contains the schedule of the factor of safety according to the application conditions of the components, and it may easily be expanded by the user to add extra data files which contain other specifications. After selecting the factor of safety,the program will connect to the Material Specification Program.

2-5 MATERIAL SPECIFICATION PROGRAM

This program is a general program which can be used for a wider selection of engineering component and allow the user to select suitable materials.According to the function of the component the designer can decide on at least one specification,which will be the principle considerations for the selection of materials. This specification may be the hardness of the material,the weight,or the yield stress,and so on

This program allows the user to chose suitable material from a special data file and print the name of the material and its specifications on the screen and in another data file to be used later.At the same time the program will assign this specifications to their variables. The program also cover the case of the designer who does not have any specification in mined.In this case he can display the data file and try to find the material. The flow chart of this program illustarted in Fig. (2.1).

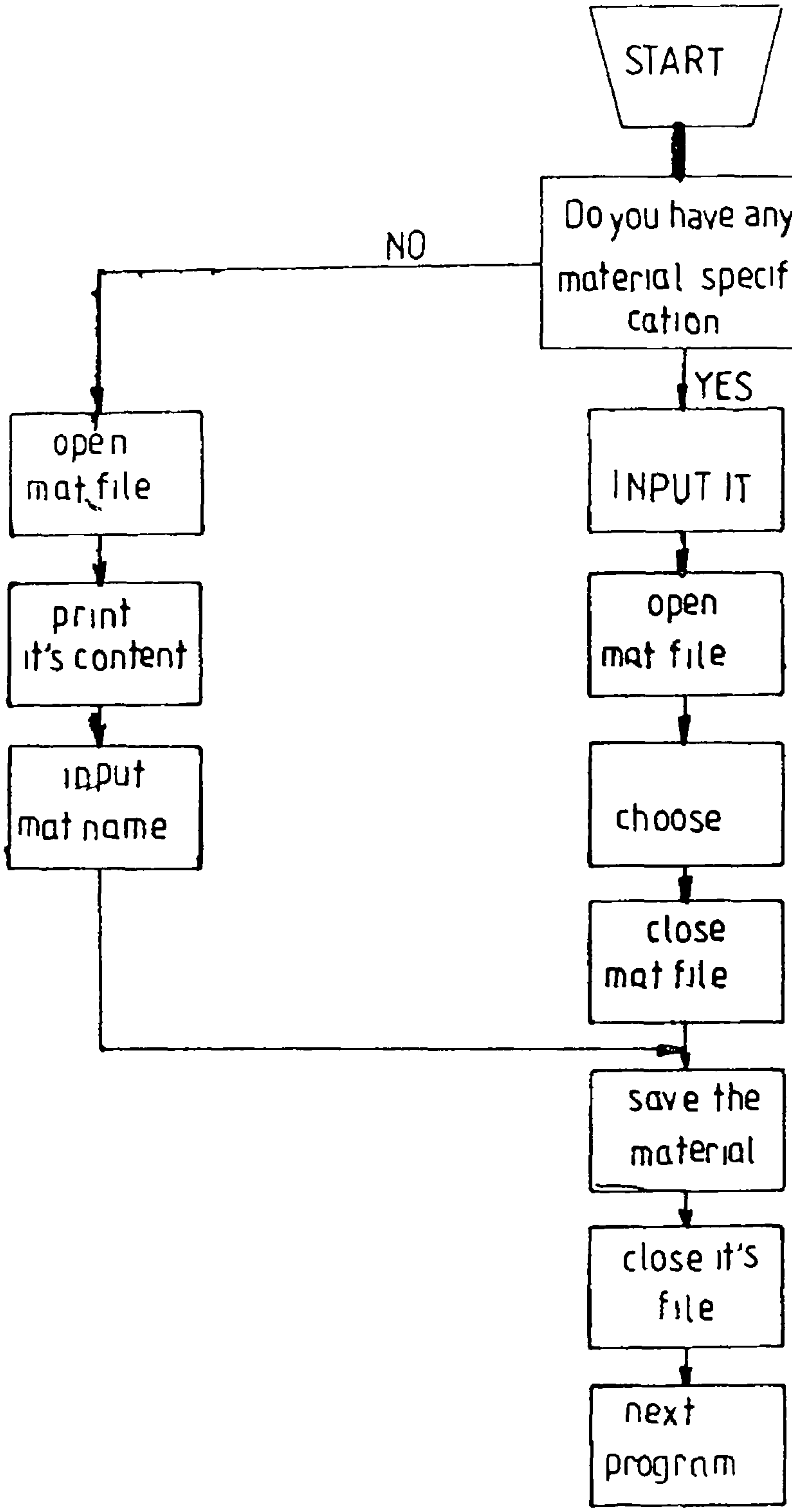


Fig (2 1) FLOWCHART OF THE MATERIAL SELECTION PROGRAM

Finally, the program will connect with the Calculation Program

2-6 CALCULATION PROGRAM

The area of investigation is a shaft subjected to the simultaneus application of a bending moment (M), as a result of various loads such as concentrated load, pure bending moments and so on, and a torqe (T) produced by the power transmitted from a motor at N(r p.m) speed.

The principal stresses set up in the shaft can be shown to be equal to those produced by an equivalent bending moment of a certain value (Me) acting alone to produce unequivalent stress.

From the simple bending theory the maximum direct stresse set up owing to bending moment M are given by [27]

$$\sigma_a = \frac{M \cdot Y_{max}}{I} = \frac{M \cdot D}{2 \cdot I}$$

Similarly, from the torsion theory, the maximum shear stress in the surface of the shaft is given by .

$$\text{Tao} = \frac{T \cdot R}{J} = \frac{T \cdot D}{2 \cdot J}$$

For a circular shaft, however, J=2I

$$\text{Tao} = \frac{T \cdot D}{4 \cdot I}$$

The principal stresses for this system can now be obtained by applying the following formula

$$\sigma_1 \text{ or } \sigma_2 = \frac{1}{2} (\sigma_x + \sigma_y) + \frac{1}{2} \sqrt{[(\sigma_x - \sigma_y)^2 + 4 \cdot \text{Tao}^2]}$$

As $\sigma_y = 0$, the maximum principal stress SIG1 is given by.

$$\sigma_1 = \frac{1}{2} \left(\frac{M \cdot D}{2 \cdot I} \right) + \sqrt{[(M \cdot D/2 \cdot I)^2 + 4(T \cdot D/4 \cdot I)]}$$

$$\sigma_1 = \frac{1}{2} \left(\frac{D}{2 \cdot I} \right) (M + \sqrt{M^2 + T^2})$$

Now after we have got the maximum principal stress σ_1 we can use the maximum principal stress theory to determine the safe design under this combined bending and torsion load.

For the shaft to be satisfactory, the following must be fulfilled ·

$$\sigma_1 \le \frac{\sigma_y}{F_s}$$

Where σ_y is the yield stress of the material and

F_S is the factor of safety.

Therefore

$$\frac{\sigma_y}{F_S} = \frac{1}{2}\left[\frac{D}{2}\left(\frac{\pi \cdot D^2}{32}\right)\right] \cdot \left[M + \sqrt{M^2 + T^2}\right]$$

$$D = \sqrt{\frac{8 \cdot F_S \left(M + \sqrt{M^2+T^2}\right)}{\pi \cdot \sigma_y}}$$

This formula gives the required diameter for a shaft subjected to a combined bending and torsion load The flow chart of this program is shown in Fig. (2 2).

After the calculated diameter has been obtained,the program will be connected with the standard components program.

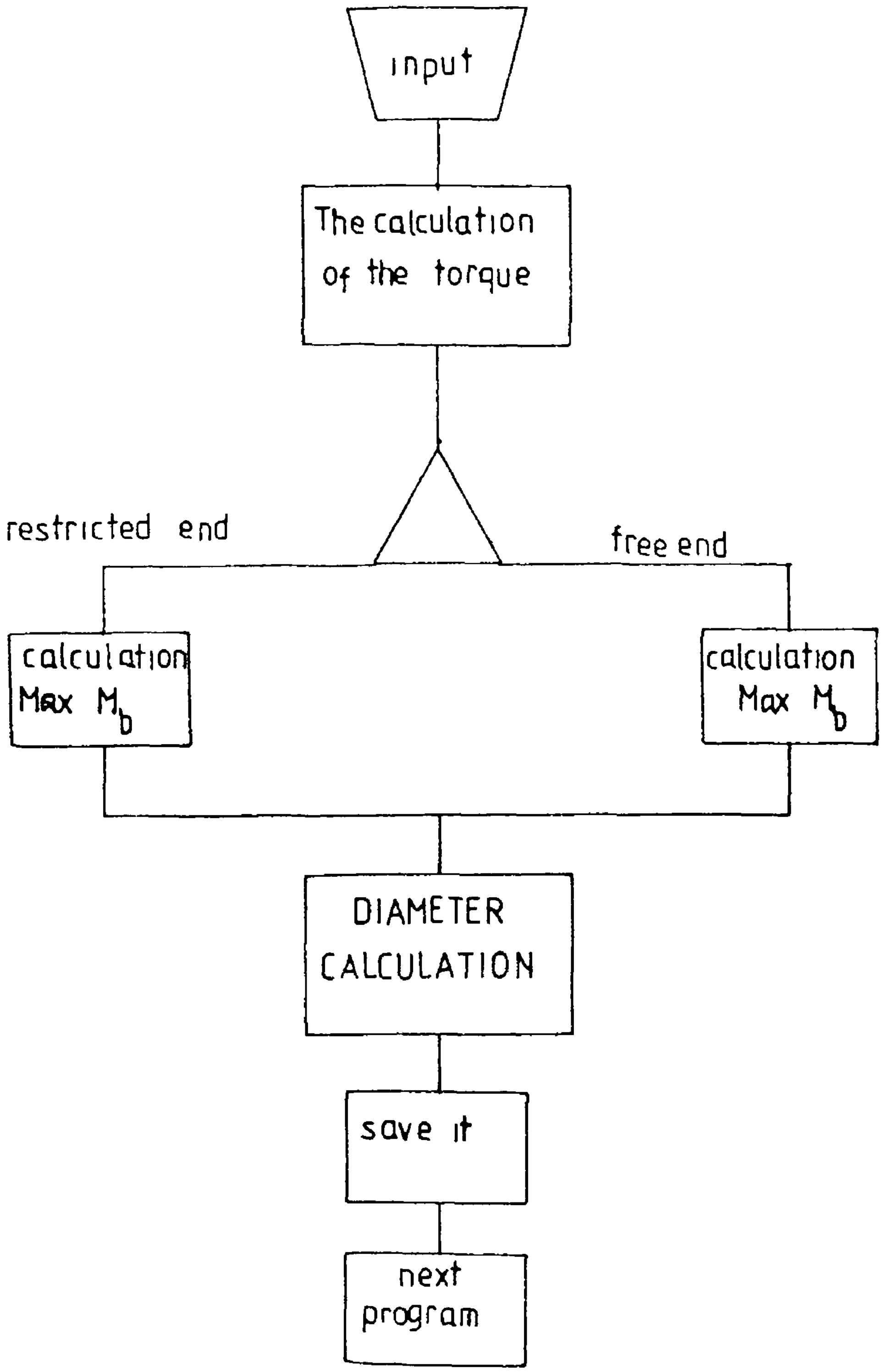


Fig (2 2) FLOWCHART OF THE CALCULATION PROGRAM

2-7 STANDARD COMPONENTS PROGRAM

After calculating the diameter of the shaft, the desiger needs to know if it matches a standard component. The program starts by opening the data file which contains the standard diameters.It picks up the first value and compares it with the calculated one, then the second value and so on

It continues its rearch until it comes across the first value which is equal to slightly or greater than the calculated value.

After finding the standard diameter the program assigns its value to the initial variable and then it connects with the input program to try again or abort The flow chart of this program is illustrated in Fig.(2.3) .

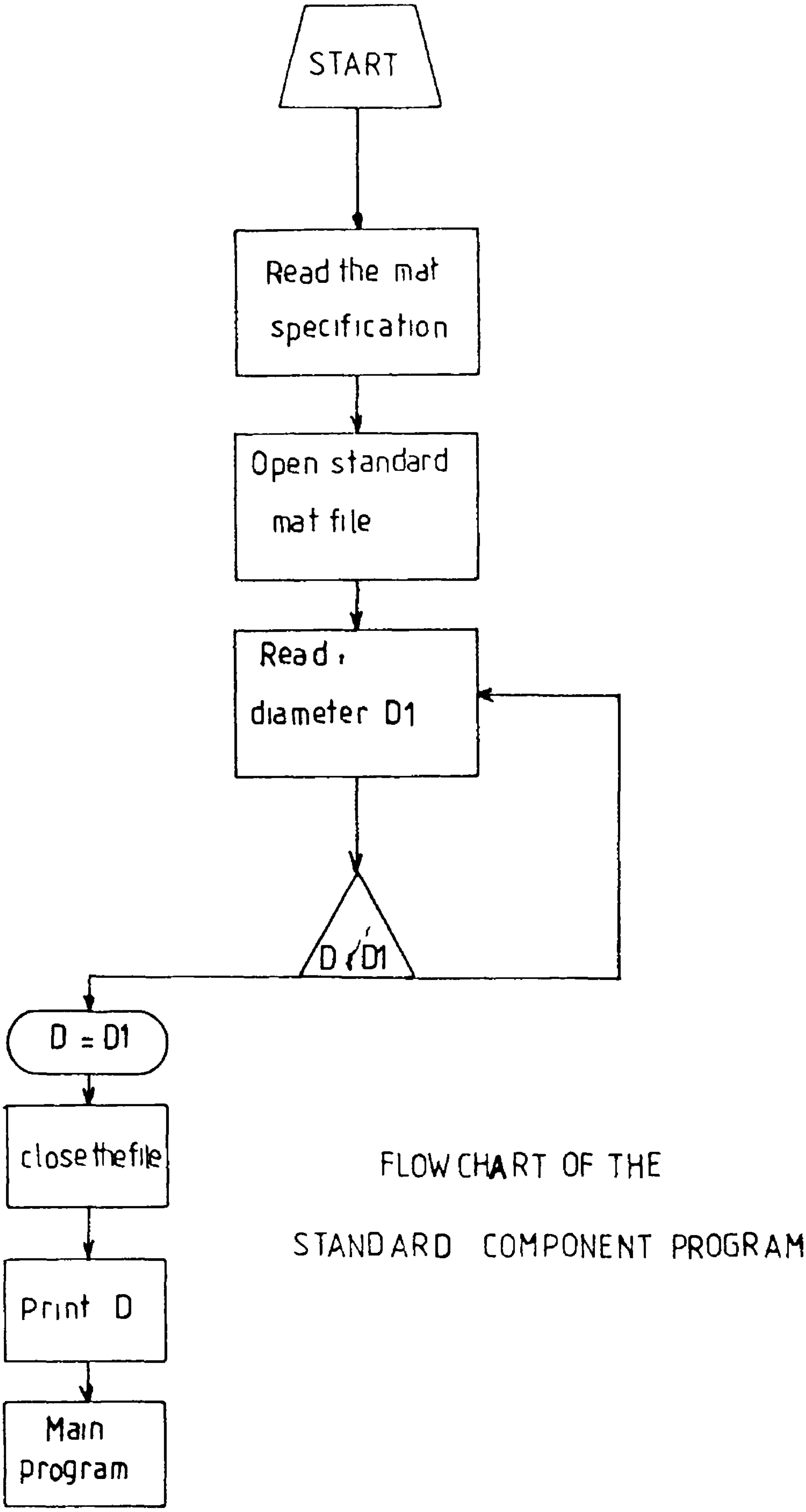


Fig (2 3) FLOWCHART OF THE STANDARD COMPONENT PROGRAM

CHAPTER THREE

COMPUTER AIDED DRAUGHTING AND DESIGN

(CADD)

3-1 COMPUTER AIDED DRAUGHTING

In this project AutoCAD package Release-10 has been used for draughting the mechanical components. This package is installed on PC(s) and occupies 4Kbyte of memory. AutoCAD provides a set of entities for use in constructing the drawing with different options to use the key board,mouse or digitizer as the input device.

Anther AutoCAD function let the user to modify the drawing in a variety of ways. It is possible to erase or move entities, or copy them to form repeated patterns

Also, it is possible to change the view of the drawing displayed on the screen, or display information about drawing. AutoCAD also provides drawing aids that help the user to position the entities accurately It has all facilities for zooming ,planning and use of blocks and layers.

AutoCAD supports the Initial Graphics Exchange Standard (IGES) file format and the DXF (Drawing Interchange) file format. DXF files are standard ASCII text files and these have been used in this project.

3-2 FINITE ELEMENT ANALYSIS

Finite Element Analysis (FEA) has become one of the most widely-used techniques for analysing mechanical loading characteristics in modern engineering components. Traditional analysis technique,though theoretically sound,can only be satisfactorily applied to a range of simpler component shapes and specific loading conditions

Unfortunately,the majority of engineering loading situations are not simple and straight forward. Therefore, the traditional techniques often need to be modified and compromised to suit situations for which they were not intended. The uncertainty thus created commonly loads the designer applying excessively high safety factors to the mechanical loads and so to "overdesign" components by specifying either unnecessarily bulky cross-sections or high- quality materials Inevitably the cost of the product is adversely affected

FEA allows the designer to effectively analyse complex components by splitting a shape into small , simpler finite elements. These elements may be of 2-node for one dimensional applications or 4-node,8-node and 9-node for two dimensional applications, where nodes are the points by which the elements are connected.

To generate these elements there is a special program used at the beginning of a finite element program called THE MESH GENERATION PROGRAM . It gives the coordinates of each node and the nodes which form each element.

3-2-1 Stages for Using Finite Element Program

The procedure for using a FEA program consists of three essential stages :

1- Preparation of the model data (Pre-Processing).

2- Analysis of the model.

3- Assessment of the results (Post-Processing).

These stages are illustrated in Fig. (3.1)

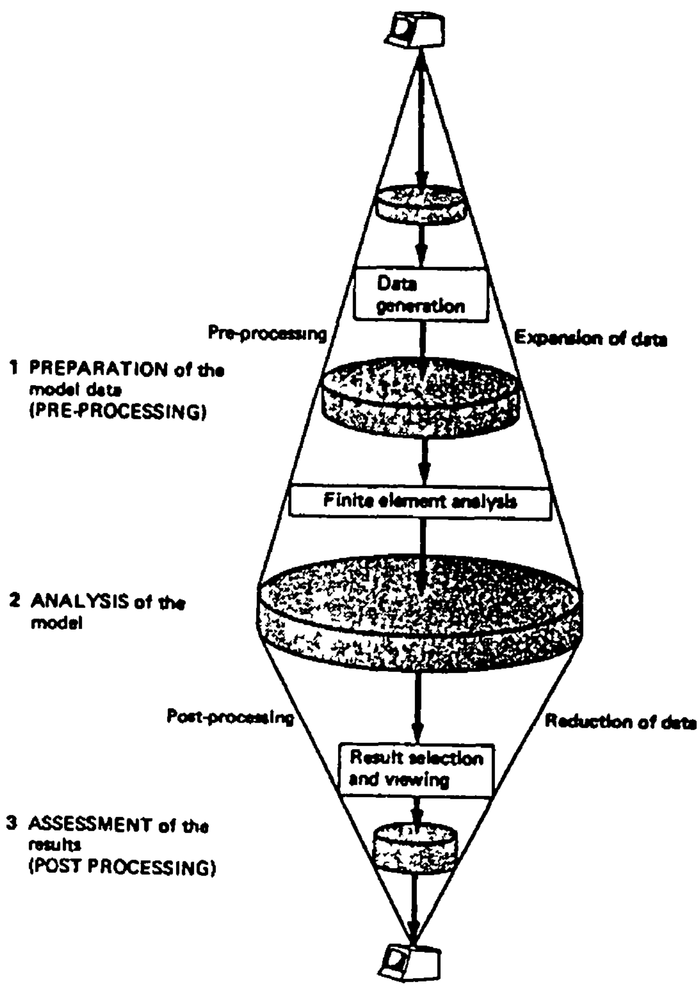


Fig. (3.1) Stages for using Finite Element Program.

The Pre-Processor is a program which enables the engineer to build a geometric model of a component design. From this model, the required mesh of finite elements may be generated .The Pre-Processor part is illustrated in Fig. (3.2)

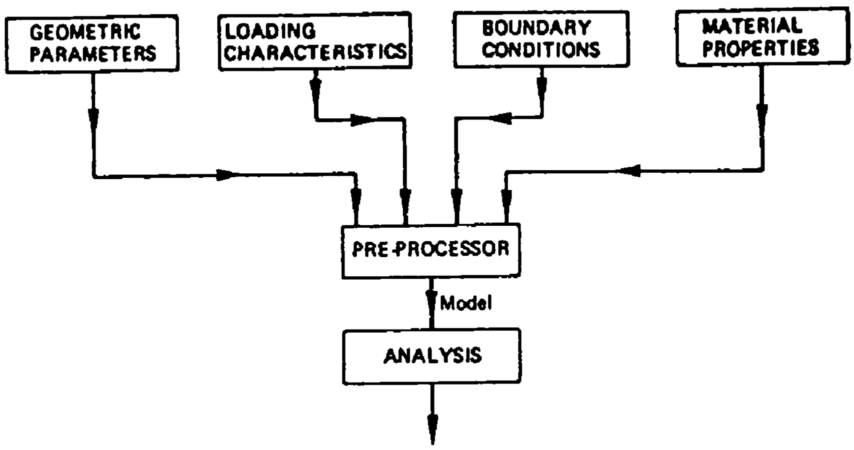


Fig. (3.2) The preprocessor for Finite Element Program.

As illustrated in Fig. (3.2), required input to the Pre-Processor includes :

1- Geometric parameters (e.g.type of element,nodal coordinates,variation of mesh intensity). These may be entered directly into the FEA software,or may be obtained via an interface with a CAD draughting or solid modelling package.

2- Loading characteristics e.g.magnitudes,positions and load directions of points; pressure, thermal.

3- Boundary conditions e.g.positions and directions of nodal fixities;rotational axes;frictional resistance; prescribed displacements.

4- Material properties e.g.Young's Modulus;Poisson Ratio; density ; coefficient of friction ; coefficient of expansion.

The Post-Processor is a program which provides the engineer with means to assess the results of the model analysis. As illustrated in Fig. (3.3) analysed results which are output from the Post-Processor may be in either data form (screen or printer) or graphical display (screen or plotter).

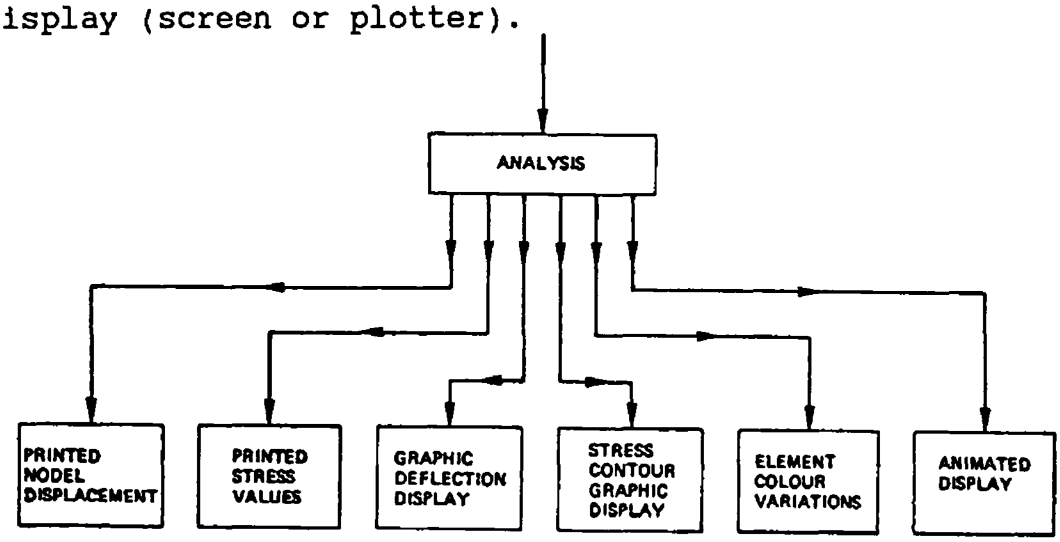


Fig. (3.3) The postprocessor for Finite Element Program.

Typical Post-Processor output includes ·

a) Printed nodal displacement values.

b) Printed element stress values

c) Graphical display of distorted component mesh under load (with ability to magnify displacements by a stated multiplication factor).

d) Graphical display of stress contours.

e) Colour or tone variation of element display according to stress-range values.

f) Animated displays of moving displacements and varying element patterns for dynamic loading analysis

3-2-2 The Package Used in The Project

The program which is used in this project is taken from the "FINITE ELEMENTS IN PLASTICITY theory and practice" by D R.J.OWEN & E.HINTON. This package is accompanied by a book to present and demonstrate the use of finite element methods. This book is arranged in three main parts

* One-dimensional problems.
* Two-dimensional applications.
* Dynamic applications

In this project the Two-dimensional applications program has been used.This program considers the elasto-plastic stress analysis of solids which conform to plane stress,plane strain or axisymmetric condition.

Most of the problems encountered in engineering can be approximated to satisfy one of this classifications.

As we said before this program has been developed for elasto-plastic applications. Some modifications had to be made in order to make it applicable for pure elastic cases.

First of all it should be possible to detect the stage when the material goes into plasticity . The user can observe the total effective plastic strain for each Gauss point which gives an immediate indication whether the Gauss point has yielded or not, since it will be zero for all elastic points [28].

As output, this program gives the Cartesian stress components,the principal stress and direction,in addition to the total effective plastic strain for each Gauss point

The calculation of equivalent stresses has been added to the subroutine OUTPUT in order to observe the achievement of certain Factor of Safety.

DATA INPUT

For any finite element analysis program the input data can be subdivided into three main classifications. Firstly, the data required to define the geometry of the structure and the support conditions must be supplied Secondly, the material properties of the constituent materials must be supplied and finally, the applied loading must be furnished.

To allow a subroutine to be employed in more than one application, several control parameters must be supplied as input data.

A list of control parameters required as input is now presented ·

NPOIN: Total number of nodal points in the structure.

NELEM: Total number of elements in the structure

NVFIX Total number of boundary points, i.e. nodal points at which one or more degrees of freedom are restrained.

NTYPE Problem type parameter

1-Plane stress.
2-Plane strain.
3-Axial symmetry

NNODE Number of nodes per element :

4-Linear isoparametric quadrilateral element.

8-Quadratic isoparametric Serendipity element

9-Quadratic isoparametric Langrangian element.

NMATS: Total number of different materials in the structure

NGAUS The order of Qaussian quadrature rule to be employed for numerical integration of the element stiffness matrices,etc..If NGAUS is prescribed as 2 a two-point Gauss rule is to be employed,if NGAUS is input as 3 a three-point rule will be used

NALGO Parameter controlling nonlinear solution algorithm

1- Initial Stiffness Method. The element stiffnesses are computed at the beginning of the analysis and remain unchanged thereafter.

2- Tangential Stiffness Method.The element stiffnesses are re-computed during each iteration of load each increment.

3- Combined Algorithm. The element stiffnesses are re-computed for the first iteration of each load increment only.

4- Combined Algorithm.The element stiffnesses are re-computed for the second iteration of each load increment only.

NCRIT The yield criterion to be employed,

1- Tresca.

2- Von mises.

3- Mohr-Coulomb.

4- Drucker-Prager.

NINCS: The total number of increments in which the final loading is to be applied.

NSTRE The number of independent stress components for the application,

1- Plane stress/strain.

2- Axial symmetry.

COORD(IPOIN,IDIME)· The coordinates of the nodes.

PROPS(NUMAT,1) Elastic modulus,E

PROPS(NUMAT,2) Poisson ratio.

PROPS(NUMAT,3) Material thickness t.

PROPS(NUMAT,4) Material mass density.

PROPS(NUMAT,5)· Uniaxial yield stress.

PROPS(NUMAT,6) Hardening parameter H'.

PROPS(NUMAT,7): Angle of internal friction for Mohr-Coulomb and Ducker-Prager materials only.

At the end we say that all these inputs are taken care of by the Pre-Processing program which writes them in the correct format to be applicable on finite element program.

3-3 SYSTEM CONFIGURATION

3-3-1 Hardware Configuration

The hardware used in this work as illustrated in Fig. (3 4) and Plate 1

a) PC(IBM compatible)with 20 Mbyte hard disk and 640 RAM. MS-DOS operating system.

b) Digitizer (LDS).

c) Printer (Star LC-10).

d) Plotter (Roland DXY-1300).

e) Graphic display unit (EAG Philips).

f) VAX mainframe computer with VMS operating system.

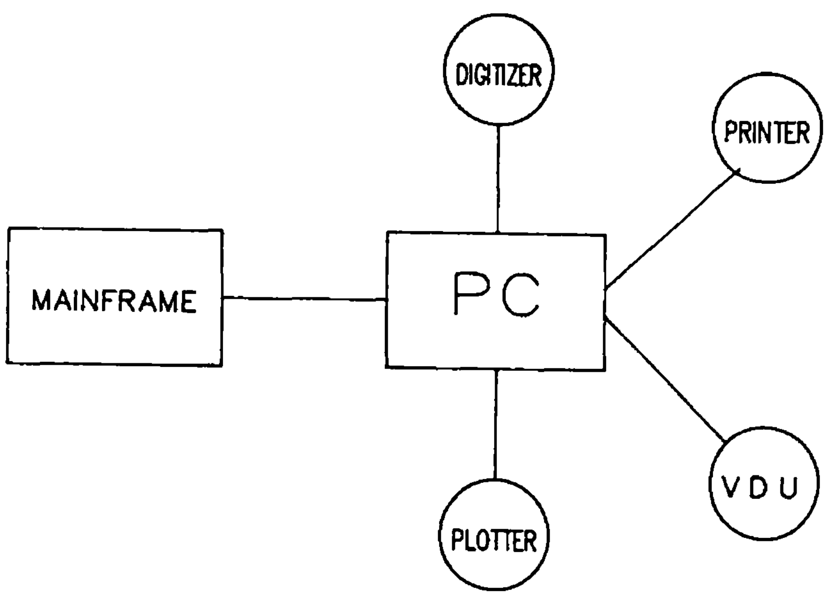


Fig. (3.4) Hardware Configuration.

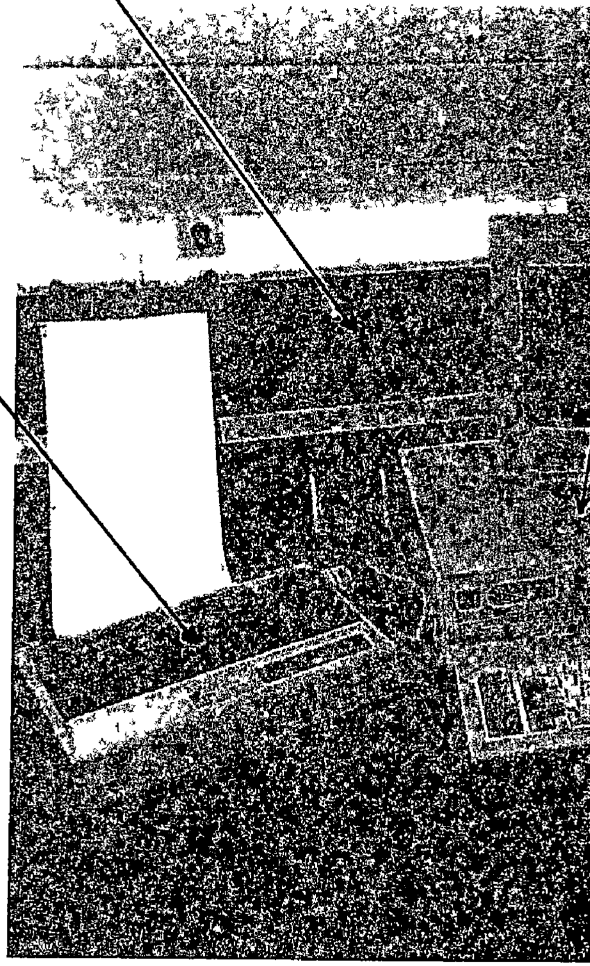
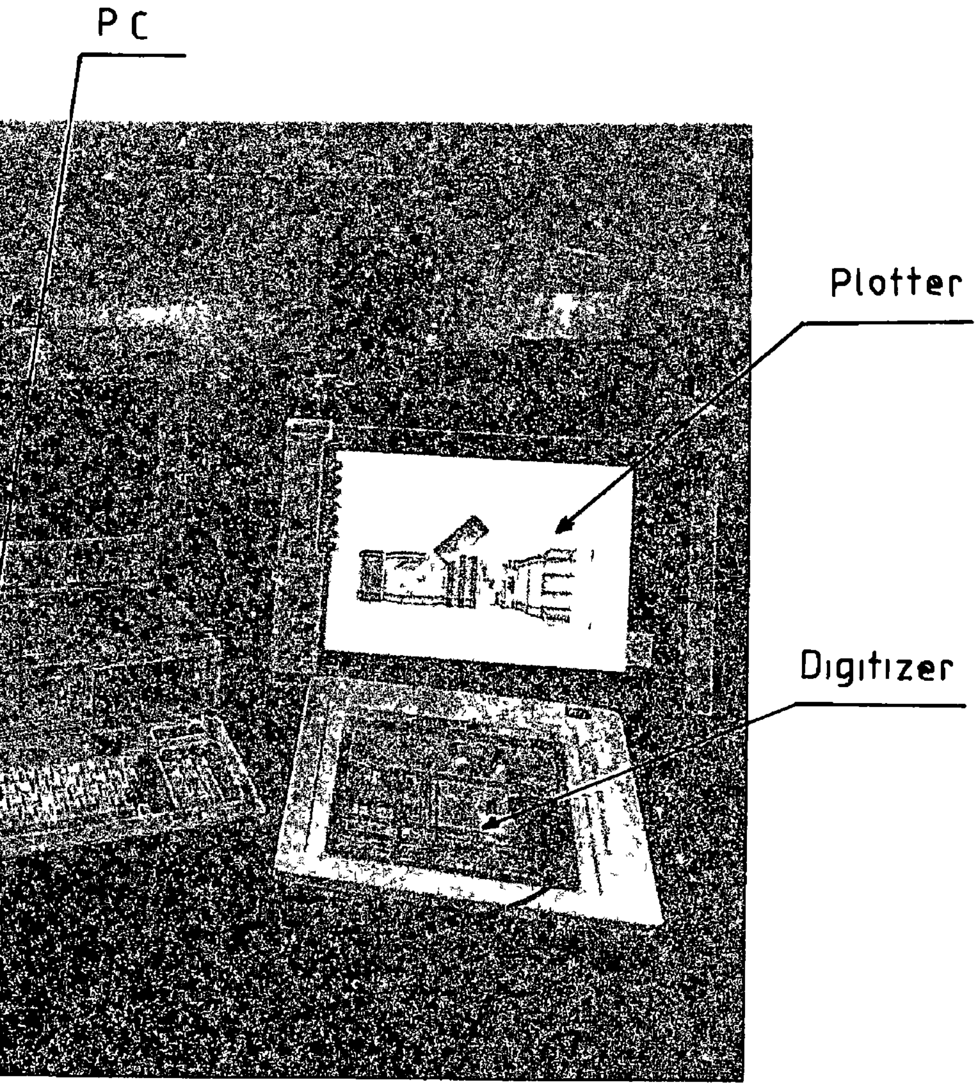


PLATE 1 Hardware



configuration

3-3-2 Software Configuration

The software packages used in this work are divided into two categories ,

3-3-2-1 The Commercial and Pre-Developed Packages

a) AutoCAD package release 10.

b) NC programmer package for milling machine

c) Kermit package for connecting PC with mainframe

d) Finite Element Program (2-D).

3-3-2-2 The Programs Developed Inhouse

The aim of this work was the development of an Integrated System for computer aided design, analysis and manufacture incorporating the above packages. In order to achieve this objective, six addition programs had to be developed to integrate the different facilities of the system,which are draughting, analysis and manufacturing

All these programs have been written in FORTRAN language and located in the mainframe.

1- An Interface Program (Interl)

This program has been developed to translate the Drawing Exchange File (.DXF) to Data File. This DXF file contains special data such as the coordinates to be used as input in the Mesh Generation Program.

2- Mesh Generation Program (Meshg)

The Finite Element Program which has been used in this project does not have Mesh Generation or Pre-Processing subroutines. A Mesh Generation Program has been developed to divide the component geometry into fine quadratic elements with four nodes. As output it produces the coordinates of each node and the nodes of each element.

3- Pre-Processing Program (Prep)

The facilities required from this program are to read the data and other information needs for the Finite Element Program from different data file and arrange them in a command file in a specific format to be used in executing the finite element program

4- An Interface Program (Inter2)

This program reads the data from the data file which contains the mesh coordinates of the nodes before deformation and translates them to a Drawing Exchange File (.DXF) to be sent back to AutoCAD.

5- An Interface Program (Inter3)

This is the last program and it is also an interface program It is similar to the Inter2 program. However, instead of receiving data from Mesh Generation Program, it receives them from finite element program as node coordinates after deformation, which are calculated by adding the displacement of the nodes to its coordinates before deformation taking account of the sign of displacement values

Primarily, this program uses these coordinates to produce a Drawing Exchange File (DXF) to be sent back to AutoCAD.

6- Stress Contour Program (Stress)

AutoCAD provides a script facility that allows commands to be read from a text file. This feature allows the user execute a predetermined sequence of commands. It is possible to run a script file from the Drawing Editor by using the SCRIPT command.

This principle has been used in this project to develop a script file for drawing the contour of the equivalent stresses for any component being analysed.

A program called "STRESS" has been developed using FORTRAN language to produce a script file as output for the component being analysed.

In AutoCAD a BLOCK has been created which contains /10/ rectangular shapes which are coloured with different colours representing different levels of stresses This block has been saved in the data base of the AutoCAD to be used in any new drawing

The "STRESS" program starts by reading the equivalent stresses and the coordinates of the nodes after deformation which have been produced by the Finite Element Program. Also it recalls modulus of elasticity from the data base.

Each element in the component being analysed has stresses which are located in the Gause points which might be two or four. So the program picks out the maximum stress in each element and saves it in a special array.

After that the program looks for the maximum stress in the component and divides the stress region between zero and the maximum value into nine selections and these stress regions are assigned to the colours in the previous block. The rectangular shape number ten will be assigned the region above the yield stress for the component being analysed.

Next, the program calculates factor of safety and saves it for the next stage.

Now the program has all the information for creating the script file. It opens a data file and writes the commands for drawing the contour and the stress scale. The sequence of the commands are as below

1- The command for creating new layer in the drawing and give it a name as "STRESS"
2- Set the current layer to "STRESS".
3- Turn off the rest of layers.
4- Insert the block which contains the stress scale in its proper place
5- Insert factor of safety as a text.

Now within a loop in the program each element stress is compared with the ten regions and according to the result it is assigned by a suitable colour number within the same loop the next commands will be written ·

6- The "DRAW" command for each element.
7- The "SOLID" command for each element.
8- The "CHANGE" command to colour the elements.

Finally ,

9- Command for blocking the contour in a block and inserting it again in a suitable scale.

10- Close the file and end up the program.

All the above softwares were incorporated in the configuration of the system's software. To make use of these packages, these have to be installed and used in the proper way.

A special directory had to be created in the PC to install AutoCAD and the NC package in it. AutoCAD occupies 4 Mbyte and NC package occupies 2 Mbyte . Kermit package should exist in PC and a path should be made to access it from AutoCAD directory

The layout of the software configuration is illustrated in Fig. (3.5).

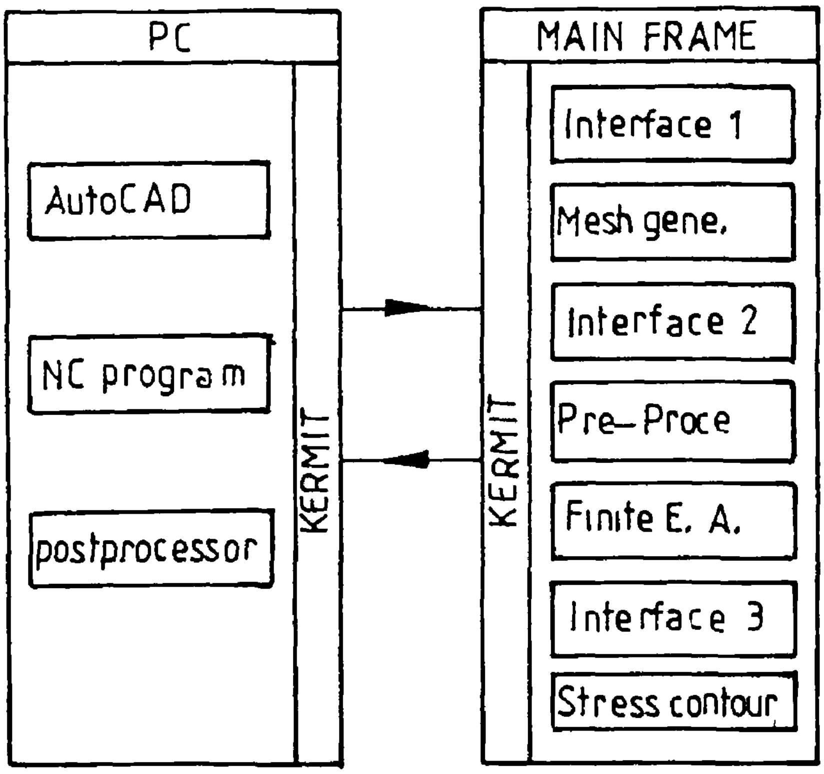


Fig. (3.5) Software Configuration.

3-3-3 System Configuration

The system configuration involved through the design of an integrated CADCAM system using the draughting , analysis and manufacturing packages by developing the communication software and some other necessary programs. Usually when a complete system is purchased from one supplier there is no problem in the communications between any two programs.

All the programs are usually integrated and a special formated file is developed to be sent to other programs. AutoCAD has the facilities to define a "Drawing Interchange" file format (DXF) which is understandable by NC package but not by the rest of the programs.

AutoCAD also supports the Initial Graphics Exchange Standard (IGES) file format.

In this work the (DXF) file has been used. Fig. (3 6) illustrate the layout of the system.

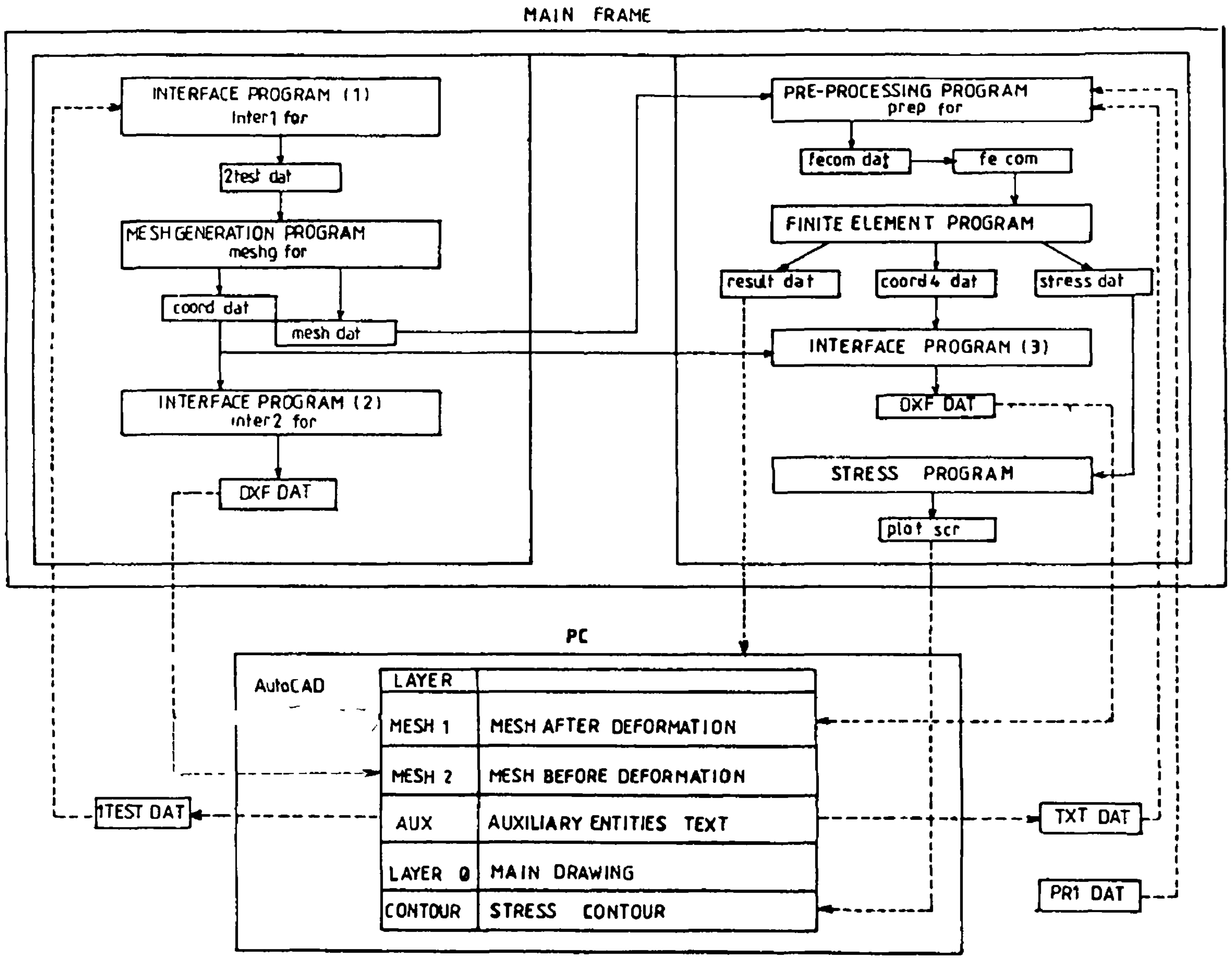


Fig. (3.6) System Configuration.

3-4 SYSTEM EXECUTION PROCEDURE

3-4-1 DRAUGHTING AND ANALYSIS

First of all, the user should be sure that the packages and programs are installed properly in their locations. AutoCAD package should be installed on the PC which is connected with mainframe by a physical connection. Kermit package should be installed also on the PC. The rest of the programs should be installed in the mainframe computer in a special directory. To illustrate the execution process clearly, a typical example of mechanical component has been chosen to be analysed and manufactured. The component with external loads is shown in Fig. (3.7) and plate 2 as appeared on the computer screen

This example has been analysed using plane stress condition The example is a component made from 30 mm thick mild steel plate. This component is subjected to three loads as shown in Fig. (3.7).It is to be hinged at point A and roller-supported at point B. The factor of safety of at least one is required on yield strength (30 dN/mm).The maximum deflection is to be less than 0.05 mm

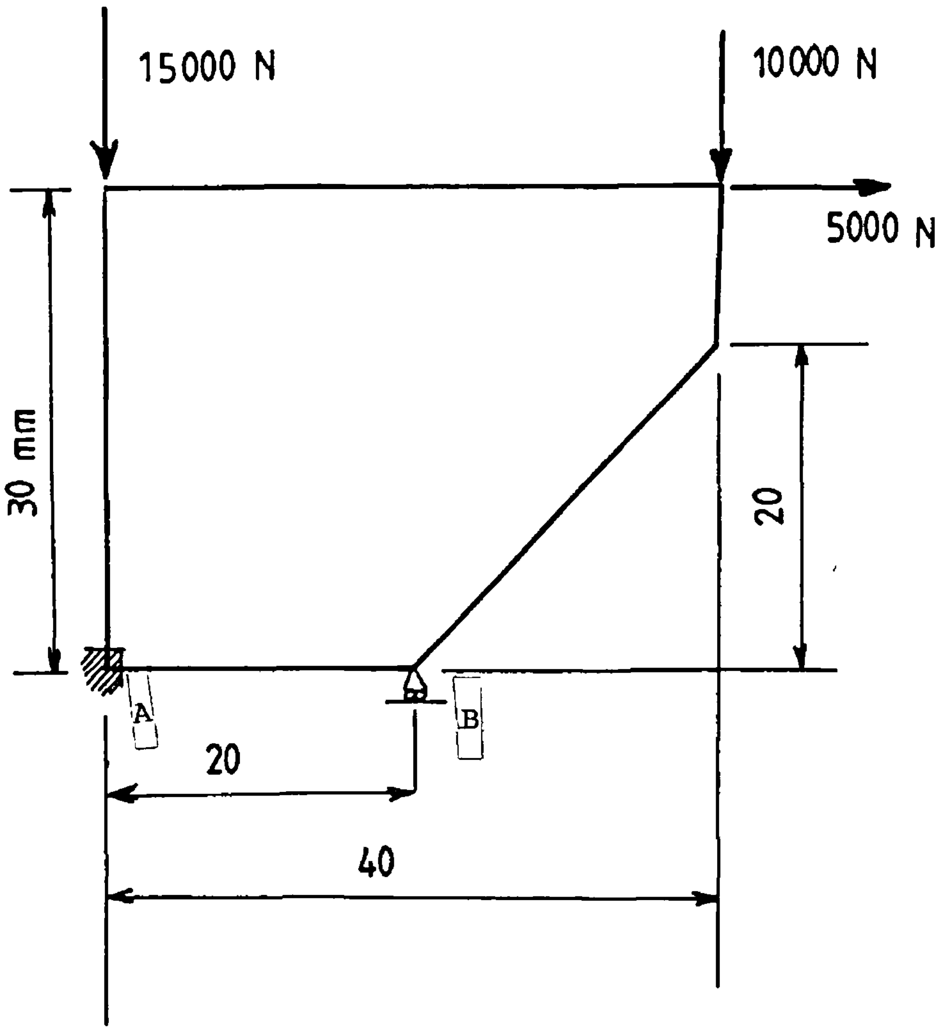


Fig. (3.7) The drawing of the analysed component.

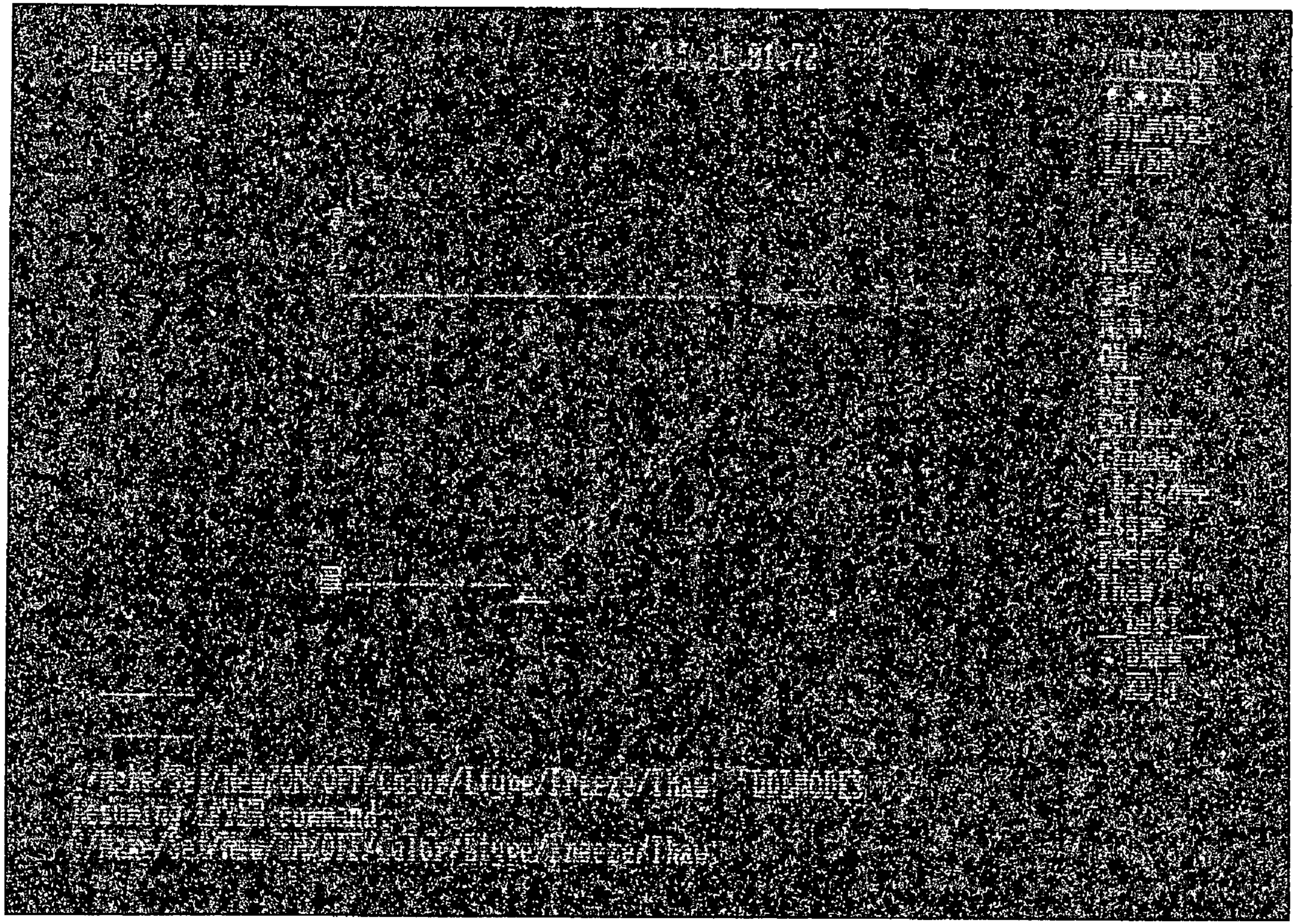


PLATE 2 Engineering drawing

a) Creating the Drawing

The first step in executing the system is to create a drawing using the digitizer and the keyboard facilities. The main entities of the drawing should be placed on the layer "0" and the text and dimensions on other layers After editing and finalizing the drawing it has to be saved in a drawing file.

b) Mesh Generation

After saving the drawing, auxiliary entities should be drawn on the component geometry to indicate the horizontal lines of the mesh These entities should not affect the main drawing so they have to be saved in a special layer. The number of these lines depend on how much the user wants the mesh to be refined. In our example 7 lines have been drawn as auxiliary entities, making sure to start the drawing of each line from the left hand side. Then the number of horizontal divisions should be inserted in the drawing as a text In our case it is equal to 4 . The lines and the number of divisions control the density of the mesh. This lines and text are illustrated in Fig. (3.8) and displayed on the screen as in Plate 3.

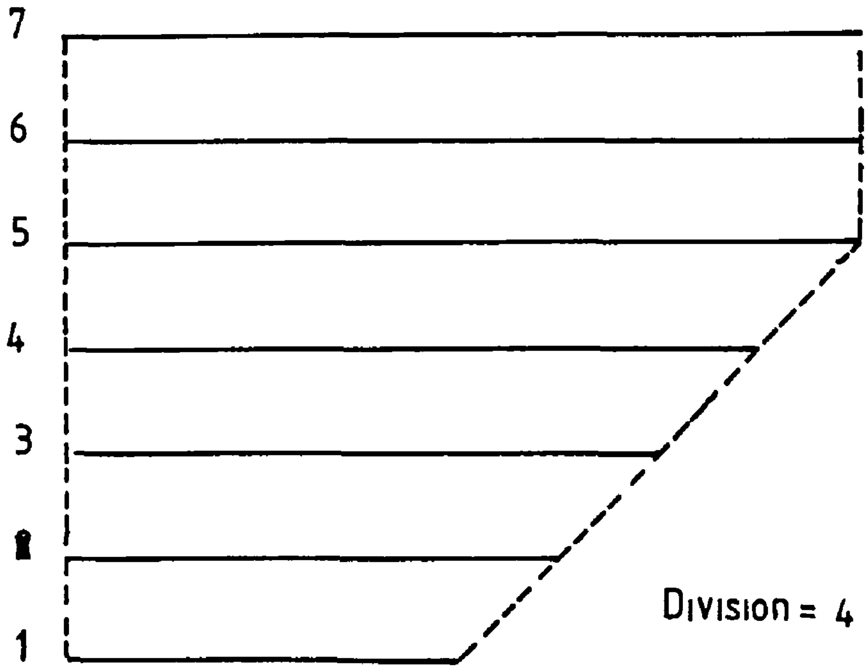


Fig. (3.8) The auxiliary entities.

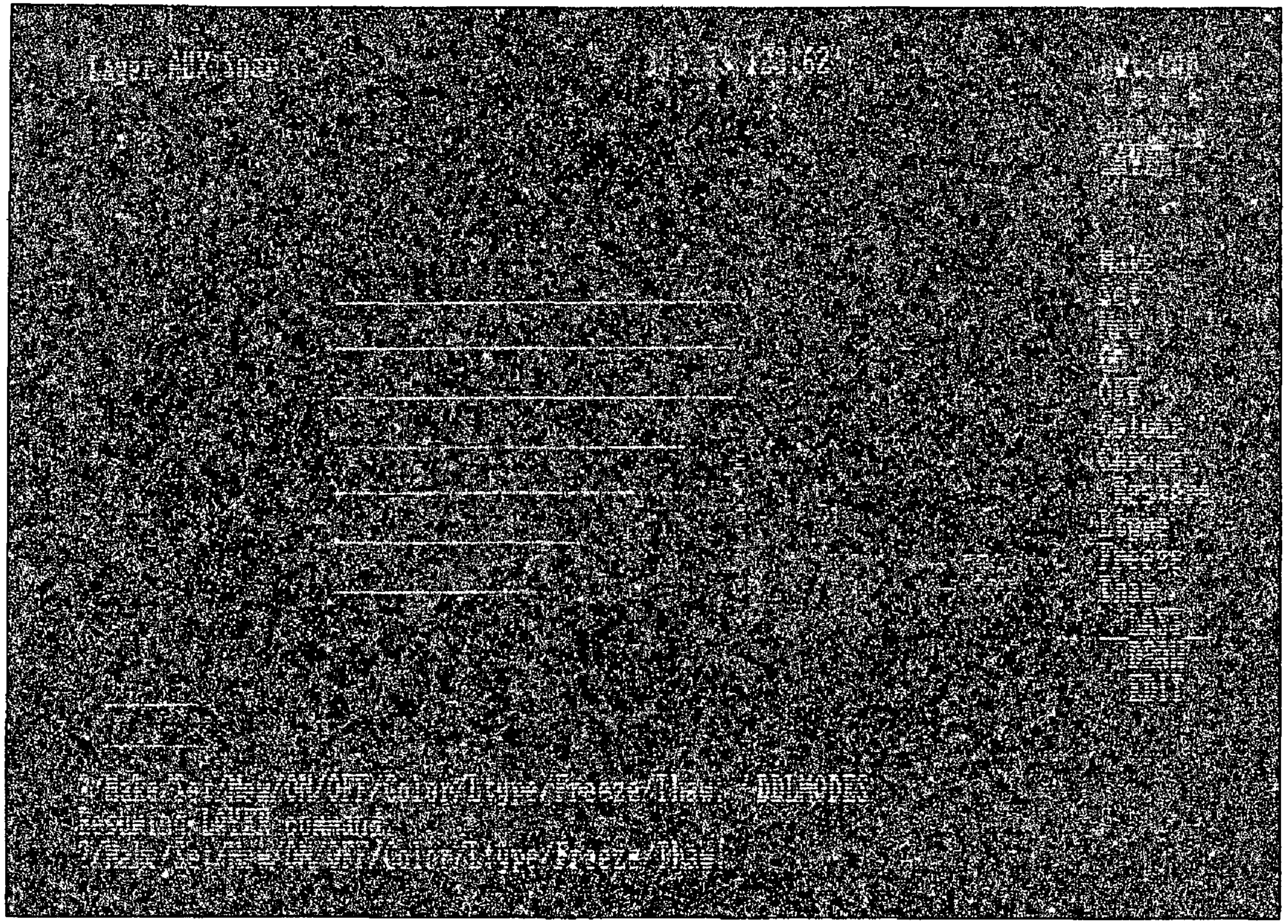


PLATE 3 The auxiliary entities

Then all the layers have to be turned off except the one which contains the auxiliary entities (The user can turn off all the layers with "*", then turn the auxiliary layer back on) Using AutoCAD command DXFOUT a DXF file for these layer has to be created considering the use of ENTITIES option and selecting the entities starting from the bottom to top

By using SHELL Command the user is able to execute utility programs while remaining in the Drawing Editor This facility should be used at this stage to access Kermit package in order to link the PC with the mainframe.

At this point the DXF file which has been created for the auxiliary entities can be sent to the mainframe using the command :

Kermit-MS> SEND <ret>

Remote source file filename DXF <ret>

Local destination file 1TEST.DAT <ret>

Kermit-MS>Finish <ret>

At this stage the working area is in the mainframe and the graphic screen is used as a terminal. In mainframe in order to make the process of executing the programs more automated,two command files have been developed :

1- PROJECT1.COM

2- PROJECT2.COM

The next procedure towards creating the mesh is to execute the command file (PROJECT1.COM) which does a batch job. The content of this file is as follow

```
PU
RUN INTER1
RUN MESHG
RUN AUX1
DEL FECOM.DAT;*
DEL FE.COM,*
EXIT
```

What actually goes on when executing this command is that the interface program (1) reads the data stored in a sequence file called (1test.dat)and picks out the important data and saves them in (2test.dat) for mesh generation program to be used as input.

After that the mesh generation program will be executed to produce two data file

- (Mesh.dat) file to be used for the pre-processing program

- (Coord.dat) to be used for interface program (3).

Thereafter, (Coord.dat)is used as input for the last program in this batch which is Interface Program (2) As a result this batch file produces a data file which contains all the information for drawing the mesh before deformation in a Drawing Exchange Format (.DXF). The name of this file is DXF.DAT. In order to be used in AutoCAD the name of this file should be changed to any other name with extension .DXF during the transfer process

Now,this file has to be sent to AutoCAD in PC through Kermit package using the command

Kermit-MS> GET <ret>

Remote source file . DXF.DAT <ret>

Local destination file : filename DXF <ret>

Then the user should go back to the Drawing Editor using EXIT Command. At this stage there is no need to create new layer for the mesh manually, because the (.DXF) file has got all the information needed for this purpose

Kermit-MS>Finish <ret>

Kermit-MS>Exit <ret>

The (DXF) should be inserted to the drawing using AutoCAD command [29].

DXFIN filename

As shown in Fig (3-9) and Plate 4 all the mesh entities will appear on the screen,the elements,nodes and node numbers These entities will be saved in a special layer called "MESH".The user can at this stage display the mesh and decide whether it is satisfactory or not. If it is not satisfactory or if it needs some modifications or refining,he can repeat the procedures starting from chosing the auxiliary entities,after erasing all the previous entities.

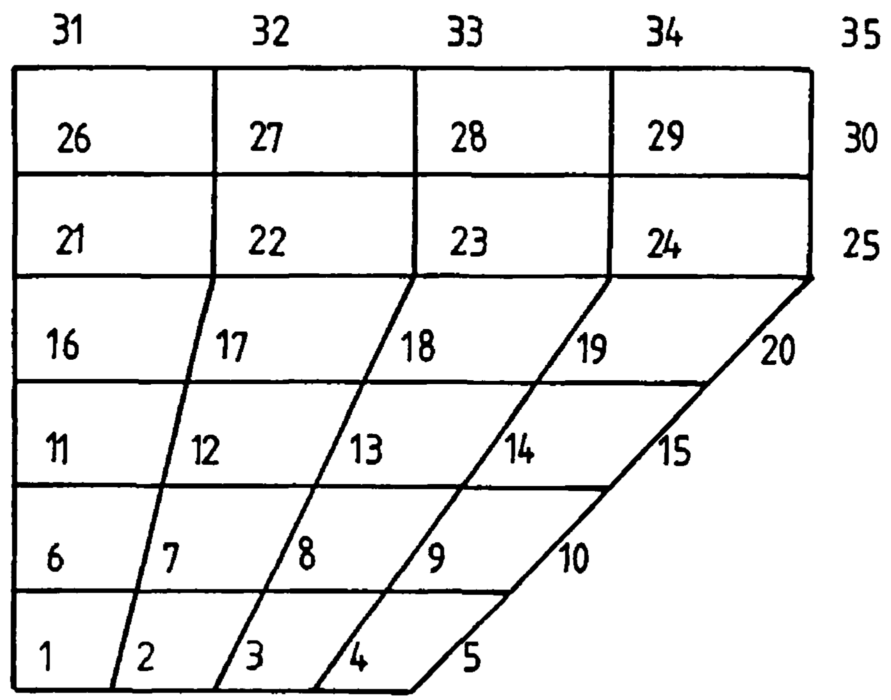


Fig. (3.9) The mesh of the component before deformation.

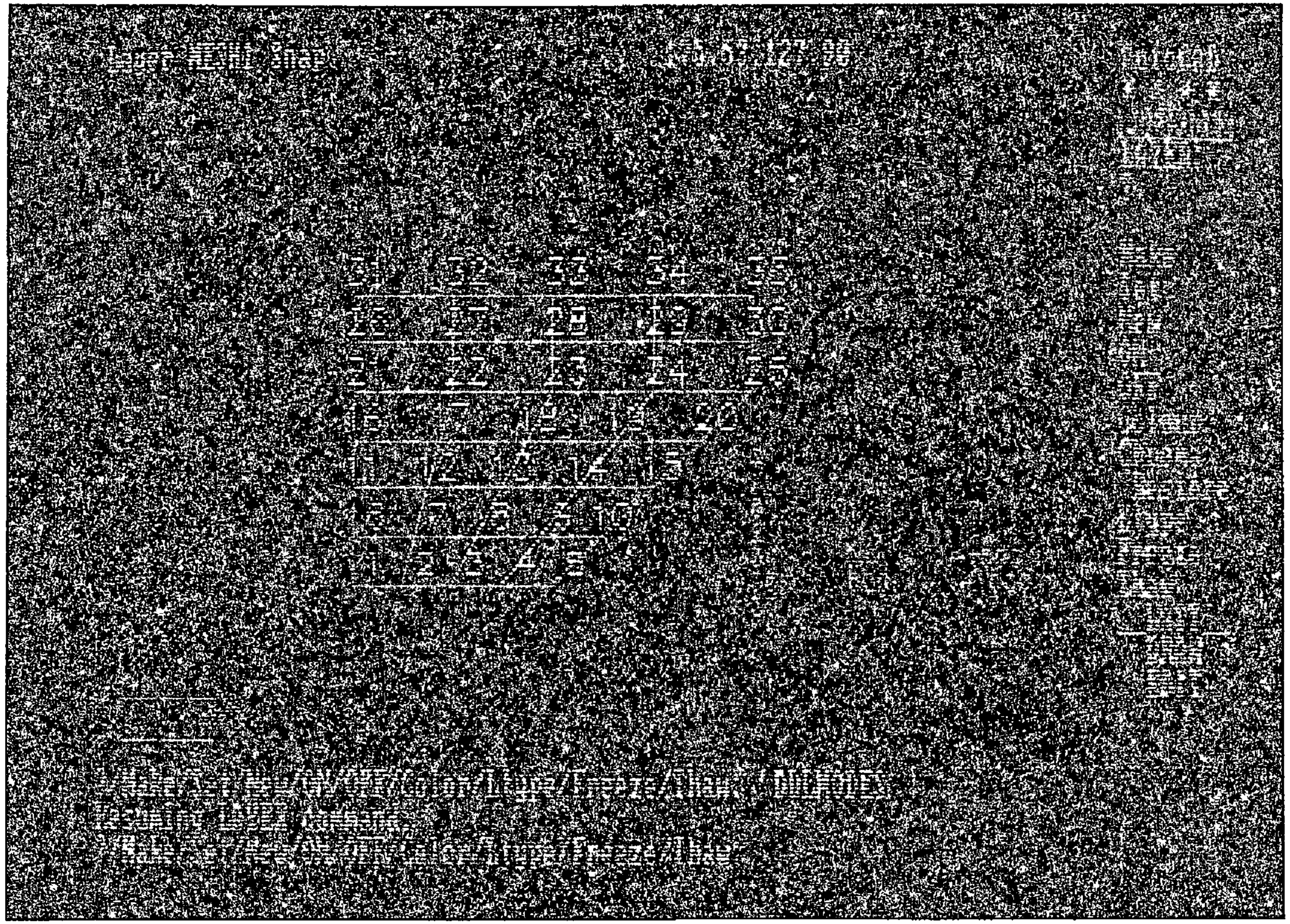


PLATE 4 The mesh

c) Inserting The Boundary Conditions and External loads.

It is obvious that the boundary conditions and the external loads have to be inserted at this stage where the user has to see the mesh in order to decide which nodes are restrained and which elements are affected by the loads. Also it was necessary to find out a way to record this information directly on the screen. Using the AutoCAD facilities and the developed programs it becomes easy to transfer this information to mainframe to be used in the programs.

The procedure to do the insertion are ·

1- The working layer should be turned to an auxiliary layer.

2- An empty area should be chosen to insert the text.

3- Then type "TEXT" at the command line,after that the user will be asked to chose a convenient spot on the screen using "pick" button Next the user will be given choices about size and scaling

Press [RETURN] should be to take the default on these and then the command line will show "TEXT ".

Now the number of restrained nodes should be typed at the first line and [RETURN] . In our example, the number of restrained nodes is 13 The text will appear on the screen. Then each restrained node number and its specifications should be inserted in the same manner.

The user does not have to choose a starting point for each line and needs only to respond by [RETURN] for any subsequent line of the text because each new line will be placed under the previous one Some spaces should be placed between the node's numbers and the restrained specifications as shown in our example .

```
2
1          11
5          01
```

where 2 is the number of restrained nodes.

1 and 5 are the numbers of restrained nodes

11 means that node number one is restrained in X and Y directions 01 means that the node number three is restrained only in Y directions

After inserting the boundary conditions the external loads have to be inserted in the same manner just after the previous insertion following the same process .First of all the number of loaded nodes should be inserted in a line which equals to four in our example. After that in each line the node numbers and load components in X an Y should be placed .Some spaces have to be left between the text elements in each line. For example :

```
2
31     0 0         -1500.0
35   500 0         -1000 0
```

where . 2 is the number of loads.

31,35 are the nodes which are affected by the loads.

0 0,500 0 are the X components of the
loads.

-1500 0,-1000.0 are the Y components of the loads

Finally, the thickness of the component should be inserted as a final line

30.0

4- Type "DXFOUT" AutoCAD command ,chose the entities option and select the text lines starting from the top to down.

Now, all the information about boundary conditions and external loads are saved in the (DXF) file which has been created. This file has to be sent to the mainframe by (TXT.DAT) name to be interpreted by a special interface program.

d) Pre-Processing Data for FE Program

At this stage (PROJECT2.COM) has to be executed. This command file contains mainly three programs in addition to some data which can be edited using the text editor :

```
RUN PREP
TEST "The title of the problem."
1 "Plane stress NTYPE."
4 "The number of nodes in each element"
1 "Number of materials"
2 "Gause point"
4 "Criteria's number"
1 "Number of increments"
3 "Number of stresses"
2 "Degree of freedom"
1 "The material's number"
RENAME FECOM.DAT;1 FE COM,1
@FE
RUN INTER3
RUN STRESS
RUN AUX2
EXIT
```

The first program will be executed in this batch job is PREP.FOR program. This program reads its data from three data fils after reading the data which existed in PROJECT2 DAT :

1- MESH.DAT Geometric specification.

2- TXT DAT Boundary conditions, external loads and thickness

3- PR1.DAT Material specifications

4- PROJECT2.COM Control parameters

As output, a data file, which contains all the inputs necessary for finite element program, will be produced and changed to a command file (FE.COM). After that the finite element program will be executed by reading the inputs from FE COM and saving the results in two files :

1- RESULT DAT contains all numerical values such as stresses and displacements

2- COORD4.DAT contains nodal displacements to be used later in Interface Program (3).

e) **The Deformed Mesh**

The next program is the Interface Program (3) This program reads the nodal displacements from COORD4.DAT and the coordinates of the nodes from COORD.DAT in order to produce the coordinates of the nodes after deformation.These coordinates are saved in a data file in (DXF) format considering the name of the layer in which these entities are going to be saved.

The name of this data file is (DXF1.DAT). The extension of this name has to be changed to (filename DXF) in order to be usable in AutoCAD .

This DXF file has to be sent back to AutoCAD and converted to drawing to be saved in the main drawing file. This DXF file has the facility to save itself in a special layer called "mesh1". For our example the mesh after deformation will be as shown in Fig (3-10)

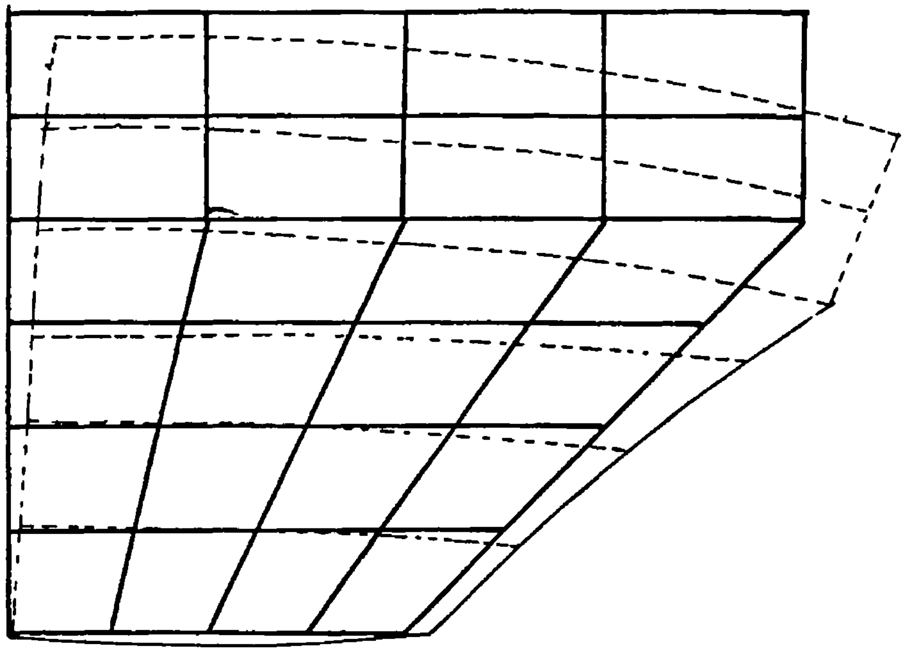


Fig. (3.10) Exagerated view for the mesh after deformation.

f) The Stress Contour

The last program as it has been mentioned before is a program to generate the script file for drawing the stress contour for a particular component. From the first sight the user can decide if there are any elements stresses to plasticity or not Also it will be usefull to find out the maximum stress and its location The factor of safety will also be calculated and displayed.

3-4-2 Analysing The Results

The last step in the draughting and analysis part is the analysis of the results by the user to determine whether the component is suitable for a particular function or not. The user has already got all the results saved in the PC, namely, the drawing of the component which include the mesh before and after deformation and the contour of the stresses in addition to the numeric results such as stresses and displacements. The stress contour is shown in Plate 5.

PLATE 5 The stress contour

All these results have to be compared and the necessary modifications have to be made such as changing the material or dimensions. Finally and after deciding the last dimensions for the component the drawing should be prepared for manufacturing process.

In our example by checking the contour of the stresses it is found that there is not any element which goes into plasticity. The maximum stress is in element number 4 and the maximum displacement is in the node number 35 as shown below

ELEMENT NO 4

XX-STRESS	=-0 449817E+01
YY-STRESS	=-0.283331E+02
XY-STRESS	=-0.166338E+00
ZZ-STRESS	= 0 000000E+00
MAX P C.	=-0.449701E+01
MIN P.C	=-0.283343E+02
ANGLE	=-0.400
E P.S	= 0.000000E+00
STREQ	= 0.263749E+02

DISPLACEMENT ·

NODE	X-DISP	Y-DISP
35	0 254976E-01	-0.292736E-01

The factor of safety =1.11

As we see the component is satisfactory under the load condition. The equivalent stress still under the yield strength point and the maximum displacement is less than 0.05 mm. Suppose the required factor of safety was 3 then the user should repeat the analyses procedure after changing the component specification such as increasing the thickness

Now as the component is satisfactory under the desired condition the user should machine it using the manufacturing package. This example has not been machined because a full machining example will be demonstrated in Chapter six

CHAPTER FOUR

COMPUTER NUMERICAL CONTROL MACHINE TOOL

(CNC)

4-1 INTRODUCTION

The merging of computer technology and traditional machine has given birth of new machine tool CNC machines are now capable of doing the work of three or four conventional machine tools at a single setting All these facilities can be achieved by giving instruction to a machine in the form of a code which is understandable by the controller of the machine. The machine responds to this coded information in a precise and ordered manner to carry out various machining functions Instructions are supplied to the machine as blocks of information which is a group of commands sufficient to enable the machine to carry out each individual machining operation

A set of instructions forms an NC program When these instructions are organized in a logical manner they drive the machine tool to carry out a specific task usually the complete machining of a workpiece or part of it. It is thus termed a part program.

4-2 NUMERICAL CONTROL (NC) MACHINE TOOL

The NC machine does not posses any memory of its own and so it is only capable of executing a single block of information,fed to it,at a time. For this reason part programs are normally produced and stored on punched tapes.

To machine a part automatically the Machine Control Unit (MCU) will read a block of information and then execute that block,read the next block and execute it and so on. It is also possible to input the data manually to obtain what is called Manual Data Input (MDI). For the repetitive production the tape has to be rewind and start again.

4-3 COMPUTER NUMERICAL CONTROL (CNC) MACHINE

CNC machine still has got the fundamental concept of NC machine but utilises a dedicated stored-program computer within the machine control unit . The CNC system attempts to accomplish as many of the (MCU) function as possible within the computer software which is programmed into the computerised control unit. This greatly specify the CNC hardware, significantly lower purchase costs, and improves reliability and maintainability. As mentioned above CNC machine tool still retain many of the constructional and physical design aspects of their NC counter part

4-4 PART PROGRAMMING

4-4-1 Manual Part Programming

The term Manual Part Programming (MPP) refers to the preparation of a numerical control part program without the assistance of a computer. All of the detailed instructions for operating the numerical control machine are listed, in precise order, on a form, which is called a manuscript. Calculations are usually prepared with the aid of pencil and paper. The instructions and data on the manuscript are then transferred to a tape.

4-4-2 Part Program Terminology

The (MCU) controls the machine tool in response to coded commands contained within the part program These various commands are identified by a capital letter which is referred to as an ADDRESS.This letter address is followed by additional numerical information to make up a command. A command made up of a letter address and its associated numerical information is known as a WORD A number of words may appear on the same program line. A complete program line is then termed as a BLOCK. The function which are used in this block are illustrated as below

N3... Three-digit block number, between N000-N999.

G2.. .Preparatory functions which determine the geometrical computer program

X+-43 Y+-43 Z+-43 are the path data Four digits before and three after the decimal point.

I43 J43 and K43... are the auxiliary parameters of the circle centre.

F7 .. Seven digits feed rate,usually given in (mm/min) or (inches/min).

S4... Four digits. Spindle (rpm).

T2 Two digits,tool number.

M2. . Two digits,miscellaneous functions for machine commands like coolant supply ON/OFF.

EOF(or $)....End of block code

4-4-3 Machining Using Linear Interpolation

Machining using linear interpolation simply means machining in straight line. These lines may be horizontal,vertical,or at an angle,in any direction All machining is done under control of feed. Linear interpolation mode is entered by issuing a G01 code within the part program. Linear interpolation operates, in a truly linear way,between the current tool/workpiece position and a commanded coordinate position. Such a move should specify .

* Set linear interpolation mode.
* Set feed rate unless already set.
* Turn coolant on (if required).
* Position spindle (Z axis move).
* Feed to desired coordinate position (in X and Y).

In A Fig. (4 1) the cutter is moved along a 45 degree angle line by making the X and Y movement equal. In B the X movement would have to be greater than the Y movement within the same time period If the component is held steady,the resultant movement will be a straight line.

4-4-4 Circular Interpolation

Circular interpolation means the programming of circular arcs. A single circular interpolation command block is capable of producing a circular arc. Circular interpolation is limited to contouring in a single plane. However, when milling, this plane may be selectable.

When machining an arc, four pieces of information need to be specified.

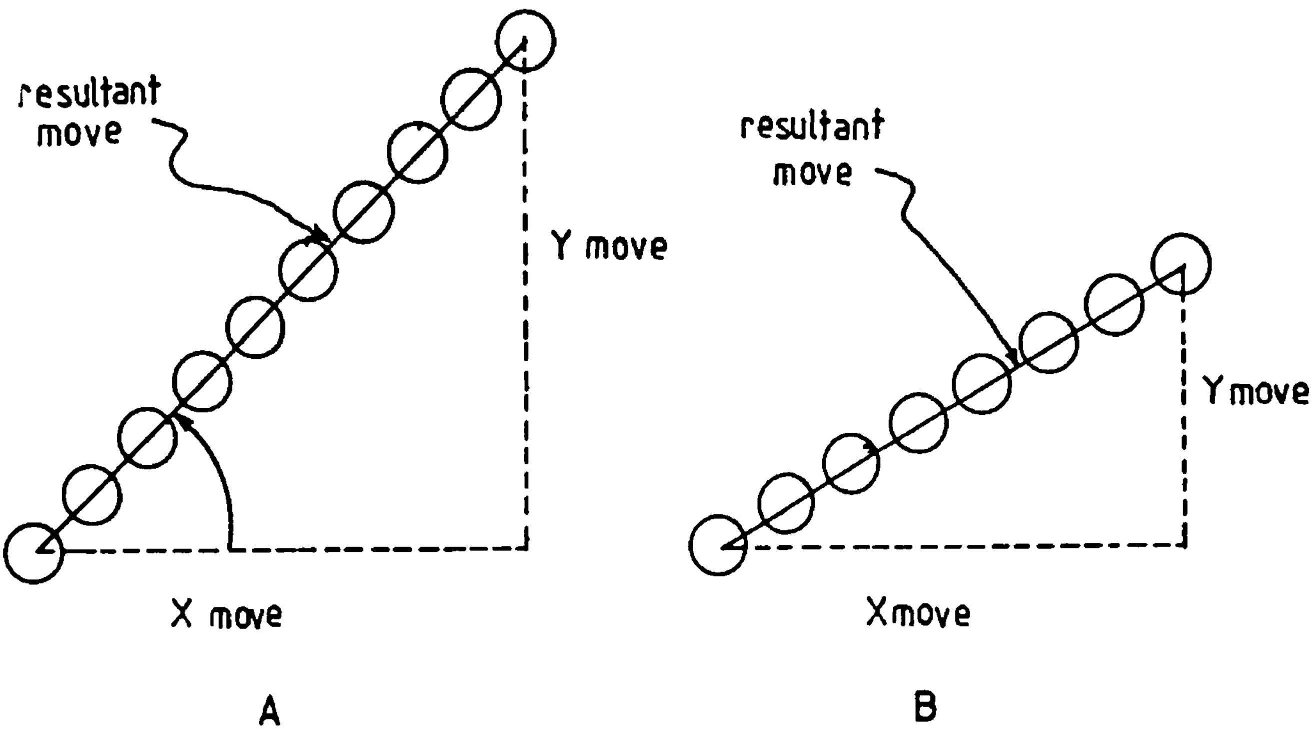


Fig. (4.1) Linear Interpolation.

* The coordinate position of the start of the arc.
* The coordinate position of the end of the arc
* The radius of the arc to be cut
* The direction (C/W or CC/W) of the cut

The radius of the circle is indicated by specifying the coordinate position of the centre of the required arc. The letters I,J and K are used for this purpose There are two common methods of specifying the centre ·

1- I,J and K values are the dimensions of the centre point measured from the start position of the arc.

2- I,J and K values are the dimensions of the centre point measured from the program datum.

4-5 OTHER CNC PROGRAMMING CAPABILITIES

4-5-1 Canned Cycles

Every machine tool has certain machining cycles which are repeated continuously and identically. These are geometrical sequential programs with only a few changing parameters. Those cycles are permanently stored in the control and can be called up by a G-Command. After the necessary parameters are entered,the cycle is carried out automatically. The G code normally fall in the 80 series. However,there are some 70 series G code for canned cycle.

4-5-2 Loops

Looping provides the programmer with the ability to jump back to an earlier part of the program and execute the intervening program blocks for a specified number of time. It is so called because the program loops back on itself. In order to repeat a section of the part program for a number of times, it is necessary to specify three pieces of information

* The start of the loop (=).
* The end of the loop (N100).
* The number of repeats of the loop (3).

All three pieces of information are provided in a single block of information like as below :

= N100/3

4-5-3 Subroutines or Sub-Programs

Sometime it is difficult to accommodate repetitive features within the loop structure In such cases the repetitive elements may be described in terms of a Sub-Program, often called Subroutine, and placed at the end of the main body of the part program These subroutines are called by special commands within the program to be executed.

After the execution of the subroutines the flow of the program return to the point immediately following that at which the subroutine was called

To describe a subroutine the following points should be considered

* The identification (START) of the subroutine
* The END of the subroutine definition
* The END of the program-after which subroutines may follow
* A means of calling a specified subroutine.

When defining subroutines,it is good practice to ensure that the machine is returned to the same condition upon leaving the subroutine as it was when the subroutine was called.

4-5-4 Macros

The term macro is short for Macro Command or Macro- Sub-Program.Macros called within the program must be accompanied by additional information.

In general, the implementation of a macro is very similar to that of a subroutine.However,the main difference is that in a macro, the values or parameters should accompany the CALL command to be used as input to the macro

During using macros it is necessary to specify

* The parameters that which change from call to call
* A means of passing true values into these parameter.

Within the macro definition,the parameters likely to change are given no numerical value,but are marked with an asterisk (*). True numerical values for these parameters are then supplied with different calling lines.

There are a few more common facilities available on CNC milling machines such as "Reflection", "Rotation" and "Scaling".

CHAPTER FIVE

COMPUTER AIDED MANUFACTURE (CAM)

5-1 COMPUTER AIDED MANUFACTURE

Computers have also been widely applied to manufacturing and the term 'Computer Aided Manufacture' (CAM) is used for manufacturing processes which use computer to assist in the planning and production of manufacturing process from inventory control to the programming of machine tools

More recently the gap between Computer Aided Design and Computer Aided Manufacture has been closed and integrated CAD/CAM systems are now commercially available

An integrated CAD/CAM system can therefore be defined as a system where the link between design and manufacture is accomplished by the use of a computer.

One application of CAM is on CNC machine tool which is also part of the aim of this project

Despite the large number of existing programming systems for NC machine tools,manual programming,as reported in statistics referred to recent data is still in use for more than 50%.

Possible reasons for the less use of automatic programming are probably due the fact that they often need large or medium computer resources,and to the fact of their complexity for which they require skilled and costly programmers and operators. Productivity can be increased up eight times following a recent estimation .

Computer aided methods are also being used for high level automation. Studies about a systematic approach with minicomputers to the solution of problems in manufacturing and automation,programming languages,tape preparation facilities are exhaustively performed in several countries and significant gains have already been attained.

5-2 CNC PROGRAMMER PACKAGE FOR MILLING MACHINE

The NCP System by Microproducts offer a set of programs which work in conjunction with AutoCAD by adding routines to generate numerical control code for NC or CNC machine tools. The NCP System adds Computer Aided Manufacturing capabilities to AutoCAD. The NCP System is totally integrated with AutoCAD,all AutoCAD capabilities as well as all the added capabilities of NCP System are constantly available

The NCP System consists of two major modules,the NC Programmer and the Complete Postprocessor,and several support programs for specialized operations The most widely used of the support programs is the Mill Productivity Package,which we concern about in this project This package provides extended capabilities for developing numerical control code for milling applications Some of the major features of the NCP System include

* Common Database with AutoCAD
* Facility for determining direction of cut.
* Tool compensation calculations.

* Ordering of non-contiguous data.
* Viewing of cutting path for validation.
* Canned cycle development.

5-3 THE NC MICROPRODUCTS SYSTEM

5-3-1 The NC Programmer

The NC Programmer is used within AutoCAD to isolate and order the part geometry to provide a continuous tool path and to apply a cutter offset to the part. The NC Programmer performs all tasks in real time, graphically, inside the AutoCAD. The original designer's part drawing is used throughout to insure accuracy in part profiling. All system features and geometry power of AutoCAD are available to the user to assist in the preparation of a part program.

5-3-2 The Complete Postprocessor

The Complete Postprocessor is used within AutoCAD to adapt Computer Aided Design data output by the NC Programmer and AutoCAD to a particular NC machine tool format. The Postprocessor is a program that reads an

AutoCAD Drawing Exchange File (.DXF) as input and produces numerical control code as output. This translation of a drawing into NC code is controlled by an ASCII text file referred to as the ($PP) file. This file is usually named after the particular machine tool/controller that is being used.

The ($PP) file is tailored for each particular machine tool/controller combination. Each line or entry in ($PP) file defines a specific translation to the post. At the simplest level an entry consist of NC code on the left of an "=" sign and the AutoCAD text on the right side of the "=" sign.

As the last stage of this project, ($PP) files have been developed for one machine tool at least. So the user will be able to generate the part program for a particular machine-controller combination by accessing the suitable ($PP) file in the postprocessor.

5-3-3 The Mill Productivity Package

The Mill Productivity Package is designed to automate and simlify the tooling process for milling applications. The Mill Productivity Package includes features for creating canned cycle and milling pockets (with or without islands) for face milling with a variety of routines.

The cycle generator is designed to allow for the creation of machining cycles which require variation from one operation to another. The cycle generator provides a logical approach to capturing the content of a machine cycle and storing it as an AutoCAD block for re-use at a later time.

Cycles such as tap drilling,counter,boring,spot drilling or combinations of each;and lead-ins and lead-outs are easily accommodated Other cycle maps can be created by the user. Operations within a cycle can be shared with other cycle as desired.

5-4 AutoCAD/NCP SYSTEM FEATURES SUMMARY

1- AutoCAD and the NC Programmer work to perform the tooling process

2- The Complete Postprocessor translates and formats data according to "LOOK UP" table configuration into NC code.

3- The NC code can be edited or modified as desired.

4- Transmitting of NC code via RS-232 serial port is performed by a user-supplied communications package.

5- The RS-232 serial port can be connected to any of the following :

* Paper tape reader/punch
* Network
* Modem
* Machine tool controller.

5-5 AutoCAD CONSIDERATIONS

A working knowledge of AutoCAD is a prerequisite to using the NCP System This includes a through understanding of the following AutoCAD Commands ·

* BLOCK
* DXFOUT
* LAYER
* SHELL
* ARRAY
* TEXT
* SELECT

The NC Programmer is capable of processing any type of AutoCAD data. AutoCAD entities not acceptable for processing by The Complete Postprocessor are trace,shape, solid and repeat.

The TRACE,SOLID,SHAPE and REPEAT items are not true geometric entities to the Complete Postprocessor These are used as drawing aids in AutoCAD to enhance the appearance of a drawing. These items can not be apart of the geometric entities representing the object to be tooled To save time in processing data for NC tooling the drawing designer should be aware of this requirement. If geometries created by these commands are encountered by The Complete Postprocessor,they will be ignored.

5-6 THE NC PROGRAMMER RULES

The following rules apply when using the NC Programmer Commands

* AutoCAD is always available. Any AutoCAD command can be entered at the NC prompt.

* When the NC command prompt is displayed,any NC programmer command can be used.

* The commands must be followed by a [RETURN]. Spaces are not recognized as the end of a command input.

* Most commands may be selected from the menu or typed at the command line. A command name can be typed in lower or upper case. Depending on the command, questions may be asked and certain actions required of the user.

* Most question indicate valid choices in parethesis() with the default response in angle brackets<>. The default response is accepted by pressing [RETURN].

* If CTRL-C is entered as a response to any NC Programmer question,The command will be terminated.

* When using the NC Programmer System and AutoCAD, the user will notice that seemingly unrelated commands appear under the AutoCAD screen on occasion. This activity indicates that the different functions of the NC Programmer are being loaded into AutoCAD and implemented.

* To exit the NC Programmer to AutoCAD, enter the NC command ACAD .

5-7 USING AutoCAD LAYERS

Normally,a drawing will consist of a variety of items that are not part geometry,such as a title block and dimensions. It is recommended that some sort of drawing organization using layers be used when developing a drawing. this will allow easy isolation of part geometry when required

A suggested layer organization is as follows :

* Layer PART contains all the actual geometry of the part to be machined.

* Layer DIM contains all the dimensional information for the part.

* Layer TITLE contains basic drawing formats such as title block,border,revision column and tables.

5-8 TOOL CONSIDERATIONS

The tool which is drawn to represent the part does not always represent the final tool path. For example,for a mill part,a drill hole might be shown as a small circle on the original drawing,wherease the actual process to create that drill hole requires only a drill code with appropriate parameters and a point (a single X,Y position).

In some cases the drawing may include more than,or less than the geometry needed for machining. For example, a lathe drawing may show the full part when only half the part is actually machined On the other hand, the drawing does not show the various roughing passes which are required for complete machining.

CHAPTER SIX

A FULL MILLING EXAMPLE USING CAM SOFTWARE

6-1 MACHINABILITY

The main reason for the continued interest in the definition and assessment of machinability is the most important problem of specifying the cutting conditions for an optimal economic utilisation of the resources.

The characteristic or behaviour of a metal when it is being cut is called machinability - a property that varies widely according to the type of metal.

6-2 FACTORS INFLUENCING MACHINABILITY

The factors which influence the machinability are shown in Fig. (6.1). These are discussed in the following sections .

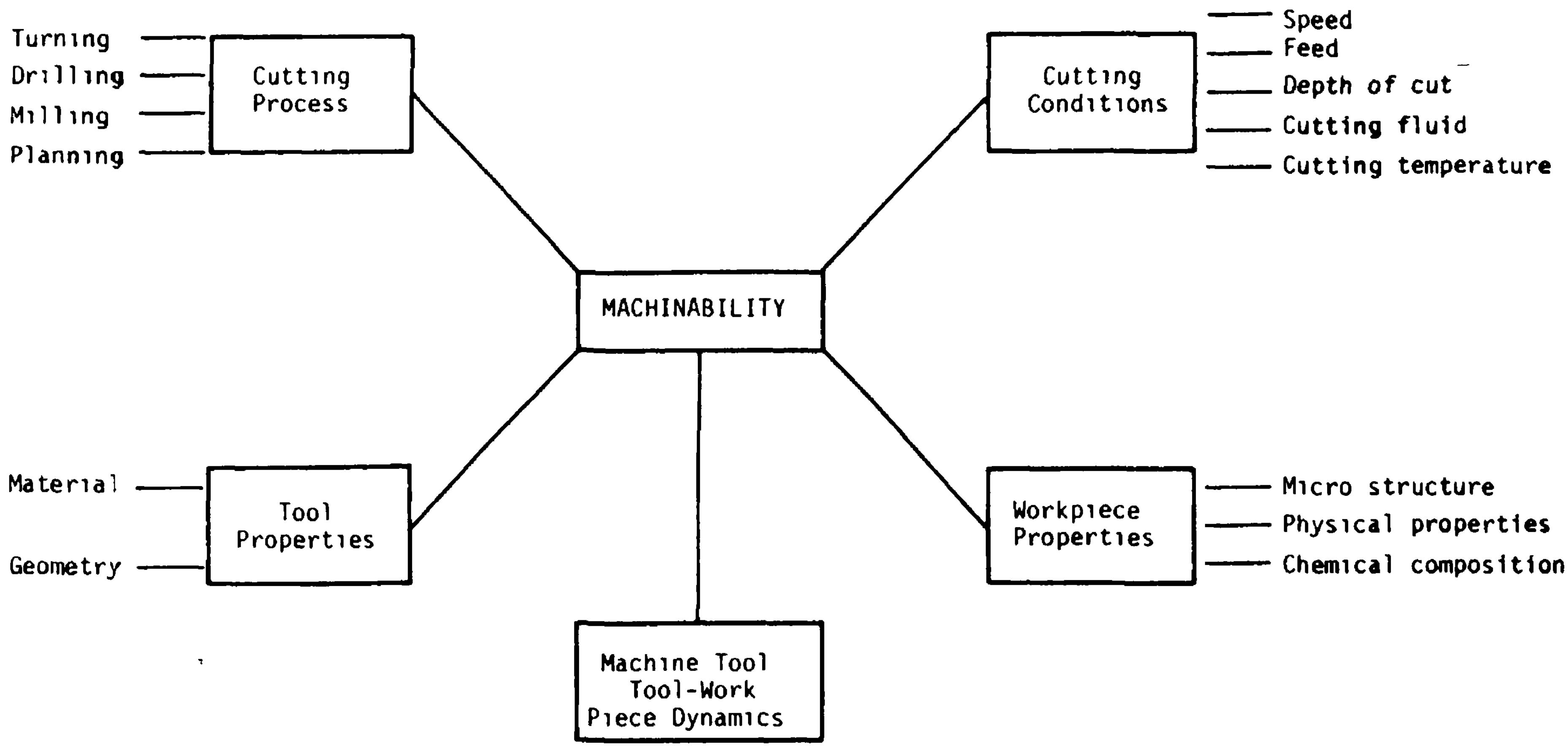


Fig. (6.1) Factors Influencing Machinability

6-2-1 Machining Operations

The type of machining operations which are used in industry include such operations as turning,milling, drilling, planing,etc.

These operations can be broadly classified as ·

(a) Continuous cutting operations.

(b) Intermittent cutting operations.

Turning can be thought of as a representative of the continuous cutting operation. So the tool used in intermittent cutting processes need to have a greater resistance to shock loading.

6-2-2 Cutting Conditions

The cutting conditions which affect machining are cutting speed,feed rate, depth of cut,cutting fluid and it's application.

Cutting Speed :

Cutting speed is the most important variable in the cutting operation. Cutting speed directly affects the type of chip,surface finish and the tool life. At very low cutting speed (<1.5 m/min) the metal which is being cut behaves in a brittle fashion and the chip is usually discontinuous. The discontinuous chip formation excites the lower frequencies of machine tool work piece system and leads to poor surface finish. In addition, tearing and rubbing cause an inferior surface finish. With higher cutting speeds, the chip becomes continuous and the surface finish improves [30]. But the major effect of cutting speed is on tool life.

Feed Rate :

The effect of increase in feed rate on tool life is similar to that of cutting speed, but the effect is much less pronounced. In addition an increase in feed rate increases the cutting forces [31,32]. Also the surface finish produced is a function of the feed rate.

Depth of Cut :

The variation in depth of cut has little effect on tool life. While depth of cut has a significant effect on cutting forces and cutting forces are directly prpotional to depth of cut in the ratio of 1 1 [31,32].

Cutting Fluid :

The action of cutting fluid is not only that of a lubricant between the chip and the tool rake face, but also that of a cooling agent. In continuous operations the application of cutting fluid results in an increase in the life of the cutting tool. But in intermittent cutting operations the cutting fluid causes thermal cycling of the cutting tool which may eventually leads to thermal fatigue and failure [33].

6-2-3 Workpiece Properties

Basically,machinability is all about efficient ways and means of machining a workpiece. The workpiece is the central figure of a machinability study. The work piece properties which have a profound effect on machinability are it's microstructure, chemical composition and physical properties.

Microstructure :

This refers to the arrangement of the crystals or grain structure of a metal Metals of similar microstructure generally have similar machining properties, but small changes in microstructure can greatly affect machinability [35].

Sections of the same bar , or of the metal produced from the same "melt" often display very wide differences in machinability owing to variations in grain structure. For good tool life the grain structure of a given patch of metal must be uniform.

Chemical Composition :

The structure and mechanical properties of any alloy are determined basically by its chemical composition. Alloying element have a strong influence on machinability. e.g. Sulpher (S), Lead (pb), and phosphorus (p) improve machinability, whereas elements such as Chromium (Cr), Vanadium (V), Nickel (Ni) and Molbdenum (Mo) reduce machinability.

Work Hardening Properties :

Production operations such as drawing, rolling and forging - which sometimes call for pre-heating - have an important influence on the final structure of a metal, and therefore on it's physical characteristics. The user must know the physical and thermal treatment a metal has undergone before deciding on the method of machining.

6-2-4 Tool Properties

Next to the workpiece properties the tool properties, which are tool geometry and tool material, have the greatest effect on the determination of machinability.

Tool Geometry :

The normal rake angle has the largest influence on tool life and thus on machinability. The tangential cutting force is greatly influenced by the rake angle [35].

Negative rake imposes a penalty in terms of higher tangetial force, so almost invariably it is better to use the maximum positive rake consistent with tool strength.

Tool Material :

The requirements of cutting tools are high hardness and toughness, good wear resistance, mechanical and thermal chock resistance and the ability to maintain these properties at the very high temperatures that occur in metal cutting.

6-3 MACHINABILITY ASSESSMENT

Generally the machinability of a material is assessed by investigating one or all of the following parameters ·

(a) Cutting tool life.

(b) Cutting forces.

(c) Surface finish.

(d) Tool chip interface temperature.

The relation between the above factors are illustrated in Fig. (6.2).

In conducting machinability investigations the procedure adopted generally takes the following form ·

(a) The establishment of optimum tool geometry.

(b) The establishment of power requirements.

(c) The establishment of tool life relationships with cutting speed and chip thickness.

(d) The effect of cutting agents.

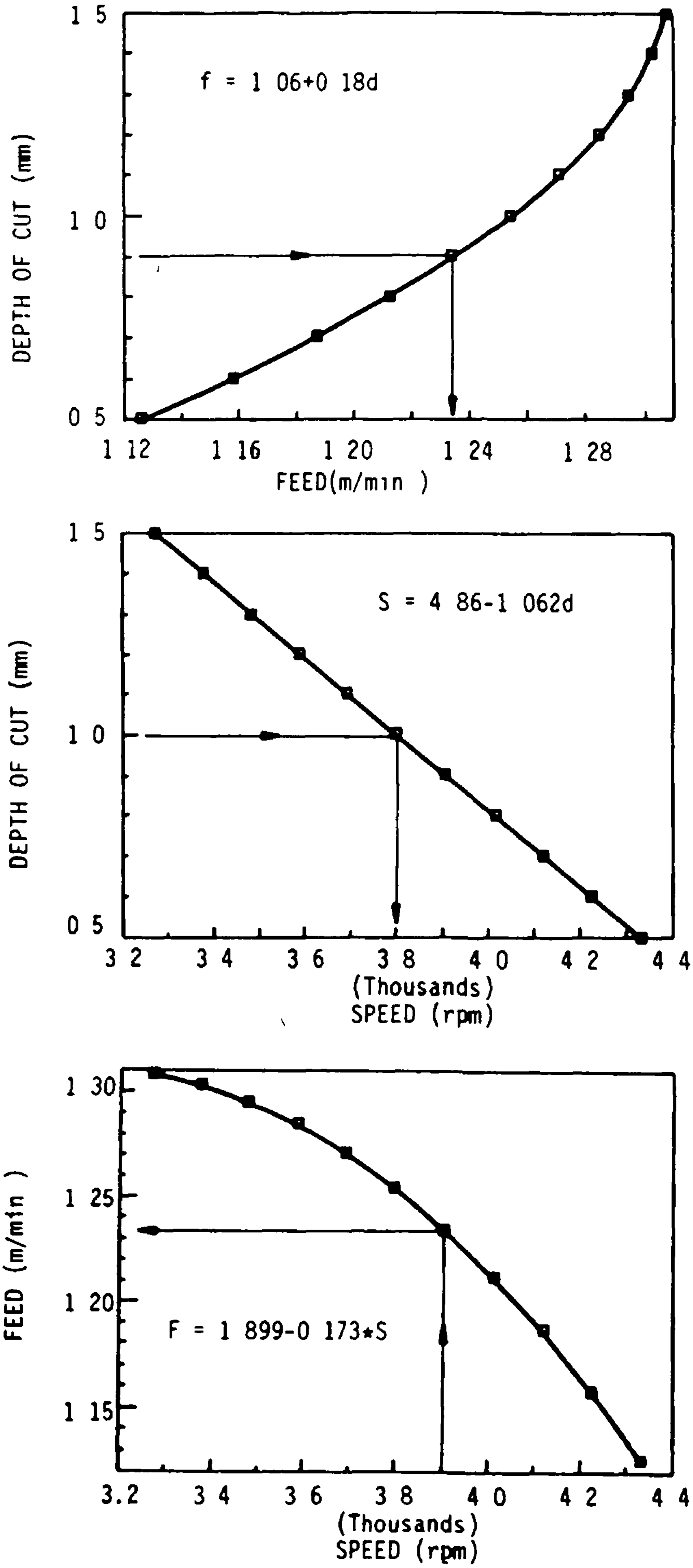


Fig. (6.2)

Mild steel

Machinability rating based on tool life tests is the most widely accepted standard. The I.S.O. standard on tool life testing is to be carried out, the criteria to be applied and the method of analysis.

In this chapter there will be a full example of machining an electrical junction box. The study of this example involves chosing of machinability data according to the material of the workpiece and the machining process. Also this study cotains the process of chosing the tools.

6-4 MILLING EXAMPLE

There are two objectives for carrying out this machining example·

1- The development of the postprocessor for a particular machine-controller combination. The milling machine which has been chosen is a HITACHI machine with FANUC 11 controller. The machine is shown in Plate 6.

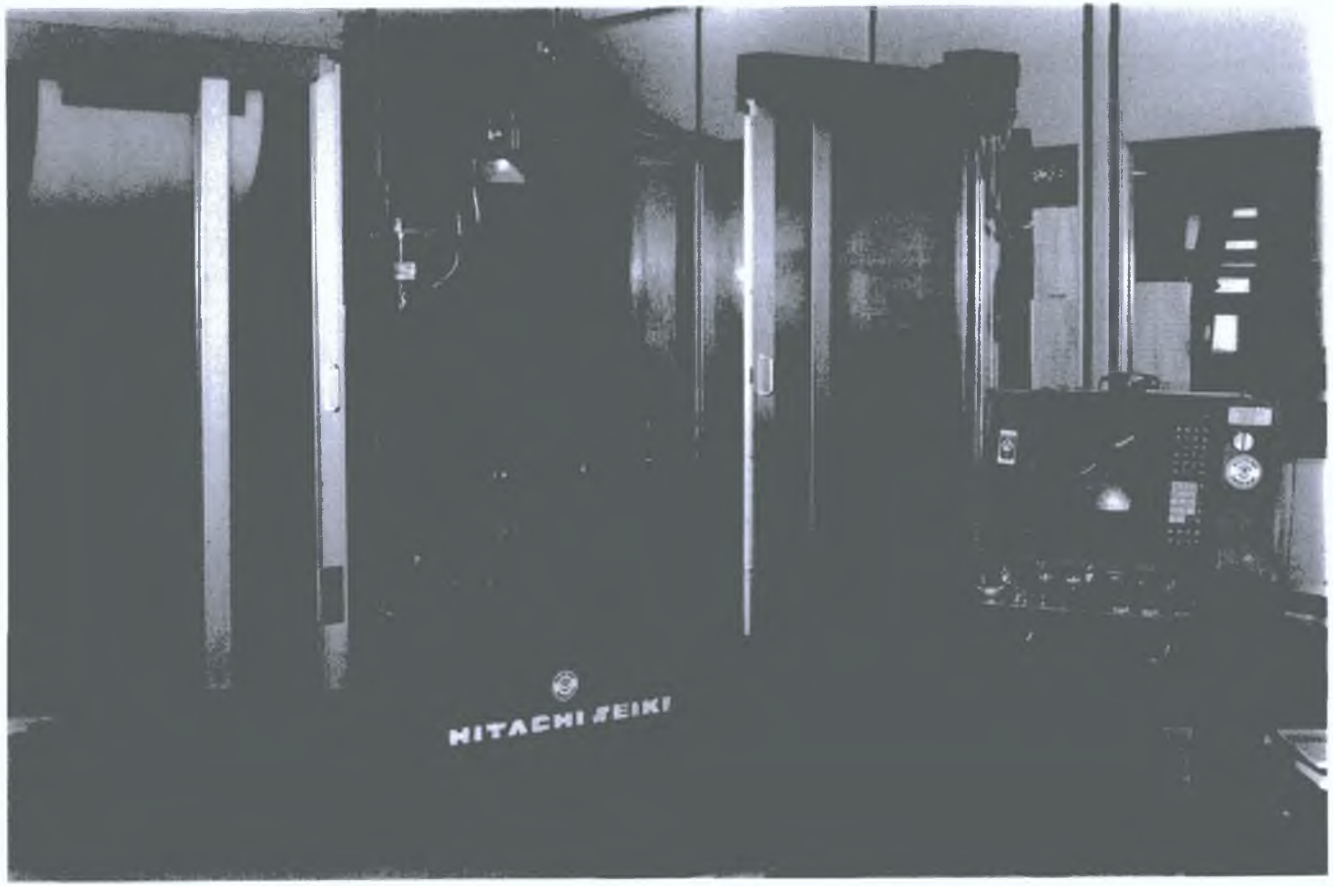


PLATE 6 The milling machine

2- To demonstrate the procedure of using the NC programmer and find out the effectiveness of using such software in general and the software developed particularly in this study.

The example used is a real engineering component, which has been selected from AERLINGUS company. This component is a junction box for electrical connection systems taken from ARIANE PROJECT the detailes of which are shown in Figs. (6.3) and (6.4). AERLINGUS is the company where the experimental machining have been carried out.

Three Part Programs have been developed to machine this component. At the same time the postprocessor for this machine has been modified to give the correct format for this machine. The postprocessor is shown in Appendix C and the part program in Appendix D. The procedure of developing each program will be explained separately.

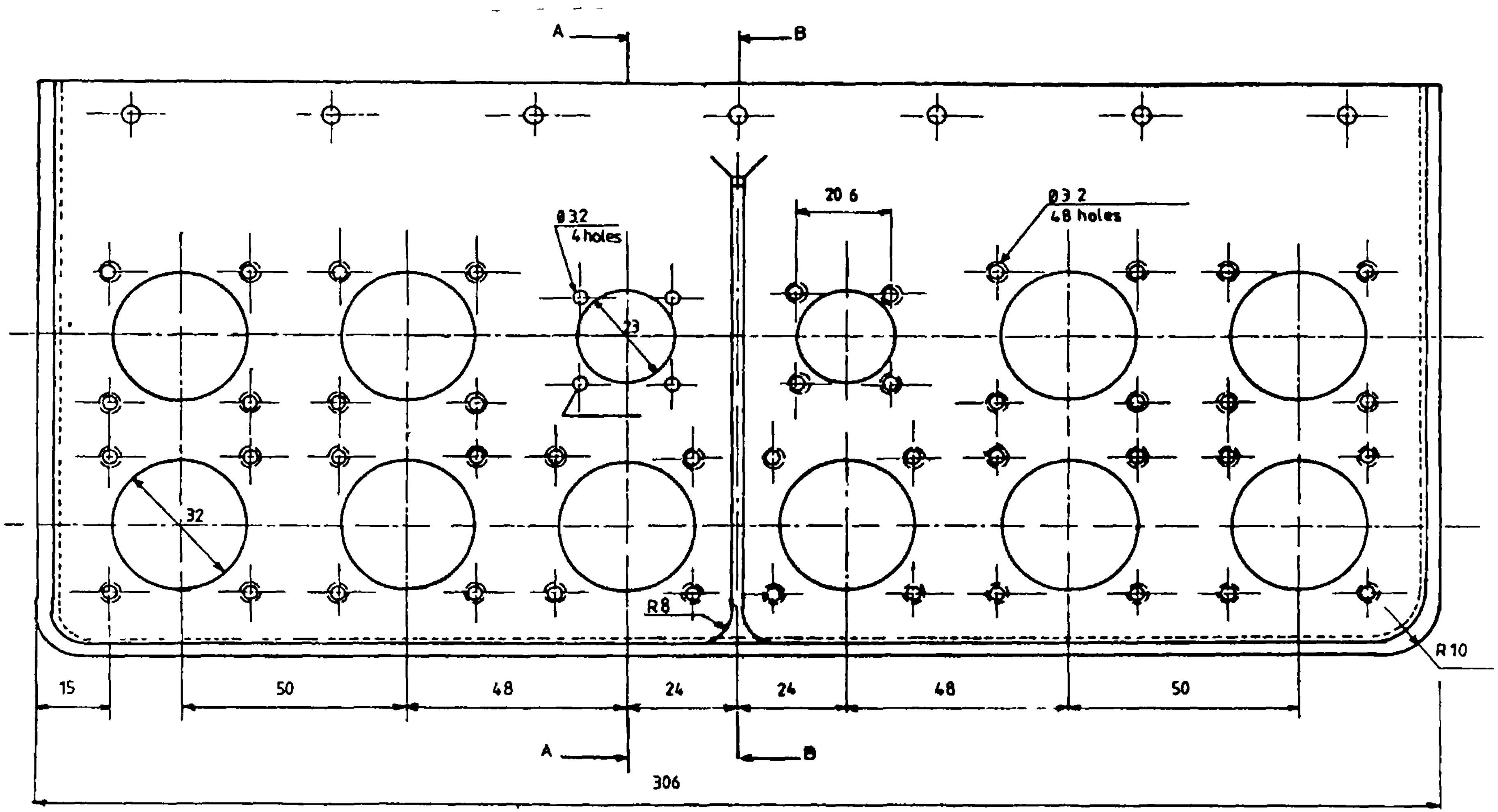


Fig. (6.3) The engineering drawing of the component

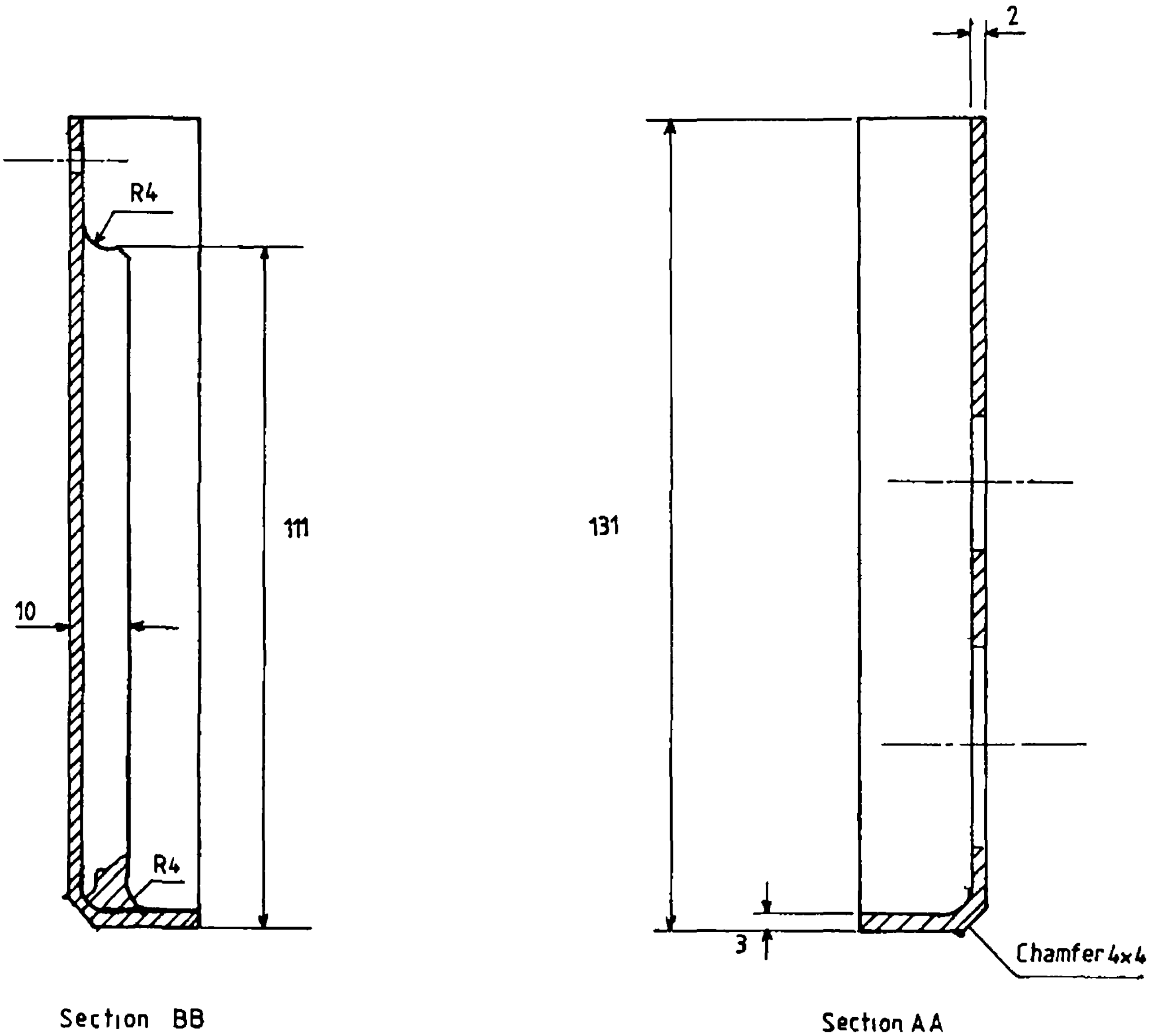


Fig. (6.4) Section AA and section BB in the drawing.

6-4-1 METHODS OF SOLVING THE SPEED/FEED SELECTION

The methods of solving the speed/feed selection problem are these :

1- Experience and judgement of process planner foreman or machine operator.

2- Handbook recommendations.

3- Computerized machinability data system.

- Experience and judgement of any individual is the least systematic approach and carries the greatest risk. Personal judgement is also undesirable because it usually has no scientific foundation. Cutting condition derived from personal experience are not based on economic criteria.

- Hand books of machinability data are generally developed from a systematic of large quantities of machining data.

- Computerized machinability data system . The importance of this system have grown with the increase in the use of NC machines and the economic need to operate these machines as efficiently as possible. This system requires the collection and storage of large quantities of data from the hand book of machinability. Example of these computerized center, the one in the U S.A. in the United State Airforce Center (USAF) which was established in 1948 and in the U.K. at the Production Engineering Research Association (PERA) [36].

Analysis of the System :

The values usually taken from the hand book of machinability are as shown in the example in Fig. (6.5). Sample of these Tables is shown in Fig. (6.6).

1- Vc = Cutting speed.(m/mm)

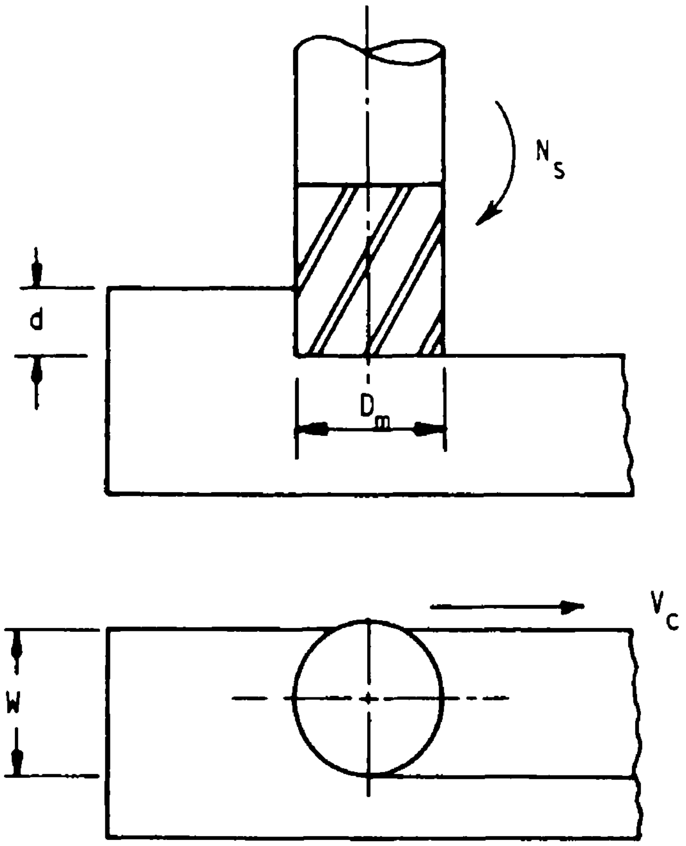
2- Dm = End milling cutter diameter.(mm)

3- ft = Feed per tooth.(mm/tooth)

4- D = Depth of cut.(mm)

5- Hardness and condition.

6- Material.



V_c = Cutting speed m/min

D_m = End milling cutter diameter mm

fT = Feed per tooth mm/tooth

d = depth of cut

N_s = Spindle speed rpm

f_m = Feed rate

$$N_s = \frac{V_c * 1000}{* D}$$

$$f_m = f_t * n_t * N_s/1000$$

Fig.(6.5) Machinability calculations

Diameter/ length	10 mm		12 mm		18 mm		25 mm	
	S mm	F m/min	S rpm	F m/min	S rpm	F m/min	S rpm	F m/mi
0.5	7798.599	1.16979	6498 833	1 325762	4332 555	1 126464	3119 44	1 1229
0 6	7607 613	1 182223	6339 678	1 354155	4226.452	1 158048	3043 045	1.1380
0.7	7416.627	1 192594	6180 523	1 379493	4120 348	1 18666	2966 651	1 1510
0 8	7225.641	1.200902	6021.367	1 401774	4014.245	1 212302	2890 256	1 1618
0 9	7034.654	1 207147	5862 213	1.421	3908 141	1.234973	2813 862	1.1705
1.0	6843 669	1 21133	5703.057	1.437171	3802.038	1.254673	2737 467	1.1771
1 1	6652 683	1 21345	5543 903	1.450285	3695 935	1 271402	2661 073	1 1815
1 2	6461.696	1 213507	5384 747	1.460343	3589 831	1.29516	2584 678	1 1837
1 3	6270.71	1.211501	5225 592	1.467346	3483 728	1.295947	2508 284	1.1839
1 4	6079 724	1 207433	5066.437	1 471293	3377 624	1.303763	2431 89	1.1819
1.5	5888 737	1 201303	4907.281	1 472185	3271 521	1 308608	2355 495	1.1777

<u>Spindle speed and feed rate</u>

Taken from table below

Aluminum Alloys, Wrought			Hardness Bhn	Condition	Radial depth of cut mm	Speed m/min	High Speed Steel Tool — Feed mm/tooth — Cutter Diameter 10mm	12mm	18mm	25x50mm
EC	3005	6066	30	Cold Drawn	5	245	·075	102	·13	18
1060	4032	6070	10		1 5	185	·102	·15	·20	·25
1100	5005	6101	80		dia/4	150	·075	102	·15	·20
1145	5050	6151	500kg		dia/2	120	·050	·075	·13	·15
1175	5052	6253								

Fig (6.6) From machinability of handbook

The following parameters are calculated from these values :

1- Ns spindle speed r.p.m

This term refers to the rotation of the spindle in revolutions per minute (r.p.m). Since the speed of an NC machine is programmed in (r p.m), it is often necessary to convert from the conventional form of describing the speed in meter per minute.

$$Ns = \frac{V_c \cdot 1000}{\pi \cdot D}$$

2- Feed rate

$$fm = ft \cdot n \cdot Ns/1000$$

where n the number of tooth.

The tools which have been chosen for machining this example is high speed steel and their dimentions will be mentioned in each program.

6-4-2 The First Program

This program has been developed for performing three functions

1- Face milling with 50 mm cutter diameter.

2- Side milling (Contouring) with 10 mm diameter.

3- Chamfer

The workpiece has been prepared for fixing on to the machine as illustrated in Fig. (6.7). Use was made of the holes which will be on the finished product to fix th workpiece at this stage.

As it was explained in the last chapter, AutoCAD blocks should be prepared to capture and store part geometry and postprocessor instructions in the order these are intended to be executed. when all the information about a given operation is stored in a

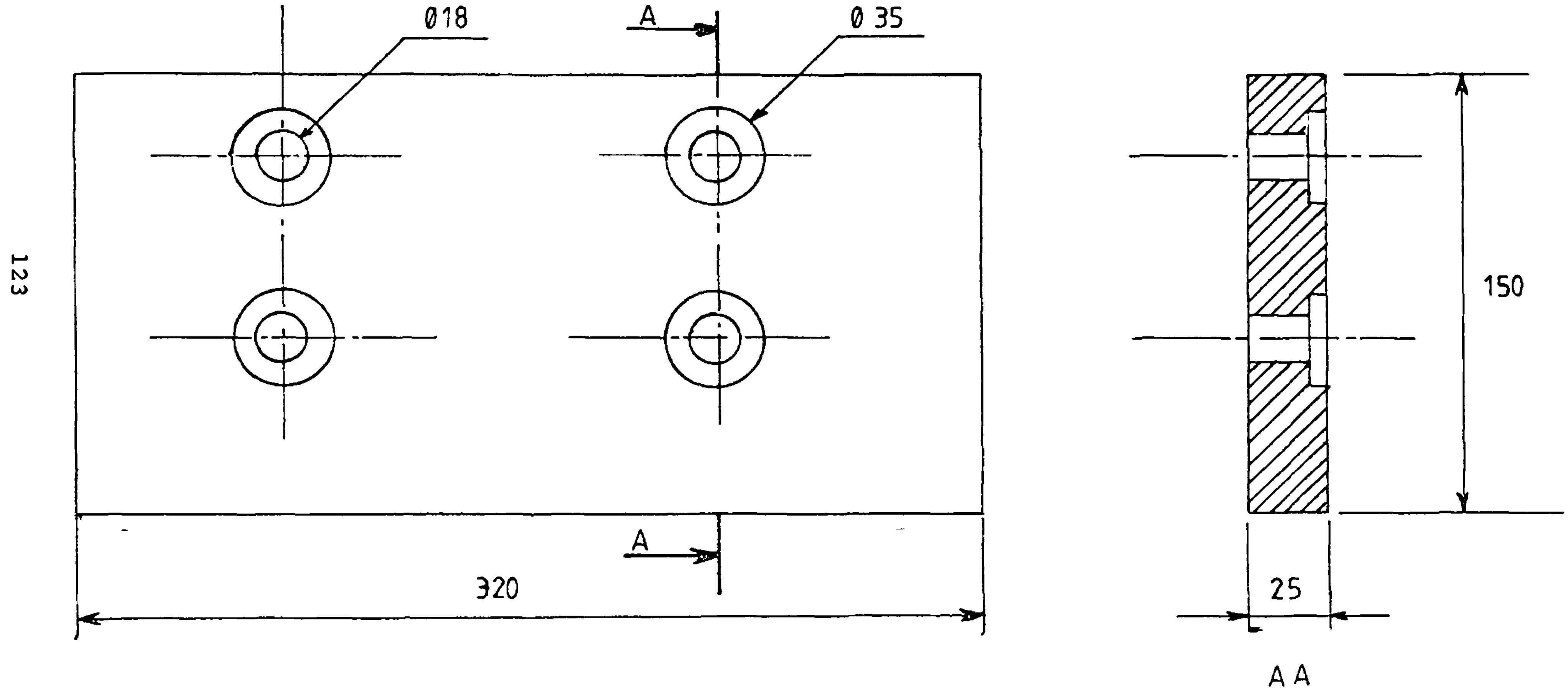


Fig. (6.7) Fixing the workpiece on machine table block, the blocks become an entity, just like a line. It can be moved, inserted or erased, just as easily as if it were a line. No matter how it is manipulated, it will always retain the information which is stored in it.

Sequencing is of major importance, and we have several tools to help us do it correctly :

1- The element of the drawing can be sequenced by running NC programmer's DEFINE command.

2- Blocks, text statements and points can be sequenced by the order in which they have been selected or inserted.

3- If items get out of order they can be re-sequenced by selecting or inserting them in the desire order.

For the first program the sub-blocks and blocks in Table (6.1) and Table(6.2) have been prepared. These Tables show the content of the blocks and the insertion point for each one.

TABLE (6.1) SUB-BLOCKS FOR THE FIRST PROGRAM

BLOCK NO.	TEXT SEQUENCE	G-CODE	
ST1	METRIC	G21	METRIC MODE
	CONVEYER/ON	G31	
ST2	Z/45.0	Z45.0	LOCATION IN Z
	INCR	G91	INCREMENTAL MODE
	RFPTTO	G28	HOME POSITION
ST3	ABS	G90	ABSOLUTE MODE
	RAPID	G00	RAPID TRAVERSE
	WRKCRD2	G55	WORK COORDINATE 2
	CUTCOM/OFF	G40	RADIUS COMPENSATION CANCEL
	CYCAN	G80	CYCLE CANCEL
	SPEED/1000	S1000	SET SPEED
	FEDRAT/200	F200	SET FEED RATE

	SPINDLE/CW TOOLNO/3	M03 T03	SPINDLE CW PREPARE TOOL NO.3
ST4	PTLC H/2 Z/10.0 COOLNT/ON	G43 H02 Z10.0 M08	LENGHT COMPENSATION MEMORY ADDRESS POSITION IN Z START COOLANT
ST5	LINEAR Z/0.5	G01 Z0.5	LINEAR MODE POSITION IN Z
ST6	SUBPRG/1000 Z/0.0 FEDRAT/400	M98P1000 Z0.0 F400	CALL SUBPROGRAM 1000 POSITION IN Z SET FEED RATE
ST7	SUBPRG/1000	M98P1000	CALL SUBPROGRAM 1000

ST8	TOOLNO/3	T03	PREPARE TOOL 3 FOR CHANGING
	TOOLCHG	M06	TOOL CHANGE
ST9	ABS	G90	ABSOLUTE MODE
	RAPID	G00	RAPID TRAVERSE
	WRKCRD2	G55	WORK COORDINATE 2
	CUTCOM/OFF	G40	RADIUS COMP. CANCEL
	CYCAN	G80	CYCLE CANCEL
	FEDRAT/200	F200	SET FEED RATE
	SPEED/1000	S1000	SET SPEED
	SPINDLE/CW	G03	SPINDLE MOVE CW
	TOOLNO/4	T04	PREPARE TOOL NO.4
ST10	PTLC	G43	LENGTH COMPENSATION
	H/3	H03	MEMORY ADDRESS TOOL 3
	Z/2.0	Z2.0	POSTION IN Z
	COOLNT/ON	M08	START COOLANT

ST11	LINEAR Z/-11.0	G01 Z-11.0	LINEAR MODE POSITION IN Z
ST12	CORNER CUTCOM/RIGHT D/53	G62 G42 D53	SLOW DOWN AT CORNERS RADIUS COMPENSATION AT THE RIGHT OF THE WORKPIECE MEMORY ADDRESS
ST13	SUBPRG/2000	M98P2000	CALL SUBPROGRAM 2000
ST14	LINEAR Z/-25.0	G01 Z-25.0	LINEAR MODE POSITION IN Z
ST15	SUBPRG/2000	M98P2000	CALL SUBPROGRAM 2000

ST16	CUTCOM/OFF	G40	RADIUS COMP.CANCEL
ST17	Z/45.0 INCR RFPTTO COOLNT/OFF	Z45.0 G91 G28 M09	POSITION IN Z INCREMENTAL MODE HOME POSITION COOLANT STOP
ST18	TOOLNO/4 TOOLCHG	T04 M06	PREPARE TOOL 4 TOOL CHANGE
ST19	ABS RAPID WRKCRD2 CUTCOM/OFF CYCAN FEDRAT/300 SPEED/1000	G90 G00 G55 G40 G80 F300 S1000	ABSOLUTE MODE RAPID TRAVERSE WORK COORDINATE 2 RADIUS COMP. CANCEL CYCLE CANCEL SET FEED RATE SET SPEED

	SPINDLE/CW	G03	SPINDLE MOVE CW
	TOOLNO/5	T05	PREPARE TOOL NO.5
ST20	PTLC	G43	LENGTH COMPENSATION
	H/4	H04	MEMORY ADDRESS
	Z/10.0	Z10.0	POSITION IN Z
	COOLNT/ON	M08	START COOLANT
ST21	LINEAR	G01	LINEAR INTERPULATION
	Z/-25.0	Z-25.0	POSITION IN Z
ST22	CORNER	G62	SLOW DOWN AT CORNERS
	CUTCOM/LEFT	G41	RADIUS COMPENSATION AT THE LEFT OF THE WORKPIECE
	D/54	D54	MEMORY ADDRESS
ST23	SUBPRG/3000	M98P3000	CALL SUBPROGRAM 3000

ST24	TOOLNO/5 TOOLCHG	T05 M06	PREPARE TOOL 5 TOOL 5 CHANGE
ST25	ABS RAPIDE WRKCRD2 CUTCOM/OFF CYCAN FEDRAT/200 SPEED/1500 SPINDLE/CW	G90 G00 G55 G40 G80 F200 S1500 G03	ABSOLUTE MODE RAPID TRAVERSE WORK COORDINATE 2 RADIUS COMP. CANCEL CYCLE CANCEL SET FEED RATE SET SPINDLE SPEED SPINDLE MOVE CW
ST26	PTLC H/5 Z/10.0 COOLNT/ON	G43 H04 Z10.0 M08	LENGTH COMPENSATION ADDRESS MEMORY POSITION IN Z START COOLANT
ST27	LINEAR	G01	LINEAR MODE

	Z/-5.0	Z-5.0	POSITION IN Z
ST28	CUTCOM/RIGHT D/55	G42 D55	RADIUS COMPENSATION MEMORY ADDRESS
ST29	FINI	G30	END OF PROGRAM
ST30	RAPID Z/10.0	G00 Z10.0	RAPID TRAVERSE POSITION IN Z

TABLE (6.2) SHOWS THE SEQUENCE OF BLOCKS AND SUB-BLOCKS

SEQ. NO.	BLOCK NAME	SUB-BLOCKS	POSITION X , Y
1	CUT1	ST1,ST2	0.0 , 0.0
2	CUT2	ST3,ST4,ST5,ST6,ST7,ST17, ST18	-20.0,-20.0
3	CUT3	ST9,ST10	-10.0 , 0.0
4	ST11	-	-10.0 , 0.0
5	ST12	-	0.0 , 0.0
6	CUT4	ST13,ST14,ST15,ST16,ST17	0.0 , 0.0
7	ST18	-	0.0 , 0.0
8	CUT5	ST19,ST20	-30.0 ,-20.0
9	ST21	-	-30.0 ,-20.0
10	ST22	-	0.0 , 0.0
11	ST23	-	0.0 , 0.0
12	ST16	-	0.0 , 0.0
13	ST17	-	0.0 , 0.0
14	ST24	-	0.0 , 0.0
15	CUT6	ST25,ST26	310.0 ,-10.0

16	ST27	-	310.0 ,-10.0
17	ST28	-	306.0 ,-10.0
18	ST30	AT THE BEGINNING OF THE LAST ENTITY	
19	CUT7	ST16,ST17,ST29	306.0 , 0.0

For face milling sub-program 1000 has been developed using the Mill Productivity Pachage. The hatch pattern has been selected from the main menu and the tool path has been created as shown in Fig. (6.8). One additional block has been inserted at the end of the tool path.

```
END : RAPID
      Z/15.0
      ENDSUB
```

After the END block has been inserted a .DXF file has been created and used in the postprocessor to produce the part program for this sub-program.

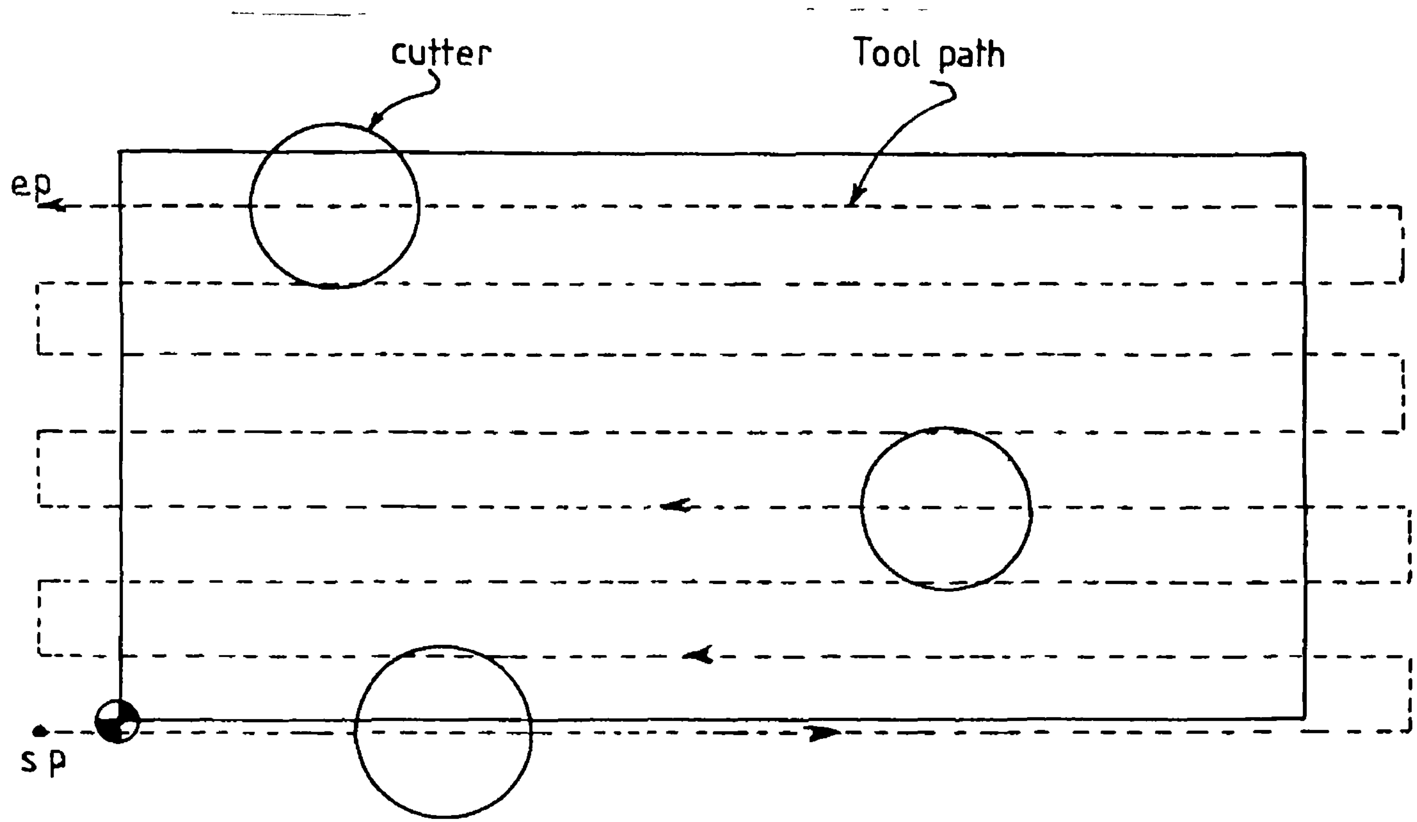


Fig. (6.8) Surface milling tool path

For the side milling operation, the tool path has been created by the Mill Productivity Package which represent the real boundary of the workpiece because the G41 command has been used in the main program. The block which contains the information about the retraction of the tool and ending the sub-program has been inserted at the end of the tool path. Then the .DXF file has been created and the sub-program 2000 was produced using the postprocessor.

Finally the NC programmer has been used to develop the main body of the program which contains the machinability information, calling sub-program statements and the tool path for chamfer operation. The NC programmer has been used because it was necessary to insert a block in the tool path just before the last line . All the blocks shown in Table (6.1) and Table (6.2) have been inserted in the sequence these are needed to be in the program. Then the .DXF file has been produced and the main program in G-Code has been produced.

At this stage there are three files :

1- Main program .

2- Sub-Program 1000 .

3- Sub-Program 2000 .

These three files have been merged using the Edline in MS-DOS and the program became ready to be sent to the machine.

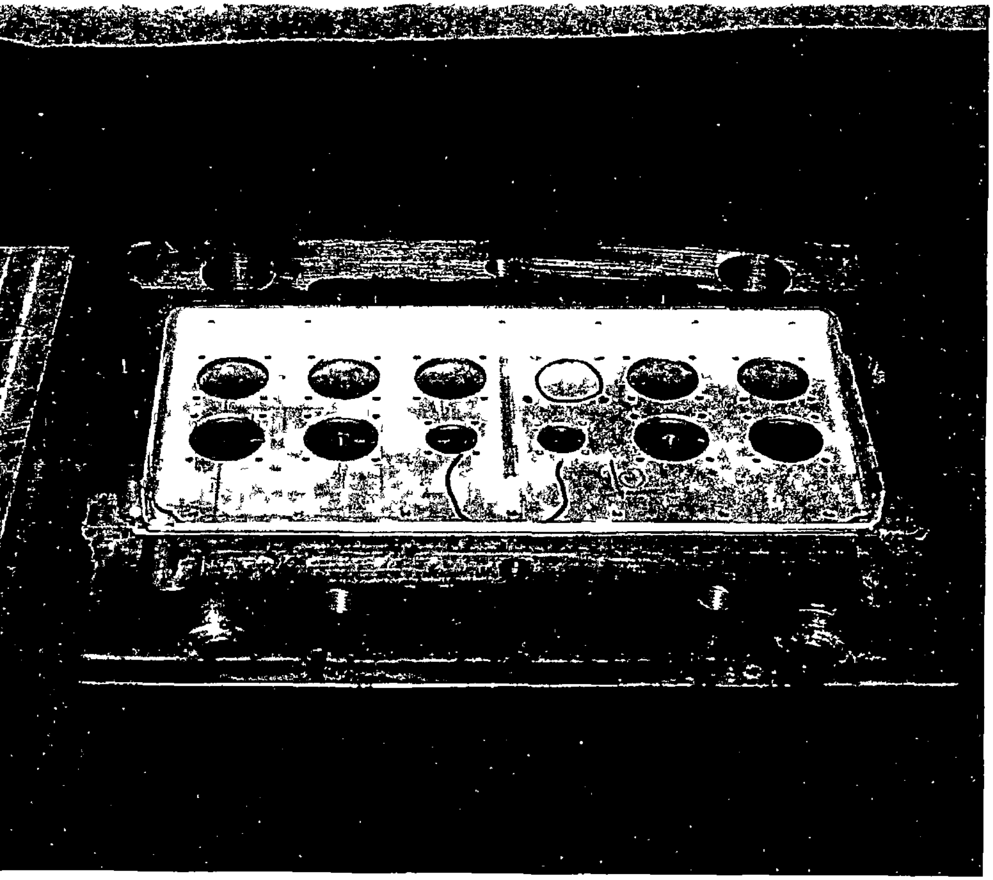
6-4-3 The second Program

This program has been developed for machining the pockets. Because the thickness of the boundary which had to be left is very small, a special fixture had to be used as illustrated in Plate 7. The clamping devices should be changed three times during the pocketting operation to overcome the loads produced by the tools.

The procedure of pocket machining is as below :

1- Facing: Machining the side facing using HSS tool with D=10 mm to machine the edge of the box only, because

PLATE 7



Pocketting fixture

the rest of material will be removed by the pocketting operation.

Clamp change

2- Pocketting the left hand side area which overlap some area of right pocket for Z=-11.0 mm to indicate the boundary between the two pockets.

Clamp change

3- Pocketting the left pocket to depth Z=-18.5 mm. Then finishing the pocket to Z=19.0 mm.

4- Pocketting the right pocket to depth Z=-19.0 mm using depth of cut Z=-5.5, Z=-11.0, Z=-18.5 and Z=-19.0 mm.

Five sub-programs have been used for the above machining steps :

Sub-Program 4000

This sub-program has been created for pocketing the workpiece for Z=-11.0 mm in order to divide the workpiece into two pockets. The Mill Productivity Package has been used to develop the tool path for this sub-program. The right hand pocket has been fixed during the machining process. First of all , the program has been loaded and then the desired geometry has been changed to a polyline. By using the REOFFSET command three polylines are created inside the original one. These polylines represent the tool path. After that these polylines have been connected together using POLYJOIN command as shown Fig. (6.9). Next two blocks of machining information have been inserted along the tool path,one of these at the begining and the other at the end of it. The content of these two blocks are shown as below:

```
1- START :    LINEAR

2- END   :    RAPID
              Z/2.0
              ENDSUB
```

Finally the DXF file has been produced using AutoCAD command and the postprocessor was used to change it to an NC-Code file.

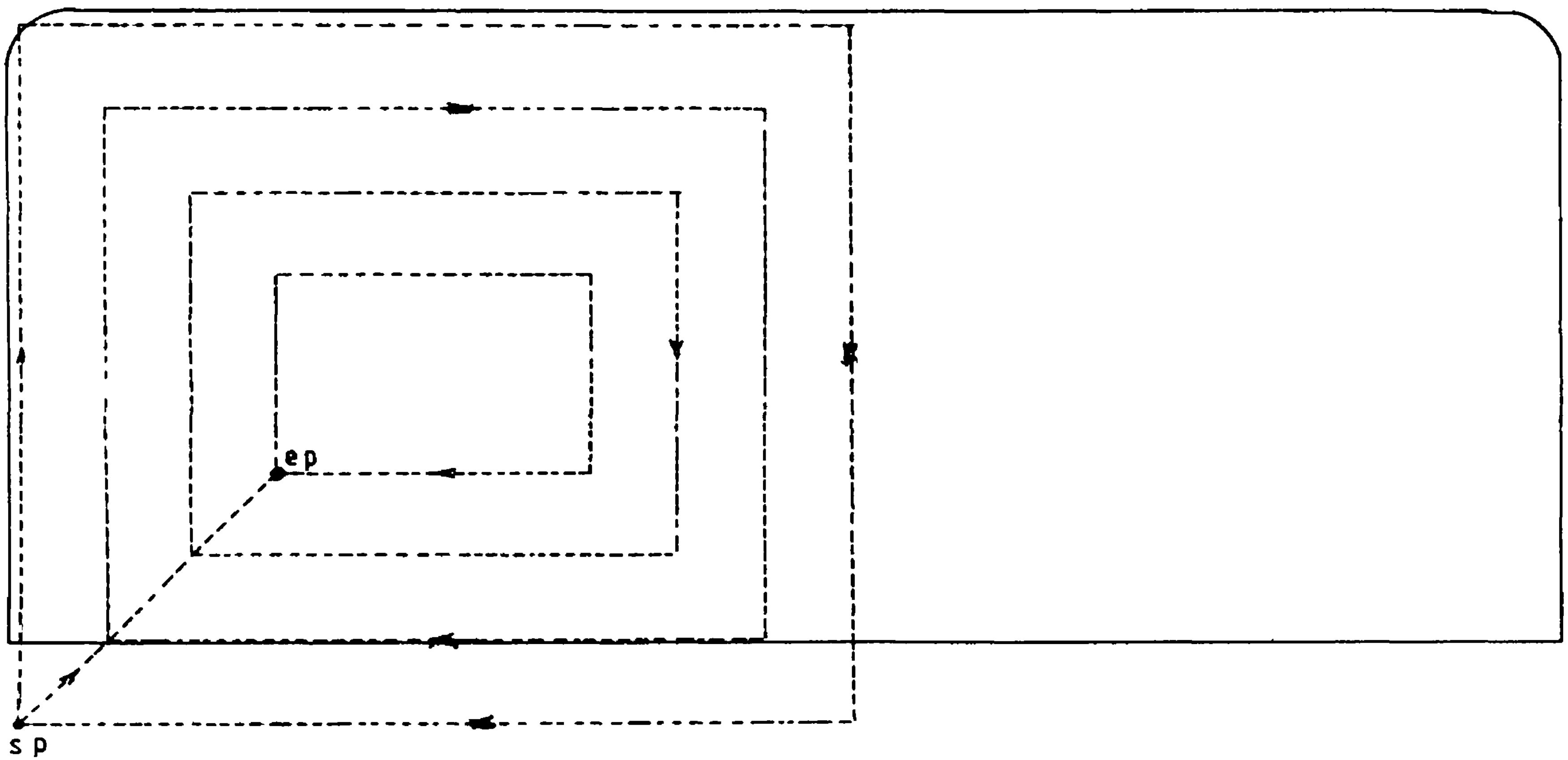


Fig. (6.9) Left hand side pocketting
(With overlap)

Sub-Program 5000

This sub-program is nearly the same as the previous on, but it gives the correct tool path for machining the left pocket without overlaping. Also the Mill Productivity Package has been used for creating the tool path and inserting the blocks. The same blocks have been used in this sub-program and the same steps to create the NC-Code program. The tool path for this sub-program is illustrated in Fig. (6.10)

Sub-Program 6000

This sub-program represents the tool path for the right pocket. The procedure is the same as for the previous sub-programs. But still needs to be said that during machining this part, the clamp has to be changed to the opposite side. The tool path which has been created is shown in Fig. (6.11).

Sub-program 7000 and 8000 have been created using the same procedure. These sub-programs have been created for finishing the two pockets as shown in Fig. (6.12) and Fig. (6.13).

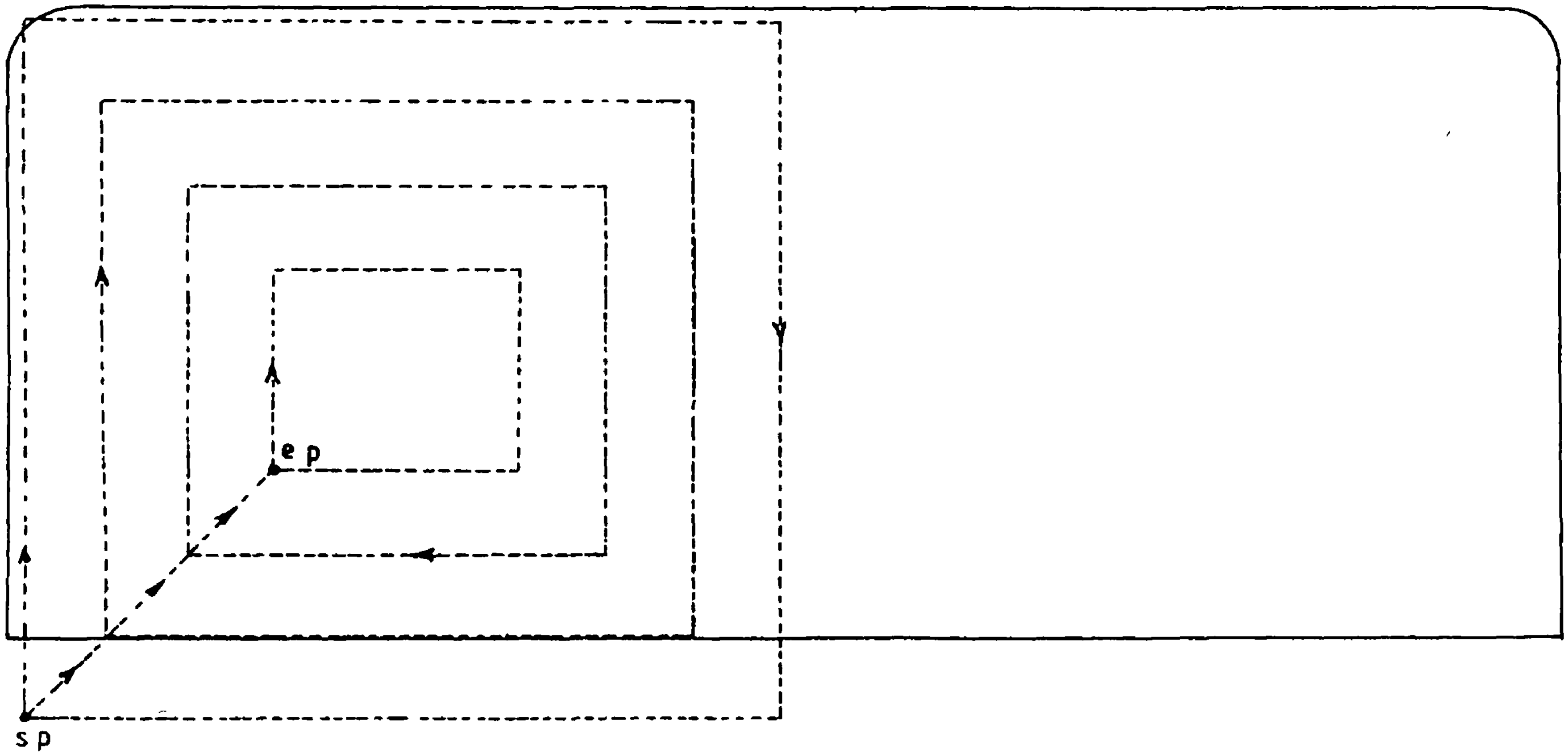


Fig. (6.10) Left hand side pocketting

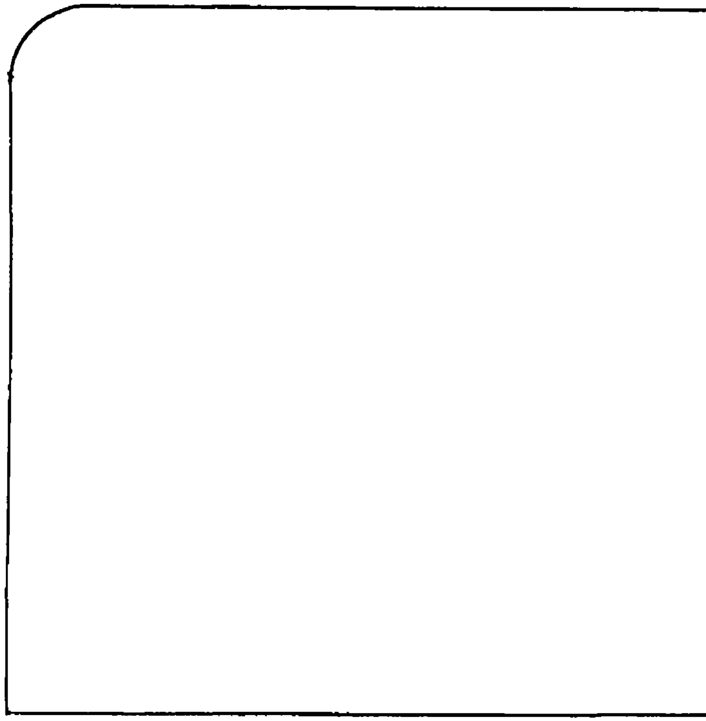
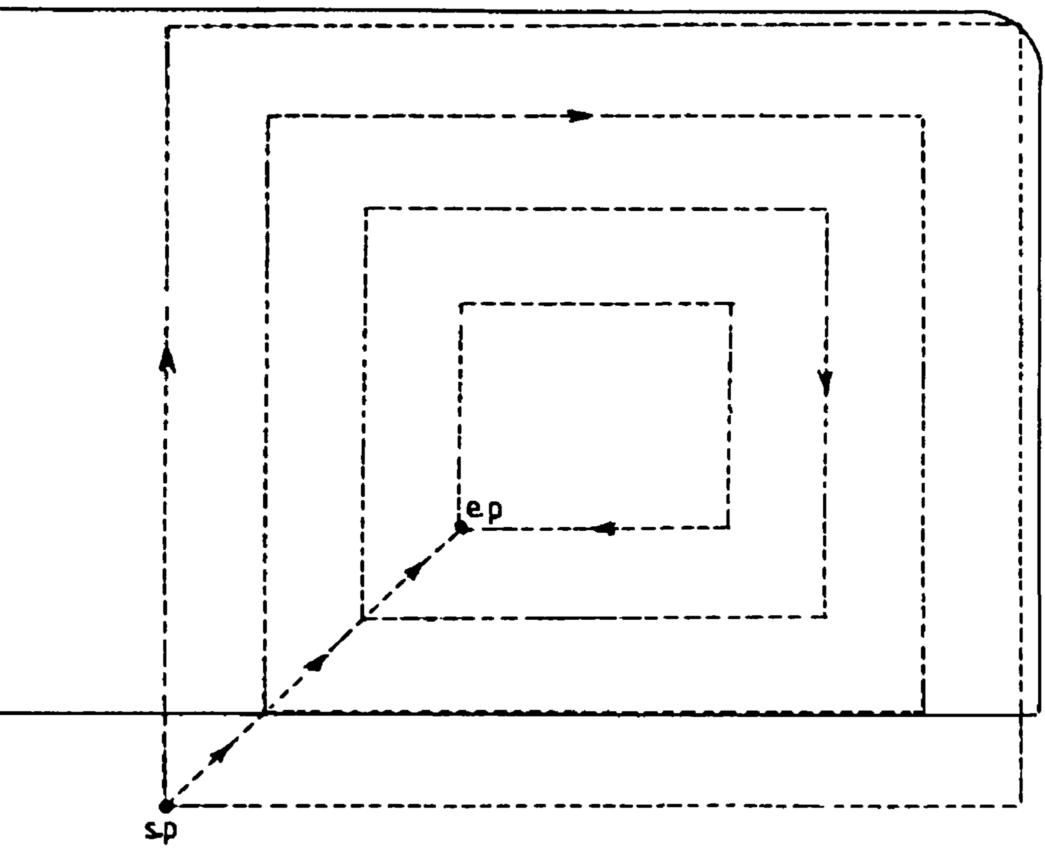


Fig. (6.11)



Right hand side pocketting

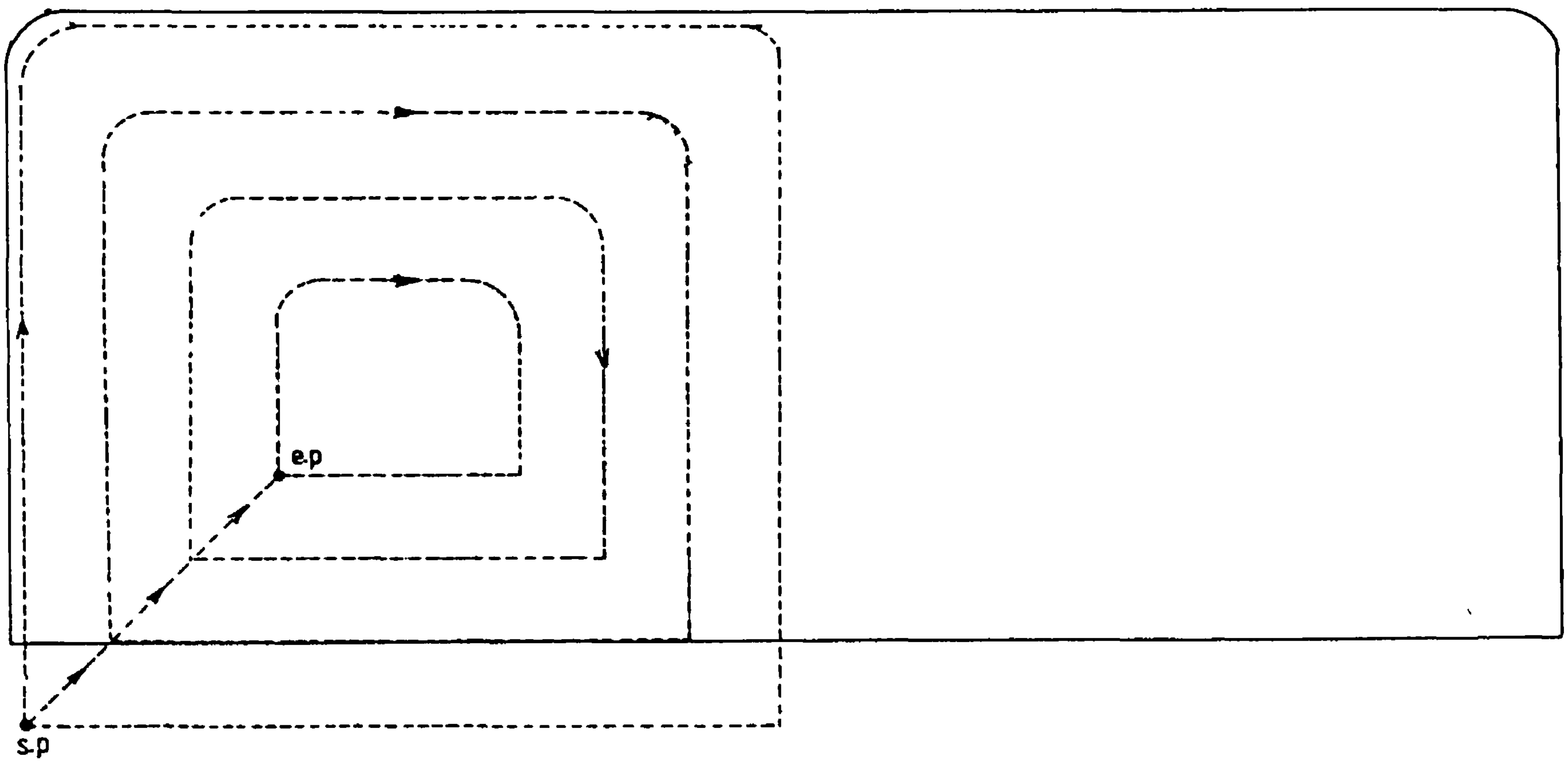


Fig. (6.12) Left hand side pocketting (Finishing)

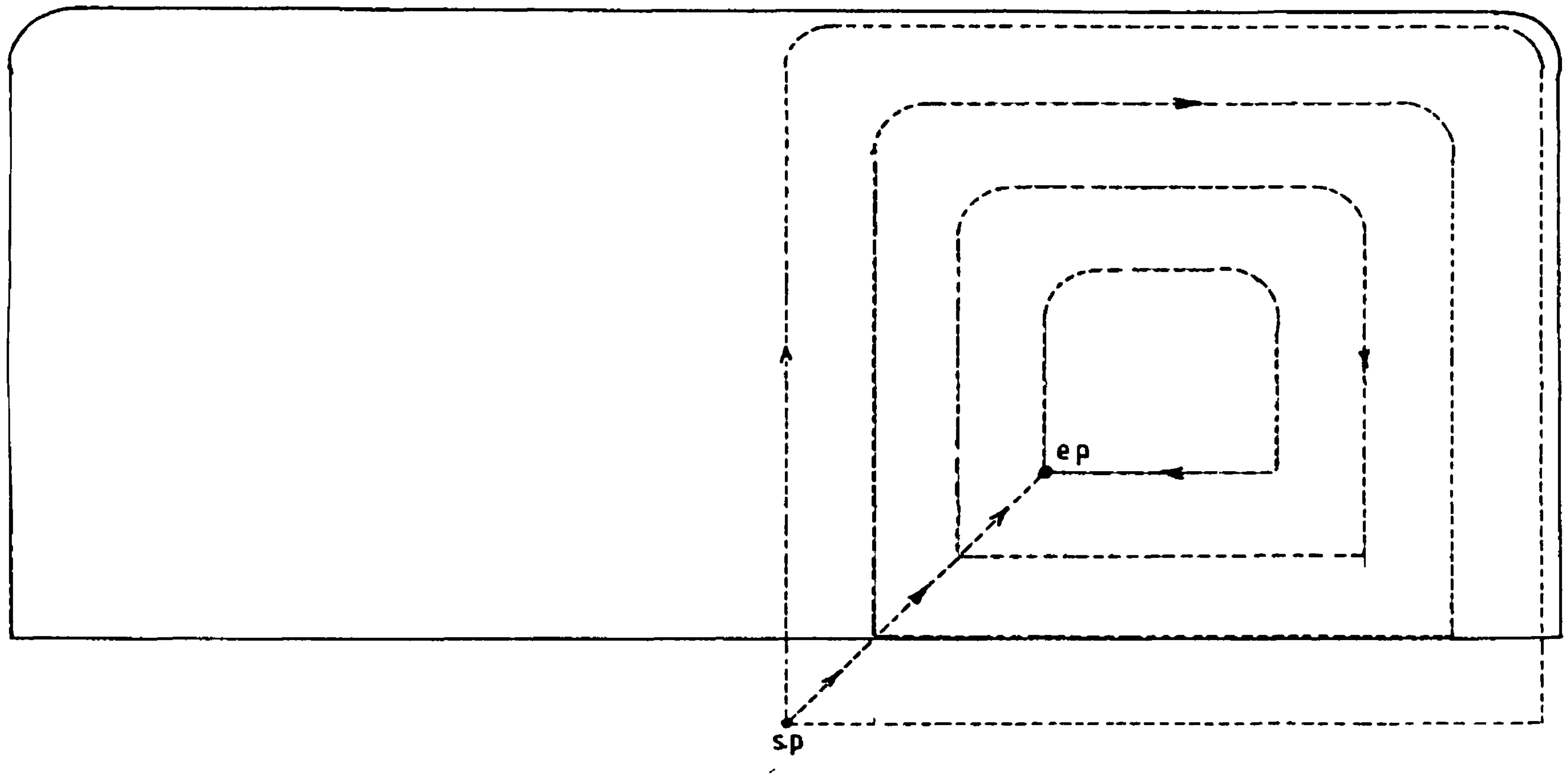


Fig. (6.13) Right hand side pocketting (Finishing)

Finally, the main program has been developed using the the blocks in Table (6.3). These tables contain all the machining information need for this program.

TABLE (6.3) SUB-BLOCKS FOR PROGRAM 2

SEQ. NO.	SUB-BLOCK	CONTENT	LOCATION
1	ST1	-	0.0 , 0.0
2	ST2	-	0.0 , 0.0
3	SB1	TOOLNO/2 TOOLCHG	0.0 , 0.0
4	SB2	RAPID ABS WRKCRD2 CUTCOM/OFF	-10.0 , -20.0

		CYCAN SPEED/1000 FEDRAT/300 SPINDLE/CW TOOLNO/3	
5	ST4	-	-10.0 , -20.0
6	SB3	LINEAR Z/0.0	-10.0 , -20.0
7	ST30	GEOMETRY + ST30 AT STARTOF THE LAST ELEMENT	
8	SB4	RAPID ABS WRKCRD2 CUTCOM/OFF CYCAN SPEED/750	3 , -15.0

		SPINDLE/CW FEDRAT/200 TOOLNO/3	
9	ST4	-	3 , -15.0
10	SB5	LINEAR CUTCOM/RIGHT D/52	3 , -13.0
11	SB6	LINEAR Z/-6.0	3 , -13.0
12	SB7	LINEAR SUBPRG/4000	3 , -13.0
13	SB8	RAPID Z/2.0	10.0 , -20.0
14	SB9	LINEAR Z/-11.0	3 , -13.0

15	SB10	SUBPRG/4000	3 , -13.0
16	SB8	-	5 , -20.0
17	SB11	LINEAR Z/-16.0	3 , -13.0
18	SB12	SUBPRG/5000	3.0 , -13.0
19	ST16	-	3.0 , -13.0
20	SB13	LINEAR CUTCOM/RIGHT D/62 SPEED/1000	3.0 , -13.0
21	SB8	-	10.0 , -20.0
22	SB14	LINEAR Z/-18.5	3.0 , -13.0
23	SB12	-	3.0 , -13.0

24	SB8	-	10.0 , -20.0
25	SB16	LINEAR Z/19.0	3.0 , -13.0
26	SB15	-	3.0 , -13.0
27	SB12	-	3.0 , -13.0
28	ST17	-	3.0 , -13.0
29	SB4	-	154.5,-15.0
30	ST4	-	154.5,-15.0
31	SB5	-	154.5,-15.0
32	SB17	Z/-5.5	154.5,-15.0
33	SB8	-	157.0,-14.0
34	SB18	SUBPRG/6000	157.0,-14.0

35	ST16	-	157.0,-14.0
36	SB19	RAPID	153.0,-30.0
37	SB11	-	153.0,-30.0
38	SB20	ABS RAPID WRKCRD2 CYCAN SPEED/1000 SPINDLE/CW FEDRAT/200	20.0 ,-20.0
39	SB21	PTLC H/3 Z/10.0 COOLNT/ON	20.0 ,-20.0
40	SB22	LINEAR CUTCOM/RIGHT	3.0 ,-10.0

41	SB23	Z/18.9	3.0 ,-10.0
42	SB24	SUBPRG/7000	3.0 ,-10.0
43	SB25	Z/19.0 FEDRAT/400	3.0 ,-10.0
44	SB24	-	3.0 ,-10.0
45	ST17	-	3.0 ,-10.0
46	SB20	-	160.0,-12.0
47	SB21	-	160.0,-12.0
48	SB22	-	155.0,-10.0
49	SB23	-	155.0,-10.0
50	SB26	SUBPRG/8000	155.0,-10.0
51	SB25	-	155.0,-10.0

52	SB26	-	155.0,-10.0
53	ST17	-	155.0,-10.0
54	SB28	ENDPRG	155.0,-10.0

6-4-4 The Third Program

This program has been developed for machining and drilling the holes. The main procedures is based on creating two sub-programs for machining the holes of diameters D=32 mm and D=23 mm. Alos the drilling cycle G81 has been used for the holes with D=3.2 mm. The component has been fixed as shown in Plate 8, where a piece of aluminium has been inserted under the work piece .

The same procedure has been carried out for preparing all the above programs. First of all, blocks and sub-blocks have been created as shown in Table (6.4) and Table (6.5). Then the NC Programmer was used for

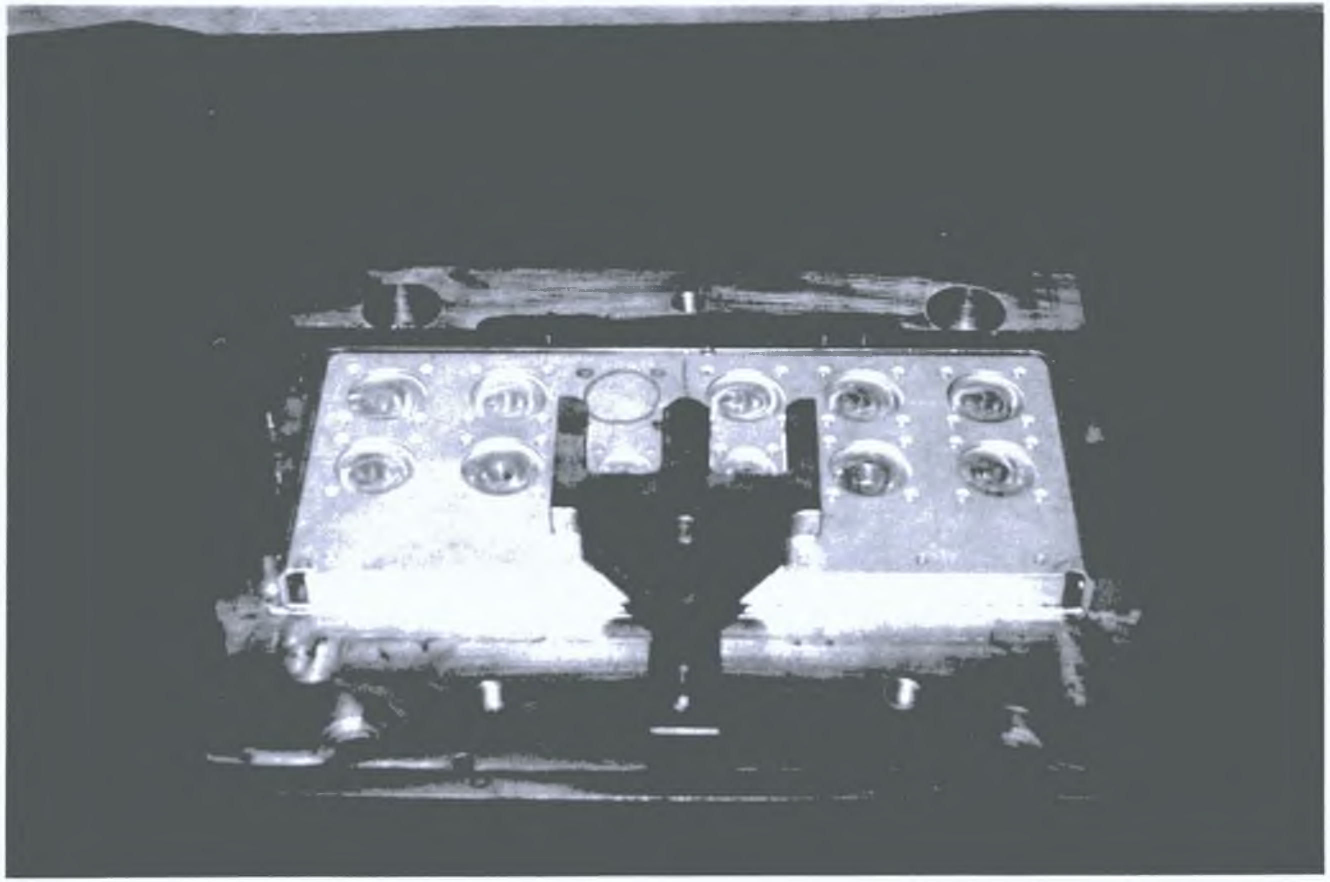


PLATE 8 Drilling fixture

creating the tool path because it offers the facilities to inset blocks at certain points along the tool path. For this reason the offset has been drawn using AutoCAD command in three rectangular shapes which represent the tool path as shown in Fig. (6.14). These drawings have been drawn using intermittent lines so each end point of a line represent the location of a hole. After that these drawing have been defined using AutoCAD command 'DEFINE' and the offset has been used twice for each drawing , one outside the drawing and the other inside it in order to get the offset value equal to zero. Then the blocks have been inserted in thier proper locations. The 'VALID' command has been used to connect between the three drawings.

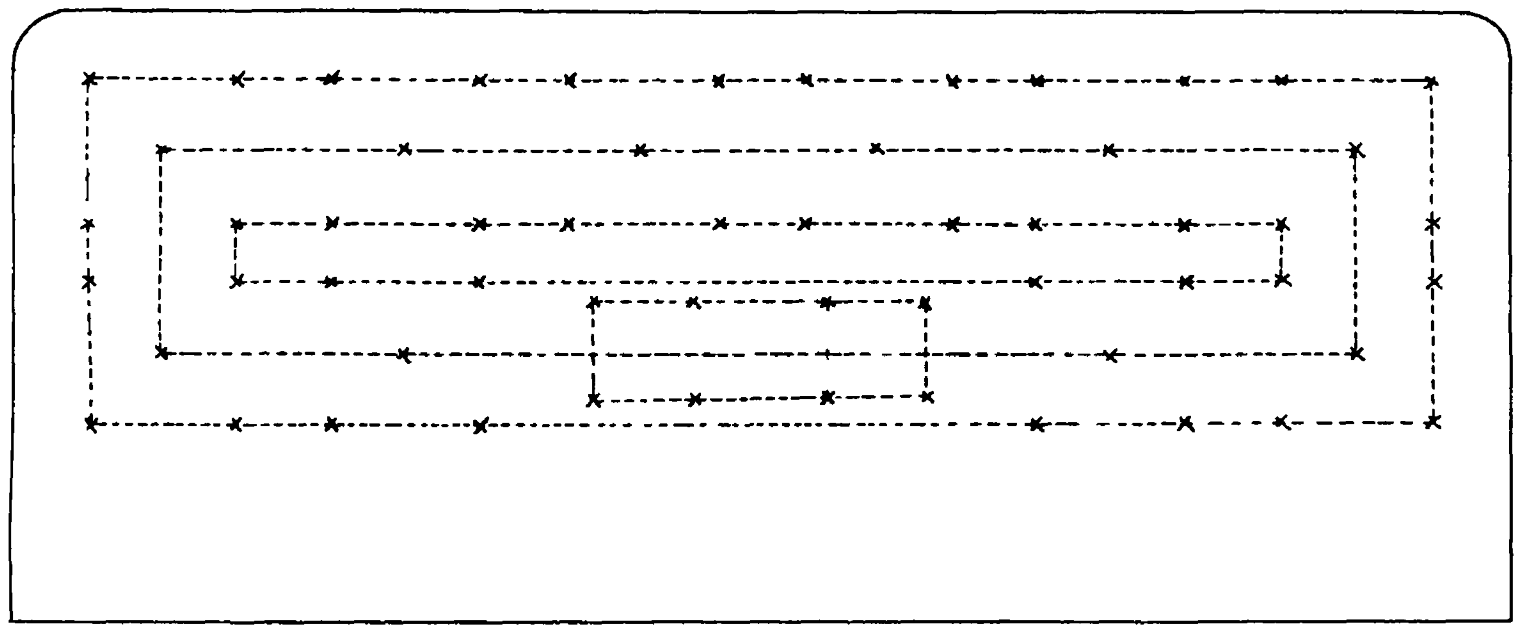


Fig. (6.14) Drilling and hole machining tool path

TABLE (6.4) BLOCKS FOR PROGRAM 3

BLOCK NANE	TEXT SEQUENCE	G-CODE	
K1	ABS	G90	ABSOLUTE MODE
	RAPID	G00	RAPID TRAVERSE
	WRKCRD2	G55	WORK COORDINATE 2
	CUTCOM/OFF	G40	RADIUS COMP.CAN.
	CYCAN	G80	CYCLE CANCEL
	SPEED/1000	S1000	SET SPEED
	FEDRAT/200	F200	SET FEED RATE
	SPINDLE/CW	M03	SPINDLE MOVE CW
	TOOLNO/8	T08	PREPARE TOOL 8
K2	PTLC	G43	LENGTH COMPENSAT- ION.
	H/7	H07	MEMORY ADDRESS
	Z/15.0	Z15.0	LOCATION IN Z
	COOLNT/ON	M08	START COOLANT

K3	SUBPROG/9000	M98P9000	CALL SUBPROGRAM
K4	ABS SUBPRG/9000	G90 M98P9000	ABSOLUTE MODE CALL SUBPROGRAM
K5	TOOLNO/8 TOOLCHG	T01 M06	PREPARE TOOL 8 TOOL CHANGE
K6	ABS RAPID WRKCRD2 CUTCOM/OFF CYCAN SPEED/1000 SPINDLE/CW	G90 G00 G55 G40 G80 S1000 M03	ABSOLUTE MODE RAPID TRAVERSE WORK COORDINAT 2 RADIUS COMP.CANC. CYCLE CANCEL SET SPEED START SPIDLE CW
K7	PTLC H/8 Z/15.0 COOLNT/ON	G43 H08 Z15.0 M08	LENGTH COMPENS- ATION. MEMORY ADDRES LOCATION IN Z START COOLANT

PC	CYCLE/81	G81	DRILLING CYCLE
	RL	G99	RETURN TO REFERE-NCE POINT.
	PZ/-5.0	Z-5.0	DEPTH OF CUT
	P1/2.0	R2.0	REFERENCE POINT
	P4/100	F100	SET FEED RATE

Table (6.5) The locations of the blocks.

SEQ. NO.	BLOCK NAME	SUB-BLOCKS	LOCATIONS X , Y
1	CUT1	ST1,ST2	0.0,0.0
2	BOR1	K1,K2,K3	31.0,57.0
3		GEOMETRY WITH INSERT-ION OF K4	
4	K5	-	-20.0,-20.0
5	BOR2	K6,K7	-20.0,-20.0
6	PC	-	15.0,41.0
7		GEOMETRY	

Finally the .DXF file for the offset geometry has been created to be used in the postprocessor.

Sub-Program 9000

This sub-program was created for machining the D=32 mm hole. The machining starts by setting the machine to incremental mode and ends by retracting out of the workpiece in absolute mode. The expected machine component in shown in Plate 9

The component

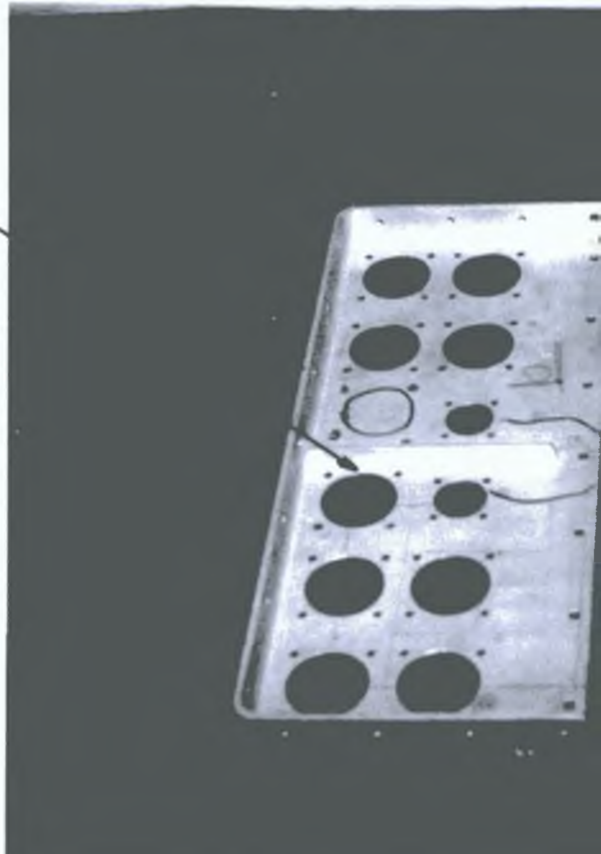
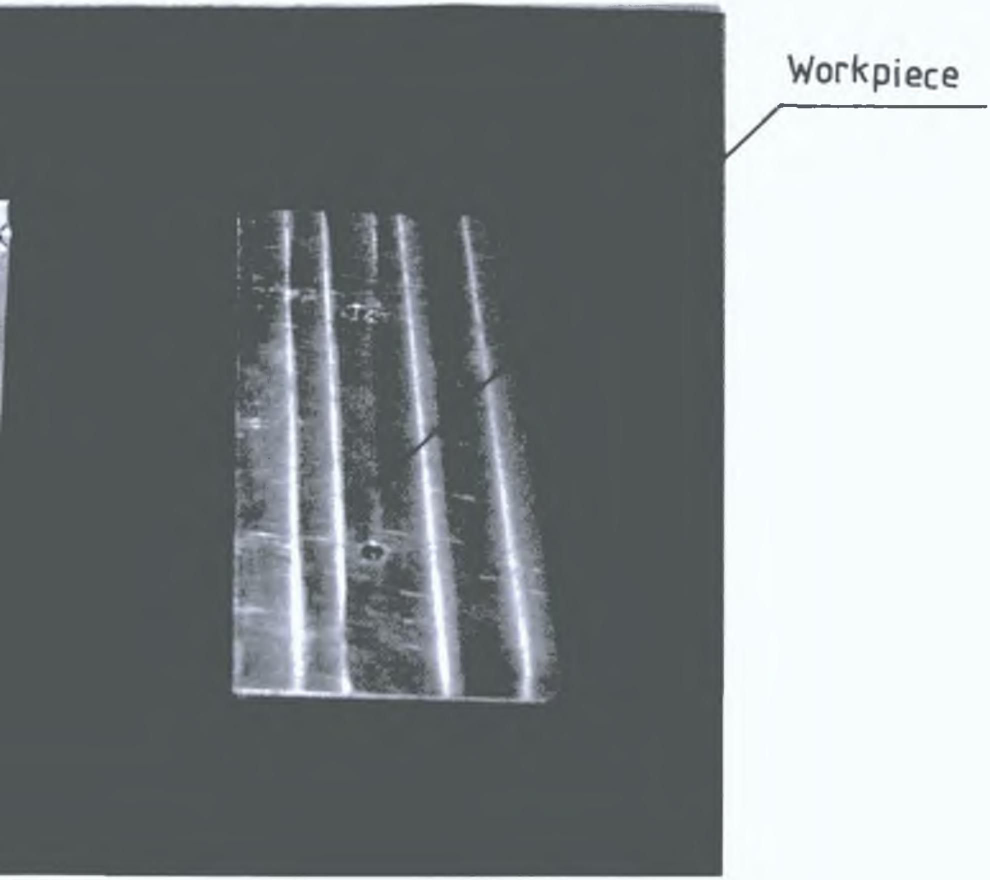


PLATE 9


Workpiece

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATION

7-1 CONCLUSION

As explained in the previous chapters, software for an integrated CAD/CAM system has been developed using three main packages, these being AutoCAD package and NC programmer in the PC and Finite Element Analysis Package in the Mainframe. A combination of PC and mainframe facilities have been used in this system. The main efforts have been directed forwards two points .

1- The interface between the AutoCAD package in the PC and the Finite Element package in mainframe computer.

2- Familarization with the CAM package which consists of two main programs, the NC programmer and the Mill Productivity program and the development of the postprocessor for a particular milling machine-controller combination . It was not necessary to develop interfacing program between the AutoCAD package and the CAM package , because these were already integrated.

A number of case studies have been carried out on the system to establish its the effectiveness and the results were were found to be satisfactory. It is possible to modify the mesh before deformation and also to re-analyse the component after changing the material, boundary condition or the external loads.

At the end of each exercise, it is possible to display the mesh before and after deformation and the stress contours additionally it is also possible to display the numerical results produced by the Finite Element Package. So that user can make an accurate dicission on whether the component meets the requirement under certain load and boundary condition.

For the CAM aspect of this study, it is found that the NC Programmer and the Mill Productivity Package are not complete and do not have a full facilities for preparing the part programs The following drawbacks have been found in these two packages :

1- The process of preparing the information in blocks and inserting them in the drawing is not satisfactory and user friendly. For example, for the first program more than 40 additional blocks had to be prepared and inserted in diferent places in the drawing and along the tool path. In addition it needs a substantial hand on experience and there are many situations where the user might make mistakes.

2- Sometimes during the creation of the tool path, many additional entities have to be drawn in order to develop the proper tool path. Because in both the NC Programmer and The Mill productivity package the ceation of the tool path is based on the offset of polylines.

3- In the Mill Productivity Package which has the facilities for ceating the pocketting tool path, there is no way of inserting the blocks of machining information along the tool path apart from at the start and end points.

4- It is not possible to load the cycles program in the NC programmer which makes the user to go through the load procedure of the Mill Productivity Package to load the cycle and prepare the blocks.

In AutoCAD package one drawback has been encountered which is the lack of facility of showing the content of two layers in diferent viewports. This facility is necessary ,in my opinion, for showing the mesh before and after deformation .

The postprocessor which has been created for Fanuc-11 controller might need a slight modification during its use , because there are some points which have not been covered and these points only arise when actual application on the machine is made. But more than 80% of its G-Code and M-Code have been covered.

7-2 SUGGESTIONS FOR FUTURE WORK

In the Finite Element Package which exists in the mainframe, the plane stress and palne strain analysis for two-dimensional component have been incorporated in this study. For future work it would be possible to use for example, the elasto-plastic midline plate bending analysis and the Finite Element Analysis for complex components. All these should be possible to acheive by carrying out some modifications in the interface programs

The mesh generation program can be improved using AutoCAD facilities such as programming in LISP language and it can be put as an option in the main menue, so that it will make the work easier and reduce the time consumption in transferring the data to mainframe and back.

Also the work can be carried out on developing the contour for principal stress because in this project only the equivelant stress has been considered.

The same principles which have been used in this study can be applied to different kind of machine. For example, turning machine or welding robots The work might be more than which has been done here in the CAM aspect , because all the facilities for developing the tool path for these machine have to be investigated and the postprocessor for each machine has to be created

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APPENDIX A

```
1 REM*************************************************************
2 REM              INTERFACE PROGRAM (1)   (Interl bas)           *
3 REM         -----------------------------------------          *
4 REM  This program translates the DXF file which contains the  *
5 REM  auxiliary entities,to a data file (2TEST DAT)             *
6 REM*************************************************************
7 REM
8 DIM N$(100),B$(100)
9 N=1
10 OPEN "1TEST DAT" FOR INPUT AS FILE £1
15 INPUT £1,A$
16 IF A$='EOF' GOTO 128
17 IF A$='LINE' GOTO 23
19 IF A$='TEXT' GOTO 111
22 GOTO 15
23 FOR I=1 TO 15
30 INPUT £1,A$
35 IF A$='EOF' GOTO 128
40 IF A$='10' OR A$='20' OR A$='11' OR A$='21' GOTO 55
50 GOTO 100
55 I=I+1
60 INPUT £1,A$
65 IF A$='EOF' GOTO 128
70 B$(N)=A$
71 N=N+1
100 NEXT I
110 GOTO 15
111 FOR I=1 TO 12
112 INPUT £1,A$
113 IF A$='EOF' GOTO 128
114 NEXT I
115 KK$=A$
116 GOTO 15
128 CLOSE £1
129 N1=N
130 OPEN "2TEST DAT" FOR OUTPUT AS FILE £2
132 PRINT £2,KK$
135 FOR I=1 TO N1-1 STEP 2
140 PRINT £2,B$(I),",",B$(I+1)
150 NEXT I
155 CLOSE £2
160 END
```

```
C*********************************************************************
C
C                    INTERFACE PROGRAM (2)
C                        (Inter2 for)
C                ----------------------------
C   this program reads the coordinates of the nodes before deformation
C   to convert it to a Drawing Exchange File DXF in order to draw the
C   mesh before deformation
C*********************************************************************
C
      DIMENSION X(100),Y(100),X1(100),Y1(100),X2(100),Y2(100)
      OPEN(UNIT=1,FILE='COORD DAT',STATUS='OLD')
      READ(1,10)N,KK,XI,YI
10    FORMAT(1X,I2,5X,I2,5X,F5 1,5XF5 1)
      READ(1,11)(X(I),Y(I),I=1,N)
11    FORMAT(5X,F5 1,5X,F5 1)
      CLOSE(UNIT=1)
      OPEN(UNIT=3,FILE='TEXT DAT',STATUS='NEW')
      DO 60 J=1,N
      X2(J)=X(J)+XI-3 0
      Y2(J)=Y(J)+YI+1 0
60    CONTINUE
      WRITE(3,61)((I,X2(I),Y2(I)),I=1,N)
61    FORMAT(1X,I3,5X,F5 1,5X,F5 1)
      CLOSE(UNIT=3)
      L=1
      DO 12 J=1,(KK-1)
      DO 13 I=J+1,(N-(KK-J)),KK+1
      X1(L)=X(I)+XI
      Y1(L)=Y(I)+YI
      L=L+1
13    CONTINUE
12    CONTINUE
      OPEN(UNIT=2,FILE='DXF DAT',STATUS='NEW',CARRIAGECONTROL='LIST')
      WRITE(2,16)
16    FORMAT(3H  0)
      WRITE(2,14)
14    FORMAT(7HSECTION/2X,1H2/8HENTITIES)
      I1=1
      DO 18 J=1,(KK-1)
      DO 19 I=I1,(((L-1)/(KK-1))*J)-1
      WRITE(2,20)
20    FORMAT(2X,1H0/4HLINE/2X,1H8/5HMESH1)
      WRITE(2,21)X1(I),Y1(I)
21    FORMAT(1X,2H10/F5 1/1X,2H20/F5 1/1X,2H30/1X,3H0 0)
      WRITE(2,23)X1(I+1),Y1(I+1)
23    FORMAT(1X,2H11/F5 1/1X,2H21/F5 1/1X,2H31/1X,3H0 0)
19    CONTINUE
      I1=I+1
18    CONTINUE
      DO 63 I=1,N
      WRITE(2,64)
64    FORMAT(2X,1H0/4HTEXT/2X,1H8/5HMESH1)
      WRITE(2,65)X2(I),Y2(I),I
```

```
65      FORMAT(1X,2H10/F5 1/1X,2H20/F5 1/1X,2H30/1X,3H0 0/1X,2H40/1X,
        3H2 5/2X,1H1/1X,I2)
63      CONTINUE
        WRITE(2,30)
30      FORMAT(2X,1H0/6HENDSEC/2X,1H0/3HEOF)
        CLOSE(UNIT=2)
        END



C****************************************************************************
C                      INTERFACE PROGRAM (3)
C                         (Inter3 for)
C                  ---------------------------------
C   This program has been developed to translate the mesh
C   after deformation to Drawing Exchange File (DXF)
C   It reads its input from COORD DAT & COORD4 DAT and
C   output the result into the file DXF1 DAT which has to
C   be sent to AutoCAD in order to convert it to a drawing
C****************************************************************************
C
        DIMENSION X(100),Y(100)
        OPEN (UNIT=1,FILE='COORD DAT',STATUS='OLD')
        READ(1,10)NP,KK,XI,YI
10      FORMAT(1X,I2,5X,I2,5X,F5 1,5X,F5 1)
        CLOSE(UNIT=1)
        OPEN (UNIT=2,FILE='COORD4 DAT',STATUS='OLD')
        READ(2,11)(I,X(I),Y(I),I=1,NP)
11      FORMAT(1X,I10,2E14 6)
        CLOSE(UNIT=2)
        DO 12 I=1,NP
        X(I)=X(I)+XI
        Y(I)=Y(I)+YI
12      CONTINUE
        OPEN (UNIT=3,FILE='DXF1 DAT',STATUS='NEW',CARRIAGECONTROL='LIST')
        WRITE(3,13)
13      FORMAT(3H  0/7HSECTION/2X,1H2/8HENTITIES)
        I=1
        DO 14 N1=1,(NP/(KK+1))
        DO 15 N2=1,KK
        WRITE(3,16)
16      FORMAT(2X,1H0/4HLINE/2X,1H8/5HMESH2)
        WRITE(3,17)X(I),Y(I)
17      FORMAT(1X,2H10/F10 6/1X,2H20/F10 6/1X,2H30/1X,3H0 0)
        WRITE(3,18)X(I+1),Y(I+1)
18      FORMAT(1X,2H11/F10 6/1X,2H21/F10 6/1X,2H31/1X,3H0 0)
        I=I+1
15      CONTINUE
        I=I+1
14      CONTINUE
        I=1
        DO 19 N1=1,(KK+1)
        DO 20 N2=1,((NP/(KK+1))-1)
```

```
      WRITE(3,21)
21    FORMAT(2X,1H0/4HLINE/2X,1H8/5HMESH2)
      WRITE(3,22)X(I),Y(I)
22    FORMAT(1X,2H10/F10 6/1X,2H20/F10 6/1X,2H30/1X,3H0 0)
      WRITE(3,23)X(I+KK+1),Y(I+KK+1)
23    FORMAT(1X,2H11/F10 6/1X,2H21/F10 6/1X,2H31/1X,3H0 0)
      I=I+KK+1
20    CONTINUE
      I=N1+1
19    CONTINUE
      WRITE(3,24)
24    FORMAT(2X,1H0/6HENDSEC/2X,1H0/3HEOF)
      CLOSE(UNIT=3)
      END


C**********************************************************************
C                                                                     *
C                 MESH GENERATION PROGRAM                             *
C                      (Meshg for)                                    *
C             ---------------------------------                       *
C       This program gets hold of its input from the 2TEST DAT file   *
C       which contains the coordinates of the horizontal lines and    *
C       number of divisions in each line                              *
C       As output it produces two data files                          *
C           - COORD DAT the data which have to be changed to DXF file *
C           - MESH DAT data need for Meshg for                        *
C**********************************************************************
C
      DIMENSION X(100),X1(100),X2(100),Y(100),Y1(100),Y2(100),K(100)
      INTEGER M1(100),N1(100),O(100),O1(100)
      I=1
      OPEN(UNIT=1,FILE='2TEST DAT',STATUS='OLD')
      READ(1,*)KK
      READ(1,*)XI,YI
      READ(1,*)X2(I),Y2(I)
      X1(1)=0
      Y1(1)=0
      X2(I)=X2(I)-XI
      Y2(I)=Y2(I)-YI
      K(I)=KK
      I=I+1
70    READ(1,*,END=71)X11,Y11
      READ(1,*,END=71)X22,Y22
      X1(I)=X11-XI
      Y1(I)=Y11-YI
      X2(I)=X22-XI
      Y2(I)=Y22-YI
      K(I)=KK
      I=I+1
      GOTO 70
71    CLOSE(UNIT=1)
```

```
      M=1
      N=I-1
      DO 5 L=1,N
      DO 5 I=0,K(L)
      A=X1(L)+I*(X2(L)-X1(L))/K(L)
      B=Y1(L)
      X(M)=A
      Y(M)=B
5     M=M+1
      NP=M-1
50    FORMAT(I5)
      J=1
      IC=NNODE
      IF (IC EQ 3) GOTO 27
      J=1
      K1=1
      DO 28 L=1,N-1
      DO 23 I=K1,(K1+K(L)-1)
      M1(J)=I
      N1(J)=I+1
      O(J)=I+K(L)+2
      O1(J)=I+K(L)+1
23    J=J+1
28    K1=K1+K(L)+1
      GOTO 24
27    K1=1
      DO 18 L=1,N-1
      IF (X1(L) LT X1(L+1)) GOTO 9
      IF (X1(L) GT X1(L+1)) GOTO 21
      DO 7 I=K1,(K(L)+K1-1)
      M1(J)=I
      N1(J)=I+1
      O(J)=K(L)+I+2
      J=J+1
7     CONTINUE
      GOTO 12
9     DO 10 I=K1,(K(L)+K1-1)
      M1(J)=I
      N1(J)=I+1
      O(J)=I+K(L)+1
10    J=J+1
      GOTO 12
21    DO 22 I=K1,(K(L)+K1-1)
      M1(J)=I
      N1(J)=I+1
      O(J)=I+K(L)+3
22    J=J+1
12    IF (X1(L) GT X1(L+1)) GOTO 14
      IF (X1(L) LT X1(L+1)) GOTO 16
      DO 13 I=K1,(K1+K(L)-1)
      M1(J)=I
      N1(J)=I+K(L)+2
      O(J)=I+K(L)+1
13    J=J+1
```

```
        GOTO 18
14      M1(J)=K1
        N1(J)=K1+K(L)+2
        O(J)=K1+K(L)+1
        J=J+1
        DO 15 I=K1,(K1+K(L)-1)
        M1(J)=I
        N1(J)=I+K(L)+3
        O(J)=I+K(L)+2
15      J=J+1
        GOTO 18
16      DO 17 I=K1,(K1+K(L)-2)
        M1(J)=I+1
        N1(J)=I+K(L)+2
        O(J)=I+K(L)+1
        J=J+1
17      CONTINUE
18      K1=K1+K(L)+1
24      NE=J-1
        OPEN(UNIT=2,FILE='COORD DAT',STATUS='NEW')
        WRITE(2,90)NP,KK,XI,YI
90      FORMAT(1X,I2,5X,I2,5X,F5 1,5X,F5 1)
        WRITE(2,91)(X(I),Y(I),I=1,NP)
91      FORMAT(5X,F5 1,5X,F5 1)
        CLOSE(UNIT=2)
        OPEN(UNIT=3,FILE='MESH DAT',STATUS='NEW')
        WRITE(3,78)NP,NE
        NUMATS=1
        WRITE(3,78)((I,NUMATS,M1(I),N1(I),O(I),O1(I)),I=1,NE)
78      FORMAT(6I5)
        WRITE(3,79)(I,X(I),Y(I),I=1,NP)
79      FORMAT(I5,2F10 5)
        CLOSE(UNIT=3)
        END


C***************************************************************************
C                                                                          *
C                       PREP-PROCESSING PROGRAM                            *
C                              (Prep for)                                  *
C               ---------------------------------------                    *
C     This program reads the data from the command file "project2 com"     *
C     and TXT DAT file which contains the text information from the        *
C     drawing Also it reads some materials informations from PR1 DAT       *
C     file                                                                 *
C     As output it produces a command file FECOM DAT which contains        *
C     the inputs for the Finite Element Program  The name and extension    *
C     of this command file will changed to FE COM in "PROJECT2 COM"        *
C***************************************************************************
C
        DIMENSION X(100),X1(100),X2(100),Y(100),Y1(100),Y2(100),K(100)
        INTEGER M1(100),N1(100),O(100),O1(100)
```

```
      DIMENSION TITLE(12),NOFIX(30),PRESC(30,2),FORCE(10,2),IN(10),IFPRE(30)
      READ(5,31)TITLE
31    FORMAT(12A6)
      READ(5,33)NTYPE
33    FORMAT(I5)
      READ(5,33)NNODE
      READ(5,33)NMATS
      READ(5,33)NGAUS
      READ(5,33)NCRIT
      READ(5,33)NINCS
      READ(5,33)NSTRE
      READ(5,33)NDOFN
      READ(5,33)NUMATS
      OPEN(UNIT=4,FILE='TXT DAT',STATUS='OLD')
      READ(4,1)
1     FORMAT(////////////////)
      READ(4,*)NVFIX
      DO 3 I=1,NVFIX
      READ(4,2)
2     FORMAT(////////////)
      READ(4,*)NOFIX(I),IFPRE(I)
3     CONTINUE
      READ(4,6) IQ
6     FORMAT(/////////////,I5)
      DO 11 I=1,IQ
      READ(4,8)
8     FORMAT(////////////)
      READ(4,*)IN(I),(FORCE(I,N),N=1,2)
11    CONTINUE
      READ(4,8)
      READ(4,*)T
      CLOSE(UNIT=4)
      OPEN(UNIT=1,FILE='MESH DAT',STATUS='OLD')
      READ(1,10)NP,NE
      READ(1,10)((I,NUMATS,M1(I),N1(I),O(I),O1(I)),I=1,NE)
10    FORMAT(6I5)
      READ(1,12)(I,X(I),Y(I),I=1,NP)
12    FORMAT(I5,2F10 5)
      CLOSE(UNIT=1)
      OPEN(UNIT=2,FILE='FECOM DAT',STATUS='NEW',CARRIAGECONTROL='LIST')
      WRITE(2,103)
103   FORMAT(40H $ASSIGN/USER_MODE RESULT DAT SYS$OUTPUT)
      WRITE(2,75)
75    FORMAT(12H $RUN TAPE17)
      WRITE(2,77)TITLE
77    FORMAT(12A6)
      NALGO=2
      WRITE(2,76)NP,NE,NVFIX,NTYPE,NNODE,NMATS,NGAUS,
      NALGO,NCRIT,NINCS,NSTRE
76    FORMAT(1X,I4,10I5)
      WRITE(2,78)((I,NUMATS,M1(I),N1(I),O(I),O1(I)),I=1,NE)
78    FORMAT(6I5)
      WRITE(2,79)(I,X(I),Y(I),I=1,NP)
79    FORMAT(I5,2F10 5)
```

```
      DO 83 IVFIX=1,NVFIX
      WRITE(2,80)NOFIX(IVFIX),IFPRE(IVFIX),(PRESC(IVFIX,IDOFN),IDOFN=1,NDOFN)
80    FORMAT(I5,5X,I5,5X,2F10 6)
83    CONTINUE
      WRITE(2,87)NUMATS
87    FORMAT(I2)
      OPEN(UNIT=3,FILE='PR1 DAT',STATUS='OLD')
      READ(3,84)E,V,RU,YP,S1,S2,S3
      E=E/10 0
      CLOSE(UNIT=3)
      WRITE(2,200)E,V,T,RU,YP,S1,S2,S3
200   FORMAT(1X,F8 1,',',F3 1,',',F4 1,',',F3 1,',',F5 1,3(',',F3 1))
84    FORMAT(F8 1,1X,F3 1,1X,F3 1,1X,F5 1,1X,F3 1,1X,F3 1,1X,F3 1)
      WRITE(2,88)
88    FORMAT(1X,10HPOINT LOAD)
      K1=1
      WRITE(2,89)K1,K2,K3
89    FORMAT(3I5)
      WRITE(2,94)(IN(I),(FORCE(I,N),N=1,2),I=1,IQ)
94    FORMAT(I5,2F10 3)
      A1=1 0
      B1=1 0
      L1=10
      L2=3
      L3=3
      WRITE(2,100)A1,B1,L1,L2,L3
100   FORMAT(2F10 5,3I5)
      WRITE(2,101)
101   FORMAT(5H$EXIT)
      CLOSE(UNIT=2)
      END
```

```
      INTEGER O(100)
      DIMENSION M(100),N1(100),L(100),X(100),Y(100),STRE(100),IC(10),Z(10)
      ,IC1(100)
      YP=30 00
C     READ(5,1)YE
C1    FORMAT(F6 2)
      OPEN(UNIT=1,FILE='MESH DAT',STATUS='OLD')
      READ(1,10)NP,NE
      DO 5 I=1,NE
      STRE(I)=0 0
5     CONTINUE
      DO 6 I=1,10
      Z(I)=0 0
      IC(I)=I
6     CONTINUE
10    FORMAT(6I5)
      READ(1,10)((I,NUMATS,M(I),N1(I),O(I),L(I)),I=1,NE)
      CLOSE (UNIT=1)
```

```
      OPEN(UNIT=2,FILE='COORD4 DAT',STATUS='OLD')
      READ(2,20,ERR=301)(N,X(I),Y(I),I=1,NP)
20    FORMAT(1X,I10,2E14 6)
      DO 700 I=1,NP
      X(I)=X(I)+20 0
      Y(I)=Y(I)+20 0
700   CONTINUE
301   CLOSE(UNIT=2)
      OPEN(UNIT=3,FILE='STRESS DAT',STATUS='OLD')
      DO 30 I=1,NE
      READ(3,40,ERR=401)ST1,ST2,ST3,ST4
40    FORMAT(1X,E14 6,/,1X,E14 6,/,1X,E14 6,/,1X,E14 6)
      STRE(I)=ST1
      IF (STRE(I) GE ST2) GOTO 50
      STRE(I)=ST2
50    IF (STRE(I) GE ST3) GOTO 60
      STRE(I)=ST3
60    IF (STRE(I) GE ST4) GOTO 30
      STRE(I)=ST4
30    CONTINUE
401   CLOSE(UNIT=3)
      DO 500 I=1,NE
      WRITE(6,*)I,STRE(I)
500   CONTINUE
      J=1
      STEM=STRE(J)
70    IF (STEM GE STRE(J+1)) GOTO 80
      STEM=STRE(J+1)
80    IF (J GE (NE-1)) GOTO 90
      J=J+1
      GOTO 70
90    WRITE(6,40)STEM
      Q=STEM/9 0
      DO 91 I=1,9
      Z(I)=I*Q
      IC(I)=I
91    CONTINUE
      Z(10)=YP*0 9
      IC(I)=10
      J=1
      XM=X(J)
280   IF (XM GE X(J+1)) GOTO 290
      XM=X(J+1)
290   IF (J GE (NP-1)) GOTO 270
      J=J+1
      GOTO 280
270   WRITE(6,40)XM
      J=1
      YM=Y(J)
300   IF (YM GE Y(J+1)) GOTO 310
      YM=Y(J+1)
310   IF (J GE (NP-1)) GOTO 320
      J=J+1
      GOTO 300
```

```
320     WRITE(6,40)YM
        FS=YP/STEM
        OPEN(UNIT=4,FILE='PLOT DAT',STATUS='NEW',CARRIAGECONTROL='LIST')
        WRITE(4,410)
410     FORMAT(5HLAYER,/,3HNEW,/,6HSTRESS,/,3HSET,/,6HSTRESS,/,3HOFF,/,
        1H*,/,1HY,/,2HON,/,6HSTRESS,/)
        X1=380 0
        Y1=190 0
        DO 93 I=1,9
        WRITE(4,94)X1,Y1,Z(I)
94      FORMAT(5HTEXT ,E10 5,1H,,E10 5,2H 7,//,E10 5)
        Y1=Y1+15 0
93      CONTINUE
        X1=X1-7 0
        WRITE(4,480)X1,Y1,X1,Y1
480     FORMAT(5HTEXT ,E10 5,1H,,E10 5,2H 8,//,10HPLASTICITY,/,7HCHANGE ,
        E10 5,1H,,E10 5,//,6HP C 10,/)
        Y1=Y1+10 0
        WRITE(4,260)
260     FORMAT(6HINSERT,/,2HQ1,/,7H444,190,/,1H1,/,1H1,/,1H0)
        Y1=Y1+10 0
        WRITE(4,370)Y1,Y1
370     FORMAT(11HTEXT F 360,,E10 5,1H ,4H480,,E10 5,3H 12,/,
        19HEQUIVALENT STRESSES)
        WRITE(4,600)FS
600     FORMAT(14HTEXT 380,170 8,//,4HFS= ,E10 5,/,14HCHANGE 380,170,//,
        5HP C 2,/)
        DO 100 I=1,NE
        DO 220 J=1,10
        IF (STRE(I) LE Z(10)) GOTO 505
        IC1(I)=IC(10)
        GOTO 210
505     IF (STRE(I) GT Z(J)) GOTO 220
        IC1(I)=IC(J)
        GOTO 210
220     CONTINUE
230     FORMAT(1X,I6)
210     NODE1=M(I)
        NODE2=N1(I)
        NODE3=O(I)
        NODE4=L(I)
        WRITE(4,110)X(NODE1),Y(NODE1),X(NODE2),Y(NODE2)
        ,X(NODE3),Y(NODE3),X(NODE4),Y(NODE4)
110     FORMAT(4HLINE,4(/,E13 7,1H,E13 7))
        WRITE(4,120)
120     FORMAT(5HCLOSE)
        WRITE(4,130)X(NODE1),Y(NODE1),X(NODE2),Y(NODE2)
        ,X(NODE4),Y(NODE4),X(NODE3),Y(NODE3)
130     FORMAT(5HSOLID,/,4(E13 7,1H,,E13 7/))
        IF (IC1(I) GT 9) GOTO 530
        WRITE(4,240)IC1(I)
240     FORMAT(8HCHANGE L,//,1HP,/,1HC,/,I1,/)
        GOTO 100
530     WRITE(4,540)IC1(I)
```

```
540     FORMAT(8HCHANGE L,//,1HP,/,1HC,/,I2,/)
100     CONTINUE
        WRITE(4,250)
250     FORMAT(5HREGEN)
        XM=XM+5
        YM=YM+5
        WRITE(4,350)XM,YM
350     FORMAT(23HBLOCK DRAWING 0,0 W 0,0,/,E10 5,1H,,E10 5,//,
        26HINSERT DRAWING 20,20 2 2 0,/,6HZOOM A)
        CLOSE(UNIT=4)
        END
```

```
560 REM              THE MAIN SYMBOLS
570 REM           ******************************
580 REM
590 REM  P    , [Kw]          THE POWER WHICH IS TRANSMITTED BY THE SHAFT
600 REM  L    , [m]           THE LENGTH OF THE MATERIAL
610 REM  N    , [rpm]         THE SPEED OF ROTATION
620 REM  H1   ,               THETHE HARDNESS WHICH IS REQUIRED
630 REM  H    ,               THE HARDNESS OF THE MATERIAL
640 REM  N$   ,               THE NAME OF THE MATERIAL
650 REM  TEN  , [N/m^2]       TENSILE STRENGTH
660 REM  COMP , [N/m^2]       COMPRESSION STRENGTH
670 REM  SH   , [N/m^2]       SHEAR STRESS
680 REM  YP   , [N/m^2]       YEILD STRESS
690 REM  D    , [m]           THE DIAMETER OF THE SHAFT
700 REM  STR  , [N/m^2]       ALLOWABLE STRESS
710 REM  FS   ,               FACTOR OF SAFTY
720 REM  W    , [1/s]         ANGULAR VELOCITY
730 REM  T    , [N/m^2]       TORQUE
740 REM
750 REM          AUXLIARY SYMBOLS
760 REM        ********************
770 REM  AL   ,[m]            THE DIAMETER OF ALUMINIUM
780 REM  CO   ,[m]            THE DIAMETER OF COPPER
790 REM  ST   ,[m]            THE DIAMETER OF STEEL
800 REM  STS  ,[m]            THE DIAMETER OF STAINLESS STEEL
810 REM
820 PRINT
840 OPEN "A DAT" FOR INPUT AS FILE £4
850 INPUT £4,FS,H,N$,TEN,COMP,SH
855 INPUT £4,YP,P,L,N,D,F
860 CLOSE £4
865 IF F=1 THEN 930
870 INPUT "P(Kw)=",P,"L(m)=",L,"N(rpm)=",N
880 OPEN "A DAT" FOR OUTPUT AS FILE £4
890 PRINT £4,FS,",",H,",",N$,",",TEN,",",COMP,",",SH
900 PRINT £4,YP,",",P,",",L,",",N,",",D,",",F
910 CLOSE £4
920 CHAIN "FS"
930 PRINT "D[m]=",D
940 F=2
950 OPEN "A DAT" FOR OUTPUT AS FILE £4
960 PRINT £4,FS,",",H,",",N$,",",TEN,",",COMP,",",SH
970 PRINT £4,YP,",",P,",",L,",",N,",",D,",",F
980 CLOSE £4
990 END
```

FACTOR OF SAFETY (FS BAS)

```
1770 OPEN "A DAT" FOR INPUT AS FILE £4
1780 INPUT £4,FS,H,N$,TEN,COMP,SH
1785 INPUT £4,YP,P,L,N,D,F
1790 CLOSE £4
1800 REM FACTOR OF SAFTY
1810 PRINT "   (FS)                    APPLICATION"
1820 PRINT "***********             *********************"
1830 PRINT "1 3 - 1 5            FOR USE WITH HIGHLY RELIABLE MATERIALS WHERE LOA-"
1840 PRINT "                     DING AND ENVIRONMENTAL CONDITION ARE NOT SERVE "
1850 PRINT "                     AND WHERE WEIGHT IS AN IMPORTANT CONSIDERATION "
1860 PRINT
1870 PRINT "1 5 - 2              FOR APPLICATION USEING RELIABLE MATERIALS WHERE "
1880 PRINT "                     LOADING AND ENVIRONMENTAL CONDITIONS ARE NOT "
1890 PRINT "                     SEVERE "
1900 PRINT
1910 PRINT "2 - 2 5              FOR USE WITH ORDINARY MATERIALS WHERE LOADING AND"
1920 PRINT "                     ENVIRONMENTAL CONDITIONS ARE NOT SEVERE "
1930 PRINT
1940 PRINT "2 5 - 3              FOR LESS TRIED AND FOR BRITTLE MATERIALS WHERE "
1950 PRINT "                     LOADING AND ENVIRONMENTAL CONDITIONS ARE NOT "
1960 PRINT "                     SEVERE "
1970 PRINT
1980 PRINT "3 - 4                FOR APPLICATIONS IN WHICH MATERIAL PROPERTIES ARE"
1990 PRINT"                      NOT RELIABLE AND WHERE LOADING AND ENVIRONMENTAL "
2000 PRINT "                     CODITIONS ARE NOT SEVERE,OR WHERE RELIABLE MATER-"
2010 PRINT"                      IALS ARE TO BE USED UNDER DIFFICULT LOADING AND "
2020 PRINT"                      ENVIRONMENTAL CODITIONS "
2030 PRINT "_____________________________________________________________________"
2040 INPUT "ENTER THE FACTOR OF SAFTY YOU CHOOSE  FS-",FS
2050 OPEN "A DAT" FOR OUTPUT AS FILE £4
2060 PRINT £4,FS,",",H,",",N$,",",TEN,",",COMP,",",SH
2070 PRINT £4,YP,",",P,",",L,",",N,",",D,",",F
2080 CLOSE £4
2090 CHAIN "MATE"
```

MATERIAL SELECTION (MATE BAS)

```
2970 OPEN "A DAT" FOR INPUT AS FILE £4
2980 INPUT £4,FS,H,N$,TEN,COMP,SH
2985 INPUT £4,YP,P,L,N,D,F
2990 CLOSE £4
3000 PRINT "TYPE  1  IF YOU HAVE ANY OF THOSE MATERIALS SPECIFICATIONS"
3010 PRINT "         HARDNESS,NAME,TENSILE,COMPRESSION,SHEAR STRESS,YIELD POINT"
3020 PRINT "TYPE  2  IF YOU WHANT TO SEE THE SCHEDULE ITSELF"
3030 INPUT "N1=",N1
3040 IF N1=1 THEN 3060
3050 IF N1=2 THEN 4163
3060 PRINT "TYPE  1  IF YOU HAVE THE NAME OF THE METAL"
3070 PRINT "TYPE  2  IF YOU HAVE THE HARDNESS OF THE METAL"
3080 PRINT "TYPE  3  IF YOU HAVE THE TENSILE STRENGHT OF THE METAL"
3090 PRINT "TYPE  4  IF YOU HAVE THE COMPRESSION STRENGTH OF THE METAL"
3100 PRINT "TYPE  5  IF YOU HAVE THE SHEAR STRESS OF THE METAL"
3110 PRINT "TYPE  6  IF YOU HAVE THE YIELD STRESSOF THE METAL"
3120 INPUT "N2=",N2
3130 ON N2 GOTO 3190,3285,3490,3640,3820,4000
3190 INPUT "THE NAME OF THE METAL IS",NA$
3200 OPEN "PRO DAT" FOR INPUT AS FILE £2
3210 INPUT £2,H,N$,TEN,COMP,SH,YP
3220 IF NA$=N$ THEN 3260
3230 IF H<>600 THEN 3210
3235 PRINT "*******************************************"
3240 PRINT "THE MATERIAL NOT FOUND"
3245 PRINT "*******************************************"
3250 GOTO 4175
3260 PRINT H,N$,TEN,COMP,SH,YP
3270 CLOSE £2
3280 GOTO 4175
3285 INPUT "INPUT THE HARDNESS YOU HAVE",H1
3290 E=9999
3300 OPEN "PRO DAT" FOR INPUT AS FILE £2
3310 INPUT £2,H,N$,TEN,COMP,SH,YP
3320 IF H>H1 THEN 3350
3330 IF H=H1 THEN 3430
3340 GOTO 3380
3350 HAA=H
3360 IF HAA>E THEN 3380
3370 E=HAA
3380 IF H<>600 THEN 3310
3390 CLOSE £2
3400 OPEN "PRO DAT" FOR INPUT AS FILE £2
3410 INPUT £2,H,N$,TEN,COMP,SH,YP
3420 IF H<>E THEN 3410
3430 PRINT H,N$,TEN,COMP,SH,YP
3440 CLOSE £2
3450 GOTO 4175
```

```
3460 INPUT "ENTER THE VALUE OF TENSILE STRENGTH",TEN1
3470 E1=1E+20
3480 OPEN "PRO DAT" FOR INPUT AS FILE £2
3490 INPUT £2,H,N$,TEN,COMP,SH,YP
3500 IF TEN>TEN1 THEN 3530
3510 IF TEN=TEN1 THEN 3610
3520 GOTO 3560
3530 TEN2=TEN
3540 IF TEN2=E1 THEN
3550 E1=TEN2
3560 IF TEN<>10E+7 THEN 3490
3570 CLOSE £2
3580 OPEN "PRO DAT" FOR INPUT AS FILE £2
3590 INPUT £2,H,N$,TEN,COMP,SH,YP
3600 IF TEN<>E1 THEN 3590
3610 PRINT H,N$,TEN,COMP,SH,YP
3620 CLOSE £2
3630 GOTO 4175
3640 INPUT "THE VALUE OF COMPRESSION STRENGTH IS",COMP1
3650 E2=1E+20
3660 OPEN "PRO DAT" FOR INPUT AS FILE £2
3670 INPUT £2,H,N$,TEN,COMP,SH,YP
3680 IF COMP>COMP1 THEN 3710
3690 IF COMP=COMP1 THEN 3790
3700 GOTO 3740
3710 COMP2=COMP
3720 IF COMP2>E2 THEN 3740
3730 E2=COMP2
3740 IF COMP<>5 6E+07  THEN 3670
3750 CLOSE £2
3760 OPEN "PRO DAT" FOR INPUT AS FILE £2
3770 INPUT £2,H,N$,TEN,COMP,SH,YP
3780 IF COMP<>E2 THEN 3770
3790 PRINT H,N$,TEN,COMP,SH,YP
3800 CLOSE £2
3810 GOTO 4175
3820 INPUT "THE VALUE OF SHEAR STRESS IS ",SH1
3830 E3=1E+20
3840 OPEN "PRO DAT" FOR INPUT AS FILE £2
3850 INPUT £2,H,N$,TEN,COMP,SH,YP
3860 IF SH>SH1 THEN 3890
3870 IF SH=SH1 THEN 3970
3880 GOTO 3920
3890 SH2=SH
3900 IF SH2>E3 THEN 3920
3910 E3=SH2
3920 IF SH<>11E+07 THEN 3820
3930 CLOSE £2
3940 OPEN "PRO DAT" FOR INPUT AS FILE £2
3950 INPUT £2,H,N$,TEN,COMP,SH,YP
3960 IF SH<>E3 THEN 3950
3970 PRINT H,N$,TEN,COMP,SH,YP
3980 CLOSE £2
3990 GOTO 4175
```

```
4000 INPUT "THE VALUE OF YIELD STRESS IS ",YP1
4010 E4=1E+20
4020 OPEN "PRO DAT" FOR INPUT AS FILE £2
4030 INPUT £2,H,N$,TEN,COMP,SH,YP
4040 IF YP>YP1 THEN 4070
4050 IF YP=YP1 THEN 4150
4060 GOTO 4100
4070 YP2=YP
4080 IF YP2>E4 THEN 4100
4090 E4=YP2
4100 IF YP<>28E+07 THEN 4030
4110 CLOSE £2
4120 OPEN "PRO DAT" FOR INPUT AS FILE £2
4130 INPUT £2,H,N$,TEN,COMP,SH,YP
4140 IF YP<>E4 THEN 4130
4150 PRINT H,N$,TEN,COMP,SH,YP
4160 CLOSE £2
4161 GOTO 4175
4163 OPEN "PRO DAT" FOR INPUT AS FILE £2
4165 INPUT £2,H,N$,TEN,COMP,SH,YP
4167 PRINT H,N$,TEN,COMP,SH,YP
4168 IF H<>600 THEN 4165
4169 CLOSE £2
4170 GOTO 3190
4175 OPEN "A DAT" FOR OUTPUT AS FILE £4
4180 PRINT £4,FS,",",H,",",N$,",",TEN,",",COMP,",",SH
4190 PRINT £4,YP,",",P,",",L,",",N,",",D,",",F
4200 CLOSE £4
4210 CHAIN "CAL"
```

CALCULATION PROGRAM (CAL BAS)

```
10 OPEN "A DAT" FOR INPUT AS FILE £4
20 INPUT £4,FS,H,N$,TEN,COMP,SH
30 INPUT £4,YP,P,L,N,D,F
40 CLOSE £4
50 REM THE CALCULATION OF SHAFT DESIGNING
60 STR=YP/FS
70 W=2*PI*N/60
80 T=P/W
90 DIM M(1000),M1(1000)
91 FOR I=1 TO 20\PRINT\NEXT I
100 PRINT "*",\FOR I=1 TO 58\PRINT "*",\NEXT I\PRINT "*"
120 PRINT "*",\FOR I=1 TO 58\PRINT " ",\NEXT I\PRINT "*"
130 PRINT "*",\FOR I=1 TO 14\PRINT " ",
140 NEXT I\PRINT " TYPE 1 IF YOU HAVE A FREE END",\PRINT "                    *"
150 PRINT "*",\FOR I=1 TO 13\PRINT " ",
160 NEXT I\PRINT " TYPE 2 IF YOU HAVE NOT FREE END",\PRINT "                 *"
170 PRINT "*",\FOR I=1 TO 58\PRINT " ",\NEXT I\PRINT "*"
180 PRINT "*",\FOR I=1 TO 58\ PRINT "*",\NEXT I\PRINT "*"
181 FOR I=1 TO 8 \PRINT\NEXT I
190 INPUT N%
```

```
192 N=N%\IF N=1 OR N=2 THEN 200
194 PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 190
200 IF N=1 THEN GOSUB 6000
210 INPUT "Type the number of pure bending moment or paralell forces O=",O%
212 O=O%\IF O<0 THEN PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 210
215 INPUT "The shaft length L=",L
216 IF L<=0 THEN PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 215
219 B(0)=-1E-05
236 FOR N=1 TO O
240 PRINT "Type the distance between RB and the moment or force B(",N,")="
250 INPUT B(N)
252 IF B(N)<=L AND B(N)>B(N-1) THEN 256
254 PRINT "ERROR ENTER  PLEACE TRY AGAIN"\GOTO 250
256 IF B(N)<0 THEN PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 250
260 NEXT N
270 ST=1\RB=0
280 FOR J=1 TO ((10*L/ST)+1+0)
290 M(J)=0\M1(J)=0
300 NEXT J
310 FOR I=1 TO 10\PRINT\NEXT I\GOSUB 10100
320 FOR I=1 TO 10\PRINT\NEXT I\INPUT A$
330 A$=MID$(A$,1,1)
340 IF A$="Y" OR A$="y" THEN GOSUB 520
350 IF A$=" " THEN PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 320
360 FOR I=1 TO 10\PRINT\NEXT I\GOSUB 10190
370 FOR I=1 TO 10\PRINT\NEXT I\INPUT A$
380 A$=MID$(A$,1,1)
390 IF A$="Y" OR A$="y" THEN GOSUB 1550
400 IF A$=" " THEN PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 370
410 FOR I=1 TO 10\PRINT\NEXT I\GOSUB 10280
420 FOR I=1 TO 10\PRINT\NEXT I\INPUT A$
430 A$=MID$(A$,1,1)
440 IF A$="Y" OR A$="y" THEN GOSUB 2650
450 IF A$=" " THEN PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 420
460 FOR I=1 TO 10\PRINT\NEXT I\GOSUB 10370
470 FOR I=1 TO 10\PRINT\NEXT I\INPUT A$
480 A$=MID$(A$,1,1)
490 IF A$="Y" OR A$="y" THEN GOSUB 3200
500 IF A$=" " THEN PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 470
510 GOTO 11500
520 GOSUB 10440
620 INPUT "Inter the number of cocentrated forces  I=",I%
621 I=I%
622 IF I>0 THEN 700
624 PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 620
630 A(0)=-1E-05
700 FOR N=1 TO I
710 PRINT "P(",N,")=","A(",N,")="
720 INPUT P(N),A(N)
722 IF A(N)=<L AND A(N)>A(N-1) THEN 726
724 PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 720
726 IF P(N)=0 OR A(N)<0 THEN PRINT "ERROR ENTER* PLEASE TRY AGAIN"\GOTO 720
730 NEXT N
780 FOR N=1 TO I
```

```
790 J=1
800 RB1=P(N)*(L-A(N))/L
810 FOR Y=0 TO (10*A(N)) STEP ST
820 X=Y/10
830 M1(J)=RB1*X
840 J=J+1
850 IF M1(J-1)=M1(J-2) THEN 890
860 FOR K=1 TO O
870 IF X=B(K) THEN 830
880 NEXT K
890 NEXT Y
900 FOR Y=(10*A(N)+ST) TO (10*L) STEP ST
910 X=Y/10
920 M1(J)=RB1*X-P(N)*(X-A(N))
930 J=J+1
940 IF M1(J-1)=M1(J-2) THEN 980
950 FOR K=1 TO O
960 IF X=B(K) THEN 920
970 NEXT K
980 NEXT Y
990 FOR J=1 TO ((10*L)/ST)+1+O
1000 M(J)=M(J)+M1(J)
1010 NEXT J
1020 RB=RB1+RB
1030 NEXT N
1040 PRINT "RB=",RB
1050 FOR J=1 TO ((10*L)/ST)+1+O
1060 PRINT "M(",J,")=",M(J)
1070 NEXT J
1080 FOR I=1 TO 10\PRINT\NEXT I\GOSUB 11220
1090 FOR I=1 TO 10\PRINT\NEXT I\INPUT N%
1092 N=N%
1094 IF N<=0 THEN PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 1090
1096 IF N=1 OR N=2 THEN 1100
1098 PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 1090
1100 IF N=1 THEN GOTO 11310
1110 RETURN
1550 GOSUB 10710
1560 IF P$="PARALELL" THEN 1620
1570 FOR N=1 TO O
1580 PRINT "MO(",N,")="
1590 INPUT MO(N)
1592 IF MO(N)=0 THEN PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 1580
1600 NEXT N
1620 B(0)=0\M(0)=0\M1=0\B(O+1)=L\J=1
1630 FOR N=1 TO O
1640 RB1=MO(N)/L
1650 RB=RB1+RB
1660 NEXT N
1670 PRINT "RB=",RB
1680 FOR N=1 TO O+1
1690 M1=MO(N-1)+M1
1700 FOR Y=10*B(N-1) TO 10*B(N) STEP ST
1710 X=Y/10
```

```
1720 M(J)=(RB*X)-M1+M(J)
1730 PRINT X,",",M(J)
1731 J=J+1
1732 NEXT Y
1733 NEXT N
1740 FOR I=1 TO 10\PRINT\NEXT I\GOSUB 11220
1750 FOR I=1 TO 10\PRINT\NEXT I\INPUT N%
1752 N=N%\IF N=1 OR N=2 THEN 1760
1754 PRINT"ERROR ENTER  PLEASE TRY AGAIN"\GOTO 1750
1760 IF N=1 THEN GOTO 11310
1770 RETURN
2650 GOSUB 10900
2660 PRINT "TYPE THE VALUES OF DIMENSION SYMBOLES WHICH IS ILLUSTRATED IN "
2670 PRINT "    ABOVE FIGURE AFTERT COMPARING IT WITH YOUR PROBLEM"
2680 INPUT "TYPE THE NUMBER OF DISTRIBUTED FORCE REGIONS  I2=",I2%
2682 I2=I2%\IF I2<=0 THEN PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 2680
2690 FOR N=1 TO I2
2700 PRINT "Q(",N,")=","A(",N,")=","B(",N,")=","C(",N,")="
2710 INPUT Q(N),A(N),B(N),C(N)
2712 IF Q(N)=0  THEN 2718
2713 IF A(N)<0 OR A(N)>L THEN 2718
2714 IF B(N)<0 OR B(N)>L THEN 2718
2715 IF C(N)<0 OR C(N)>L THEN 2718
2716 IF L=A(N)+B(N)+C(N) THEN 2720
2718 PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 2710
2720 C1(N)=C(N)\B1(N)=(C(N)+B(N))\RB1(N)=0
2730 NEXT N
2750 L1=L
2760 FOR N=1 TO I2
2770 J=1
2780 RB1(N)=Q(N)*((2*A(N)*B(N))+(B(N)^2))/(2*(A(N)+B(N)+C(N)))
2790 PRINT "RB1(",N,")=",RB1(N)
2800 FOR Y=0 TO (10*C1(N)) STEP ST
2810 X=Y/10
2820 M1(J)=RB1(N)*X
2830 J=J+1
2840 IF M1(J-1)=M1(J-2) THEN 2880
2850 FOR K=1 TO IO
2860 IF X=BB(K) THEN 2820
2870 NEXT K
2880 NEXT Y
2890 FOR Y=(10*C1(N)+ST) TO (10*B1(N)) STEP ST
2900 X=Y/10
2910 M1(J)=(RB1(N)*X)-Q(N)*((X-C(N))^2)/2
2920 J=J+1
2930 IF M1(J-1)=M1(J-2) THEN 2970
2940 FOR K=1 TO IO
2950 IF X=BB(K) THEN 2910
2960 NEXT K
2970 NEXT Y
2980 FOR Y=(10*B1(N)+ST) TO (10*L1) STEP ST
2990 X=Y/10
3000 M1(J)=(RB1(N)*X)-(Q(N)*B(N)*(X-C(N)-(B(N)/2)))
3010 J=J+1
```

```
3020 IF M1(J-1)=M1(J-2) THEN 3060
3030 FOR K=1 TO IO
3040 IF X=BB(K) THEN 3000
3050 NEXT K
3060 NEXT Y
3070 RB=RB1(N)+RB
3080 FOR J=1 TO ((10*L)/ST)+1+IO
3090 M(J)=M(J)+M1(J)
3100 NEXT J
3110 NEXT N
3120 FOR I=1 TO 10\PRINT\NEXT I\GOSUB 11220
3130 FOR I=1 TO 10\PRINT\NEXT I\INPUT N%
3132 N=N%\IF N=1 OR N=2 THEN 3140
3134 PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 3130
3140 IF N=1 THEN GOTO 11310
3150 RETURN
3200 GOSUB 11010
3210 P$="PARALELL"
3220 PRINT"  TYPE THE NUMBER OF FORCES PARALELL TO THE SHAFT AXES "
3230 PRINT"        WHICH IS APPLIED IN THE SAME PLANE                 "
3232 INPUT O%
3234 O=O%\IF O<0 THEN PRINT "ERROR ENETR  PLEASE TRY AGAIN"\GOTO 3232
3240 FOR I=1 TO O
3250 PRINT"TYPE THE DISTANCES BETWEEN THE SHAFT AND THE FORCES  ","E(",I,")=",
3260 INPUT E(I)
3262 IF E(I)=<0 THEN PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 3260
3270 PRINT "THE VALUES FO PARALELL FORCES  ","F(",I,")=",
3280 INPUT F(I)
3282 IF F(I)=0 THEN PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 3280
3290 MO(I)=E(I)*F(I)
3300 NEXT I
3310 GOSUB 1560
3320 RETURN
6000 INPUT "Type the number of pure bending moments and paralell forces  O=",O%
6001 INPUT "The shaft length L=",L
6002 IF L<=0 THEN PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 6001
6005 B(0)=-1E-05
6010 O=O%\IF O<0 THEN PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 6000
6020 FOR N=1 TO O
6030 PRINT "Type the distance between RB and the moment or force B(",N,")="
6040 INPUT B(N)
6042 IF B(N)<=L AND B(N)>B(N-1) THEN 6046
6044 PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 6040
6046 IF B(N)<0 THEN PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 6040
6050 NEXT N
6053 INPUT "The distance between the reactions RA & RB AR=",AR
6054 IF AR<=0 OR AR>=L THEN PRINT"ERROR ENTER  PLEASE TRY AGAIN"\GOTO 6053
6062 ST=1\RB=0
6064 FOR J=1 TO ((10*L/ST)+1+O)
6066 M(J)=0\M1(J)=0
6068 NEXT J
6069 FOR I=1 TO 10\PRINT\NEXT I\GOSUB 10100
6070 FOR I=1 TO 10\PRINT\NEXT I\INPUT A$
6080 A$=MID$(A$,1,1)
```

```
6090 IF A$="Y" OR A$="y" THEN GOSUB 6500
6100 IF A$=" " THEN PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 6070
6110 FOR I=1 TO 10\PRINT\NEXT I\GOSUB 10190
6120 FOR I=1 TO 10\PRINT\NEXT I\INPUT A$
6130 A$=MID$(A$,1,1)
6140 IF A$="Y" OR A$="y" THEN GOSUB 7500
6150 IF A$=" " THEN PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 6120
6160 FOR I=1 TO 10\PRINT\NEXT I\GOSUB 10280
6170 FOR I=1 TO 10\PRINT\NEXT I\INPUT A$
6180 A$=MID$(A$,1,1)
6190 IF A$="Y" OR A$="y" THEN GOSUB 8500
6200 IF A$=" " THEN PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 6170
6210 FOR I=1 TO 10\PRINT\NEXT I\GOSUB 10370
6220 FOR I=1 TO 10\PRINT\NEXT I\INPUT A$
6230 A$=MID$(A$,1,1)
6240 IF A$="Y" OR A$="y" THEN GOSUB 9900
6250 IF A$=" " THEN PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 6220
6260 GOTO 11500
6500 GOSUB 10440
6510 INPUT "The number of cocentrated forces I=",I%
6520 I=I%
6522 IF I>0 THEN 6540
6524 PRINT "ERROR ENTER  PLEASAE TRY AGAIN"\GOTO 6510
6526 A(0)=-1E-05
6530 RA1=0\RB1=0
6540 FOR N=1 TO I
6550 PRINT "P(",N,")=","A(",N,")="
6560 INPUT P(N),A(N)
6562 IF A(N)<=L AND A(N)>A(N-1) THEN 6566
6564 PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 6560
6566 IF P(N)=0 OR A(N)<0 THEN PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 6560
6570 NEXT N
6620 FOR N=1 TO I
6630 J=1
6640 RA1=P(N)*A(N)/AR
6650 PRINT "RA1=",RA1
6660 RB1=P(N)-RA1
6670 PRINT "RB1",RB1
6680 IF A(N)<AR THEN 6720
6690 P2=P(N)\A2=A(N)
6700 P1=-RA1\A1=AR
6710 GOTO 6740
6720 P2=-RA1\A2=AR
6730 P1=P(N)\A1=A(N)
6740 FOR Y=0 TO (10*A1) STEP ST
6750 X=Y/10
6760 M1(J)=RB1*X
6770 PRINT "M1(",J,")=",M1(J)
6780 J=J+1
6790 IF M1(J-1)=M1(J-2) THEN 6830
6800 FOR K=1 TO O
6810 IF X=B(K) THEN 6760
6820 NEXT K
6830 NEXT Y
```

```
6840 FOR Y=(10*A1+ST) TO (10*A2) STEP ST
6850 X=Y/10
6860 M1(J)=RB1*X-P1*(X-A1)
6870 J=J+1
6890 IF M1(J-1)=M1(J-2) THEN 6930
6900 FOR K=1 TO O
6910 IF X=B(K) THEN 6860
6920 NEXT K
6930 NEXT Y
6940 FOR Y=(10*A2) TO (10*L) STEP ST
6950 X=Y/10
6960 M1(J)=RB1*X-P1*(X-A1)-P2*(X-A2)
6970 IF M1(J)<1E-5 THEN 6990
6980 GOTO 7000
6990 M1(J)=0
7000 J=J+1
7010 IF M1(J-1)=M1(J-2) THEN 7050
7020 FOR K=1 TO O
7030 IF X=B(K) THEN 6960
7040 NEXT K
7050 NEXT Y
7060 FOR J=1 TO ((10*L)/ST)+1+O
7070 M(J)=M(J)+M1(J)
7080 NEXT J
7090 RB=RB1+RB
7100 NEXT N
7110 PRINT "RB=",RB
7120 FOR J=1 TO (( 10*L)/ST)+1+O
7130 PRINT "M(",J,")=",M(J)
7140 NEXT J
7150 FOR I=1 TO 10\PRINT\NEXT I\GOSUB 11220
7160 FOR I=1 TO 10\PRINT\NEXT I\INPUT N%
7162 N=N%
7164 IF N<=0 THEN PRINT"ERROR ENTER  PLEASE TRY AGAIN"\GOTO 7160
7166 IF N=1 OR N=2 THEN 7170
7168 PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 7160
7170 IF N=1 THEN GOTO 11310
7180 RETURN
7500 FOR I=1 TO 10\PRINT\NEXT I\GOSUB 10710
7502 IF P$="PARALELL" THEN 7540
7504 FOR N=1 TO O
7506 PRINT "MO(",N,")="
7507 INPUT MO(N)
7510 IF MO(N)=0 THEN PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 7507
7530 NEXT N
7540 J=1
7550 FOR N=1 TO O
7560 J=1
7570 RB1(N)=MO(N)/AR
7580 RA1(N)=MO(N)/AR
7590 PRINT "RB1(",N,")=",RB1(N),"RA1(",N,")=",RA1(N)
7600 IF AR<B(N) THEN 8000
7610 FOR Y=0 TO 10*B(N) STEP ST
7620 X=Y/10
```

```
7630 FOR I=1 TO O
7640 IF X<>B(I) THEN   7680
7650 IF X=B(N) THEN 7680
7660 M1(J)=RB1(N)*X
7670 J=J+1
7680 NEXT I
7690 M1(J)=RB1(N)*X
7700 PRINT "M1(",J,")=",M1(J)
7710 J=J+1
7720 NEXT Y
7730 FOR Y=10*B(N) TO 10*AR STEP ST
7740 X=Y/10
7750 FOR I=1 TO O
7760 IF X<>B(I) THEN 7800
7770 IF X=B(N) THEN 7800
7780 M1(J)=RB1(N)*X-MO(N)
7790 J=J+1
7800 NEXT I
7810 M1(J)=RB1(N)*X-MO(N)
7820 PRINT "M1(",J,")=",M1(J)
7830 J=J+1
7840 NEXT Y
7850 FOR Y=10*AR+ST TO 10*L STEP ST
7860 X=Y/10
7870 FOR I=1 TO O
7880 IF X<>B(I) THEN 7930
7890 IF X=B(N) THEN 7930
7900 M1(J)=0
7910 PRINT "M1(",J,")=",M1(J)
7920 J=J+1
7930 NEXT I
7940 M1(J)=0
7950 PRINT "M1(",J,")=",M1(J)
7960 J=J+1
7970 NEXT Y
7980 RB=RB1(N)+RB\RA=RA1(N)+RA
7990 GOTO 8370
8000 FOR Y=0 TO 10*AR STEP ST
8010 X=Y/10
8020 FOR I=1 TO O
8030 IF X<>B(I) THEN 8070
8040 IF X=B(N) THEN 8070
8050 M1(J)=RB1(N)*X
8060 J=J+1
8070 NEXT I
8080 M1(J)=RB1(N)*X
8090 PRINT "M1(",J,")=",M1(J)
8100 J=J+1
8120 NEXT Y
8130 FOR Y=10*AR+ST TO 10*B(N) STEP ST
8140 X=Y/10
8150 FOR I=1 TO O
8160 IF X<>B(I) THEN 8200
8170 IF X=B(N) THEN 8200
```

```
8180 M1(J)=RB1(N)*X-RA1(N)*(X-AR)
8190 J=J+1
8200 NEXT I
8210 M1(J)=RB1(N)*X-RA1(N)*(X-AR)
8220 PRINT "M1(",J,")=",M1(J)
8230 J=J+1
8240 NEXT Y
8250 FOR Y=10*B(N) TO 10*L STEP ST
8260 X=Y/10
8270 FOR I=1 TO O
8280 IF X<>B(I) THEN 8320
8290 IF X=B(N) THEN 8320
8300 M1(J)=0
8310 J=J+1
8320 NEXT I
8330 M1(J)=0
8340 PRINT "M1(",J,")=",M1(J)
8350 J=J+1
8360 NEXT Y
8370 RB=RB+RB1(N)\RA=RA+RA1(N)
8380 FOR J=1 TO ((10*L/ST)+1+O)
8390 M(J)=M(J)+M1(J)
8400 NEXT J
8410 NEXT N
8420 PRINT "RB=",RB,"RA=",RA
8430 FOR J=1 TO ((10*L/ST)+1+O)
8440 PRINT "M(",J,")=",M(J)
8450 NEXT J
8460 FOR I=1 TO 10\PRINT\NEXT I\GOSUB 11220
8470 FOR I=1 TO 10\PRINT\NEXT I\INPUT N%
8472 N=N%\IF N=1 OR N=2 THEN 8480
8474 PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 8470
8480 IF N=1 THEN GOTO 11310
8490 RETURN
8500 GOSUB 10900
8510 INPUT "Type the number of distrebuted force regions I2=",I2%
8512 I2=I2%\IF I2<=0 THEN PRINT "ERROR ENTER  PLEAESE TRY AGAIN"\GOTO 8510
8520 FOR N=1 TO I2
8530 PRINT "Q(",N,")=","A(",N,")=","B(",N,")=","C(",N,")="
8540 INPUT Q(N),A(N),B(N),C(N)
8542 IF Q(N)=0 THEN
8544 IF A(N)<0 OR A(N)>L THEN 8549
8545 IF B(N)<0 OR B(N)>L THEN 8549
8546 IF C(N)<0 OR C(N)>L THEN 8549
8548 IF L=A(N)+B(N)+C(N) THEN 8550
8549 PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 8540
8550 C1(N)=C(N)\B1(N)=C(N)+B(N)\RB1=0\RA1=0
8560 NEXT N
8580 L1=L
8620 FOR N=1 TO I2
8630 J=1
8640 RA1(N)=Q(N)*(((2*C(N)*B(N))+B(N)^2))/(2*AR)
8650 RB1(N)=Q(N)*B(N)-RA1(N)
8660 PRINT "RA1(",N,")=",RA1(N),"RB1(",N,")=",RB1(N)
```

```
8670 IF AR>=C1(N) THEN 8860
8680 FOR Y=0 TO 10*AR STEP ST
8690 X=Y/10
8700 M1(J)=RB1(N)*X
8705 J=J+1
8710 IF M1(J-1)=M1(J-2) THEN 8750
8720 FOR K=1 TO O
8730 IF K=B(K) THEN 8700
8740 NEXT K
8750 NEXT Y
8760 FOR Y=10*AR+ST TO 10*C1(N) STEP ST
8770 X=Y/10
8780 M1(J)=RB1(N)*X+RA1(N)*(X-AR)
8790 J=J+1
8800 IF M1(J-1)=M1(J-2) THEN 8840
8810 FOR K=1 TO O
8820 IF X=B(K) THEN 8780
8830 NEXT K
8840 NEXT Y
8850 GOTO 8950
8860 FOR Y=0 TO 10*C1(N) STEP ST
8870 X=Y/10
8880 M1(J)=RB1(N)*X
8890 J=J+1
8900 IF M1(J-1)=M1(J-2) THEN 8940
8910 FOR K=1 TO O
8920 IF X=B(K) THEN 8880
8930 NEXT K
8940 NEXT Y
8950 IF AR<C1(N) THEN 9180
8960 IF AR>=B1(N) THEN 9070
8970 FOR Y=10*C1(N)+ST TO 10*AR STEP ST
8980 X=Y/10
8990 M1(J)=RB1(N)*X-Q(N)*((X-C1(N))^2)/2
9000 J=J+1
9010 IF M1(J-1)=M1(J-2) THEN 9050
9020 FOR K=1 TO O
9030 IF X=B(K) THEN 8990
9040 NEXT K
9050 NEXT Y
9060 GOTO 9270
9070 FOR Y=10*C1(N)+ST TO 10*B1(N) STEP ST
9080 X=Y/10
9090 M1(J)=RB1(N)*X-Q(N)*((X-C1(N))^2)/2
9100 J=J+1
9110 IF M1(J-1)=M1(J-2) THEN 9150
9120 FOR K=1 TO O
9130 IF X=B(K) THEN 9090
9140 NEXT K
9150 NEXT Y
9160 GOTO 9360
9170 IF AR<=C1(N) THEN 9270
9180 FOR Y=10*C1(N)+ST TO 10*B1(N) STEP ST
9190 X=Y/10
```

```
9200 M1(J)=(RB1(N)*X)-Q(N)*((X-C1(N))^2)/2+RA1(N)*(X-AR)
9210 J=J+1
9215 IF M1(J-1)=M1(J-2) THEN 9250
9220 FOR K=1 TO O
9230 IF X=B(K) THEN 9200
9240 NEXT K
9250 NEXT Y
9260 GOTO 9360
9270 FOR Y=10*AR+ST TO 10*B1(N) STEP ST
9280 X=Y/10
9290 M1(J)=(RB1(N)*X)+(RA1(N)*(X-AR)-Q(N)*((X-C1(N))^2)/2)
9300 J=J+1
9310 IF M1(J-1)=M1(J-2) THEN 9350
9320 FOR K=1 TO O
9330 IF X=B(K) THEN 9290
9340 NEXT K
9350 NEXT Y
9360 IF AR<=B1(N) THEN 9570
9370 FOR Y=10*B1(N)+ST TO 10*AR STEP ST
9380 X=Y/10
9390 M1(J)=RB1(N)*X-Q(N)*B(N)*(X-(C(N)+B(N)/2))
9400 J=J+1
9410 IF M1(J-1)=M1(J-2) THEN 9450
9420 FOR K=1 TO O
9430 IF X=B(K) THEN 9390
9440 NEXT K
9450 NEXT Y
9460 FOR Y=10*AR+ST TO 10*L STEP ST
9470 X=Y/10
9480 M1(J)=0
9490 J=J+1
9500 IF M1(J-1)=M1(J-2) THEN 9540
9510 FOR K=1 TO O
9520 IF X=B(K) THEN 9480
9530 NEXT K
9540 NEXT Y
9560 GOTO 9680
9570 FOR Y=10*B1(N)+ST TO 10*L STEP ST
9580 X=Y/10
9590 M1(J)=RB1(N)*X+RA1(N)*(X-AR)-Q(N)*B(N)*(X-(C(N)+B(N)/2))
9600 IF M1(J)>1E-05 THEN 9630
9610 M1(J)=0
9620 J=J+1
9630 IF M1(J-1)=M1(J-2) THEN 9670
9640 FOR K=1 TO O
9650 IF X=B(K) THEN 9610
9660 NEXT K
9670 NEXT Y
9680 RB=RB1(N)+RB
9690 FOR J=1 TO  ((10*L)/ST)+1+O
9700 M(J)=M(J)+M1(J)
9710 PRINT "M1(",J,")=",M1(J),"M(",J,")=",M(J)
9720 NEXT J
9730 NEXT N
```

```
9740 PRINT "RB=",RB
9750 FOR J=1 TO ((10*L)/ST)+1+0
9760 PRINT "M(",J,")=",M(J)
9770 NEXT J
9780 FOR I=1 TO 10\PRINT\NEXT I\GOSUB 11220
9790 FOR I=1 TO 10\PRINT\NEXT I\INPUT N%
9792 N=N%\IF N=1 OR N=2 THEN 9800
9794 PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 9790
9800 IF N=1 THEN GOSUB 11310
9810 RETURN
9900 GOSUB 11010
9910 P$="PARALELL"
9920 PRINT " Type the number of forces paralell to the shaft axes "
9930 PRINT "      which are applied in the same plane           "
9940 INPUT O%
9942 O=O%\IF O<O THEN PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 9940
9950 FOR N=1 TO O
9960 PRINT " Type the distances between the shaft and the forces ","E(",N,")",
9970 INPUT E(N)
9972 IF E(N)<=0 THEN PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 9970
9980 PRINT "F(",N,")=",
9990 INPUT F(N)
9992 IF F(N)=0 THEN PRINT "ERROR ENTER  PLEASE TRY AGAIN"\GOTO 9990
10020 MO(N)=F(N)*E(N)
10030 NEXT N
10040 GOSUB 7502
10050 GOTO 11500
10100 PRINT "+",\FOR I=1 TO 58\PRINT "-",\NEXT I\PRINT "+"
10110 PRINT "|",\FOR I=1 TO 58\PRINT " ",\NEXT I\PRINT "|"
10120 PRINT "| DO YOU HAVE CONCENTRATED FORCES ACTING ON YOUR SHAFT ?    |"
10130 PRINT "|",\FOR I=1 TO 58\PRINT " ",\NEXT I\PRINT "|"
10140 PRINT "+",\FOR I=1 TO 58\PRINT "-",\NEXT I\PRINT "+"
10180 RETURN
10190 PRINT "+",\FOR I=1 TO 63\PRINT "-",\NEXT I\PRINT "+"
10200 PRINT "|",\FOR I=1 TO 63\PRINT" ",\NEXT I\PRINT "|"
10210 PRINT "|     DO YOU HAVE PURE BENDING MOMENTS ACTING ON YOUR SHAFT ?     |"
10220 PRINT "|",\FOR I=1 TO 63\PRINT " ",\NEXT I\PRINT "|"
10230 PRINT "+",\FOR I=1 TO 63\PRINT "-",\NEXT I\PRINT "+"
10270 RETURN
10280 PRINT "+",\FOR I=1 TO 58\PRINT "-",\NEXT I\PRINT"+"
10290 PRINT "|",\FOR I=1 TO 58\PRINT" ",\NEXT I\PRINT "|"
10300 PRINT "| DO YOU HAVE DISTREBUTED FORCES ACTING ON YOUR SHAFT ?     |"
10310 PRINT "|",\FOR I=1 TO 58\PRINT " ",\NEXT I\PRINT"|"
10320 PRINT "+",\FOR I=1 TO 58\PRINT "-",\NEXT I\PRINT"+"
10360 RETURN
10370 PRINT "+",\FOR I=1 TO 58\PRINT "-",\NEXT I\PRINT"+"
10380 PRINT "|",\FOR I=1 TO 58\PRINT" ",\NEXT I\PRINT "|"
10390 PRINT "|          DO YOU HAVE FORCES ACTING ON YOUR SHAFT          |"
10400 PRINT "|          PARALELL WITH THE SHAFT AND IN THE SAME          |"
10410 PRINT "|                        PLANE                              |"
10420 PRINT "|",\FOR I=1 TO 58\PRINT " ",\NEXT I\PRINT"|"
10430 PRINT "+",\FOR I=1 TO 58\PRINT "-",\NEXT I\PRINT"+"
10435 RETURN
```

```
10440 PRINT "                                  A3              "
10450 PRINT "                       |<----------------------->|"
10460 PRINT "                       |               A2        |"
10470 PRINT " The shaft             |      |<---------------->|"
10480 PRINT "    \                  |      |          A1      |"
10490 PRINT "     \                 |      |      |<--------->|"
10500 PRINT "      \                | P3   | P2   | P1        |"
10510 PRINT "       \               V      V      V           |"
10520 PRINT "      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX"
10530 PRINT "      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX"
10532 IF AR=0 THEN 10550
10534 PRINT "      |     ^   ^                                |"
10535 PRINT "      |     |   |                                |"
10536 PRINT "      |     <----------------AR------------------>"
10540 PRINT "      |         ^                                |"
10550 PRINT "      |         |                                |"
10560 PRINT "      |         | P(I)         A(I)              |"
10570 PRINT "      |         |<------------------------------>|"
10580 PRINT "      |                                          |"
10590 PRINT "      |<------------------ L ------------------->|"
10600 PRINT "                                                  "
10700 RETURN
10710 PRINT "                          B(I)                    "
10720 PRINT "                 <------------------------------>|"
10730 PRINT "                                   B(2)          |"
10740 PRINT "                               <---------------->|"
10750 PRINT "                                       B(1)      |"
10760 PRINT " The shaft                             <--------->|"
10770 PRINT "    \                                            |"
10780 PRINT "     \      <---+             +--->  +--->       |"
10790 PRINT "      \         |MO(I1)       |MO(2) | MO(1)     |"
10800 PRINT "       \        |             |      |           |"
10810 PRINT "      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX"
10820 PRINT "      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX"
10830 PRINT "      |         |             |      |           |"
10840 PRINT "      |         |             |      |           |"
10850 PRINT "      |         +--->     <---+  <---+           |"
10860 PRINT "      |                                          |"
10870 PRINT "      |<------------------ L ------------------->|"
10880 PRINT
10890 RETURN
10900 PRINT "         |<----A----->|<--------B-------->|<----C----->|"
10910 PRINT "         |            |                   |            |"
10920 PRINT "         |            |        Q          |            |"
10930 PRINT "         |          B1|||||||||||||||||||||C1          |"
10940 PRINT "      L1 |\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\|0"
10950 PRINT "         |/////////////////////////////////////////////|"
10960 PRINT "         ^                                             ^"
10970 PRINT "       RA|-------------------- L ----------------------|RB"
10980 PRINT
10990 PRINT
11000 RETURN
```

```
11010 PRINT "                                      B(2)                     "
11020 PRINT "                          |<---------------------------->|     "
11030 PRINT "                          |                     B(1)     |     "
11040 PRINT "                          |               |<------------>|     "
11050 PRINT "                  +F(2)   |               |- F(1)        |     "
11060 PRINT "                  ------->|               |<-----        |     "
11070 PRINT "                  ^       |               |     ^        |     "
11080 PRINT "                  |E(2)   |               |     |E(1)    |     "
11090 PRINT "                  |       |               |     |        |     "
11100 PRINT "                  V       |               |     V        |     "
11110 PRINT "       L1 |\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\|0    "
11120 PRINT "          |//////////////////////////////////////////////|     "
11130 PRINT "                 _ -------->              <-------- +          "
11140 PRINT "                                                               "
11150 PRINT "                                                               "
11160 RETURN
11170 PRINT "+",\FOR I=1 TO 58\ PRINT "-",\NEXT I\PRINT "+"
11180 PRINT "|     NOW YOU SHOULD TYPE THE VALUES OF THE MOMENTS AFFECTED|"
11190 PRINT "|   FORCES AND DIMENSIONS AS IT IS ILLUSTRATED IN THE FIGUR |"
11200 PRINT "+",\FOR I=1 TO 58\ PRINT "-",\NEXT I\PRINT "+"
11210 RETURN
11220 PRINT "+",\FOR U=1 TO 64 \PRINT "-",\NEXT U\PRINT "+"
11230 PRINT"|",\FOR U=1 TO 64\ PRINT " ",\NEXT U\PRINT "|"
11240 PRINT"|Type 1 if you haven't any more kinds of forces affecting on the |"
11250 PRINT"|shaft and you want to know the maximum bending moment            |"
11260 PRINT"|",\FOR U=1 TO 64\ PRINT " ",\NEXT U\PRINT"|"
11270 PRINT"|Type 2 if you have another sort of force                         |"
11280 PRINT"|",\FOR U=1 TO 64\PRINT " ",\NEXT U\PRINT "|"
11290 PRINT"+",\FOR U=1 TO 64\PRINT "-",\NEXT U\PRINT "+"
11300 RETURN
11310 M=0
11320 FOR J=1 TO ((10*L/ST)+1+0)
11330 IF M>ABS(M(J)) THEN 11350
11340 M=ABS(M(J))
11350 NEXT J
11360 PRINT"RB=",RB
11370 PRINT "Mmax=",M
11380 D=((8*FS*(M+SQRT(M^2+T^2)))/(PI*YP))^(1/3)
11500 OPEN "A DAT" FOR OUTPUT AS FILE £4
11560 PRINT £4,FS,",",H,",",N$,",",TEN,",",COMP,",",SH
11570 PRINT £4,YP,",",P,",",L,",",N,",",D,",",F
11580 CLOSE £4
11590 CHAIN "DIAM"
11600 END
```

STANDARD COMPONENT (DIAM BAS)

```
1160 OPEN "A DAT" FOR INPUT AS FILE £4
1170 INPUT £4,FS,H,N$,TEN,COMP,SH
1175 INPUT £4,YP,P,L,N,D,F
1180 CLOSE £4
1245 OPEN "DIA DAT" FOR INPUT AS FILE £1
1280 INPUT £1,ST,STS,AL,CO
1290 IF ST<>999999 THEN 1310
1295 PRINT "********************************************************************"
1300 PRINT "NO STANDERD DIAMETER"
1302 PRINT "********************************************************************"
1305 GOTO 5000
1310 IF N$="ALOMINUM" THEN 1350
1320 IF N$="COPPER" THEN 1370
1330 IF N$="STEEL" THEN 1384
1340 IF N$="STAINLESS STEEL" THEN 1388
1350 IF D>AL THEN 1280
1360 D=AL
1365 GOTO 1400
1370 IF D>CO THEN 1280
1380 D=CO
1382 GOTO 1400
1384 IF D>ST THEN 1280
1386 D=ST
1387 GOTO 1400
1388 IF D>STS THEN 1280
1390 D=STS
1400 CLOSE £1
1405 PRINT "**********************************************************************"
1410 PRINT "THE APPROPRIATE DIAMETER IS D(m)=",D,,"[m]"
1420 PRINT "**********************************************************************"
1425 F=1
1430 OPEN "A DAT" FOR OUTPUT AS FILE £4
1440 PRINT £4,FS,",",H,",",N$,",",TEN,",",COMP,",",SH
1450 PRINT £4,YP,",",P,",",L,",",N,",",D,",",F
1460 CLOSE £4
1470 CHAIN "MAIN"
5000 END
```

APPENDIX C

POSTPROCESSOR

```
,,
,, The NC code translations are based on the RS-274-D Standard and
,, the FANUC 10-12M control
,,
,, *NAME - MILL
,, *CONTROL - FANUC 10-12M
,, *TYPE - MILL
,, *COMMENTS - Based on the FANUC 10-12M Operator's Manual
,, *DATE - 1-8-89
,, *AUTHOR - DIKO
,, *POSTREV - 4 50 OR GREATER
,,
,, HEADER Information
,,
ORIGIN\0 0,0 0,0 0 = $HEADER 1
HOME\0 0,0 0,0 0 = $HEADER 2
ABS=$HEADER 3
RAPID=$HEADER 4
,, =$FIRSTINDEXOFF
,, =$COMMASON
0 0001=$MATCHTOL
8=$OUTTOL
,,
,,      GEOMETRY Information
,,
#SEQNO#PB#LINEAR#RAPID#X#Y#Z#PA=$POINT1 1
#SEQNO#PB#LINEAR#RAPID#X#Y#Z#PA=1 1
#SEQNO#PB#CIRCUL#CIRCUL#X#Y#XCI#YCI#Z#PA=$ARC1 1
X#5 3#6 2,M#2=X
Y#5 3#6 2,M#2=Y
Z#5 3#6 2,M#2=Z
=ZA
```

```
=ZI
I#5 3#6 2,M#1=XCI
J#5 3#6 2,M#1=YCI
K#5 3#6 2,M#1,A=K
U#5 3#6 2,M#1,A=U
V#5 3#6 2,M#1,A=V
W#5 3#6 2,M#1,A=W
R#5 3#6 2,M#1,A=RADIUS
A#5 3#6 2,M#1,A=A
B#5 3#6 2,M#1,A=B
C#5 3#6 2,M#1,A=C
,,
,,      Additional Geometry variables - Ref  CPOST manual
,,
,, =SA
,, =EA
,, =ANGLE
,, =SWEEP
,, =LENGTH
,, =X1
,, =X1A
,, =X2
,, =X2A
,, =X2I
,, =XA
,, =XCA
,, =XC
,, =XI
,, =Y1
,, =Y2
,, =YA
,, =YCA
,, =YC
,, =YI
,,
```

```
,,     TEXT Information
,,
#SEQNO#PB#PC#PA=$TEXT1 1
,,
,, CODE Format
,,
ASCII=FORMAT
,,
,,     DELIMITERS
,,
%=BEGIN
%=END
,, =FIRST
,, =LAST
0̂130̂10=EOB
N#5#5,I#1=SEQNO
,I#1=SEQINC
,,
,,     MODAL G CODES - General
,,
   G00,D#LINEAR,E#RAPID,M#0#CIRCULCLW#CIRCULCCLW=RAPID
   G01,D#RAPID,E#LINEAR,M#0#CIRCUL\CLW#CIRCUL\CCW =
LINEAR
   G02,D#CIRCUL\CCLW, E#CIRCUL\CLW, M#0#LINEAR#RAPID =
CIRCUL\CLW
   G03,D#CIRCUL\CLW, E#CIRCUL\CCLW, M#0#LINEAR#RAPID =
CIRCUL backslashCCLW
   G90,B,D#INCR,E#ABS=ABS
   G91,B,D#ABS,E#INCR,M#0=INCR
   G20,C=INCH
   G21,C=METRIC
   G61,B=EXSTOP
   G62,B=CORNER
   G63,B=TAP
   G64,B=CUT
```

```
G93,B=FRN
G94,B=FPM
G95,B=FPR
"
"     ONE-SHOT G CODES - General
"
G04P#5 2#5 3,C=DWELL
G07,B=HYPO
G60,B=SINGLE
G#2#2,B=G
"
"     PROGRAM CONTROL
"
P#5#5,A=PROGRAM
 =JOBID
M00,C=PSTOP
M01,C=OPSTOP
M02,C=ENDP
M08,C=COOLON
M31,C=CONVEYER
M30,C=FINI
(,C=COMMENT
M98P#4#4,F#ZL,C=SUBPRG
M99,C=ENDSUB
L#3#3,A=REPCNT
%,C=REWIND
"
"     TOOL Information
"
F#5 4#6 4,A=FEDRAT
T#2#2,F#ZL,A=TOOLNO
S#8#8,A=SPEED
H#2#2,F#ZL,A=H
D#2#2,F#ZL,A,M#0=D
G92S#4#4,B,M#0=MAXSPD
```

```
"
,, AutoCAD text format for CSS RPM is
,, CSS < speed >,M03 (or M04)
,, RPM < speed >,M03 (or M04)
"
G96S#4#4,C,M#0,D#RPM,E#CSS=CSS
G97S#4#4,C,M#0,D#CSS,E#RPM=RPM
M03,A=SPINDLE\CW
M04,A=SPINDLE\CCW
M05,A=SPINDLE\OFF
M06,A=TOOLCHG
"
,,     TOOL Length Compensation
"
G43,B,D#NTLC,E#PTLC=PTLC
G44,B,D#PTLC,E#NTLC,M#0=NTLC
G49,C,D#PTLC#NTLC=TLCOFF
"
,,     TOOL Radius Compensation
"
G40,B,D#CUTCOM#CUTCOM=CUTCOM\OFF
G41,B,D#CUTCOM,E#CUTCOMLEFT, M#0=CUTCOMLEFT
G42,B,D#CUTCOM\LEFT, E#CUTCOM\RIGHT, M#0 = CUTCOM\RIGHT
"
,,     COORDINATE System
"
,, All assignments that switch to group code 2 must be addressed
,, by the appropriate TEXT statement followed by a POINT
"
G92,B,G#2#1=PRESET
#SEQNO#PB#XNON#YNON#ZNON#PA=2 1
#SEQNO#PB#PC#PA=$TEXT2 1
X#5 3#6 2,V#X=XNON
Y#5 3#6 2,V#Y=YNON
Z#5 3#6 2,V#Z=ZNON
```

```
G52,B,G#2#1=LOCAL
G53,B,G#2#1=MACHINE
G54,B=WRKCRD1
G55,B=WRKCRD2
G56,B=WRKCRD3
G57,B=WRKCRD4
G58,B=WRKCRD5
G59,B=WRKCRD6
G17,B,G#2#1=XYPLANE
G18,B,G#2#1=ZXPLANE
G19,B,G#2#1=YZPLANE
G17,B=G17
G18,B=G18
G19,B=G19
G27,B,G#2#1=RFPTCHK
G28,B,G#2#1=RFPTTO
G29,B,G#2#1=RFPTFRM
G30,B,G#2#1=RFPTRET
,,
,,      THREAD
,,
,, The assignment that switch to group code 3 must be addressed
,, by the THREAD, LEAD, RIDGE, and SHFANG text statement
,, followed by a POINT
,,
#SEQNO#PB#THREAD#X#Y#LEAD#RIDGE#SHFANG#PA=$POINT3 1
#SEQNO#PB#PC#PA=$TEXT3 1
G33,G#3#1=THREAD
F#5 3#6 2=LEAD
E#3 1#3 1=RIDGE
Q#5 3#6 2=SHFANG
,,
,,      AUXILIARY Functions
,,
M#8#8,A=AUX
```

```
B#8#8,C=INDEX
M08,A=COOLNT
M09,A=COOLNT
M11,A=SPND1ON
M12,A=SPNDOFF
"
"     CANNED CYCLES
"
" All assignments that switch to group code 4 must be addressed
" by the CYCLE text statement  Each following text statement must
" be a parameter to the cycle (P1,P2,P3  P10)  After all text
" statements are defined a POINT is required to complete the cycle
" definition
"
"     CYCLE # # = 73,74,76,80-89
G80,B,D#CYCLE=CYCAN
"
#SEQNO#PB#CYCLE#IL#RL#X#Y#PZ#P1#P2#P3#P4#P5#P6#P7
#P8#P9#P10#PA=$POINT4 1
#SEQNO#PB#PC#PA=$TEXT4 1
G#2#2,M#0,G#4#1=CYCLE
"     Return to initial point mode
G98,D#RL,E#IL,M#0=IL
"     Return to R point mode
G99,D#IL,E#RL,M#0=RL
"     Distance from R point to Bottom
Z#5 3#6 2,M#1=PZ
" Distance from initial level to point R level
R#5 3#6 2,M#1=P1
"     Cut-in or Shift value
Q#5 3#6 2,M#1=P2
"     Dwell time
P#5 2#5 3,M#1=P3
"     Feed rate
F#5 4#6 4,M#1=P4
```

```
,,     Repetition count
L#3#3,M#1=P5
=P6
=P7
=P8
=P9
=P10
,,
,,     CUSTOM MACROS
,,
,, All assignments that switch to group code 5 must be addressed
,, by the CUSTOM text statement  Each following text statement must
,, be a parameter to the macro (C1,C2,C3  C10)  After all text
,, statements are defined a FLUSH text statement is required to
,, complete the macro definition
,,
,,     CUSTOM # # = 65 or 66
,,
G67,C=MODALEND
#SEQNO#PB#CUSTOM#PRG#IT#C1#C2#C3
#C4#C5#C6#C7#C8#C9#C10#PA=$POINT5 1
G#2#2,M#0,G#5#1=CUSTOM
,,     Program Number
P#5#5=PRG
P#5#5=SUB
,,     Iteration counter
L#3#3=IT
=C1
=C2
=C3
=C4
=C5
=C6
=C7
=C8
```

=C9
=C10
,,
,, Mill Productivity Package special terms
,,
=CONTINUE

APPENDIX D

```
%
 1
N1G21
N2M31
N3G91G28Z0
N4G91G28X0 Y0
N5G90G55G40G80G00X-50 Y-50 S1000F200 M03T03
N6G43Z10.H02M08
N7G01Z 5
N8M98P1000
N9Z0 F400
N10M98P1000
N11G91G28Z0
N12G91G28X0 Y0 M09
N13T03M06
N14G90G55G40G80G00X-10 Y-10 F200 S1000M03T04
N15G43Z10 H04M08
N16G01Z-11
N17G62G42X0 Y0.D53
N18M98P2000
N19Z-25
N20M98P2000
N21G40G91G28Z0
N22G91G28X0 Y0 M09
N23T04M06
N24G90G55G40G80G00X-30 Y-20 F300 S1000M03T05
N25G43Z10 M08
N26G01Z-25
N27G62G41X0 Y0 D54
N28M98P2000
N29G40G91G28X0 Y0 Z0 M09
N30T05M06
N31G90G55G40G80G00X310 Y-10 F200 S1500M03
N32G43Z10 H05M08
N33G01Z-5
N34G42X306 D55
N35Y0
N36Y121
N37G03X296 Y131 I-10
N38G01X10
N39G03X0 Y121 J-10
N40G01Y0
N41G00Z10.
N42X306
N43G40G91G28Z0
N44G91G28X0 Y0 M09
N45M30
%
%
 1000
N1G01X-30 Y-5.
```

```
N2X336
N3Y15
N4X-30
N5Y35
N6X336
N7Y55
N8X-30
N9Y75.
N10X336
N11Y95
N12X-30
N13Y115
N14X336
N15Y135.
N16X-30.
N17G00Z15
N18M99
%
%
 2000
N1G01Y121
N2G02X10 Y131 I10
N3G01X296
N4G02X306 Y121 J-10
N5G01Y0
N6X0.
N7M99
%
%
 1
N1G21M31
N2G91G28Z0
N3G91G28X0 Y0
N4T02M06
N5G90G55G40G80G00X-10 Y-20 S1000F300 M03T03
N6G43Z10 H02M08
N7G01Z0
N8X10
N9Y121
N10X296.
N11Y-20.
N12G00Z10
N13X10
N14G90G55G40G80G00X3 Y-15.S750M03F200 T03
N15G43Z10 H02M08
N16G42G01Y-13 D52
N17Z-6
N18M98P4000
N19G00Z2
N20G01Z-11
N21M98P4000
N22G00Z2.
N23G01Z-16
N24M98P5000
```

```
N25G40G42D62S1000
N26G00Z2.
N27G01Z-18.5
N28M98P5000
N29G00Z2.
N30G01Z19
N31F400
N32M98P5000
N33G91G28Z0
N34G91G28X0 Y0.
N35G90G55G40G80G00X154 5Y-15 S750M03F200.T03
N36G43Z10 H02M08
N37G42G01D52
N38G00X157.Y-14 Z2
N39Z-5.5
N40M98P6000
N41G00X154.5Y13 Z2
N42Z-11.
N43M98P6000
N44G00X154.5Y-13 Z2.
N45Z-16.
N46M98P6000
N47G40
N48G00X147.Y-15 S1000
N49G01G42D62F400
N50Z-18 5
N51M98P6000
N52X154 5Y-13
N53Z-19
N54M98P6000
N55G40
N56G00X153.Y-30
N57G01Z-16.
N58Y6
N59Y-30
N60Z-19
N61Y3
N62G00Z45 M09
N63G91G28Z0
N64G91G28X0 Y0
N65T03M06
N66M31
N67G90G00G55G40G80X20 Y-20.S1000M03F200
N68G43H03Z10 M08
N69G01G42D63X3 Y-10
N70Z-18 9
N71M98P7000
N72G00X20 Y-40
N73Z10
N74G01Y-15.
N75Z-19.F400
N76M98P7000
N77G91G28Z0
N78G91G28X0 Y0.
```

```
N79M31
N80G90G00G55G40G80X160 Y-12 S1000M03F200
N81G43H03Z10 M08
N82G01G42G63X155 Y-10
N83Z-18 9
N84M98P8000
N85G00X160 Y-10.
N86Z10
N87G01Z/19
N88M98P8000
N99G91G28Z0
N90G91G28X0 Y0
N91M30
%
%
 4000
N1G01X3 Y-13
N2Y128
N3X165
N4Y-13
N5X3
N6X23 Y7
N7Y108
N8X145
N9Y7
N10X23
N11X43 Y27
N12Y88
N13X125
N14Y27
N15X43
N16X63 Y47
N17Y68
N18X105
N19Y47
N20X63
N21G00Z2
N22M99
%
%
 5000
N1G01X3 Y-13
N2Y128.
N3X151.5
N4Y-13
N5X3
N6X23 Y7
N7Y108
N8X131.5
N9Y7
N10X23
N11X43 Y27
N12Y88
N13X111.5
```

```
N14Y27
N15X43
N16X63 Y47
N17Y68.
N18X91 5
N19Y47.
N20X63
N21G00Z2
N22M99
%
%
 6000
N1G01X154.5Y-13
N2Y128.
N3X303.
N4Y-13
N5X154 5
N6X174 5Y7
N7Y108.
N8X283
N9Y7
N10X174 5
N11X194 5Y27
N12Y88
N13X263
N14Y27
N15X194 5
N16X214 5Y47
N17Y68
N18X243
N19Y47
N20X214 5
N21G00Z2
N22M99
%
%
 7000
N1G01X3 Y-10
N2Y121
N3G02X10 Y128 I7
N4G01X143 5
N5G02X151 5Y120 J-8
N6G01Y-10
N7G00Z10
N8X3.
N9M99
%
%
 8000
N1G01X154 5Y-10
N2Y120.
N3G02X162 5Y128 I8.
N4G01X296
N5G02X303 Y121 J-7.
```

```
N6G01Y-10
N7G00Z10
N8X154 5
N9M99
%
%
 2
N1G21
N2M31
N3G91G28Z0
N4G91G28X0 Y0
N5G90G55G40G80X31 Y57 S1000F200 M03T08
N6G43Z15 H07M08
N7M98P9000
N8Y100
N9G90M98P9000
N10X81.
N11G90M98P9000
N12X129
N13G90M98P9000
N14X177.
N15G90M98P9000
N16X225
N17G90M98P9000
N18X275
N19G90M98P9000
N20Y57
N21G90M98P9000
N22X225
N23G90M98P9000
N24X81
N25G90M98P9000
N26X31
N27X-20 Y-20
N28G91G28Z0
N29G91G28X0 Y0
N30T08M06
N31G90G55G40G80S1000M03
N32G43H08M08
N33G81G99X15 Y41 Z-5 R2 F100
N34Y73
N35Y84
N36Y116
N37X47
N38X65
N39X97
N40X113
N41X145.
N42X161
N43X193
N44X209
N45X241.
N46X259
N47X291
```

```
N48Y84
N49Y73
N50Y41
N51X259
N52X241
N53X209
N54X97
N55X65
N56X47
N57X15
N58X47 Y73
N59Y84
N60X65.
N61X97.
N62X113
N63X145
N64X161.
N65X193
N66X209
N67X241
N68X259
N69Y73
N70X241
N71X209
N72X97
N73X65
N74X47
N75X117 5Y68 5
N76X140 5
N77X165 5
N78X188 5
N79Y45 5
N80X165 54
N81X140 5
N82X117 5
N83G91G28Z0
N84G91G28X0 Y0
N85M30
%
%
 9000
N1G91G00Z-13
N2G01Z-5 F150
N3G41Y16 D57
N4G02X16 Y-16 J-16
N5X-32 I-16
N6X15 002Y15 969I16
N7X 998Y 031I 998J-15 969
N8G01X16 Y-16
N9G90G00Y0.Z15
N10M99
%
```

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Integrated Computer Aided Engineering For 2-D Components

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Abstract

Over the past twenty years tremendous research effort has been devoted towards developing computer software for various engineering applications. A large number of very powerful packages have been developed for Computer Aided Design, Analysis, and Manufacture. However, in most cases these are standalone packages with poor facility for communicating with other packages.

Recently attempts have been made to develop standard software for better communication between different software packages with some success. However, much more needs to be done in order to develop a satisfactory system.

In the present an integrated system for computer aided design, analysis and manufacture has been developed incorporating AutoCAD Draughting Package, Finite Element Analysis Software and NC Machining Software. In this

system, the Draughting and NC Machining Software are resident in a PC and the Finite Element and Mesh-Generation Programs are resident in the main frame computer. The difficulties experienced in making the system work and the way these difficulties were solved are described in this paper with special reference to communication software.

1- INTRODUCTION :

Computer application in manufacturing companies are now widely spread. Due to the development of micro electronics, computers have become cheaper, more sophisticated and more powerful. In the present competitive commercial environment, the use of computer technology in the design of parts and production processes is perhaps the most promising development for increasing productivity.

Both the Computer-aided design (CAD) and Computer-aided manufacture (CAM) technologies are currently advancing very rapidly. The present CAD and CAM technologies have come about from firstly the development of numerically-controlled (NC) machine tool during the Second World War [1],and secondly the work of Ivan Sutherland in 1963 on 'SKETCHPAD' [2], the world's first computer graphics system.

To date, CAD is used to assist the design engineer to develop designs for products, analyse them and graphically describe them. CAM on the other hand, assists the production engineer to plan the method of manufacture, design tool, fixtures, test rigs and gauges, prepare factory plant layout and program NC machine tools and measuring machines.

In general, CAD refers to the use of interactive computer graphics to produce designs, while CAM uses the information from the Computer-aided design and draughting as a direct input to control manufacturing plant (such as numerically controlled machine tools).

The aim of this work is to develop standard software for better communication between the different software packages which will eventually form the desired CADCAM system.

2-SYSTEM CONFIGURATION

2-1 Hardware Configuration

The hardware involved in this work as illustrated in Fig (1) are :

a) PC IBM compatible with 20 Mbyte hard disk and 640 RAM. MS-DOS operating system.

b) Digitizer (LDS)

c) Printer (Star LC-10).

d) Plotter (Roland DXY-1300).

e) Graphic display unit (EAG Philips).

f) VAX mainframe computer with VMS operating system.

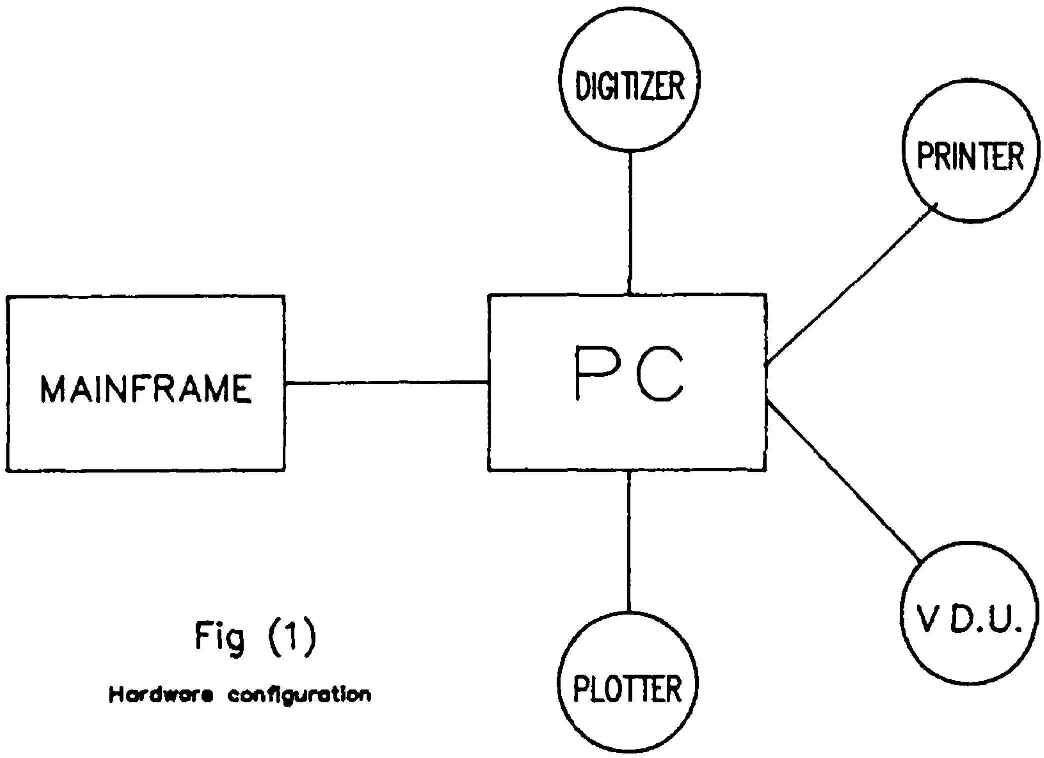


Fig (1)
Hardware configuration

2-2 Software Configuration

The software packages used in this work are divided into two categories :

2-2-1 The Commercial or Predeveloped Packages

a) AutoCAD package release 10.
b) NC programmer package for milling machine.
c) Kermit package for connecting PC with mainframe.
d) Finite Element Program (2-D).

2-2-2- The Programs developed inhouse

The aim of this work was the development of an Integrated System for computer aided design, analysis and manufacture incorporating the above packages. In order to achieve this objective, five programs had to be developed to integrate the different facilities of the system, which are draughting, analysis and manufacturing.

All these programs have been written in FORTRAN language and located in the mainframe.

1- An Interface Program (Inter1)

This program has been developed to translate the Drawing Exchange File (.DXF) to Data File. This DXF file contains special data such as the coordinates to be used as input in the Mesh Generation Program.

2- Mesh Generation Program (Meshg)

The Finite Element Program which has been used in this project does not have Mesh Generation or Pre-Processing subroutines. A Mesh Generation Program has been developed to devide the component geometry into fine quadratic elements with four nodes. As output it produces the coordinates of each node and the nodes of each element.

3- Pre-Processing Program (Prep)

The facilities required from this program are to read the data and other information needs for the Finite Element Program from different data file and arrange them in a command file in a specific format to be used in executing the finite element program.

4- An Interface Program (Inter2)

This program reads the data from the data file which contains the mesh coordinates of the nodes before deformation and translates them to a Drawing Exchange File (.DXF) to be sent back to AutoCAD.

5- An Interface program (Inter3)

This is the last program and it is also an interface program. It is similar to the Inter2 program. However instead of receiving data from Mesh Generation Program, it receives them from finite element program as node coordinates after deformation, which are calculated by adding the displacement of the nodes to its coordinates before deformation taking account of the sign of displacement values.

Primarily, this program uses these coordinates to produce a Drawing Exchange File (.DXF) to be sent back to AutoCAD.

All the above softwares will involved in the configuration of the system's software. To make use of these packages, these have to be installed and used in the proper way.

A special directory has to be created in the PC to install AutoCAD and the NC package in it. AutoCAD will occupy (4 Mbyte) and NC package (2 Mbyte). Kermit package should exist in PC and a path should be made to access it from AutoCAD directory.

The layout of the software configuration is illustrated in Fig (2).

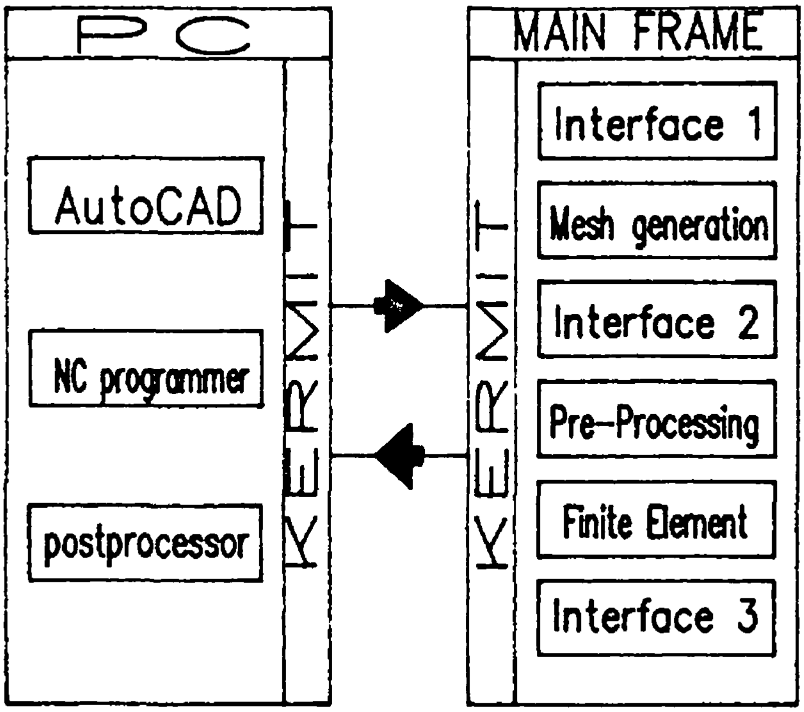


Fig (2) Software configuration

2-2-3- System Configuration

The system configuration envolved through the design of an integrated CADCAM system using the draughting, analysis and manufacturing packages by developing the communication software and some other necessary programs. Usually when a complete system is purchased from one supplier there is no problem in the communications between any two programs.

All the programs are usually integrated and a special formated file is developed to be sent to other programs. AutoCAD has the facilities to define a "Drawing Interchange" file format (DXF) which is understandable by NC package but not by the rest of the programs.

AutoCAD also supports the Initial Graphics Exchange Standard (IGES) file format.

In this work the (DXF) file has been used.

Fig (3) illustrate the layout of the system.

3- SYSTEM EXECUTION PROCEDURE

3-1- DRAUGHTING AND ANALYSIS

First of all, the user should be sure that the packages and programs are installed properly in their locations. AutoCAD package should be installed on the PC which is connected with mainframe by a physical connection. Kermit package should be installed also on the PC. The rest of the programs should be installed in the mainframe computer in a special directory. To illustrate the execution process clearly, a typical example of mechanical component has been chosen to be analysed and manufactured. The component with external loads is shown in Fig (4).

a) Creating the Drawing

The first step in executing the system is to create a drawing using the digitizer and the keyboard facilities. The main entities of the drawing should be placed on the layer "0" and the text and dimensions on other layers. After editing and finalizing the drawing it has to be saved in a drawing file.

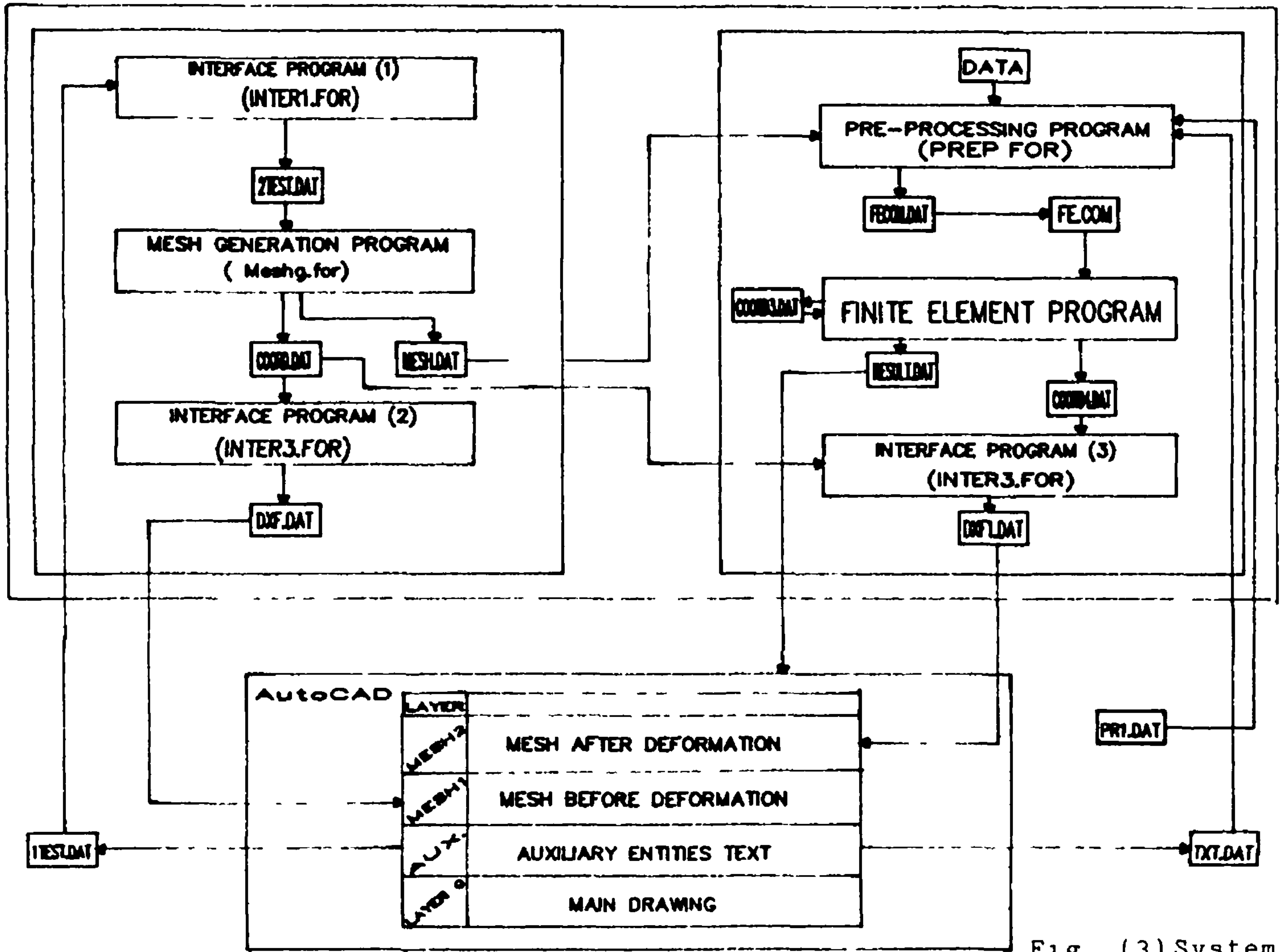


Fig (3) System Configuration

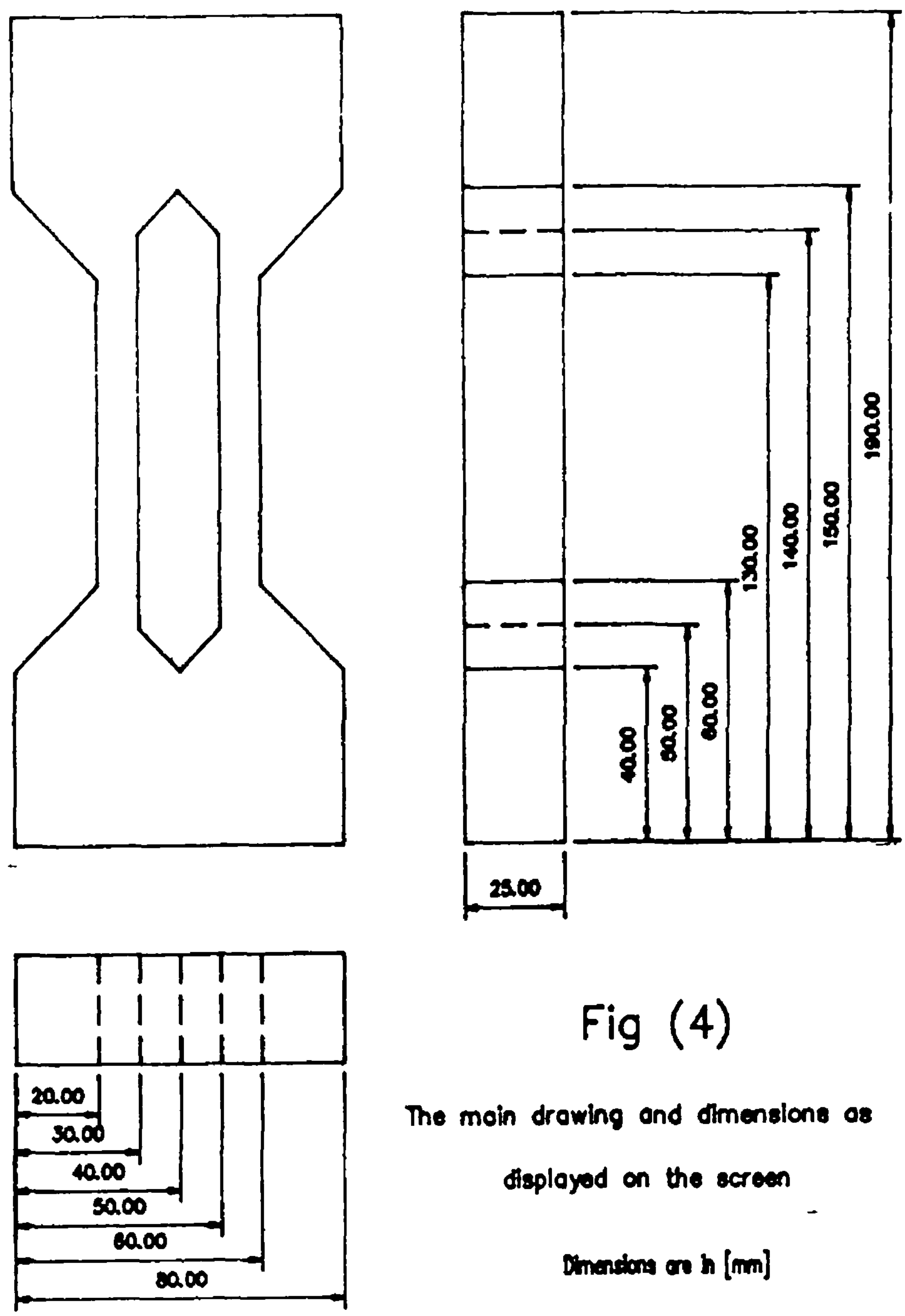


Fig (4)

The main drawing and dimensions as displayed on the screen

Dimensions are in [mm]

b) Mesh Generation

After saving the drawing auxiliary entities should be drawn on the component geometry to indicate the horizontal lines of the mesh. These entities should not affect the main drawing so they have to be saved in a special layer. The number of these lines depend on how much the user wants the mesh to be fined. In our example 12 lines have been drawn as auxiliary entities, making sure to start the drawing of each line from the left hand side. Then the number of horizontal divisions should be inserted in the drawing as a text. In our case it is equal to 3. The lines and the number of divisions are illustrated in Fig (5)A.

Then all the layers have to be turned off except the one which contains the auxiliary entities (The user can turn off all the layers with "*", then turn the auxiliary layer back on). Using AutoCAD command DXFOUT a DXF file for these layer has to be created considering the use of ENTITIES option and selecting the entities starting from the bottom to top.

By using SHELL Command the user is able to execute utility programs while remaining in the Drawing Editor. This facility should be used at this stage to access Kermit package in order to link the PC with the mainframe.

At this point the DXF file which has been created for the auxiliary entities can be sent to the mainframe using the command :

Kermit-MS> SEND <ret>

Remote source file : filename.DXF <ret>

Local destination file : 1TEST.DAT <ret>

Kermit-MS>Finish <ret>

the name of the file should become (1TEST.DAT).

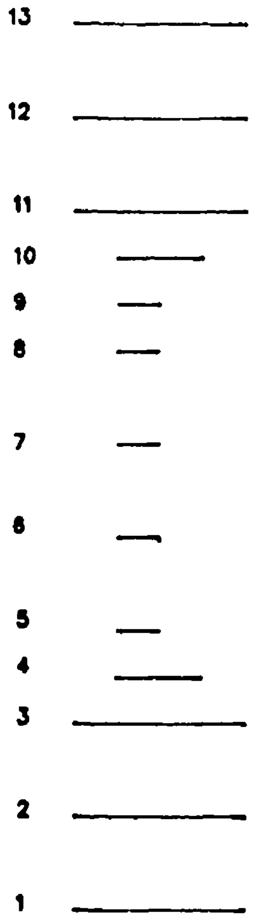
At this stage the working area is in the mainframe and the graphic screen is used as terminal. In mainframe in order to make the process of executing the programs more automated, two command files have been developed :

1- PROJECT1.COM
2- PROJECT2.COM

the next procedure towards creating the mesh is to execute the command file (PROJECT1.COM) which does a batch job. The content of this file is as follow :

```
PU
RUN INTER1
RUN MESHG
RUN INTER2
RUN AUX1
DEL FECOM.DAT;*
DEL FE.COM,*
EXIT
```

What actually goes on when executing this command is that the interface program (1) reads the data stored in a sequence file called (1test.dat) and picks out the important data and saves them in (2test.dat) for mesh generation program to be used as input.



Horizontal Divisions = 3

9
1 11
2 01
3 01
4 01
5 10
9 10
41 10
45 10
49 10
4
49 0.0 450.0
50 0.0 900.0
51 0.0 900.0
52 0.0 900.0
10.0

– B –

– A –

Fig (5)

The auxiliary layer in the main drawing

A) The horizontal lines.

B) The boundary conditions and external loads

After that the mesh generation program will be executed to produce two data files.

- Mesh.dat file to be used for the pre-processing program.

- Coord.dat to be used for interface program (3)

Thereafter, Coord.dat is used as input for the last program in this batch which is Interface Program (2). As a result this batch file produces a data file which contains all the informations for drawing the mesh before deformation in a Drawing Exchange Format (.DXF). The name of this file is DXF.DAT. In order to be used in AutoCAD the name of this file should be changed to any other name with extension .DXF during the transfer process.

Now, this file has to be sent to AutoCAD in PC through Kermit package using the command :

Kermit-MS> GET <ret>

Remote source file : DXF.DAT <ret>

Local destination file : filename.DXF <ret>

Then the user should go back to the Drawing Editor using EXIT Command. At this stage there is no need to create new layer for the mesh manually, because the (.DXF) file has got all the information needed for this purpose.

Kermit-MS>Finish <ret>

Kermit-MS>Exit <ret>

The (.DXF) should be inserted to the drawing using AutoCAD command [5].

DXFIN filename

As shown in Fig (6), all the mesh entities will appear on the screen, the elements, nodes and node numbers. These entities will be saved in a special layer called "MESH".The user can at this stage display the mesh and decide whether it is satisfactory or not. If it is not satisfactory or if it needs some modifications or refining, he can repeat the procedures starting from chosing the auxiliary entities, after erasing all the previous entities.

c) Inserting The Boundary Conditions and External Loads

It is obvious that the boundary conditions and the external loads have to be inserted at this stage where the user has to see the mesh in order to decide which nodes are restrained and which elements are affected by the loads. Also it was necessary to find out a way to record this information directly on the screen. Using the AutoCAD facilities and the developed programs it becomes easy to transfer this information to mainframe to be used in the programs.

The procedure to do the insertion are :

1- The working layer should be turned to an auxiliary layer.
2- An empty area should be chosen to insert the text.
3- Then type "TEXT" at the command line, after that you will

be asked to chose a convenient spot on the screen using "pick" button. Next you will be given choices about size and scaling. Press [RETURN] to take the default on these and then the command line will show "TEXT:".

Now type at the first line the number of restrained nodes and press [RETURN]. In our example, the number of restrained nodes is 13, the text will appear on the screen. Then each restrained node number and its specifications should be inserted in the same manner.

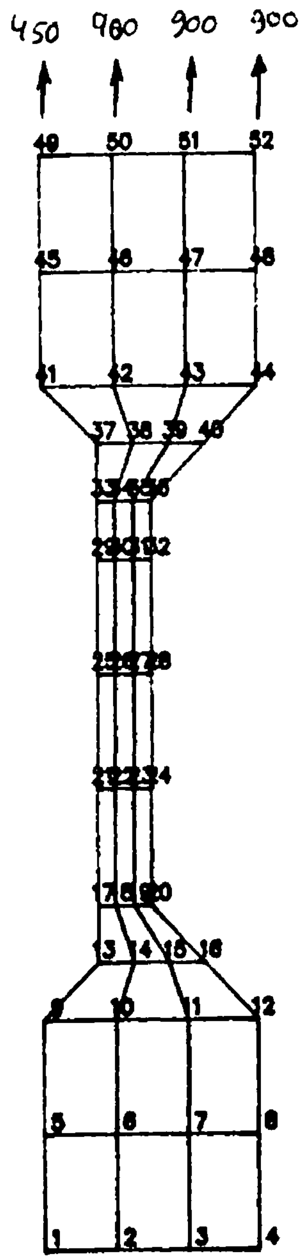


Fig (6)

The mesh of half of the component

52 nodes and 36 elements

The user does not have to choose a staring point for each line and needs only to respond by [RETURN] for any subsequent line of the text because each new line will be placed under the previous one. Some spaces should be placed between the node's numbers and the restrained specifications for example :

```
2
1        11
3        01
```

where 2 is the number of restrained nodes. 1 and 3 are the numbers of restrained nodes. 11 means that node number one is restrained in X and Y. 01 means that the node number three is restrained only in Y.

After inserting the boundary conditions the external loads have to be inserted. In the same manner just after the previous insertion following the same process. First of all the number of loaded nodes should be inserted in a line which equals to four in our example. After that in each line the node numbers and load components in X an Y should be placed. Some spaces have to be left between the text elements in each line. For example :

```
1
20   0.0   1000.0
```

where :

1	number of loads.
20	the node which is affected by the load.
0.0	the X component of the load.
1000.0	Y component of the load.

Finally, the thickness of the component should be inserted as a final line.

4- Type "DXFOUT" AutoCAD command, chose the entities option and select the text lines starting from the top to down.

Now, all the information about boundary conditions and external loads are saved in the (DXF) file which has been created. This file has to be sent to the mainframe by (TXT.DAT) name to be interpreted by a special interface program.

d) Pre-Processing Data for FE Program

At this stage (PROJECT2.COM) has to be executed. This command file contains mainly three programs in addition to some data which can be edited using the text editor :

```
RUN PREP
TEST     "The title of the problem."
1        "Plane stress NTYPE."
4        "The number of nodes  in each element"
1        "Number of materials"
2        "Gause point"
4        "Criteria's number"
1        "Number of increments"
3        "Number of stresses"
2        "Degree of freedom"
1        "The material's number"
RENAME FECOM.DAT;1 FE.COM;1
@FE
RUN INTER3
RUN AUX2
EXIT
```

The first program will be executed in this batch job is PREP.FOR program. This program reads its data from three data files after reading the data which existed in PROJECT2.DAT ·

1- MESH.DAT Geometric specification.
2- TXT.DAT Boundary conditions, external loads and thickness
3- PR1.DAT Material specifications.
4- PROJECT2.COM Control parameters

As output, a data file, which contains all the inputs necessary for finite element program, will be produced and changed to a command file (FE.COM). After that the finite element program will be executed by reading the inputs from FE.COM and saving the results in two files :

1- RESULT.DAT contains all numerical values such stresses and displacements
2- COORD4.DAT contains nodal displacements to be used later in Interface Program (3)

e) The Deformed Mesh :

The last program is the Interface Program (3). This program reads the nodal displacements from COORD4.DAT and the coordinates of the nodes from COORD.DAT in order to produce the coordinates of the nodes after deformation. These coordinates are saved in a data file in (DXF) format considering the name of the layer in which these entities are going to be saved.

The name of this data file is (DXF1.DAT). The extension of this name has to be changed to (filename.DXF) in order to be usable in AutoCAD .

This DXF file has to be sent back to AutoCAD and converted to drawing to be saved in the main drawing file. This DXF file has the facility to save itself in a special layer called "mesh1". For our example the mesh after deformation will be as shown in Fig (7).

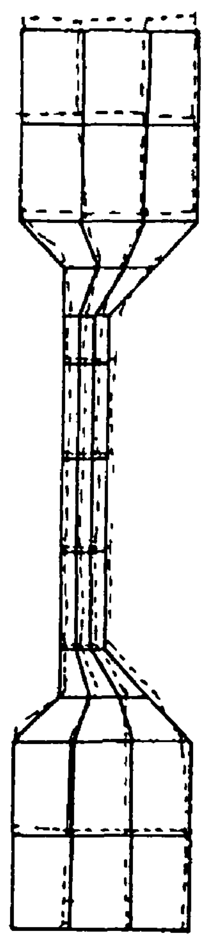


Fig (7)

The mesh after deformation.

f) Analyzing The Results :

The last step in the draughting and analysis part is the analysis of the results by the user to determine whether the component is suitable for a particular function or not. The user has already got all the results saved in the PC, namely, the drawing of the component which include the mesh before and after deformation in addition to the numeric results such as stresses and displacements.

All these results have to be compared and the necessary modifications have to be made such as changing the material or dimensions. Finally and after deciding the last dimensions for the component the drawing should be prepared for manufacturing process.

In our example in the first execution of the system, it is found that the design of the component is unsatisfactory and it deformed plastically. In this case a modification had to be made considering the function of the component. As an example the thickness of the component was changed from 10 mm to 15 mm. After the second successful execution the maximum equivalent stress was at element number (21) and the maximum displacements at nodes (25) and (52) were as shown below :

ELEMENT NO. 21

```
XX-STRESS = 0.180116E+00
YY-STRESS = 0.228893E+02
XY-STRESS =-0.103071E+01
ZZ-STRESS = 0.000000E+00
MAX.P.C.  = 0.229360E+02
MIN.P.C.  = 0.133431E+00
ANGLE     = 2.593
E.P.S.    = 0.000000E+00
STREQ     = 0.228695E+02
```

DISPLACEMENT ·

NODE	X-DISP	Y-DISP
25	0.238773E-01	0.650227E-01
52	-0.848014E-02	0.127815E+00

The factor of safety =1.399

Because this example is not real the value of factor of safety has been chosen purely arbitrarily which could be more or less than this value depending on the function of the component.

3-2- MANUFACTURING

Computer Aided Manufacturing refers to using a computer to assist in creating the part program that is used to drive a machine tool. The NC programmer is the tooling module or CAM part of the system. Its main function is to provide the means to isolate part data (the actual geometry to be machined) from a CAD drawing and then to insert tooling commands to machine the part geometry properly. It provides all the necessary tools and procedures to create a graphic description of what geometry is to be processed using the graphics of the CAD module.

Once the part geometry has been isolated from a CAD drawing, the power of NC Programmer goes to work. Since CAD data is random in its description of a part, the NC Programmer converts the random data into an ordered sequence of motions such that contiguous shapes are developed. Offsetting then can be applied to the part data, developing the centre-line tool path for cutting, if desired.

NC machine tool systems are all different and the many varieties of machine tools possess a wide range of features and capabilities. Most of them use different NC format. Nearly all of the part programming languages, including APT, are designed to be general purpose languages, not limited to one or two machine tool types. Therefore, the final task of the computer in computer-assisted part programming is to take the general instructions and make them specific to a particular machine tool system. The unit that performs this task is called a postprocessor.

The postprocessor is a separate program that has been written to prepare the NC program for a specific machine tool. The input to the postprocessor is the out put from the other two components - a series of cutter locations and other instructions. The output of the post processor is the NC program in the correct format for the machine it is to be used.

In order to prepare our example for machining, first of all, we had to decide the machinability factors as follow:

- The material of the cutter has been chosen as high speed steel because the material of the workpiece happened to be mild steel.

- The cutter diameter has been selected as D=5 mm.

From the Machinability tables [5] it is found that the suitable cutting speed Vc=25 m/min and the feed f=0.63 mm/tooth. Using the machinability formulae the spindle speed and feed rate has been calculated considering the number of teeth n=2.

S=1600 (r.p.m)
F=2000 mm/min

Then the workpiece was decided to be supported by two fixing points as shown in Fig (8). It was decided to support the work piece from outside instead of drilling holes in the body of the component itself which may change the design specifications of the component later. These two extra piece of material have to be removed from the component after machining.

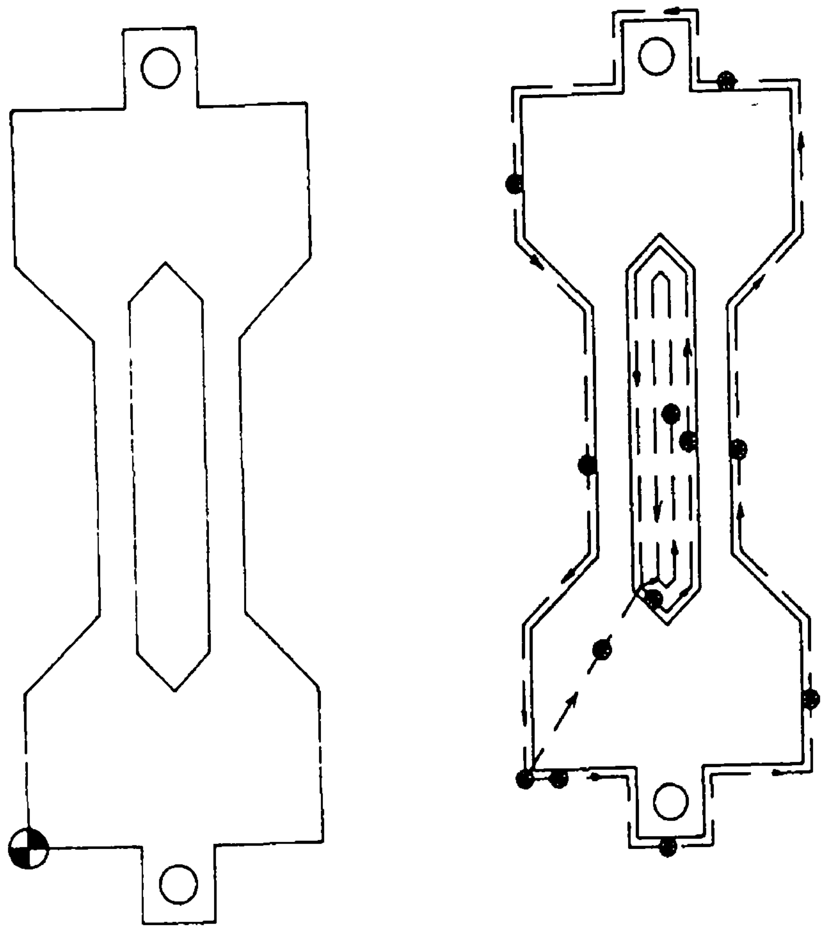


Fig (8)

TOOL PATH AND FIXING POINTS

The last stage is to develop the tool path necessary for machining this component and prepare suitable information blocks to be inserted in the tool path.

Because the NC programmer package is still raw, some cycles have to be developed such as the cycle for approaching from the work piece, retracting and calling subroutines.

This cycles have been executed in the Mill Productivity Package and all cutting data have been inserted and saved as blocks.

Then the tool path has been developed using pocketing facilities and the blocks inserted in proper locations.

Finally, the drawing has been cleaned from unnecessary entities and three DXF files have been created for the main program and two other subroutines. Using the post-processor these DXF files have been changed to (.NC) files in general G-code [4].

Going back to MS-DOS and using the EDLIN these three files have been merged in a unique file to be sent to the machine APPENDIX [1].

CONCLUSION

On conclusion an integrated CADCAM system has been developed incorporating some commercial and other in-house developed packages. In this study both plane stress and plane strain cases in two dimension have been involved.

For future work it should be possible to extend this part which is concerned about stress analysing by slightly modifying the communication programs. Also, it has been found during this study that there are some inadequacies in the AutoCAD facilities, such as the inability to display the mesh of the component before and after deformation simultaneously on the screen in different viewports.

The postprocessor which has been used for generating the preceding part program, is for general G-Code. The work is being currently extended to develop a post processor for a particular machine-controller combination.

APPENDIX

```
%
:1
N1G90G00X-2.5Y-2.5Z10.S1600M08M04
N2G91Z-9.
N3M98P0010
N4Z16.
N5M98P0020
N6G90Z10.
N7M05M09
N8M30
%
:10
N1G91G01Z-2.F2000.
N2X30.
N3Y-20.
N4X25.
N5Y20.
N6X30.
N7Y43.536
N8X-20.Y20.
N9Y67.929
N10X20.Y20.
N13Y43.536
N12X-30.
N13Y20.
N14X-25.
N15Y-20.
N16X-30.
N17Y-43.536
N18X20.Y-20.
N19Y-67.929
N20X-20.Y-20.
```

```
N21Y-43.536
N22M99L8
%
%
:20
N1G00X32.5Y51.036
N2G91G01Z-2.F2000.
N3X7.5Y-7.5
N4X7.5Y7.5
N5Y87.929
N6X-7.5Y7.5
N7X-7.5Y-7.5
N8Y-87.929
N9X5.Y2.071
N10X2.5Y-2.5
N11X2.5Y2.5
N12Y83.787
N13X-2.5Y2.5
N14X-2.5Y-2.5
N15Y-83.787
N16M99L8
%
```

REFERENCES :

1. Ferguson, N.C. `A History of Numerically Controlled Machine Tools', Chartered Mechanical Engineer, Sept. 1978, pp89-92

2. Sutherland, I.E. `Sketchpad' - A Man-Machine Graphical Communication System'. Proc. Spring Joint Computer Conference 1963, pp 329-346

3. The NC Programmer Manual, The Complete Postprocessor Manual Auto Desk Ltd.,

4. AutoCAD Reference Manual, Auto-Desk Ltd.,

5. Machine Tools, Metal and Cutting Fluids. BP Trading Limited.