COMPUTER INTEGRATED SYSTEM
FOR FORM-ROLL MANUFACTURE

by

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to

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DECLARATION

The work carried out in this thesis 'Computer Integrated System for Form-Roll Manufacture' was my own work. No part of the work described in the thesis was done in collaboration, unless specifically so described. The work has not been submitted for any other academic award in any other institution.

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SUMMARY

Computer integrated manufacture has brought about great advances in manufacturing technology and its recognition is world wide. Cold roll forming of thin-walled sections, and in particular the design and manufacture of form-rolls, the special tooling used in the cold roll forming process, is but one such area where computer integrated manufacture can make a positive contribution. The work reported in this thesis, concerned with the development of an integrated manufacturing system for assisting the design and manufacture of form-rolls, was undertaken in collaboration with a leading manufacturer of thin-walled sections.

A suit of computer programs, written in FORTRAN 77, have been developed to provide computer aids for every aspect of work in form-roll design and manufacture including cost estimation and stock control aids. The first phase of the development programme dealt with the establishment of CAD facilities for form-roll design, comprising the design of the finished section, the flower pattern, the roll design and the interactive roll editor program. Concerning the CAM facilities, dealt with in the second phase, an expert system roll machining processor and a general post-processor have been developed for considering the roll geometry and automatically generating NC tape programs for any required CNC lathe system. These programs have been successfully implemented, as an integrated manufacturing software system, on the VAX 11/750 super-minicomputer with graphics facilities for displaying drawings interactively on the terminal screen.

The development of the integrated system has been found beneficial in all aspects of form-roll design and manufacture. Design and manufacturing lead times have been reduced by several weeks, quality has improved considerably and productivity has increased. The work has also demonstrated the promising nature of the expert systems approach to computer integrated manufacture.

Keywords: Computer Integrated Manufacture
Cold Roll Forming
Form-Rolls
Expert Systems
NC Part-Programming

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CHAPTER 1

CHAPTER 1

INTRODUCTION

1.1 COMPUTER AIDED MANUFACTURE - STATE OF THE ART

Manufacturing industry is entering a new era of advanced creativity and productivity made possible by computer aided manufacture. This augmentation of the human intellect is a product of man-computer synergism: a partnership between the man and the computer, combining the best qualities of each to form a capability of great power. The progress expected in this field during the next decade has been likened in magnitude to the progress already achieved by the use of the digital computer itself since its introduction.

During the last decade the application of computer technology in the manufacturing process has concentrated on plant control. Peripheral activities such as process planning and design were not greatly affected. The recognition of a need for improvements in these areas of CAD (Computer Aided Design) and CAM (Computer Aided Manufacture) has been a feature of the last few years (1). The advances now being introduced in CAM will redress the balance in technological level in different parts of the manufacturing process.

CAD/CAM systems available today provide either an aid to the engineer which enables him interactively to combine his skill with the speed, memory and computational ability of the computer, or a computerised and automated batch processing facility which from a relatively small amount of input data will complete a sequence of tasks previously undertaken by the engineer. In the case of the interactive approach the systems tend to be adaptable to a very wide range of tasks, on the basis that much of the critical decision is carried out by the operator. Whereas in the case of the data-input systems the very fact that the computer system has to make an often complex series of decisions tends to limit their application to specific types of activity [2].

The integration of CAD and CAM takes place through using the stored geometry of components and the CAD/CAM system at many other stages in the production cycle. While 'integration' sounds straightforward enough in theory, the practical realities for any particular company are not always so clear or easy [3]. Many companies see how to use CAD/CAM systems for carrying out design, for the automatic production of drawings, and for the preparation of NC tapes. Companies are not, however, so aware or able to appreciate how to exploit or develop the design-manufacturing link. For many, it is still a missing link.

The major rewards which can be reaped from computer aided manufacture come from integration [4]. It can shorten lead time in all activities dealing with design and manufacture, and small or medium size manufacturing companies can gain huge benefits from this technology by developing, according to their own specifications, a tailor-made computer aided software system on a low cost minicomputer.

1.2 INDUSTRIAL APPLICATION

Many unexplored areas of manufacturing engineering suitable for implementing computer integrated systems are swiftly being opened up to take advantage of this new technology. The design and manufacture of form-rolls, the special tooling used in cold roll forming of thin-walled sections, is but one such area where the integrated systems approach can make a positive contribution.

The cold roll forming of each shape presents individual problems in roll design and manufacture, and the success of the cold roll forming process is mainly dependent on the shape of the rolls used. However, there is a lack of scientific principles for roll designers to use. In fact, the roll design process requires experience, good judgement and a knowledge of the bending of metals [5]. Thus it is not surprising that people treat the designing of rolls as an art rather than exact science.

The slowness of the manual process, coupled with the inconsistency in design styles and human performance, are among the chief obstables to the process of form roll design and production. With this in mind and after investigating the traditional roll design and manufacturing activities of a leading West Midlands company in the sheet-metal manufacturing industry, it was decided to firstly improve the company's roll design software and secondly, to design and develop additional expert system software to form the complete integration between the design and manufacturing activities. The expert system concept was applied to all newly developed software, in an attempt to eliminate all the decision making process carried out by roll designers and NC part-programmers.

The complete system has been successfully implemented on a VAX 11/750 32-bit super-minicomputer at the University. All software programs were written in FORTRAN 77 and using GINO-F library for graphics.

1.3 RESEACH OBJECTIVES

This research is concerned with the development of an integrated manufacturing system. In essence, the following activities are considered:

1. A review of the science of cold roll forming, and a study on the design and manufacture of form-rolls.

2. Implementation of the computer aided design software on the computer workstation.

3. Design and development of a form-roll editor with interactive graphics program.

4. Design and development of a form-roll editor with interactive graphics facilities, capable of displaying all the edited form-rolls within a forming stage.

5. Design and development of an expert system roll machining processor, incorporating a knowledge base with decision rules, for automatic generation of the cutter location data information.

6. Design and development of a general post-processor for providing NC tape programs for form-roll manufacture, for any required CNC lathe.

7. Design and development of a general NC tape checking program.

8. Design and development of a roll machining cost estimation program for the production of form-rolls.

9. Design and development of a stock control program for capturing and processing form-roll manufacturing and costing information.

CHAPTER 2

CHAPTER 2

REVIEW OF THE COLD ROLL FORMING PROCESS

2.1 INTRODUCTION

Cold roll forming is a process of forming metal from sheet or coiled stock into shapes of uniform cross-section (6), generally feeding the stock through longitudinally successive pairs of rolls. It is a relatively new process when compared to other ancient metals 'arts' such as casting, forging, wire drawing and other processes.

The process of cold roll forming of thin sections can be applied to a wide variety of metals and shapes. Generally, all metals that can be formed by other common forming processes can be successfully cold roll formed (7). Carbon Steel, stainless steel, aluminium and its alloys, copper, brass, bronze and zinc are just some of the materials that can be cold roll formed. Stainless steel and aluminium are often roll formed for decorative and for architectural applications - often starting as pre-painted, plated anodised or polished stock. The main types of application include building components such as purlins, rails and channels, automobile components such as chasis and bumpers, frames for cargo containers, consumer goods like office equipment, furniture and domestic appliances, shop fittings, shelving and racking, and also aircraft and shipbuilding components.

A combination of metals and non-metals, or dissimilar strips of metals can be fed into a roll forming machine at the same time to produce composite sections with multiple properties, such as corrosion resistance or decorative finish with strength [8]. Normally metal as thin as 0.1mm (0.005 in) and up to 20mm (0.75 in) of thickness can be satisfactorily formed [9], and the raw materials used may come in the form of strips of sheet or coiled stock.

2.2 GROWTH OF THE COLD ROLL FORMING PROCESS

The history of cold roll forming can be divided into three phases:

1. The first half of the 20th Century was the age of development for roll forming. This period may be called the 'formative years'.

2. From the Second World War to the late 1960s and into the early 70s, roll forming technology spread widely - the number of lines in operation greatly increased and other operations such as piercing, curving and welding, were added to the lines. This interval may be called the period of 'quantitative change'.

3. In addition to further proliferation of roll forming, the last fifteen years can be considered a time of 'qualitative change' i.e. the introduction of refinements, improvements, additional processes and electronics into the roll forming process [10].

Considering that the average life of a good roll forming line is 20 to 25 years, it is not expected that sudden changes will upset the industry. However, by extrapolating the present trend, it is anticipated that the following principles will have wider acceptance in the future:

(a) More products will be specifically designed to suit roll forming operations.

(b) More secondary operations will be incorporated into the roll forming line.

(c) Computerised tool design will be widely used.

(d) High technology will be more frequently applied.

(e) More attention will be paid to material handling.

(f) The utilisation of roll forming lines will increase.

(g) Equipment manufacturing will aim for standardisation.

(h) New tool materials will be applied.

(i) Comfort of the operator will be given greater consideration at the design stage and organised operator training will commence.

(j) Education of engineers and technologists, hopefully, will improve.

(k) Roll forming research and development will increase.

2.3 ROLL FORMING MACHINES

A typical roll forming machine (Plate 2.1) generally consists of a horizontal steel table of a fixed width on which a number of roll forming stations are successively mounted. The capacity of a roll forming machine is usually limited by its table width, the maximum number of roll forming stations it carries and the size of the stations. The maximum number of stations carried by a standard machine may range from about ten to as many as twenty-five. Most cold rolled sections are manufactured from thin materials, hence standard machines which carry relatively small stations are more frequently used.

Each roll forming station contains two roll spindles for holding a pair of rolls horizontally. One or two vertical rolls may be included at the same station to perform part of the forming operation. They are usually referred to as side-rolls and are blended to the top and bottom rolls, either on one side or on both sides. Roll spindles are supported by housings either :-

(a) on one side, as in an outboard type roll forming machine (Fig. 2.1), or

(b) on both sides, as in an inboard type roll forming machine (Fig. 2.2).

The outboard type of machine is usually used in the forming of narrow sections, as the roll spindles are easily accessible and the form rolls can be set up more easily. The inboard type of machine, on the other hand, supporting the spindles at both ends, is capable of handling much thicker and wider strip and sheet materials in forming most structural shapes. The distance between the mounting of inboard type roll stations (Plate 2.2) and the height of top and bottom rolls can be adjusted, so as to cope with various stock widths and roll diameters.

The rolls of each station are usually power driven through a system of gears and have their peripheral speeds synchronised. The speed of forming or the speed of material travel may vary from station to station and usually that too requires synchronisation. Roll surfaces are usually lubricated to reduce friction between roll surface and material surface so as to maintain a good surface of the material. Also, to cool both the rolls and the material which may expand as a result of heat generated during forming.

2.4 TOOLINGS AND ACCESSORIES

Accessories are sometimes used in order to aid forming operations. Strip guides (Plate 2.3) are normally used before and in between the roll passes to keep the material in the right track. Inter-station idler-rolls (Fig. 2.3) may also be used for keeping the material in the right track, and in addition for doing partial forming on the material as well. A straightening-device (Fig. 2.4) may be placed immediately after the last roll forming station to straighten the section. If coiled stock is used for forming while products of fixed length are required, then an additional cutting-off operation with a special machine (Plate 2.4) will be included at the end of the entire forming process.

2.5 FORM-ROLL DESIGN

The production of each new section requires an entirely different set of rolls to be designed and manufactured. The reasons are that each set of rolls is only useful for producing the section shape it is intended and that in practice, except for a few standardised products, a section is rarely manufactured in repeated batches.

The cold roll forming of each shape presents individual problems in roll design, and the success of the cold roll forming process is mainly dependent on the shape of the rolls used. However, there is a lack of scientific principles for roll designers to use. In fact, the roll design process requires experience, good judgement and a knowledge of the bending of metals. Thus it is not surprising that people treat the designing of rolls as an art rather than an exact science.

2.5.1 Design of the Finished Section

The final cross-section of the metal strip after forming, which is the product of the whole roll forming process, is called the finished section (Fig. 2.5). Until a design of the finished section is available and accepted, it is normally impossible to initiate the roll design process. This is so because the entire roll design work has to be based upon the shape or geometry of the section. Section design criteria are basically application orientated and are based on product requirements. Details of usual practices employed in section design for various applications can be found in other more relevant literatures (11,12,13). As illustrated in

(Plate 2.5), the designed sections can often come in a great variety of shapes and sizes.

Given the finished section drawing of the desired cold roll formed product, it is necessary to calculate the strip size or width of the raw material required. The geometry of the section is made up of only two kinds of elements, namely, linear elements and circular elements. The meanlength of each individual element, either linear or circular, is firstly determined. This strip size S, for m linear elements and n circular elements, can then be calculated using the equation:-

$$S = \sum_{i=1} l_i + \sum_{j=1} r_j \theta_j \qquad (2.1)$$

where l_i is the meanlength of individual linear elements,

r_j is the mean radius of individual circular elements,

and θ_j is the final angle of bend of the individual circular elements

This meanlength refers to the length of that part of the element which remains constant throughout forming. Theoretically linear elements do not undergo deformation in any way during forming since bending does not occur in them. For most practical purposes, such assumption is valid even though it is not strictly true. It is possible for slight deformation to occur in linear elements situated adjacent to circular elements being bent as a result of the rolling action.

Precise calculation of the meanlength of circular elements is more difficult as both their dimensions and shape may change during forming. As shown in equation 2.1, the meanlength of a circular is based on its mean radius, the radius of the element measured from its centre point to the neutral-axis. Different methods and different empirical formulae have been recommended by different experts in calculating the mean radius (or bend allowance):

1. The American Society for Metals [7] recommends the following:-

For $r = 0$

$$r_m = r + t/3 \quad \text{(normal metal)} \tag{2.2}$$

$$r_m = r + t/2 \quad \text{(less formable metal)} \tag{2.3}$$

For $0 < r < t$

$$r_m = r + t/3 \tag{2.4}$$

For $r < 2t$

$$r_m = r + t/2 \tag{2.5}$$

where r_m is the mean radius

t is the material thickness

r is the inside radius of bend

2. Angel [14] recommends the following formula:-

$$BA = (0.01743R + 0.0078T)A \tag{2.6}$$

where BA is the bend allowance

R is the inside radius of bend

A is the angle of bend in degrees

T is the material thickness

3. The method of calculation used by the company is similar, but is based on different criteria:-

$$r_m = r + kt \qquad (2.7)$$

where r_m is the mean radius

r is the inside radius of bend

k is a factor based on the magnitude of the angle of bend (Table 2.1)

ANGLE OF BEND	0° TO 80°	ABOVE 80° TO 100°	ABOVE 100°
K	0.3	0.4	0.5

Table 2.1 Mean Radius Factor based on Angle of Bend

2.5.2 Design of the Forming Sequence

The first consideration for the roll designer is to determine the number roll stations required to produce the desired shape. A 'Forming

Angel Method', suggested by Angle [14], has been found to be a dependable guide for the determination of the number of roll stations required for a particular bend (Fig. 2.6). The strip length over which the bend is to be completed is determined from the following equation:

$$F = H\ (\text{Cot}\ \phi) \qquad (2.8)$$

where F is the forming length

H is the height of the leg to be bent up

$\phi = 1^{\circ}25'$ for carbon steel

The number of roll stations required is determined by dividing the forming length (F) by the horizontal centre distance of the roll forming machine, rounding up if necessary. For multiple bends on complicated shapes, the section must be broken down and each bend or pair of bends calculated to perform that bend. Then, after combining stations (or roll passes) wherever possible, the total number of roll stations can be determined.

This technique does not always give optimum results, and generally roll designers use their experience and material behaviour considerations such as springback, thinning, stretching and persistence of flow, to determine the number of roll stations required. To keep down the cost of roll design and manufacture, normally only the minimum number of roll stations required are used, unless the production quantity is large enough to justify the use of more stations for prolonged roll life with less severe bending at each station.

The next consideration for the roll designer is to determine the sequence and degree of bending at each roll station for the circular elements. The forming sequence is essentially a series of transitional shapes of the section to be formed station by station. Basically, roll designers have to determine the angles and radii for successive bending of each non-linear part in a proper manner so as to ensure satisfactory forming performance during production. The usual tool used by roll designers to represent the forming sequence is the drawing of flower pattern or flower plan (Fig. 2.7), which shows the progressive development of the section shapes in successive stages of forming, form start to finish.

2.5.3 Wire Templates

With the required forming sequence, which is in the form of flower pattern, a set of wire templaters can then be designed and manufactured accordingly. The wire templates are created as intermediate simulated sections of the strip at each successive forming stage and are used subsequently as the master contours or shapes in roll machining. Hence they in fact form an integral part of roll design and manufacture.

The technique used to design and produce the wire templates is simple, but practical. Based on the flower pattern, the shape of each element bent to the required angle at a particular forming stage is worked out and all of the element shapes are then grouped together to form the required section shape at that stage. The simulated section shapes are usually drawn ten times as large as the actual size. With the help of a shadowgraph projector, or perhaps some other similar equipment, straight wires are bent to the exact simulated shapes according to the 10-1 template drawings. The entire process is manually operated and some consider skill in wire bending is necessary.

2.5.4 Design of Rolls

It is common practice to produce only simplified roll drawings, which carry information regarding roll dimensions, roll material, general tolerances for machining, pinch-difference surface allowances, the use of side-rolls or spigots, and approximate shape of the rolls. Each roll drawing corresponds to each forming stage and is used to complement the wire template during machining of the rolls. Roll diameters are adjusted at the time of drawing to give a smooth variation of strip pass heights from station to station for better forming.

Decisions have to be taken about things like whether to use whole rolls or split rolls, whether to use side-rolls, idler-rolls or just guides, the number of ironing stations and so on. Suitable allowance and adjustments to the roll contours must also be incorporated for smooth forming. Having finalised the roll design, a set of drawings is then produced for roll manufacturing purposes.

2.6 FORM-ROLL MANUFACTURE

There are different but equally valid approaches regarding how the rolls should be manufactured. Despite the differences, rolls are normally machined on lathes of some kind. After machining, a test run is usually grinding. Once set up for production, the rolls are seldom replaced unless some unusual faults develop.

The accuracy of the roll contours so produced relies heavily upon the skill of the machinist whose only guides are the wire templates and the simplified roll drawings. Much discretion has to be exercised by the machinist during machining and mistakes are normally irrecoverable. The success of existing practice therefore depends upon consistent performance from machinists with the right skill. With some firms, the more elaborate approach of using detailed drawings for roll design without the use of wire templates is preferred for manufacturing purposes.

2.7 ADVANTAGES OF COLD ROLL FORMING

The following are some of the main advantages of cold roll forming and its products:

(a) The process has a very high production capacity. For Simple shapes, a production rate of 900 to 1500m (3000 to 5000ft) per working hour can be achieved.

(b) Roll forming will allow other functions to be added into the process allowing the product to be more complete as it leaves the machine [15].

(c) The material can be pre-cut to length or run directly from a coil and pre-cut or post-cut to length as the forming cycle is complete.

(d) Roll forming combines in its function many operations and handlings that would be required by any other process.

(e) Virtually any profile can be produced by the process.

(f) High strength to weight ratio of the sections, especially thin-walled sections, means greater value and less expenses.

(g) A wide range of ferrous and non-ferrous metals can be readily formed by the process.

(h) The sections can be produced to exact lengths thus reducing waste.

(i) Pre-coated materials can be roll-formed without damaging the surface finish.

2.8 ALTERNATIVE PROCESSES

The press-brake and extrusion processes are the two main alternatives to cold roll forming. The press-brake process is not as versatile in terms of the section shapes it can cope with. It requires very bulky machinery and is usually suited for low quantity production. Extrusion, however, involves high tonnage presses, introduces lubrication problems and is usually carried out with material in a hot or warm state. This process is fundamentally different to cold roll forming in that it transforms solid rather than sheet stocks. Extrusion is, in fact, becoming less popular than cold roll forming due to the less appealing properties of its products.

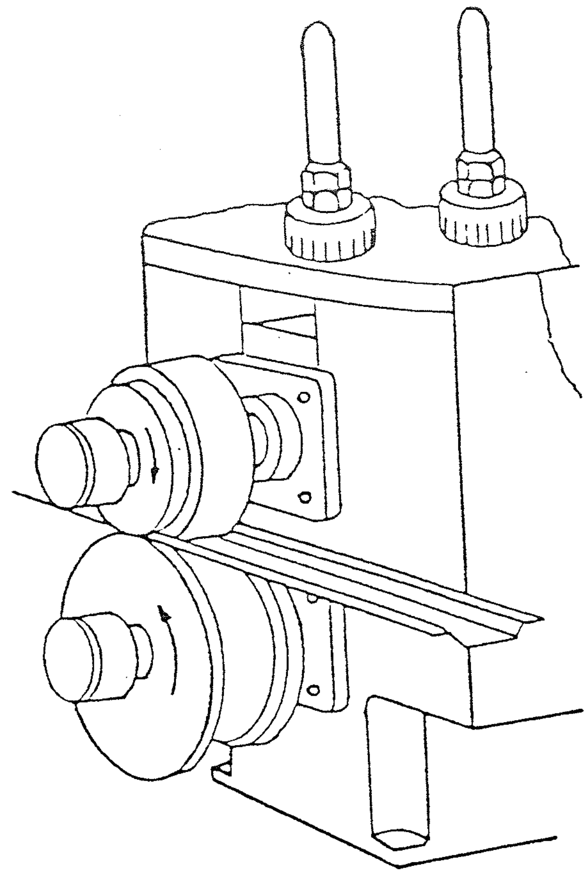


Fig. 2.1 ROLL STATION IN AN OUTBOARD TYPE ROLL FORMING MACHINE

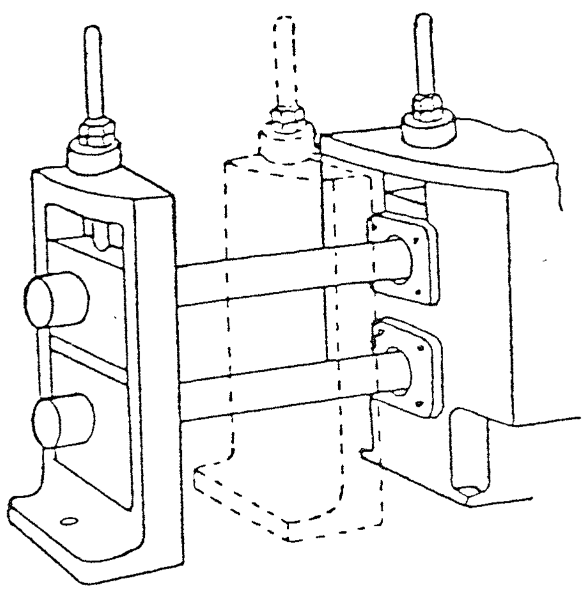


Fig. 2.2 ROLL STATION IN AN INBOARD TYPE ROLL FORMING MACHINE

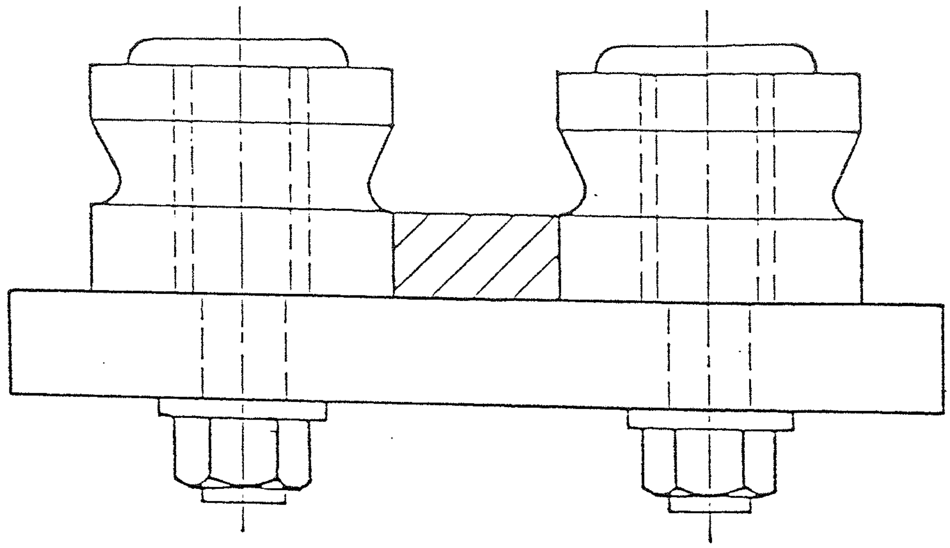


Fig. 2.3 AN EXAMPLE OF THE IDLER-ROLLS

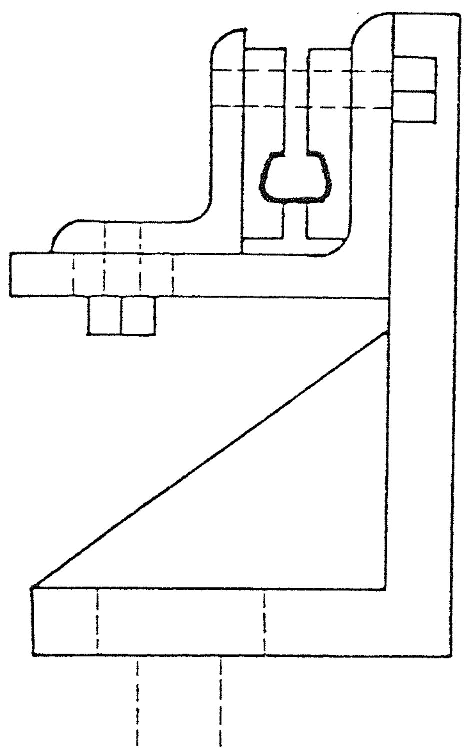


Fig. 2.4 AN EXAMPLE OF THE STRAIGHTENING-DEVICE

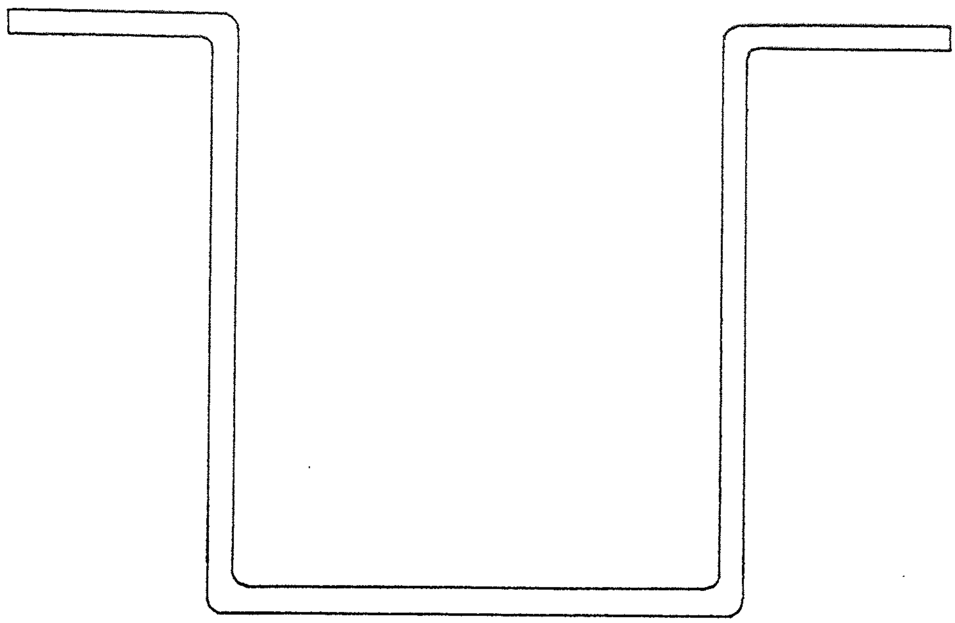


Fig. 2.5 A TYPICAL FINISHED SECTION

$$F = H \cot(\phi)$$

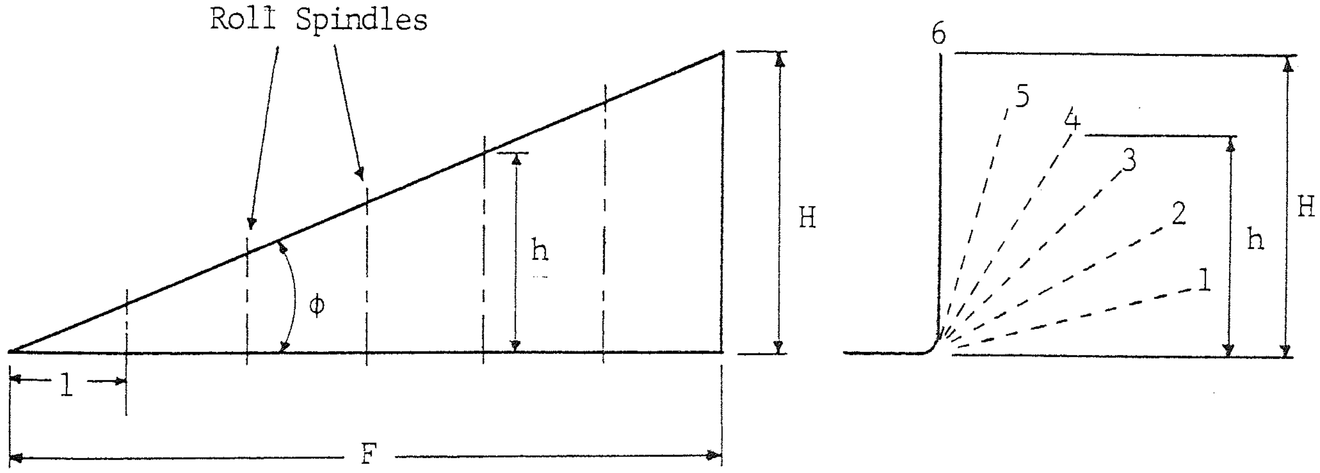


Fig. 2.6 THE FORMING ANGLE METHOD

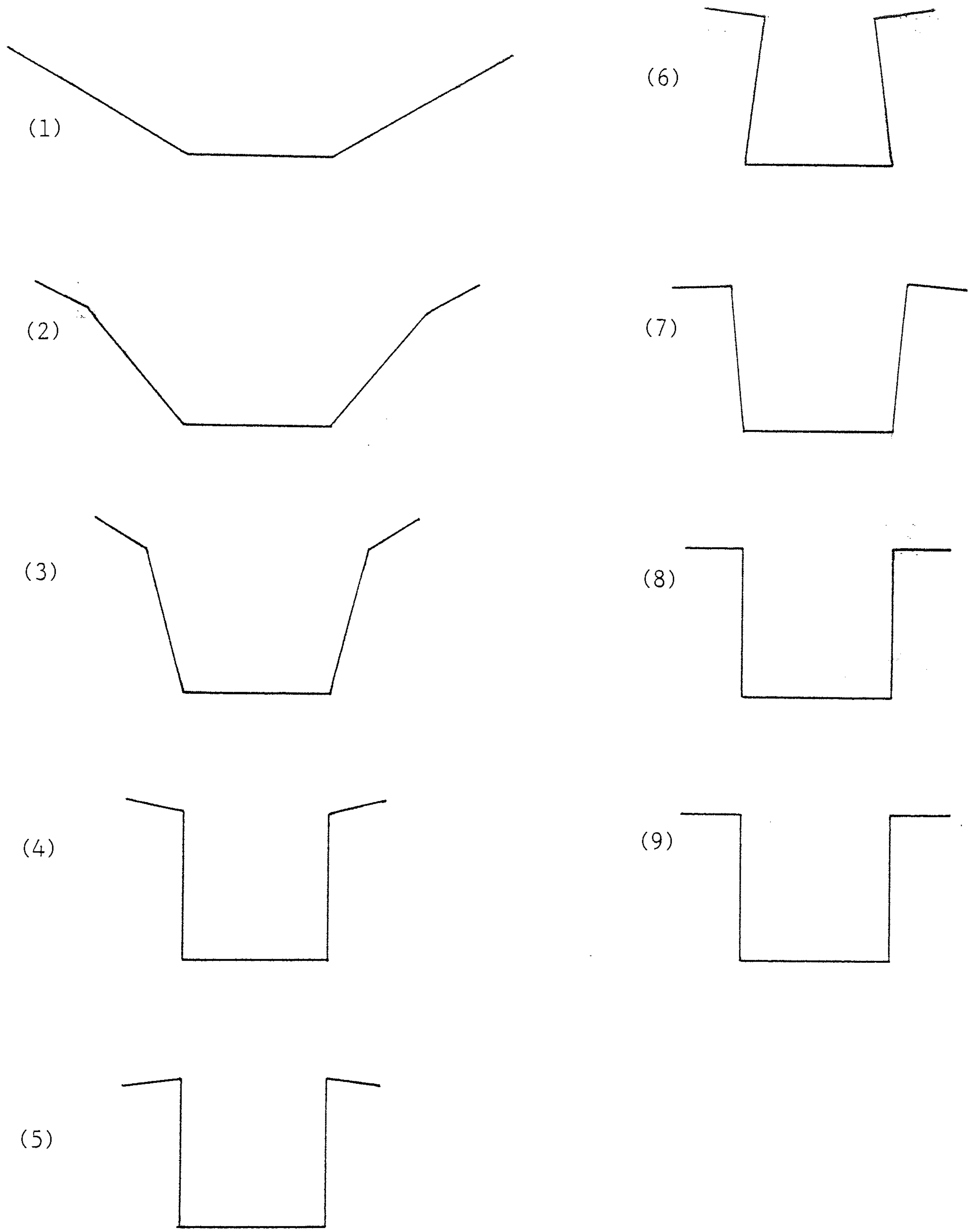


Fig. 2.7 A TYPICAL FLOWER PATTERN

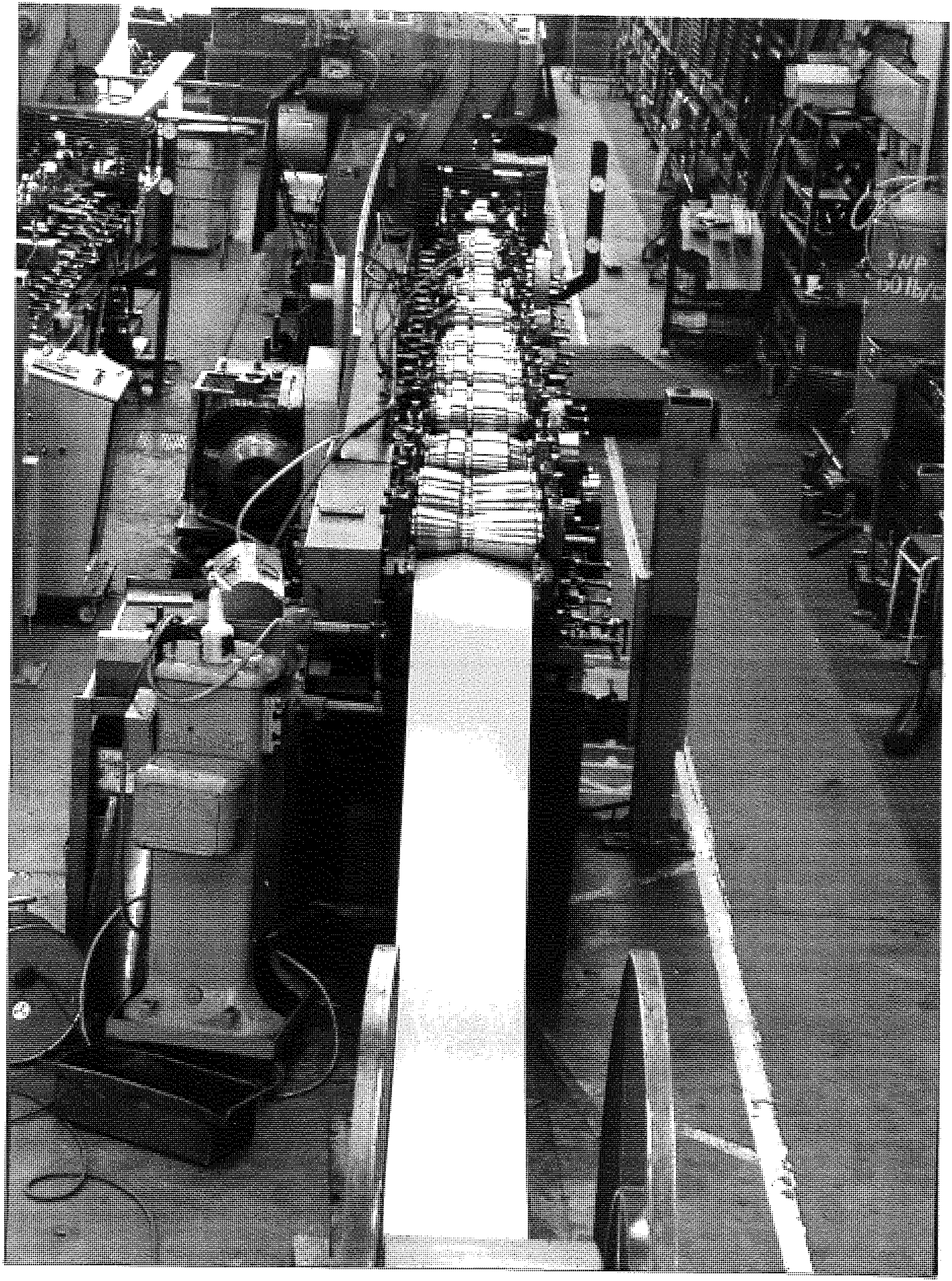


Plate 2.1 A TYPICAL ROLL FORMING MACHINE

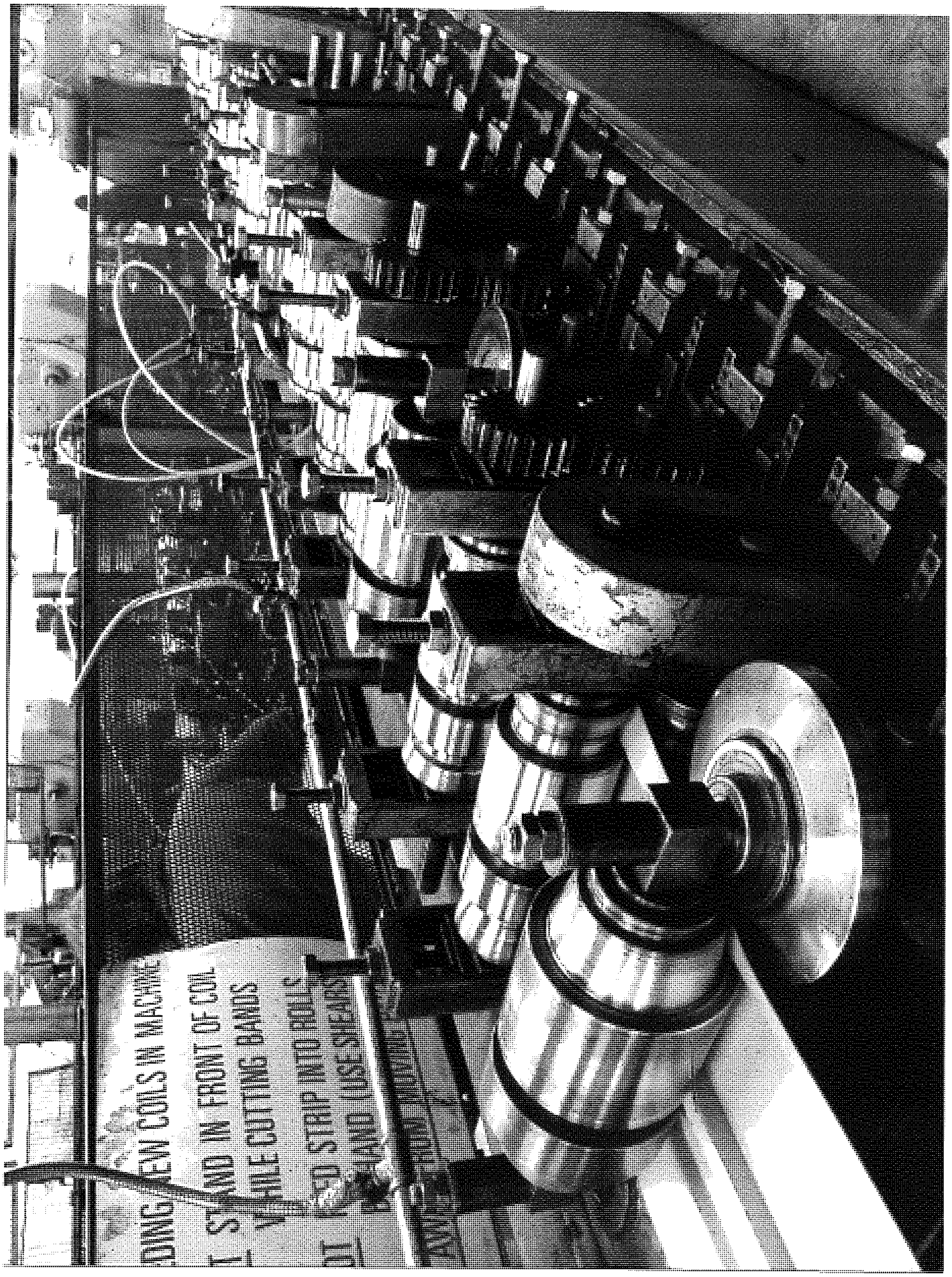


Plate 2.2 INBOARD TYPE ROLL STATIONS

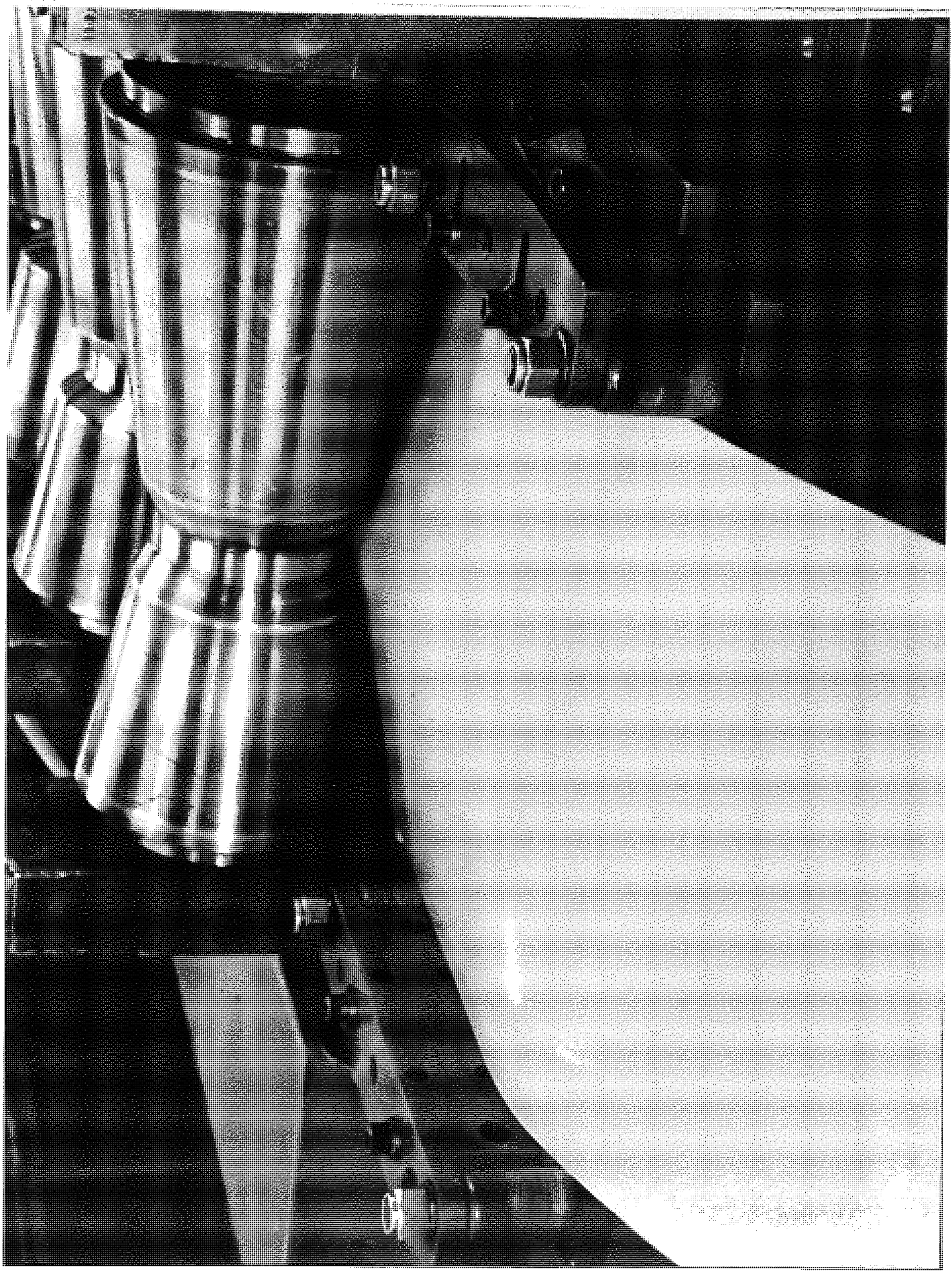


Plate 2.3 A STRIP GUIDE

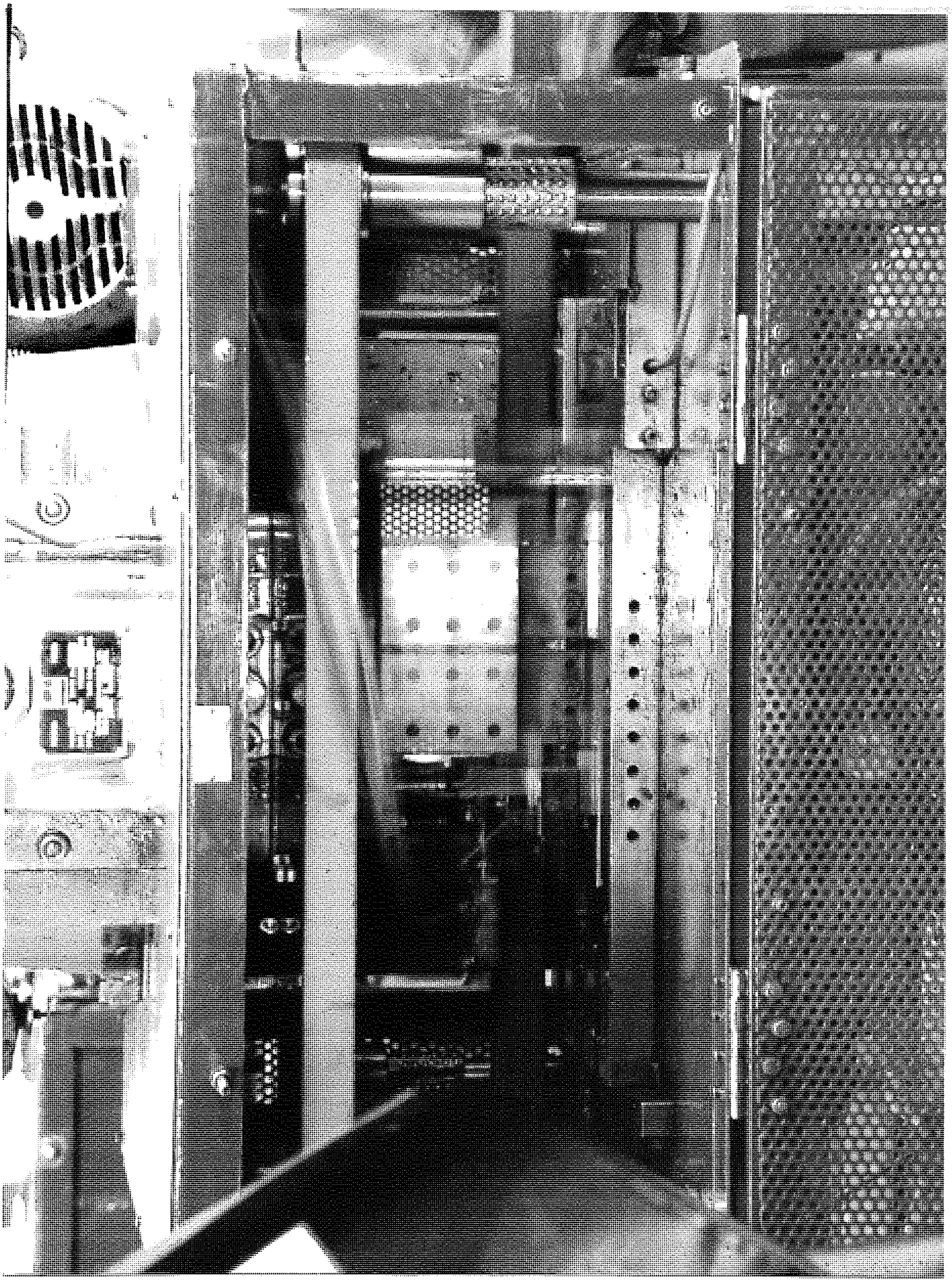


Plate 2.4 THE CUTTING-OFF OPERATION

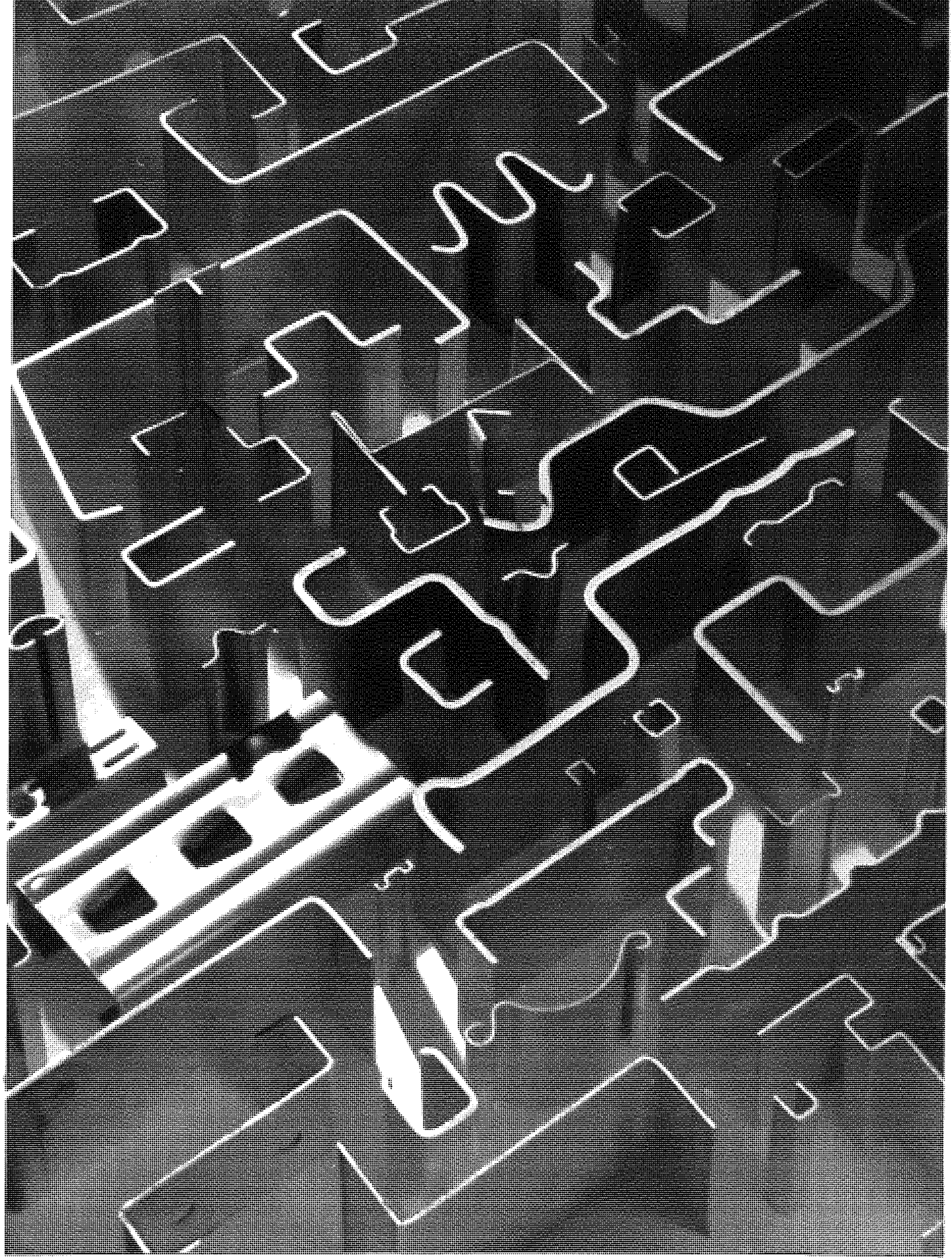


Plate 2.5 A VARIETY OF FINISHED SECTIONS

CHAPTER 3

CHAPTER 3

COMPUTER INTEGRATED MANUFACTURING SYSTEMS

3.1 INTRODUCTION

The main objective of this research is to design and develop an integrated manufacturing system for cold roll forming. System development, like any other development work, requires systematic planning, especially when the software involved is of some appreciable scale and complexity. It is therefore important at the initial stage of the research programme, to study the concept of integration and review the technology of CIMS (Computer Integrated Manufacturing Systems).

In most manufacturing organisations design and manufacture are separate areas, and information has to be passed across the boundaries. Traditional methods of data exchange via paper often result in duplication of data, the occurence of errors, time delays and more generally lack of organisational and occupational flexibility [16]. The emerging integrated systems are potentially a means of integrating design and manufacture, and other functions within the organisation, via software in real time.

The purpose of a computer integrated manufacturing system or CIMS, is to transform product designs and materials into saleable goods at a minimum cost in the shortest possible period of time [17]. Unlike traditional manufacturing approaches, the process in a CIMS begins with the design of a product and ends with the production of that product. The customary split between the design and manufacturing functions disappears. CIMS builds on the premise that management should work to optimise the whole business process rather than individual functions [18].

3.2 THE CONCEPT OF INTEGRATION

Integration, in the context of CIMS, is defined by Buchanan and Boddy [19] as 'the automatic linking of previously discrete stages of production and administrative processes. A fully integrated manufacturing system, shown in Fig. 3.1, includes CAD and CAM, plus linkages to business management functions such as cash flow, projections, sales forecasting and so on. There are basically three key features to the concept of integration:

1. Data can be transferred automatically between different modules and user groups within the system.

2. There is a standard entry to any part of the system [20]. The system is controlled by an overall 'Executive' so that it provides all the facilities of user security checking and control of data flow between modules.

3. The modules are designed with a common user interface. The command structure is identical; the same word means the same thing; menus are driven in a compatible way; prompts are consistent in their meaning and style; error messages and help systems are compatible.

These features are the visible ones but there are also a whole set of hidden factors to do with software engineering and the use of common software tools across an integrated system which make it inherently more flexible for expansion and upgradeability in the future.

3.3 FUNDAMENTALS OF CAD

Computer aided design involves any type of design activity which makes use of the computer to develop, analyse, or modify an engineering design. Modern CAD systems are based on interative computer graphics [21]. This denotes a user-oriented system in which the computer is employed to create, transform, and display data in the form of pictures or symbols. The user in the computer graphics design system is the designer, who communicates data and commands to the computer through any of several input devices. The computer communicates with the user via a cathode ray tube (CRT). The designer creates an image on the CRT screen by entering commands to call the desired software subroutines stored in the computer.

A CAD system consists mainly of an interactive graphics CRT, a minicomputer, an alphanumeric CRT, a plotter and a digitiser [22,23]. The interactive graphics CRT is an electronics drawing board on which the designer may 'sketch' his design ideas. An intelligent terminal in a CAD workstation provides for both graphics and text manipulation. When a designer completes a design, he stores the design and all accompanying data in the database, which can then be accessed by everyone who needs the information. The design data makes it possible to produce instructions necessary to create the part, order raw materials, sequence the operations, or predict manufacturing costs [24].

3.3.1 The Design Process

According to Shigley (25), the design process consists of six identifiable steps or phases:

1. Recognition of need
2. Definition of problem
3. Synthesis
4. Analysis and Optimisation
5. Evaluation
6. Presentation

Recognition of need involves the realisation by someone that a problem exists for which some corrective action should be taken. Definition of the problem involves a thorough specification of the item to be designed. Synthesis and analysis are closely related and involve redesigning the item, subject to analysis, until the design has been optimised within the constraints imposed on the designer. Evaluation is concerned with measuring the design against the specifications established in the problem definition phase. The final phase in the design process is the presentation of the design, which includes documentation of the design by means of drawings, material specifications, assembly lists, and so on.

3.3.2 Applications of CAD

Briefly, CAD applications can be grouped into four functional areas:

1. Geometric modelling

2. Engineering analysis

3. Design review and evaluation

4. Automated drafting

Fig. 3.2 illustrates the relationship between the design process and the CAD applications. Geometric modelling is concerned with the computer-compatible mathematical description of the geometry of an object. This is the most critical feature of the CAD system, and ever since the emergence of the CAD concept a lot of work has been done in developing the geometric model of a part [26]. Most modelling today is done with wire frame models with 2D, 2 1/2D or 3D capability.

The engineering analysis may involve stress-strain calculations, heat-transfer computations, or the use of differential equations to describe the dynamic behaviour of the system being designed. The finite-element method is probably the most powerful analysis feature of a CAD system. In some cases, by specifying material properties and the loading and boundary conditions, the CAD system can then generate the finite element model from a geometric model [27].

Design review and evaluation involve checking the accuracy of the design. Semi-automatic dimensioning and tolerancing routines which assign size specifications to surfaces indicated by the user help to reduce the possibility of dimensioning errors. The designer can zoom in on part design details and magnify the image on the graphics screen for close scrutiny.

Automated drafting involves the creation of hard-copy engineering drawings directly from the CAD database. CAD systems can increase productivity in the drafting function by roughly five times over manual drafting.

3.4 ASPECTS OF CAM

In the broader sense, computer aided manufacturing (CAM) can be defined as the use of computer systems to plan, manage, and control the operations of a manufacturing plant through either direct or indirect computer interface with the plant's production resources. The applications of CAM fall into two broad categories.

1. 'Computer monitoring and control'. These are the direct applications in which the computer is connected directly to the manufacturing process for the purpose of monitoring or controlling the process.

2. 'Manufacturing support applications'. These are the indirect applications in which the computer is used in support of the production operations in the plant but there is no direct interface between the computer and the manufacturing process.

In the indirect applications, the computer is not linked directly to the manufacturing process, but instead, it is used 'off-line' to provide plans, schedules, forecasts, instructions and information by which the firm's production resources can be managed more effectively. Some examples of CAM for manufacturing support include:

1. Numerical control part programming by computers.
2. Computer-automated process planning.
3. Production scheduling.
4. Computer-generated work standards.
5. Material requirements planning.
6. Shop floor control.

3.4.1 Numerical Control by Computers

NC Technology has been applied to a wide variety of operations, including drafting, assembly, inspection, sheet metal pressworking, and spot welding. However, numerical control finds its principal applications in metal machinery processes. Indeed, the early CAD systems were originally developed to incorporate and exploit the NC technology for manufacturing complex shapes [28].

The computer's tasks in computer-assisted part programming include input translation, arithmetic calculations, cutter offset computation and post-processor. The part programmer enters the program written in APT (Automatically Programmed Tools) or other language, and the input translation component converts the coded instructions contained in the program into computer-usable form, preparatory for further processing. The arithmetic calculations unit of the system solves the mathematics required to generate the part surface, and then the part programmer constructs the tool path. The post-processor is a separate computer program that has been written to prepare the punched tape for a specific machine tool.

Use of the digital computer has permitted substantial improvements to be made in the controls for NC. Computer numerical control (CNC) involves the replacements of the conventional hard-wired NC controller unit by a small computer (minicomputer or microcomputer). One of the distinguishing features of CNC is that one computer is used to control one machine tool [29]. This contrasts with direct numerical control (DNC), in which a larger computer is used to control a number of separate NC machine tools [30].

3.4.2 Computer-Aided Process Planning

Process planning is concerned with determining the sequence of individual manufacturing operations needed to produce a given part or product. Due to the many problems encountered with manual process planning, attempts have been made in recent years to capture the logic, judgement and experience required for this important function and incorporate them into computer programs [31]. Based on the characteristics of a given part, the program automatically generates the manufacturing operation sequence.

Because modern manufacturing plants offer thousands of alternative process plans, computer aided process planning (CAPP) depends heavily on the idea of group technology [32]. The two basic approaches to CAPP are the 'variant type', based on standard process plans developed for families, and the 'generative type', which generates a process plan from information provided about the product. Overall, CAPP systems offer the potential for reducing the routine clerical work of manufacturing engineers. At the same time, it provides the opportunity to generate production routings which are rational, consistent, and perhaps even optimal (33).

3.4.3 Inventory Management

In the manufacturing environment, inventory management is clearly tied to material requirements planning. The main objective is to keep the investment in inventory low while maintaining good customer service. The use of computer systems has provided opportunities to accomplish this objective more effectively. There are four types of inventory with which a manufacturing firm must concern itself.

1. Raw materials and purchased components
2. In-process inventory
3. Finished Products
4. Maintenance, repair and tooling inventories

Material requirements planning (MRP) is an inventory control procedure applied to each of the four types of inventory. MRP has been adopted on a large scale by the motor industry, particularly in the USA. It is a very powerful technique which is made possible only by the use of computer, as in most companies there is too much data involved to do the work manually (34). The three inputs to MRP are the master production schedule, the bill-of-materials file and the inventory record file. When properly applied, MRP can provide massive savings in inventory costs and can also reduce obsolescent stock and improve material flow within stores areas.

3.4.4 Cost Planning and Control

Cost planning is concerned with expected or estimated costs to manufacture and sell each of the company's products. It attempts to determine the standard cost for the product, which is the aggregate cost of labour, materials, and allocated overhead costs. To accomplish this task effectively and determine a meaningful cost value, use of a common database for engineering, manufacturing and accounting, is involved. Development of standard costs for all of the company's products provides a yardstick against which the actual production cost performance can be measured.

Cost control is concerned with the actual costs to manufacture and sell each of the company's products, and the variances between standard and actual costing [35]. It involves the collection of data on materials, labour costs and direct overhead costs, with which the actual cost of the product can be calculated.

3.5 FACTORY AUTOMATION

The introduction of highly automated computer-controlled machinery into industry has been a significant recent development for industry. These advanced manufacturing systems are designed to fill the gap between high-production transfer lines and low-production NC machines. This gap includes parts produced in mid-range volumes which are of fairly commplex geometry, and the production equipment must be flexible enough to handle a variety of part designs. Transfer lines are not suited because they are inflexible and NC machines have low-production rates [36].

Flexible factory automation is superior to 'hard' automation, because the automation is in the software and not in the hardware of the machine [37]. To change machine functions or their sequence, 'hard' automation must be replaced or physically rebuilt; soft automation, on the other hand, simply requires new instructions or programs to be put into the machine. This greatly reduces the time and cost of altering product lines and permits the extension of automation beyond mass production to small batch production.

Flexible manufacturing systems (FMS) represent this level of advanced flexible automation. In general terms, FMS combines Direct Numerical Control (DNC) capabilities with automated material handling [38,39]. Palletised workpieces of different kinds are randomly and simultaneously transported between machine tools and other workstations for processing according to individual requirements under automatic computer control [40]. Industrial robots are applied in some FMS's to do tool and workpiece handling, automatic palletising of parts and even limited transport [41,42,43].

It is estimated by the year 2000, the totally automated factory will come into widespread existence. Robots and computer-controlled machines working together with CAD/CAM systems and other business systems, will be able to perform most of the manufacturing operations that now require human skills. This will have an enormous impact on productivity.

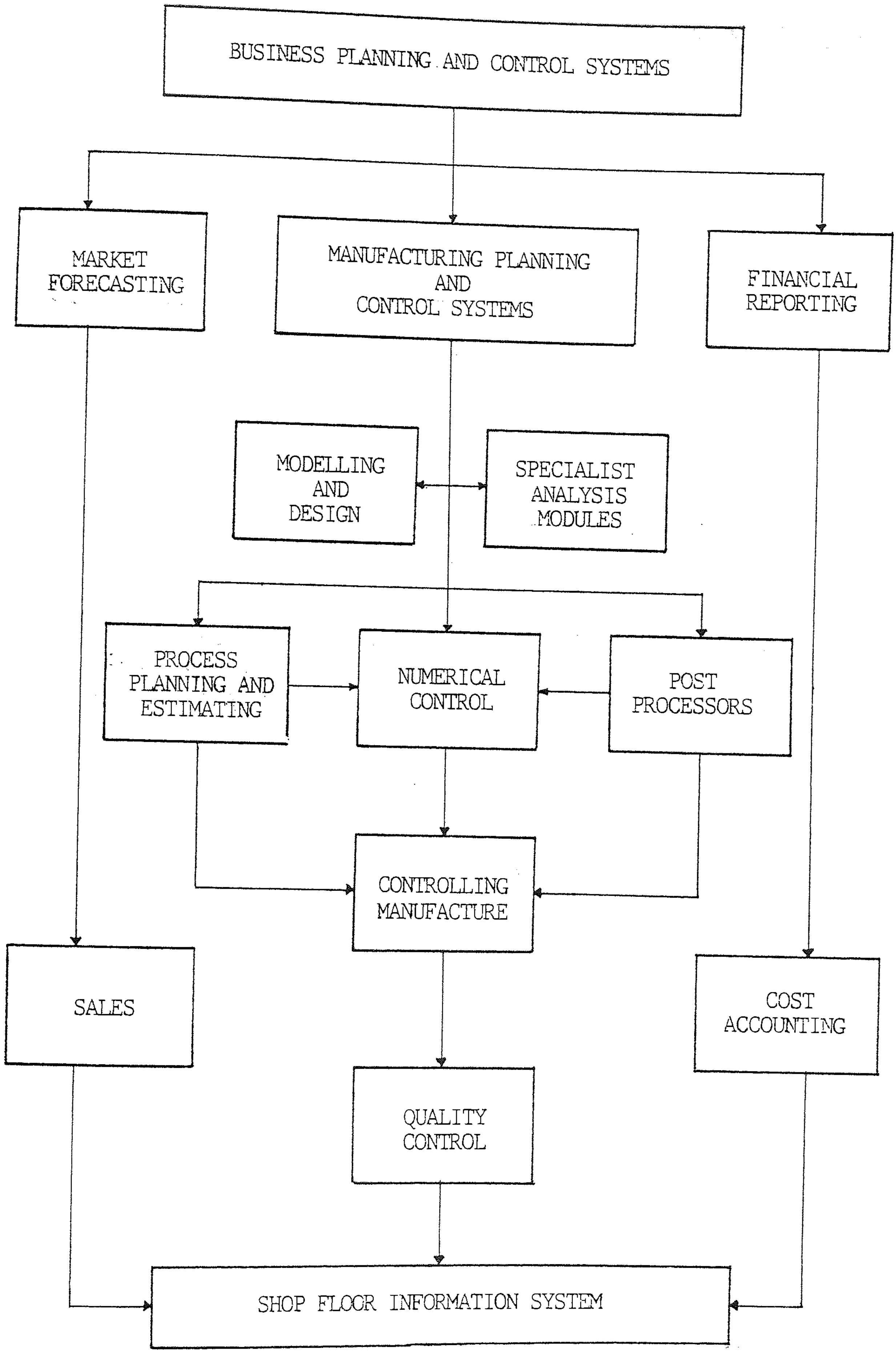


Fig. 3.1 MODULAR REQUIREMENTS OF A COMPUTER INTEGRATED MANUFACTURING SYSTEM

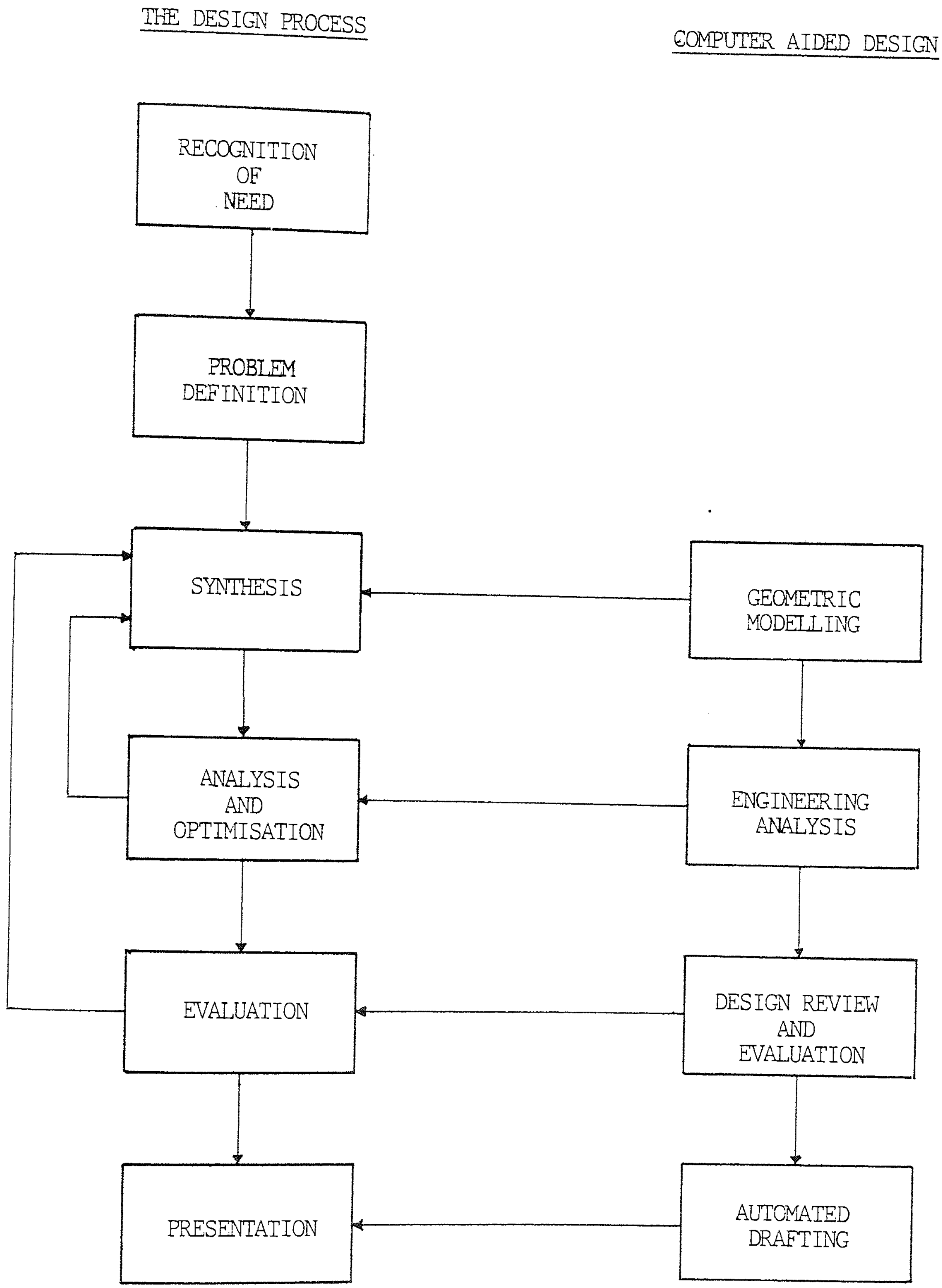


Fig. 3.2 APPLICATION OF COMPUTERS TO THE DESIGN PROCESS

CHAPTER 4

CHAPTER 4

ARTIFICIAL INTELLIGENCE IN COMPUTER INTEGRATED MANUFACTURE

4.1 INTRODUCTION

As part of this research programme it is intended to apply the concept of artificial intelligence or expert system to the design and manufacture of form-rolls, by representing the scientific and heuristic knowledge, which the roll designers and NC part-programmers possess, in a knowledge base. To achieve this objective effectively, a review of artificial intelligence and expert system technology is initially carried out.

Artificial intelligence is concerned with enabling computers to mimic the characteristics that make people seem intelligent. It began to become an active field of research within computer science (or possibly half-way between computer science and psychology) in about 1955. Since that time, the study of artificial intelligence has enhanced a wide range of topics, including problem solving, theorem proving, game playing, pattern recognition, search methods, heuristics, linguistics, learning and teaching (44).

Artificial intelligence systems are likely to have a significant impact on the automation of engineering design and manufacture. Among the potential benefits of the use of artificial intelligence techniques is the packaging of human expertise into expert system software. This will provide intelligent interfaces to sophisticated engineering analysis software, automate the use of design and manufacturing databases, and provide engineering assistants to handle low-level engineering tasks.

4.2 EXPERT SYSTEMS

Expert Systems technology is a branch of artificial intelligence. Forsyth (45) defines an expert system as a computer system containing organised knowledge, both factual and heuristic, that concerns some area of human expertise and that is able to produce inferences for the user. The British Computer Society's Specialist Group on the subject, define an expert system as the embodiment within a computer of a knowledge-based component, from an expert skill, in such a form that the system can offer intelligent advice or take on intelligent decision about a processing function. A desirable additional characteristic, which many would consider fundamental is the capability of the system, on demand, to justify its own line of reasoning in a manner directly intelligible to the engineer.

Nevertheless, the style adopted with both definitions to attain these characteristics is rule-based programming, i.e. using 'IF-THEN' statement (46) as a method for representing the domain knowledge base. Expert Systems differ from conventional systems in that they use heuristic and rule of thumb processes, rather than orderly and deterministic processes. They also differ in that they possess a separate knowledge base, which can be amended relatively easily and is intentionally made visible to the user.

4.2.1 Structure of Expert Systems

The basic structure of an expert system, as outlined in Fig. 4.1, normally consists of a knowledge base and an inference engine. The knowledge base is the database in which both facts and heuristics are represented as individual elements of knowledge about a particular field (domain). The inference engine is the problem-solving algorithm, or rule interpreter, which applies the knowledge in the knowledge base to the problem. A typical expert system normally has a working memory for keeping track of the status of the problem, for inputing data, and for recording the relevant history of what has been done so far.

The representation and handling of knowledge in the knowledge base are still dominant themes in expert systems research. Several researchers have recommended 'Production Rules' or 'IF-THEN' rules, to represent the decision-making process [47]. Each rule says that if a certain kind of situation occurs, a certain kind of action can be taken. It can also represent the linkage of evidence and hypothesis. These rules are then manipulated by the inference engine to form inferences, to make diagnoses and so forth. The MYCIN program [48] is a well known medical diagnosis program which can diagnose bacterial infections and recommend antibiotic therapy. It is a simple expert system which includes only 15 rules for identifying animals, and the knowledge is encoded in situation-action rules.

4.2.2 Expert System Languages

List processing languages are the natural software environment for building expert systems, because knowledge can be represented best in the form of symbolic declarative expressions [49]. The two most popular languages which provide facilities for manipulating lists are 'LISP' and 'PROLOG'.

'LISP' language is one of the standard vehicles for embodying symbolic processes. It is an invaluable aid for processing descriptions, and is the main language used by academics and commercial organisations in the United States. The uniform syntax of the language and its dynamic memory management have made it the natural choice for such efforts. Lisp is extremely useful as a development language, and interactive interpreter makes it easy to enter new programming ideas and quickly evaluate their effects [(50)]. Lisp is most often used not in its basic form, but instead as a vehicle for developing a higher-level language which implements a set of artificial intelligence techniques.

'PROLOG' is a declarative programming language based on logical relationships between objects. It was developed and first implemented by Alain Colmeraner's research group in Marseilles, and was originally devised for the purpose of implementing a natural language question-answering system [(51)]. 'PROLOG' is a higher level language than 'LISP', it is easier to learn and use, and the resulting programs are clear, concise and readable. The user runs a 'PROLOG' program by entering a 'goal' (i.e. a logical formula) and the system executes the program by searching for a proof of the formula. At any time the system has a database of clauses (i.e. a collection of statements of fact), from which to prove goals entered by the user. 'PROLOG' has been chosen by the Japanese as the core language for directly programming the logic architecture of Japan's fifth generation computer.

4.3 APPLICATION OF EXPERT SYSTEMS IN COMPUTER AIDED DESIGN AND MANUFACTURE

In the domain of engineering design and manufacture, there seems to be an underlying body of knowledge or expertise on how to solve engineering problems which is common to most engineers, although there are also great differences between the expertise of engineers in different areas (52). This suggests that there are in existence and available large bodies of practical knowledge about engineering design and manufacture that can be captured in expert systems.

A major characteristic of engineering design and manufacture is that while the specification includes a number of evaluation criteria (cost, reliability, weight, etc), there is usually insufficient information available to determine whether any given candidate solution is the optimum solution, or even to prove whether theoretically any optimum solution exists. Some local, but not global, tests of optimality might be possible. Thus, the engineer needs to use heuristic means to decide when to stop exploring further options, and report the best solution found thus far. It therefore, seems that there do exist bodies of engineering expertise which might be extracted and packaged in expert systems for engineering. The goal is to make all the engineers in an organisation as effective as the best few and to improve consistency (53).

In many organisations the process of design is carried out primarily by analogy with previous efforts. One of the most valuable possessions of such a company is their collective experience in past design and manufacturing efforts. The experienced engineer in many companies is valuable at least partly because of his memory of those previous efforts, and his ability to recall the solutions which were effective in those cases. Fig. 4.2 outlines the components of an expert system for engineering manufacture. Expert system techniques could be useful in automating the entry, indexing and searching of past solutions in databases to allow previous problems with similarities to a new problem to be found, and thus suggesting candidate solutions for adaptation to new requirements [54]. Expert system programs will work as an assistant to the engineer and will take care of various low-level tasks involved in developing the design and manufacturing solution, conducting analyses and documenting the work, thus leaving the engineer free to concentrate on higher level concepts.

4.4 APPLICATION OF EXPERT SYSTEMS IN COMPUTER AIDED PROCESS PLANNING

Process planning is traditionally performed by a skilled planner on the basis of years of accumulated experience . With the ever diminishing number of such planners, the need for an automated process planning system becomes more urgent. Some success in automating the planner's role has been achieved using the 'variant' method of process planning, by which a plan for a new component is adapted from the existing plan for a similar component. 'TOJICAP' [56] and 'AUTOCAP' [57] are examples of such systems. The planning logic used in 'ICAPP' is a combination of variant planning via the part family concept, and the generative planning concept.

A process planner is also capable of formulating plans for completely new components for which there is no existing variant. A 'generative' process planning system must be capable of emulating the planner's logic.

This logic is found to be so complex that solution by algorithmic methods is too cumbersome, naive and inflexible. Expert systems provide a method of solution which can overcome these problems. 'EXCAP' [58] is an expert computer aided process planning system written in PASCAL, which attempts to resolve these inadequacies.

Within integrated CADCAM based process planning systems, it is possible to capture production engineering practice, which can be exploited either by production engineers or draughtsmen [59,60]. It is within such systems that expert computer aided process planning packages will provide manufacturing industry with the expected benefits.

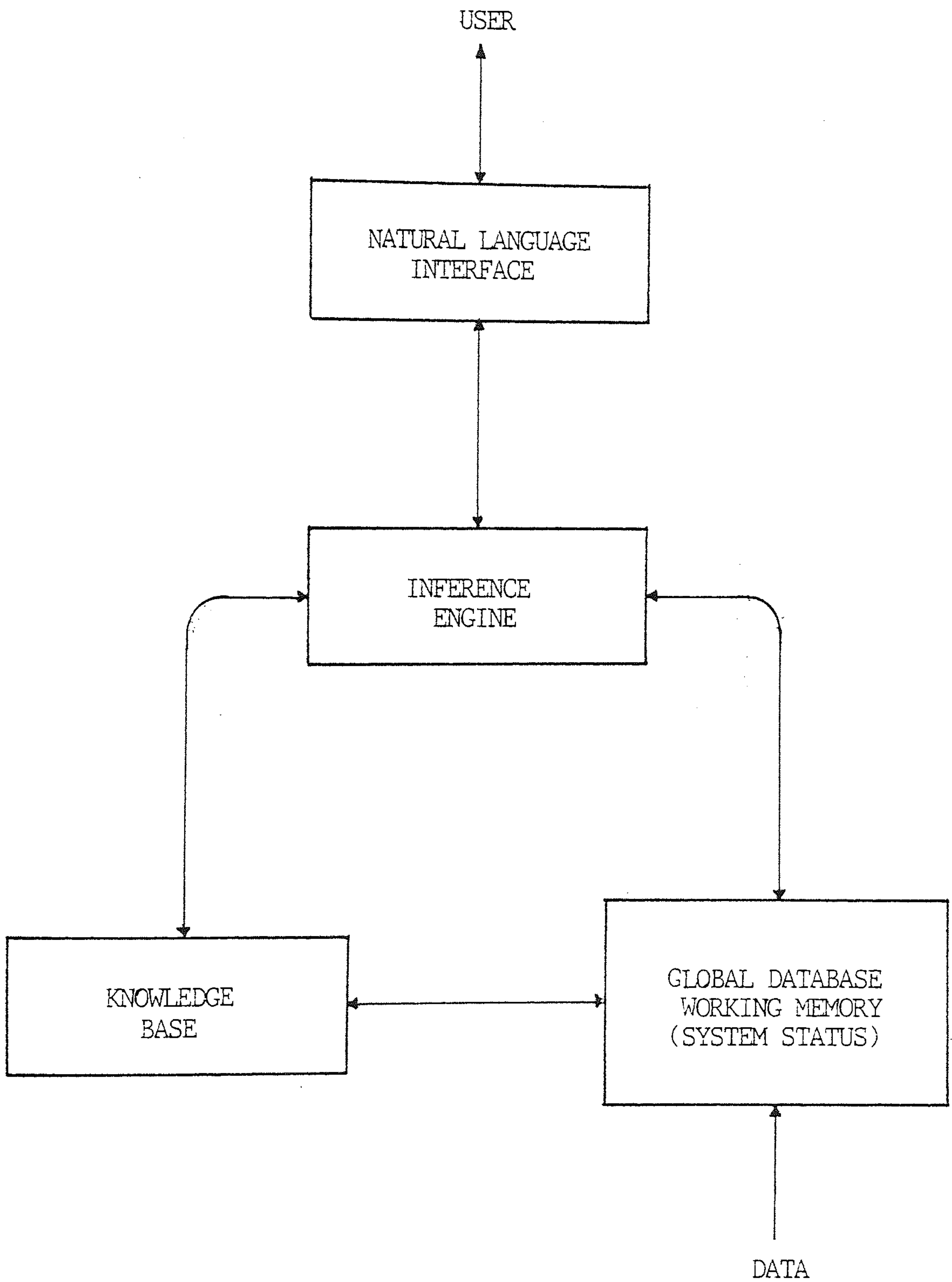


Fig. 4.1 STRUCTURE OF AN EXPERT SYSTEM

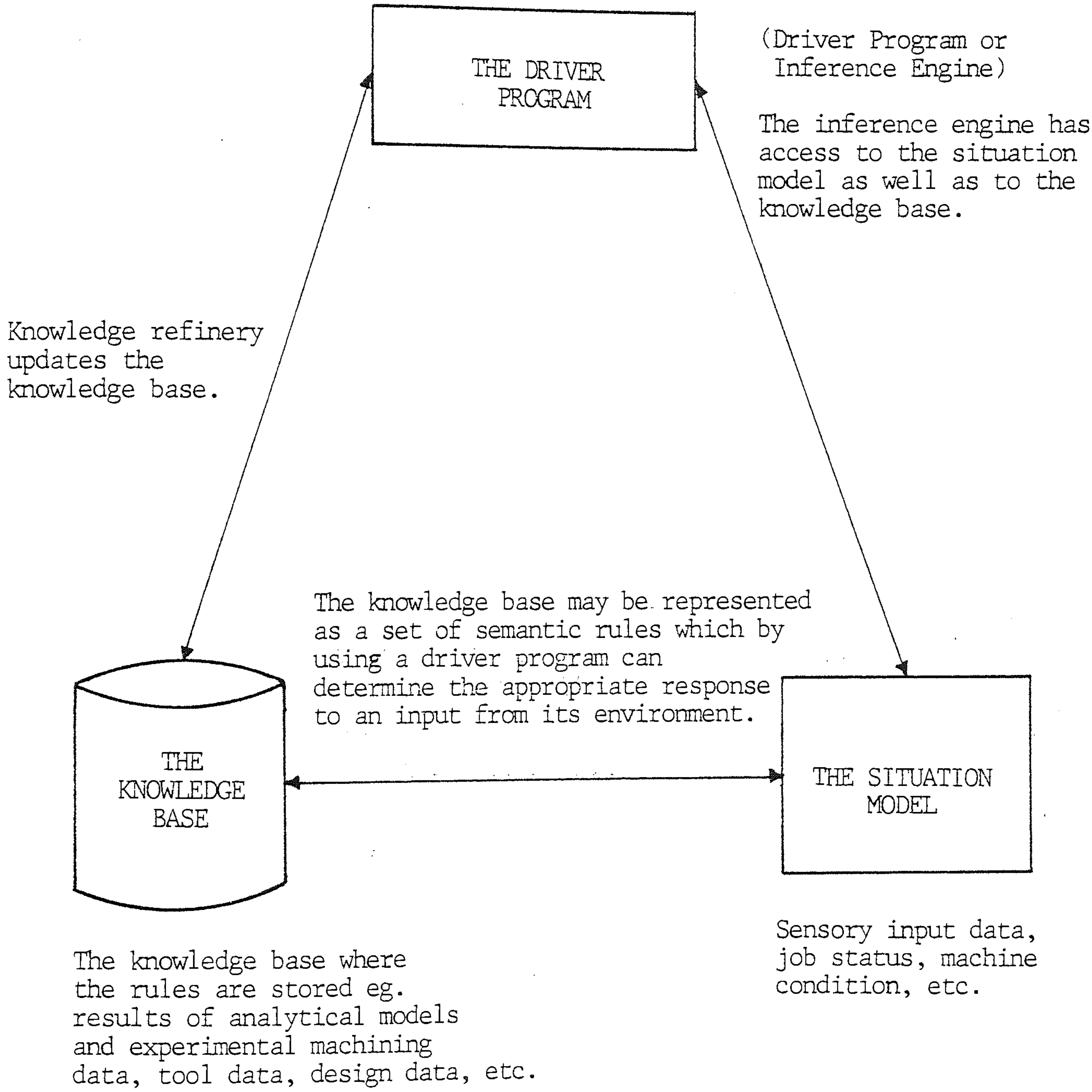


Fig. 4.2 COMPONENTS OF AN EXPERT SYSTEM FOR ENGINEERING MANUFACTURE

CHAPTER 5

CHAPTER 5

SYSTEM OVERVIEW

5.1 INTRODUCTION

The traditional approach for designing and manufacturing form-rolls, as described in Chapter 2, relies heavily on the knowledge and expertise of the roll designer in determining the forming sequence, and on the skill of the machinist in selecting the appropriate machining instructions. This manual method lacks well defined scientific principles and may entail great expense in time and cost.

Such inefficiency in the final product, being largely the results of human inadequacy, can to an appreciable extent be remedied or at least improved through the application of computer aided facilities. However, before embarking on a complex task of this nature it is essential to carry out careful planning [61]. Common lack of scientific approach for software design and development, coupled with frequent mismanagement in software projects, has in the past resulted in the creation of many unreliable and inflexible software products with heavy penalties [62].

5.2 PLANNING FOR THE SOFTWARE DEVELOPMENT OF THE INTEGRATED SYSTEM

Software development, like any other development work, requires systematic planning, especially when the software involved is of some appreciable scale and complexity. A set of software objectives and computerisation requirements based upon the existing needs against the constraints of the available resources, facilities, and knowhow has to be evaluated and established to guide the whole development process.

For successful computerisation a clear understanding of existing practices in the company and the company's needs, was necessary. It was also necessary to capture the knowledge possessed by the roll designers and NC part-programmers, in order to incorporate this knowledge in the expert system manufacturing software. To achieve this, frequent and comprehensive discussions had been held with all relevant company personnel, in preparing a suitable and beneficial computerisation programme throughout this research. Priority was given to the satisfaction of more pressing primary needs, with the secondary needs considered only when the primary needs had been satisfied.

Strategic measures were taken in adopting a development sequence which suited both the short-term and long-term requirements of the company for computerisation, and which contributed significantly to efficient development. This was necessary to avoid upsetting existing operations in the company and reduce the possibility of resource wastage and delay in completion.

5.2.1 Software Objectives

The software development programme of this research was planned to integrate with the previous phases of software development, those by Ng [63] and Wong [64]. These phases had been completed with the construction of software programs for the automatic draughting of the finished section, the flower patterns, the 10 to 1 template drawings, and the generation of NC tape programs for machining the form-rolls. This system had been implemented on the company's PERQ (ICL) 16-bit minicomputer, and all software programs were written in ICL PERQ FORTRAN 77 (65), utilising the GINO-F and ICL PERQ GRAPHICS (66) library routines for processing graphics.

According to this phase of software development, the following activities, as given in Section 1.3, were planned for computerisation:

1. Design and development of an improved interactive roll design program

2. Design and development of a form-roll editor with interactive graphics facilities, capable of displaying all the edited form-rolls within a forming stage.

3. Design and development of an expert system roll machining processor, incorporating a knowledge base with decision rules, for automatic generation of the cutter location data information.

4. Design and development of a general post-processor for producing NC tape programs for form-roll manufacture, for any required CNC lathe.

5. Design and development of a general NC tape checking program.

6. Design and development of a roll machining cost estimation program for the production of form-rolls.

7. Design and development of a stock control program for capturing and processing form-roll manufacturing and costing information.

All the above software objectives have been successfully carried out according to the plan of this research.

5.3 THE COMPUTER WORKSTATION

The computer plays a dynamic role in the development of integrated manufacturing systems, and its processing capabilities are important factors in the success of the system. As all software were written in FORTRAN 77 [67] and using GINO-F [68] library for graphics, the acquired system should therefore provide a FORTRAN compiler as well as the GINO-F graphics software library.

Bearing in mind these considerations, the VAX 11/750 32-bit superminicomputer with 4 Mbytes of RAM, a 300 Mbyte disc drive and 75 in/s dual density tape drive, was chosen. The VAX 11/750 is supplied by Digital Equipment Corporation and its high speed shortens program execution time.

The workstation is a Tektronix 4107 microprocessor controlled terminal [69] with a 640 x 480 pixel resolution (Plate 5.1). The terminal has 241 x 178 mm (9.5 x 7 inch) viewing area on its 330 mm (13 inch) screen. The resolution is considerably enhanced by an addressable display matrix of 4096 x 4096 points. The user can zoom in on a portion of the display, and the 4107 terminal will recompute the coordinate information and display the designated section in much greater detail. Rather than 'pixel replication', which simply enlarges the picture without providing additional detail, this true zoom significantly increases resolution.

Other peripherals include a printer, a Tektronix 4113 graph plotter (70) to provide hardcopy drawings, and a paper tape punch to produce NC tapes when necessary.

5.3.1 Design for Portability

Portability is considered an important quality characteristic in modern software design and development, mainly for the ability in converting a software system to suit a new operating environment. This situation arises when the developed software tends to become popular, but it is rarely the case that all prospective users will have identical computer systems installed at their premises. Although it is not always possible to produce a universally portable software system in current state of software practices, it is still possible to design the software in such a way that the effort of modifying the software for transference is minimised.

In this research, there is a high probability that the software developed will eventually be implemented on a different system in the near future, thus portability is an important consideration and has to be incorporated as far as possible. The programming and graphic languages are the two basic areas of concern. However, considerations have been based upon the existing software developed previously, against the facilities available. Since all existing software were written in FORTRAN 77 and as this language was available on the University's VAX 11/750, it was perfectly justified. Being a high level language, FORTRAN 77 is also highly portable and in fact it is one of the most popularly supported scientific languages used in most computer systems. As regards the use of graphic facilities, the choice of GINO-F was also justified because of its portability capability.

It is envisaged in the near future to implement the system on a stand alone powerful microcomputer. For this purpose, the DEC Professional 350 16-bit microcomputer with 512 Kbytes of RAM and a 5 Mbyte disk drive has been chosen (Plate 5.2). The DEC Professional 350 can be linked to the VAX 11/750, and all software can be downloaded from one computer to the other.

5.4 CNC LATHES FOR ROLL MANUFACTURE

In this research, a special purpose NC lathe programming system has been developed in order to produce NC tapes for use on a CNC lathe. The system has been designed to be flexible and capable of producing NC tapes for any CNC lathe. However, as the company have acquired a Mori-Seki lathe equipped with a Fanuc CNC controller (Plate 5.3) and since the Numerical Control Laboratory of the University possesses a Torshalla (S160) lathe equipped with a SAAB MTC-10 CNC controller a tool library for these two lathes has been incorporated in the software system.

Standard procedures for NC form-roll turning have been established, that is, deciding on the work holding method, selection of cutting tools, and NC tape preparation. During the NC turning process, the roll blank is held on the mandrel and supported by the tailstock, which makes possible machining of the roll from both ends. A typical roll being held by a mandrel in the Fanuc controlled Mori Seki CNC lathe is shown in Plate 5.4.

Turning of form-rolls is basically divided into two sections, roughing out and finish profiling. A set of carbide tip turning tools has therefore been chosen as standard cutting tools for the form-roll turning process. This set of standard cutting tools has been deployed into permanent positions in the 12-station turret and the 8-station turret of the Mori-Seki and Torshalla CNC lathes respectively (Plate 5.5).

5.4.1 NC Part-Program Pattern

In the NC part-program, details of machining operations have to be set down in sequence. Each line of the program should be numbered in sequence, details of the operation have to be stated and the X and Z co-ordinates should be given. The basic information should then be supplemented by code numbers representing the preparatory functions; feed rate; spindle speed; required tool; and miscellaneous functions.

Nevertheless, the format or pattern for an NC part-program may vary according to the type and make of machine control system. Details for the part-program format for the Fanuc controlled Mori-Seki and the Saab controlled Torshalla CNC lathes can be referred to the programming manuals (71,72). However, a list of the preparatory functions (G-codes) and miscellaneous functions (M-codes), and some program format functions are given in Appendix 1. More details concerning the NC part-programs for the production of form-rolls, and the databases within which the NC functions and formats are stored, will be described in Chapter 9.

5.5 SOFTWARE FUNCTIONS

With regard to the entire computerisation plan, covering all phases of the development programme, the following application software programs have been designed and developed:

1. THE FINISHED SECTION SOFTWARE

   (a) Section drawing

   (b) Automatically generated meanlengths and strip size

   (c) Dimensioning

   (d) Paper size selection and scaling of drawing

   (e) Title block content printing

2. THE FLOWER PATTERN SOFTWARE

   (a) Flower pattern with common origin

   (b) Flower pattern with separate origin

   (c) Automatic bending radii control

   (d) Ability to process multiple element bending at the same stage

3. THE TEMPLATE SOFTWARE

   (a) 10 to 1 template drawings for all forming stages according to the flower pattern.

(b) Automatic scaling down of template drawing sizes to fit paper width limit.

(c) Generation of template contour data output for further use.

(d) Percentage composite length definition for circular elements.

(e) Radii-sharpening option.

This software was originally developed for the conventional roll manufacturing process, and thus it has then lost its main purpose following the implementation of NC turning of the rolls. Nevertheless, apart from the use of templates for quality control purposes, the template contour data output for the final stage can be used as an input to a post-processor for the manufacture of cut-off die blocks by an NC EDM machine.

4. THE ROLL DESIGN SOFTWARE

(a) Automatic generation of top and bottom roll contour based on the template contour.

(b) Automatic incorporation of pinch-difference surfaces based on the supplied clearance values.

(c) Automatic separation of side-roll contour from the top and bottom roll contour when required.

(d) Automatic addition of extension-contours when required.

(e) Generation of roll drawings incorporating the selected optional features for all forming stages.

(f) Ability to interactively edit the roll drawings by altering the selected input data.

(g) Ability to begin processing at any selected forming stage.

(h) Generation of roll contour data output.

5. THE INTERACTIVE ROLL EDITING SOFTWARE

(a) Display the profile of the selected roll on the Tektronix screen.

(b) Provide editing functions for interactively modifying the roll profile. Facilities available at present are Insertion, Replacement or Deletion of an element, Corner Modification and Mirror Imaging.

(c) Update the edited roll profile data.

(d) Generate a separate roll contour data file.

(e) Display all the edited rolls of a complete forming stage on the Tektronix screen, to ensure correct edits have been carried out.

6. THE EXPERT SYSTEM FORM-ROLL MACHINING SOFTWARE

(a) Automatic selection of the appropriate cutting cycles, tools, speed, feed, tolerance and depth of cut, to machine the roll in the most optimum manner according to the roll profile data input.

(b) Automatic generation of the Cutter Location Data file for turning a selected roll according to the machine instructions determined by the software system.

(c) Automatic generation of the cutter path for the selected cutting cycle. At present, four types of lathe cutting cycles have been equipped, namely, roughing, grooving, pocketing and finishing.

(d) Automatic display of the cutter path on the Tektronix screen.

(e) Automatic generation of a process plan for optimum machining of the roll.

7. THE GENERAL POST-PROCESSOR SOFTWARE

(a) Ability to create a post-processor for any CNC lathe, simply by inputting interactively the preparatory and miscellaneous functions, and the part-program format of CNC lathe machine.

(b) Automatic generation of the NC part program from the Cutter Location Data file of the selected roll for the specified CNC lathe system.

(c) Automatic display of the cutter path on the Tektronix screen by reading data from the NC part-program.

8. THE NC TAPE CHECKING SOFTWARE

(a) Automatic display of the cutter path on the Tektronix screen while reading an NC part-program for the specified CNC lathe machine.

9. THE COST ESTIMATION SOFTWARE

(a) Determines the metal cutting time, tool change and positioning time, and total machining time to produce a selected roll.

(b) Determines the total cost to produce a roll, and also a set of rolls, by inputting interactively the labour, material and overhead costs.

10. THE STOCK CONTROL SOFTWARE

(a) Controls the record keeping of all manufactured rolls and other related tools.

(b) Facilities include entering, listing, updating and deleting records.

5.6 THE INTEGRATED SYSTEM SOFTWARE LAYOUT

The complete integrated software system has been implemented on the VAX 11/750 in a sequential manner, and all the program units must be executed in sequence. Fig. 5.1 gives an outline of the integrated system showing clearly the interface between the three main functions; CAD; CAM; and Production Control. All functions are inter-linked by having access to common data files.

During the operation of the system, the user is led to supply input data to the system through the interactive man/machine dialogue. However, later retrieved. Hence, if it is required to re-execute a program, it is then not necessary for the user to supply the input data through the man/machine dialogue again, but the system will retrieve the data from the designated files automatically.

5.6.1 Input and Output Data Files

The Finished Section Program is the first stage of the system software. A set of finished section design data is required for execution of this program. The input information is stored in a section definition data file under a file name (D"SECNO"), where "SECNO" is the section number, which can contain up to 12 alphanumeric characters and is the part number of the finished section. Meanwhile, an intermediate section data file (TD"SECNO") is generated and stored in the disc memory for later stage of processing.

The input to the Flower Pattern Program is the bending information which is stored in the bending data file (F"SECNO"). In addition to the bending information, the intermediate section data file (TD"SECNO") is also input at this stage. The Flower Pattern Program, unlike the Finished Section Program, does not generate any intermediate output data file.

The execution of the Template Program does not require any special data inputs, instead, the program retrieves information from the bending data file (F"SECNO") and the intermediate output data file (TD"SECNO"). An intermediate output data file (TF"SECNO") is generated and kept in the disc memory for later stage of processing.

For the operation of the Roll Design Program, a set of roll design data is required to be input which is stored in the roll design data file (R"SECNO"). The section definition data and bending data are also retrieved directly from the data files (TD"SECNO") and (F"SECNO") respectively. Additionally, the side-contour extension information is retrieved directly from the data file (CONTOUR.DATA). The execution of the Roll Design Program generates a roll profile data file, with a file name (AR"SECNO"), which contains the roll profile geometry data for all rolls in all forming stages.

The Roll Editor Program picks up the appropriate roll geometry information from the data file (AR"SECNO"), and the specified roll profile data is then modified interactively, again, through the specially designed man/machine dialogue. The updated roll profile data is then stored in the data file (E"SECNO""s""r"), where "s" is the stage number and "r" is the code which equals 'T' for a top roll, 'B' for a bottom roll, and 'L' or 'R' for a left or right hand side roll respectively.

The operation of the Roll Machining Program does not require the user to input any information whatsoever. The only input to the program is the roll profile data file (E"SECNO""s""r"). The system automatically determines the machining instructions appropriate to the roll profile, by applying the knowledge in the database to the problem. The outputs from the system are the machining instructions data file (CI"SECNO""s""r"), the machining process plan (CP"SECNO""s""r"), and the cutter location data file (CO"SECNO""s""r").

The General Post-processor Program retrieves the cutter location data file (CO"SECNO""s""r) and also the machine code/format data file ("NAME".DATA), where "NAME" is the name of the CNC lathe machine for which NC programming is required. Consequently, the NC tape program is generated which is stored in the data file (NC"SECNO""s""r"), and an NC control tape can then be obtained by copying this file to a tape punch.

The Tape Checking Program is not a necessary function of the integrated system. It decodes the NC machining data from a (NC"SECNO""s""r") file, in order to ensure the accuracy and correctness of the NC program.

The Cost Estimation Program retrieves the cutter location data file (CO"SECNO""s""r"), and outputs the machining time and cost information which is stored in the data file ("COST".DATA), where "COST" is the chosen name for the related costing file.

The Stock Control Program, on the other hand, uses direct access files whereby access to all relevant data files and records is conducted through the programs. This program performs a filing operation and therefore uses the same data files for both input and output operations. The data files concerned with the Stock Control Program are FILE5, FILE6 and FILE15.

The above mentioned data files are generated during the different stages of execution of the integrated software system, as summarised in Table 5.1. All data files are kept in the disc memory storage of the VAX computer for further processing. Explanatory notes concerning the data input format is given in Appendix 2.

5.6.2 The Processing Commands

In order to facilitate the execution of the integrated system, the developed programs are deployed into different command files for different stages of execution. Table 5.2 outlines the commands for execution at different stages of the integrated system software, and the contents of all the command files are given in Appendix 3.

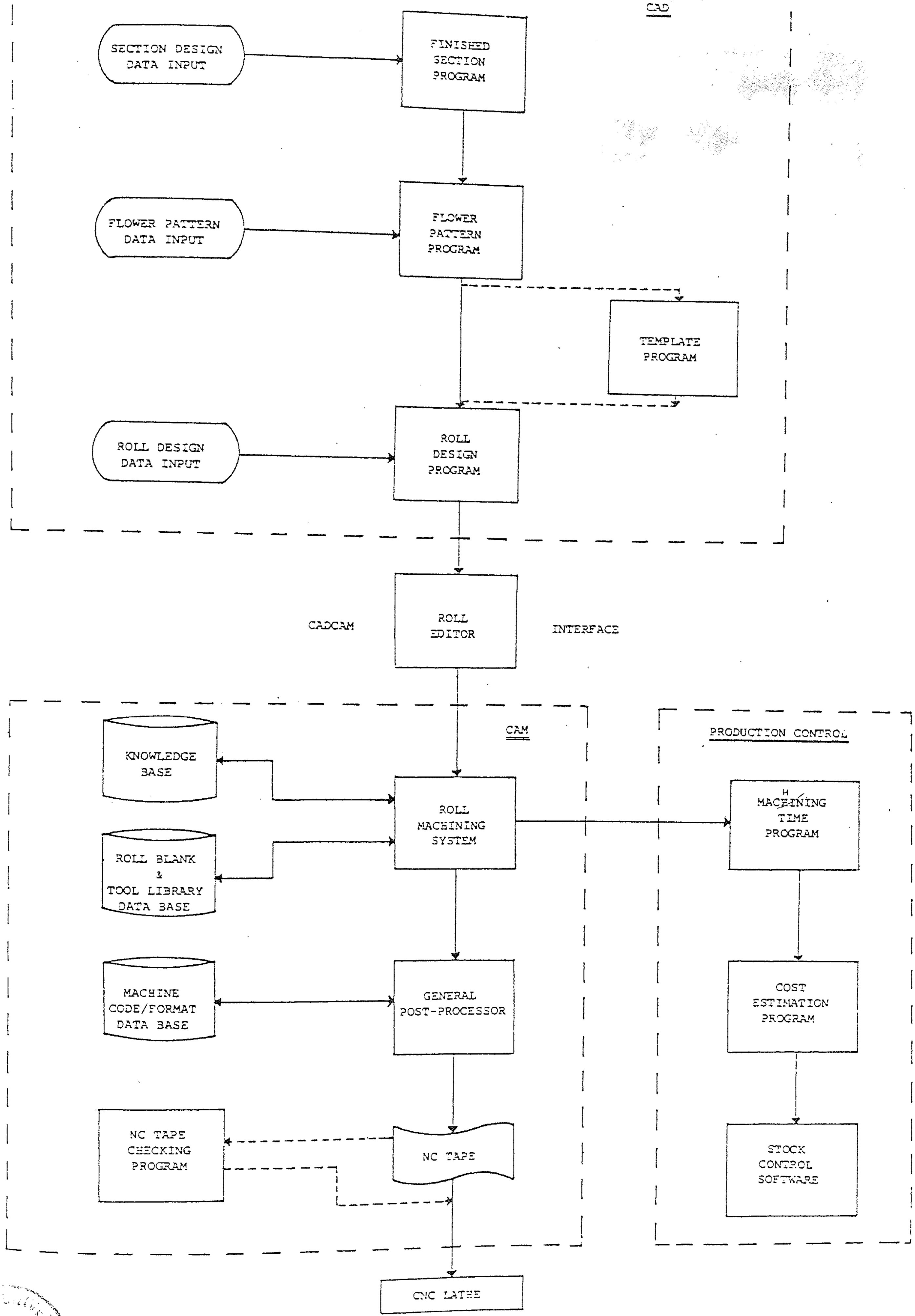


Fig. 5.1 THE INTEGRATED SOFTWARE SYSTEM FOR FORM-ROLL MANUFACTURE

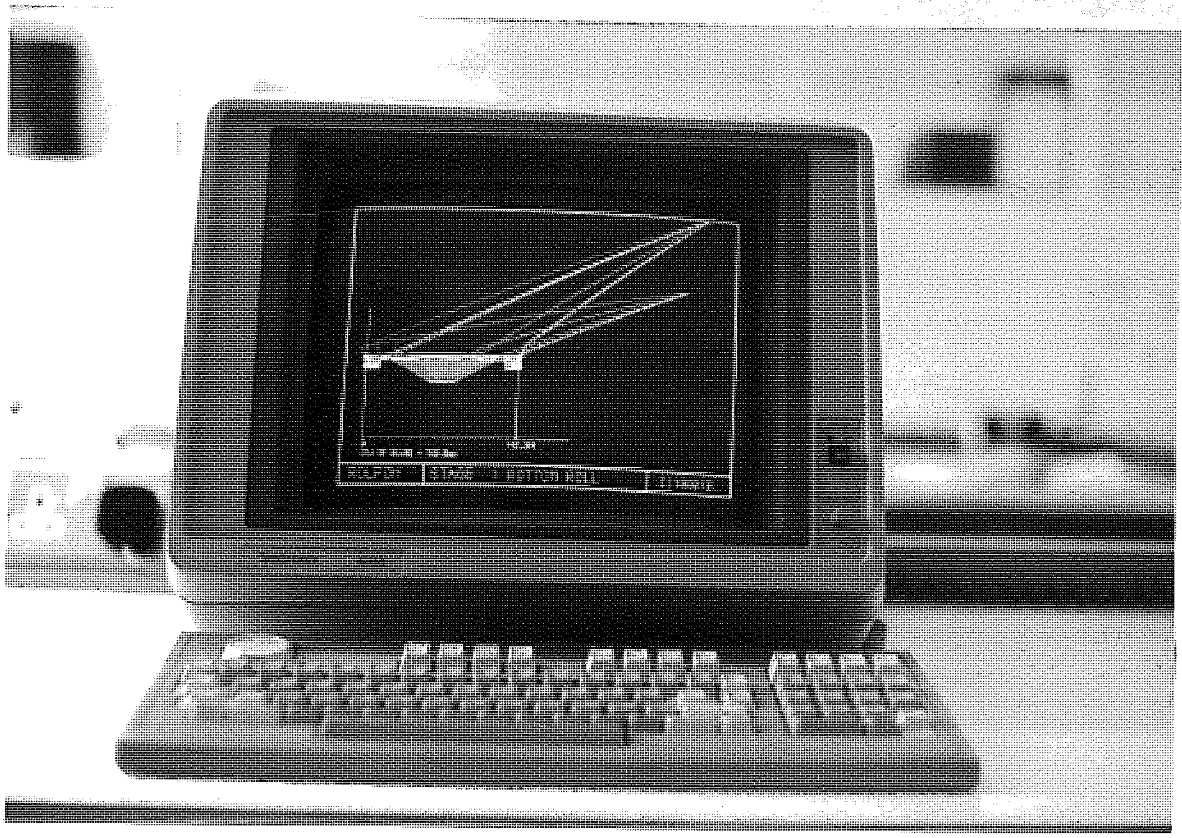


Plate 5.1 THE TEKTRONIX WORKSTATION

Plate 5.2 THE DEC/PROFESSIONAL WORKSTATION

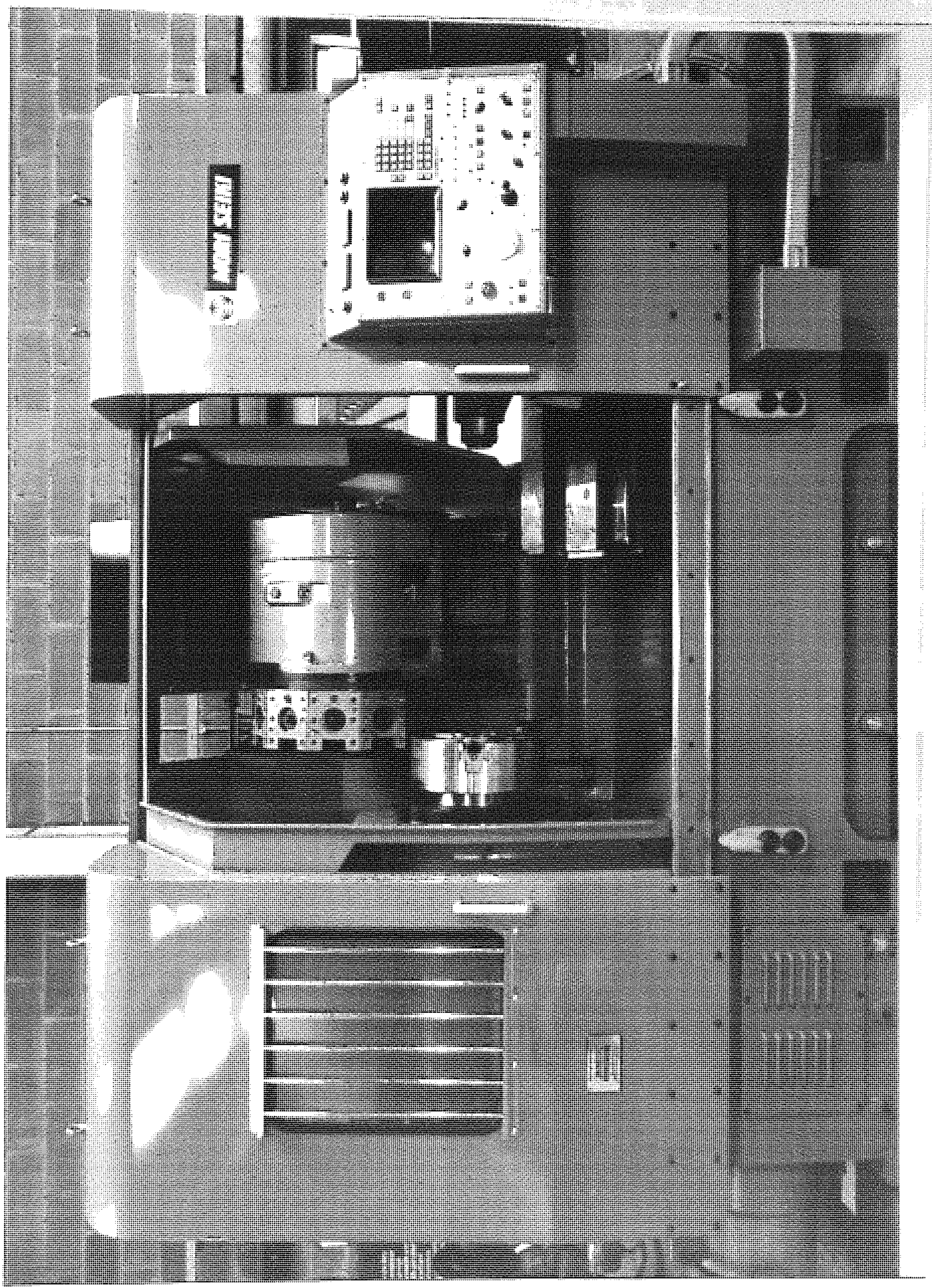


Plate 5.3 THE FANUC CONTROLLED MORI-SEKI CNC LATHE

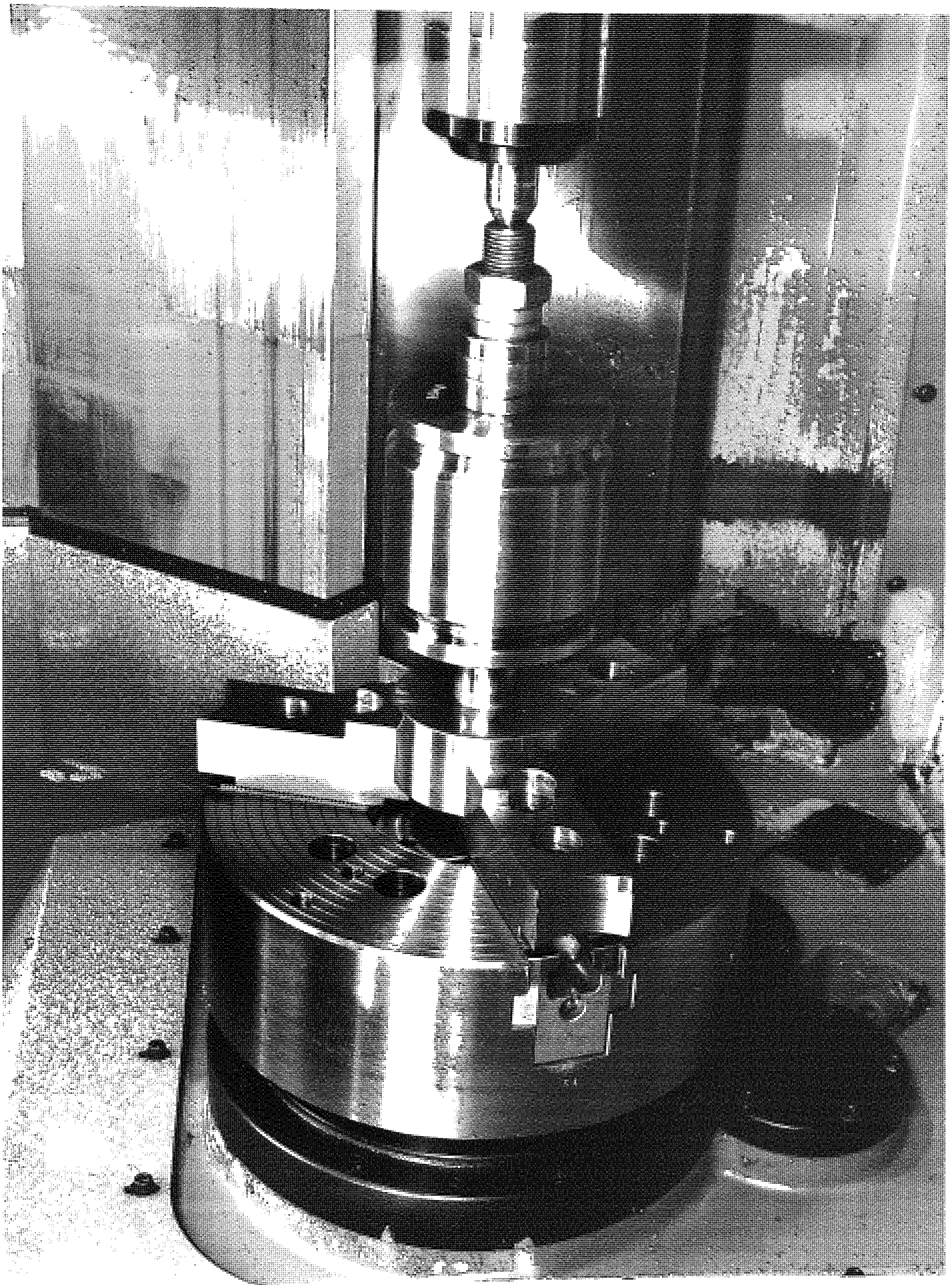


Plate 5.4 A TYPICAL ROLL BEING HELD BY A MANDREL

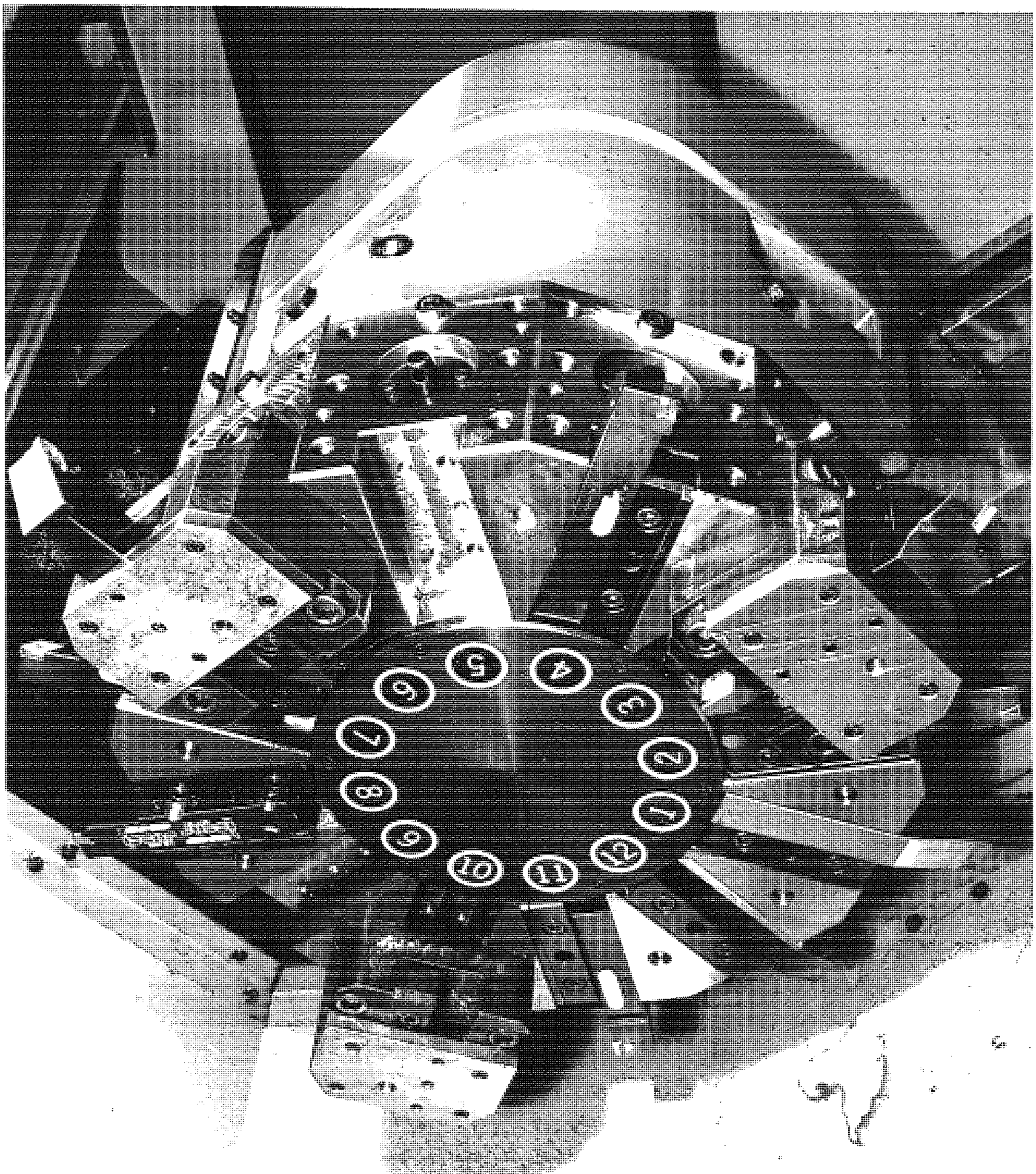


Plate 5.5 TOOLING SETUP IN THE TURRET OF THE CNC LATHE

Table 5.1 DATA FILES INVOLVED IN DIFFERENT STAGES OF THE INTEGRATED SOFTWARE SYSTEM (PART 1)

PROGRAM	INPUT DATA FILE	OUTPUT DATA FILE
FINISHED SECTION	<D"SECNO">	<TD"SECNO">
FLOWER PATTERN	<TD"SECNO"> <F"SECNO">	
TEMPLATE	<TD"SECNO"> <F"SECNO">	<TF"SECNO">
ROLL DESIGN	<TD"SECNO"> <F"SECNO"> <R"SECNO"> <CONTOUR>	<AR"SECNO">
ROLL EDITOR	<AR"SECNO">	<E"SECNO""s""r">
EXPERT SYSTEM ROLL MACHINING PROCESSOR	<E"SECNO""s""r">	<CI"SECNO""s""r"> <CO"SECNO""s""r"> <CP"SECNO""s""r">
GENERAL POST-PROCESSOR	<CO"SECNO""s""r"> <"NAME">	<NC"SECNO""s""r">
NC TAPE CHECKING	<NC"SECNO""s""r">	
COST ESTIMATION	<CO"SECNO""s""r">	<"COST">
STOCK CONTROL		<FILE5> <FILE6> <FILE15>

Table 5.1 (PART 2)

NB:- "SECNO" : Section No. (Finished section number, containing up to 10 alphanumeric characters)

"NAME" : Name of the CNC lathe machine (containing up to 20 alphanumeric characters)

"s" : Stage No. (1-99)

"r" = T for Top roll
= B for Bottom roll
= L got Left side roll
= R for Right side roll

Table 5.2 THE PROCESSING COMMANDS (PART 1)

COMMAND	DESCRIPTION
SECTION	Operating the Finished Section Program, while acquiring data interactively through the terminal keyboard
NSECTION	Re-executing the finished Section program, while retrieving the finished section data input file
FLOWER	Operating the Flower Pattern Program with simultaneous generation of both flower drawings, while acquiring data interactively through the terminal keyboard
SFLOWER	Operating the Flower Pattern Program with separate generation of flower drawings, while acquiring data interactively through the terminal keyboard
NFLOWER	Re-executing the Flower Pattern Program, while retrieving the flower pattern data input file
TEMPLATE	Operating the Template Program
DESIGN	Operating the Roll Design program with batch drawing processing, while acquiring data interactively through the terminal keyboard
SDESIGN	Operating the Roll Design Program with stage by stage interactive drawing processing, while acquiring data interactively through the terminal keyboard
NDESIGN	Re-executing the Roll Design Program, while retrieving the roll design data input file
EDITOR	Operating the Roll Editor Program
EXPSYS	Operating the Expert System Roll Machining Processor
NCUTPL	Operating the Roll Machining Processor, while retrieving the machining instructions data input file

Table 5.2 (PART 2)

COMMAND	DESCRIPTION
GNPOST	Operating the General Post-Processor
MFPOST	Operating the Special-Purpose Post-Processor for the Mori-Seki CNC lathe
SBPOST	Operating the Special-Purpose Post-Processor for the Saab-Torshalla CNC lathe
TAPCHK	Operating the NC Tape Checking Program
CACE	Operating the Cost Estimation Program
TOOL	Operating the Stock Control Program

CHAPTER 6

CHAPTER 6

COMPUTER AIDED DESIGN SOFTWARE FUNCTIONS

6.1 INTRODUCTION

In this chapter, the software developed during the first phase of the computerisation programme, namely: the finished section program; the flower pattern program; the template program and the roll design program; are briefly described. A detailed description of these programs is given by NG (63), whereas, the aim in this chapter is simply to outline some significant aspects of the programs, with special emphasis on their implementation on the VAX workstation.

These programs were originally written in FORTRAN 66, and were developed for batch processing on the ICL 1904S mainframe computer system. All data input for the programs had to be pre-entered in separate data files. During the second phase of the computerisation programme (64), all these programs were implemented on the PERQ ICL minicomputer at the company, using the PERQ's FORTRAN 77 language.

In this research, however, all these programs have been implemented on the VAX 11/750, and have therefore been modified accordingly to suit the VAX/VMS operating system. Data acquisition is achieved, while running the programs, interactively through a question/answer sequence via the terminal screen and keyboard. At the same time, the input information is stored in assigned data files, which can be recalled when re-running the programs so that the keyboard entry can be minimised. The software is structured to lead the designer through the conventional stages of the design by the series of clear requests and prompts which appear on the terminal screen.

The roll design program has been re-designed in this research, so as to meet the company's current requirements, in the process of eliminating the tedious and time consuming input data required by the system users. This program is therefore described in greater detail, and the functions of the various subroutines are outlined.

6.2 THE FINISHED SECTION SOFTWARE

The finished section is the ultimate product that the form-rolls are designed to manufacture, therefore its geometry must be accurately and adequately defined. The finished section program enables the designer to distinctly define the section geometry and to produce the finished section automatically either on the Tektronix screen or to obtain a hardcopy by a graph plotter.

6.2.1 Section Definition Scheme

The sole purpose of the section definition scheme is to help users to define a wide range of section shapes accurately and without ambiguity in a convenient way. The type of section geometry normally encountered in practice consists of only linear and circular elements with uniform thickness (Fig. 6.1). Non-linear type of elements other than circular elements are normally not used but if used they may be approximated with circular elements.

In essence, as the thickness is uniform and should be initially defined, the only information required for each element is the length l if the element is linear (Fig. 6.2), or the inside radius r and the angle of bend A if the element is circular (Fig. 6.3). The convention adopted for specifying the directions of bending is positive for upward bending and negative for downward bending, irrespective of which side of the section the bend is required (Fig. 6.4).

6.2.2 Selection of the Type of Definition Sequence

To cater for the various types of section geometry with different numbers and combinations of circular and linear elements, five different types of definition sequence have been incorporated in the program. Users are requested to choose the type of definition sequence by specifying the starting point or point of reference (ORIGIN) type. These are as follows:

ORIGIN = 1 (Starting from the left of the section and ending at the right)

ORIGIN = 2 (Starting from the right of the section and ending at the left)

ORIGIN = 3 (Starting from the middle of the section, towards the right and then from the middle towards the left)

ORIGIN = 4 (Starting from the middle of the section, towards the left and then from the middle towards the right)

ORIGIN = 5 (Starting from the middle of the section, towards the right and the section is symmetrical)

6.2.3 Automatic Strip Size Calculation

The finished section program automatically calculates the individual meanlength of each element as well as the required strip size (or material width) for forming the desired section. Various methods for computation in this respect have already been mentioned in Section 2.5.1. However, in this program, equation 2.7 has been adopted in conjunction with Table 2.1 for calculating the mean radius of a circular element, while the strip size is determined in equation 2.1.

6.2.4 Generating the Finished Section Drawing

Facilities for selecting the plotting frame size, ranging from A0 to A4, and for controlling the scale of the drawing have been incorporated in the finished section program. Also available, is an optional dimensioning facility which enables the designer to keep track of the details of each element. However, the size of the plotter drawings is limited by the size of the graph plotter, and the size of the printed drawings on the VDU is inevitably limited by the size of the Tektronix screen.

In addition to the drawing, an intermediate data file is generated to retain data which will be needed in later stages of processing. This intermediate data file is retrieved during the operation of the flower pattern program, as well as the roll design program, for obtaining the geometric data of the finished section.

A terminal listing for data input for the finished section program is given in Fig. 6.5, and the display of the finished section drawing on the

Tektronix screen is shown in Fig. 6.6.

6.3 THE FLOWER PATTERN SOFTWARE

Flower patterns are the tools used by roll designers to produce a satisfactory forming sequence for a particular section. The flower pattern program has been developed to automatically generate the flower pattern drawings for roll designers to prove out the forming sequence they design.

6.3.1 Element Bending

The program assumes all elements of the section to be straight at the start of the forming sequence, conforming to the raw material which is a flat strip. During each bending stage or roll forming stage, certain elements are bent to certain angular values and remain so unless they are bent again to new angular values at other subsequent stages. A system of bending status update for each element has been adopted such that users are required to supply new bending information regarding only the affected elements, bending status of all other elements in the preceding stage is automatically assumed in the current stage. The bending definition scheme is based upon the type of element definition sequence selected, as described in Section 6.2.2.

6.3.2 Opening-Radii Method for Monitoring Bending Radius

The Opening-Radii method is a computerised technique which automatically generates suitable radius of bending for each circular element at successive stages. Provided that the relative positions of the elements adjacent to the particular circular element being bent can be precisely monitored at each bending stage, it is theoretically feasible to maintain a constant cross-sectional area and a uniform thickness for the circular element throughout forming, as illustrated in Fig. 6.7, such that:-

$$r_i\theta_i = r_j\theta_j = \ldots\ldots = K \qquad (6.1)$$

where r_i is the radius of bend at stage i

θ_i is the angle of bend (in radians) at stage i

r_j is the inside radius of bend at stage j

θ_j is the angle of bend (in radians) at stage j

K is a constant

The main advantages of using the Opening-Radii method are that it enhances the wear characteristics of the form-roll, due to the use of larger radii of bend, and that it permits smoother forming of circular elements, thus reducing the tendency of thinning.

6.3.3 Generating the Flower Pattern Drawings

The flower pattern shapes are generated one by one in accordance with the sequence of forming, starting with a flat strip. The meanlength of each element is obtained from the intermediate data file via input, and normally remain unchanged throughout forming except in situations where length adjustments become necessary.

A typical terminal listing for data input for the flower pattern program is given in Fig. 6.8. Two types of flower pattern drawings are produced by the software which are displayed on the Tektronix screen. The first type is a flower pattern with common origin (Fig. 6.9), while the second type is a flower pattern with separate origins (Fig. 6.10). With the flower patterns, roll designers can project each of their forming sequence designs in drawing, and can perform visual inspection and alterations until they are satisfied. The flower patterns are drawn to be proportionally accurate with automatic scaling so that interference material as a result of certain bends, as well as awkward bends which prevent roll contact, can be easily detected and corrected.

6.4 THE 10 TO 1 TEMPLATE SOFTWARE

The 10 to 1 template program has been developed for the purpose of generating wire templates, ten times full size, which are used in the manufacture of the wire templates. Wire templates are only required as an aid in manual turning of the form-rolls. Therefore, due to the installation of an NC lathe and the development computer aided roll manufacturing facilities, the wire templates are no longer required.

The template program has thus been implemented on the VAX system, merely as a supporting function, which produces the template drawing for every forming stage, and the size of the template drawing is automatically scaled down to fit on the Tektronix screen. The template drawings can be used by the designer as a reference for checking the shape of the product during each forming stage.

Apart from being just a suppporting function, the template program can be used in future work for providing the input data for a post-processor in the manufacture of die-blocks by an NC EDM machine. The cross-section of the die-block closely resembles the finished section, and therefore its design co-ordinates can be obtained from the template program.

6.5 THE ROLL DESIGN SOFTWARE

The roll design program developed during the first phase of the computerisation programme, for generating the roll drawings and profile data to design specification, required the user to supply information for all forming stages before obtaining any roll design drawings. This was very inefficient and gave rise to numerous errors, due to inability to display roll design drawings at the end of every forming stage data input.

The new roll design program developed in this research is a major improvement to the process of roll design. The user is only required to supply information for one forming stage, automatically display the roll drawings for that stage, edit the roll drawings by altering the input data if required, and then proceed to the next stage if satisfied with the roll drawings of the present forming stage. More details concerning the operation of the new roll design program are discussed in Section 6.5.5.

Regarding the entire roll design function, four major areas have been computerised, namely:-

1. Basic Roll Contour Design

2. The Pinch-Difference Option

3. The Side-Roll Option

4. The Extension-Contour Option

6.5.1 Basic Roll Contour Design

This function involves the design of top and bottom roll contours, forming a gap resembling the template shape for every bending stage. In certain cases, the roll contours actually follow the template shape exactly (Fig. 6.11), but more often this is not the case. As shown in Fig. 6.12, part of the roll contour following the template shape has to be modified to prevent interference between the roll and the strip material when the roll turns. The roll design program automatically modifies parts of the template profiles to avoid any such interference.

Similar to the template contours, roll contours also consist of linear and circular elements. During contour modification, part or whole of the linear or circular element contour may have to be removed and replaced by a new element contour (Fig. 6.13). The new element contour is always linear and vertical in order to avoid roll interference with the material being formed. The working model of the roll contour, therefore, contains data which represents the template contour at the start, which can then be removed or modified and which permits new data defining the new contour to be added.

6.5.2 The Pinch-Difference Option

Pinch-difference is a quantity for controlling the variation of the gap size between opposing surfaces of a roll pair at different points across the strip width at a particular bending stage (Fig. 6.14). At certain parts of the roll periphery, firm contact between the roll surface and strip surface is necessary for drawing the strip forward, while at other parts a clearance between the surfaces is more appropriate to avoid undesirable friction during forming. Facilities for designing the pinch-difference surfaces of the required type have therefore been included in the software.

For computerisation purposes two kinds of pinch-difference surfaces have been considered, namely, the drive-surface and the clearance-surface. Methods for defining these two different surfaces have been created to enable designers decide where the surfaces should be and what clearance value to use at different bending stages.

The first, the double thickness method, uses a constant clearance-surface gap and a drive surface gap (Fig. 6.15). The gap (D) at the drive-surface is always smaller than the gap (C) at the clearance-surface. The second, the single thickness method, uses only one constant clearance-surface gap (Fig. 6.16). For both methods, the size of the gaps are determined as follows:-

Clearance-surface gap (C) = thickness at maximum material condition + clearance (6.2)

Drive-surface gap (D) = C - constant (6.3)

Normally by taking a maximum tolerance of +10% of thickness for the material and a constant value of 0.07mm (or 0.003in), it is adequate to obtain the required pinch-difference clearances for forming. For simplicity in usage, a surface definition scheme requiring the designers to define only the starting element and the ending element of the drive-surface has been adopted. With that the drive-surface elements can be distinguished from the clearance-surface elements without ambiguity.

6.5.3 The Side-Roll Option

It is sometimes inadequate to form a required shape satisfactorily with only the top and bottom rolls, hence the use of side-rolls is desirable to perform part of the forming, especially when bending legs to a near vertical orientation (Fig. 6.17). The side-roll option enables designers to precisely define which parts of the section are to be formed by side-rolls instead of top and bottom rolls.

The definition scheme adopted consists of designating each possible face of an element with a particular face number with respect to the direction of the element definition sequence (Fig. 6.18), and specifying the beginning and the end of the side-roll contour in terms of the element faces. Side-roll contours are then automatically generated with a side accessibility of roll material instead of the normal top and bottom accessibility.

6.5.4 The Extension-Contour Option

Rolls produced which are based on template contours alone have the tendency to slide along their axes of rotation creating forming problems. To prevent this from happening, extension-contours which interlock the matching rolls in position are used in practice. Such contours, sometimes referred to as gates, are not part of the template surface contours but they are instead contours extended from the break-points which separate one roll contour from the other.

For the top and bottom rolls without side-rolls (Fig. 6.19(a)), a pair of extension-contours on both sides of the rolls, called spigots, are used. If side-rolls are used (Fig. 6.19(b)), the extension-contours which still serve the same purpose are slightly different in shape, and there are also two of them instead of one. A definition scheme has been incorporated in the software to enable designers to specify extension-contours of the commonly used shapes and sizes to be used in the roll designs (Table 6.1). A database of extension-contour definitions has also been created to aid designers in the selection of the appropriate extension-contours (Table 6.2).

6.5.5 Program Operation

While running the program, the roll designer is guided by requests and prompts on the terminal screen to input the roll design data and choose the appropriate roll design options directly through the keyboard. A terminal listing for this program is given in Fig. 6.20.

Firstly, the roll designer specifies the section number and the stage number (NSTAGE) at which roll design processing is to begin. If the stage number is not equal to one, then there must be a corresponding roll design input data file for (NSTAGE-1) stages of information. This technique is to enable roll designers run the program up to a certain stage, then stop the program and continue at a later time from the next stage of processing.

Next, the roll designer inputs the roll design data and specifies the required options for one roll design stage. As a result, roll design drawings for that particular stage are produced on the Tektronix screen (Fig. 6.21). The roll designer then has to specify whether or not the roll drawings are satisfactory. If not, an edit facility has been incorporated in the software, during the course of this research, by which the roll designer can alter the data input interactively until satisfied with the roll drawings. Once satisfied, the roll designer can then procede to the next stage of processing.

In conjunction with the roll drawings, the roll design program produces a digitised roll profile data file. This file, which stores the geometric data for all the rolls in all forming stages, is required in further processing of the integrated system for providing geometric description of roll profiles.

6.5.6 Software Structure

The hierarchy of the software structure is shown in Chart 6.1, with the main program residing at the highest level of execution, controlling the sequence of execution of the subroutines at lower levels. The roll design software consists of four distinctive parts, namely:

1. The Roll Design Program (DESIGN)

2. The Flower Pattern Input Decoder (DCOFR)

3. The Roll Input Decoder (DECODE)

4. The Element Length Monitor (CLENG)

A brief account of the nature of the subroutines is given in Table 6.3.

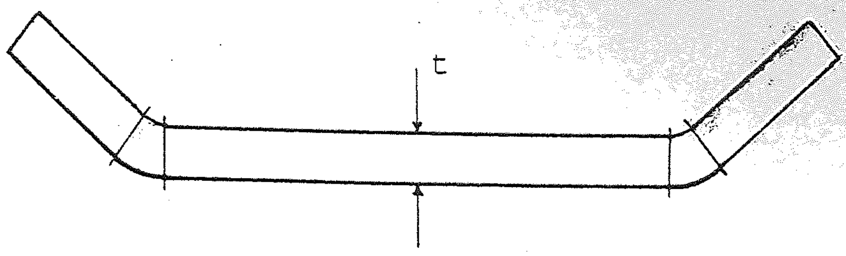


Fig. 6.1 ELEMENTS OF THE SECTION GEOMETRY

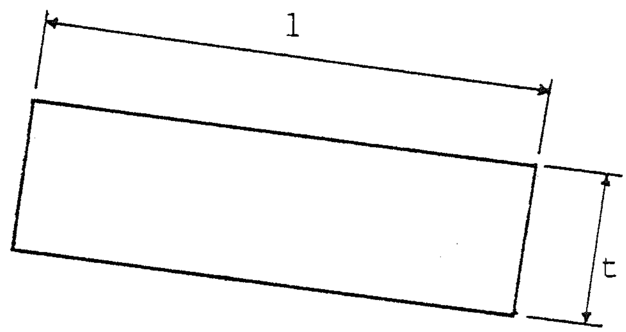


Fig. 6.2 DEFINITION OF A LINEAR ELEMENT

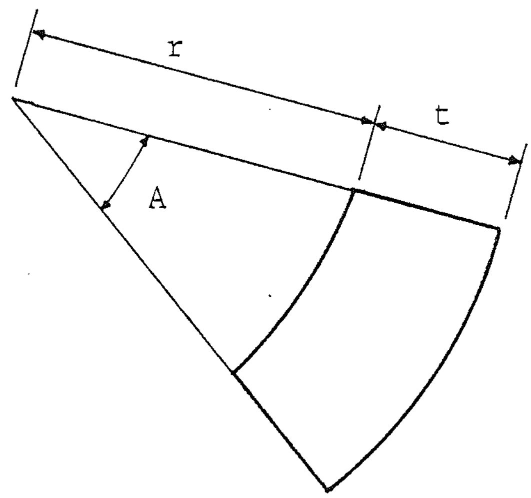
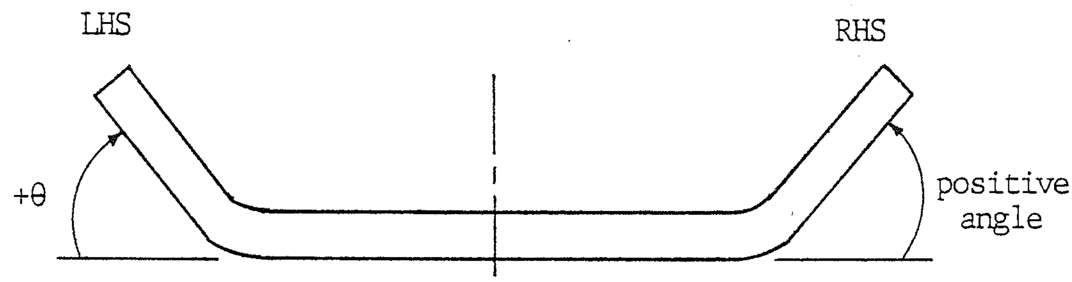
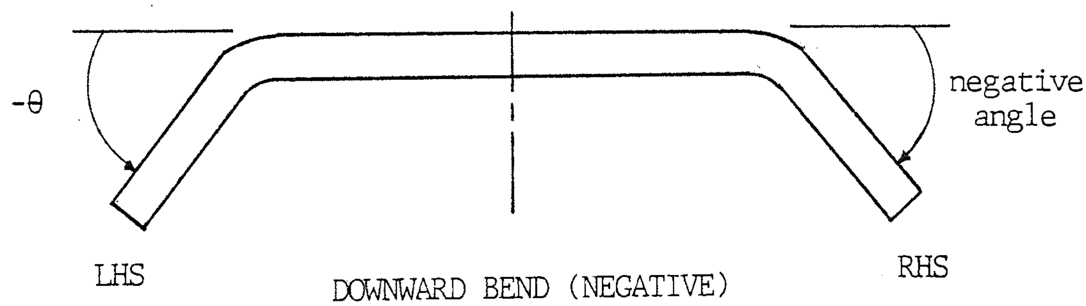


Fig. 6.3 DEFINITION OF A CIRCULAR ELEMENT



UPWARD BEND (POSITIVE)



DOWNWARD BEND (NEGATIVE)

Fig. 6.4 CONVENTION FOR THE BENDING DIRECTION

```
                    *** ROLFOM ***
                       ******


            ** FINISHED SECTION PROGRAM **


*** PLEASE INPUT THE SECTION NO. ***
section no. = ?
  1250A


 ****************************************
 **                                    **
 **         TERMINAL DEFINITION        **
 **         PLEASE INPUT  1,2,3,4      **
 **         (1) FOR T4010              **
 **         (2) FOR T4107              **
 **         (3) FOR T4113              **
 **         (4) FOR VT125              **
 **                                    **
 ****************************************
  2
```

```
** PLEASE SUPPLY THE FOLLOWING DATA ACCORDING TO THE GIVEN FORMAT:-

INPUT UNIT          OUTPUT UNIT         THICKNESS           ORIGIN
----------          -----------         ---------           ------
(INTEGER)           (INTEGER)           (REAL)              (INTEGER)

WHERE,

INPUT UNIT IS IN INCH(1) OR MM(2),
OUTPUT UNIT IS ALSO IN INCH(1) OR MM(2),
THICKNESS IS THICKNESS OF STRIP,
ORIGIN IS THE STARTING POINT FOR ELEMENT DEFINITION SEQUENCE LATER ON.

ORIGIN=1 IF FROM LEFT TOWARDS RIGHT (ONE-SIDED).
ORIGIN=2 IF FROM RIGHT TOWARDS LEFT (ONE-SIDED).
ORIGIN=3 IF FROM CENTRE TOWARDS RIGHT AND THEN FROM CENTRE TOWARDS LEFT.
ORIGIN=4 IF FROM CENTRE TOWARDS LEFT AND THEN FROM CENTRE TOWARDS RIGHT.
ORIGIN=5 IF FROM CENTRE TOWARDS RIGHT (SYMMETRICAL SECTION).

** PLEASE INPUT IUNIT,OUNIT,THICK,ORIGIN **
IUNIT     OUNIT     THICK     ORIGIN
  2         2       0.900       5
```

Fig. 6.5 A TYPICAL TERMINAL LISTING FOR DATA INPUT FOR THE FINISHED SECTION PROGRAM (PART 1)

** PLEASE ENTER THE DATA FOR ELEMENT DEFINITION SEQUENCE ACCORDING TO THE GIVEN FORMAT, ONE DEFINITION STATEMENT FOR EVERY ELEMENT ENTERED :-

SEQUENCE NUMBER (N)	ELEMENT TYPE (TYPE)	LENGTH OR RADIUS	ANGLE OF BENDING
(INTEGER)	(INTEGER)	(REAL)	(REAL)
START FROM 1, INCREMENT BY 1 UP TO 5Ø, TO TERMINATE ENTER Ø.	1 = LINEAR, 2 = CIRCULAR, THE REST ARE ILLEGAL.	POSITIVE LENGTH FOR TYPE 1, INSIDE RADIUS FOR TYPE 2 (MAY BE Ø).	FOR TYPE 2 ELEMENTS ONLY, ZERO FOR TYPE 1, NON-ZERO FOR TYPE 2. *

*THE EXCEPTION BEING, WHEN N=1 AND TYPE=1 (AND ORIGIN NOT 5!), ANGLE OF BENDING IS TAKEN AS THE ANGLE OF INCLINATION BETWEEN THE HORIZONTAL-AXIS AND THE FIRST LINEAR ELEMENT, PERMISSIBLE RANGE IS FROM -9Ø TO +9Ø DEGREES.

NOTE THAT WHEN ORIGIN IS 3 OR 4 (DOUBLE SIDED DEFINITION), 2 SETS OF DEFINITION SEQUENCE ARE REQUIRED, ONLY 1 SET IS REQUIRED WHEN ORIGIN IS 1,2 OR 5.
FIRST ELEMENT AND LAST ELEMENT OF THE SEQUENCE MUST BE LINEAR.
MAXIMUM NO. OF ELEMENTS IN EACH SEQUENCE MUST BE LESS THAN 5Ø.

1	1	1Ø.7ØØØ	Ø.ØØØØ
2	2	Ø.9ØØØ	9Ø.ØØØØ
3	1	21.4ØØØ	Ø.ØØØØ
4	2	Ø.9ØØØ	-9Ø.ØØØØ
5	1	8.2ØØØ	Ø.ØØØØ
Ø	Ø	Ø.ØØØØ	Ø.ØØØØ

** PLEASE SELECT THE PAPERSIZE AND THE SCALE ACCORDING TO THE GIVEN FORMAT :-

PAPERSIZE	SCALE
(INTEGER)	(REAL)

PAPERSIZE = Ø,1,2,3,4 FOR AØ,A1,A2,A3,A4 SIZES RESPECTIVELY.
SCALE= ANY POSITIVE VALUE LESS OR EQUAL TO THE FOLLOWING LIMITS BASED ON THE SELECTED PAPERSIZE.

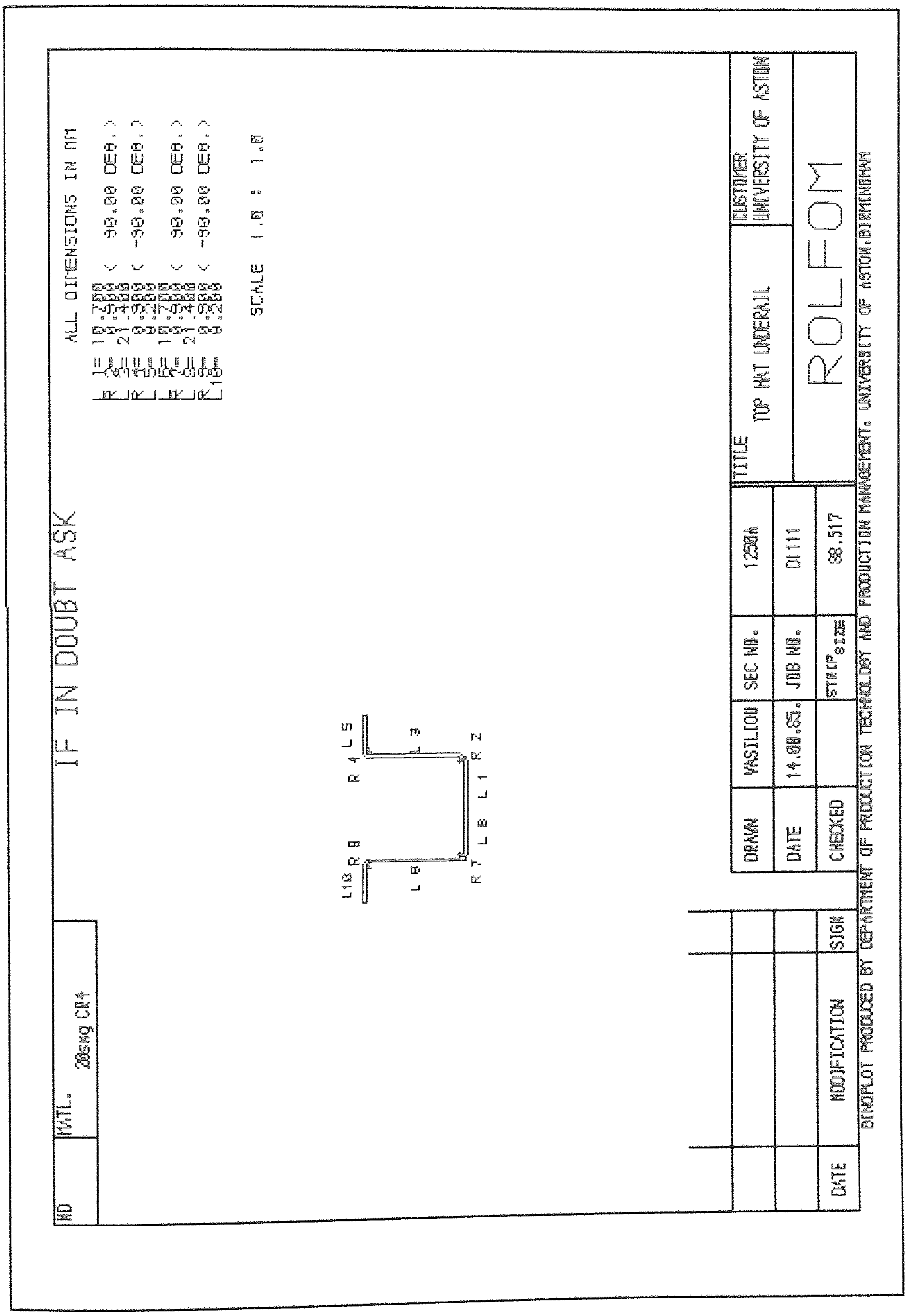
FOR PAPERSIZE AØ, MAXIMUM PERMISSIBLE SCALE = 24.31
FOR PAPERSIZE A1, MAXIMUM PERMISSIBLE SCALE = 15.97
FOR PAPERSIZE A2, MAXIMUM PERMISSIBLE SCALE = 1Ø.42
FOR PAPERSIZE A3, MAXIMUM PERMISSIBLE SCALE = 6.25
FOR PAPERSIZE A4, MAXIMUM PERMISSIBLE SCALE = 3.47
** PLEASE INPUT THE PSIZE AND PSCALE
4 1.ØØØØ

Fig. 6.5 (PART 2)

```
** DO YOU WANT ANY DIMENSIONING?
ENTER 1 IF YES, OR Ø IF NO.
 1


 ** DO YOU WISH TO SUPPLY ANY TITLE-BLOCK INFORMATION ?
 ENTER 1 IF YES, OR Ø IF NO.
  1


 ** PLEASE MAKE THE SELECTION ACCORDING TO THE GIVEN LIST
 WITH THE REQUIRED FORMAT :-
 NO.  DESCRIPTION  BLOCK  MAXIMUM NO. OF CHARACTERS
 ---  -----------  -----  -------------------------

  1   TITLE          2              29
  2   CUSTOMER       2              19
  3   SEC. NO.       3              14
  4   JOB NO.        3              14
  5   STRIP SIZE     3     (DETERMINED INTERNALLY)
  6   DRAWN          3               9
  7   DATE           3               9
  8   CHECKED        3               9
  9   NO.            4               9
 1Ø   MATL.          4              24
  Ø            (TERMINATION)

 EACH SELECTION INPUT CONSISTS OF 2 LINES:-
 LINE 1 SHOULD CONTAIN ITEM NO.,
 LINE 2 SHOULD CONTAIN NO. OF CHARACTERS PLUS TEXT.

        16 CHARACTERS FOR :- TOP HAT UNDERAIL
        19 CHARACTERS FOR :- UNIVERSITY OF ASTON
         4 CHARACTERS FOR :- 1ØØØ
         5 CHARACTERS FOR :- D1111
         8 CHARACTERS FOR :- VASILIOU
         9 CHARACTERS FOR :- 14.Ø5.85.
         9 CHARACTERS FOR :- 2Øswg CR4
```

Fig. 6.5 (PART 3)

Fig. 6.6 A TYPICAL FINISHED SECTION DRAWING



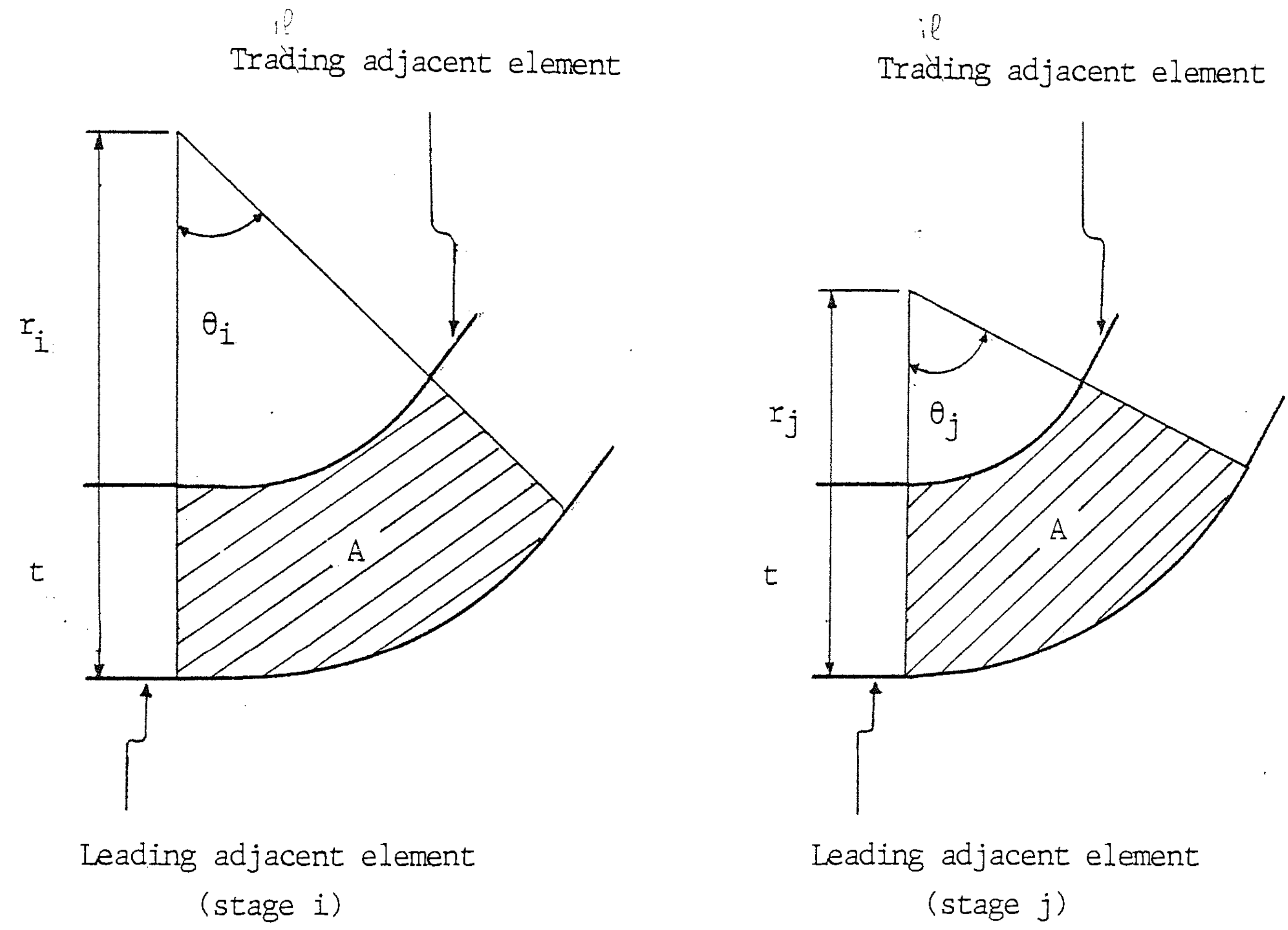


Fig. 6.7 THE OPENING-RADII METHOD OF FORMING

```
                              **** ROLFOM ****
                                  ******

                      ** FLOWER PATTERN PROGRAM **

*** PLEASE INPUT THE SECTION NO. ***
section no. = ?
  125ØA

  ***************************************
  **                                  **
  **        TERMINAL DEFINITION       **
  **        PLEASE INPUT  1,2,3,4     **
  **        (1) FOR T4Ø1Ø             **
  **        (2) FOR T41Ø7             **
  **        (3) FOR T4113             **
  **        (4) FOR VT125             **
  **                                  **
  ***************************************
   2

** INPUT JRUN = 1 IF FLOWER PATTERN ONLY,OR
                2 IF ROLLER-PLOTTINGS ONLY,OR
                3 IF BOTH OF THE ABOVE
 JRUN = ?
  3

** INPUT NSTAGE (NSTAGE = TOTAL NO. OF PASS,MAXIMUM 5Ø
 NSTAGE = ?
  9

** INPUT JBEND (SELECTION OF CIRCULAR-ELEMENT BENDING OPTION,
(TYPE Ø IF SIMPLE ELEMENT DEFINITION, OR
      1 IF COMPOSITE PERCENTAGE ELEMENT DEFINITION)
  JBEND = ?
   Ø

** THE SECTION IS A SYMMETRICAL SECTION **
------THUS INPUT THE FOLLOWING :
PASS      ELEMENT TO        ANGLE OF
 NO.      BE BENT(RIGHT)    BEND
(terminate input by typing
 Ø         Ø           Ø.Ø)
```

Fig. 6.8 A TYPICAL TERMINAL LISTING FOR DATA INPUT FOR THE FLOWER PATTERN PROGRAM (PART 1)

1	2	3Ø.ØØ
2	2	55.ØØ
2	4	-25.ØØ
3	2	75.ØØ
3	4	-45.ØØ
4	2	9Ø.ØØ
4	4	-75.ØØ
5	2	9Ø.ØØ
5	4	-91.ØØ
6	2	95.ØØ
6	4	-9Ø.ØØ
7	2	85.ØØ
7	4	-9Ø.ØØ
8	2	9Ø.ØØ
8	4	-9Ø.ØØ
9	2	9Ø.ØØ
9	4	-9Ø.ØØ
Ø	Ø	Ø.ØØ

```
** DO YOU WANT THE OPTION FOR SHARPENING OF INSIDE RADII ?
— input JSHARP = Ø if radii-sharpening is not required at all, or
                 1 if stage no. are to be entered individually, or
                -1 if all stages except last stage require sharpening
JSHARP =?
 -1


** DO YOU WANT THE FIXED PERCENTAGE OPTION ?
   INPUT THE FOLLOWING :-
LINE     RHS ELEMENT     STAGE NO     STAGE NO
NO.      NO.             START        FINISH
(skip or terminate the input for this option by typing :
Ø        Ø                Ø           Ø)

Ø        Ø        Ø        Ø


 PAPERSIZE A4, MAXIMUM SCALE USED =  2.58
```

Fig. 6.8 (PART 2)

Fig. 6.9 A TYPICAL FLOWER PATTERN DRAWING WITH COMMON ORIGIN

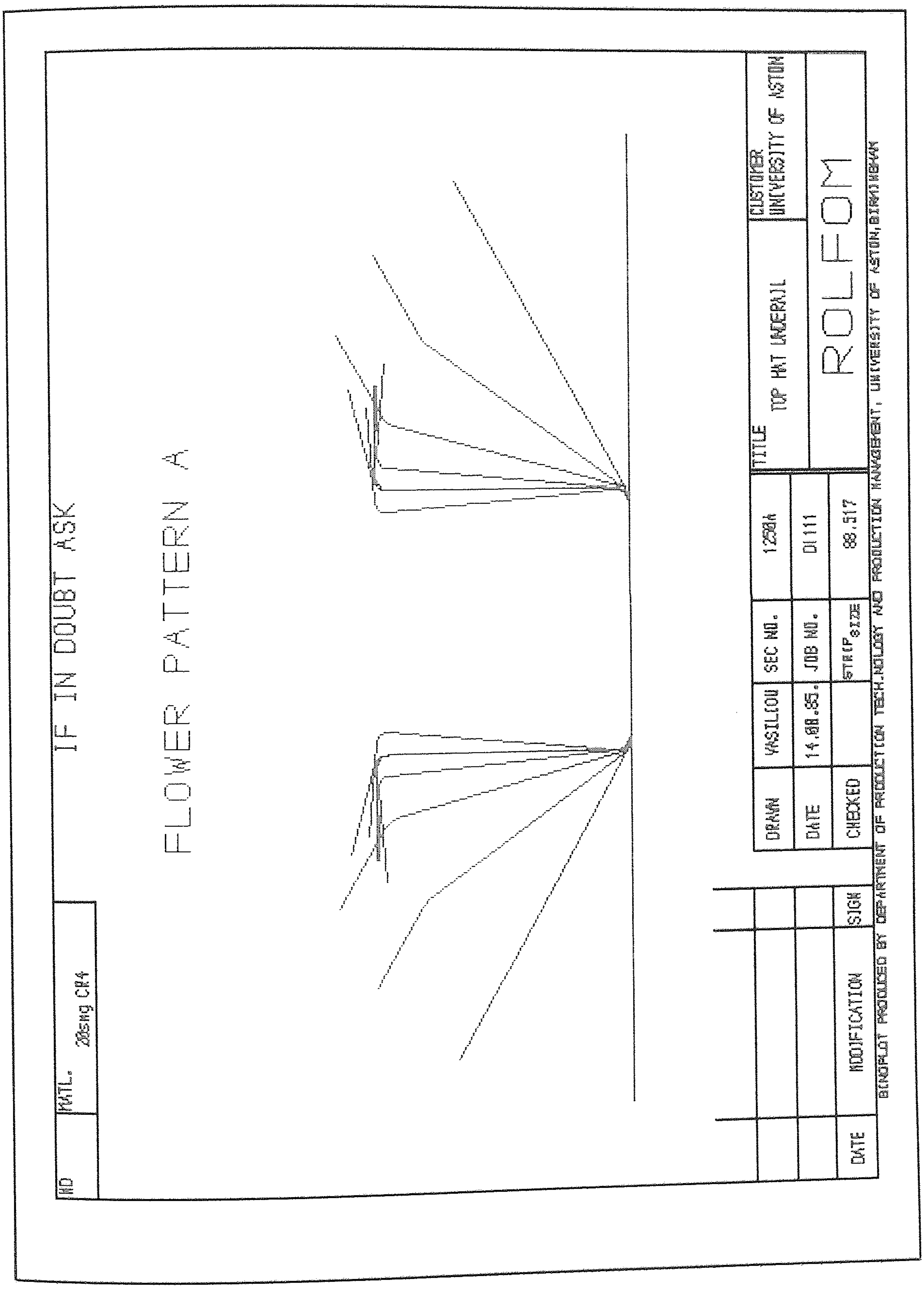
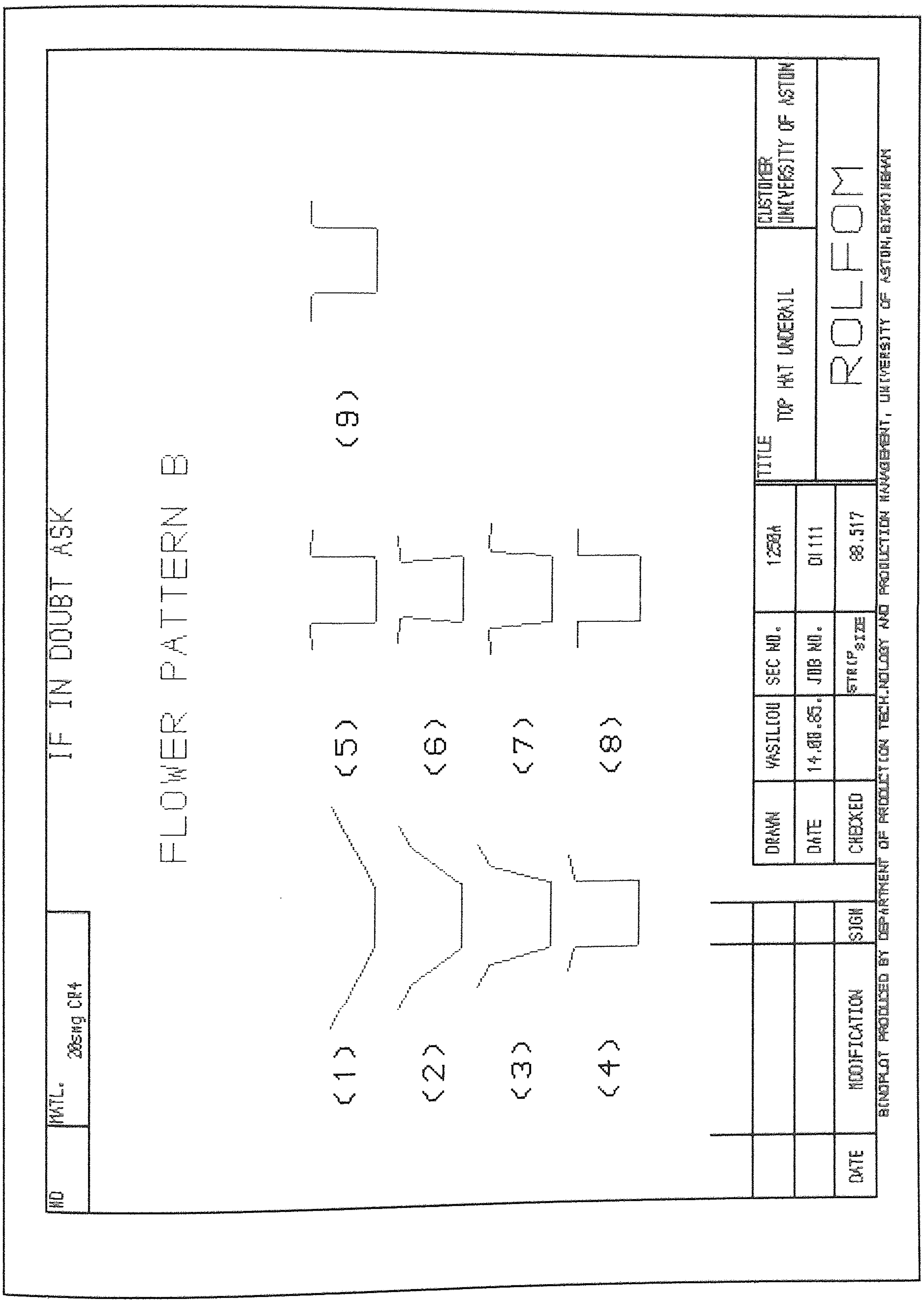


Fig. 6.10 A TYPICAL FLOWER PATTERN DRAWING WITH SEPARATE ORIGIN



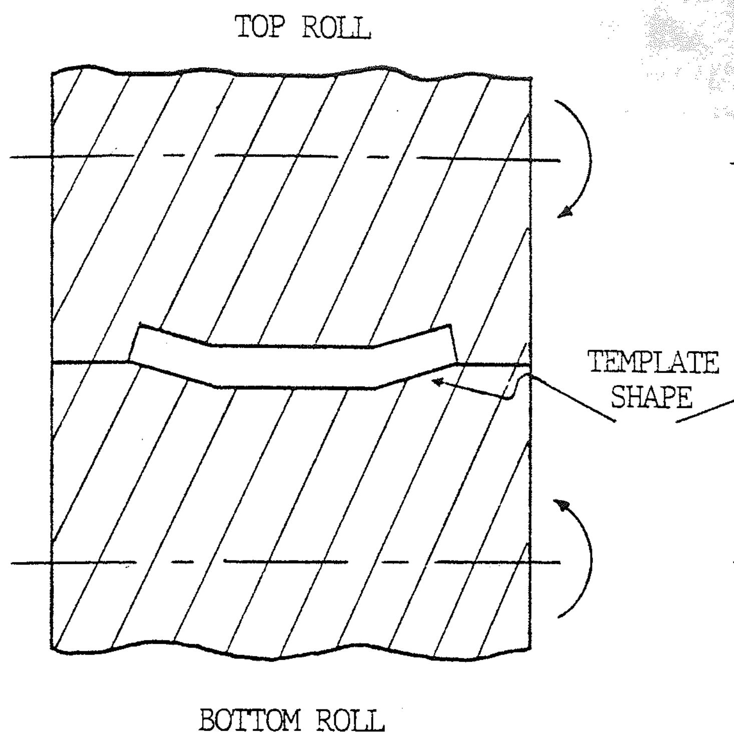


Fig. 6.11 A CASE OF ROLL CONTOUR FOLLOWING THE TEMPLATE SHAPE EXACTLY

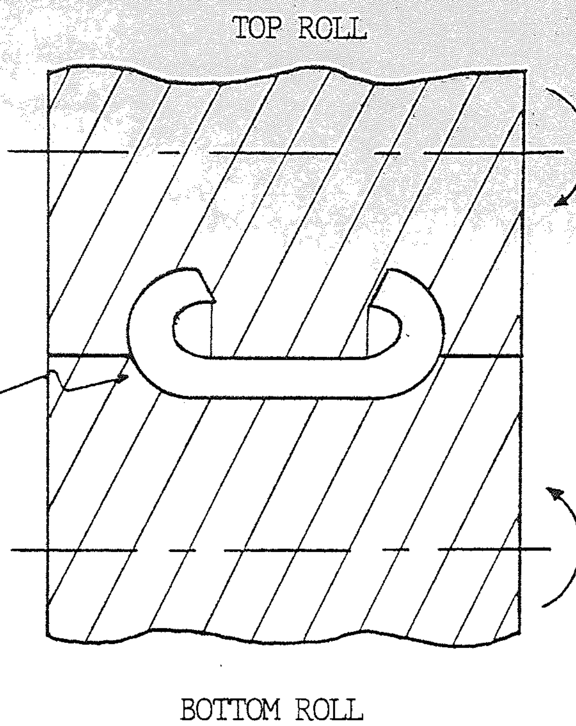


Fig. 6.12 A CASE OF ROLL CONTOUR PARTIALLY FOLLOWING THE TEMPLATE SHAPE

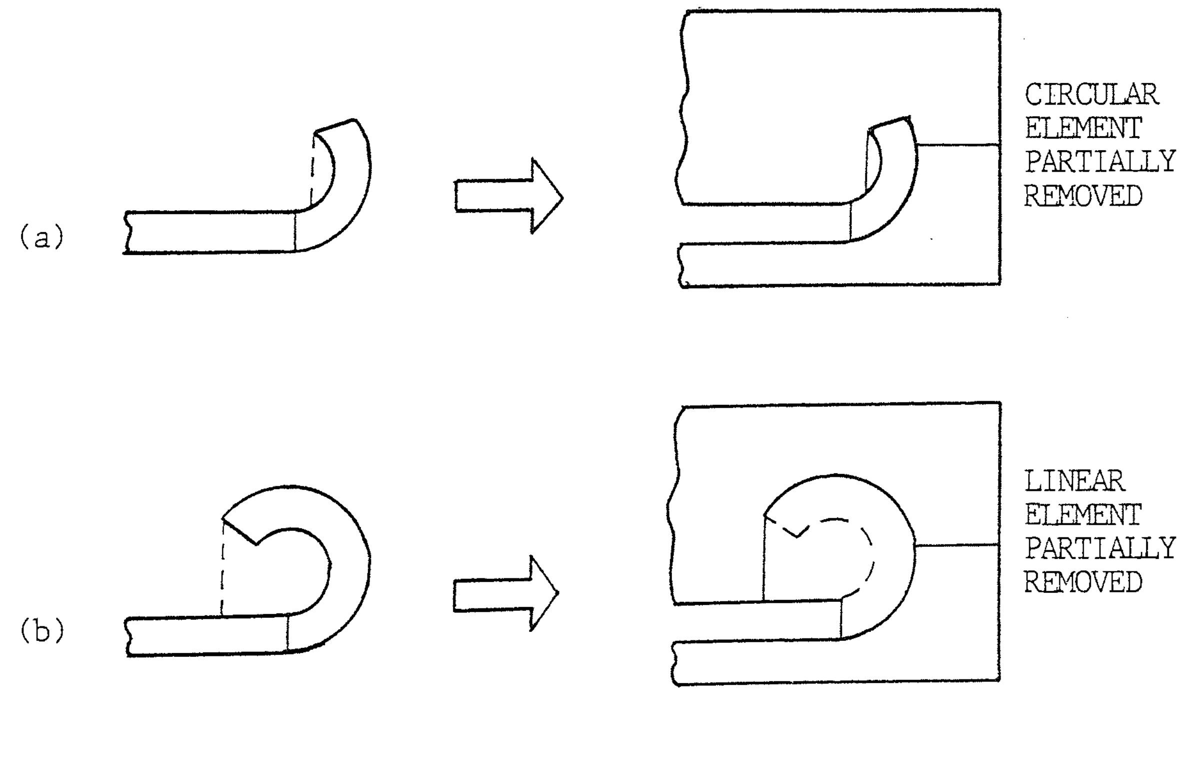
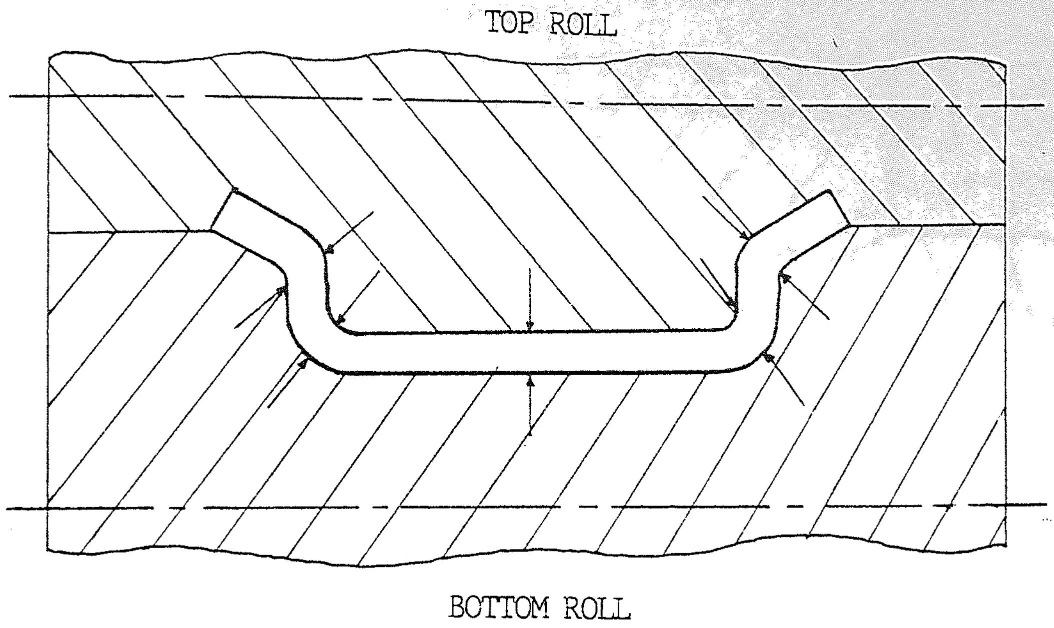


Fig. 6.13 ROLL CONTOUR MODIFICATION INVOLVING PART OR WHOLE OF LINEAR AND CIRCULAR ELEMENTS



(Varying gap distances a, b, c, d and e)

Fig. 6.14 PINCH-DIFFERENCE SURFACES

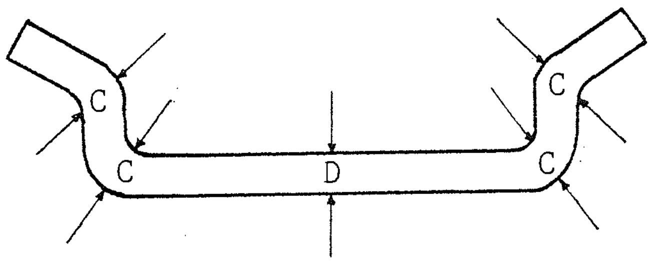


Fig. 6.15 THE DOUBLE THICKNESS METHOD

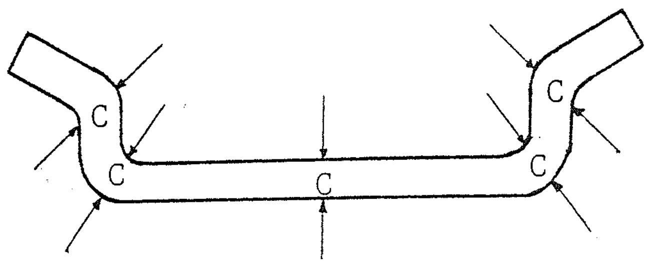


Fig. 6.16 THE SINGLE THICKNESS METHOD

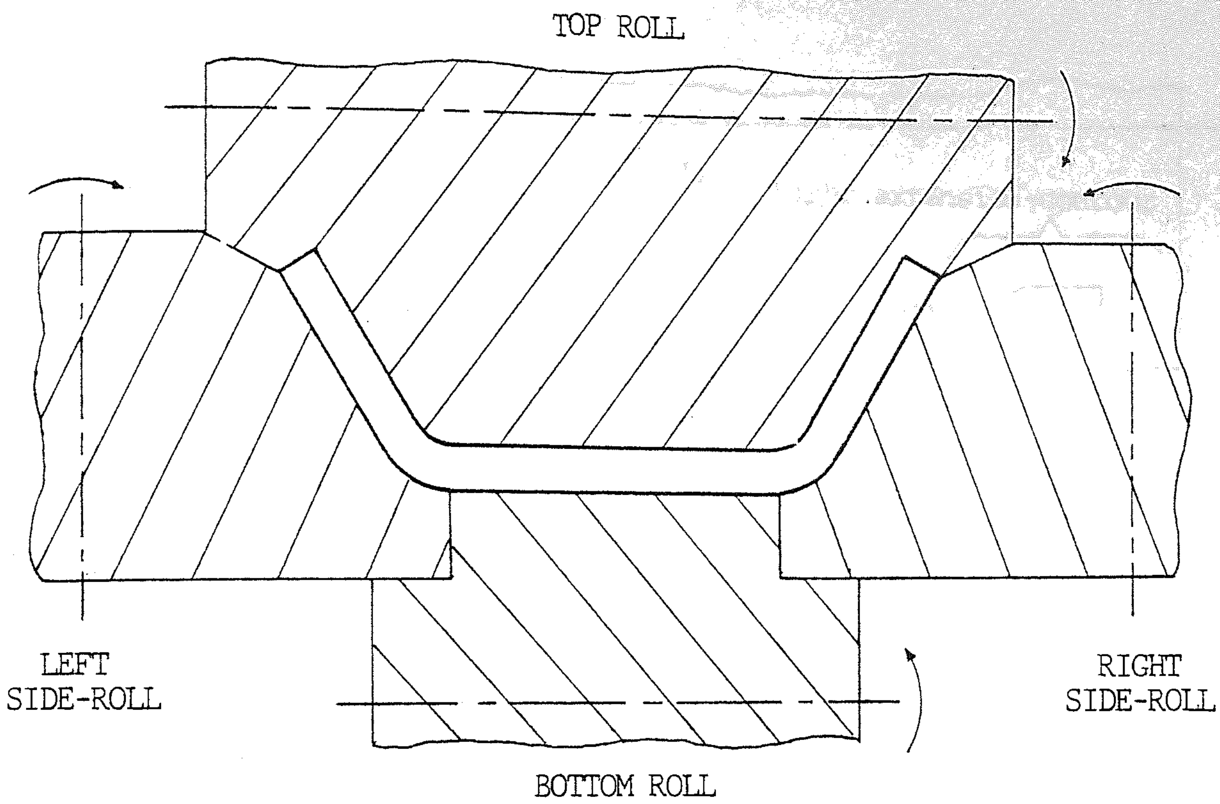


Fig. 6.17 THE NECESSITY OF USING SIDE-ROLLS

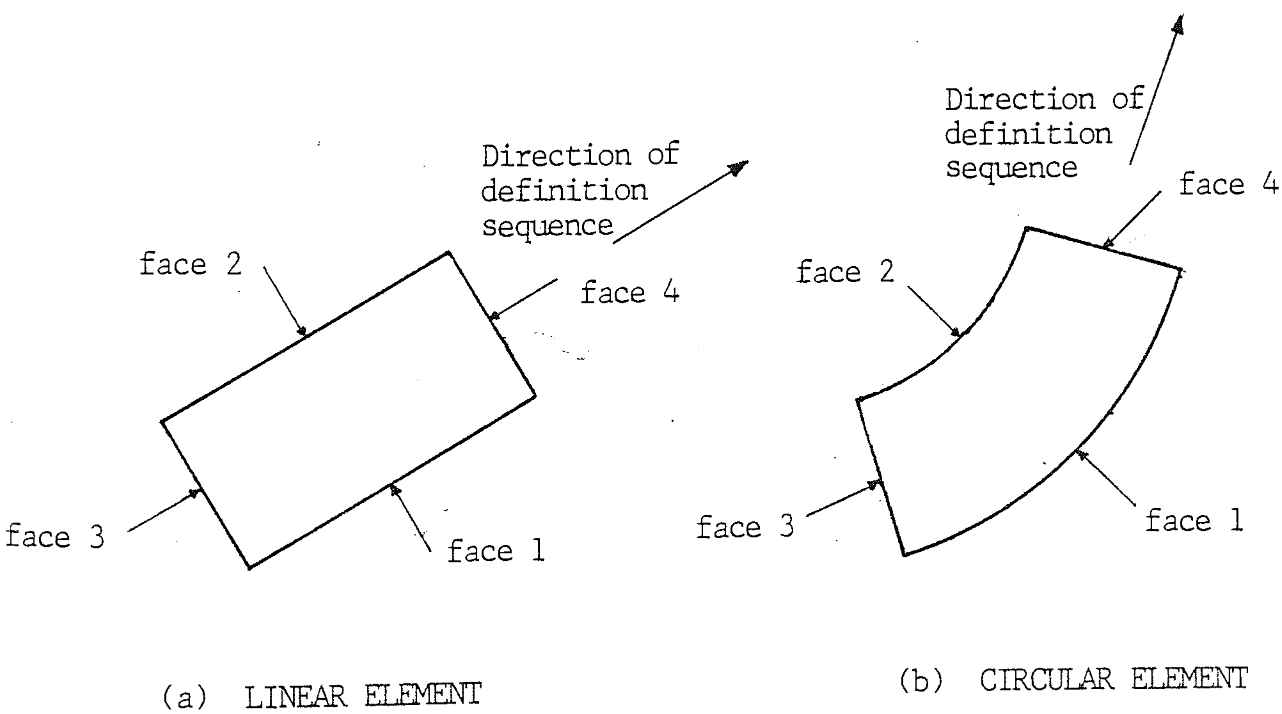
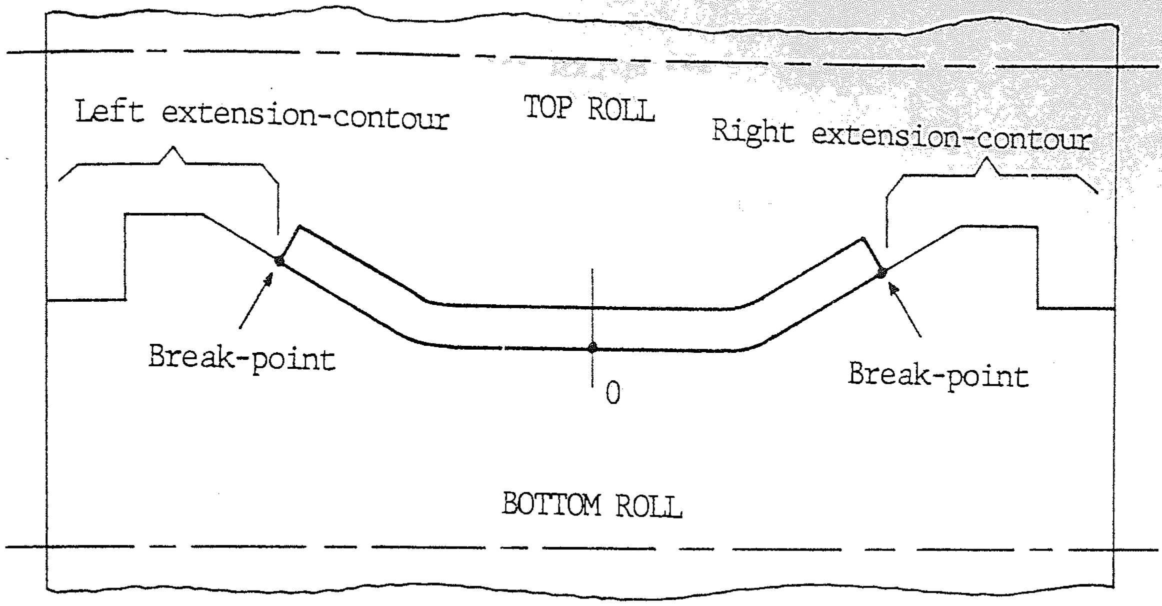
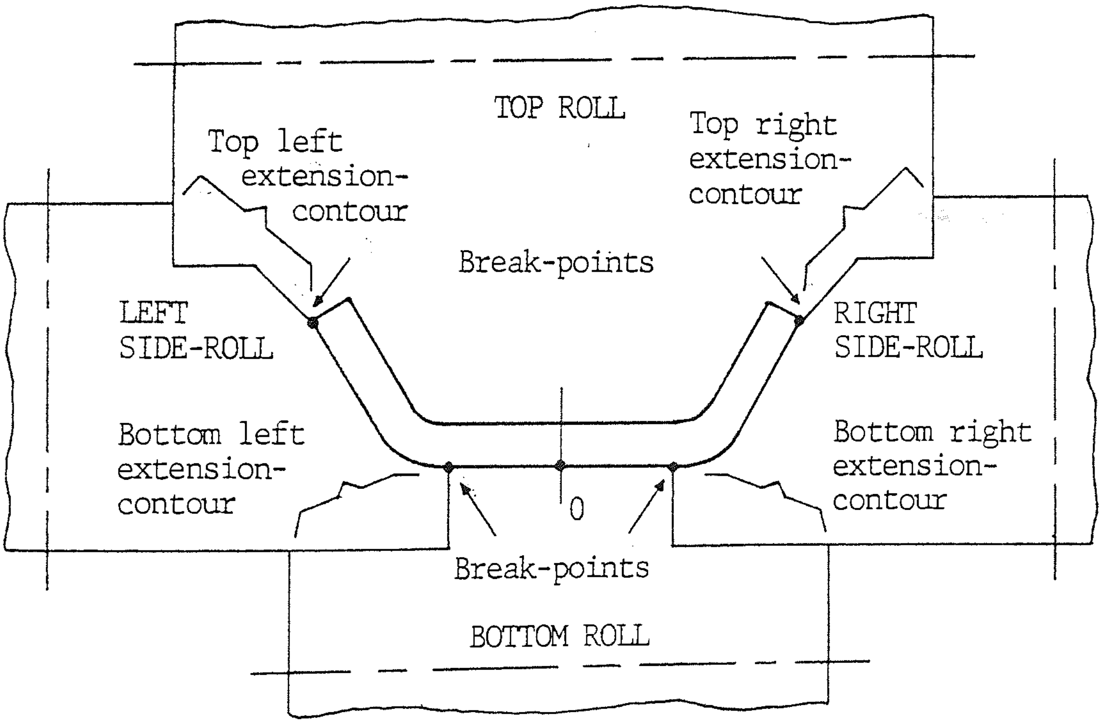


Fig. 6.18 THE ELEMENT FACES FOR DEFINING SIDE-ROLL CONTOURS



(a) EXTENSION-CONTOURS FOR TOP AND BOTTOM ROLLS ONLY (SPIGOTS)



(b) EXTENSION-CONTOURS FOR TOP AND BOTTOM ROLLS WITH SIDE-ROLLS

Fig. 6.19 USE OF EXTENSION-CONTOURS FOR PREVENTING SLIDING IN ROLLS

```
                              *** ROLFOM ***
                                 ******

                       ** ROLL DESIGN PROGRAM **


*** PLEASE INPUT THE SECTION NO. ***
section no. = ?
 1250A


 ***************************************
 **                                   **
 **        TERMINAL DEFINITION        **
 **        PLEASE INPUT  1,2,3,4      **
 **        (1) FOR T4010              **
 **        (2) FOR T4107              **
 **        (3) FOR T4113              **
 **        (4) FOR VT125              **
 **                                   **
 ***************************************
  2


** DO YOU WANT CONSISTENT PASS-HEIGHTS & C-C DISTANCE?
INPUT IPASHT =  1 IF YES,OR
               -1 IF YOU WANT INCONSISTENT PASS HEIGHTS AND C-C DISTANCE
IPASHT = ?
 -1


** PLEASE INPUT THE PASS HEIGHT (PASHT) AND C-C DISTANCE (CTOC)
INPUT PASHT & CTOC FOR STAGE  1 PLEASE
  53.340      113.180


** INPUT 1 FOR ITOC IF YOU WANT CONSISTENT LH & RH TOLERANCE, OTHERWISE
INPUT -1 FOR INCONSISTENT TOLERANCES
ITOC=?
  1


** NOW INPUT THE TOLERANCES, WHERE
    TOLLH = LH TOLERANCE BETWEEN ROLLER & LAST ELEMENT,
    TOLRH = RH TOLERANCE BETWEEN ROLLER & LAST ELEMENT.
     TOLLH       TOLRH
     0.100       0.100
```

Fig. 6.20 A TYPICAL TERMINAL LISTING FOR DATA INPUT FOR THE ROLL DESIGN PROGRAM (PART 1)

```
** INPUT JTEMP = 1 IF YOU WANT COMPONENT DRAWING IN HIDDEN LINE,OTHERWISE Ø
      RSCALE = DESIRED SCALE FOR THE ROLLER DRAWINGS
      RGAP = THE GAP DIMENSION BETWEEN TOP AND BOTTOM ROLL
  JTEMP    RSCALE    RGAP
    Ø       1.ØØØ     1Ø.ØØØ


** INPUT JSTAGE(1) =-1 IF ALL STAGES REQ'D FOR ROLLERS,OR
      JSTAGE(1) = 1 IF NO STAGES REQ'D ,OR
      JSTAGE(1) = ANY POSITIVE INTEGER LESS THAN NSTAGE
                  IF SELECTED STAGES REQ'D FOR ROLLERS
JSTAGE(1)=?
 -1


** DO YOU WANT THE PINCH DIFFERENCE OPTION?
INPUT JPINCH = Ø IF NO EXTERNAL PINCH DIFFERENCE DIMENSION
                 DEFINITION IS SUPPLIED, OR
               1 IF ONLY ONE PINCH DIFFERENCE DIMENSION DEFINITION
                 IS SUPPLIED FOR ALL BENDING STAGES, OR
              -1 IF PINCH DIFFERENCE DIMENSION DEFINITION IS SUPPLIED
                 INDIVIDUALLY FOR EACH BENDING STAGE, OR
               2 IF SINGLE THICKNESS OPTION WITH ONE COMMON CLEARANCE
                 VALUE FOR ALL STAGES SELECTED, OR
              -2 IF SINGLE THICKNESS OPTION WITH INDIVIDUAL CLEARANCE
                 VALUE FOR EACH STAGE SELECTED.
JPINCH=?
 -1


** INPUT THE PINCH DIFFERENCE DIMENSIONS,WHERE
PDIM1 = THICKNESS BETWEEN THE DRIVE SURFACES
PDIM2 = THICKNESS BETWEEN THE CLEARANCE SURFACES
INPUT PDIM1 & PDIM2 FOR STAGE  1 PLEASE
  Ø.787     Ø.864


** NOW INPUT ELEMENT NO. WHICH DEFINES DRIVE SURFACE FOR EVERY STAGE,
2 DEFINITION STATEMENTS PER STAGE REQUIRED,WHERE
ISQP=CURRENT BENDING STAGE SEQUENCE NO.
IEPL = L.H.S. ELEMENT DEFINING THE DRIVE SURFACE CONTOUR
IEPR = R.H.S. ELEMENT DEFINING THE DRIVE SURFACE CONTOUR
ISQP  IEPL  IEPR
  1     1     1
  1     1     1


**THE NEW PINCH OPTION**
PLEASE INDICATE WHERE THE CLEARANCE TO BE ADDED
  ENTER 1 FOR OUTSIDE FACES
        2 FOR INSIDE FACES
     OR 3 IF EQUALLY DISTRIBUTED ON BOTH FACES
 (1/2/3) ?
   3
```

Fig. 6.20 (PART 2)

```
** ARE YOU GOING TO CHOOSE THE SIDE ROLL OPTION?
ENTER ISROL = 1 IF YES,OR
            = Ø IF NO
ISROL = ?
  1


** ENTER IOTOS = 1 IF CONSISTENT ORIGIN TO SIDE-ROLL AXES,OR
                -1 IF INCONSISTENT ORIGIN TO SIDE-ROLL AXES DISTANCES
IOTOS = ?
 -1


** INPUT ORIGIN TO SIDE-ROLL AXES DISTANCE,WHERE
OTOSL = DISTANCE BETWEEN ORIGIN AND LEFT SIDE-ROLL CENTRE, AND
OTOSR = DISTANCE BETWEEN ORIGIN AND RIGHT SIDE-ROLL CENTRE.
INPUT OTOSL & OTOSR FOR STAGE 1 PLEASE
  1ØØ.ØØØ      1ØØ.ØØØ


** INPUT THE SIDE-ROLL CONTOUR DEFINITION, WHERE
ISQS  = CURRENT BENDING STAGE SEQUENCE NO.,
IESL1 = L.H.S. ELEMENT CONSTITUTING L.H.S. SIDE-ROLL CONTOUR,
IESL2 = WHICH FACE OF THE L.H.S. ELEMENT IS DESIRED,
IESR1 = R.H.S. ELEMENT CONSTITUTING R.H.S. SIDE-ROLL CONTOUR,
IESR2 = WHICH FACE OF THE R.H.S. ELEMENT IS DESIRED.
INPUT ISQS,IESL1,IESL2,IESR1 & IESR2 PLEASE
  Ø    Ø    Ø    Ø    Ø


** INPUT SELECTION FOR EXTENSION-CONTOUR OPTION,ENTER
IEXTN = 1 IF EXTENSION CONTOUR OPTION WILL BE USED
      = Ø IF EXTENSION CONTOUR OPTION WILL NOT BE USED
  1


** INPUT SIDE-CONTOUR SELECTION FOR EACH BENDING STAGE, WHERE
ISQD  = BENDING STAGE NO. FOR WHICH SIDE-CONTOUR DEFINITION IS
        INTENDED
IELD1 = TYPE OF SIDE-CONTOUR ON L.H.S.
IELD2 = SIDE-CONTOUR NO. WHICH HAS BEEN DEFINED PREVIOUSLY AND
        IS TO BE SELECTED FOR THIS STAGE NO. ON L.H.S.
IERD1 = TYPE OF SIDE-CONTOUR ON R.H.S.
IERD2 = SIDE-CONTOUR NO. WHICH HAS BEEN DEFINED PREVIOUSLY AND
        IS TO BE SELECTED FOR THIS STAGE NO. ON R.H.S.
ISQD  IELD1  IELD2  IERD1  IERD2
  1     3      1      3      1
```

Fig. 6.20 (PART 3)

Fig. 6.21 (a) A TYPICAL ROLL DESIGN DRAWING FOR STAGE 1 OF THE FORMING PROCESS (TOP & BOTTOM ROLLS ONLY)

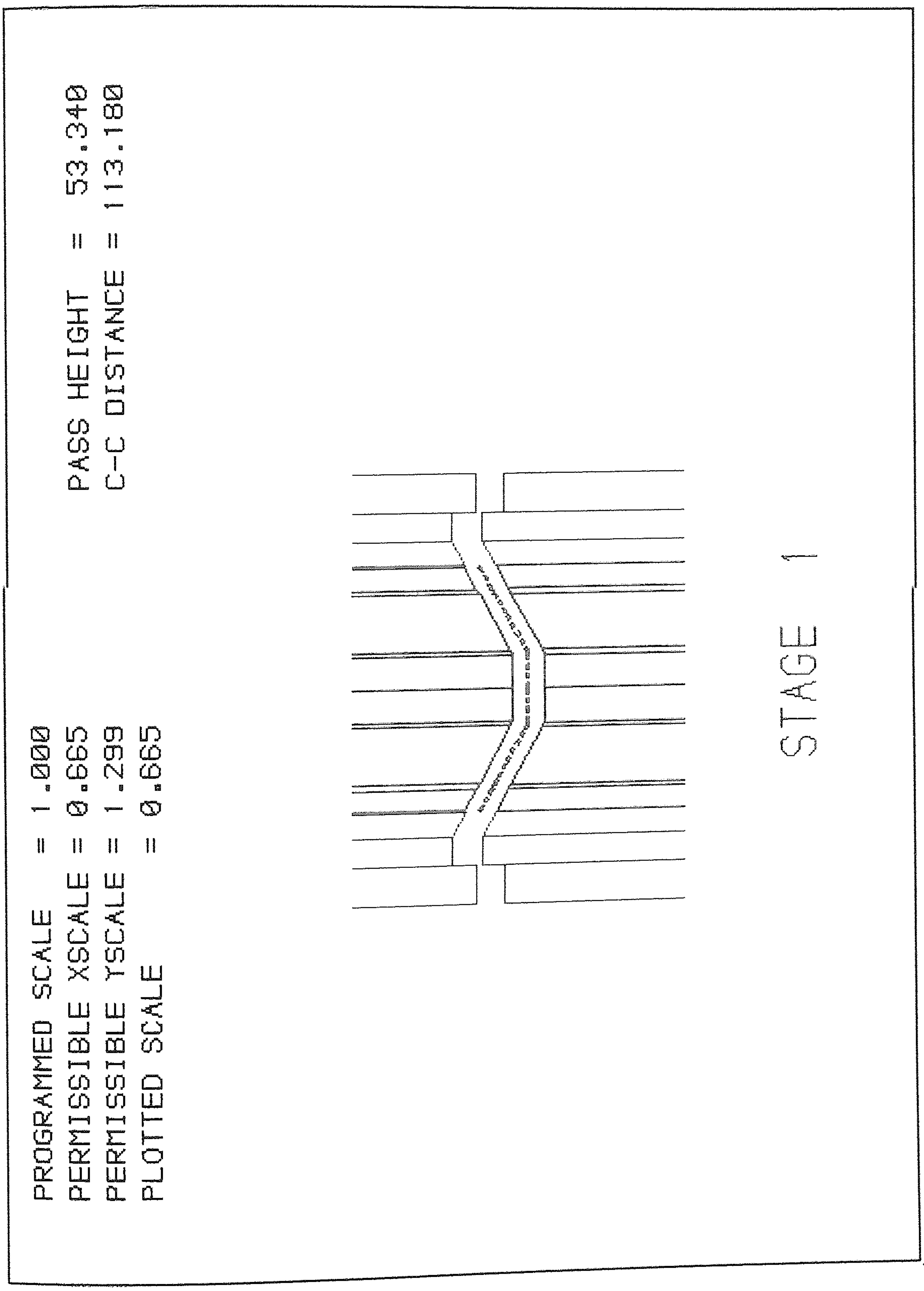


Fig. 6.21 (b) A TYPICAL ROLL DESIGN DRAWING FOR STAGE 3 OF THE FORMING PROCESS (TOP, BOTTOM & SIDE ROLLS)

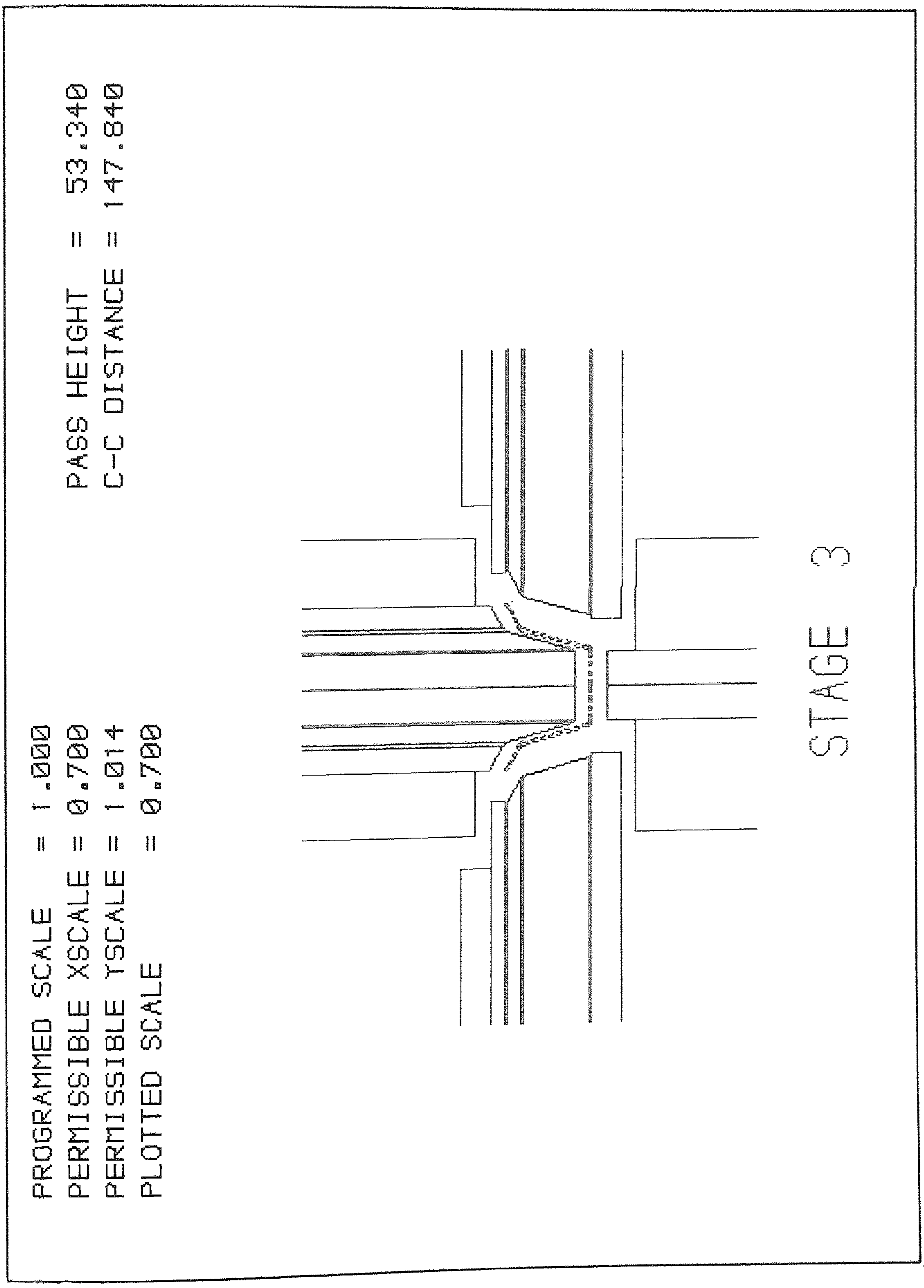


Table 6.1 EXTENSION-CONTOUR DEFINITION SCHEME

CONTOUR TYPE	LINEAR PART NUMBER	ANGLE OF ORIENTATION	LENGTH
Spigot Type A	1	As break-point	Positive
	2	0°	Zero or Positive
	3	+90°	Positive
	4	0°	Positive
Spigot Tybe B	1	As break-point	Positive
	2	0°	Zero or Positive
	3	-90°	Positive
	4	0°	Positive
Top Extension-Contour For Side-Roll	1	+30°	Zero or Positive
	2	+90°	Zero or Positive
	3	0°	Zero or Positive
	4	+90°	Positive
Bottom Extension-Contour For Side-Roll	1	-30°	Zero or Positive
	2	-90°	Zero or Positive
	3	0°	Zero or Positive
	4	-90°	Positive

(Note that a part with zero length means absence of that part)

Table 6.2 THE EXTENSION-CONTOUR DIMENSIONS DATA STORE

VARIABLE NAME (SUBSCRIPT)	DESCRIPTION
ISC(1,I)	Side-contour no.
ISC(2,I)	Side-contour type.
SCDIM(1,I)	Dimension definition for side-contour part 1.
SCDIM(2,I)	Dimension definition for side-contour part 2.
SCDIM(3,I)	Dimension definition for side-contour part 3.
SCDIM(4,I)	Dimension definition for side-contour part 4.

(ISC(J,I), J = 1,2) are integer values.

(SCDIM(J,I), J = 1,4) are real values.

I is a data store number ranging from 1 to 50.

Table 6.3 SUBROUTINES OF THE ROLL DESIGN SOFTWARE (PART 1)

SUBROUTINE	LEVEL	FUNCTION
DESIGN (MAIN PROGRAM)	1	Calls upon subordinate subroutines to decode data from the flower pattern input file, the roll control input file and the intermediate file, to generate basic roll design contours with pinch-difference surfaces, side-rolls and extension-contours if required, and to output the roll contour data for further processing.
INIT4R	2	Initialisers the roll design data structure
RDPL	2	Inputs reference data from the intermediate data file.
DCOFR	2	Inputs and decodes data for the flower-pattern and the template stages.
DECODE	2	Decodes general roll design control and definition data, one stage at a time, and controls other decoding subroutines.
BENDT	3	Decodes bending status data without composite element length definition.
BENDX	3	Decodes bending status data with composite element length definition.
BENDY	3	Decodes instructions for the radii-sharpening option.

Table 6.3 (PART 2)

SUBROUTINE	LEVEL	FUNCTION
BENDZ	3	Decodes instructions for the short-leg bending option.
PINCH	3	Pinch-difference input data decoder.
SIDCON	3	Side-roll and extension-contour input data decoder.
DRTEMP	3	Controls the roll contour processing and the update of element bending status at the current stage.
STGTM	4	Updates the bending angle for the current stage.
CLENG	4	Calls relevant subroutines for monitoring length definitions of left-hand side and right-hand side elements at the current bending stage.
INITP	4	Initialises the roll contour data stores, sets up reference flags and values for side-roll processing, extension-contour processing and pinch-difference surface processing.
PLOT3	4	Controls the pinch-difference processing, the roll contour processing, the drawing of rolls and the output of roll contour data.
STGLN	5	Distributes the element lengths according to the percentages defined via input for the composite circular elements. Linear parts of each composite element are added to the adjacent elements to keep a balanced sum of all the element meanlengths.

Table 6.3 (PART 3)

SUBROUTINE	LEVEL	FUNCTION
STGCP	5	As subroutines STGLN, but with fixed percentages, being 50% for linear parts and 50% for circular parts.
STGSH	5	Adjusts element lengths and radii for radii sharpening.
STGSR	5	Sets up identifier flags for all side-roll contour elements and also the reference flags for both side-roll processing and extension-contour processing.
STGPN	5	Sets up identifier flags for all drive-surface elements.
PLOT3A	5	Controls the execution of the pinch-difference computation procedures.
PLOT3B	5	Controls the restoration of the true template contour for drawing if required.
ROLL	5	Converts the template contour data to the roll contour data and incorporates the insert contours at transitional points as a result of pinch-difference adjustments.
ROLLA	5	Controls the roll contour modification procedures, the side-roll processing, the break-point processing and the extension-contour processing.
WRTRD	5	Sets up the current stage pass-height and centre-to-centre distance values.
RDOUTI	5	Generates intermediate roll contour data for printing if required.

Table 6.3 (PART 4)

SUBROUTINE	LEVEL	FUNCTION
ROLLC	5	Controls the restoration of circular element contours, the drawing of roll contours, including the side-roll contours, the extension-contours and the template contours if required.
ROLLD	5	Controls the repacking of the roll contour data in a correct sequence for output purposes.
CSURF	6	Initialises and monitors the required conditions for pinch-difference surfaces computation.
PLOT3C	6	Computes the true template contour.
ROLL1	6	Computes and stores roll contour data from the template contour data, with vertical inserts added for the circular elements if necessary.
SMOD	6	Incorporates the insert contours at transitional points of the pinch-difference surfaces into the roll contour.
RSHOW1	6	Prints the content of intermediate roll data stores if necessary.
RPACK	6	Controls the packing of the roll contour data into top and bottom roll contours.
RPICK	6	Packs the end contour for the cases when origin is 1 or 2.
RSA	6	The side-roll contour processor.

Table 6.3 (Part 5)

SUBROUTINE	LEVEL	FUNCTION
CBRK	6	The break-point processor.
EXTND	6	The extension-contour processor.
PLTIB	6	Draws the template contour.
PLOT6	6	Plots the top and bottom roll contours.
OPTBR	6	Outputs the top or bottom roll contour data, with extension-contours if required.
OPSR	6	Outputs the side-roll contour-data, with extension-contours if required.
STL2	7	Computes the linear element geometry with pinch-difference adjustments.
ARC2	7	Computes the circular element geometry with pinch-difference adjustments.
POSTD	7	Copies the element definition data from first half-section to second half-section (symmetrical section).
STL1	7	Computes the linear element geometry.
ARC1	7	Computes the circular element geometry.
RSHOW	7	Prints the specified roll contour array.
EXTRX	7	Sets up the extreme-X point.

Table 6.3 (PART 6)

SUBROUTINE	LEVEL	FUNCTION
ROEND	7	Repacks the roll contour elements into actual top and bottom roll parts separated by the extreme-X point.
RSANG	7	Repacks the relevant part of the top or bottom roll contour in preparation for side-roll contour processing.
RS1	7	Forms the side-roll contour from relevant top and bottom roll parts.
PLOT6A	7	Plots the side-roll contour.
SBRK	7	Computes the break-points for either spigot or side-roll selection.
WBRK	7	Prints the break-point details if required.
COMEX	7	Computes the extension-contour change-points.
PEXT1	7	Plots the spigot contours.
PEXT2	7	Plots the extension-contours for top and bottom rolls with side-rolls.
ROLL2	7	Performs roll contour modifications by identifying and removing the inaccessible parts when scanning through the roll contour data stores.
GENCIR	7	Restores circular element contours from their linear enveloping form.

Table 6.3 (Part 7)

SUBROUTINE	LEVEL	FUNCTION
RDEXR	7	Outputs the extension-contour data for top or bottom roll.
RDROL	7	Outputs the top or bottom roll contour data.
RDEXS	7	Outputs the extension-contour data for side-rolls.
RDSID	7	Outputs the side-roll contour data.
STOMAX	8	Stores the extreme-X point details.
RS2	8	Transforms the angles and coordinates of top and bottom roll orientation to side-roll orientation.
OPRD	8	Outputs data for one roll element contour.
CIRMOD	9	Incorporates vertical inserts for circular element contours.

Chart 6.1 HIERARCHY OF THE ROLL DESIGN SOFTWARE (PART 1)

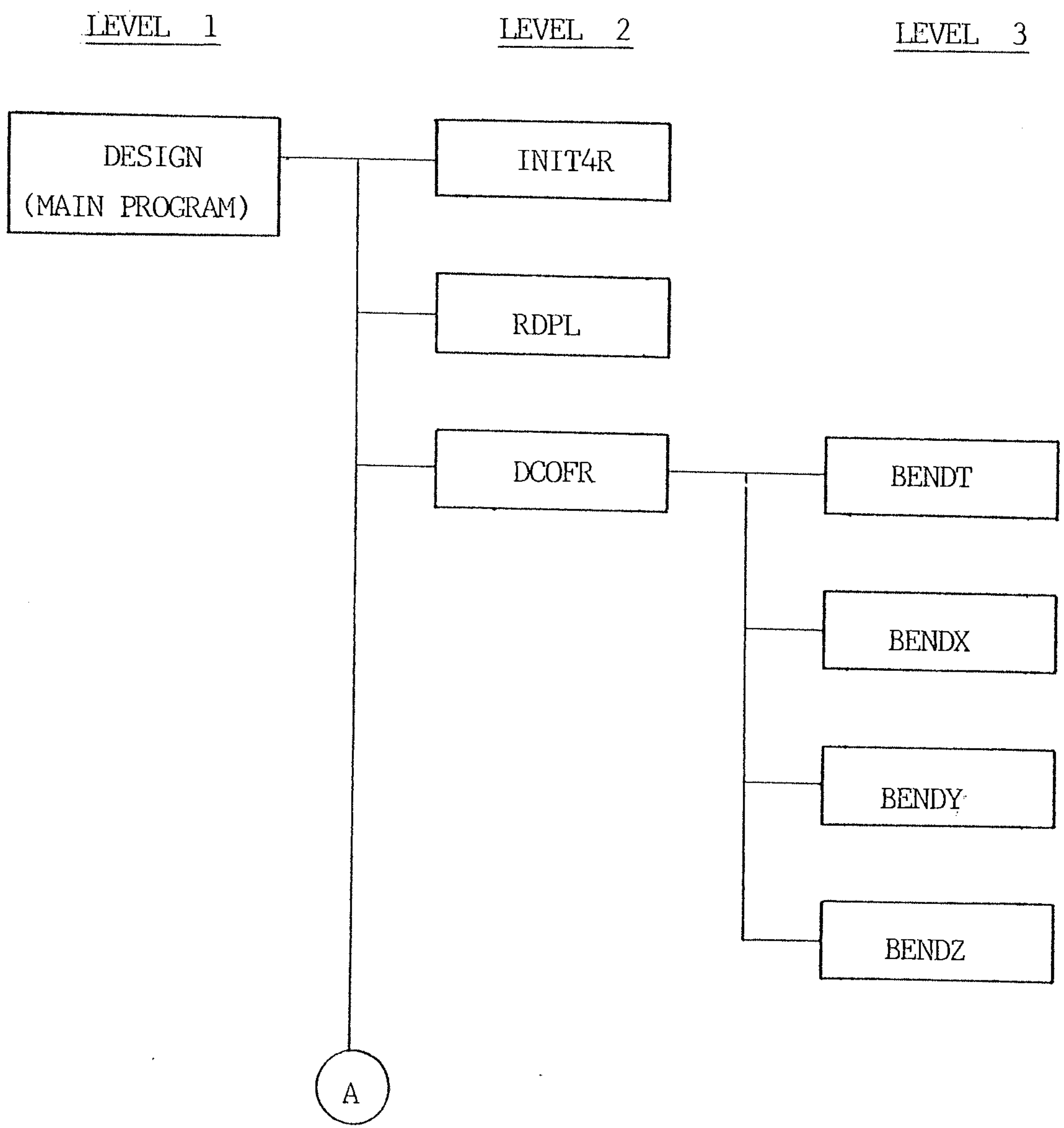


Chart 6.1 (PART 2)

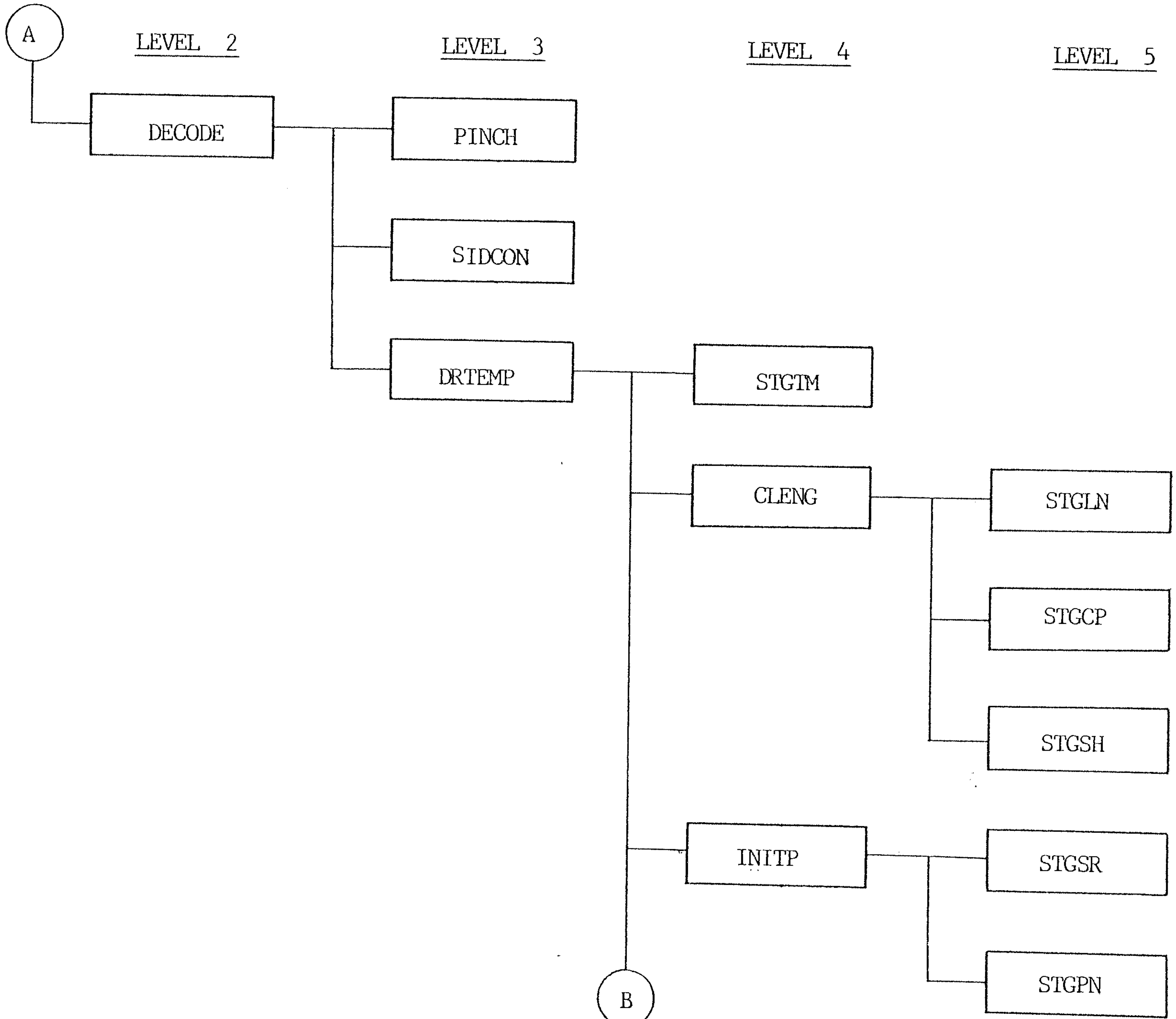


Chart 6.1 (PART 3)

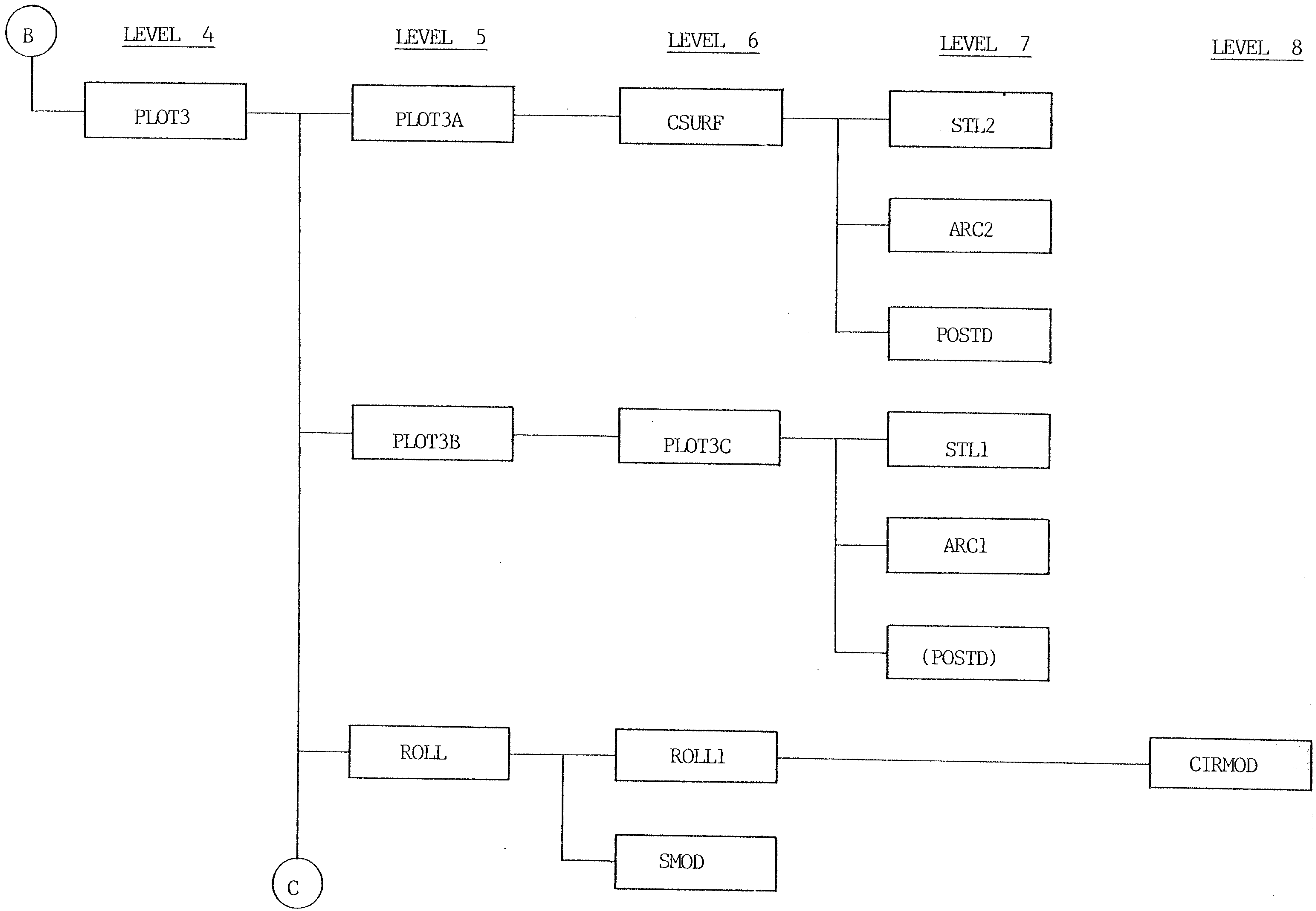


Chart 6.1 (PART 4)

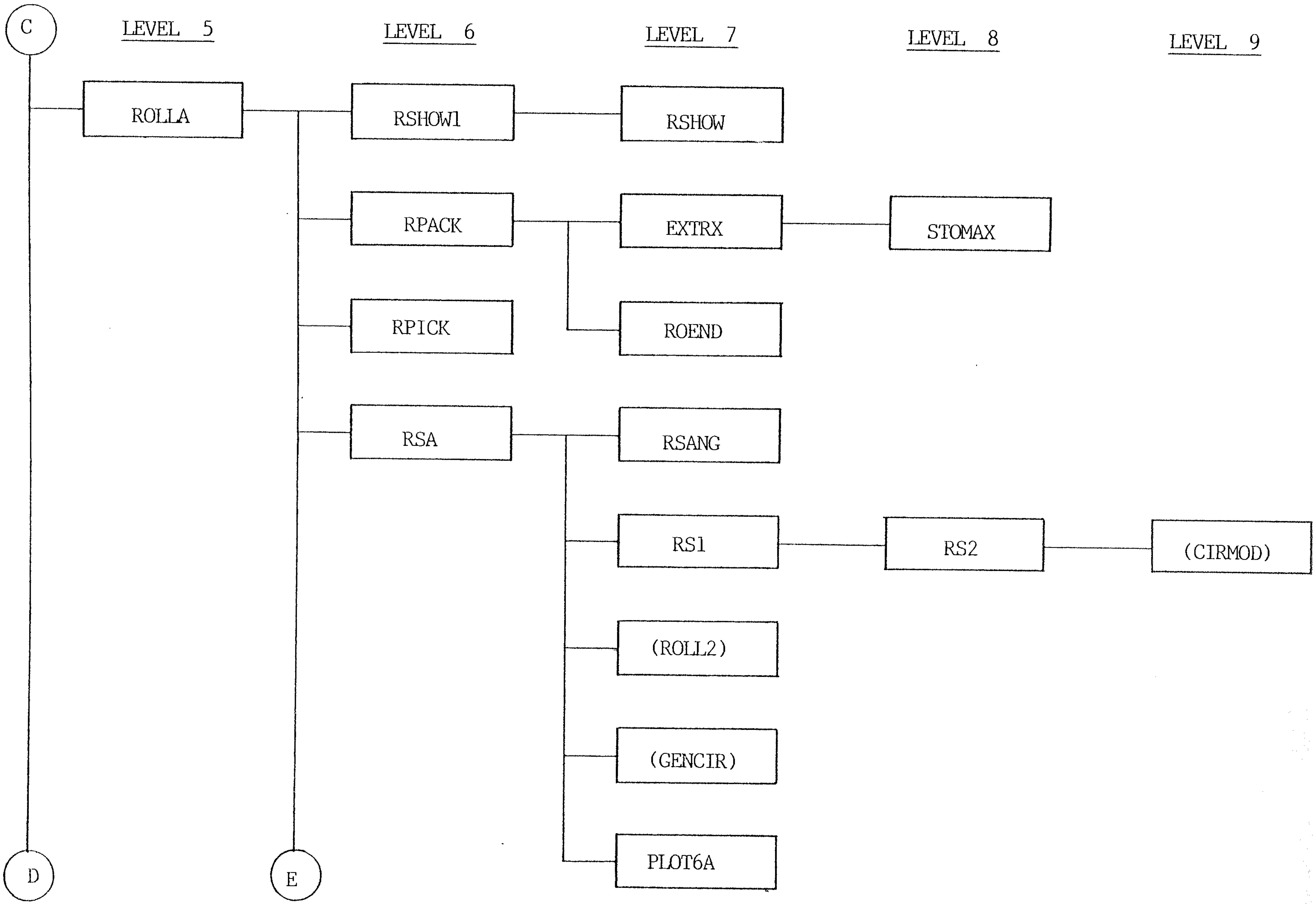


Chart 6.1 (PART 5)

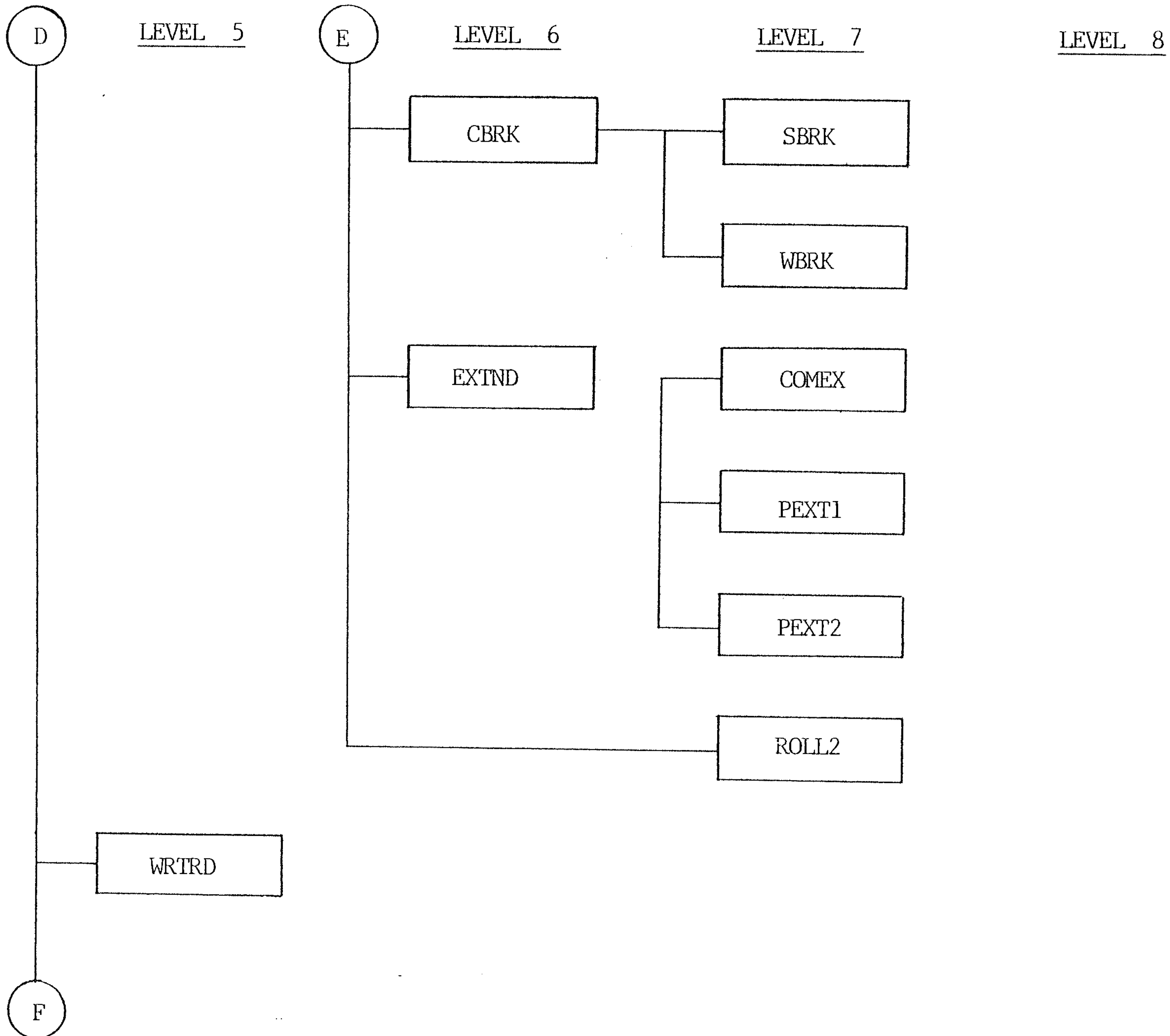


Chart 6.1 (PART 6)

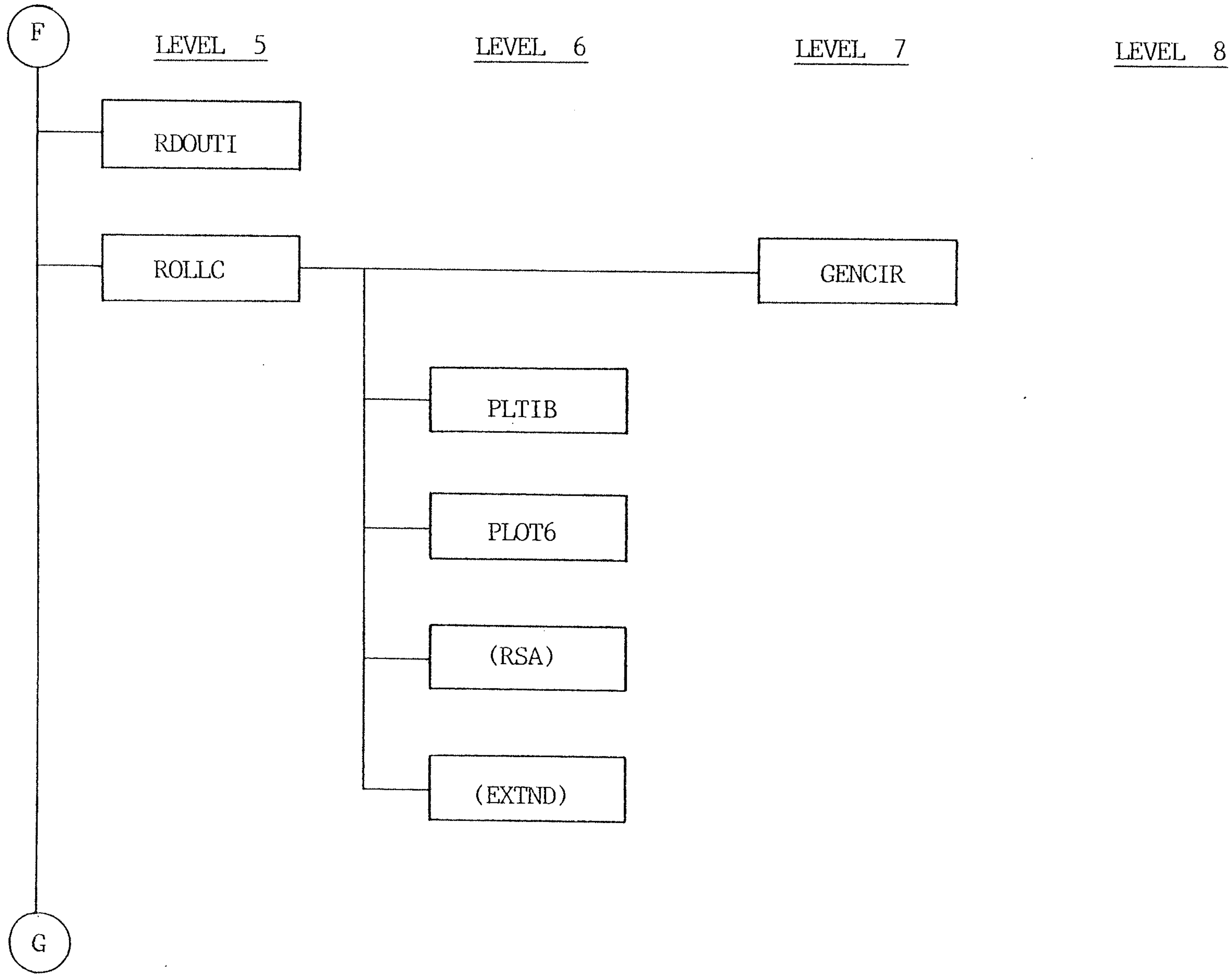
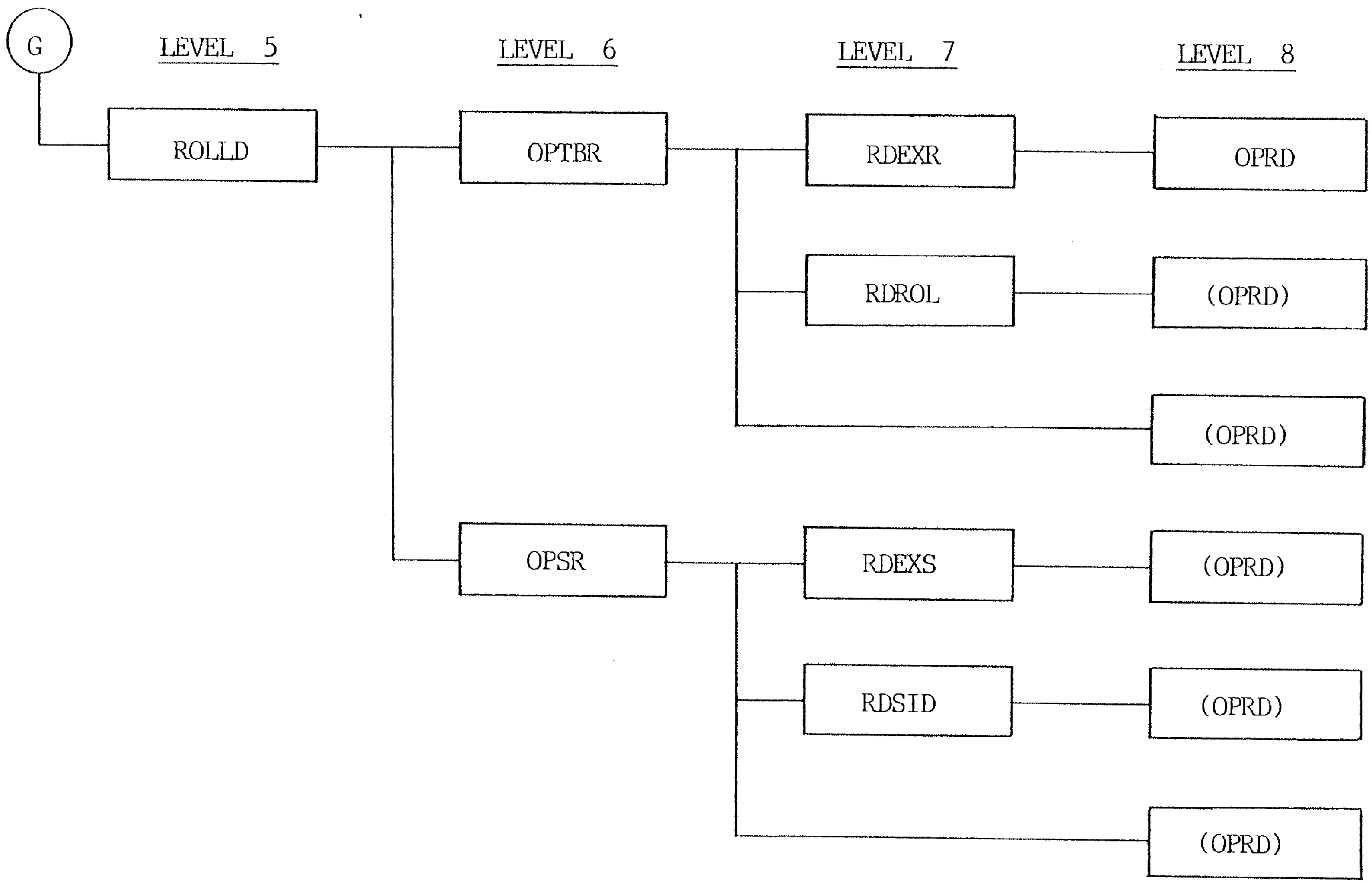


Chart 6.1 (PART 7)



CHAPTER 7

CHAPTER 7

THE INTERACTIVE GRAPHICS FORM-ROLL EDITOR

7.1 INTRODUCTION

For freedom of design, it may sometimes be desirable to modify a sharp corner by a blending circular arc or a chamfer, or to perform some final refinements to the roll profile. However, the roll design program does not cater for these important requirements. The editing facility incorporated in the roll design program can only be used for major adjustments to the roll drawings, such as altering pass-heights, centre-to-centre distances, pinch-difference values, extension-contours, tolerances, clearances, or even removing or inserting side-rolls.

The roll editor program has, therefore, been developed for executing random and minor design changes interactively. This program also forms the interface between the design and manufacturing software, hence it must be executed despite whether editing is needed, to create an individual digitised roll profile geometric data file for every single roll in all forming stages.

All roll profile elements, similar to the elements constituting a thin-section, are either linear or circular, therefore, the roll editor program has been equipped with facilities to handle linear and circular elements. Based on the company's requirements, the following functions have been incorporated in the interactive roll editing software:

1. Displaying the specified roll profile on the Tektronix screen.

2. Replacing an existing element, either linear or circular, by a new element.

3. Inserting a new element, either linear or circular, to the profile.

4. Deleting an existing element.

5. Modifying a corner by adding a chamfer or a blending arc.

6. Mirror imaging facility, i.e. reversing the shape of the roll profile.

7. Displaying all the edited rolls of a complete forming stage on the Tektronix screen, to ensure correct edits have been carried out.

7.2 APPLICATION OF INTERACTIVE GRAPHICS FOR THE DISPLAY

The roll editor program has been designed to dynamically change the displayed roll profile drawing. By utilisng the Tektronix's interactive graphics facilities, the program can display on the terminal screen an updated drawing of the edited roll profile after each editing function. The main input device for graphic information is the keyboard, while the output device is the screen. Regarding the graphics software, GINO-F is used which enables graphical information to be interactively displayed.

The roll designer may sometimes find it necessary, especially after editing, to enlarge any selected part of the roll drawing in order to obtain a clearer view of any particular details of the roll profile. This can be achieved by zooming in on a portion of the roll profile with the aid of the cursor, and the Tektronix 4107 terminal will recompute the co-ordinate information and display the designated roll section in much greater detail. Zoom functions are handled at the terminal locally, without line delays with the VAX computer.

7.3 DATA STRUCTURE OF THE ROLL PROFILE

The roll profile is represented by a set of linear and circular elements joining each other, from left to right, in ascending order. Fig. 7.1 shows the co-ordinate system for a roll profile drawing, where the first element is always the contour element on the far left. The data structure has been designed to hold all information about the element identity and status, plus all reference data related to the element.

The data structure comprises of several substores, as shown in Table 7.1. The substore NEL is an integer array for identifying element numbers from 1 to 100, and the substore ITYPE is also an integer array for identifying the type of element whereby it equals 1 for linear elements and 2 for circular elements. The substore RXA is a real array for holding all geometric information about the element . In this array, linear elements are represented by the general line equation AX + BY + C = 0, and circular elements by the co-ordinates (F,G) for the centre point together with its radius R. The substore IDIR is an integer array for identifying the direction of the arc for circular elements, being equal to 1 for CCW and -1 for CW.

7.4 GEOMETRIC PRINCIPLES AND PROCEDURES

In this section, some of the commonly used geometric algorithms which have been developed for handling roll profile geometry under different situations and constraints, are introduced. These mathematical algorithms have been incorporated into various subroutines in the roll editor program.

7.4.1 The Basic Line and Circle Equations

Throughout the roll editor program, as described in Section 7.3, all linear and circular elements are represented by the general equations:-

Linear $AX + BY + C = 0$ (7.1)

where A, B, and C are constants

Circular $(X-F)^2 + (Y-G)^2 = R^2$ (7.2)

where (F,G) are the co-ordinates of the centre and R is the radius

7.4.2 Intersection Between Two Linear Elements

An algorithm has been developed for computing the intersecting point between two linear elements. The equations for the two linear elements are given by

$$A_1X + B_1Y + C_1 = 0 \quad (7.3a)$$

and $A_2X + B_2Y + C_2 = 0$ (7.3b)

If these two lines are not parallel, i.e.

$$\frac{A_1}{B_1} \neq \frac{A_2}{B_2}$$

the co-ordinates (x,y) of the intersecting point are given by

$$x = \frac{B_1 C_2 - B_2 C_1}{A_1 B_2 - A_2 B_1} \quad (7.4)$$

and $$y = \frac{A_2 C_1 - A_1 C_2}{A_1 B_2 - A_2 B_1} \quad (7.5)$$

7.4.3 Intersection Between a Linear and a Circular Element

The co-ordinates (x,y) for the intersecting point between a linear and a circular element can be determined by solving between the basic line and circle equations, as given in equations (7.1) and (7.2) respectively. The solutions for (x,y) are hence given by

$$x = \frac{-Z_1 \mp \sqrt{P_1}}{2S} \quad (7.6)$$

and $$y = \frac{-Z_2 \mp \sqrt{P_2}}{2S} \quad (7.7)$$

where $$S = A^2 + B^2 \quad (7.8)$$

$$Z_1 = 2AC + 2ABG - 2B^2F \quad (7.9)$$

$$Z_2 = 2BC + 2ABF - 2A^2G \quad (7.10)$$

$$P_1 = Z_1^2 - 4S\,(B^2(F^2 + G^2 - R^2) + C^2 + 2BCG) \quad (7.11)$$

and $$P_2 = Z_2^2 - 4S\,(A^2(F^2 + G^2 - R^2) + C^2 + 2ACF) \quad (7.12)$$

Depending on the values of P_1 and P_2 in the above equations, there are three different cases. In the first case, if either P_1 or P_2 is less than zero, then obviously, the line and the circle are not intersected. In the second case, if both P_1 and P_2 are equal to zero, then the line is tangent to the circle and there is only one solution for (x,y) as given by equations (7.6) and (7.7).

However, in the third case, if both P_1 and/or P_2 are greater than zero, then there are two intersecting points between the line and the circle. Therefore, the roll designer has to interact with the program in order to select the appropriate solutions:

(a) If P_1 is greater than zero but P_2 equals zero, the line being horizontal, then there are two solutions for x from equation (7.6) and one solution for y from equation (7.7). It therefore has to be specified whether the intersection point on the right or the left is desired. The plus sign in equation (7.6) is used if the intersection on the right is selected, and the minus sign if the one on the left is selected.

(b) If P_1 equals zero but P_2 is greater than zero, the line being vertical, then there is only one solution for x from equation (7.6) and two solutions for y from equation (7.7). If the desired solution is the intersection point located above then the plus sign is used in equation (7.7), while the minus sign is used if the intersection point located below is desired.

(c) Finally, if both P_1 and P_2 are greater than zero, then both of the X - co-ordinates and Y - co-ordinates for the two intersecting points are not equal to zero. Therefore, if the intersection point located above is selected, then the solution for (x,y) is given by

$$y = \frac{-Z_2 + \sqrt{P_2}}{2S} \tag{7.13}$$

and $$x = \frac{-(By + C)}{A} \tag{7.14}$$

For the intersection point located below,

$$y = \frac{-Z_2 - \sqrt{P_2}}{2S} \tag{7.15}$$

and $$x = \frac{-(By + C)}{A} \tag{7.14}$$

For the intersection point located to the left,

$$x = \frac{-Z_1 - \sqrt{P_1}}{2S} \tag{7.16}$$

and $$y = \frac{-(Ax + C)}{B} \tag{7.17}$$

Lastly, for the intersection point located on the right,

$$x = \frac{-Z_1 + \sqrt{P_1}}{2S} \tag{7.18}$$

and $$y = \frac{-(Ax + C)}{B}$$

7.4.4 Intersection Between Two Circular Elements

Three possibilities exist for the case when two circular elements intersect as there may be one intersecting point; two intersecting points; or none at all. The algorithm explained in Section 7.4.4 can be applied for determining these intersection points. However, the algorithm for this case has been simplified.

The equations for the two circles are given by

$$(X - F_1)^2 + (Y - G_1)^2 = R_1^2 \tag{6.19}$$

and $$(X - F_2)^2 + (Y - G_2)^2 = R_2^2 \tag{6.20}$$

By subtracting equation (7.20) from equation (7.21), the equation of the common chord (the line joining the two intersection points) can be obtained, which gives

$$2(F_2 - F_1)X + 2(G_2 - G_1)Y + (F_1^2 + G_1^2 - R_1^2 - F_2^2 - G_2^2 + R_2^2) = 0 \tag{7.21}$$

This is a general line equation analogous to equation (7.1), where

$$A = 2\,(F_2 - F_1) \tag{7.22}$$

$$B = 2\,(G_2 - G_1) \tag{7.23}$$

and $$C = F_1^2 + G_1^2 - R_1^2 - F_2^2 - G_2^2 + R_2^2 \tag{7.24}$$

7.4.5 Determining the Identification Sign for a Line Parallel to a Given Line

It is sometimes necessary to determine the equation of a line being parallel and at a certain distance away from a given line. An identifier must be used, that is, being 'A', 'B', 'L' or 'R', to specify whether the new line is above, below, on the left or on the right of the given line. Consider a line L_1 defined by

$$AX + BY + C = 0$$

If a line L_2 is parallel to L_1 and at a distance D away from it, the equation for L_1 is given by

$$AX + BY + C \pm D\sqrt{A^2 + B^2} = 0 \qquad (7.25)$$

or $$AX + BY + C + Jsign * D\sqrt{A^2 + B^2} = 0 \qquad (7.26)$$

If the new line L_2 is specified to be below the given line L_1, then the sign must be the same as that of B, in order to obtain a smaller value of Y, hence

$$Jsign = + B/|B| \qquad (7.27)$$

If the new line L_2 is specified to be above the given line L_1, then the sign must be apposite to that of B, in order to obtain a greater value of Y, hence

$$Jsign = - B/|B| \qquad (7.28)$$

On the other hand, if the new line is specified to be on the right of the given line L_1, then the sign must be opposite to that of A, in order to obtain a greater value of X, hence

$$Jsign = -A/|A| \tag{7.29}$$

Lastly, if the new line is specified to be on the left of the given line L_1, then the sign must be the same as that of A, in order to obtain a smaller value of X, hence

$$Jsign = +A/|A| \tag{7.30}$$

The above definition scheme has been incorporated in the roll editing software into a subroutine called DSINE, which by utilising equations (7.27) to (7.30) generates the appropriate value for the code Jsign automatically.

7.5 DEFINITION OF NEW ELEMENTS

When selecting the Insertion or Replacement modes during execution of the roll editor program, it is necessary to input the geometric data for the new element, which can be either linear or circular. Therefore, facilities for defining lines and circles have been developed and incorporated into a subroutine called DEFNEL. The most simple and commonly used methods have been selected, to enable roll designers define new elements easily and without ambiguity.

7.5.1 Definition of Linear Elements

For simplicity, three methods have been adopted in the roll editor program for defining linear elements:

(1) A line passing through two given points (Fig. 7.2)

By substituting the co-ordinates of two given points (X_1,Y_1) and (X_2,Y_2) respectively in the general line equation (6.1), the coefficients A, B, and C are determined by solving the equations, obtaining

$$A = Y_2 - Y_1 \tag{7.31}$$

$$B = X_1 - X_2 \tag{7.32}$$

$$C = X_2 Y_1 - X_1 Y_2 \tag{7.33}$$

(2) A line through a point that makes an angle with the X-axis (Fig. 7.3)

The gradient m of a line at an angle θ to a point (X_1, Y_1) is given by

$$m = \tan(\theta) \tag{7.34}$$

Solving the equation for point slope, the coefficients can thus be obtained

For $m \neq \infty$

$$A = -m \tag{7.35}$$

$$B = 1 \tag{7.36}$$

$$C = -Y_1 + mX_1 \tag{7.37}$$

For $m = \infty$ (i.e. $\theta = 90^o, 270^o, -90^o, -270^o$),

$$A = 1 \tag{7.38}$$

$$B = 0 \tag{7.39}$$

$$C = -X_1 \tag{7.40}$$

(3) A line through a point and parallel to a given line (Fig. 7.4).

A line passing through a given point (X_1,Y_1) and parallel to an existing line L_1, then L_1 is given by

$$A_1 X + B_1 Y + C_1 = 0$$

where the coefficients A and B are the same as those for the given line L_1, obtaining

$$A = A_1 \tag{7.41}$$

$$B = B_1 \tag{7.42}$$

and

$$C = -(AX_1 + BY_1) \tag{7.43}$$

7.5.2 Definition of Circular Elements

After an examination of the general requirements of the roll profiles, four methods have been adopted in the roll editor program for defining circular elements:

(1) Circle with known co-ordinates of its centre and with known radius (Fig. 7.5).

This is the easiest way to prescribe a circle, which is given in equation (6.2) for a centre point co-ordinates (F,G) and a radius R.

(2) Circle with known co-ordinates of its centre and passing through a given point (Fig. 7.6).

If the co-ordinates (F,G) for the centre point and the co-ordinates (X,Y) of a point on the circumference are given then the radius R of the circle is given by

$$R = \sqrt{(F - X)^2 + (G - Y)^2} \tag{7.44}$$

(3) Circle which is the translation of an existing circle (Fig. 7.7).

A new circle, which is obtained by translating on existing circle, of centre point co-ordinatres (F',G') and Radius R, through a distance (x,y) must have the same radius R. The co-ordinates (F,G) for the centre point of the new circle are obtained by

$$F = F' + x \tag{7.45}$$

and

$$G = G' + y \tag{7.46}$$

(4) Circle tangent to two existing elements (linear or circular), with known radius.

The new circular element is tangential to both of its preceding and succeeding elements. However, depending on the type of these two elements there are three different possibilities:

(a) Both of the preceding and succeeding elements are linear (Fig. 7.8)

Suppose the two lines are given by

$$A_1X + B_1Y + C_1 = 0$$

and $$A_2X + B_2Y + C_2 = 0$$

As the circle is of given radius R, the equations of parallel lines at a distance R that intersect, can be derived. The solution is the centre of the tangential circle, as it is R units from both original lines. The two equations parallel to the given lines are given by

and $$A_1X + B_1Y + C_1' = 0 \tag{7.47a}$$

$$A_2X + B_2Y + C_2' = 0 \tag{7.47b}$$

where $$C_1' = C_1 \pm R\sqrt{A_1^2 + B_1^2} \tag{7.48}$$

$$C_2' = C_2 \pm R\sqrt{A_2^2 + B_2^2} \tag{7.49}$$

With known values of C_1' and C_2', the two equations (7.47a) and (7.47b) may be solved simultaneously, as described in Section 7.4.2, to derive the co-ordinates (F, G) for the circle centre. The plus or minus sign in equations (7.48) and (7.49) is chosen automatically by using the sign in equations (7.48) and (7.49) is chosen automatically by using the algorithm DSINE as described in Section 7.4.5, according to the location of the circle relative to the two lines respectively.

(b) Both of the preceding and succeeding elements are circles (Fig. 7.9).

In this case, it is necessary to specify whether the new elements is located inside or outside of the two given circles. Suppose the equations for the two circles are given by

$$(X - F_1)^2 + (Y - G_1)^2 = R_1^2$$

and $$(X - F_2)^2 + (Y - G_2)^2 = R_2^2$$

The centre point for the new circular element is the intersection between two circles, which are concentric to the two given circles respectively, with the radii being $(R_1 \pm R)$ and $(R_2 \pm R)$. The equations for these two circles of radius R are given by

$$(X - F_1)^2 + (Y - G_1)^2 = (R_1 \pm R)^2 \quad (7.50)$$

and $$(X - F_2)^2 + (Y - G_2)^2 = (R_2 \pm R)^2 \quad (7.51)$$

The algorithm described in Section 7.4.4 can be used for solving equations (7.50) and (7.51). The plus or minus sign in these quations is chosen according to whether the new circle is located outside or inside the given circles respectively.

(c) One of the preceding and succeeding elements is linear while the other one is circular (Fig. 7.10).

If the given radius of the new circle is R, then the centre of it is R units from both the given line and circle, therefore by taking the general line and circle equations

$$AX + BY + C = 0$$

and $$(X - F_1)^2 + (Y - G_1)^2 = R_1{}^2$$

the new equations are given by

$$AX + BY + C \pm R\sqrt{A^2 + B^2} = 0 \tag{7.52}$$

and $$(X - F_1)^2 + (Y - G_1)^2 = (R_1 \pm R)^2 \tag{7.53}$$

By utilising the procedures for obtaining intersection between a line and a circle, as described in Section 7.4.3, the centre point co-ordinates (F,G) for the new circle can be determined. The plus or minus sign in equation (7.52) is determined by the algorithm explained in Section 7.4.5, and depends on the location of the new circle with respect to the given line. For equation (7.53), on the other hand, the plus or minus sign is chosen according to whether the circle is located outside or inside the given line respectively.

7.6 INSERTING, REPLACING AND DELETING ELEMENTS

The roll editing software has been designed to enable roll designers to insert, replace and delete elements, both linear and circular. For inserting and replacing elements, the principles and procedures described in Section 7.5 can be applied to obtain the centre co-ordinates (F,G) and radius R for a circle, or the coefficients A, B and C for a line. After establishing the precise mathematical model of the new element, the system calculates the starting and ending points of the new element by utilising the algorithms developed and incorporated into the software, outlined in Section 7.4. However, if an element is to be deleted, its preceding and succeeding elements become adjacent elements.

In all three cases, the system updates the complete data structure of the edited roll profile, and draws the new roll profile, interactively, on the Tektronix screen.

7.7 MODIFYING A CORNER

Modifications of sharp corners on the roll profile, either by adding a chamfer or a blending arc, is restricted to the following conditions:

1. Both of the elements forming the sharp corner must be linear

2. The including angle between the two intersecting lines must be less than 135°.

3. The depth of the chamfer or the blending radius cannot be greater than 60% of anyone of the lengths of the two intersecting elements.

If two given lines L_1 and L_2 are joined together to form a sharp corner, two other lines L_1 and L_2 can be constructed at a distance D away from L_1 and L_2, and parallel to them respectively (Fig. 7.11). If the equations for L_1 and L_2 are given by

$$A_1X + B_1Y + C_1 = 0$$

and $$A_2X + B_2Y + C_2 = 0$$

then the equations of the offset lines L_1 and L_2 are given by

$$A_1X + B_1Y + C_1 \pm D\sqrt{A_1^2 + B_1^2} = 0 \qquad (7.54)$$

and $$A_2X + B_2Y + C_2 \pm D\sqrt{A_2^2 + B_2^2} = 0 \qquad (7.55)$$

The plus or minus sign in equations (7.54) and (7.55) is determined automatically by the DSINE algorithm, outlined in Section 7.4.5, according to the relative position between L_1 and L_2.

7.7.1 Chamferring

For chamferring, the depth of chamfer C is specified (Fig. 7.12), which is in fact a new linear element joining the two points P and Q, where P is the intersecting point between lines L_1 and L_2', and Q is the intersecting point between L_1' and L_2. By using equations (7.4) and (7.5) as described in Section 7.4.2, the co-ordinates P and Q can be computed. Also, by using equations (7.31) to (7.33) as in section 7.5.1, the coefficients A, B and C can be computed for the line equation of the chamfer.

7.7.2 Blending Arc

For a blending arc, the blending radius R is specified (Fig. 7.13), whose centre is the intersecting point between the lines L_1 and L_2. The co-ordinates (F,G) of the centre point can therefore be computed by using equations (7.4) and (7.5). The starting point co-ordinates (Xs,Ys) of the arc, which is the intersecting point between L_1 and a line perpendicular to L_1 and passes through (F,G), are given by

$$Xs = \frac{B_1^2F - A_1B_1G - A_1C_1}{A_1^2 + B_1^2} \tag{7.56}$$

and

$$Ys = \frac{A_1^2G - A_1B_1F - B_1C_1}{A_1^2 + B_1^2} \tag{7.57}$$

Similarly, the co-ordinates (Xe,Ye) for the ending point are given by

$$Xe = \frac{B_2^2F - A_2B_2G - A_2C_2}{A_2^2 + B_2^2} \tag{7.58}$$

and

$$Ye = \frac{A_2^2G - A_2B_2F - B_2C_2}{A_2^2 + B_2^2} \tag{7.59}$$

7.8 PROGRAM OPERATION

The roll design program generates a digitised roll profile data file containing data for all rolls (top roll, bottom roll, left side roll and right side roll) in every forming stage. Therefore, while executing the roll editor program the roll designer is required to specify the section part number; the forming stage number; and the roll number for selecting among the top, bottom, left and right side rolls. The corresponding set of digitised roll profile geometric data is then decoded and stored in memory, while the shape of the roll profile is displayed on the Tektronix screen.

The roll designer can then select the appropriate roll editing functions in a step by step approach. After each step of editing, the software displays the modified roll profile on the Tektronix screen, and also updates roll profile geometric data structure. If the mirror imaging facility is selected, the displayed roll profile is cleared from the screen and its reverse shape is automatically displayed.

When the roll designer finally decides to exit from the roll editor program, the updated roll profile data structure is into a geometric data file for the edited roll. If the roll designer requires a hardcopy of this data file, a printer listing, as shown in Fig. 7.14, can be obtained. Typical roll profile drawings for one of the forming stages, as displayed on the Tektronix screen during execution of the roll editor program, are shown in Fig. 7.15 and 7.16.

7.9 SOFTWARE STRUCTURE

The hierarchy of the software structure is shown in Chart 7.1, with the main program EDITOR residing at the highest level of execution, controlling the sequence of execution of the subroutines at lower levels. The roll editor software consists of two distinctive parts, namely:

1. The Roll Editor Program (EDITOR)

2. The Tektronix Screen Display Module (TKPLOT)

A brief account of the nature of the subroutines is given in Table 7.2.

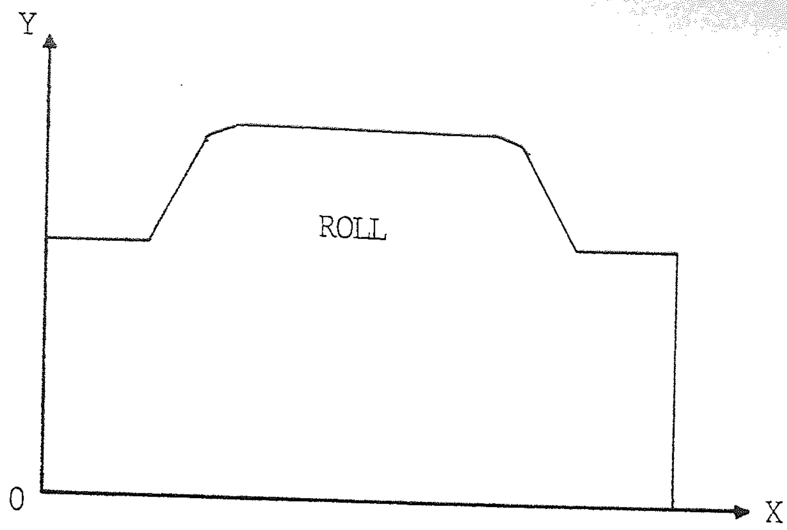


Fig. 7.1 COORDINATE SYSTEM FOR ROLL PROFILE DRAWING

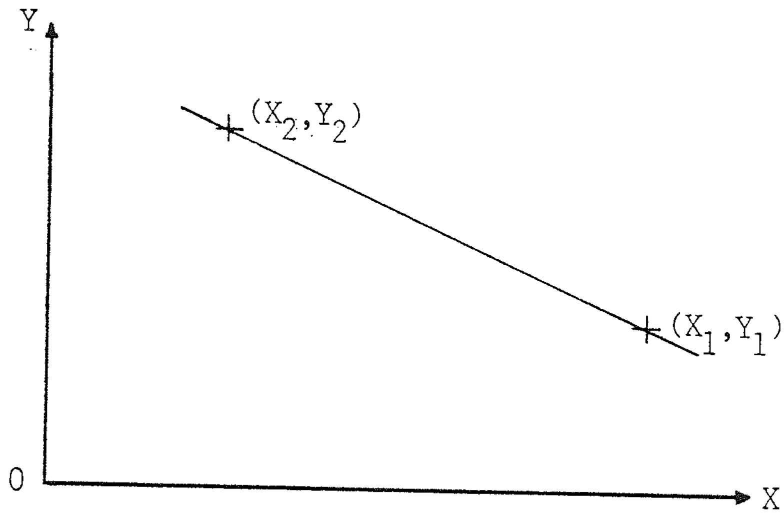


Fig. 7.2 LINE THROUGH TWO POINTS

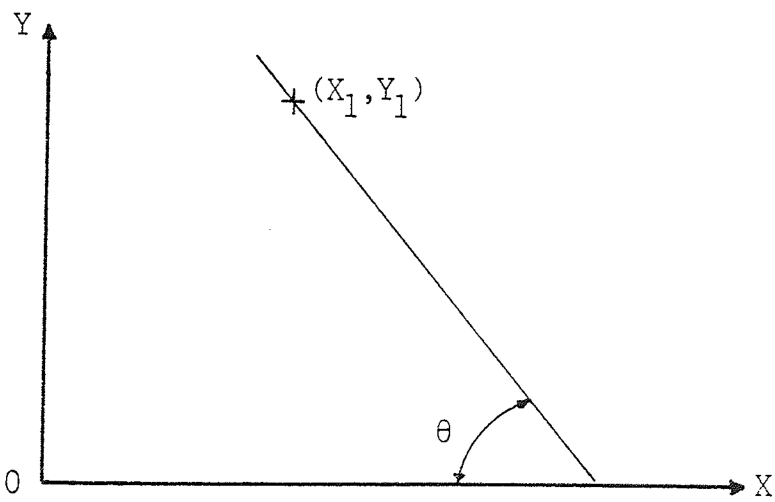


Fig. 7.3 LINE DEFINED BY A POINT AND ANGLE

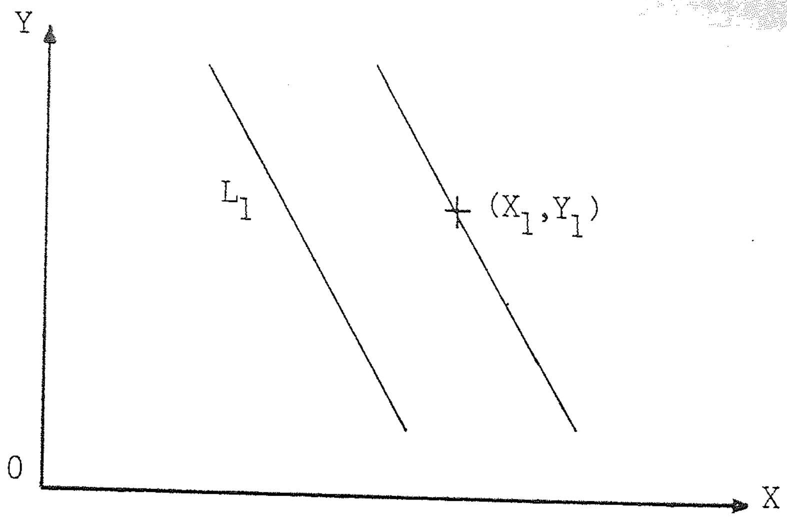


Fig. 7.4 LINE DEFINED THROUGH A POINT AND PARALLEL TO A LINE

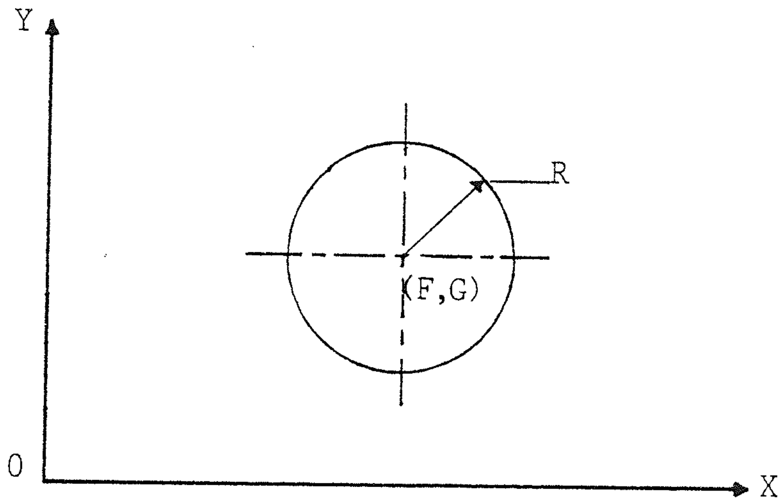


Fig. 7.5 CIRCLE DEFINED BY ITS CENTRE & RADIUS

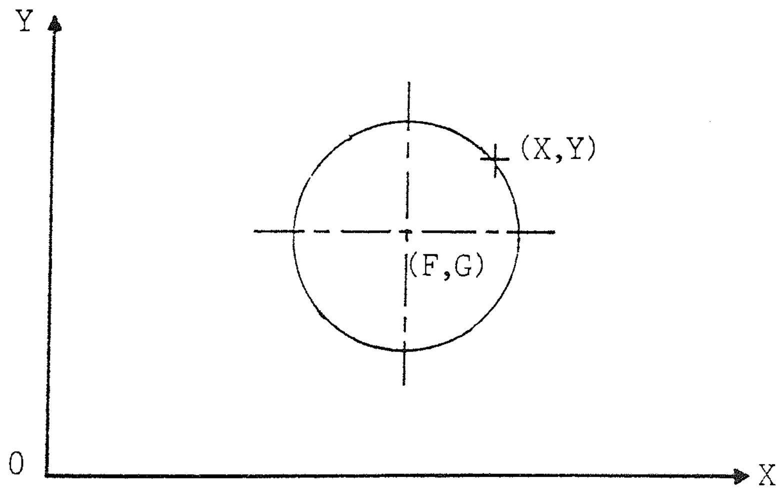


Fig. 7.6 CIRCLE DEFINED BY ITS CENTRE AND THROUGH A POINT

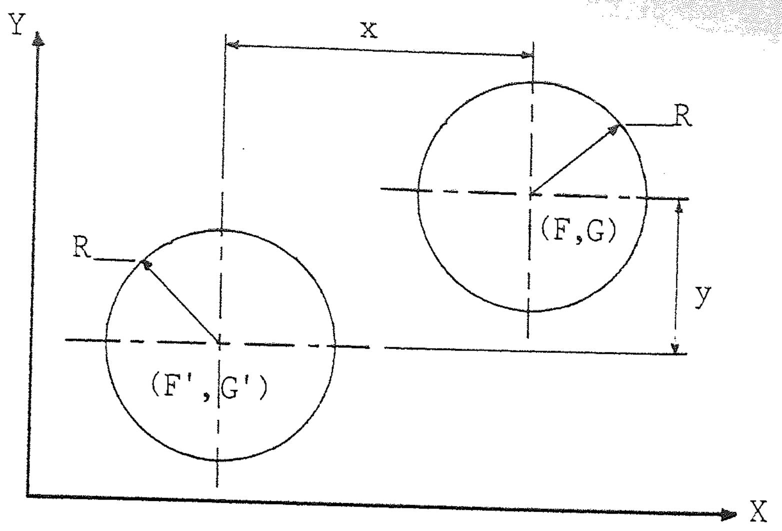


Fig. 7.7 CIRCLE DEFINED AS A GIVEN CIRCLE TRANSLATED

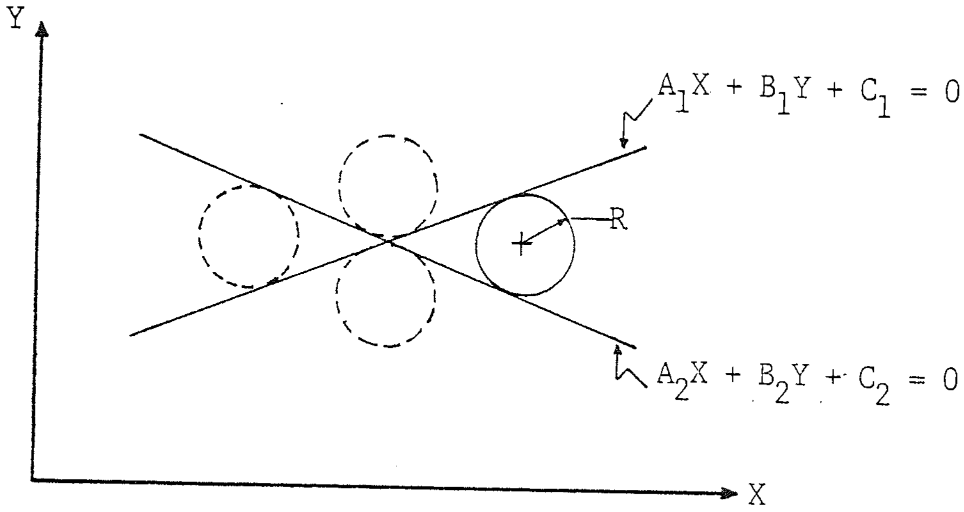


Fig. 7.8 CIRCLE DEFINED TANGENT TO TWO LINES

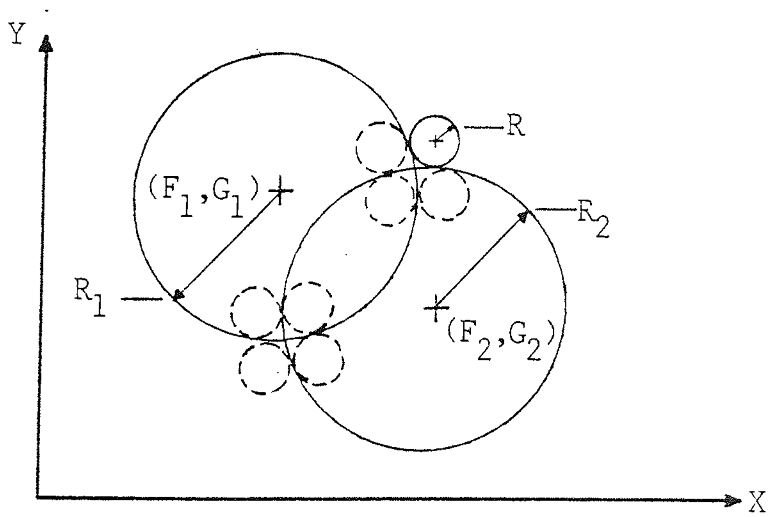


Fig. 7.9 CIRCLE DEFINED TANGENT TO TWO CIRCLES

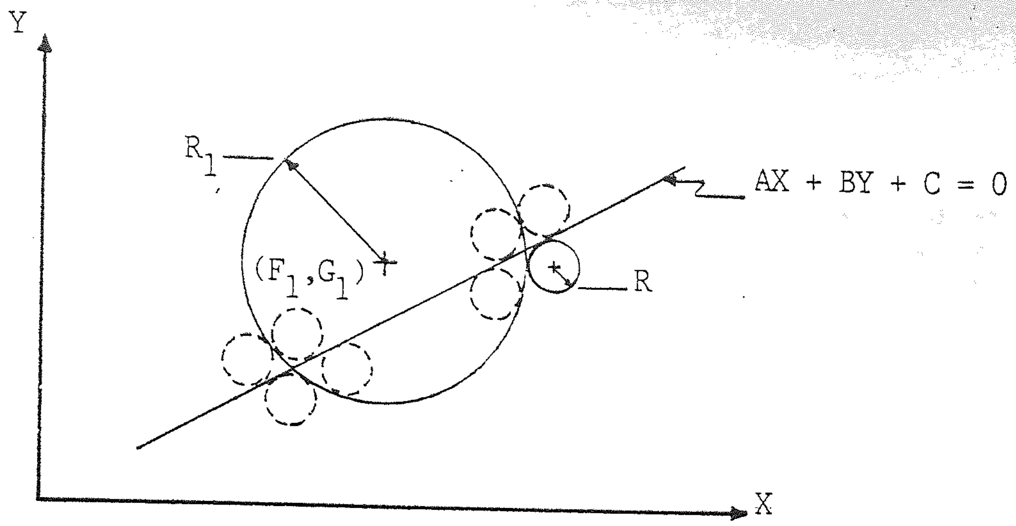


Fig. 7.10 CIRCLE DEFINED THROUGH A LINE AND CIRCLE

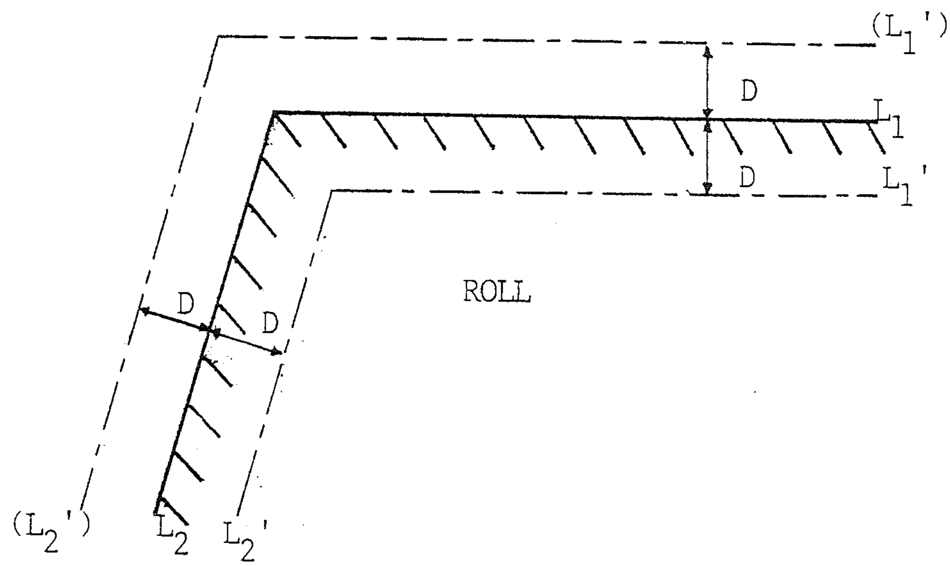
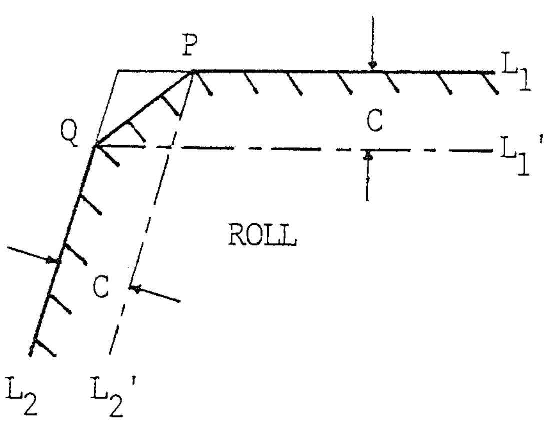


Fig. 7.11 OFFSET IMAGES OF GIVEN LINES



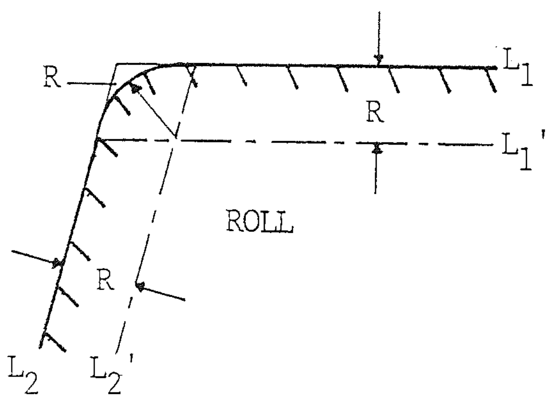


Fig. 7.12 CHAMFER

Fig. 7.13 BLENDING ARC

E1250A1T

1	1	0.000	0.000	0.000	46.681	1.000	0.000	0.000	0
2	1	0.000	46.681	13.000	46.681	0.000	1.000	-46.681	0
3	1	13.000	46.681	13.000	38.681	1.000	0.000	-13.000	0
4	1	13.000	38.681	22.500	38.681	0.000	1.000	-38.681	0
5	1	22.500	38.681	30.727	43.431	-0.577	1.000	-25.690	0
6	1	30.727	43.431	31.159	42.682	1.734	1.000	-96.705	0
7	1	31.159	42.682	58.995	58.753	-0.577	1.000	-24.692	0
8	2	58.995	58.753	60.114	59.053	60.114	56.814	2.239	-1
9	1	60.114	59.053	82.150	59.053	0.000	1.000	-59.053	0
10	2	82.150	59.053	83.270	58.753	82.150	56.814	2.239	-1
11	1	83.270	58.753	102.203	47.822	0.577	1.000	-106.829	0
12	1	102.203	47.822	103.917	46.832	0.578	1.000	-106.854	0
13	1	103.917	46.832	111.105	42.682	0.577	1.000	-106.829	0
14	1	111.105	42.682	111.537	43.431	-1.734	1.000	149.952	0
15	1	111.537	43.431	119.764	38.681	0.577	1.000	-107.829	0
16	1	119.764	38.681	129.264	38.681	0.000	1.000	-38.681	0
17	1	129.264	38.681	129.264	46.681	1.000	0.000	-129.264	0
18	1	129.264	46.681	142.264	46.681	0.000	1.000	-46.681	0
19	1	142.264	46.681	142.264	0.000	1.000	0.000	-142.264	0
0	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0

(a) TOP ROLL

E1250A1B

1	1	0.000	0.000	0.000	66.499	1.000	0.000	0.000	0
2	1	0.000	66.499	13.000	66.499	0.000	1.000	-66.499	0
3	1	13.000	66.499	13.000	74.499	1.000	0.000	-13.000	0
4	1	13.000	74.499	22.500	74.499	0.000	1.000	-74.499	0
5	1	22.500	74.499	37.915	65.599	0.577	1.000	-87.490	0
6	1	37.915	65.599	39.630	64.610	0.577	1.000	-87.464	0
7	1	39.630	64.610	58.438	53.751	0.577	1.000	-87.491	0
8	2	58.438	53.751	59.970	53.340	59.970	56.405	3.065	1
9	1	59.970	53.340	82.294	53.340	0.000	1.000	-53.340	0
10	2	82.294	53.340	83.826	53.751	82.294	56.405	3.065	1
11	1	83.826	53.751	102.635	64.610	-0.577	1.000	-5.356	0
12	1	102.635	64.610	104.349	65.599	-0.577	1.000	-5.388	0
13	1	104.349	65.599	119.764	74.499	-0.577	1.000	-5.353	0
14	1	119.764	74.499	129.264	74.499	0.000	1.000	-74.499	0
15	1	129.264	74.499	129.264	66.499	1.000	0.000	-129.264	0
16	1	129.264	66.499	142.264	66.499	0.000	1.000	-66.499	0
17	1	142.264	66.499	142.264	0.000	1.000	0.000	-142.264	0
0	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0

(b) BOTTOM ROLL

Fig. 7.14 A PRINTER LISTING OF THE ROLL PROFILE DATA FILE

Fig. 7.15 A ROLL PROFILE DRAWING AS DISPLAYED ON THE SCREEN DURING INTERACTIVE EDITING (TOP ROLL)

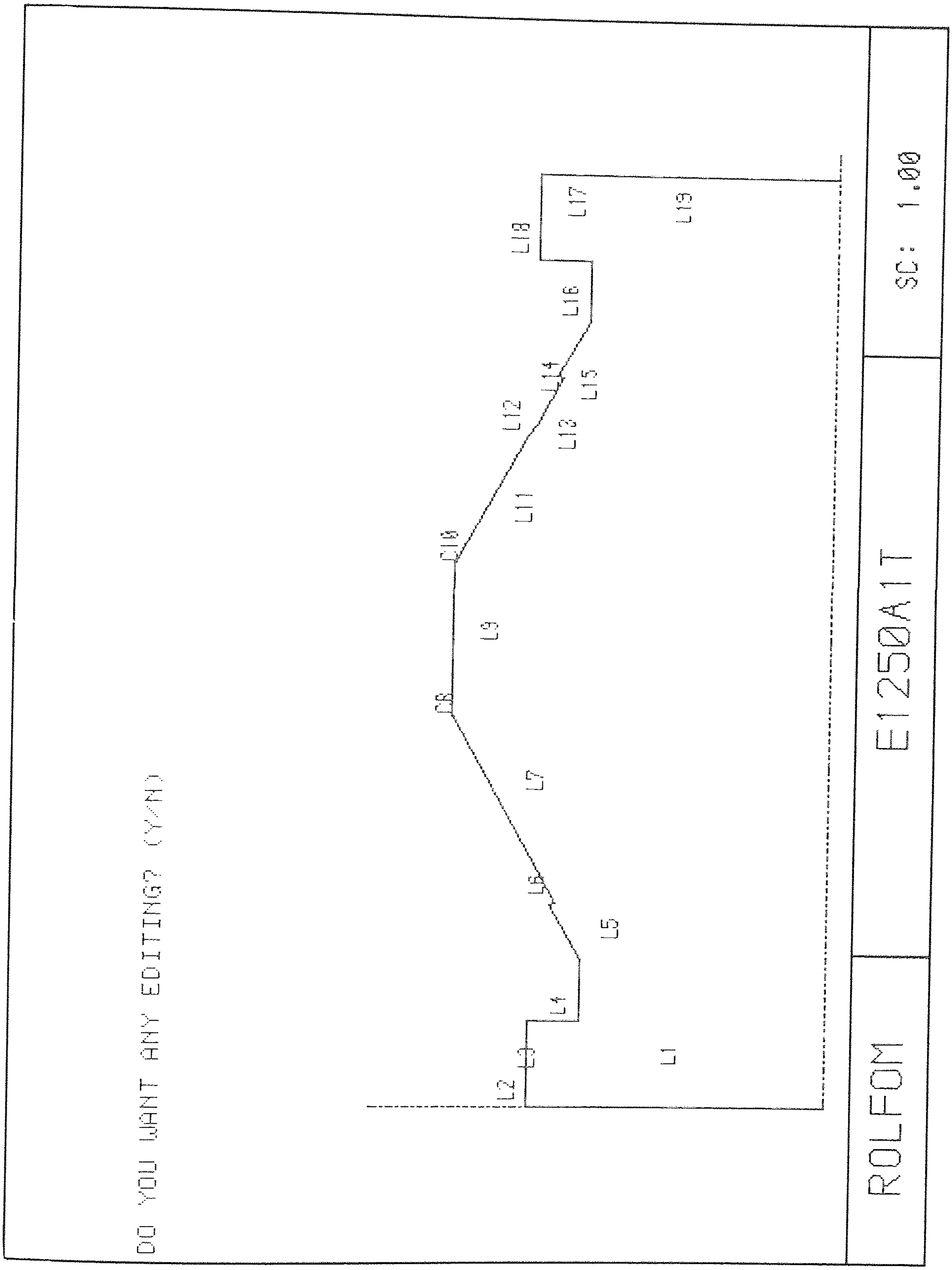


Fig. 7.16 (a) ROLL PROFILE DRAWINGS FOR A COMPLETE FORMING STAGE (WITH NO GAP BETWEEN ROLLS)

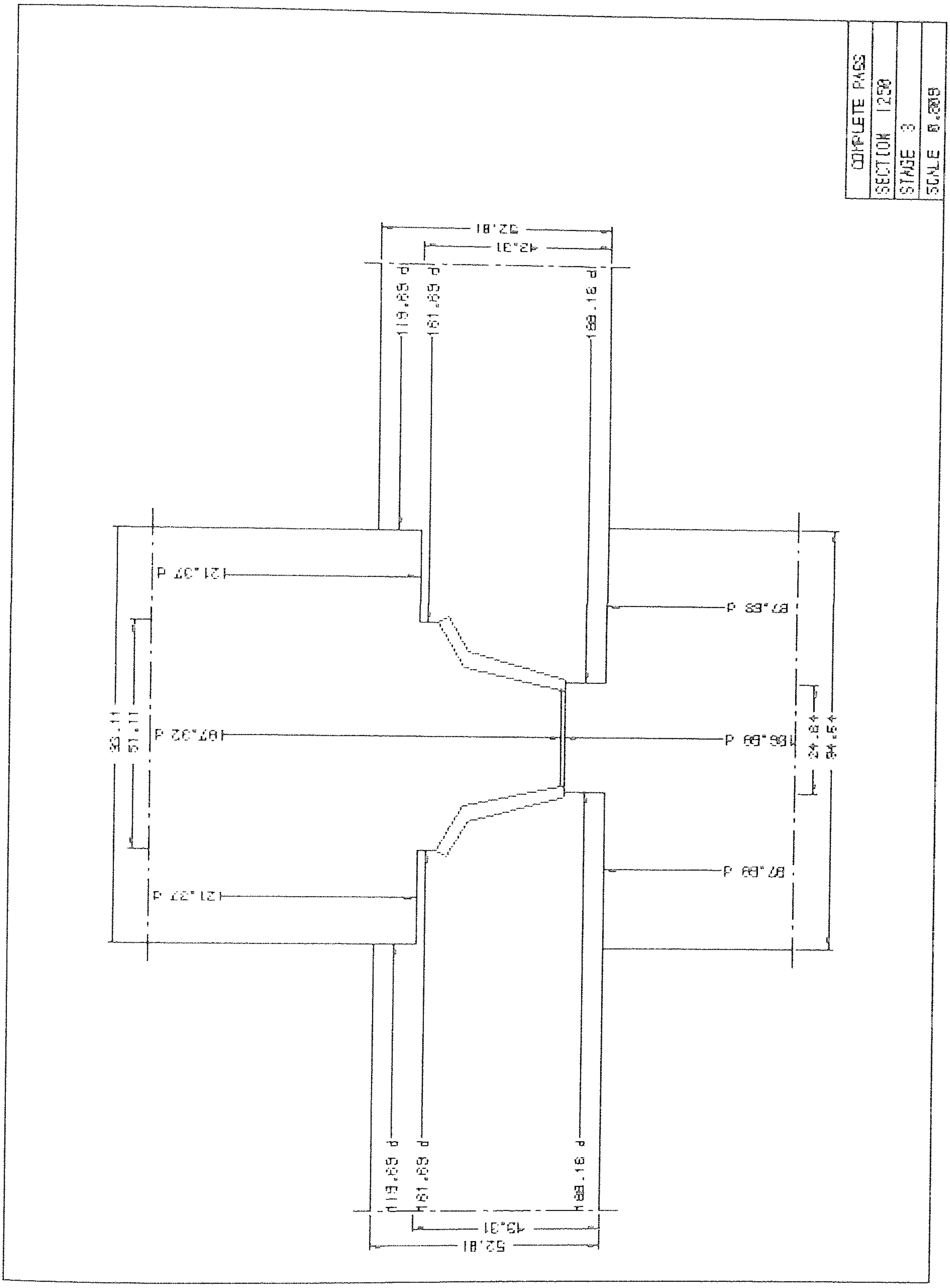


Fig. 7.16 (b) ROLL PROFILE DRAWINGS FOR A COMPLETE FORMING STAGE (WITH GAP BETWEEN ROLLS)

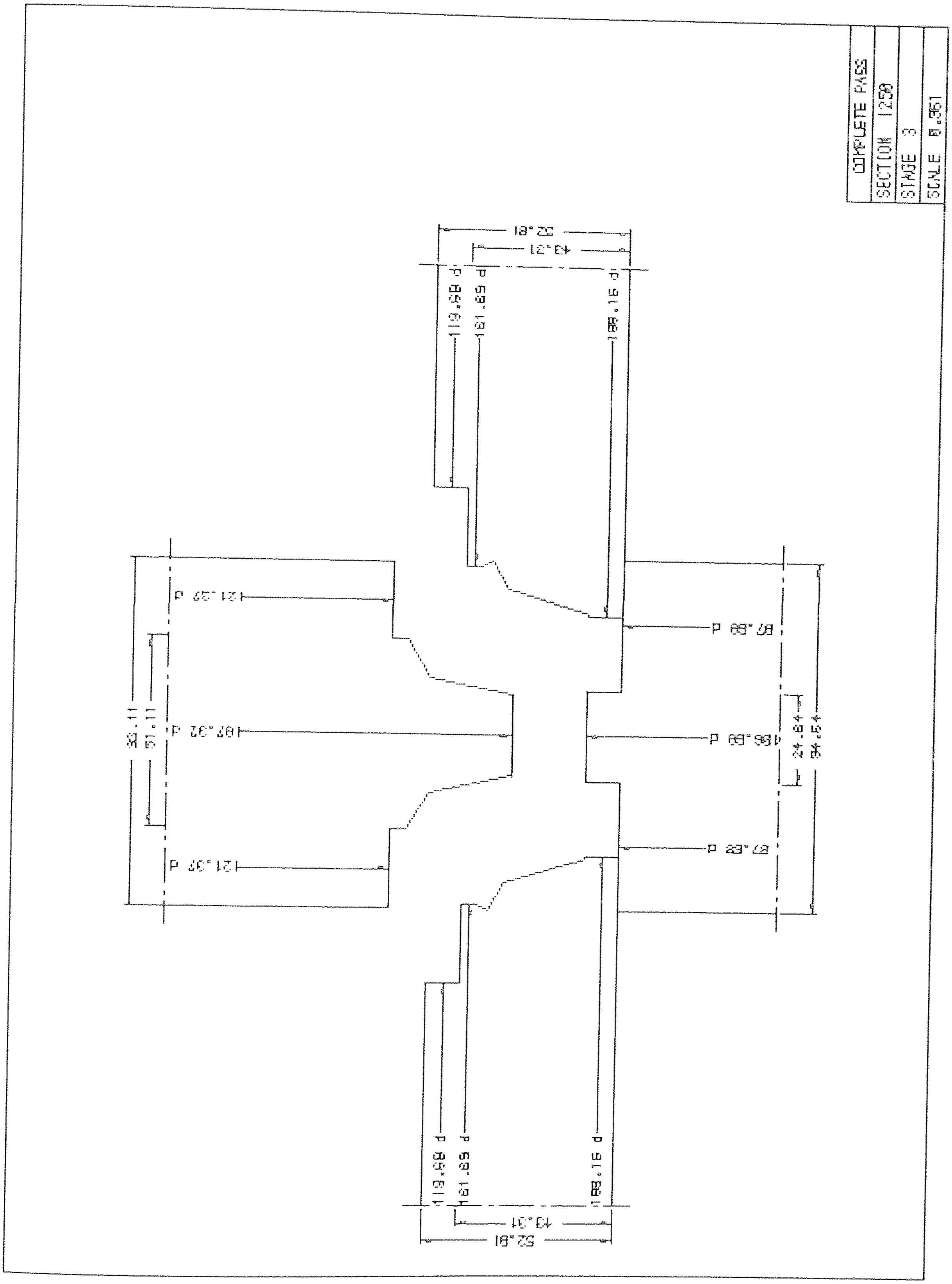


Table 7.1 ROLL PROFILE DATA STRUCTURE

DATA SUBSTORE	SUBSCRIPTS	DESCRIPTION AND VALUES
NEL(n) (Integer)	n	Element sequence number, varies from 1 to 100
ITYPE(N) (Integer)	n	Element type, 1 for linear, and 2 for circular
RXA(n,5) (Real)	n,1	X-coordinate of starting point
	n,2	Y-coordinate of starting point
	n,3	The coefficient 'A' for linear element, or X-coordinate for centre point of circular element
	n,4	The coefficient 'B' for linear element, or Y-coordinate for centre point of circular element
	n,5	The coefficient 'C' for linear element, or radius 'R' for circular element
IDIR(n) (Integer)	n	Direction of arc, 1 for CCW, and -1 for CW arc

Notes:- (1) n is the element number from 1 to 100

(2) equation of linear element is $AX + BY + C = 0$

(3) all dimensions are in mm

Table 7.2 SUBROUTINES OF THE INTERACTIVE ROLL EDITING SOFTWARE (PART 1)

SUBROUTINE	LEVEL	FUNCTION
EDITOR (MAIN PROGRAM)	1	Calls upon subordinate subroutines to decode roll geometry data from the output of the Roll Design Program, select the appropriate editing functions, display the roll profile on the Tektronix screen, and to generate the updated roll profile data structure. Option for complete pass drawing is also provided.
RIN	2	Decodes the geometric roll contour data files for a given forming stage from the output of the Roll Design Program.
ROREAD	2	Decodes the geometric roll contour data for a particular roll from the output of the Roll Design Program.
CMLPSS	2	Calls upon subordinate subroutines to plot the complete pass drawing of the given section and stage number on the Tektronix screen.
TKPLOT	2	Calls upon subordinate subroutines to plot the particular roll profile drawing on the Tektronix screen.
INSERT	2	Inserts a new element after a specified element, and updates the roll data structure.
REPLAC	2	Replaces an existing element by a new element, and updates the roll data structure.
CORNER	2	Modifies a sharp corner by inserting a chamfer or a blending arc, and updates the roll data structure.
DELETE	2	Deletes a current element and updates the roll data structure.

Table 7.2 (PART 2)

SUBROUTINE	LEVEL	FUNCTION
MIRROR	2	Reverses the shape of the roll profile and shifts the origin back to the far left point.
NAMFIL	2	Stores the edited data file under the specified file name.
INITRP	3	Initialises the roll profile geometric data file.
INITCS	3	Initialises the current roll profile data structure.
CURSTR	3	Loads the roll profile data onto the current data structure.
VIEW	3	Plots the frame for the complete pass drawing.
AXIALN	3	Plots an axial line on the complete pass drawing.
DIMLEN	3	Dimensions the lengths on the complete pass drawing.
GATE	3	Computes and dimensions the gate lengths.
PROFIL	3	Plots the roll profiles for the complete pass drawing.
FRAME	3	Plots the frame for the particular roll profile drawing.
ROPLTK	3	Plots the particular roll profile within the drawing frame.

Table 7.2 (PART 3)

SUBROUTINE	LEVEL	FUNCTION
DEFNEL	3	Calls upon subordinate subroutines to define a new element, either linear or circular.
ARROW	4	Draws an arrow head for the complete pass drawing dimensioning.
TRSFOR	4	Co-ordinate transformation for roll profile plot.
DIMDIA	4	Dimensions the different diameters on the complete pass drawing.
PLCIRC	4	Plots a circular arc with starting and ending points and given centre point, at the given direction.
LINNO	4	Outputs the element number for linear elements.
DLINEL	4	Defines a linear element.
INLNLN	4	Determines the intersection point between two elements.
INCRCR	4	Determines the intersection point between two circular elements.
DCIREL	4	Defines a circular element.

Table 7.2 (PART 4)

SUBROUTINE	LEVEL	FUNCTION
INLNCR	4	Determines the intersection point between a linear and a circular element.
ARCNO	5	Outputs the element number for circular elements.
DSINE	5	Determines the identification sign for the relative position between a new line and a given line.

Chart 7.1 HIERARCHY OF THE INTERACTIVE ROLL EDITING SOFTWARE (PART 1)

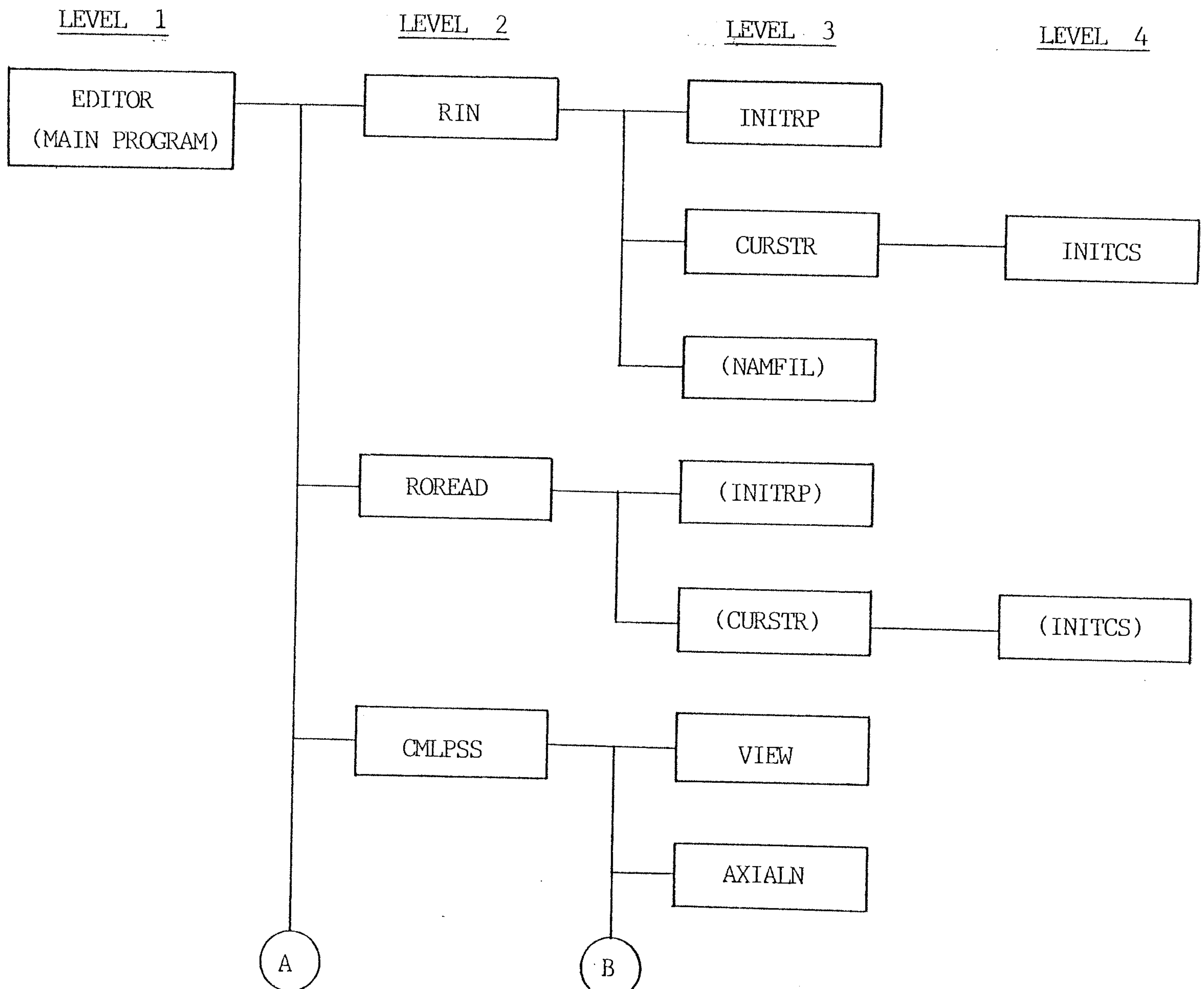


Chart 7.1 (PART 2)

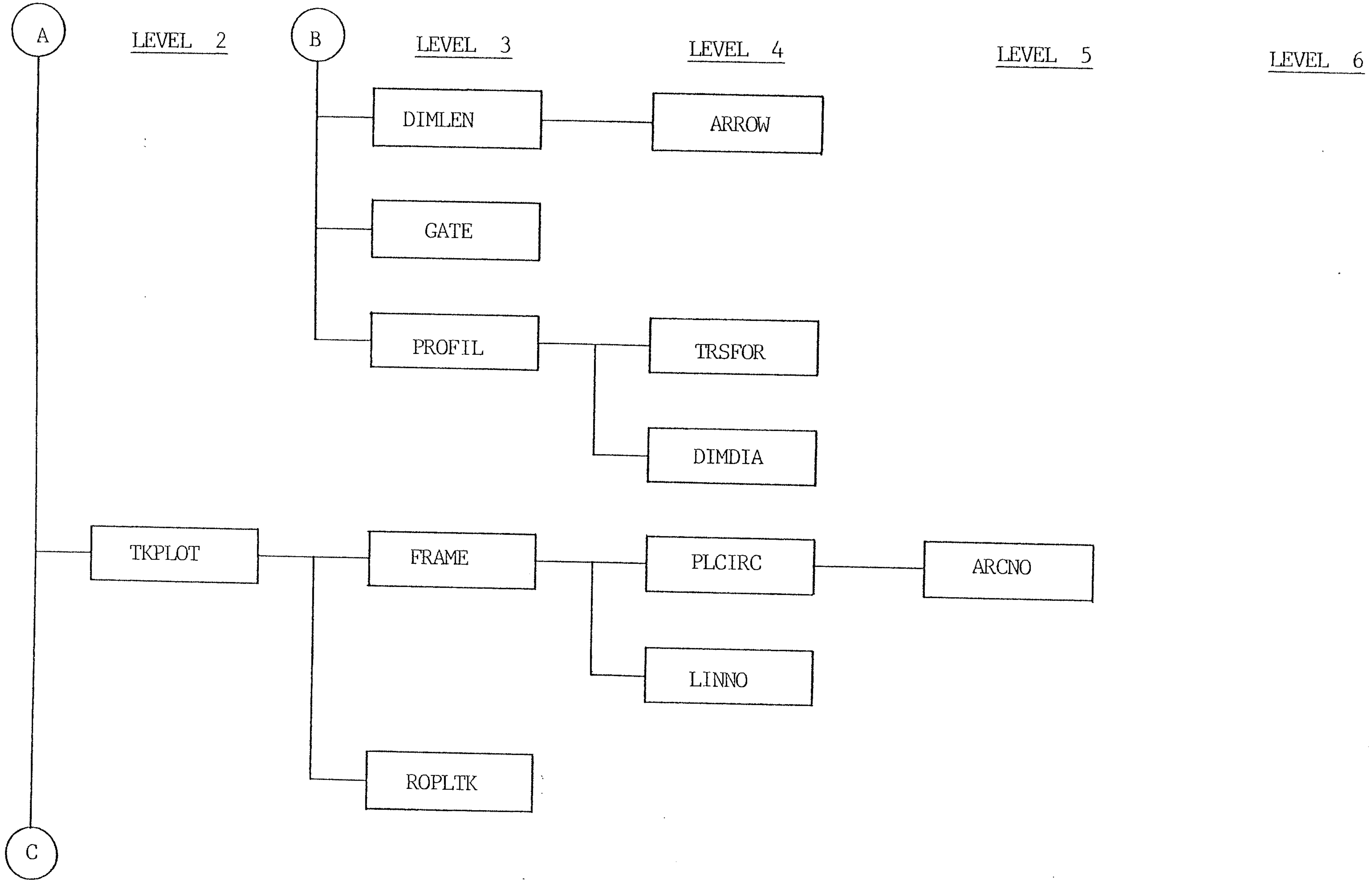


Chart 7.1 (PART 3)

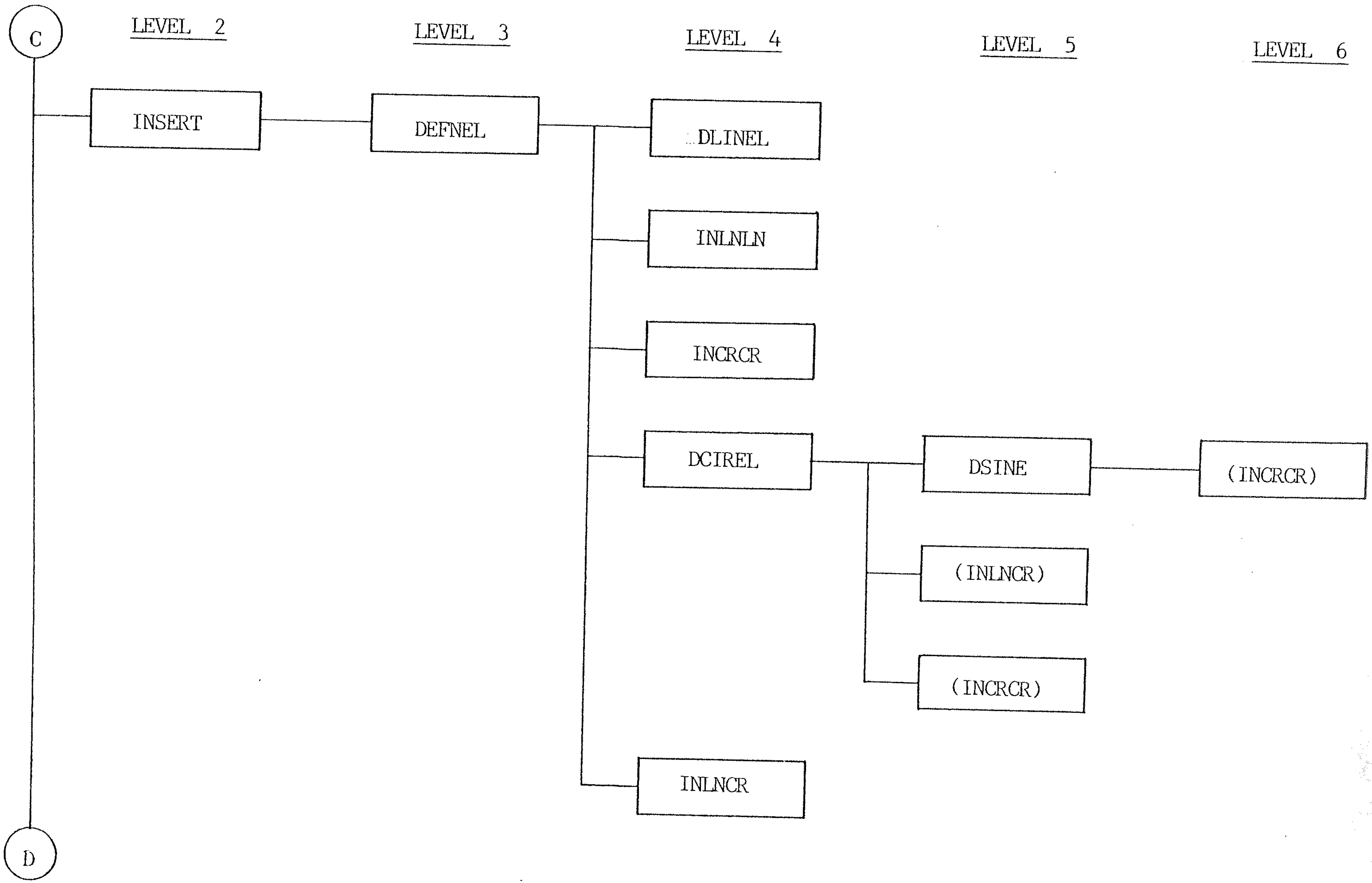
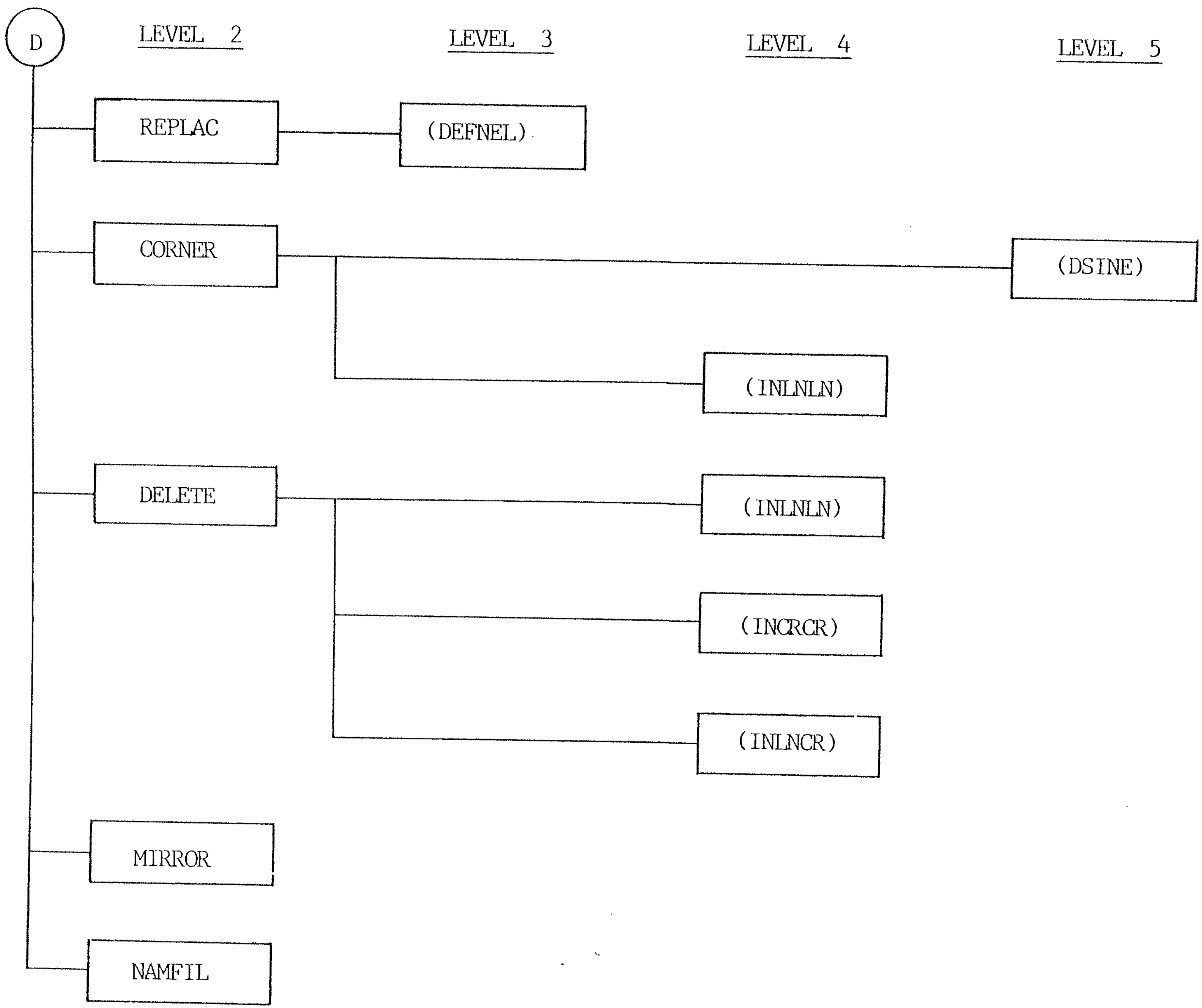


Chart 7.1 (PART 4)



CHAPTER 8

CHAPTER 8

THE EXPERT SYSTEM FORM-ROLL MACHINING PROCESSOR

8.1 INTRODUCTION

The conventional manual method for producing form-rolls, with the aid of wire templates, relies heavily upon the skill of the machinist. If the shape of the roll profile is complex, then the demand on skill becomes even greater and also very time consuming. Thus, numerical control machining had been applied to improve the traditional manufacturing method. This had been enhanced with the development of computer aided part-programming facilities for the preparation of NC tapes for machining the form-rolls.

Despite the successful operation of the system, it had been observed that the roll designers and part-programmers still played an important role in the decision making of the process. The form-roll machining plan, constituting the cutting cycle i.e. roughing, grooving, pocketing and finishing; the cutting sequence and the appropriate cutting tools to remove the material; the cutting angle at which the tool will cut into the material; the optimum speed, feed and depth of cut; all had to be determined by the part-programmer in liaison with the roll designer.

It has, therefore, been decided to apply the expert system concept to the machining of form-rolls, in an attempt to eliminate all the decision making process carried out by roll designers and part-programmers. The software system developed for machining the form-rolls, EXPSYS, is an expert system processor which considers the geometry of the form-rolls to be turned, and automatically generates the cutter location data file, the machining instructions data file and the machining process plan. The cutter location data file is retrieved at a later stage by the general post-processor and the cost estimation program, described in Chapter 9, which automatically generate the NC tape program for the specified CNC lathe and the total machining cost report respectively.

8.2 EXPERT SYSTEM APPROACH TO THE ROLL MACHINING PROCESSOR

Various expert system languages such as LISP and PROLOG, outlined in Section 4.2, were studied carefully as to their applicability to the nature of the problem of form-roll manufacture. However, due to the inability of either language to integrate its knowledge database and communicate its decisions to a FORTRAN program, it was decided to develop the expert system software for form-roll manufacture in FORTRAN 77. Fig. 8.1 gives an outline of the form-roll machining software indicating the links between the main program and the core of expert system.

The knowledge base is the database in which both facts and heuristics, regarding the manufacture of form-rolls, are represented as individual elements of knowledge with the aid of 'IF-THEN' statements. The decision rule interpreter is the problem-solving algorithm which is in the form of a subroutine, called EXPERT, that applies the knowledge in the database to the machining problem. The rules say that if the form-roll profile has certain characteristics then a certain kind of situation arises, thereby a certain kind of action must be taken. The system scans through the roll profile geometric data file in order to recognise the pattern of the roll profile, and hence machine it according to the knowledge of the roll designer and part-programmer which is incorporated into the software.

The use of 'IF - THEN' rules offer several important advantages:

1. The ease of collection of the knowledge from the expert because the 'IF - THEN' format is familiar to the way humans think.

2. The ease in fitting the program to other circumstances because the rules are completely independent of each other and easily checked and modified by the user.

3. The ease in attaching the explanation function which shows how the program has inferred the results, making the program more responsive to the user.

4. The ability to describe uncertain knowledge.

The rules have the following format in the expert system processor for form-roll machining:

IF < consequent roll profile geometry >
AND < >
OR < >
:
THEN < recommendable machining operation >
< specified parameters and their values >
:

8.3 FORM-ROLL MACHINING KNOWLEDGE BASE

The decision rules concerning the selection of the appropriate cutting cycle (roughing, grooving, pocketing or finishing), the selection of the corresponding cutting tools and machinability data, and the evaluation of the starting and ending cutting elements, are stored in the knowledge base in modules EXPERT and COMPAR. A list of the machinability data (cutting tool number, depth of cut, cutting speed, feedrate and finishing tolerance) for each cutting cycle, stored in the knowledge base, is given in Table 8.1. The primary decision rules regarding the cutting cycles, cutting tools and the starting and ending cutting elements are briefly described in this section.

While executing the system, the user specifies the CNC lathe machine for which NC programming is required, so that the appropriate cutting tools are retrieved from the tool library database. Initially, the system performs a roughing operation, as follows:

1. IF <the height (X-coordinate) of the roll profile increases upwards from left to right by at least 0.1mm> Fig. (8.2)

   THEN <select a left hand roughing tool from the tool library>
   <obtain the corresponding machinability data from the database>
   <start the roughing cycle from element 1 or 2, depending on the co-ordinates of the two elements, and end the roughing cycle at the highest element number>

2. IF <the height (X-coordinate) of the roll profile decreases downwards from left to right by at least 0.1mm> (Fig. 8.3)

THEN <select a right hand roughing tool from the tool library>

<obtain the corresponding machinability data from the database>

<start the roughing cycle from the highest element number and end the roughing cycle at element 1 or 2, depending on the co-ordinates of the two elements>

3. IF <the height (X-coordinate) of the roll profile increases upwards and then decreases downwards, from left to right, by at least 0.1mm> (Fig. 8.4).

THEN <select both a right hand and a left hand roughing tool from the tool library>

<obtain the corresponding machinability data for each tool from the database>

<start the first roughing cycle using the right hand tool from the highest element number and end the roughing cycle at element 1 or 2, depending on the co-ordinates of the two elements>

<start the second roughing cycle using the left hand tool from element 1 or 2, depending on the co-ordinates of the elements, and end the roughing cycle at the highest element number>

With completion of the roughing operation, the system scans through the roll profile data file and the roughing operation cutter location data file, to compare the geometry of the two data files in order to determine whether any roll material in excess of 0.1mm thickness requires additional roughing operation. This may occur where the roughing tools were unable to dig into small roll caps and remove the material. The system evaluates the starting and ending cutting elements, requiring either a grooving or a pocketing cycle, depending on the shape and size of the unmachined roll gap, as follows:

1. IF <an unmachined gap exists on the machined roll profile after the roughing operation>

   AND <the gap is less or equal to 18.0mm> (Fig. 8.5)

   THEN <select a grooving tool from the tool library with the appropriate width>

   <obtain the corresponding machinability data from the database>

   <start and end the grooving cycle at the element numbers where the unmachined roll gap begins and finishes respectively>

2. IF <an unmachined gap exists on the machined roll profile after the roughing operation>

   AND <the gap is in excess of 18.0mm, but less than 50.0mm>

   AND <the slope of the ending element of the gap is steeper than the starting element of the gap> (Fig. 8.6)

   THEN <select a left hand pocketing tool from the tool library>

<obtain the corresponding machinability data from the database>

<evaluate the pocketing starting point co-ordinates (Zp,Xp) with a fixed cutting angle of 90°>

<start and end the pocketing cycle at the element numbers where the unmachined roll gap begins and finishes respectively>

3. IF <an unmachined gap exists on the machined roll profile after the roughing operation>

   AND <the gap is in excess of 18.0mm, but less than 50.0mm>

   AND <the slope of the starting element of the gap is steeper than the ending element of the gap> (Fig. 8.7)

   THEN <select a right hand pocketing tool from the tool library>

   <obtain the corresponding machinability data from the database>

   <evaluate the pocketing starting point coordinates (Zp,Xp) with a fixed cutting angle of 90°>

   <start and end the pocketing cycle at the element numbers where the unmachined roll gap finishes and begins respectively>

4. IF <an unmachined gap exists on the machined roll profile after the roughing operation>

   AND <the gap is in excess of 50.0mm> (Fig. 8.8)

THEN <select both a left hand and a right hand pocketing tool from the tool library>

<obtain the corresponding machinability data for each tool from the database>

<evaluate the pocketing starting point co-ordinates (Zp,Xp) and the cutting angle ANG, depending on the slope of the right hand side of the gap>

<start the first pocketing cycle, using the right hand tool, from the element number which forms the angle ANG with the cutting point, and end the cycle at the starting element of the gap>

<start the second pocketing cycle, using the left hand tool from the element number which forms the angle ANG with the cutting point, and end the cycle at the ending element of the gap>

The above rules are repeated for as many different independent unmachined roll gaps exist on the roll profile. The final operation is a finishing cycle, again the system evaluating the starting and ending cutting elements, as follows:

1. IF <neither a grooving nor a pocketing cycle were used during the roughing operation of the roll profile> (Fig. 8.9)

THEN <select both a right hand and a left hand finishing tool from the tool library>

<obtain the corresponding machinability data for each tool from the database>

<start the first finishing cycle, using the right hand tool, from the highest point (X-coordinate) on the roll profile and end the cycle at element 1 or 2, depending on the co-ordinates of the two elements>

<start the second finishing cycle, using the left hand tool, from the highest point (X-coordinate) on the roll profile and end the cycle at the highest element number>

2. IF <either a grooving or a pocketing cycle were used during the roughing operation of the roll profile> (Fig. 8.10)

   THEN <select both a right hand and a left hand finishing tool from the tool library>

   <obtain the corresponding machinability data for each tool from the tool library>

   <start the first finishing cycle, using the left hand tool, from element 1 or 2, depending on the co-ordinates of the two elements, and end the cycle at the highest point (X-coordinate) on the roll profile>

   <start the second finishing cycle, using the right hand tool, from the highest element number and end the operation at the highest point (X-coordinate) on the roll profile>

These primary decision rules or 'production rules' as they are sometimes called, control the application of the secondary rules and the machinability data. More details concerning the machining cycles which automatically generate the sequence of the cutting operation, are discussed in Section 8.5.

8.3.1 Tool Library Database

The expert system software for form-roll machining has been designed to cater for a number of tool libraries for various CNC lathe machines. However, as it has been the intention of this research to produce NC programs for the SAAB controlled Torshalla and the Fanuc controlled Mori-Seki CNC lathes, tool libraries for only these two lathe systems have been incorporated into the software in modules TLIBS and TLIBM respectively. A list of the tools stored in each lathe turret is given in Table 8.2, and the data stored in the tool libraries for each cutting tool is given in table 8.3.

In the tool libraries TLIBS and TLIBM, the geometry of a cutting tool is defined by its tip nose radius r and the virtual tip nose circle centre co-ordinates (Z,X) in the tool co-ordinate system (Fig. 8.11). For a parting-off tool, the tool nose width w is also defined (Fig. 8.12). In addition, the distances (Zs,Xs) in both Z and X directions from the roll blank origin to the pre-set starting point (Fig. 8.13) of each individual cutting tool is also encoded.

8.3.2 Roll Blank Database

A database of standard roll blank diameters used by the company has been incorporated into the software in module ROLL. The standard blank diameters are 115, 130, 145, 160, 175, 190 and 210mm. The width of the blank is the maximum Z-dimension of the roll, while the diameter of the blank is selected from the range of standard blank diameters.

The system evaluates the largest finished roll diameter, adds a 10mm clearance to obtain the precise roll blank diameter required, and then selects the nearest larger roll blank diameter from the database. If the final finished roll diameter plus 10mm clearance is greater than 210mm, then the user will be requested to provide the roll blank diameter manually.

8.4 CUTTING TOOL OFFSET

The point of contact between the cutting tool and the roll blank depends on the tool tip nose radius, which affects the actual profile of the finished form-roll. Therefore, the tool tip nose radius r and the tool tip nose circle centre co-ordinates (z,x) must be taken into consideration in the roll machining software. By adding the tool tip nose radius r to the finishing tolerance t, which is the allowance left by the machining cycles (roughing, grooving and pocketing) for finishing, the total amount of offset (OFF) can be obtained, (Fig. 8.14) that is:

$$OFF = t + r \qquad (8.1)$$

The expert system software for form-roll machining has been designed to evaluate the offset contour of the machining area in every machining cycle. The tool tip nose radius r for the corresponding cutting tool to be used is retrieved directly from the tool library TLIBS or TLIBM depending on the specified CNC lathe machine, and the finishing tolerance t for each machining cycle is retrieved directly from the machinability database stored in module EXPERT. The offset tool paths for all contour elements is determined by the OFFSET module, which determines the geometry of the offset contour by joining all the offset tool paths together.

The cutting direction is also determined automatically according to the relative position between the starting and ending elements of the machining area. If the cutting direction is from right to left, the cutting tool is located on the right hand side of the contour, denoted by IK equals -1 in the OFFSET module (Fig.8.15a). Converseley, if the cutting direction is from left to right, the cutting tool is located on the left hand side, denoted by IK equals +1 (Fig. 8.15b).

If the cutting tool is located outside a circular element, then this is denoted by JK equals +1 in the module VIGN, while if the cutting tool is located inside the circular element JK equals -1. There are four different cases for the location of the cutting tool relative to circular elements, as shown in Fig. 8.16, which depend on the cutting direction (IK) and the direction of the circular arc (IDIR).

8.4.1 Cutter Path Offset for Linear Elements

Linear elements are represented in the roll profile data file by their starting and ending points. The OFFSTL module has, therefore, been designed to compute the offset of given points on straight lines. Assuming, the starting point P and the ending point Q of a linear element have co-ordinates (Z_1,X_1) and (Z_2,X_2) respectively, then the direction of the linear element is determined by the relative position of the two points P and Q. In order to obtain the offset co-ordinates PA and QA for P and Q respectively, eight different cases must be considered separately, as shown in Fig. 8.17. Having obtained the magnitude of the offset (OFF) and the relative position of the cutting tool (IK), the offset line co-ordinates can be calculated as follows:

Case 1 $(Z_1 = Z_2 \text{ and } X_1 < X_2)$

$$Z_1A = Z_1 - (IK * OFF) \tag{8.2}$$

$$X_1A = X_1 \tag{8.3}$$

$$Z_2A = Z_2 - (IK * OFF) \tag{8.4}$$

$$X_2A = X_2 \tag{8.5}$$

Case 2 $(Z_1 = Z_2 \text{ and } X_1 > X_2)$

$$Z_1A = Z_1 + (IK * OFF) \tag{8.6}$$

$$X_1A = X_1 \tag{8.7}$$

$$Z_2A = Z_2 + (IK * OFF) \tag{8.8}$$

$$X_2A = X_2 \tag{8.9}$$

Case 3 $(Z_1 > Z_2 \text{ and } X_1 = X_2)$

$$Z_1A = Z_1 \tag{8.10}$$

$$X_1A = X_1 - (IK * OFF) \tag{8.11}$$

$$Z_2A = Z_2 \tag{8.12}$$

$$X_2A = X_2 - (IK * OFF) \tag{8.13}$$

Case 4 $(Z_1 < Z_2 \text{ and } X_1 = X_2)$

$$Z_1A = Z_1 \tag{8.14}$$

$$X_1A = X_1 + (IK * OFF) \tag{8.15}$$

$$Z_2A = Z_2 \tag{8.16}$$

$$X_2A = X_2 + (IK * OFF) \tag{8.17}$$

Case 5 $(Z_1 > Z_2 \text{ and } X_1 < X_2)$

$$Z_1A = Z_1 - (IK * OFF * \sin(A)) \tag{8.18}$$

$$X_1A = X_1 - (IK * OFF * \cos(A)) \tag{8.19}$$

$$Z_2A = Z_2 - (IK * OFF * \sin(A)) \tag{8.20}$$

$$X_2A = X_2 - (IK * OFF * \cos(A)) \tag{8.21}$$

<u>Case 6</u> $(Z_1 < Z_2 \text{ and } X_1 < X_2)$

$$Z_1A = Z_1 - (IK * OFF * \sin(A)) \tag{8.22}$$

$$X_1A = X_1 + (IK * OFF * \cos(A)) \tag{8.23}$$

$$Z_2A = Z_2 - (IK * OFF * \sin(A)) \tag{8.24}$$

$$X_2A = X_2 + (IK * OFF * \cos(A)) \tag{8.25}$$

<u>Case 7</u> $(Z_1 > Z_2 \text{ and } X_1 > X_2)$

$$Z_1A = Z_1 + (IK * OFF * \sin(A)) \tag{8.26}$$

$$X_1A = X_1 - (IK * OFF * \cos(A)) \tag{8.27}$$

$$Z_2A = Z_2 + (IK * OFF * \sin(A)) \tag{8.28}$$

$$X_2A = X_2 - (IK * OFF * \cos(A)) \tag{8.29}$$

<u>Case 8</u> $(Z_1 < Z_2 \text{ and } X_1 > X_2)$

$$Z_1A = Z_1 + (IK * OFF * \sin(A)) \tag{8.30}$$

$$X_1A = X_1 + (IK * OFF * \cos(A)) \tag{8.31}$$

$$Z_2A = Z_2 + (IK * OFF * \sin(A)) \tag{8.32}$$

$$X_2A = X_2 + (IK * OFF * \cos(A)) \tag{8.33}$$

8.4.2 <u>Cutter Path Offset for Circular Elements</u>

The equal intercept theorem along the normals to the circle at the points of the contours, as shown in Fig. 8.18, is utilised in the OFFNML module to obtain the cutter offset points. For a circular arc PQ, provided the offset (OFF) and the relative position of the cutting tool (JK) with respect to the circular arc have been obtained, the co-ordinates of the offset points PA and QA can be calculated as follows:

$$Z_1A = F + ((R + JK * OFF)/R) * (Z_1 - F) \quad (8.34)$$

$$X_1A = G + ((R + JK * OFF)/R) * (X_1 - G) \quad (8.35)$$

$$Z_2A = F + ((R + JK * OFF)/R) * (X_2 - G) \quad (8.36)$$

$$X_2A = G + ((R + JK * OFF)/R) * (X_2 - G) \quad (8.37)$$

where R is the radius of the arc, and

(F,G) is the centre co-ordinates of the arc

8.4.3 Cutter Path Offset for Intersecting Elements

When either a linear and a circular element intersect, or two linear/circular elements intersect, the OFFSTL and OFFNML modules are initially utilised to obtain the co-ordinates for the terminal points of the two offset tool paths respectively, as explained in Sections 8.4.1 and 8.4.2. Thereafter, the geometric principles and procedures described in Section 7.4 for the Roll Editing software are applied to obtain the intersecting point between the two elements. Nevertheless, subroutines LINLIN, CIRCIR and LINCIR have been designed and incorporated into the software to calculate the offset cutter location for two intersecting linear elements, two intersecting circular elements, and a linear element intersecting with a circular element respectively.

8.5 MACHINING CYCLES

The system has been designed to include software facilities for four machining cycles which are divided into two sections, roughing out (area clearance) and finish profiling. These machining cycles (roughing, grooving, pocketing and finishing) are automatically selected by the system, as described in Section 8.3, and generate the entire sequence of motions to rough or finish the part, by making all the decisions for tool placements at the beginning and end of each cut and throughout the entire machining sequence.

The machining cycle is denoted by the variable ICYCLE in the software, whereby ICYCLE equals 1 for the roughing cycle; 2 for grooving; 3 for finishing and 4 pocketing. For every machining cycle selected by the system, corresponding machining data (cutting tool, depth of cut, cutting speed, feedrate and tolerance) is retrieved from the database, as shown in Table 8.1. Each of the four machining cycles are described separately in the following sections.

8.5.1 Roughing Cycles

The roughing cycle facility, installed in the module ROUGH, has been designed with the following features:

1. The first tool movement of the roughing cycle is positioning the tool at rapid traverse from the pre-set tool changing position to the machining start point, which is at a clearance value of 2mm away from the start line (Fig. 8.19)

2. The machining is done in parallel to the Z-axis, as a repetition of a three-stroke cutting cycle, as shown in Fig. 8.20. In the first stroke, the tool advances in cutting feed from its previous position P

to the cutting point S, in order to achieve the depth of cut d. In the second stroke, the tool cuts parallel to the Z-axis from the start point S to the end point E, being a distance t (the finishing tolerance) away from the contour. Finally, in the third stroke, the tool returns at rapid traverse from point E to point R which is at a clearance value c (fixed at 2mm) away from the point S.

3. The end point of a cutting stroke is determined by computing the point of intersection between the cutting line and the offset profile element. For a linear profile element, as shown in Fig. 8.21a, the co-ordinates (Ze,Xe) are given by

$$Xe = Xs \tag{8.38}$$

$$Ze = Zp + (Xp - Xe) \times (Xp - Xq) / (Zp - Zq) \tag{8.39}$$

for a circular element, as shown in Fig. 8.21b,

$$Xe = Xs \tag{8.41}$$

$$Ze = F \pm \sqrt{R^2 - (G - Xs)^2} \tag{8.41}$$

where (F,G) are the co-ordinates of the circle, and the application of the + or - sign in equation (8.41) depends on whether the tool is located outside or inside the circular arc respectively.

4. All concave contour segments or undercuts are ignored by the roughing cycle, as shown in Fig. 8.22.

5. When all possible Z-directional cuts are completed, a final cut parallel to the computed contour segment is performed, leaving a material tolerance for finishing.

6. The tool finally returns at rapid traverse to its pre-set tool changing position.

8.5.2 Grooving Cycle

For removing material in concave areas, a parting-off tool is utilised to perform a grooving operation in the diameter direction, as shown in Fig. 8.23. The grooving cycle facility, installed in module GROOVE, has therefore been designed for this purpose with the following features:

1. The first tool movement of the grooving cycle is positioning the tool at rapid traverse from the pre-set tool changing position to the machining start point, which is at a clearance value of 3mm above the maximum radius of the blank (Fig. 8.23).

2. The machining is done in parallel to the X-axis, as a repetition a three-stroke cutting cycle, as shown in Fig. 8.24. In the first stroke, the tool advances in cutting feed from the cutting start point S to the end point E. In the second stroke, the tool returns in rapid traverse to the cutting start point S. Finally, in the third stroke, the tool advances in cutting feed to a new start point N, the distance being equal to half the width of the grooving tool.

3. As cutting is done in parallel to the X-axis, the Z-coordinate of the cutting end point is the same as that for the cutting start point. For the X-coordinate of the cutting end point the largest

radius of the offset profile segment within the width of the grooving tool is selected.

4. The tool finally returns at rapid traverse to its tool changing position.

8.5.3 Pocketing Cycle

The pocketing cycle facility, installed in module POCKET, has been designed for removing material in concave areas by utilising a turning tool of larger clearance angle so that the tool can be directed to dig in and remove the material. As shown in Fig. 8.25, the angle (ANG) between the cut-in line L and the Z-axis is smaller than the clearance angle (CL) of the tool.

Most of the features of the pocketing cycle are the same as those for the roughing cycle. The only main difference being the introduction of the cut-in line in the pocketing cycle, which subdivides the machining area ABCD in Fig. 8.25 into two segments. Thereafter, the area RSCD can be machined by a right hand tool and the area RSBA by a left hand tool. The cut-in line L is defined by the co-ordinates (Zp, Xp) of a point P and the angle (ANG). The expert system roll machining software computes the cut-in line where necessary automatically, according to the angle between the lines AB and BC and according to the clearance angle (CL) of the tool. That is, the system ensures that the angle (ANG) is smaller than the clearance angle (CL) of the tool, and that the point R on the cut-in L is at least 5mm away from the point A.

The machining is done as a repetition of a four-stroke cutting cycle, as shown in Fig. 8.26. In the first stroke, the tool advances in cutting feed from point K to the cutting start point L along the cut-in line. In the second stroke, the tool cuts parallel to the Z-axis from the cutting start point L to the cutting end point M, being a distance t (the finishing tolerance) away from the contour. The third stroke is a rapid traverse movement of the tool to a point N, which is at a vertical clearance value c away from the point L. Finally, in the fourth stroke, the tool advances in cutting feed back to the cutting start point L in order to start another cycle.

8.5.4 Finishing Cycle

When all the roughing operation is completed, the system calls up a finishing cycle to perform the finish profiling. The finishing cycle facility, installed in module FINISH, has therefore been designed to achieve this by cutting along the offset contour with zero material allowance until reaching the ending point of the machining area, as shown in Fig. 8.27.

The system selects the starting and ending cutting points according to the shape of the roll profile, but the user can also intervene to designate the desired starting and ending cutting points. It is also possible to perform medium finishing before the final profiling by specifying a desired material allowance left for finishing. At the end of the finishing cycle the tool returns at rapid traverse to its pre-set tool changing position.

8.6 OPERATION OF THE ROLL MACHINING PROCESSOR

The operation of the processor does not require the user to supply any information as all the decision making concerning the geometry of the roll profile and the cutting data instructions is handled by the system, as outlined in Section 8.3. The only input required by the user is the thin-walled finished section number, the stage and roll numbers so that the processor can retrieve the required roll profile geometric data file, and the CNC lathe machine for which NC programming is required.

A plot of the tool paths is displayed on the Tektronix screen, as shown in Fig. 8.28. The tool path plot is a graphical representation of the cutter location data. This enables the user to follow the path of the tool on the screen, and determine whether the roll is being machined in the correct manner.

The processor automatically generates the cutter location data file (CO"SECNO""s""r"), the machining instructions data file (CI"SECNO""s""r") and the machining process plan (CP"SECNO""s""r"), where "SECNO" is the thin-walled finished section number, "s" is the stage number and "r" is the roll number. Typical listings of these data files are shown in Fig. 8.29, Fig. 8.30 and Fig. 8.31 respectively. The cutter location data file is stored in memory to be retrieved at a later stage for post-processing, to generate the NC tape program for the required NC system. The machining instructions data file is a listing of all the machining data selected by the system from the knowledge base to perform the complete cutting operation. The machining process plan differs from the machining instructions data file only in that a more detailed explanation of the various cutting instructions is given, which makes it a valuable tool for machine operators on the shop floor.

8.7 SOFTWARE STRUCTURE

The expert system roll machining processor, EXPSYS, consists of four distinctive units, namely:

1. The Expert System Roll Machining Program (EXPSYS)
2. The Expert System Module (EXPERT)
3. The Interactive Data Input Module (MANINP)
4. The Tool Offset Module (OFFSET)

A brief account of the nature of the subroutines for the expert system roll machining software and those for the tool offset module are given in Tables 8.4 and 8.5 respectively. The hierarchy of the system software structure is shown in Chart 8.1 with the main program EXPSYS residing at the highest level of execution, while the hierarchy of the subroutines in the OFFSET module is shown in Chart 8.2.

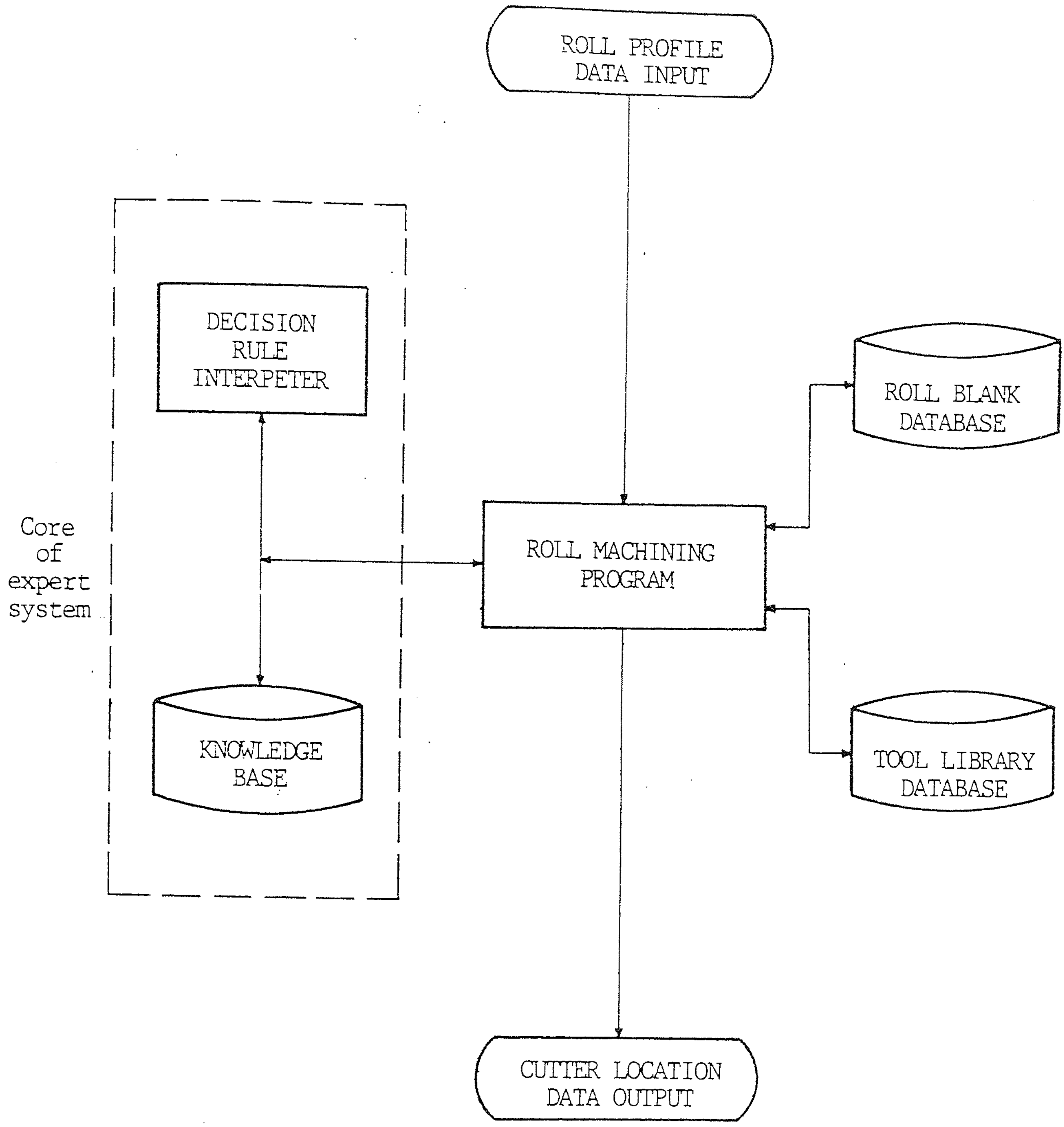


Fig. 8.1 FORM-ROLL MACHINING SOFTWARE

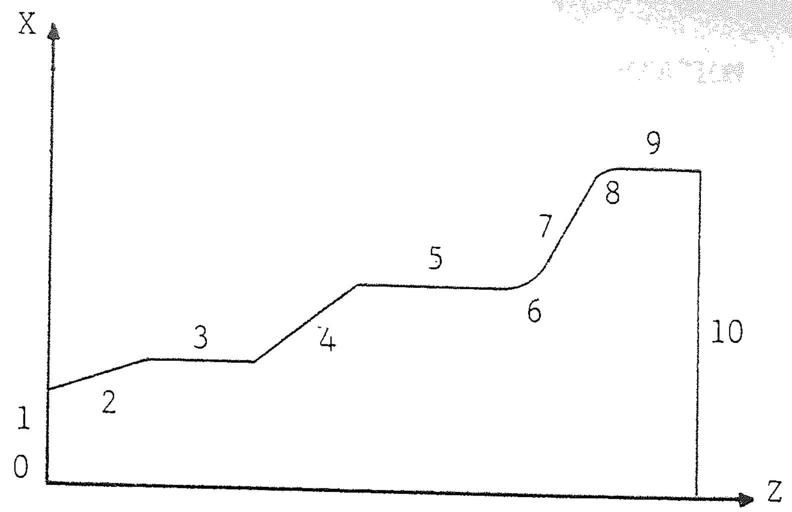


Fig. 8.2 ROLL PROFILE INCREASING UPWARDS FROM LEFT TO RIGHT

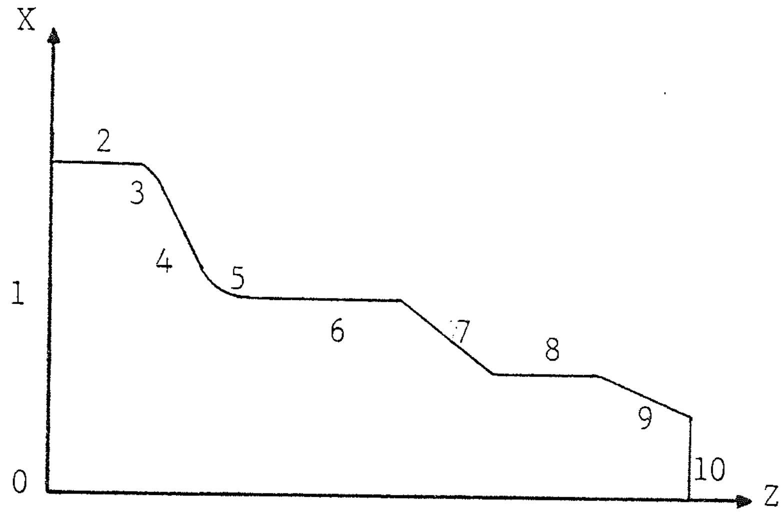


Fig. 8.3 ROLL PROFILE DECREASING DOWNWARDS FROM LEFT TO RIGHT

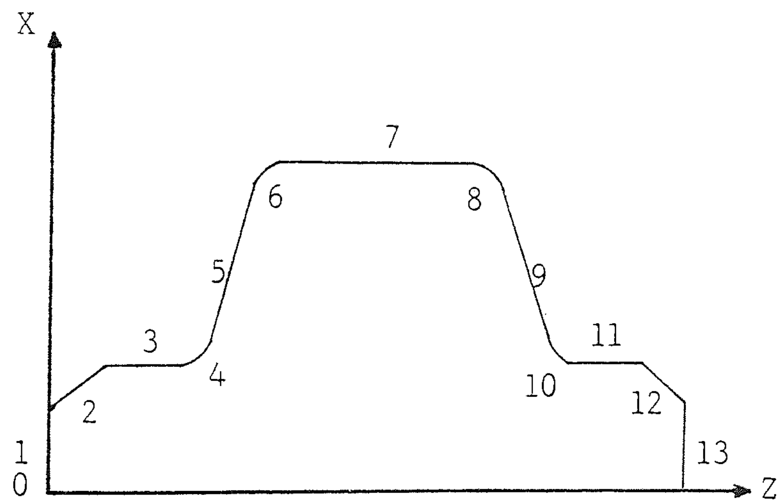


Fig. 8.4 ROLL PROFILE INCREASING UPWARDS AND THEN DECREASING DOWNWARDS FROM LEFT TO RIGHT

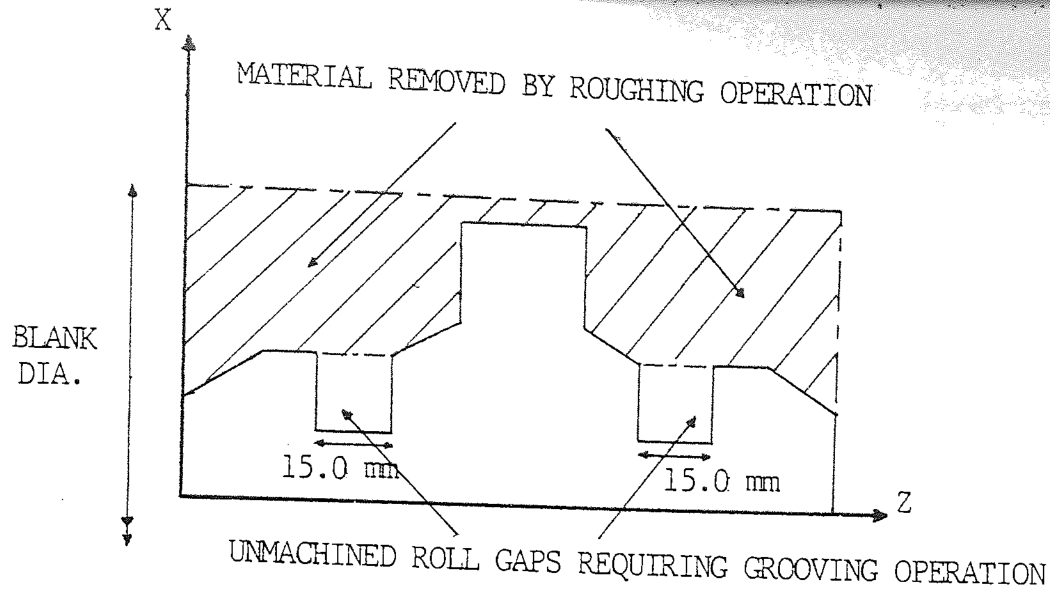


Fig. 8.5 ROLL PROFILE REQUIRING A GROOVING CUTTING TOOL

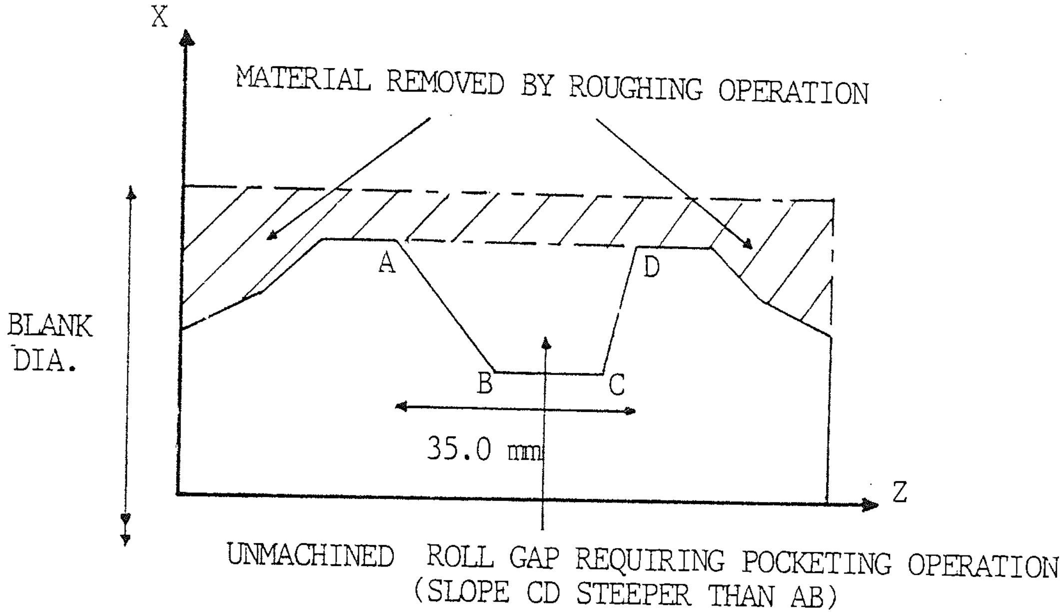


Fig. 8.6 ROLL PROFILE REQUIRING A LEFT HAND POCKETING TOOL

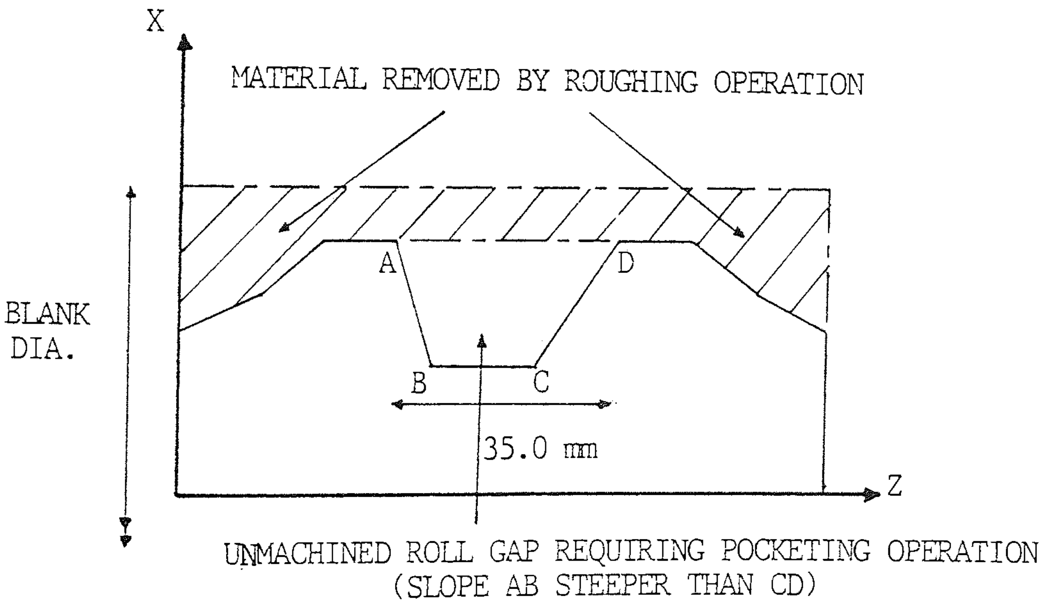


Fig. 8.7 ROLL PROFILE REQUIRING A RIGHT HAND POCKETING TOOL

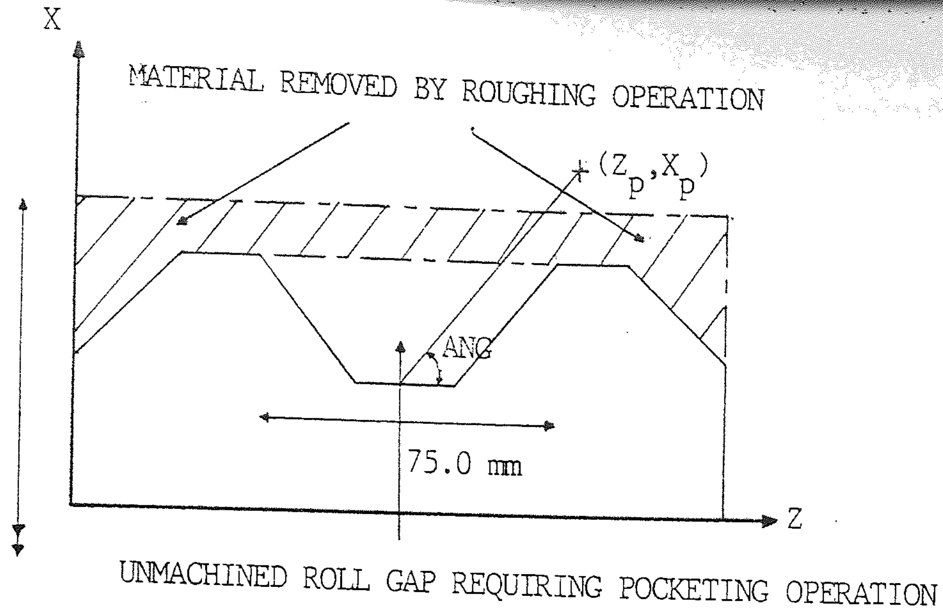


Fig. 8.8 ROLL PROFILE REQUIRING BOTH A LEFT HAND AND A RIGHT HAND POCKETING TOOL

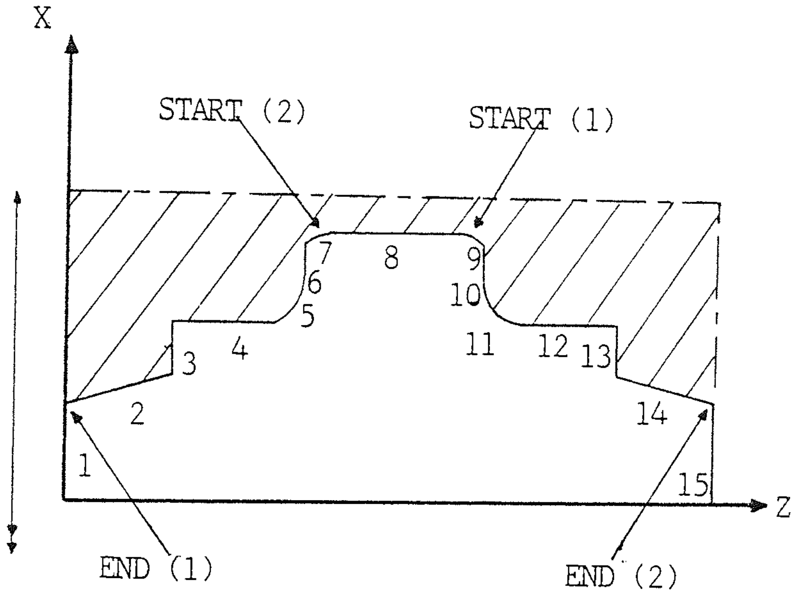


Fig. 8.9 STARTING AND ENDING ELEMENTS FOR FINISHING CYCLE (CASE 1)

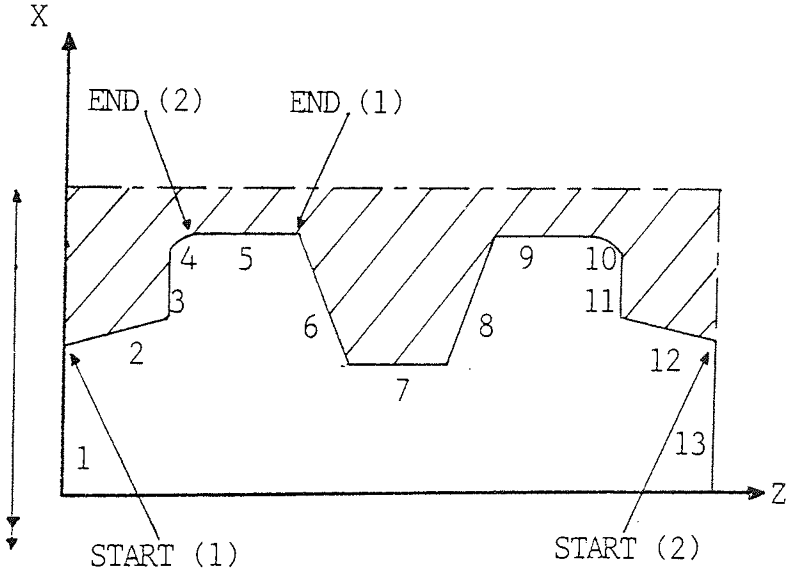


Fig. 8.10 STARTING AND ENDING ELEMENTS FOR FINISHING CYCLE (CASE 2)

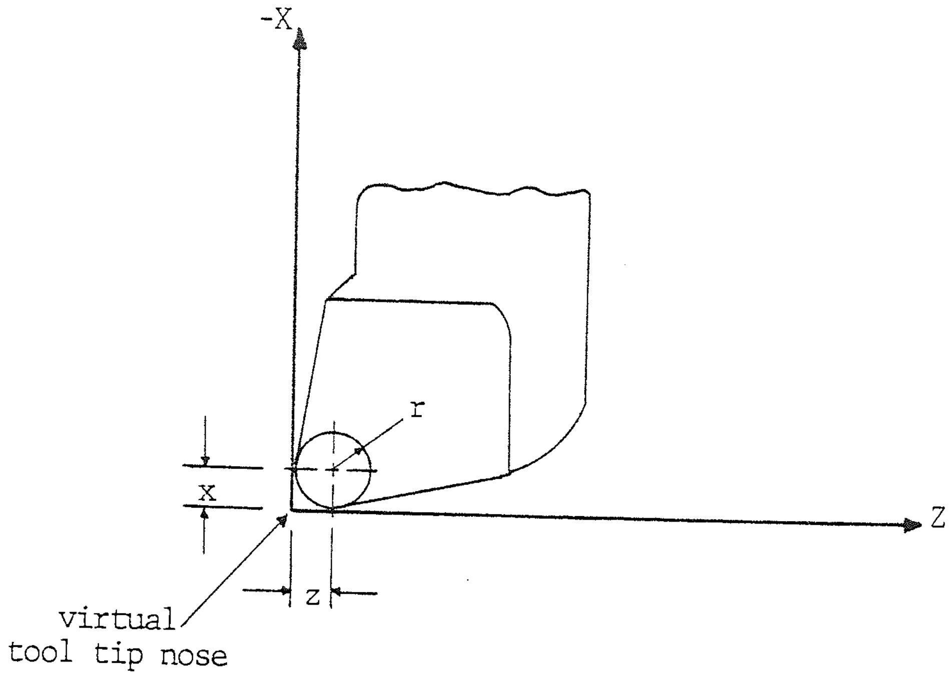


Fig. 8.11 TOOL COORDINATE SYSTEM

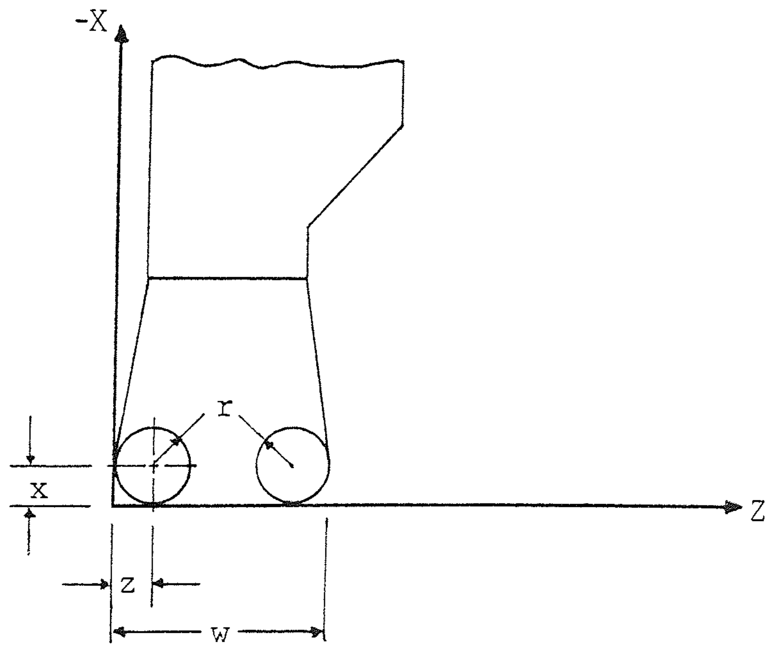


Fig. 8.12 TOOL COORDINATE SYSTEM FOR PARTING-OFF TOOL

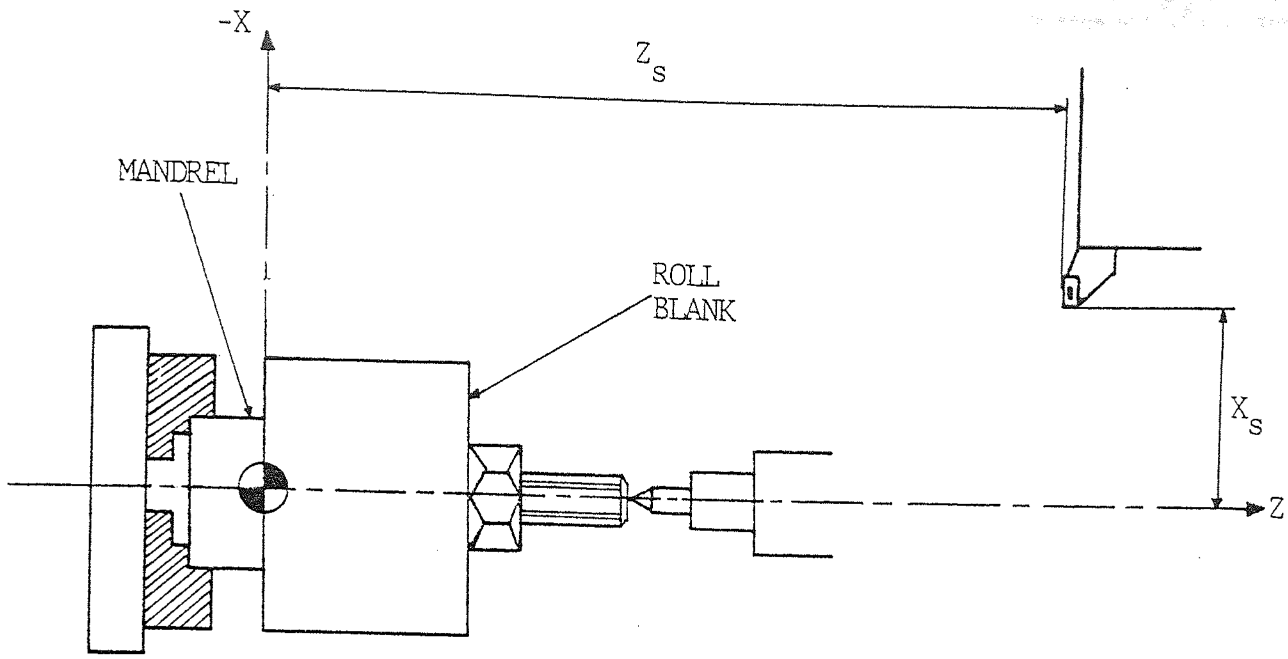


Fig. 8.13 PRE-SET STARTING POSITION

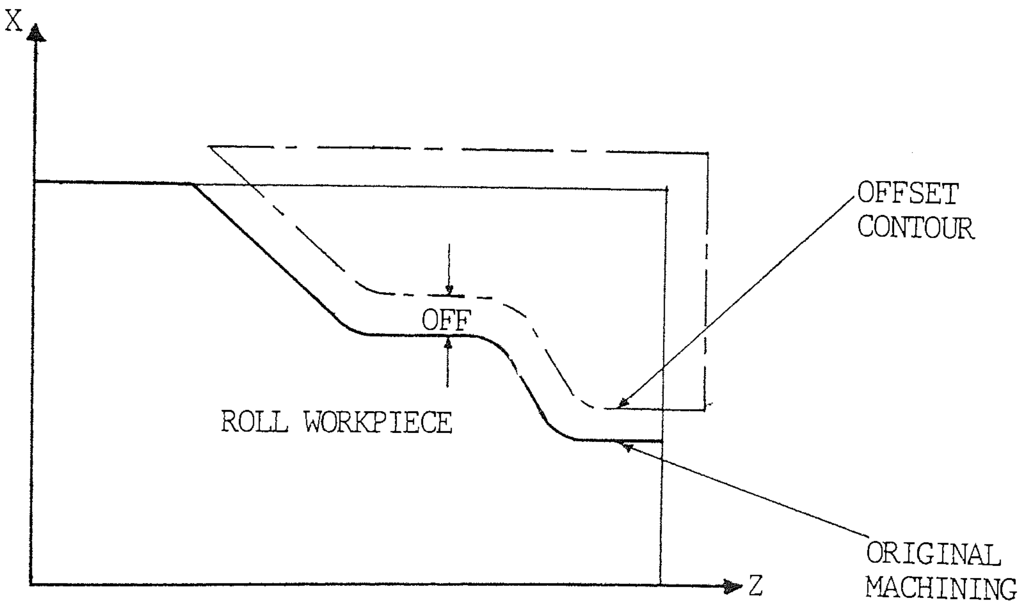


Fig. 8.14 OFFSET CONTOUR FOR A MACHINING AREA

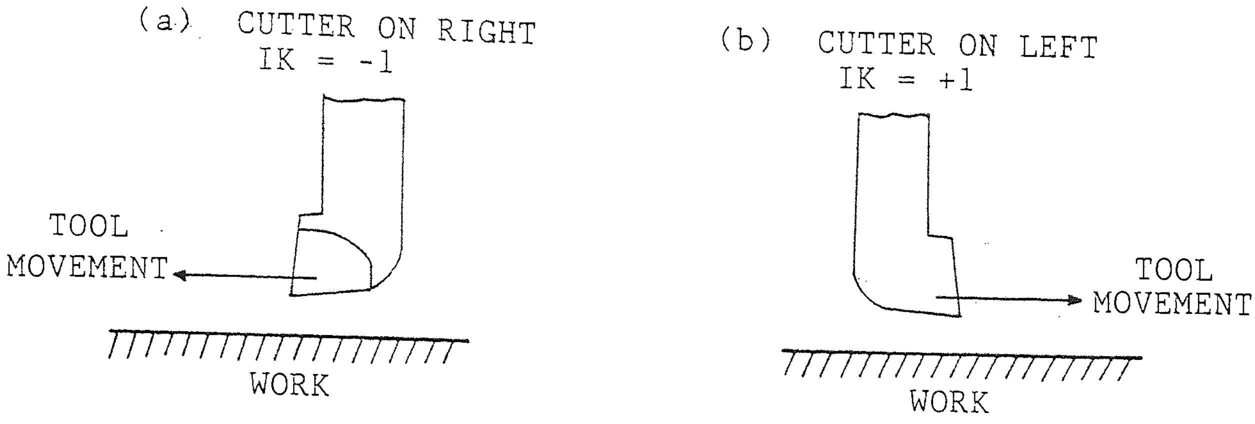


Fig. 8.15 SIGN CONVENTION FOR CUTTER POSITION

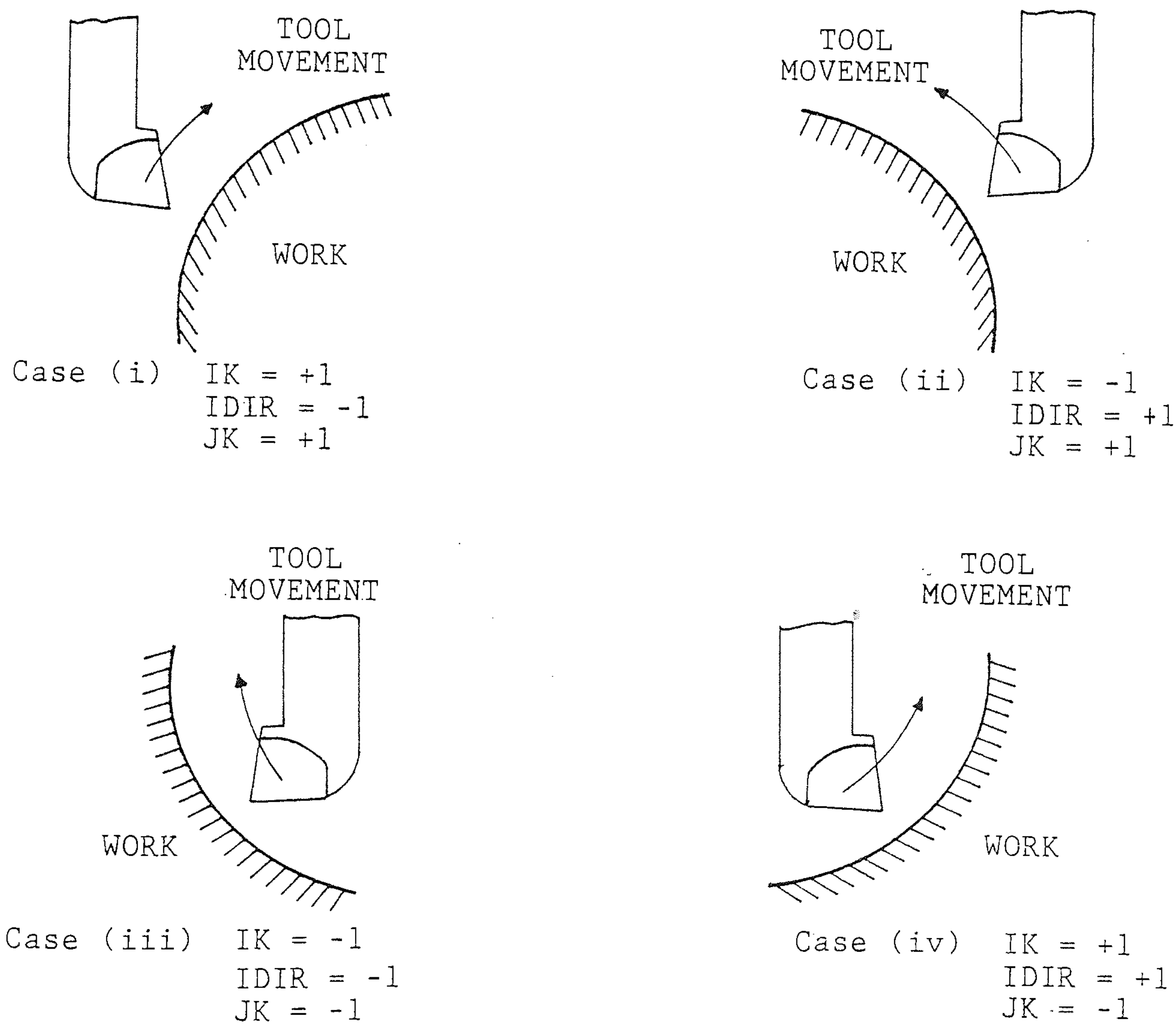


Fig. 8.16 POSITION OF CUTTER RELATIVE TO CIRCULAR ELEMENT

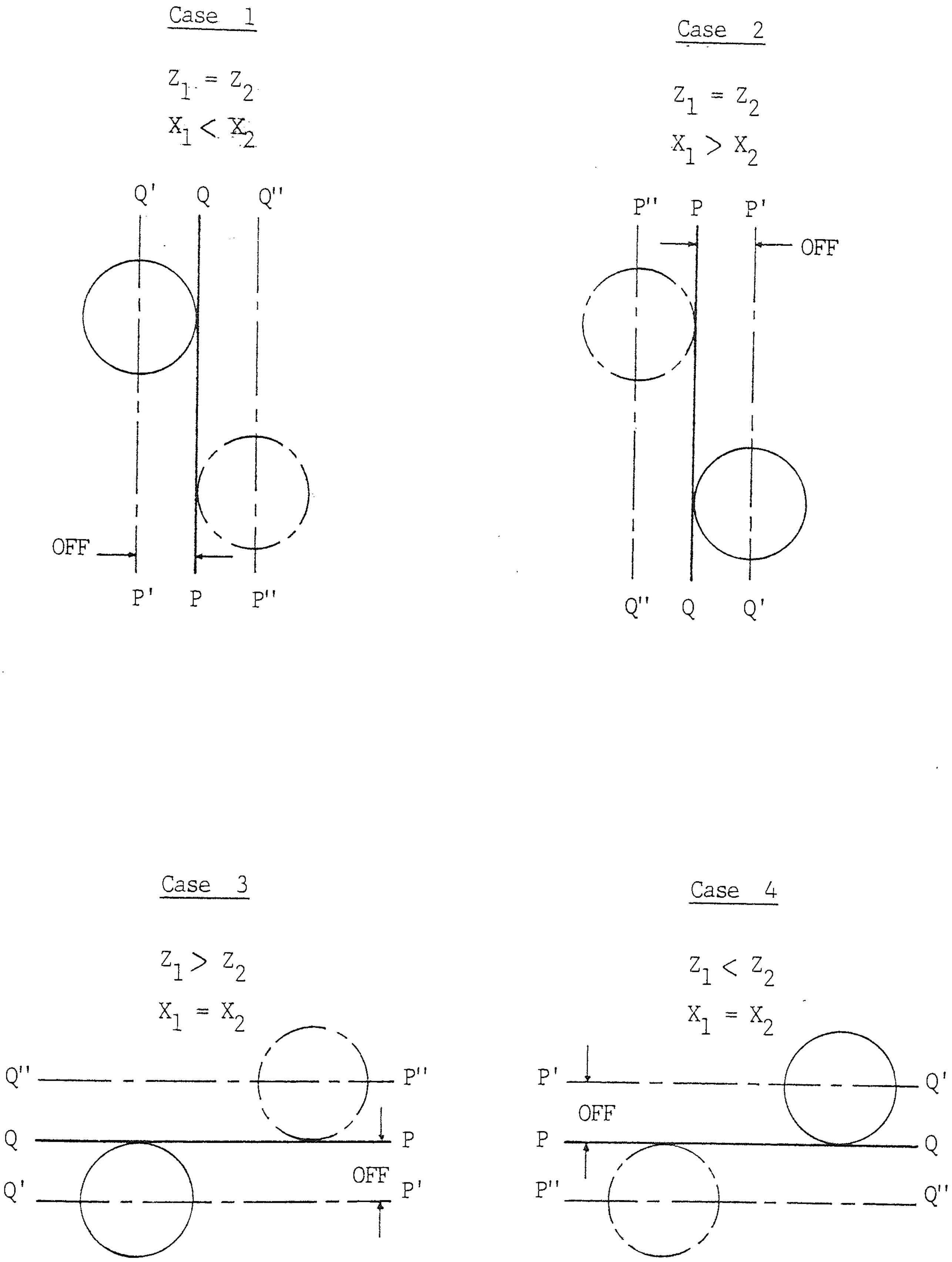
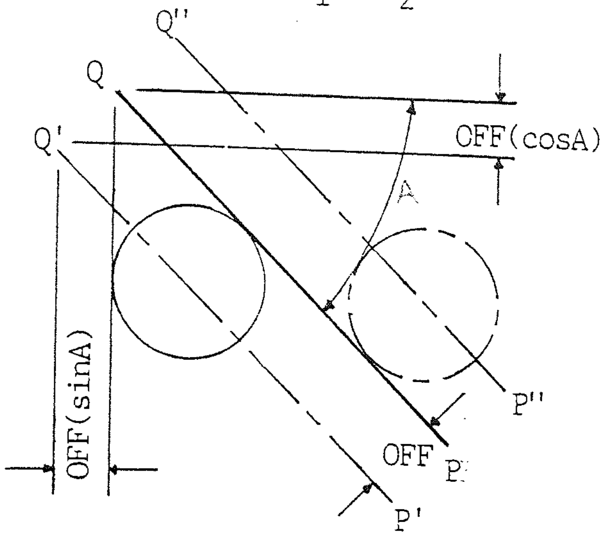


Fig. 8.17 OFFSET OF POINTS ON STRAIGHT LINES (PART 1)

Case 5

$Z_1 > Z_2$

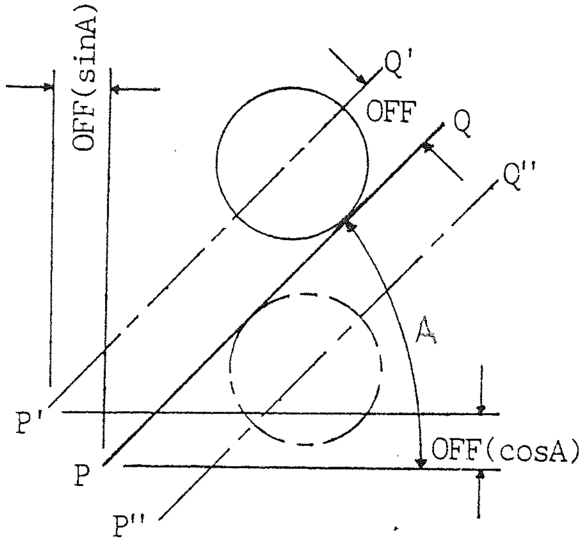
$X_1 < X_2$



Case 6

$Z_1 < Z_2$

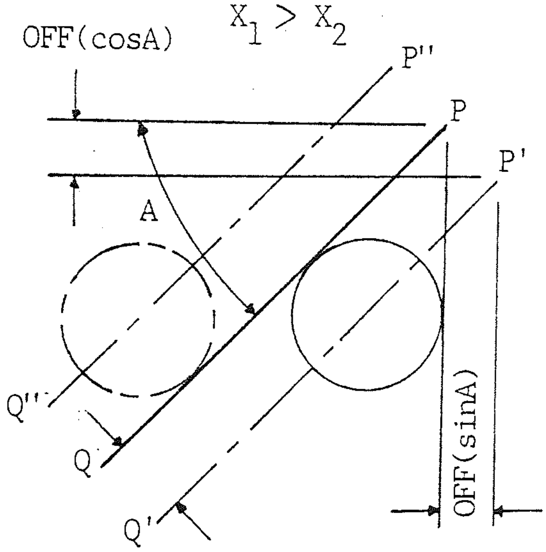
$X_1 < X_2$



Case 7

$Z_1 > Z_2$

$X_1 > X_2$



Case 8

$Z_1 < Z_2$

$X_1 > X_2$

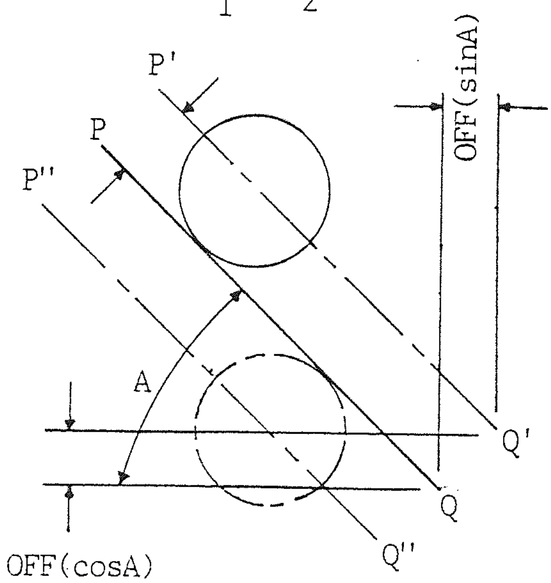
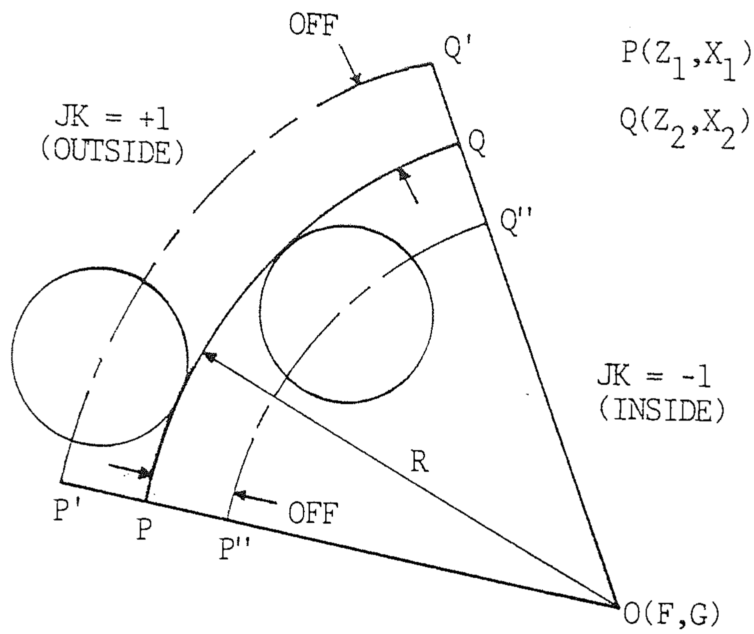


Fig. 8.17 (PART 2)



THE EQUAL INTERCEPT THEOREM

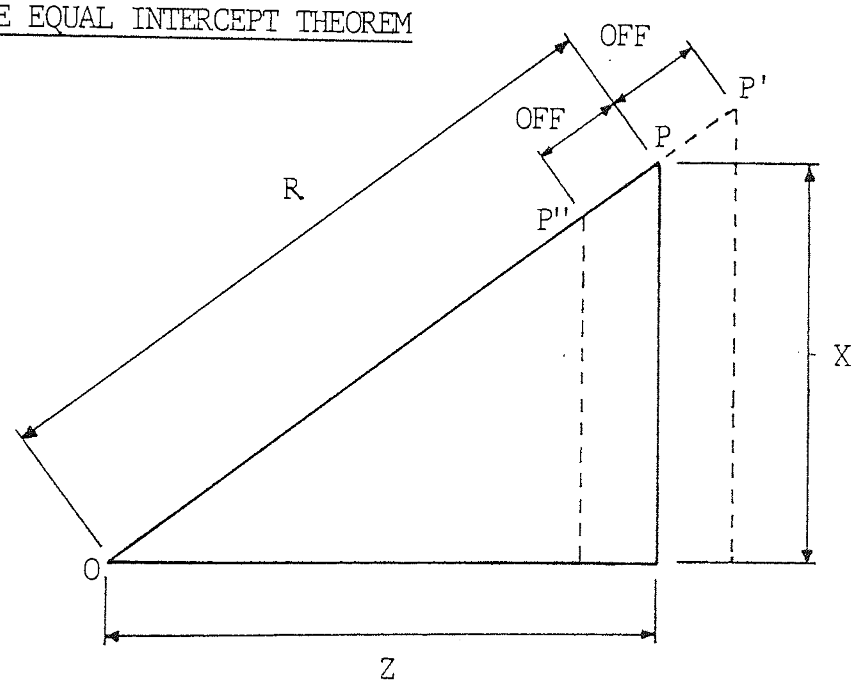


Fig. 8.18 OFFSET OF POINTS ON CIRCULAR ARC

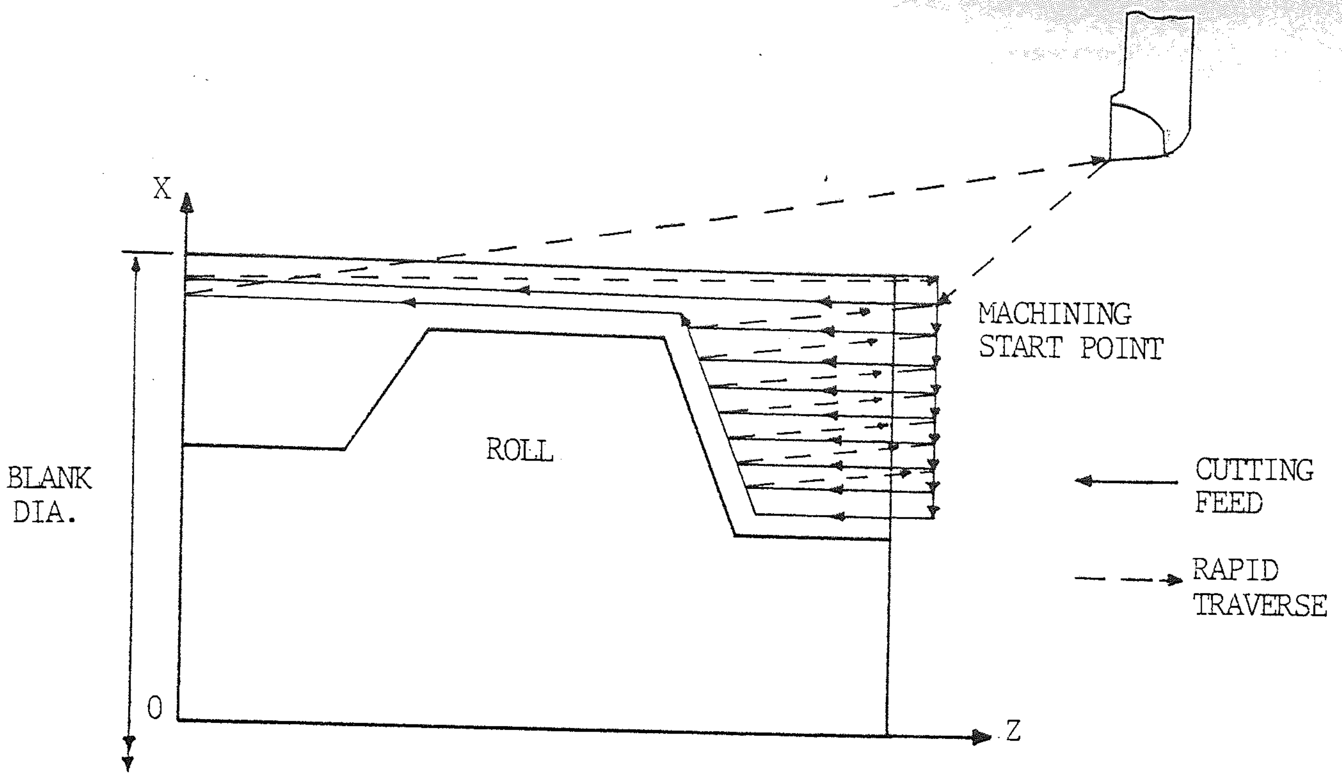
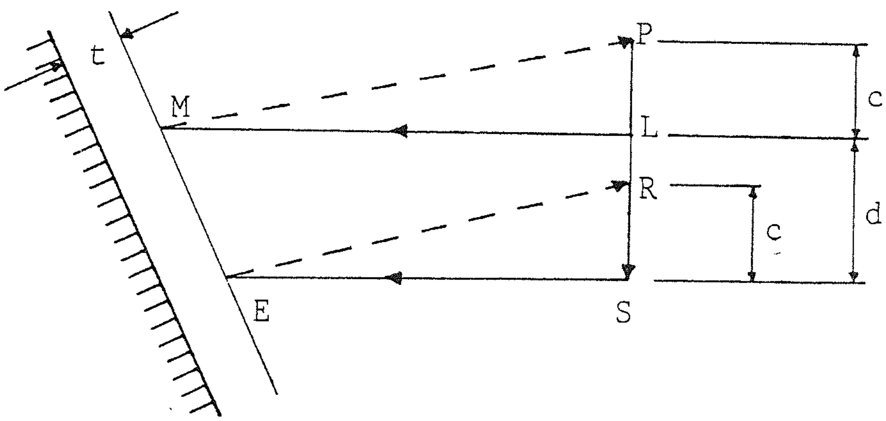


Fig. 8.19 ROUGHING CYCLE

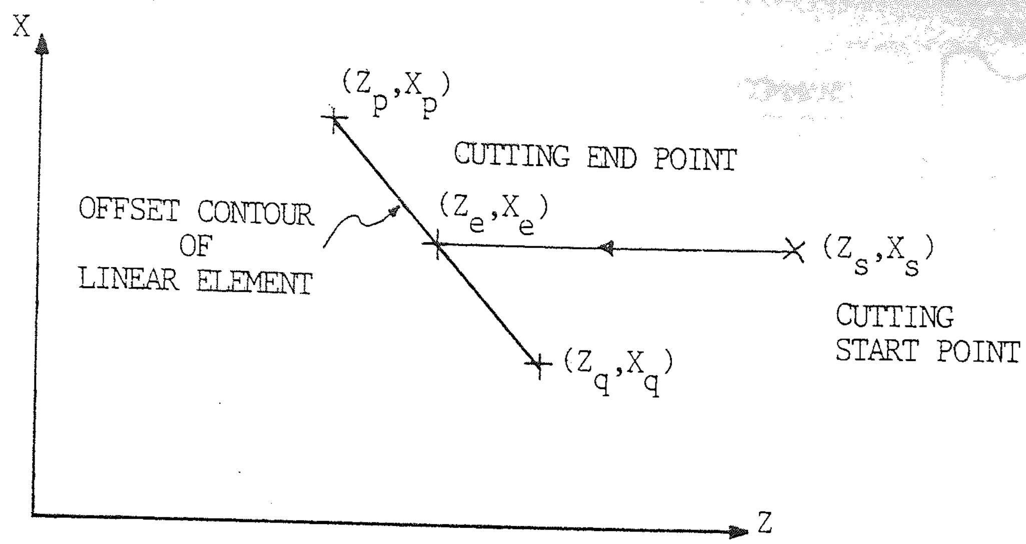


c = clearance value

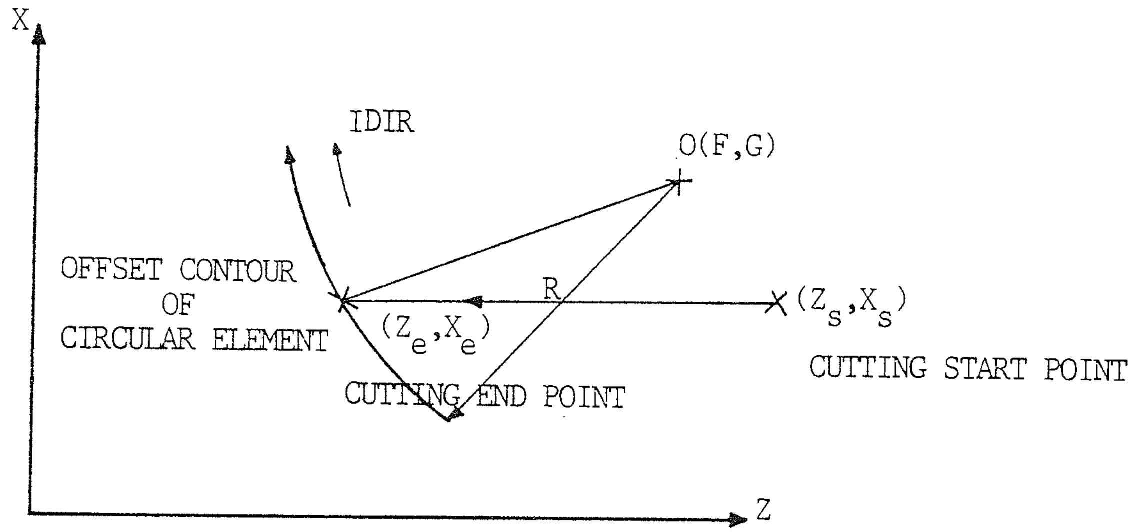
d = depth of cut

t = finishing tolerance

Fig. 8.20 3-STROKE CUTTING CYCLE FOR ROUGHING



(a) LINEAR ELEMENT



(b) CIRCULAR ELEMENT

Fig. 8.21 END POINT OF A CUTTING STROKE

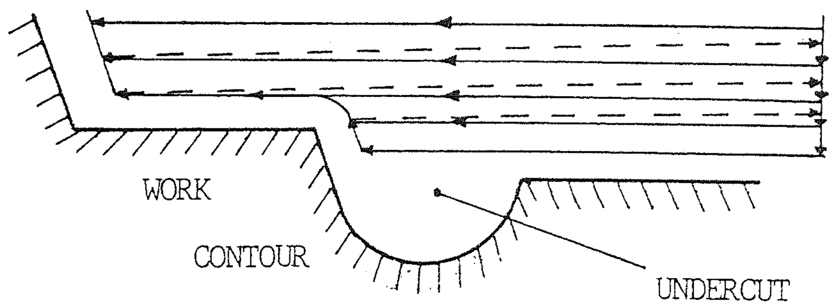


Fig. 8.22 UNDERCUT WILL BE IGNORED IN ROUGHING

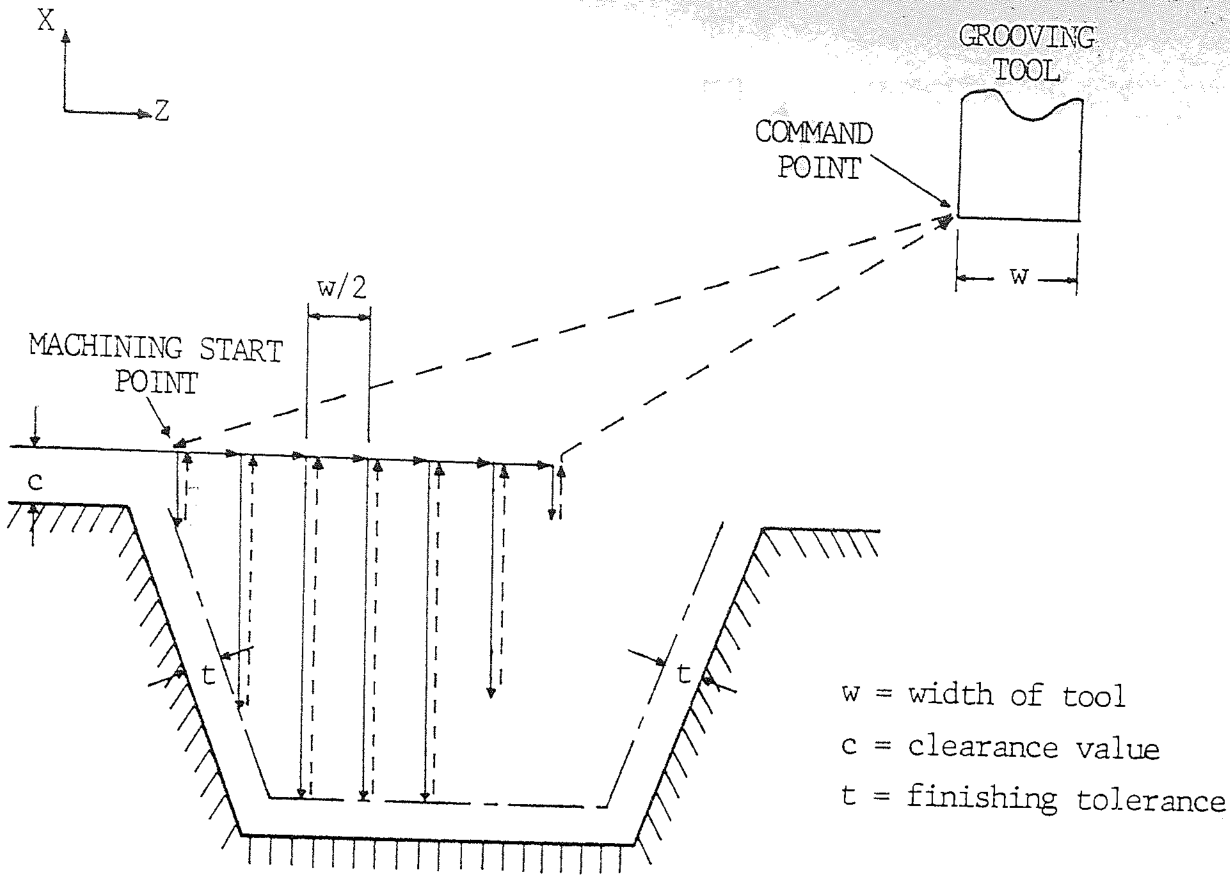


Fig. 8.23 GROOVING CYCLE

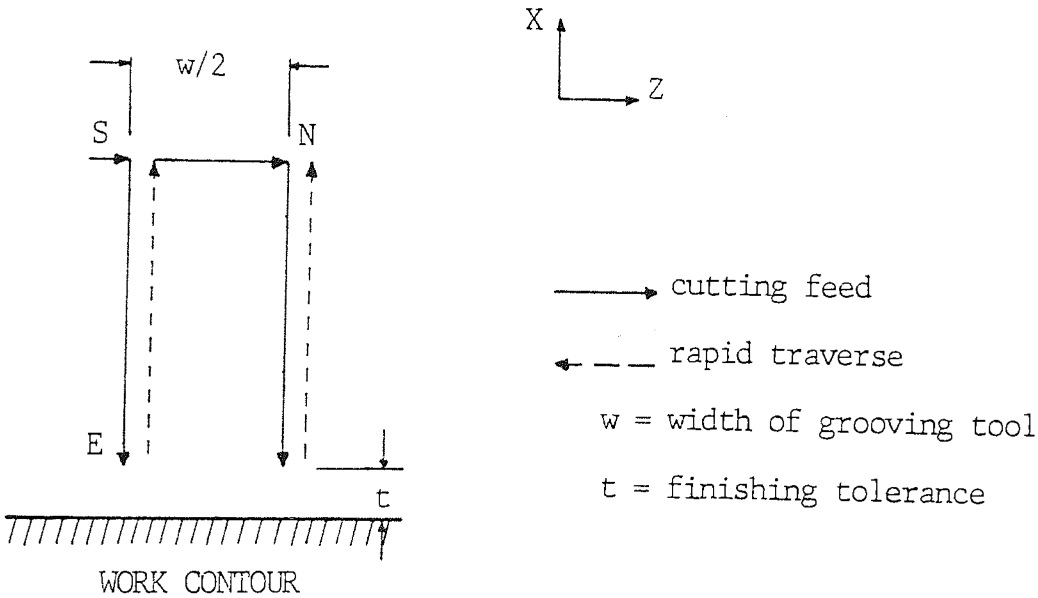


Fig. 8.24 3-STROKE CUTTING CYCLE FOR GROOVING

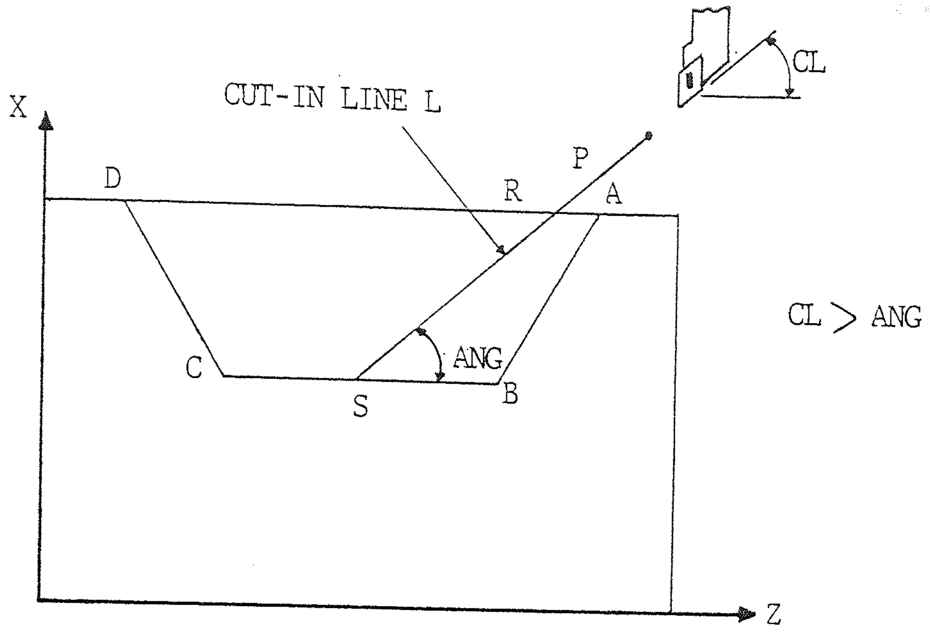


Fig. 8.25 CUT-IN LINE FOR POCKETING CYCLE

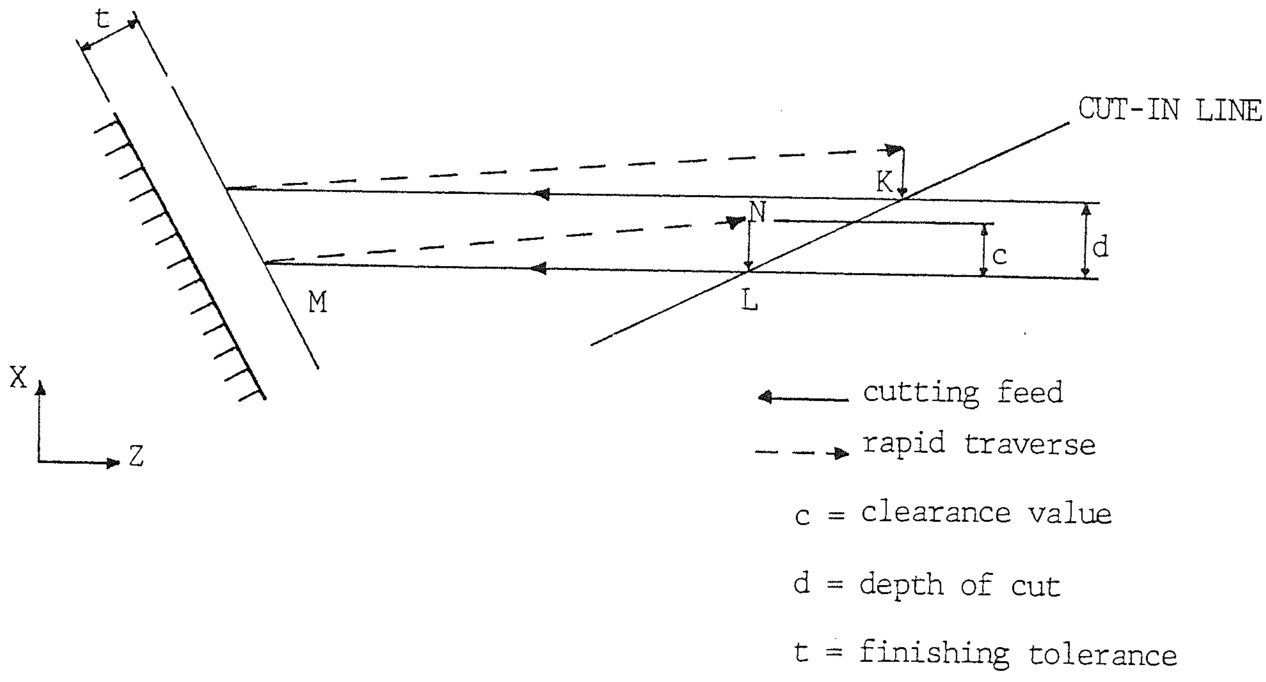
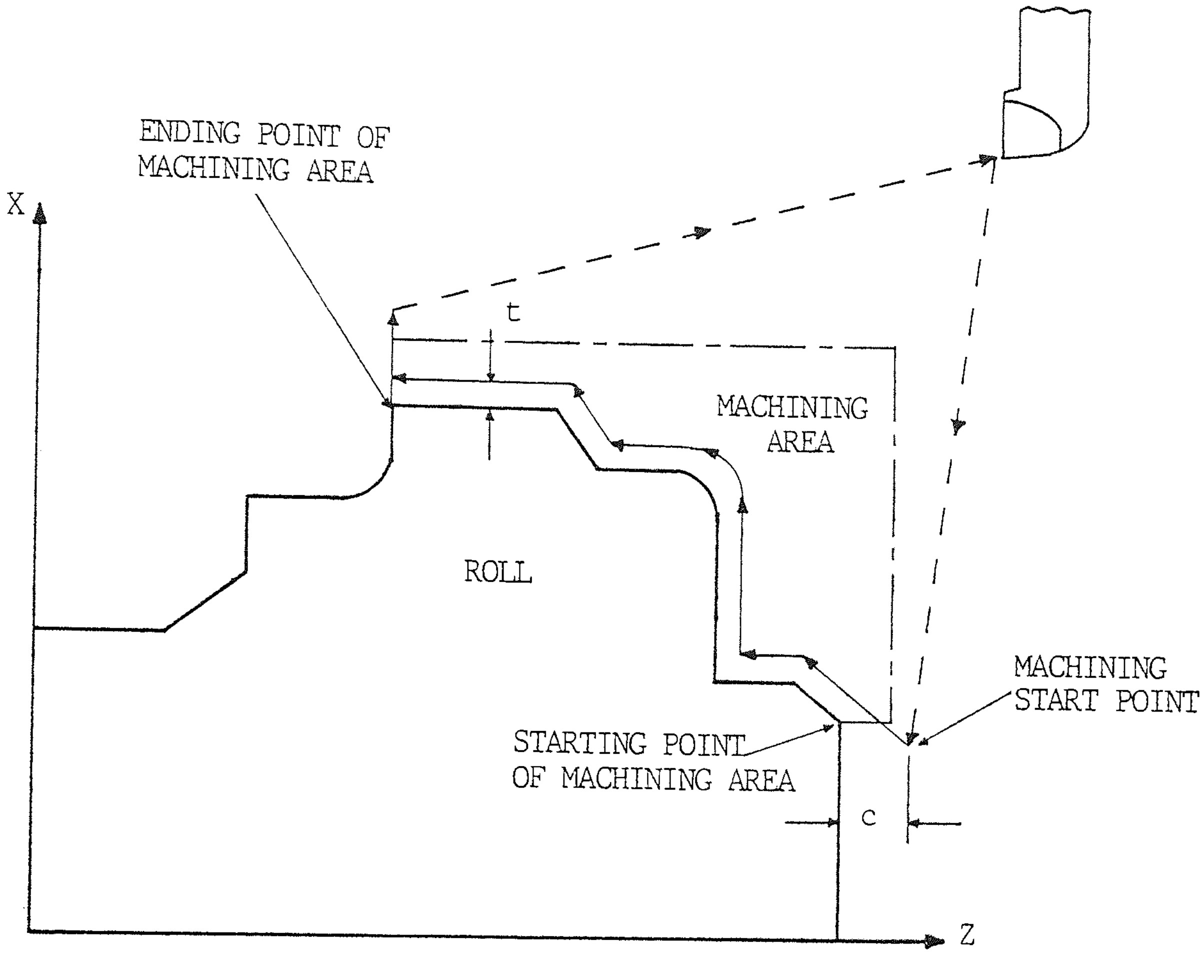


Fig. 8.26 4-STROKE CUTTING CYCLE FOR POCKETING



cutting feed

rapid traverse

c = clearance value

t = material tolerance (t = 0 for final finishing)

Fig. 8.27 FINISHING CYCLE

Fig. 8.28 A CUTTER TOOL PATH PLOT (a) TOP ROLL

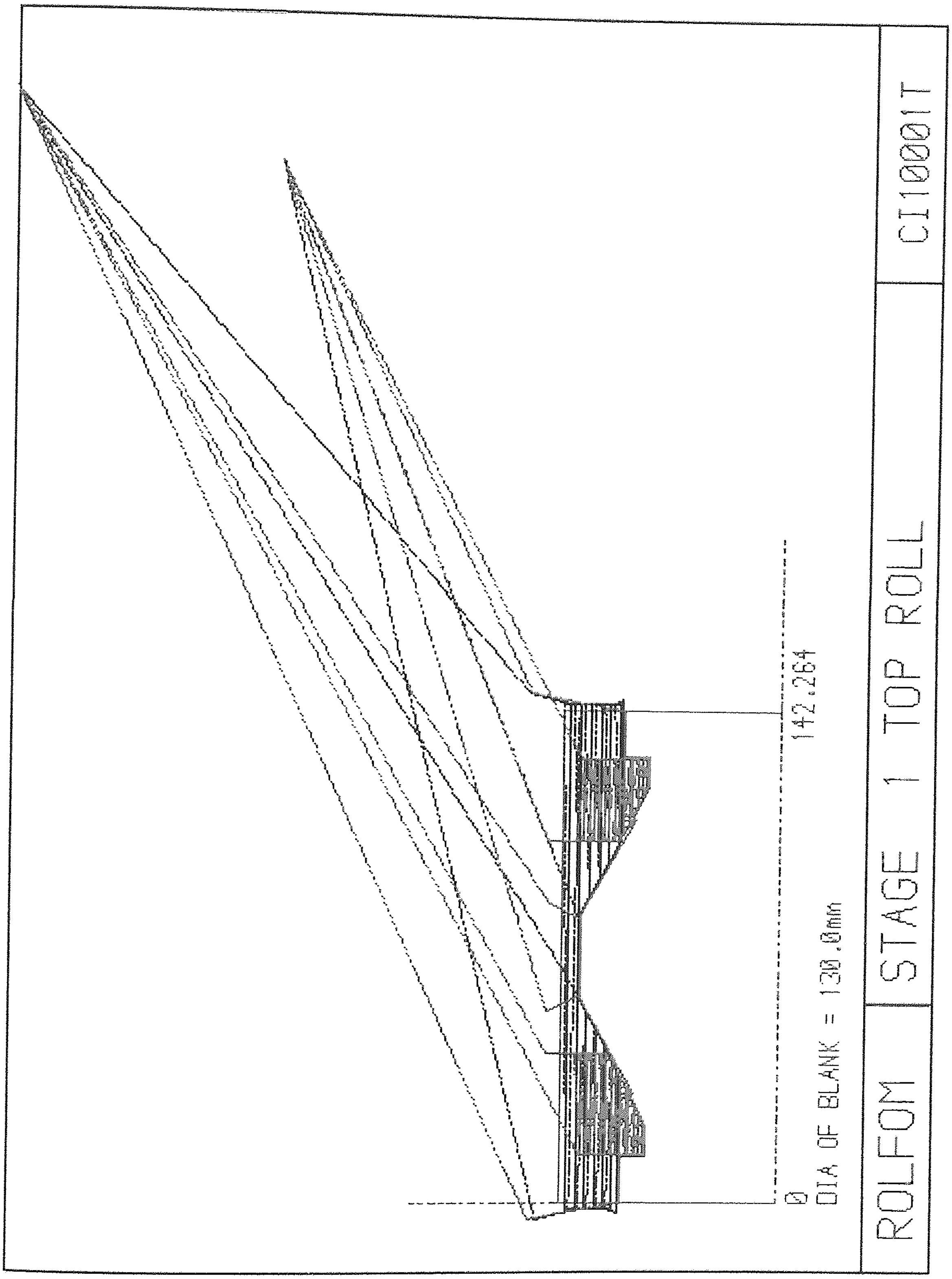
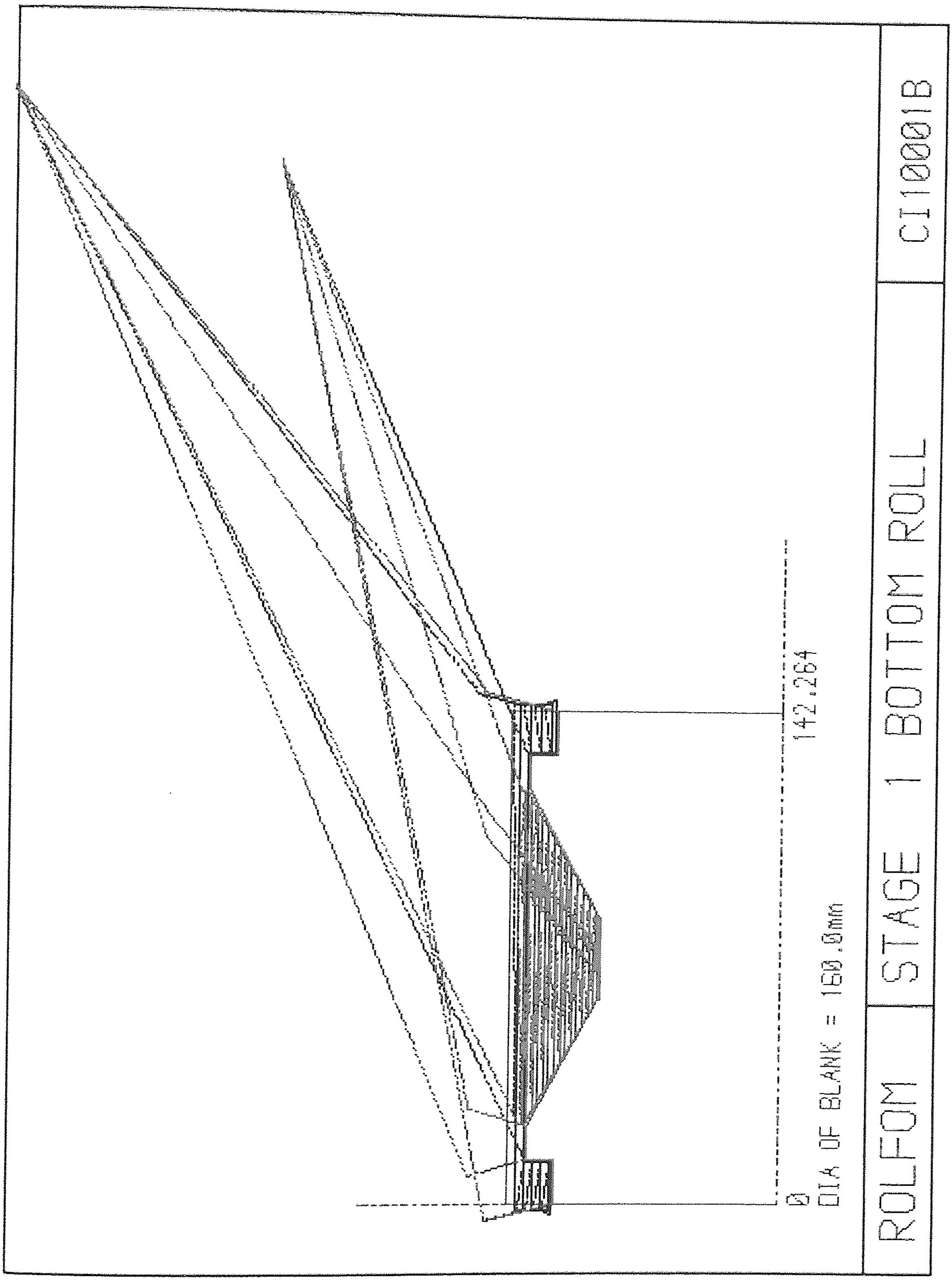


Fig. 8.28 A CUTTER TOOL PATH PLOT (b) BOTTOM ROLL



```
1      2
320.000    -455.000      0.000      0.000    99
4      200      0.30
147.264    -180.000      0.000      0.000    00
143.464    -154.000      0.000      0.000    02
 -2.800    -154.000      0.000      0.000    02
143.464    -158.000      0.000      0.000    00
143.464    -148.000      0.000      0.000    02
129.312    -148.000      0.000      0.000    02
143.464    -152.000      0.000      0.000    00
143.464    -142.000      0.000      0.000    02
129.364    -142.000      0.000      0.000    02
143.464    -146.000      0.000      0.000    00
143.464    -136.000      0.000      0.000    02
129.364    -136.000      0.000      0.000    02
143.464    -140.000      0.000      0.000    00
144.464    -133.198      0.000      0.000    02
141.464    -133.198      0.000      0.000    02
129.364    -133.198      0.000      0.000    02
129.364    -147.398      0.000      0.000    02
128.464    -149.198    128.464   -147.398     1
118.964    -149.198      0.000      0.000    02
 21.700    -149.198      0.000      0.000    02
 12.200    -149.198      0.000      0.000    02
300.000    -300.000      0.000      0.000    99
6      200      0.25
 -5.000    -174.000      0.000      0.000    00
 -1.200    -149.000      0.000      0.000    02
 13.390    -149.000      0.000      0.000    02
 -1.200    -153.000      0.000      0.000    00
 -1.200    -144.000      0.000      0.000    02
 12.900    -144.000      0.000      0.000    02
 -1.200    -148.000      0.000      0.000    00
 -1.200    -139.000      0.000      0.000    02
 12.900    -139.000      0.000      0.000    02
 -1.200    -143.000      0.000      0.000    00
 -1.200    -134.000      0.000      0.000    02
 12.900    -134.000      0.000      0.000    02
 -1.200    -138.000      0.000      0.000    00
 -2.200    -133.198      0.000      0.000    02
  0.800    -133.198      0.000      0.000    02
 12.900    -133.198      0.000      0.000    02
 12.900    -147.398      0.000      0.000    02
 13.800    -149.198     13.800   -147.398    -1
 23.300    -149.198      0.000      0.000    02
120.564    -149.198      0.000      0.000    02
130.064    -149.198      0.000      0.000    02
320.000    -455.000      0.000      0.000    99
7      200      0.20
112.414    -172.400      0.000      0.000    00
 99.543    -150.800      0.000      0.000    02
 22.150    -150.800      0.000      0.000    02
 99.543    -154.800      0.000      0.000    00
 99.543    -150.800      0.000      0.000    02
```

Fig. 8.29 A TYPICAL TERMINAL LISTING OF THE CUTTER LOCATION DATA FILE (PART 1)

97.636	-147.6ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
23.325	-147.6ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
97.636	-151.6ØØ	Ø.ØØØ	Ø.ØØØ	ØØ
97.636	-147.6ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
95.729	-144.4ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
26.Ø96	-144.4ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
95.729	-148.4ØØ	Ø.ØØØ	Ø.ØØØ	ØØ
95.729	-144.4ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
93.823	-141.2ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
28.868	-141.2ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
93.823	-145.2ØØ	Ø.ØØØ	Ø.ØØØ	ØØ
93.823	-141.2ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
91.916	-138.ØØØ	Ø.ØØØ	Ø.ØØØ	Ø2
31.639	-138.ØØØ	Ø.ØØØ	Ø.ØØØ	Ø2
91.916	-142.ØØØ	Ø.ØØØ	Ø.ØØØ	ØØ
91.916	-138.ØØØ	Ø.ØØØ	Ø.ØØØ	Ø2
9Ø.ØØ9	-134.8ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
34.411	-134.8ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
9Ø.ØØ9	-138.8ØØ	Ø.ØØØ	Ø.ØØØ	ØØ
9Ø.ØØ9	-134.8ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
88.1Ø2	-131.6ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
37.182	-131.6ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
88.1Ø2	-135.6ØØ	Ø.ØØØ	Ø.ØØØ	ØØ
88.1Ø2	-131.6ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
86.196	-128.4ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
39.953	-128.4ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
86.196	-132.4ØØ	Ø.ØØØ	Ø.ØØØ	ØØ
86.196	-128.4ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
84.289	-125.2ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
42.725	-125.2ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
84.289	-129.2ØØ	Ø.ØØØ	Ø.ØØØ	ØØ
84.289	-125.2ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
82.382	-122.ØØØ	Ø.ØØØ	Ø.ØØØ	Ø2
45.496	-122.ØØØ	Ø.ØØØ	Ø.ØØØ	Ø2
82.382	-126.ØØØ	Ø.ØØØ	Ø.ØØØ	ØØ
82.382	-122.ØØØ	Ø.ØØØ	Ø.ØØØ	Ø2
8Ø.475	-118.8ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
48.268	-118.8ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
8Ø.475	-122.8ØØ	Ø.ØØØ	Ø.ØØØ	ØØ
8Ø.475	-118.8ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
78.568	-115.6ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
51.Ø39	-115.6ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
78.568	-119.6ØØ	Ø.ØØØ	Ø.ØØØ	ØØ
78.568	-115.6ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
76.662	-112.4ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
53.81Ø	-112.4ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
76.662	-116.4ØØ	Ø.ØØØ	Ø.ØØØ	ØØ
76.662	-112.4ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
74.755	-1Ø9.2ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
56.582	-1Ø9.2ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
74.755	-113.2ØØ	Ø.ØØØ	Ø.ØØØ	ØØ
74.755	-1Ø9.2ØØ	Ø.ØØØ	Ø.ØØØ	Ø2
73.372	-1Ø6.88Ø	Ø.ØØØ	Ø.ØØØ	Ø2
59.17Ø	-1Ø6.88Ø	Ø.ØØØ	Ø.ØØØ	Ø2

Fig. 8.29 (PART 2)

58.088	-107.461	59.170	-111.210	-1
22.150	-148.957	0.000	0.000	02
22.150	-152.400	0.000	0.000	02
300.000	-300.000	0.000	0.000	99
10 200	0.20			
106.503	-172.400	0.000	0.000	00
93.453	-150.500	0.000	0.000	02
120.114	-150.500	0.000	0.000	02
93.453	-154.500	0.000	0.000	00
93.453	-150.500	0.000	0.000	02
91.368	-147.000	0.000	0.000	02
118.419	-147.000	0.000	0.000	02
91.368	-151.000	0.000	0.000	00
91.368	-147.000	0.000	0.000	02
89.282	-143.500	0.000	0.000	02
115.388	-143.500	0.000	0.000	02
89.282	-147.500	0.000	0.000	00
89.282	-143.500	0.000	0.000	02
87.197	-140.000	0.000	0.000	02
112.357	-140.000	0.000	0.000	02
87.197	-144.000	0.000	0.000	00
87.197	-140.000	0.000	0.000	02
85.111	-136.500	0.000	0.000	02
109.326	-136.500	0.000	0.000	02
85.111	-140.500	0.000	0.000	00
85.111	-136.500	0.000	0.000	02
83.026	-133.000	0.000	0.000	02
106.294	-133.000	0.000	0.000	02
83.026	-137.000	0.000	0.000	00
83.026	-133.000	0.000	0.000	02
80.940	-129.500	0.000	0.000	02
103.263	-129.500	0.000	0.000	02
80.940	-133.500	0.000	0.000	00
80.940	-129.500	0.000	0.000	02
78.855	-126.000	0.000	0.000	02
100.232	-126.000	0.000	0.000	02
78.855	-130.000	0.000	0.000	00
78.855	-126.000	0.000	0.000	02
76.769	-122.500	0.000	0.000	02
97.201	-122.500	0.000	0.000	02
76.769	-126.500	0.000	0.000	00
76.769	-122.500	0.000	0.000	02
74.683	-119.000	0.000	0.000	02
94.170	-119.000	0.000	0.000	02
74.683	-123.000	0.000	0.000	00
74.683	-119.000	0.000	0.000	02
72.598	-115.500	0.000	0.000	02
91.138	-115.500	0.000	0.000	02
72.598	-119.500	0.000	0.000	00
72.598	-115.500	0.000	0.000	02
70.512	-112.000	0.000	0.000	02
88.107	-112.000	0.000	0.000	02
70.512	-116.000	0.000	0.000	00
70.512	-112.000	0.000	0.000	02

Fig. 8.29 (PART 3)

68.427	-108.500	0.000	0.000	02
85.076	-108.500	0.000	0.000	02
68.427	-112.500	0.000	0.000	00
68.427	-108.500	0.000	0.000	02
67.462	-106.880	0.000	0.000	02
83.094	-106.880	0.000	0.000	02
84.176	-107.461	83.094	-111.210	1
120.114	-148.957	0.000	0.000	02
120.114	-152.400	0.000	0.000	02
300.000	-300.000	0.000	0.000	99
3 250	0.10			
-5.000	-174.000	0.000	0.000	00
0.400	-132.998	0.000	0.000	02
13.000	-132.998	0.000	0.000	02
13.000	-148.198	0.000	0.000	02
13.400	-148.998	13.400	-148.198	-1
22.900	-148.998	0.000	0.000	02
27.500	-184.000	0.000	0.000	00
320.000	-455.000	0.000	0.000	99
11 250	0.10			
147.264	-174.000	0.000	0.000	00
141.864	-132.998	0.000	0.000	02
129.264	-132.998	0.000	0.000	02
129.264	-148.198	0.000	0.000	02
128.864	-148.998	128.864	-148.198	1
119.364	-148.998	0.000	0.000	02
119.164	-148.891	119.364	-148.198	1
83.226	-107.395	0.000	0.000	02
81.894	-106.680	81.894	-112.010	-1
59.570	-106.680	0.000	0.000	02
58.238	-107.395	59.570	-112.010	-1
22.300	-148.891	0.000	0.000	02
22.100	-148.998	22.100	-148.198	1
12.600	-148.998	0.000	0.000	02
8.000	-184.000	0.000	0.000	00
-999.999	-999.999	-999.999	-999.999	00

Fig. 8.29 (PART 4)

1	1			
1	18	2	0.10	
4		3.000	200	0.30
1	2	18	0.10	
6		2.750	200	0.25
4	7	3	0.10	
7		1.500	200	0.20
	44.157		48.681	90.00
4	13	17	0.10	
10		1.500	200	0.20
	103.917		48.832	90.00
3	9	2	0.00	
11		0.000	250	0.10
3	9	18	0.00	
3		0.000	250	0.10
0	0	0	0.00	

(a) TOP ROLL

1	2			
1	16	2	0.10	
4		3.000	200	0.30
1	2	16	0.10	
6		2.500	200	0.25
4	9	5	0.10	
7		1.600	200	0.20
	76.132		54.840	40.00
4	9	13	0.10	
10		1.750	200	0.20
	66.132		54.840	40.00
3	2	4	0.00	
3		0.000	250	0.10
3	16	4	0.00	
11		0.000	250	0.10
0	0	0	0.00	

(b) BOTTOM ROLL

Fig. 8.30 A PRINTER LISTING OF THE MACHINING INSTRUCTIONS DATA FILE

```
*****************************************
*                                       *
*          COMPUTER - AIDED             *
*          PROCESS PLANNING             *
*                                       *
*    MORI-SEKI   CNC LATHE MACHINE      *
*                                       *
*   This planning sheet shows the       *
*   cutting tools which have been used  *
*   for the production of form rolls.   *
*   In addition to this, it specifies   *
*   the starting and finishing elements *
*   for each cycle, the depth of cut,   *
*   tolerance, and speeds and feeds     *
*   used in every machining cycle.      *
*                                       *
*****************************************
```

SECTION NO.	STAGE NO.	ROLL TYPE
2500A	1	TOP ROLL

****

CYCLE TYPE	STARTING ELEMENT	ENDING ELEMENT	STOCK LEFT
1	19	2	0.100MM

TOOL NO.	DEPTH OF CUT	SPEED	FEED
4	3.00	200	0.300

NTOOL	RAD	RZ	RX	WID	ZREF	XREF
4	0.800	0.800	-0.800	0.000	320.000	-455.000

****

CYCLE TYPE	STARTING ELEMENT	ENDING ELEMENT	STOCK LEFT
1	2	19	0.100MM

TOOL NO.	DEPTH OF CUT	SPEED	FEED
6	2.75	200	0.250

NTOOL	RAD	RZ	RX	WID	ZREF	XREF
6	0.800	-0.800	-0.800	0.000	300.000	-300.000

****

Fig. 8.31 A TYPICAL TERMINAL LISTING OF THE MACHINING PROCESS PLAN
(a) MORI-SEKI CNC LATHE (PART 1)

CYCLE TYPE	STARTING ELEMENT	ENDING ELEMENT	STOCK LEFT
4	7	3	0.100MM

TOOL NO.	DEPTH OF CUT	SPEED	FEED
7	1.50	200	0.200

NTOOL	RAD	RZ	RX	WID	ZREF	XREF
7	0.800	0.800	-0.800	0.000	320.000	-455.000

THE STARTING POINT (ZP,XP) AND THE ANGLE OF THE CUT-IN LINE

ZP	XP	ANG
44.155	48.647	90.000

****

CYCLE TYPE	STARTING ELEMENT	ENDING ELEMENT	STOCK LEFT
4	14	18	0.100MM

TOOL NO.	DEPTH OF CUT	SPEED	FEED
10	1.50	200	0.200

NTOOL	RAD	RZ	RX	WID	ZREF	XREF
10	0.800	-0.800	-0.800	0.000	300.000	-300.000

THE STARTING POINT (ZP,XP) AND THE ANGLE OF THE CUT-IN LINE

ZP	XP	ANG
102.164	49.789	90.000

****

CYCLE TYPE	STARTING ELEMENT	ENDING ELEMENT	STOCK LEFT
3	10	2	0.000MM

TOOL NO.	DEPTH OF CUT	SPEED	FEED
11	0.00	250	0.100

NTOOL	RAD	RZ	RX	WID	ZREF	XREF
11	0.400	0.400	-0.400	0.000	320.000	-455.000

****

Fig. 8.31 (a) (PART 2)

CYCLE TYPE	STARTING ELEMENT	ENDING ELEMENT	STOCK LEFT
3	1Ø	19	Ø.ØØØMM

TOOL NO.	DEPTH OF CUT	SPEED	FEED
3	Ø.ØØ	25Ø	Ø.1ØØ

NTOOL	RAD	RZ	RX	WID	ZREF	XREF
3	Ø.4ØØ	-Ø.4ØØ	-Ø.4ØØ	Ø.ØØØ	3ØØ.ØØØ	-3ØØ.ØØØ

****

Fig. 8.31 (a) (PART 3)

```
****************************************
*                                      *
*          COMPUTER - AIDED            *
*          PROCESS PLANNING            *
*                                      *
*     SAAB        CNC LATHE MACHINE    *
*                                      *
*   This planning sheet shows the      *
*   cutting tools which have been used *
*   for the production of form rolls.  *
*   In addition to this, it specifies  *
*   the starting and finishing elements*
*   for each cycle, the depth of cut,  *
*   tolerance, and speeds and feeds    *
*   used in every machining cycle.     *
*                                      *
****************************************
```

SECTION NO.	STAGE NO.	ROLL TYPE
2500A	1	BOTTOM ROLL

****

CYCLE TYPE	STARTING ELEMENT	ENDING ELEMENT	STOCK LEFT
1	16	2	0.100MM

TOOL NO.	DEPTH OF CUT	SPEED	FEED
4	3.00	200	0.300

NTOOL	RAD	RZ	RX	WID	ZREF	XREF
4	0.800	0.800	-0.800	0.000	410.000	-455.000

****

CYCLE TYPE	STARTING ELEMENT	ENDING ELEMENT	STOCK LEFT
1	2	16	0.100MM

TOOL NO.	DEPTH OF CUT	SPEED	FEED
3	2.50	200	0.250

NTOOL	RAD	RZ	RX	WID	ZREF	XREF
3	0.800	0.800	-0.800	0.000	332.000	-455.000

****

Fig. 8.31 A TYPICAL TERMINAL LISTING OF THE MACHINING PROCESS PLAN
(b) SAAB CNC LATHE (PART 1)

CYCLE TYPE	STARTING ELEMENT	ENDING ELEMENT	STOCK LEFT
4	9	5	0.100MM

TOOL NO.	DEPTH OF CUT	SPEED	FEED
2	1.60	200	0.200

NTOOL	RAD	RZ	RX	WID	ZREF	XREF
2	0.800	0.800	-0.800	0.000	410.000	-455.000

THE STARTING POINT (ZP,XP) AND THE ANGLE OF THE CUT-IN LINE

ZP	XP	ANG
76.132	54.840	40.000

****

CYCLE TYPE	STARTING ELEMENT	ENDING ELEMENT	STOCK LEFT
4	9	13	0.100MM

TOOL NO.	DEPTH OF CUT	SPEED	FEED
1	1.75	200	0.200

NTOOL	RAD	RZ	RX	WID	ZREF	XREF
1	0.800	0.800	-0.800	0.000	332.000	-455.000

THE STARTING POINT (ZP,XP) AND THE ANGLE OF THE CUT-IN LINE

ZP	XP	ANG
66.132	54.840	40.000

****

CYCLE TYPE	STARTING ELEMENT	ENDING ELEMENT	STOCK LEFT
3	2	4	0.000MM

TOOL NO.	DEPTH OF CUT	SPEED	FEED
6	0.00	250	0.100

NTOOL	RAD	RZ	RX	WID	ZREF	XREF
6	0.800	0.800	-0.800	0.000	332.000	-455.000

****

Fig. 8.31 (b) (PART 2)

CYCLE TYPE	STARTING ELEMENT	ENDING ELEMENT	STOCK LEFT
3	16	4	Ø.ØØØMM

TOOL NO.	DEPTH OF CUT	SPEED	FEED
5	Ø.ØØ	25Ø	Ø.1ØØ

NTOOL	RAD	RZ	RX	WID	ZREF	XREF
5	Ø.8ØØ	Ø.8ØØ	-Ø.8ØØ	Ø.ØØØ	41Ø.ØØØ	-455.ØØØ

****

Fig. 8.31 (b) (PART 3)

Table 8.1 MACHINABILITY DATA STORED IN THE KNOWLEDGE BASE

CUTTING CYCLE		CUTTING TOOL NO. 'SAAB'	CUTTING TOOL NO. 'FANUC'	DEPTH OF CUT (DCUT)-mm	CUTTING SPEED (SPEED)-m/min	FEEDRATE (FEED)-mm/rev	STOCK LEFT FOR FINISHING (TOL)-mm
ROUGHING	RIGHT HAND CUT	4	4	TOP ROLL 3.000 BOTTOM & SIDE ROLLS 2.750	200	0.300	0.100
	LEFT HAND CUT	3	6	TOP ROLL 2.750 BOTTOM & SIDE ROLLS 2.500	200	0.250	0.100
GROOVING		8	GAP< 18mm 8 GAP= 18mm 5	0.000	150	0.200	0.100
POCKETING	RIGHT HAND CUT	2	7	1.500	200	0.200	0.100
	LEFT HAND	1	10	1.750	200	0.200	0.100
FINISHING	RIGHT HAND	5	11	0.000	250	0.100	0.000
	LEFT HAND CUT	6	3	0.000	250	0.100	0.000

Table 8.2 CUTTING TOOL LISTS FOR THE SAAB CONTROLLED TORSHALLA AND FANUC CONTROLLED MORI-SEKI CNC LATHES (PART 1)

	SAAB CONTROLLED TORSHALLA CNC LATHE
TURRET POSITION	CUTTING TOOL
1	55° Romboid LH Fine Rough Tool for Pocketing
2	55° Romboid RH Fine Rough Tool for Pocketing
3	80° Romboid LH Tool for Roughing
4	80° Romboid RH Tool for Roughing
5	35° Diamond RH Tool for Finishing
6	35° Diamond LH Tool for Finishing
7	Not in Use
8	4.1 mm Parting-off Tool Grooving

Table 8.2 (PART 2)

	FANUC CONTROLLED MORI-SEKI CNC LATHE
TURRET POSITION	CUTTING TOOL
1	5mm Button Tool for Finishing
2	55° Romboid RH Tool for Roughing
3	35° Diamond LH Tool for Finishing
4	80° Romboid RH Tool for Roughing
5	6mm RH Parting-off Tool for Grooving
6	55° Romboid LH Tool for Roughing
7	35° Diamond RH Fine Rough for Pocketing
8	4.1 mm RH Parting-off Tool for Grooving
9	Not in Use
10	35° Diamond LH Fine Rough Tool for Pocketing
11	35° Diamond RH Tool for Finishing
12	70° Copying Tool for Pocketing or Finishing

Table 8.3 DATA STORED IN THE 'TLIBS' AND 'TLIBM' TOOL LIBRARIES (PART 1)

TLIBS - SAAB CONTROLLED TORSHALLA CNC LATHE						
TURRET POSITION	RAD	RZ	RX	WID	ZREF	XREF
1	0.8	-0.8	-0.8	0.0	332.0	-455.0
2	0.8	0.8	-0.8	0.0	410.0	-455.0
3	0.8	-0.8	-0.8	0.0	332.0	-455.0
4	0.8	0.8	-0.8	0.0	410.0	-455.0
5	0.8	0.8	-0.8	0.0	410.0	-455.0
6	0.8	-0.8	-0.8	0.0	332.0	-455.0
7*	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	4.1	245.0	-300.0

Table 8.3 (PART 2)

TLIBM - FANUC CONTROLLED MORI-SEKI CNC LATHE						
TURRET POSITION	RAD	RZ	RX	WID	ZREF	XREF
1	2.5	0.0	-2.5	0.0	320.0	-455.0
2	0.8	0.0	-0.8	0.0	320.0	-455.0
3	0.4	-0.4	-0.4	0.0	300.0	-300.0
4	0.8	0.8	-0.8	0.0	320.0	-455.0
5	0.0	0.0	0.0	6.0	320.0	-455.0
6	0.8	-0.8	-0.8	0.0	300.0	-300.0
7	0.8	0.8	-0.8	0.0	320.0	-455.0
8	0.0	0.0	0.0	4.1	320.0	-455.0
9*	0.0	0.0	0.0	0.0	0.0	0.0
10	0.8	-0.8	-0.8	0.0	300.0	-300.0
11	0.4	0.4	-0.4	0.0	320.0	-455.0
12	0.8	0.0	-0.8	0.0	320.0	-455.0

Table 8.3 (PART 3)

NOTES:-

(1) All Dimensions are in mm

(2) * Refers to the turret position not in use

(3) RAD = tool tip nose radius

RZ = Z-coordinate of the tip nose circle centre

RX = X-coordinate of the tip nose circle centre

WID = Width of the parting-off tool

ZREF = Z-coordinate of the tool offset position

XREF = X-coordinate of the tool offset position

Table 8.4 SUBROUTINES OF THE EXPERT SYSTEM SOFTWARE FOR FORM-ROLL MACHINING (PART 1)

SUBROUTINE	LEVEL	FUNCTION
EXPSYS (MAIN PROGRAM)	1	Calls upon subordinate subroutines to decode data from the form-roll profile geometric data file, and to automatically generate the machining instructions data file, the machining process plan and the cutter location data file by calculating the compensated tool-paths for the appropriate machining cycles. A plot of the tool paths is also displayed on the Tektronix screen by calling GINO-F graphics routines.
DECRCD	2	Decodes the form-roll profile geometric data, which is generated by the Interactive Roll Editor program
PLTITL	2	Draws the axes and the title for the cutter location path drawing by calling GINO-F graphics routines.
ROLL	2	Determines the roll blank diameter size by computing the maximum radius of the form-roll profile.
EXPERT	2	Determines the optimum cutting data for machining the roll blank, by applying the knowledge in the database subroutines to the machining problem. Also outputs the machining instructions and process plan.
MANINP	2	Invites the user to supply machining data input interactively, and then determines the cutter path location.
INITRP	3	Initialises the form-roll profile data.
TLIBS	3	Stores the tool geometric data for all the cutting tools deployed in the turret of the Torshalla CNC lathe.

Table 8.4 (PART 2)

SUBROUTINE	LEVEL	FUNCTION
TLIBM	3	Stores the tool geometric data for all the cutting tools deployed in the turret of the Mori-Seki CNC lathe
WRIT4	3	Outputs the co-ordinates of the starting point of a machining cycle to the cutter location data file.
ROUGH	3	Generates the cutter location data for roughing cut.
COMPAR	3	Determines whether any gaps exist on the form-roll profile which require grooving or pocketing cutting cycles, by comparing the initial roughing cutter path location with the form-roll profile geometry.
GROOVE	3	Generates the cutter location data for the grooving cycle by means of a parting off tool
POCKET	3	Generates the cutter location data for the pocketing cycle.
FINISH	3	Generates the cutter location data for finishing cut.
OFFSET	4	(See the OFFSET module)
VIGN	4	(See the OFFSET module)
WRIT1	4	Outputs the cutter location data for a 3-stroke roughing cut.

Table 8.4 (PART 3)

SUBROUTINE	LEVEL	FUNCTION
WRIT2	4	Outputs the cutter location data for a single stroke tool path for linear interpolation
WRIT3	4	Outputs the cutter location data for an arc (circular interpolation).
CUTLIN	4	Defines the cut-in line and the cutting start point for a pocketing cycle or a finishing cycle.

Table 8.5 SUBROUTINES OF THE OFFSET MODULE

SUBROUTINE	LEVEL	FUNCTION
OFFSET	1	Determines the cutting direction and calculates the offset form-roll profile for the corresponding cutting tool to be used.
INITOR	2	Initialises the offset form-roll profile data
VIGN	2	Determines the identification sign for a circular arc
LINANG	2	Determines the angle theta of a given line joining two points (Z_1,X_1) and (Z_2,X_2), w.r.t. the Z-axis.
ARCANG	2	Determines the angle theta of the line joining a point (Z,X) and the centre of an arc, w.r.t. the Z-axis.
OPPANG	2	Determines the opposite angle between two cutter paths according to the cutter position
LINLIN	2	Calculates the offset cutter location when a straight line joins another straight line
LINCIR	2	Calculates the offset cutter location when a line joins a circle
CIRCIR	2	Calculates the offset cutter location when an arc joins another arc
OFFSTL	3	Determines the offset coordinate (Z_1A,X_1A) for a given point (Z_1,X_1) on a line joining with another point (Z_2,X_2).
OFFNML	3	Determines the offset coordinate (Z_1A,X_1A) for a given point (Z_1,X_1) on a circle of centre (F,G) and radius R.
QUADEQ	3	Obtains the coordinates for points on a circle by solving two quadratic equations, $A_1*Z*Z+B_1*Z+C_1=0$ and $A_2*X*X+B_2*X+C_2=0$

Chart 8.1 HIERARCHY OF THE EXPERT SYSTEM SOFTWARE FOR FORM-ROLL MACHINING (PART 1)

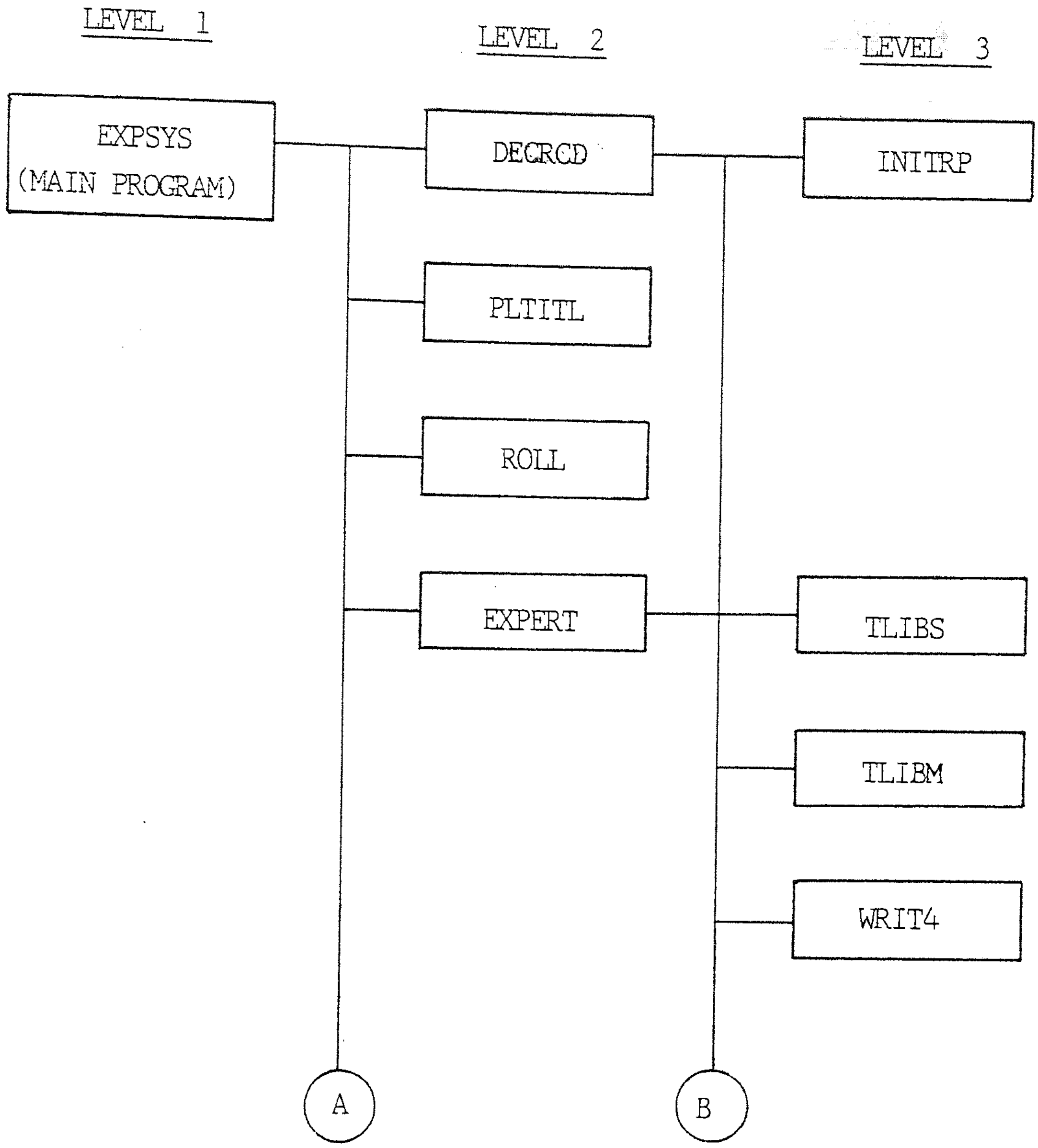


Chart 8.1 (PART 2)

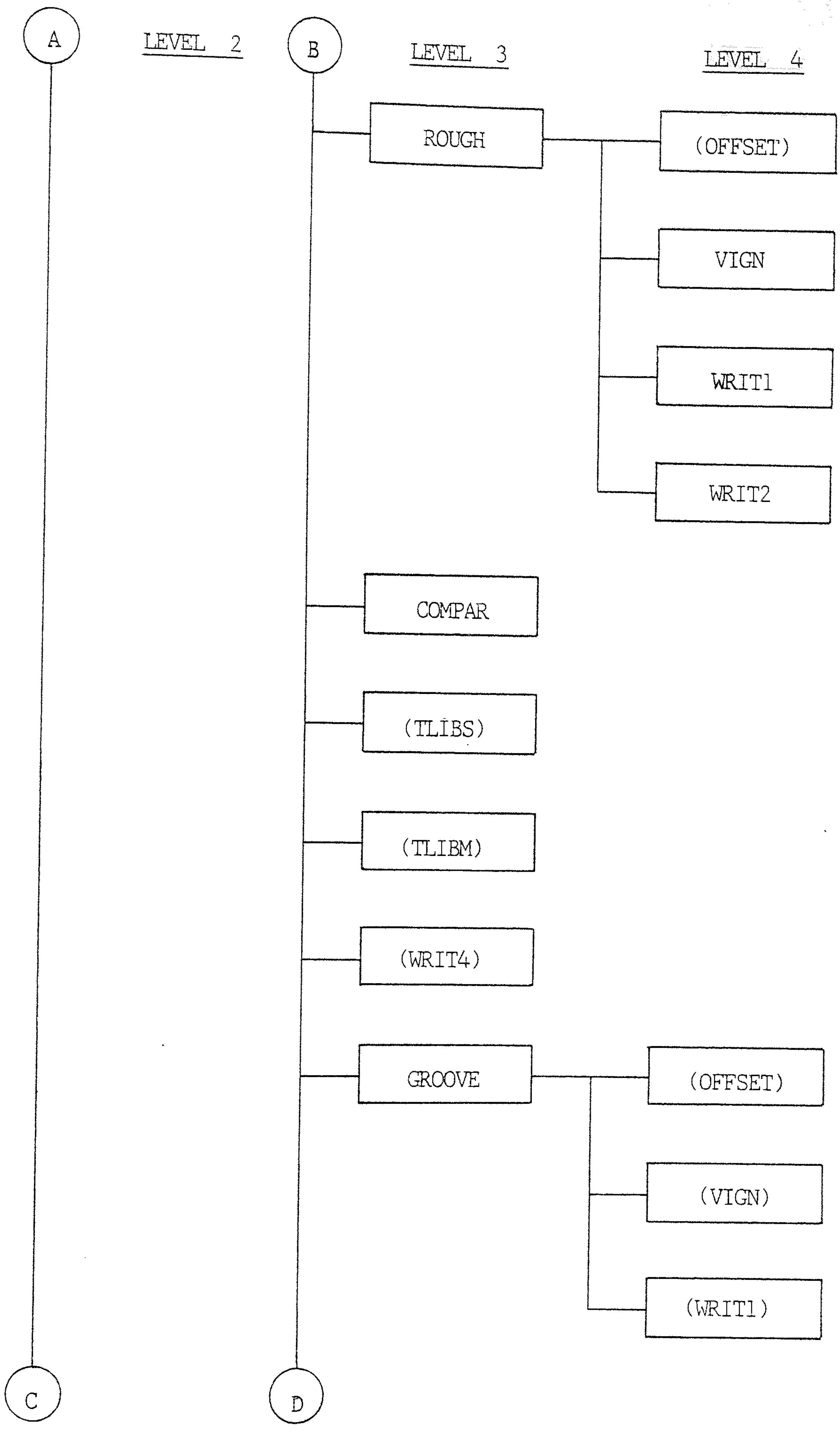


Chart 8.1 (PART 3)

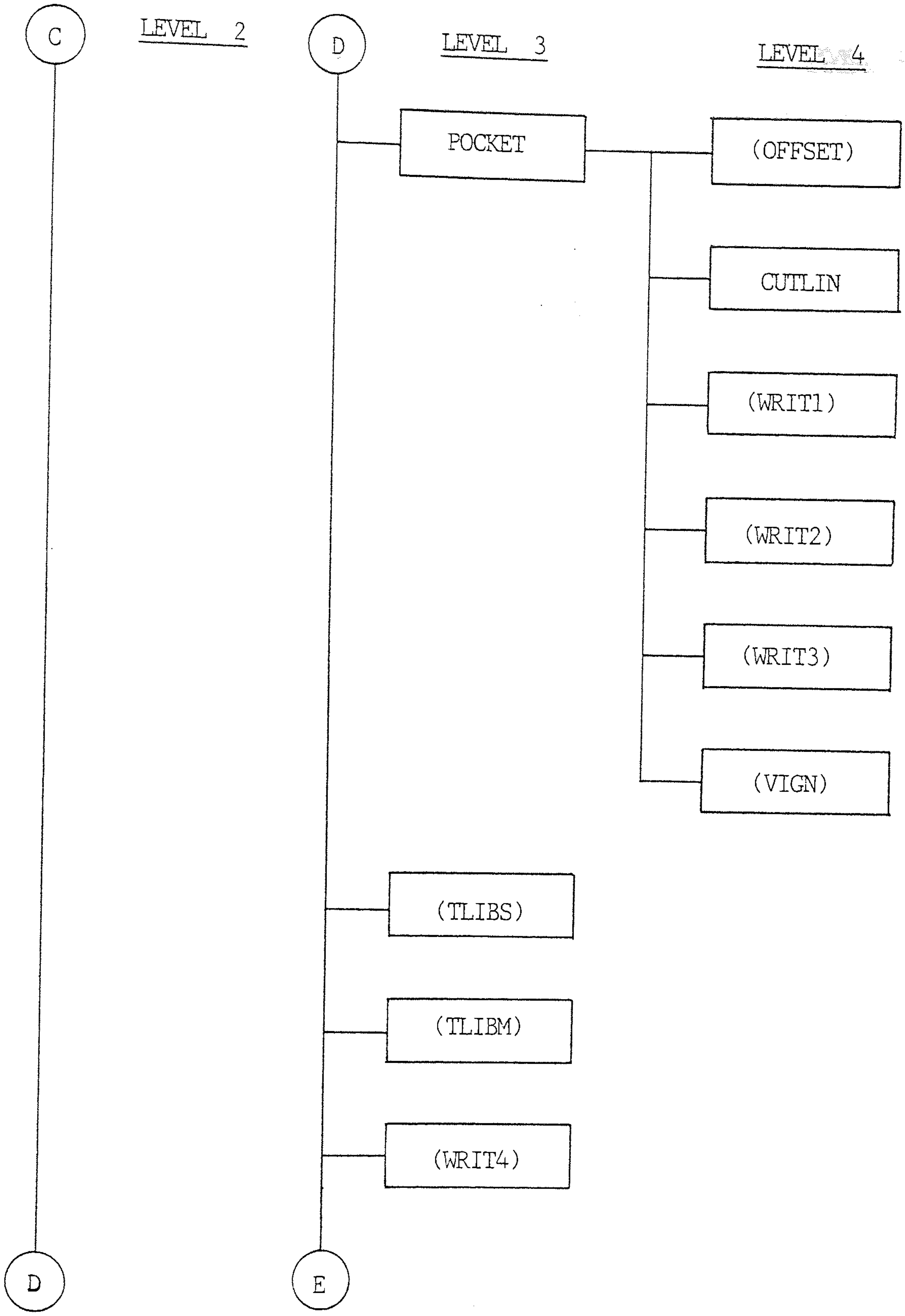


Chart 8.1 (PART 4)

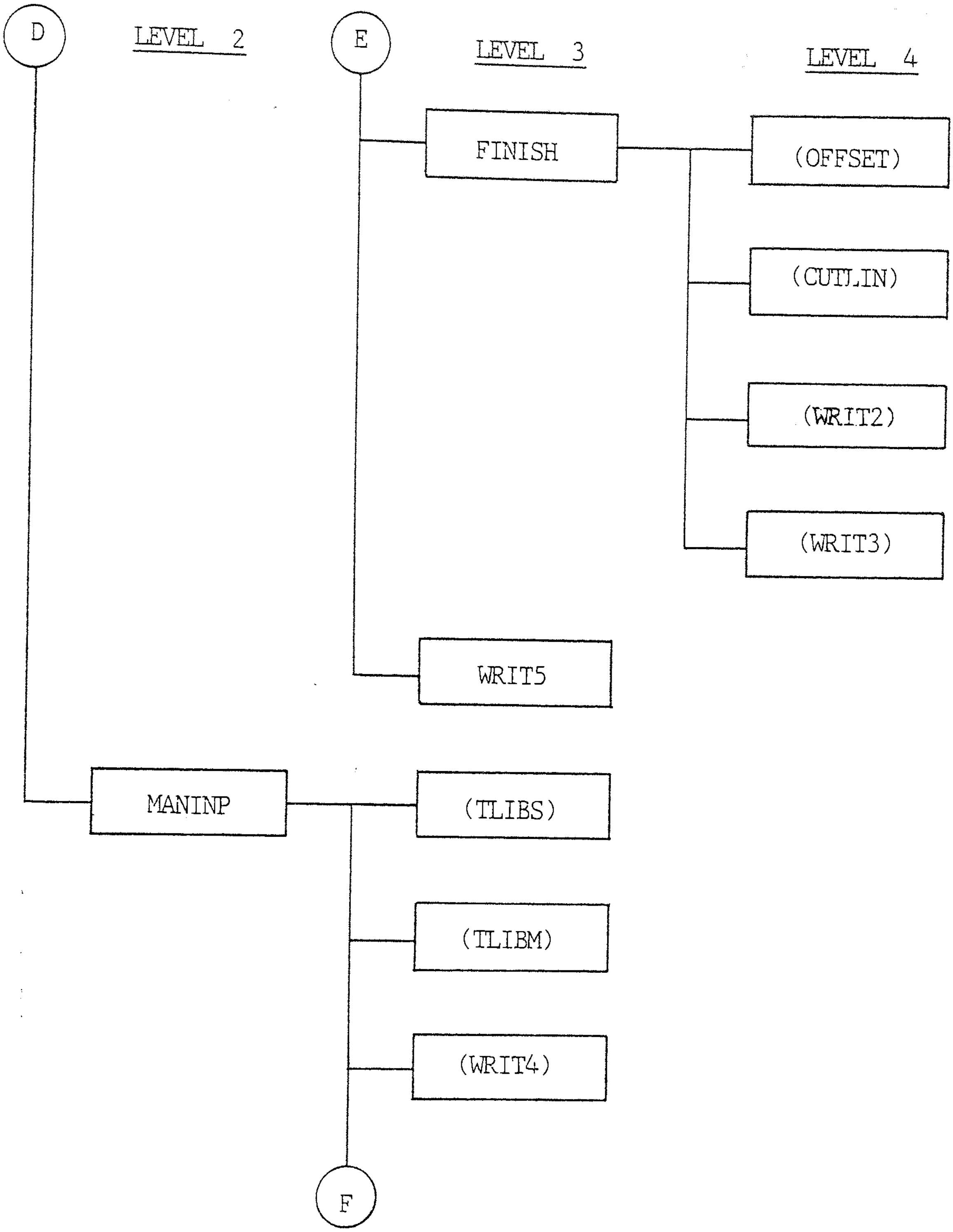


Chart 8.1 (PART 5)

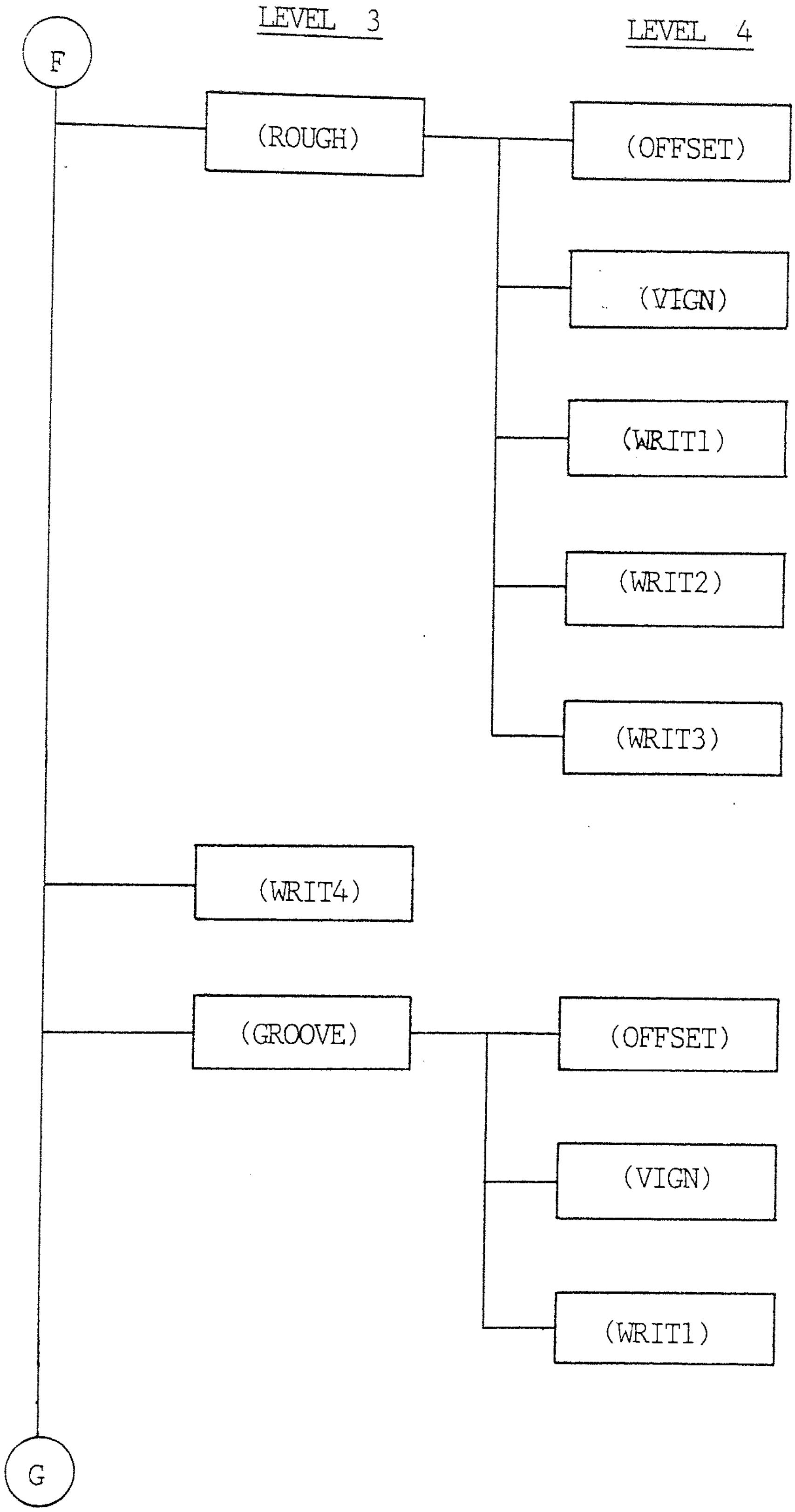


Chart 8.1 (PART 6)

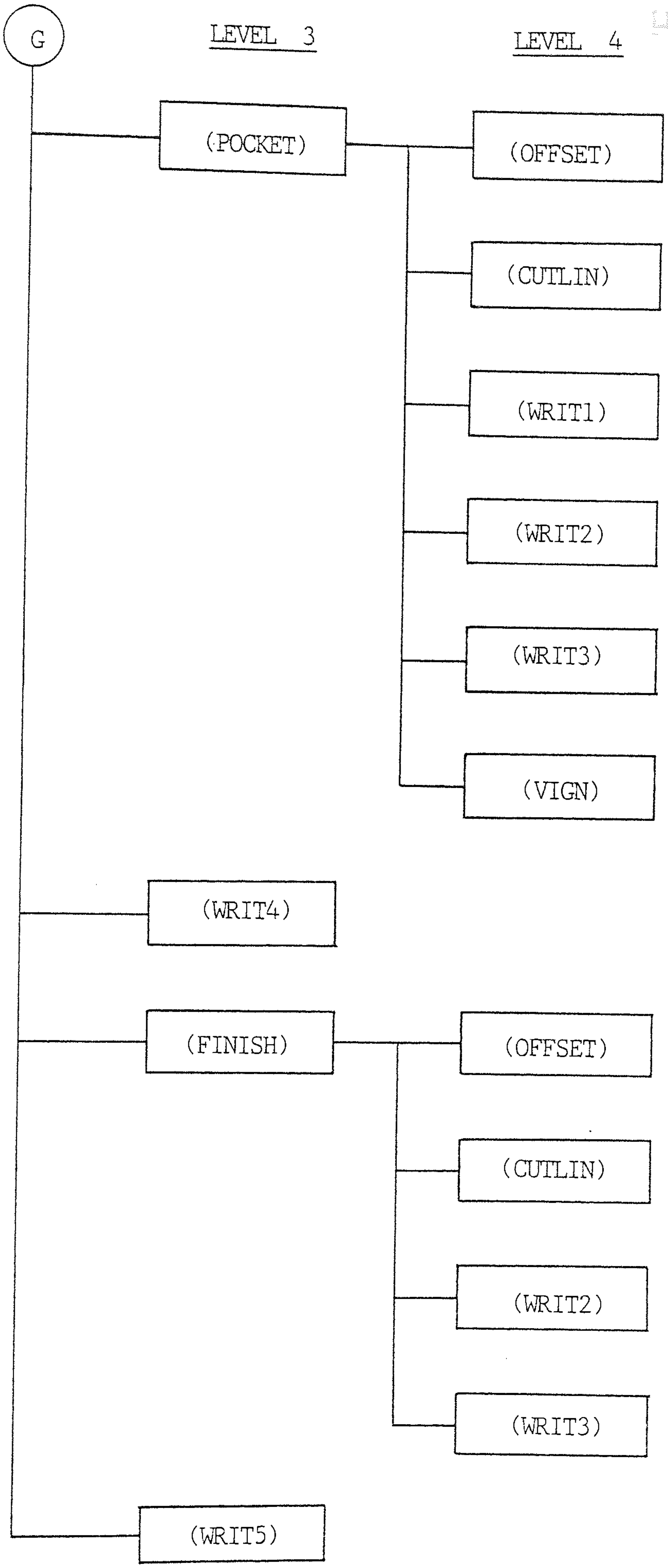
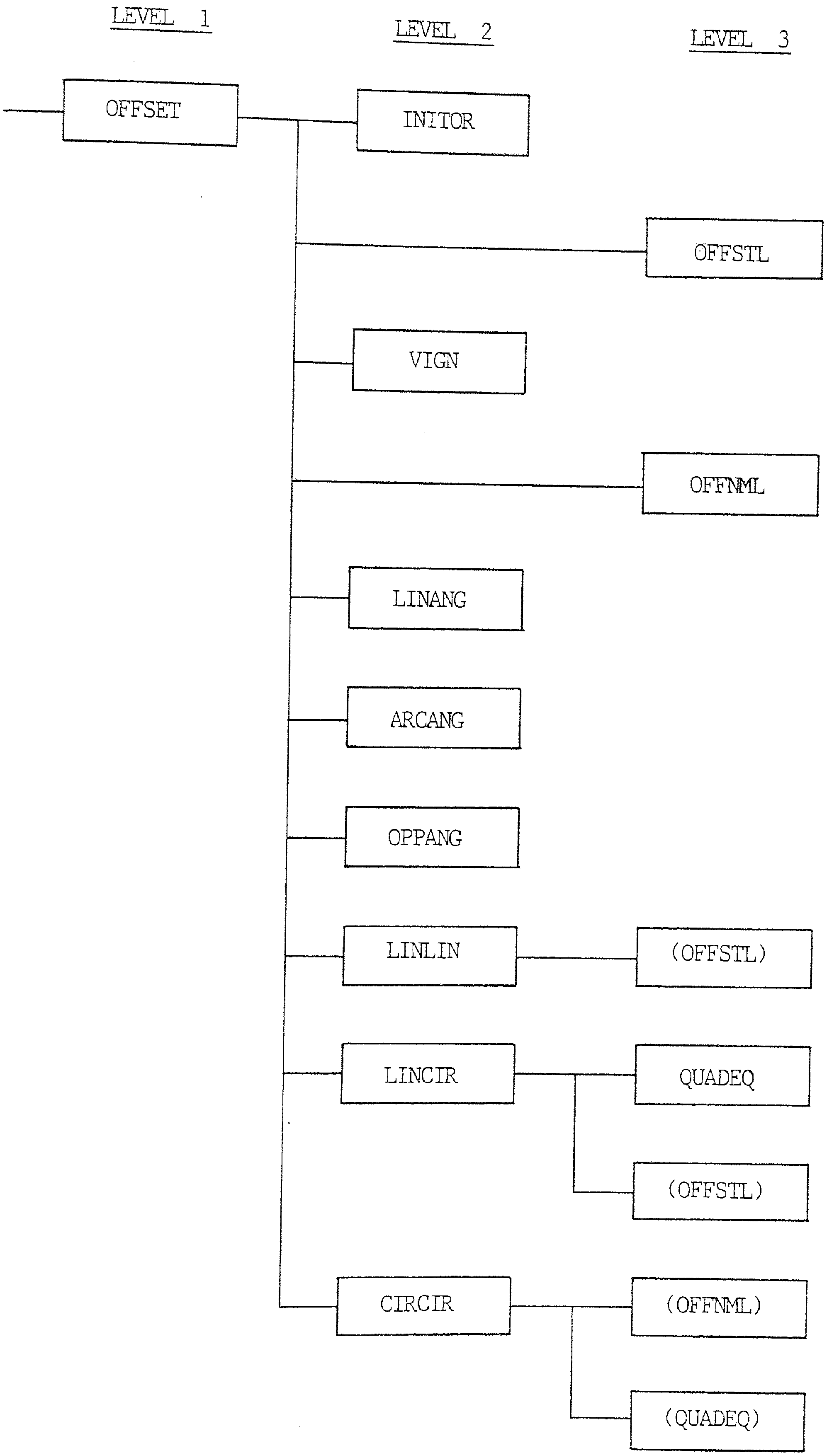


Chart 8.2 HIERARCHY OF THE OFFSET MODULE



CHAPTER 9

CHAPTER 9

POST-PROCESSING AND COST ESTIMATING OF FORM-ROLLS

9.1 INTRODUCTION

The preparation of accurate quotations is critical to the operation of any job shop (73,74). Low bids are likely to be more competitive and, therefore, produce a high proportion of orders, but they will erode profitability. On the other hand, jobs that are priced too high will go more often to the competition. The dilemma for management is that accurate bidding requires the careful preparation for each job and the associated tedius and time-consuming calculations of setup and run times, all of which creates significant manufacturing-engineering overhead.

With this in mind, it was decided to fully automate the manufacturing process of form-rolls by developing, firstly, a general post-processor for converting the cutter location data information into NC programming, and secondly, a cost estimation system for providing accurate form-roll production cost information for quotation purposes. This has been enhanced with the development of a stock control system for capturing and processing the relevant manufacturing information.

9.2 THE GENERAL POST-PROCESSOR

Post-processors are necessary for converting the cutter location data information into an NC tape program that suits the exact requirements of the particular NC system on which the component is to be machined. There are two types of post-processors, namely: specific post-processors which output the precise code for a particular machine tool; and general post-processors which output a generalised format which needs to be edited to satisfy the requirements of a particular machine tool [75,76].

In this research, as it has been the intention to design an NC part-programming system to cope with more than one machine tool, a general post-processor has been designed and developed. This post-processor retrieves and processes the cutter location data information (CO"SECNO""s""r"), and generates an NC tape program for any CNC lathe system. It differs from most common general post-processors, in that, the generated NC tape program does not require any final editing, apart from minor alterations. This has been achieved by designing the general post-processor in such a manner, as to allow the user to supply the relevant machine codes and programming formats for the required CNC lathe system interactively via the keyboard.

However, the flexibility of the general post-processor is limited to the availability of the tool libraries in the expert system roll machining processor. That is, if a tool library for a certain CNC lathe does not exist, then the cutter location data information cannot be post-processed into an NC tape program for that machine. Currently, the expert system roll machining processor includes tool libraries for the Saab controlled Torshalla and Fanuc controlled Mori-Seki CNC lathers, therefore, the general post-processor can only be used to provide NC programming for these two lathe systems.

9.2.1 Machine Code Data Input

The user supplies, interactively via the keyboard information relating to the preparatory functions (G-codes), the miscellaneous functions (M-codes) and other NC program formats as follows:

G-codes

(1)	Inch Mode	Metric Mode	Pure Absoulte Programming	Reference Point Search
(2)	Rapid Linear Interpolation	Linear Interpolation	Circular Interpolation (CW)	Circular Interpolation (CCW)
(3)	Spindle Cutting Surface Speed	Spindle Speed	Dwell Cycle	Thread Cutting
(4)	Feed Per Time	Feed Per Spindle Rotation	Radius Compensation (Tool to the left)	Radius Compensation (Tool to the right)

M-codes

(5)	Spindle Forward	Spindle Reverse	Coolant On	Spindle Stop	Spindle Forward and Coolant On	Spindle off and Coolant Off

(6)	Program Stop	Optional Stop	End of Program	End of Program with Rewind

(7)	Low Speed Range (Lower range and higher range)	High Speed Range (Lower range and higher range)

Other Program Formats

(8)	X-Coordinate Code for the Centre Point of an Arc	Z-Coordinate Code for the Centre Point of an Arc

(9) Tool Number Code   Tool Compensation Code

(10) Code for Cancelling the Tool Offset

All the data supplied by the user is stored in a data file ("NAME".DATA), where "NAME" is the name of the CNC lathe machine, which can be retrieved when further processing is required for the same machine.

9.2.2 Post-Processor Output

During the processing of the GNPOST program, the NC part-program and the tool path plot are displayed on the Tektronix screen. The display of the tool path plot is the actual interpretation of the NC part-program, while in the case of the form-roll machining software, as described in Section 8.6, the tool path plot is based on the information from the cutter location data file. This approach, therefore, can provide a check on the syntax of the NC tape program. The NC tape program is kept in memory as a permanent file under the name specified by the user. If the user selects the option for supplying machine code data, this will also be output in a data file under the name of the CNC lathe system. An example of an NC tape program generated by the GNPOST program, is listed in Fig. 9.1. This file can then be downloaded onto an NC tape reader for producing a paper tape, which can then be used on the CNC lathe for the machining process. A set of form-rolls made on the CNC lathe is shown in Plate 9.1.

9.2.3 Post Processor Software Structure

The general post-processor, GNPOST, consists of three distinctive units, namely:

(1) The General Post-Processor Program (GNPOST)

(2) The Interactive Machine Code Data Input Module (CREATE)

(3) The Tool Path Plot (DECDNC)

A brief account of the nature of the subroutines for the general post-processor software is given in Table 9.1 while the hierarchy of the software structure is shown in Chart 9.1, with the main program GNPOST residing at the highest level of execution.

9.3 THE NC TAPE CHECKING SOFTWARE

The tape checking program has been developed to provide the user the facility for re-checking the information contained in the NC tape program. This tape checking program, TAPCHK, is in fact developed from the DECDNC module in the GNPOST program. The operation of the TAPCHK program produces a tool path plot on the Tektronix screen which is similar to the display from the general post-processor program. Therefore, the tape checking program acts as a means for inspecting the NC tape program. Eventhough its operation is only optional and is literally a quality control, the program gains usefulness when the NC tape program is edited by the user and requires checking. A brief account of the nature of the subroutines is given in Table 9.2, while the hierarchy of the software is shown in Chart 9.2.

9.4 THE COST ESTIMATION OF FORM-ROLLS

The determination of production times and costs for components represents one of the most complex problems for the manufacturing personnel

[77]. Since cutting values are influenced by multiple technological parameters and economical rules depending on the costs of machine tools and of cutting tools, the quantitative and changeable conditions can only be estimated [78].

A cost estimation program has been developed to compute the total cost involved in producing the form-rolls. The program forms an integrated link between the manufacturing and process planning functions, by retrieving the cutter location data information form the expert system roll machining processor, EXPSYS, and processing the relevant machining data. A block diagram of the flow of information in determining the total manufacturing cost for form-rolls, is shown in Fig. 9.2.

9.4.1 Operation of the Cost Estimated Program

During operation of the program, the user is requested to initially specify the thin-walled section number and the roll number for which cost information is required. Then the user is guided by requests and prompts on the terminal screen to supply the labour costs per hour, overhead cost per hour and the material cost. The program retrieves the cutter location data file (CO"SECNO""s""r"), calculates the metal cutting time and the tool change and positioning time, and computes the total manufacturing cost based on the information supplied by the user. A typical machining time and cost information report as displayed on the Tektronix screen, is shown in Fig. 9.3.

The calculation of the tool positioning time, PTIME, has been based on the expression

$$PTIME = \frac{L}{1000 * S} \tag{9.1}$$

where L is the tool displacement in mm, and

S is the cutting speed in m/min.

Whereas, the actual metal cutting time, CTIME, has been based on the expression

$$CTIME = \frac{\pi * D * L}{1000 * S * F} \tag{9.2}$$

where D is the diameter of the roll blank,

L is the tool displacement in mm,

S is the cutting speed in m/min, and

F is the feedrate in mm/rev.

9.4.2 Cost Estimation Software Structure

The cost estimation software consists of two distinctive parts, namely:

(1) The Cost Estimation Program (CACE)

(2) The Total Machining Time Module (TMCALC)

A brief account of the nature of the subroutines for the cost estimation software is given in Table 9.3, while the hierarchy of the software is shown in Chart 9.3.

9.5 THE STOCK CONTROL INTERFACE

Interfacing a stock control system to a computer aided design and manufacturing system, establishes the utilisation of a common database which ensures that everybody within the organisation is working on the same problem (79,80). This contrasts with the more conventional situation, where the state of the problem at any one time is distributed among several hundred brains and several hundred pieces of paper.

A stock control program, TOOL, has been designed with the aim of reducing paper work and providing job information efficiently. The program, which was based on the company's manual stock control system, is in effect a filing system for storing and retrieving information related to form-roll manufacture. At this stage, the communication interface between the stock control program and the NC programming system and cost estimation system, is not fully automatic. That is, the user is required to retrieve the relevant data from the manufacturing and costing output files, and input these interactively into the stock control filing system.

9.5.1 Data System Files

The program filing system utilises a direct access facility, whereby each file and each individual record can be accessed only by executing the program. Therefore, any changes or additions to the files can be made without the necessity for extensive re-writing of the files. Temporary files are created during the operation of the program for the updating or deleting of records, which are deleted when the operation stops, whereas permanent files are created for the final storing of required records. The only disadvantage of using a direct access filing system is that each record must have the same length, so if there is only one long record all the shorter ones will leave some space unused.

9.5.2 Program Operation

The stock control program has been designed to allow the user the following command operations:

EN	:	Enter
AP	:	Append
L	:	List
UP	:	Update
DE	:	Delete
IRE	:	Information Retrieval
STOP	:	Exit
PRINT	:	Printout

The user enters the data interactively by the keyboard and it is displayed on the screen for correctness. If it is wrong, the correction of the individual field is provided instead of writing the whole record again. When the user is sure that the data is correct the program accepts it, otherwise, the operation cannot continue until all the mistakes are corrected.

During updating and appending, the user is provided with the facility of doing as little work as possible and avoiding the duplication. Individual field updating is provided for easiness and speed, whereas in some other stock control systems the user has to rewrite a whole record to update one field. A security facility is also incorporated, which requires the user to type a password to obtain access to the updating and deleting activities. If the program cannot meet the authorised password after four trials, then it stops the execution.

There is multi-user availability during information retrieval, listing and printing out. For any other operation access is central. However, this feature entirely depends upon the operating system of the computer.

```
O0101
N10G21
N15G50X-455.000Z320.000M08
N20T0404M42
N25G96S200M03
N30G0X-150.000Z147.226
N35G1X-124.000Z143.426F0.30
N40Z-2.800
N45G0X-128.000Z143.426
N50G1X-118.000
N55Z81.833
N60G0X-122.000Z143.426
N65G1X-112.000
N70Z87.557
N75G0X-116.000Z143.426
N80G1X-106.000
N85Z92.753
N90G0X-110.000Z143.426
N95G1X-100.000
N100Z97.949
N105G0X-104.000Z143.426
N110G1X-94.000
N115Z103.145
N120G0X-98.000Z143.426
N125G1X-93.494Z144.426
N130Z141.426
N135Z128.426
N140Z103.583
N145X-117.255Z83.006
N150G2X-117.908Z82.263I2.900K-1.675
N155G1Z81.896
N160G2X-118.306Z81.331I0.701K-0.565
N165G1Z58.395
N170G0X-455.000Z320.000
N175T0400
N180M01
N185G50X-300.000Z300.000M08
N190T0606M42
N195G96S200M03
N200G0X-144.000Z-5.000
N205G1X-118.500Z-1.200F0.25
N210Z145.026
N215G0X-122.500Z-1.200
N220G1X-113.000
N225Z55.535
N230G0X-117.000Z-1.200
N235G1X-107.500
N240Z50.772
N245G0X-111.500Z-1.200
N250G1X-102.000
N255Z46.009
N260G0X-106.000Z-1.200
N265G1X-96.500
N270Z41.246
```

Fig. 9.1 NC PROGRAM GENERATED BY THE GENERAL POST-PROCESSOR (PART 1)

```
N275GØX-1ØØ.5ØØZ-1.2ØØ
N28ØG1X-93.494Z-2.2ØØ
N285ZØ.8ØØ
N29ØZ13.8ØØ
N295Z38.643
N3ØØX-117.255Z59.22Ø
N3Ø5G3X-117.9Ø5Z59.993I2.9ØØK1.675
N31ØG1Z6Ø.329
N315G3X-118.3Ø6Z6Ø.895IØ.7ØØKØ.566
N32ØG1Z83.831
N325GØX-3ØØ.ØØØZ3ØØ.ØØØ
N33ØTØ6ØØ
N335MØ1
N34ØG5ØX-455.ØØØZ32Ø.ØØØMØ8
N345TØ7Ø7M42
N35ØG96S2ØØMØ3
N355GØX-136.9ØØZ42.555
N36ØG1X-115.5ØØFØ.2Ø
N365Z13.1ØØ
N37ØGØX-119.5ØØZ42.555
N375G1X-115.5ØØ
N38ØX-112.5ØØ
N385Z13.1ØØ
N39ØGØX-116.5ØØZ42.555
N395G1X-112.5ØØ
N4ØØX-1Ø9.5ØØ
N4Ø5Z13.1ØØ
N41ØGØX-113.5ØØZ42.555
N415G1X-1Ø9.5ØØ
N42ØX-1Ø6.5ØØ
N425Z13.1ØØ
N43ØGØX-11Ø.5ØØZ42.555
N435G1X-1Ø6.5ØØ
N44ØX-1Ø3.5ØØ
N445Z13.1ØØ
N45ØGØX-1Ø7.5ØØZ42.555
N455G1X-1Ø3.5ØØ
N46ØX-1ØØ.5ØØ
N465Z13.1ØØ
N47ØGØX-1Ø4.5ØØZ42.555
N475G1X-1ØØ.5ØØ
N48ØX-97.5ØØZ4Ø.512
N485Z13.1ØØ
N49ØGØX-1Ø1.5ØØZ4Ø.512
N495G1X-97.5ØØ
N5ØØX-94.5ØØZ37.914
N5Ø5Z13.1ØØ
N51ØGØX-98.5ØØZ37.914
N515G1X-94.5ØØ
N52ØX-91.5ØØZ35.316
N525Z13.1ØØ
N53ØGØX-95.5ØØZ35.316
N535G1X-91.5ØØ
N54ØX-88.5ØØZ32.718
```

Fig. 9.1 (PART 2)

```
N545Z13.1ØØ
N55ØGØX-92.5ØØZ32.718
N555G1X-88.5ØØ
N56ØX-86.157Z3Ø.688
N565Z3Ø.687
N57ØGØX-9Ø.157Z3Ø.688
N575G1X-86.157
N58ØX-86.753Z29.477
N585Z13.1ØØ
N59ØGØX-9Ø.753Z29.477
N595G1X-86.753
N6ØØX-83.753Z26.879
N6Ø5Z13.1ØØ
N61ØGØX-87.753Z26.879
N615G1X-83.753
N62ØX-8Ø.753Z24.281
N625Z13.1ØØ
N63ØGØX-84.753Z24.281
N635G1X-8Ø.753
N64ØX-77.753Z21.683
N645Z13.1ØØ
N65ØGØX-81.753Z21.683
N655G1X-77.753
N66ØX-77.494Z21.459
N665Z13.1ØØ
N67ØX-91.694
N675X-116.9ØØ
N68ØGØX-455.ØØØZ32Ø.ØØØ
N685TØ7ØØ
N69ØMØ1
N695G5ØX-3ØØ.ØØØZ3ØØ.ØØØMØ8
N7ØØT1Ø1ØM42
N7Ø5G96S2ØØMØ3
N71ØGØX-136.9ØØZ1Ø3.764
N715G1X-115.5ØØ
N72ØZ129.126
N725GØX-119.5ØØZ1Ø3.764
N73ØG1X-115.5ØØ
N735X-112.5ØØ
N74ØZ129.126
N745GØX-116.5ØØZ1Ø3.764
N75ØG1X-112.5ØØ
N755X-1Ø9.5ØØ
N76ØZ129.126
N765GØX-113.5ØØZ1Ø3.764
N77ØG1X-1Ø9.5ØØ
N775X-1Ø6.5ØØ
N78ØZ129.126
N785GØX-11Ø.5ØØZ1Ø3.764
N79ØG1X-1Ø6.5ØØ
N795X-1Ø3.5ØØ
N8ØØZ129.126
N8Ø5GØX-1Ø7.5ØØZ1Ø3.764
N81ØG1X-1Ø3.5ØØ
```

Fig. 9.1 (PART 3)

```
N815X-100.500
N820Z129.126
N825G0X-104.500Z103.764
N830G1X-100.500
N835X-97.500
N840Z129.126
N845G0X-101.500Z103.764
N850G1X-97.500
N855X-94.500Z104.312
N860Z129.126
N865G0X-98.500Z104.312
N870G1X-94.500
N875X-91.500Z106.910
N880Z129.126
N885G0X-95.500Z106.910
N890G1X-91.500
N895X-88.500Z109.508
N900Z129.126
N905G0X-92.500Z109.508
N910G1X-88.500
N915X-86.157Z111.538
N920Z111.539
N925G0X-90.157Z111.538
N930G1X-86.157
N935X-86.753Z112.749
N940Z129.126
N945G0X-90.753Z112.749
N950G1X-86.753
N955X-83.753Z115.347
N960Z129.126
N965G0X-87.753Z115.347
N970G1X-83.753
N975X-80.753Z117.945
N980Z129.126
N985G0X-84.753Z117.945
N990G1X-80.753
N995X-77.753Z120.543
N1000Z129.126
N1005G0X-81.753Z120.543
N1010G1X-77.753
N1015X-77.494Z120.767
N1020Z129.126
N1025X-91.694
N1030X-116.900
N1035G0X-300.000Z300.000
N1040T1000
N1045M01
N1050G50X-455.000Z320.000M08
N1055T1111M42
N1060G96S250M03
N1065G0X-138.500Z87.131
N1070G1X-118.106Z81.731F0.10
N1075Z59.295
N1080X-117.896Z59.294
```

Fig. 9.1 (PART 4)

```
N1Ø85G2X-117.189Z58.27ØI2.821KØ.4Ø1
N1Ø9ØG1X-85.591Z3Ø.9Ø5
N1Ø95X-86.394Z3Ø.673
N11ØØG2X-86.687Z3Ø.127IØ.2ØØK-Ø.346
N11Ø5G1X-77.294Z21.993
N111ØZ13.ØØØ
N1115X-92.494
N112ØG2X-93.294Z12.6ØØIØ.ØØØK-Ø.4ØØ
N1125G1Z-Ø.4ØØ
N113ØGØX-148.5ØØZ-5.ØØØ
N1135GØX-455.ØØØZ32Ø.ØØØ
N114ØT11ØØ
N1145MØ1
N115ØG5ØX-3ØØ.ØØØZ3ØØ.ØØØMØ8
N1155TØ3Ø3M42
N116ØG96S25ØMØ3
N1165GØX-138.5ØØZ55.Ø95
N117ØG1X-118.1Ø6Z6Ø.495
N1175Z82.931
N118ØX-117.895Z82.933
N1185G3X-117.189Z83.956I2.82ØK-Ø.4Ø2
N119ØG1X-85.591Z111.321
N1195X-86.394Z111.553
N12ØØG3X-86.687Z112.Ø99IØ.2ØØKØ.346
N12Ø5G1X-77.294Z12Ø.233
N121ØZ129.226
N1215X-92.494
N122ØG3X-93.294Z129.626IØ.ØØØKØ.4ØØ
N1225G1Z142.626
N123ØGØX-148.5ØØZ147.226
N1235GØX-3ØØ.ØØØZ3ØØ.ØØØ
N124ØTØ3ØØ
N1245M3Ø
```

Fig. 9.1 (PART 5)

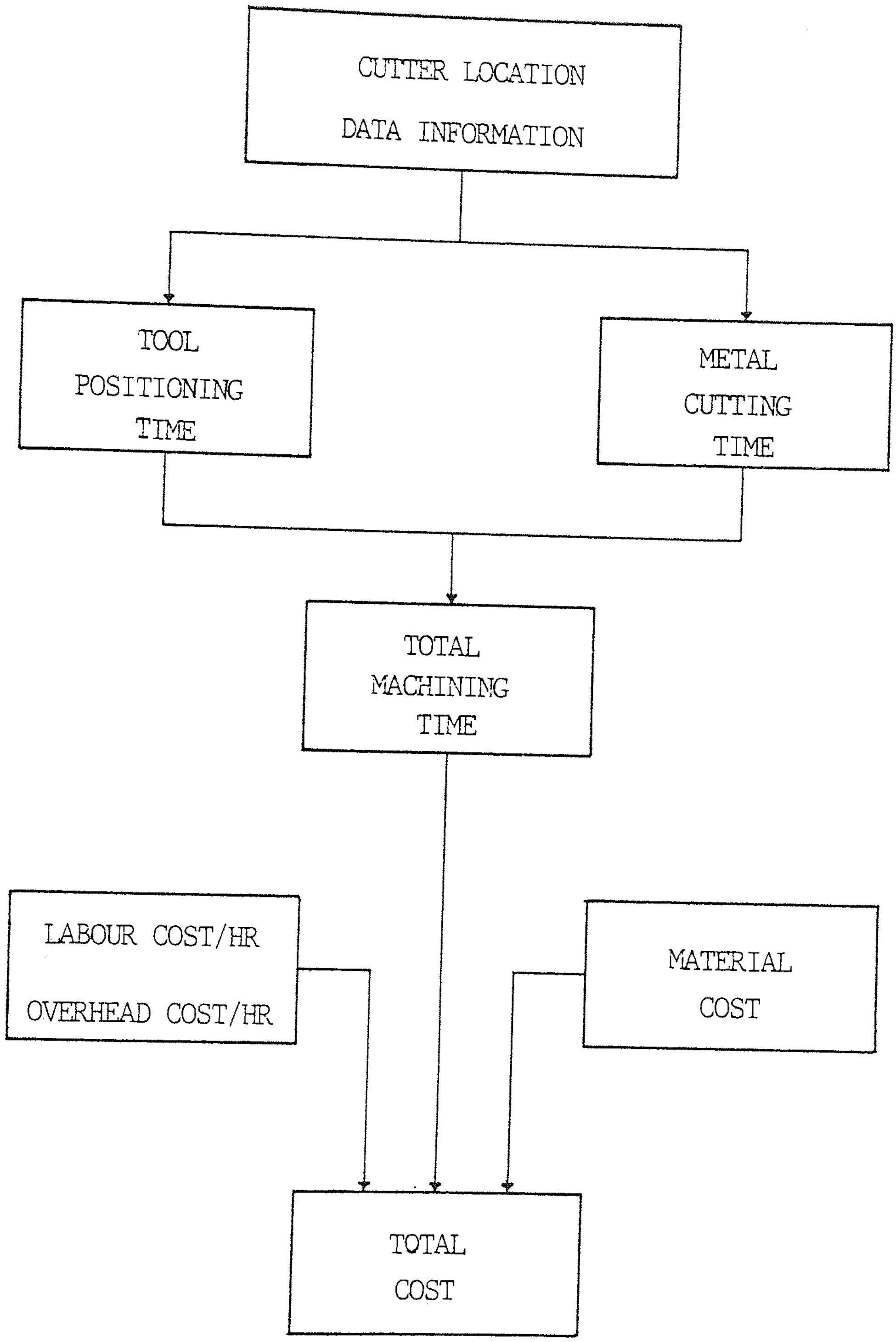


Fig. 9.2 FLOW OF INFORMATION IN DETERMINING THE TOTAL MANUFACTURING COST FOR FORM-ROLLS

Fig. 9.3 A TYPICAL MACHINING TIME AND COST ESTIMATION REPORT

METAL CUTTING TIME = 35.55 MINS

TOOL CHANGE AND POSITIONING TIME = 6.79 MINS

TOTAL TIME = 42.34 MINS

LABOUR COST = 8 3.53

OVERHEAD COST = 8 4.23

TOTAL COST (INCL. MATERIAL) = 8 13.76

ROLFOM	STAGE 1 BOTTOM ROLL	CO125ØA1B

Plate 9.1 A SET OF FORM-ROLLS PRODUCED BY CNC

Table 9.1 SUBROUTINES OF THE GENERAL POST-PROCESSOR SOFTWARE (PART 1)

SUBROUTINE	LEVEL	FUNCTION
GNPOST (MAIN PROGRAM)	1	Calls upon subordinate subroutines to decode the cutter location data file and the specified machine code/format data file, generates the NC tape program and displays cutting tool-path on the Tektronix screen.
CREATE	2	Invites the user to supply the preparatory functions (G-codes), miscellaneous functions (m-codes) and the part-program format of the CNC lathe machine.
EXIST	2	Decodes the preparatory functions, miscellaneous functions and part-program format from the specified CNC lathe machine data file
GRPLOT	2	Sets up the viewport and draws the axes for the tool-path drawing, by calling GINO-F graphics routines.
DECDNC	2	Decodes data from the NC tape program file and plots the tool-path on the Tektronix screen.
IGLIN	2	Outputs the G-code and co-ordinates for linear interpolation.
IGSLIN	2	Outputs the co-ordinates for linear interpolation, where G-code is the same as the preceding one.
IGCIR	2	Outputs the G-code and co-ordinates for circular interpolation.
IGSCIR	2	Outputs the co-ordinates for circular interpolation where G-code is the same as the preceding one.

Table 9.1 (PART 2)

SUBROUTINE	LEVEL	FUNCTION
CHARNC	3	Decodes a block of NC tape program data according to the corresponding address.
PLTCIR	3	Plots a circular arc with starting and ending points and given circle centre points, at the given direction.

Table 9.2 SUBROUTINES OF THE NC TAPE CHECKING SOFTWARE

SUBROUTINE	LEVEL	FUNCTION
TAPCHK (MAIN PROGRAM)	1	Calls upon subordinate subroutines to decode an NC tape program file and plot the tool-path on the Tektronix screen for checking.
TAPEIN	2	Decodes data from the NC tape program file
CHARNC	3	Decodes a block of NC tape program data according to the corresponding address.
PLTCIR	3	Plots a circular arc with starting and ending points and given centre points, at the given direction.

Table 9.3 SUBROUTINES OF THE FORM-ROLL COST ESTIMATION SOFTWARE

SUBROUTINE	LEVEL	FUNCTION
CACE (MAIN PROGRAM)	1	Calls upon subordinate subroutines to decode the cutter location data file and compute the total machining time and the total manufacturing cost.
TMCALC	2	Determines the total machining time
PLOT	2	Plots the form-roll manufacturing cost report on the Tektronix screen
POST	3	Calculates the time for positioning the tool close to the roll blank at recorded feedrate.
FDRATE	3	Calculates the actual metal cutting time for linear elements at the recorded feedrate.
CIRC	3	Calculates the actual metal cutting time for circular elements at the recorded feedrate.
RAPID	3	Calculates the time for a rapid traverse

Chart 9.1 HIERARCHY OF THE GENERAL POST-PROCESSOR SOFTWARE

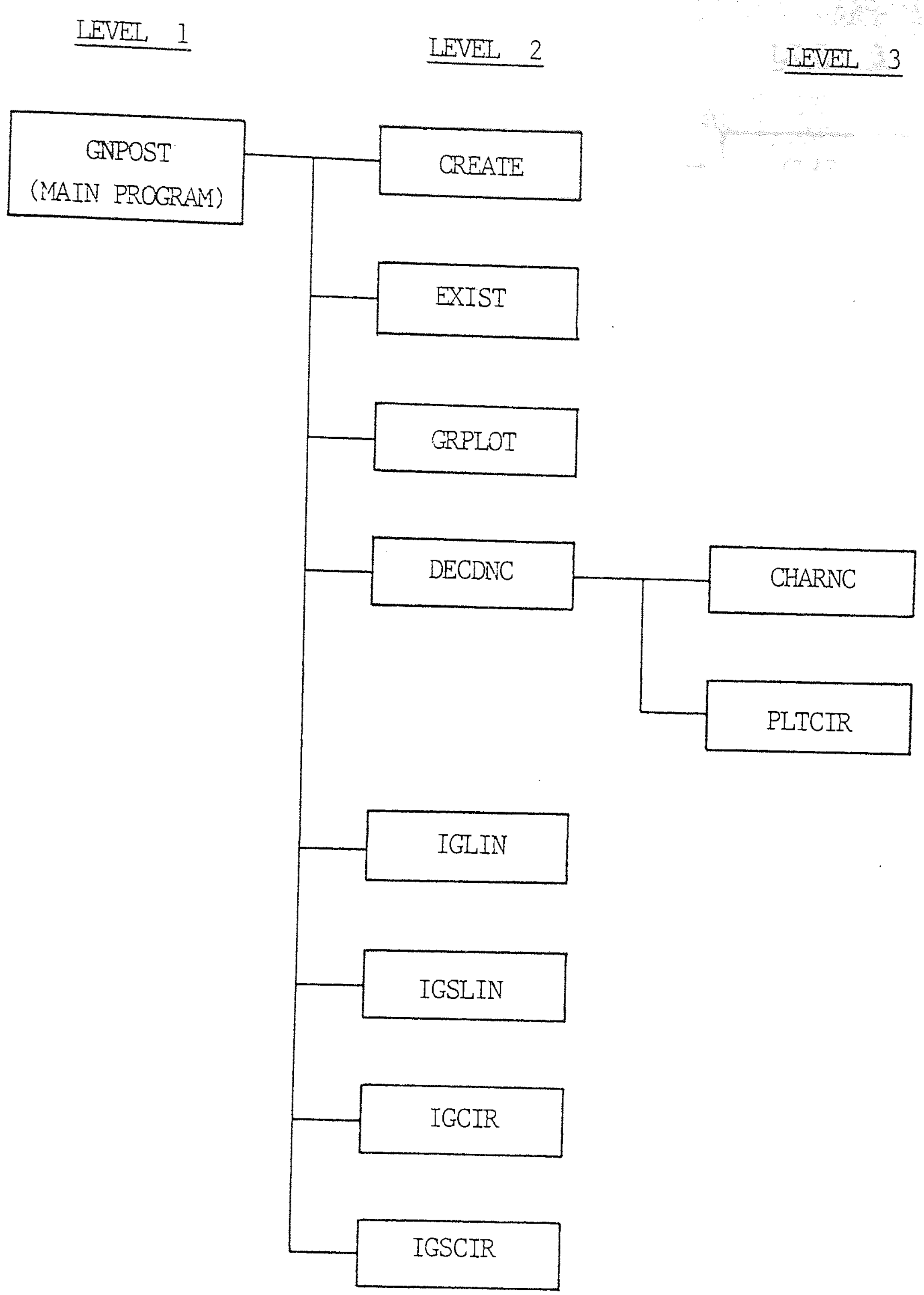


Chart 9.2 HIERARCHY OF THE NC TAPE CHECKING SOFTWARE

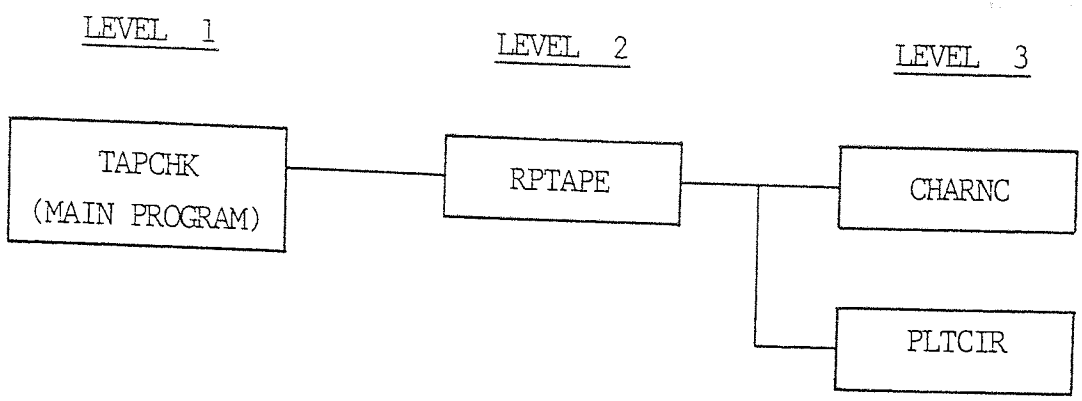
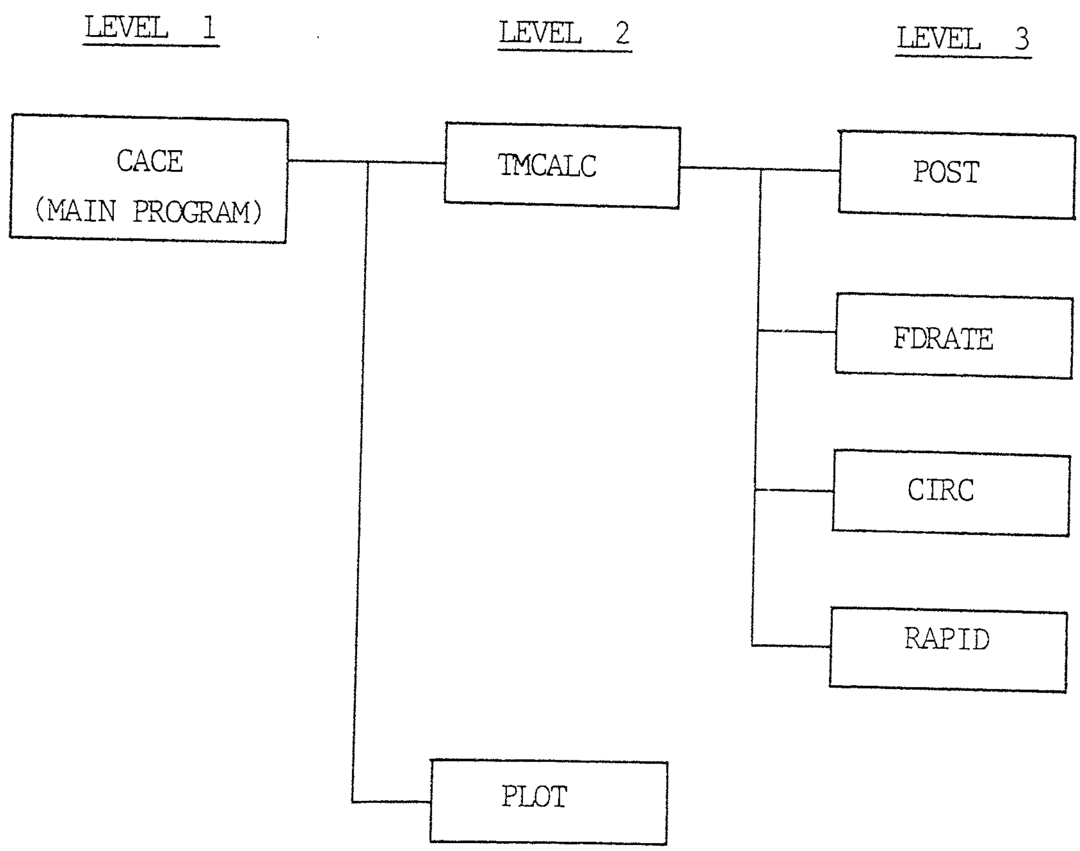


Chart 9.3 HIERARCHY OF THE FORM-ROLL COST ESTIMATION SOFTWARE



CHAPTER 10

CHAPTER 10

CONCLUSIONS AND FUTURE WORK

10.1 CONCLUSIONS AND REMARKS

The research objectives outlined at the initial stage of this development programme have been achieved accordingly. All the computer programs have been successfully implemented on the VAX 11/750 computer system forming an integrated form-roll manufacturing system, comprising the design, manufacture, cost estimation and stock control of form-rolls. Based upon all aspects of the research programme, the following results and conclusions are obtained.

1. A systematic investigation into the company's form-roll design and manufacturing activities was initially undertaken which revealed many weaknesses and inefficiencies in the existing system, most being the result of human inadequacies arising from a lack of consistent and precise procedures. Frequent and comprehensive discussions were held with all relevant company personnel, in preparing a suitable and beneficial computerisation programme throughout this research, giving priority to the satisfaction of more pressing primary needs. The software development of this research has been successfully integrated with the previous phases of software development, without disruption to the existing design and manufacturing activities in the company.

2. All the application software programs were written in FORTRAN 77 utilising the GINO-F library routines for processing graphics, and

were developed into program modules which allows the application programs to be maintained easily. A careful study of the expert system languages, LISP and PROLOG, was also undertaken as to their applicability to the nature of the problem, but due to the inability of either language to integrate its knowledge database and communicate its decision rules to a FORTRAN program, it was decided not to use these software languages.

3. The software developed during the previous phases of software development, namely: the finished section program, the flower pattern; the template program and the roll design program, have been successfully implemented on the VAX 11/750 computer system by modifying all programs accordingly to suit the VAX/VMS operating system. Data acquisition for these programs is achieved while running the programs interactively through a question/answer sequence via the terminal screen and keyboard. The input and output data information is stored into designated data files which can be later retrieved.

4. The roll design program developed during the first phase of the computerisation programme, has been re-designed in this research in order to improve the process of roll design. The user is now only required to supply information for one forming stage at a time, and the program will automatically display the roll drawings for that stage. Also, the addition of the editing facility which allows the user to interactively alter the data input until satisfied with the roll drawings, and the creation of a database for storing extension-contour definitions, have all contributed to a more efficient roll design system. Roll designers are now able to process only a few of

the total number of forming stages for a particular thin-walled section, and then proceed to the form-roll machining process to obtain NC tape programs for the designed form-rolls, thus reducing manufacturing lead times.

5. The development of the roll editor program has established the link between the design and manufacturing software functions. It has been designed to execute random and minor design changes interactively with the aid of an editing facility which handles both linear and circular elements. Mathematical algorithms have been constructed to handle the analytic geometry of the four editing functions, namely: replacing an existing element with a new one; inserting a new element; deleting an existing element and modifying a sharp corner by a chamfer or a blending arc. It has been found that these four editing functions are generally sufficient for carrying out roll design modifications. However, the additional mirror imaging facility and the facility for displaying all the edited rolls of a complete forming stage, have greatly enhanced the roll editing system. The latter facility has given roll designers the opportunity for checking the edited rolls of a required forming stage, and ensuring that top, bottom and side rolls, are properly designed in conjunction with each other. Hence, by utilising the Tektronix's interactive graphics facilities, the roll editor program can dynamically change the displayed roll profile drawing on the terminal screen.

6. A study on the manufacture of form-rolls revealed that the company's NC part-programming method, based on a special-purpose programming system, was inefficient because it was very time-consuming and prone

to errors due to the complex roll profile geometry. The form-roll machining plan, constituting the cutting cycle and sequence, the appropriate cutting tools and cutting angles, and the optimum machinability data, all had to be determined by the part-programmer in liaison with the roll designer. The demand on skill was therefore great and increased even further with greater complexity of the shape of the roll profile.

7. The development of the expert system roll machining processor has eliminated the decision making, undertaken by roll designers and part-programmers, in preparing NC tape programs. The processor, which considers the geometry of the form-rolls to be turned, automatically generates the cutter location data file, the machining instructions data file and the machining process plan. By capturing all the decision making and expertise of the company personnel into a knowledge base module, the processor simply retrieves the roll profile geometric data file and performs a simulated machining operation to the roll blank according to the machining decision rules. To achieve this, four machining cycles (roughing, grooving, pocketing and finishing) were incorporated into the software, which have been sufficient enough to deal with the roughing out and finishing out of all roll profiles.

Machine flexibility has also been achieved by designing the roll machining processor to store a number of tool libraries for CNC lathe machines. A plot of the tool path is displayed on the Tektronix screen which enables the user to observe the tool location paths generated by the program. This provides a spontaneous check for the user to ensure that the correct roll profile shape is being machined in the correct manner. This expert system approach has helped to eliminate the requirement of the user's special knowledge in NC part-programming.

8. Being the intention of this research to design an NC part-programming system to cope with more than one machine tool, a general post-processor has been designed and developed. It retrieves and processes the cutter location data information and generates an NC tape program for the required CNC lathe systems, the user may supply the relevant machine codes and programming formats interactively via the keyboard. However, the flexibility of the general post-processor is limited to the availability of the tool libraries in the expert system roll machining processor. A tool path plot, based on the NC tape program, is displayed on the Tektronix screen while the general post-processor is being executed, providing a check on the syntax of the actual NC tape program.

9. A facility for re-checking the NC tape program information has been incorporated in the NC tape program. This program, similar to the general post-processor, produces a tool path plot on the Tektronix screen, hence acting as a means for visually inspecting the NC tape program before loading the tape in the CNC lathe for actual machining.

10. The cost estimation program, developed to compute the total cost in producing the form-rolls, has established an integrated link between the manufacturing and process planning functions. The program retrieves the cutter location data file, calculates the metal cutting

time and the tool change and positioning time, and computes the total manufacturing cost based on the information supplied by the user.

11. The stock control program, designed as a filing system for storing and retrieving information related to form-roll manufacture, reduces paper work and provides job information efficiently. At this stage, the stock control program is not fully integrated with the manufacturing software.

12. It has been shown that the major rewards which can be reaped from computer aided manufacture come from integration. In this research, the development of a computer integrated manufacturing system for cold roll forming has been found beneficial in all aspects of form-roll design and manufacture. It has shorten lead times in all related activities and has reduced labour and overhead costs, while productivity has increased. Material costs have also been reduced as a result of higher yields or lower scrap rates. Quality has improved with the application of the expert system machining processor, which captures the expertise of the roll designers and part-programmers and eliminates inconsistency. Finally, flexibility has increased as a result of the development of the general post-processor for NC tape program preparation.

10.2 SUGGESTIONS FOR FUTURE WORK

The computer integrated manufacturing system, successfully developed in this research, can be enhanced with the design and development of additional software modules. To achieve this, fundamental research would have to be carried out into the following related areas.

1. The computer aided roll design software for constructing form-roll drawings has been based on the flower pattern representation of the forming sequence. The roll designer is, therefore, required to have the knowledge and expertise to determine, mainly through trial and error, the number of forming stages required to produce the desired shape. The next consideration for the roll designer is to determine the sequence and degree of bending for each forming stage. This may entail great expense in time and cost.

   Future work can be undertaken to establish a precise method for determining the forming sequence. This can be achieved by simulating mathematically the cold roll forming process, thus providing sufficient information to assess flower pattern design on a quantitative basis. Graphical illustration of the simulated states of stress and longitudinal strain between forming stages, will prove very useful to roll designers since many common section defects are caused by excessive and especially plastic longitudinal straining. Furthermore, it is also of practical importance to establish methods for predicting springback allowance in the roll forming process. The results of this research can be incorporated into a flower pattern design mathematical model, which will be installed in the integrated software system for providing flower pattern design information as a guide to roll designers.

2. The expert system roll machining processor has been based on a conventional computer software language, FORTRAN 77. Future research

can be undertaken into artificial intelligence and expert system techniques for determining a more efficient language to capture the roll machining decision making. Establishing a knowledge base by which users can alter easily the decision rules, will prove very useful to roll designers and part-programmers. It is likely, that the geometric and other mathematical algorithms within the roll machining processor will still remain written in FORTRAN 77, but the expert system subroutines will be replaced by the re-designed knowledge base. However, this research will depend largely on future available resources.

3. The finished stock enters a mating die block aperture on a cut-off die at the end of a roll forming line, which cuts the stock to appropriate lengths. As the cross-section of the die-block closely resembles the finished section, it will then be possible to create the particular geometric statements required by an NC EDM machine, which is used for manufacturing die blocks.

   This can be achieved by developing, first, a processor which will consider the geometry of the die block to be machined and generate the cutter location information, while the input being the final forming stage of the template output. Secondly, a special purpose post-processor will be developed for converting the cutter location data information to a control tape program for the NC EDM machine. Thus, the design and manufacture of die blocks can be interfaced to the integrated form-roll manufacturing system.

4. Concerning the NC part-programming system for form-roll production, other machining cycles such as threading and boring cycles can be included into the software to cover all the jobs done on a CNC lathe machine.

5. Finally, the stock control program developed in this research is merely a filing system for storing and retrieving information related to form-roll manufacture. Future work can be undertaken to broaden the scope of this system by developing a production control module for further system integration. More advanced work can also be undertaken on developing a computer based production monitoring system, for monitoring the form-roll machining process and also the roll forming lines. This will provide continuous feedback on the performance of each roll forming line, so that line management can respond to shop floor problems as they occur, rather than having to rely on historic reporting.

APPENDICES

APPENDIX 1

NC PART-PROGRAM CODES AND FORMAT FOR THE SAAB CONTROLLED TORSHALLA AND FANUC CONTROLLED MORI-SEKI CNC LATHES

1. PREPARATORY FUNCTIONS (G-CODES)

2. MISCELLANEOUS FUNCTIONS (M-CODES)

3. PROGRAM FORMAT

1. PREPARATORY FUNCTIONS (G-CODES)

'SAAB' G-CODE	'FANUC' G-CODE	FUNCTION
G00	G00	Positioning
G01	G01	Linear Interpolation
G02	G03	Circular Interpolation (Clockwise)
G03	G02	Circular Interpolation (Counterclockwise)
G04	G04	Dwell
G70	G20	Inch-mode (Programming in inches)
G71	G21	Metric-mode (Programming in mm)
-	G27	Zero return check
G92	G28	Zero return (offset)
-	G29	Return from zero
G33	G32	Thread Cutting
G40	G40	Cancel cutter tool tip R compensation
G42	G41	Cutter tool tip R compensation right
G41	G42	Cutter tool tip R compensation left
G90	G50	Pure absolute programming
-	G70	Finishing cycle
-	G71 & G75	O.D., I.D., rough cutting cycles
-	G72	End surface rough cutting cycle
-	G73	Closed loop cutting cycle
-	G74	End surface cutting off cycle
G82 & G83	-	Measurement cut
G86 & G87	G76 & G92	Thread cutting cycles

'SAAB' G-CODE	'FANUC' G-CODE	FUNCTION
-	G90 & G94	Cutting cycle A & B
G88	-	Parting-off
G97	-	Programming spindle speed
G96	G96	Constant surface cutting speed
-	G97	Cancel constant surface cutting speed
G94	G98	Feed per time (mm/min or inch/min)
G95	G99	Feed per spindle rotation (mm/rev or inch/rev)
G91	-	Incremental programming

2. MISCELLANEOUS FUNCTIONS (M-CODES)

'SAAB' M-CODE	'FANUC' M-CODE	FUNCTION
M00	M00	Program stop - Stops machine operation during program - Spindle, cutting oil supply and feed stop
M01	M01	Optional Stop - ON/OFF can be controlled by switch on control panel
M01	M02	End of program
M04	M03	Normal spindle rotation (CCW)
M03	M04	Reverse spindle rotation (CW)
M05	M05	Spindle stop
M06	-	Tool shift
M07 & M08	M08	Cutting oil supply (coolant) on
M09	M09	Cutting oil supply (coolant) off
-	M10	Chuck clamping - M00 function must be on
-	M11	Chuck unclamping - Bar feeder must be used
-	M12	Tail stock spindle out
-	M13	Tail stock spindle in
M13	-	Spindle on (CW) and coolant on
M14	-	Spindle on (CCW) and coolant on
-	M17	Normal tool post rotation
-	M18	Reverse tool post rotation
-	M21	Tail stock direction forward
-	M22	Tail stock direction backward
-	M23	Clamping chamfering
-	M24	Unclamping chamfering
M30	M30	End of program with rewind

'SAAB' M-CODE	'FANUC' M-CODE	FUNCTION
-	M41	Low spindle speed range
-	M42	High spindle speed range
M20	-	Spindle speed series I 20 - 600 rpm
M21	-	Spindle speed series II 40 - 1200 rpm
M22	-	Spindle speed series III 80 - 2400 rpm
M23	-	Spindle speed series IV 160 - 480 rpm
-	M98	Sub-tape call from main-tape
-	M99	Main-tape call from sub-tape

3. PROGRAM FORMAT

'SAAB' FORMAT	'FANUC' FORMAT	FUNCTION
T01D01	T0101	Tool offset and tool station number
D00	T0100	Tool offset cancel
G96 S150	G96 S150	Cutting speed (150 m/min)
G97 S150	G97 S150	Spindle speed (150 rev/min)
G94 F100	G98 F100	Feed rate (100 mm/min)
G95 F0.25	G99 F0.25	Feed rate (0.25 mm/rev)
I & J	I & K	X & Z - coordinates of the centre point of an arc

Notes:-

(1) Only one M function can be commanded in a single block for the 'Fanuc' CNC lathe.

(2) Four M functions can be commanded in a single block for the 'Saab' CNC lathe.

APPENDIX 2

DATA INPUT FORMAT FOR THE INTEGRATED MANUFACTURING SOFTWARE SYSTEM

Explanatory notes for input data items in the Finished Section Program, Flower Pattern Program, Roll Design Program and Expert System Roll Machining Program.

A. FINISHED SECTION PROGRAM

THIS PROGRAM PLOTS THE COMPLETE FINISHED SHAPE OF
THE ROLLED-SECTION (LINEAR & CIRCULAR ELEMENTS ONLY)

INPUT DATA SEQUENCE
****

1. IUNIT = INPUT DIMENSION UNIT (1 = INCH & 2 = MM.)
OUNIT = OUTPUT DIMENSION UNIT (1 = INCH & 2 = MM.)
THICK = THICKNESS OF STRIP
ORIGIN = STARTING POINT FOR FIRST ELEMENT

* 1 = AT LEFT, MOVING RIGHT ONLY
* 2 = AT RIGHT, MOVING LEFT ONLY
* 3 = AT CENTRE, MOVING RIGHT, THEN LEFT(NON-SYMMETRICAL)
* 4 = AT CENTRE, MOVING LEFT,THEN RIGHT(NON-SYMMETRICAL)
* 5 = AT CENTRE, MOVING RIGHT ONLY(SYMMETRICAL)

2. NEXT ENTER DEFINITION STATEMENTS FOR ELEMENT DEFINITION SEQUENCE,
EACH STATEMENT CONSISTS OF 4 DATA VALUES AS FOLLOWS :-

SEQUENCE NUMBER (N)	ELEMENT TYPE (TYPE)	LENGTH OR RADIUS	ANGLE OF BENDING
(INTEGER)	(INTEGER)	(REAL)	(REAL)
START FROM 1, INCREMENT BY 1 UP TO 5Ø, TO TERMINATE ENTER Ø.	1 = LINEAR 2 = CIRCULAR THE REST ARE ILLEGAL.	POSITIVE LENGTH FOR TYPE 1, INSIDE RADIUS FOR TYPE 2 (MAY BE Ø).	FOR TYPE 2 ELEMENTS ONLY, ZERO FOR TYPE 1 NON-ZERO FOR TYPE 2 *

*THE EXCEPTION BEING, WHEN N=1 AND TYPE=1,
ANGLE OF BENDING IS TAKEN AS THE ANGLE OF INCLINATION
BETWEEN THE AXIS OF THE FIRST LINEAR ELEMENT
AND THE HORIZONTAL AXIS. (RANGE = -9Ø.Ø TO +9Ø.Ø, IN DEGREES)

NOTE THAT WHEN ORIGIN IS 3 OR 4 (DOUBLE SIDED DEFINITION),
2 SETS OF DEFINITION SEQUENCE ARE REQUIRED, ONLY 1 SET
IS REQUIRED WHEN ORIGIN IS 1,2 OR 5.
FIRST ELEMENT AND LAST ELEMENT OF THE SEQUENCE MUST BE LINEAR.
MAXIMUM NO. OF ELEMENTS IN EACH SEQUENCE MUST BE LESS THAN 5Ø.

3. NEXT ENTER DATA VALUES FOR PAPERSIZE AND SCALE AS FOLLOWS :-

PAPERSIZE	SCALE
(INTEGER)	(REAL)

PAPERSIZE= 3 (FOR A3 SIZE) OR 4 (FOR A4 SIZE),
SCALE= ANY POSITIVE VALUE OF MAGNITUDE LESS THAN THE GIVEN LIMITS WHICH ARE BASED ON THE PAPERSIZE SELECTED.

4. NEXT ENTER DATA FOR DIMENSIONING OPTION, 1 IF YES OR Ø IF NO.

5. NEXT ENTER DATA FOR TITLE-BLOCK INPUT SELECTION OPTION :-
1 IF TITLE-BLOCK INFORMATION WILL BE SUPPLIED SUBSEQUENTLY, OR
Ø IF NO TITLE-BLOCK INFORMATION WILL BE SUPPLIED
(IF 1 REFER TO SUBROUTINE DTVAL FOR FURTHER INFORMATION REGARDING TITLE-BLOCK INPUTS)

B. FLOWER PATTERN PROGRAM

THIS PROGRAM PLOTS THE FLOWER-PATTERNS OF
ALL THE BENDING STAGES OF THE ROLLED-SECTION

INPUT DATA SEQUENCE
****

```
1.  JRUN = 1 (IF FLOWER PATTERNS ONLY), OR
           2 (IF ROLLER-PLOTTINGS ONLY), OR
           3 (IF FLOWER-PATTERNS AND ROLLER-PLOTTINGS).

2.  NSTAGE = TOTAL NUMBER OF STAGES
             (THE PERMISSIBLE RANGE IS FROM 1 TO 5Ø)

3.  JBEND = SELECTION OF CIRCULAR-ELEMENT BENDING DEFINITION OPTION:-
            Ø (IF SIMPLE ELEMENT DEFINITION), OR
            1 (IF COMPOSITE PERCENTAGE ELEMENT DEFINITION).

4A.  ISEQ  = BENDING STAGE SEQUENCE NUMBER (LARGEST OF WHICH = NSTAGE).
     IELML = LEFT-HAND ELEMENT (CIRCULAR) TO BE BENT
     XANGL = CUMULATIVE ANGLE OF BENDING FOR THE LEFT-HAND ELEMENT.
     IELMR = RIGHT-HAND ELEMENT (CIRCULAR) TO BE BENT.
     XANGR = CUMULATIVE ANGLE OF BENDING FOR THE RIGHT-HAND ELEMENT.

4B.  ** THIS IS THE COMPOSITE PERCENTAGE ELEMENT DEFINITION OPTION **

     ISEQ  = (AS IN NOTE 4A)
     IELML = (AS IN NOTE 4A)
     XANGL = (AS IN NOTE 4A)
     IPCL1 = PERCENTAGE LENGTH OF LEADING LINEAR PART.
     IPCL2 = PERCENTAGE LENGTH OF CIRCULAR PART.
     IPCL3 = PERCENTAGE LENGTH OF TRAILING LINEAR PART.
     IELMR = (AS IN NOTE 4A)
     XANGR = (AS IN NOTE 4A)
     IPCR1 = PERCENTAGE LENGTH OF LEADING LINEAR PART.
     IPCR2 = PERCENTAGE LENGTH OF CIRCULAR PART.
     IPCR3 = PERCENTAGE LENGTH OF TRAILING LINEAR PART.

     (NOTE THAT THE IPCL'S AND THE IPCR'S SHOULD BE INTEGER VALUES
      IN THE RANGE Ø TO 1ØØ AND THE SUM SHOULD BE 1ØØ EXACTLY IN
      EACH CASE).
```

N.B. :- TO TERMINATE THE DEFINITION SEQUENCE FOR EITHER 4A OR 4B, JUST ENTER Ø FOR ISEQ AND DUMMY VALUES FOR THE REST.

5. ** THIS IS THE RADII-SHARPENING OPTION **

JSHARP = 1 (IF STAGE NO. ARE TO BE ENTERED INDIVIDUALLY), OR
-1 (IF ALL STAGES EXCEPT LAST STAGE REQUIRE SHARPENING OF RADII), OR
Ø (IF RADII-SHARPENING IS NOT REQUIRED AT ALL).

N.B. :- IF JSHARP IS Ø OR -1, NO FURTHER INPUT DATA IS REQUIRED FOR THIS OPTION, PROCEED TO THE NEXT OPTION INPUT.

ISQSH = STAGE NO. WITH RADII-SHARPENING ACTIVE.

6. ** THIS IS THE FIXED PERCENTAGE COMPOSITE LENGTH OPTION **

ISQCP = ENTRY NO. WITH FIXED PERCENTAGE COMPOSITE LENGTHS
IECL1 = L.H.S. ELEMENT NO. WITH SUCH COMPOSITION.
IECL2 = STAGE NO. WHEN IT STARTS TO BE ACTIVE.
IECL3 = STAGE NO. WHEN IT CEASES TO BE ACTIVE.
IECR1 = R.H.S. ELEMENT NO. WITH SUCH COMPOSITION.
IECR2 = STAGE NO. WHEN IT STARTS TO BE ACTIVE.
IECR3 = STAGE NO. WHEN IT CEASES TO BE ACTIVE.

N.B. :- IF ONLY ELEMENT ON ONE-SIDE IS DESIRED, THEN ENTER Ø FOR ELEMENT NO. ON THE IRRELEVANT SIDE.
TO TERMINATE THIS SEQUENCE, ENTER Ø FOR ALL VALUES IN A LINE.

C. ROLL DESIGN PROGRAM

THIS PROGRAM PLOTS THE ROLLER-PROFILES OF
ALL THE BENDING STAGES OF THE ROLLED-SECTION

INPUT DATA SEQUENCE
****

R1. IPASHT = +1 (IF CONSISTENT PASS-HEIGHT & C-TO- DISTANCE),OR
-1 (IF INCONSISTENT PASS-HEIGHTS & C-TO- DISTANCES)

R2. PASHT = PASS-HEIGHT (OR RADIUS OF THE BOTTOM-ROLL)
CTOC = CENTRE-TO-CENTRE DISTANCE BETWEEN TOP & BOTTOM ROLLS

N.B.:- GIVE ONLY ONE VALUE EACH OF IPASHT=+1 ,OTHERWISE
GIVE THE CORRECT NUMBER (= NSTAGE) OF VALUES EACH IF IPASHT=-1;
BOTH PASHT & CTOC VALUES MUST BE POSITIVE.

R3. ITOL =+1 (IF CONSISTENT LH & RH TOLERANCES),OR
-1 (IF INCONSISTENT LH & RH TOLERANCES).

R4. TOLLH = LEFT-HAND TOLERANCE BETWEEN ROLLER AND LAST ELEMENT
TOLLR = RIGHT-HAND TOLERANCE BETWEEN ROLLER AND LAST ELEMENT.

N.B.:- GIVE ONLY ONE VALUE EACH IF ITOL=+1, OTHERWISE
GIVE THE CORRECT NUMBER (= NSTAGE) OF VALUES EACH
IF ITOL=-1; BOTH TOLLH AND TOLRH MUST BE POSITIVE.

R5. JTEMP = 1 IF COMPONENT DRAWING IN HIDDEN-LINE FORM
IS REQUIRED, OTHERWISE Ø

RSCALE = DESIRED SCALE FOR THE ROLLER DRAWINGS (AUTOMATICALLY
REDUCED IF IT EXCEEDS THE MAXIMUM PERMISSIBLE SCALE)

RGAP = THE GAP DIMENSION BETWEEN TOP AND BOTTOM ROLLERS

R6. JSTAGE(1)=-1 (IF ALL STAGES REQUIRED FOR ROLLERS),OR
JSTAGE(1)= Ø (IF NO STAGES REQUIRED FOR ROLLERS),OR
JSTAGE(1)=ANY POSITIVE VALUE(INTEGER LESS THAN NSTAGE) (IF
SELECTED STAGES REQUIRED FOR ROLLERS).

N.B.:- IF JSTAGE(1) IS -1 OR Ø, NO FURTHER INPUT DATA IS REQUIRED; IF JSTAGE(1) IS POSITIVE, THEN SUPPLY OTHER DESIRED BENDING STAGE NO. IN ASCENDING ORDER, ENTER Ø TO TERMINATE. THE TOTAL NUMBER OF JSTAGE DATA MUST NOT EXCEED NSTAGE VALUE.

****

SPECIAL OPTIONS

****

PINCH-DIFFERENCE OR DRIVE/CLEARANCE SURFACE OPTION:-

P1. JPINCH = Ø (IF NO EXTERNAL PINCH DIFFERENCE DIMENSION DEFINITION IS SUPPLIED), OR
1 (IF ONLY ONE PINCH DIFFERENCE DIMENSION DEFINITION IS SUPPLIED FOR ALL BENDING STAGES), OR
-1 (IF PINCH DIFFERENCE DIMENSION DEFINITION IS SUPPLIED INDIVIDUALLY FOR EACH BENDING STAGE).

2 (IF SINGLE THICKNESS OPTION WITH ONE COMMON CLEARANCE VALUE FOR ALL STAGES SELECTED),OR

-2 (IF SINGLE THICKNESS OPTION WITH INDIVIDUAL CLEARANCE VALUE FOR EACH STAGE SELECTED)

N.B. :- IF JPINCH IS Ø,1 OR -1 THEN PROCEED TO SECTION P2.
IF JPINCH IS 2 OR -2 THEN PROCEED TO SECTION P2A.

P2. PDIM1 = THICKNESS BETWEEN THE DRIVE SURFACES.
PDIM2 = THICKNESS BETWEEN THE CLEARANCE SURFACES.

N.B. :- IF JPINCH IS Ø, DATA FOR PDIM1 AND PDIM2 ARE NOT REQUIRED;
IF JPINCH IS 1, ONLY 1 SET IS REQUIRED; AND
IF JPINCH IS -1, 1 SET FOR EACH STAGE SHOULD BE SUPPLIED.

P3. ISQP = CURRENT BENDING STAGE SEQUENCE NO.
IEPL = L.H.S. ELEMENT DEFINING THE DRIVE SURFACE CONTOUR.
IEPR = R.H.S. ELEMENT DEFINING THE DRIVE SURFACE CONTOUR.

N.B. :- TO TERMINATE DEFINITION STATEMENT SEQUENCE, ENTER Ø FOR ISQP, AND DUMMY VALUES FOR THE OTHER ITEMS.
TWO STATEMENTS REQUIRED FOR EACH BENDING STAGE TO DEFINE THE BEGINNING AND THE END OF DRIVE-SURFACE.
TOTAL NO. OF DEFINITION STATEMENT SHOULD BE 5Ø OR LESS.
IF ONLY EITHER L.H.S. OR R.H.S. IS TO BE DEFINED THEN THE NON-APPLICABLE SIDE SHOULD HAVE ELEMENT Ø ENTERED.

P4. ** THIS IS THE SINGLE THICKNESS OPTION FOR H&E **
CLEAR = CLEARANCE VALUE TO BE ADDED ONTO THE THICKNESS WITH 8 PER CENT OF THICKNESS ALREADY ADDED .

N.B. :- IF JPINCH IS 2, THEN SUPPLY ONLY ONE VALUE; IF JPINCH IS -2, THEN SUPPLY THE CORRECT NUMBER (=NSTAGE) OF VALUES FOR EACH INDIVIDUAL STAGE.

SIDE-CONTOUR OPTION:-

S1. ISROL = 1 (IF SIDE-ROLL OPTION WILL BE USED), OR
Ø (IF SIDE-ROLL OPTION WILL NOT BE USED)

N.B. IF ISROL IS Ø, THEN NO FURTHER DATA IS REQUIRED FOR OTHER SIDE-ROLL INPUT AND EXTENSION-CONTOUR INPUT.

S2. IOTOS = 1 (IF CONSISTENT ORIGIN TO SIDE-ROLL AXES) OR
-1 (IF INCONSISTENT ORIGIN TO SIDE-ROLL AXES DISTANCES)

S3. OTOSL = DISTANCE BETWEEN ORIGIN AND LEFT SIDE-ROLL CENTRE
OTOSR = DISTANCE BETWEEN ORIGIN AND RIGHT SIDE-ROLL CENTRE

(SEE DIAGRAM).

N.B. :- GIVE ONLY 1 SET OF VALUES IF IOTOS IS 1; IF IOTOS IS -1 THEN GIVE CORRECT NUMBER (=NSTAGE) OF SETS OF VALUES FOR EVERY STAGE; BOTH OTOSL AND OTOSR MUST BE POSITIVE.

S4. ISQS = CURRENT BENDING STAGE SEQUENCE NO.
IESL1 = L.H.S. ELEMENT CONSTITUTING L.H.S. SIDE-ROLL CONTOUR.
IESL2 = WHICH FACE OF THE L.H.S. ELEMENT IS DESIRED
IESR1 = R.H.S. ELEMENT CONSTITUTING R.H.S. SIDE-ROLL CONTOUR.
IESR2 = WHICH FACE OF THE R.H.S. ELEMENT IS DESIRED

(SEE DIAGRAM FOR DETAIL OF ELEMENT FACE DEFINITION).

N.B. :- IF SIDE-ROLLS ARE NOT REQUIRED FOR A PARTICULAR BENDING STAGE, THEN SKIP AND GO ON TO DEFINE THE NEXT STAGE WHICH HAS SIDE-ROLLS.
THE SIDE-ROLL CONTOUR IS DEFINED BY 2 BOUNDARY ELEMENT FACES, NAMELY THE STARTING ELEMENT FACE AND THE ENDING ELEMENT FACE. THEY MUST BE ENTERED IN THAT SEQUENCE IN 2 CONSECUTIVE DEFINITION STATEMENTS.
THE DEFINITION CONVENTION IS FROM BOTTOM UPWARDS, HENCE THE COMPLETE SIDE-ROLL CONTOUR WILL CONSIST OF THE BOTTOM LEADING PART, FOLLOWED BY THE PART IN CONTACT WITH THE STRIP AND THEN FOLLOWED BY THE TRAILING TOP PART.

NO MORE THAN 2 DEFINITION STATEMENTS SHOULD BE ENTERED
FOR EACH SIDE-ROLL.
TO TERMINATE DEFINITION STATEMENT SEQUENCE,
ENTER Ø FOR ISQS, AND DUMMY VALUES FOR THE OTHER ITEMS.
IF ONLY EITHER L.H.S. OR R.H.S. ELEMENT IS TO BE DEFINED
IN THE CURRENT STATEMENT, THEN ENTER Ø FOR THE ELEMENT
ON THE NON-APPLICABLE SIDE.
TOTAL NO. OF DEFINITION STATEMENTS SHOULD BE 5Ø OR LESS.

S5. ** THIS SECTION ON EXTENSION-CONTOUR OPTION CAN BE USED
ONLY IF SIDE-ROLL OPTION IS USED, ELSE IT IS IRRELEVANT **

IEXTN = 1 (IF EXTENSION-CONTOUR OPTION WILL BE USED), OR
Ø (IF EXTENSION-CONTOUR OPTION WILL NOT BE USED).

N.B. :- IF IEXTN IS Ø, THEN NO FURTHER DATA INPUT FOR THIS
OPTION IS REQUIRED.

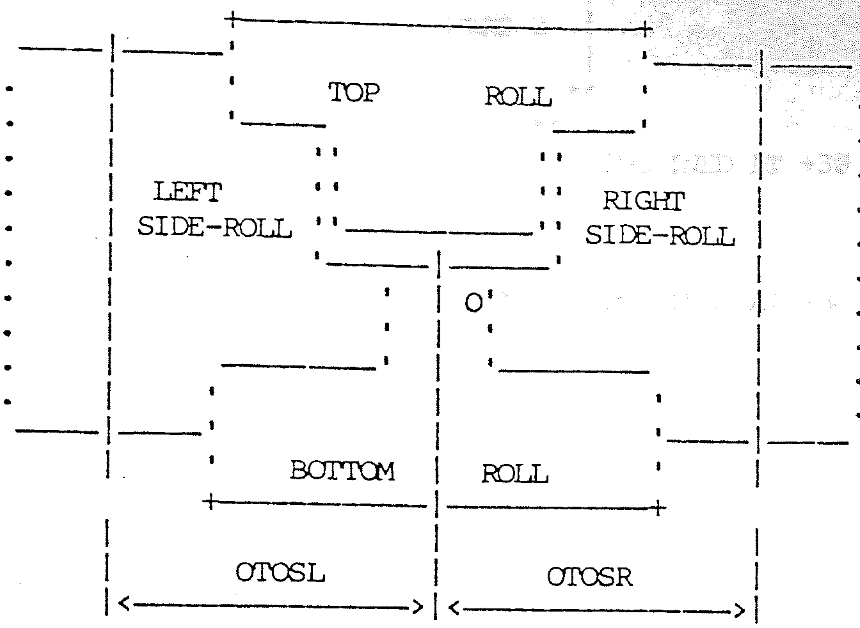
S6. ISC1 = SIDE-CONTOUR NO.
ISC2 = SIDE-CONTOUR TYPE (1 FOR SIDE-ROLL, 2 FOR SPIGOT TYPE A,
3 FOR SPIGOT TYPE B.)
SCDIM1 = DIMENSION DEFINITION FOR SIDE-CONTOUR PART 1
SCDIM2 = DIMENSION DEFINITION FOR SIDE-CONTOUR PART 2
SCDIM3 = DIMENSION DEFINITION FOR SIDE-CONTOUR PART 3
SCDIM4 = DIMENSION DEFINITION FOR SIDE-CONTOUR PART 4

(SEE DIAGRAM FOR DETAILS OF EACH DEFINITON).

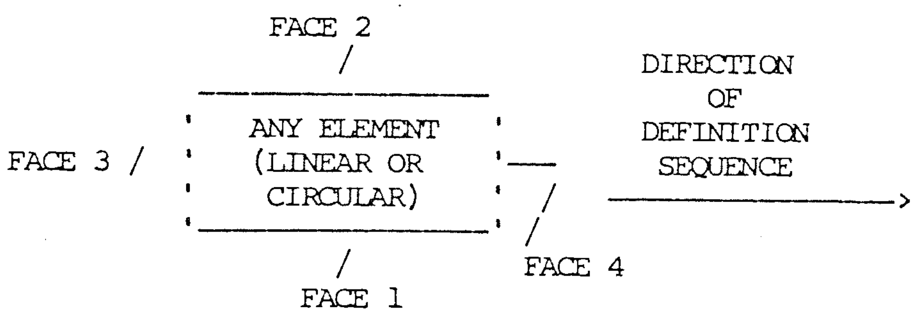
S7. ISQD = BENDING STAGE NO. FOR WHICH SIDE-CONTOUR DEFINITION
IS INTENDED
IELD1 = TYPE OF SIDE-CONTOUR ON L.H.S.
IELD2 = SIDE-CONTOUR NO. WHICH HAS BEEN DEFINED PREVIOUSLY AND
IS TO BE SELECTED FOR THIS STAGE NO. ON L.H.S.
IERD1 = TYPE OF SIDE-CONTOUR ON R.H.S.
IERD2 = SIDE-CONTOUR NO. WHICH HAS BEEN DEFINED PREVIOUSLY AND
IS TO BE SELECTED FOR THIS STAGE NO. ON R.H.S.
N.B. :- THE SIDE-CONTOUR TYPE MUST MATCH WITH THE DEFINED TYPE
DESCRIBED IN SECTION S2.
IF THE SELECTED CONTOUR TYPE IS 1 (I.E. SIDE-ROLL),
THEN 2 DEFINITION STATEMENTS FOR BOTTOM LEADING PART AND
TOP TRAILING PART RESPECTIVELY MUST BE ENTERED IN
SUCCESSION WHEREAS IF THE SELECTED CONTOUR TYPE IS 2 OR 3
(I.E. SPIGOTS), THEN ONLY 1 DEFINITION STATEMENT IS REQUIRED.

DIAGRAMS FOR ROLL INPUT DATA NOTES IN ROLL DESIGN
****

(1) DISTANCES BETWEEN ORIGIN AND SIDE-ROLL AXES

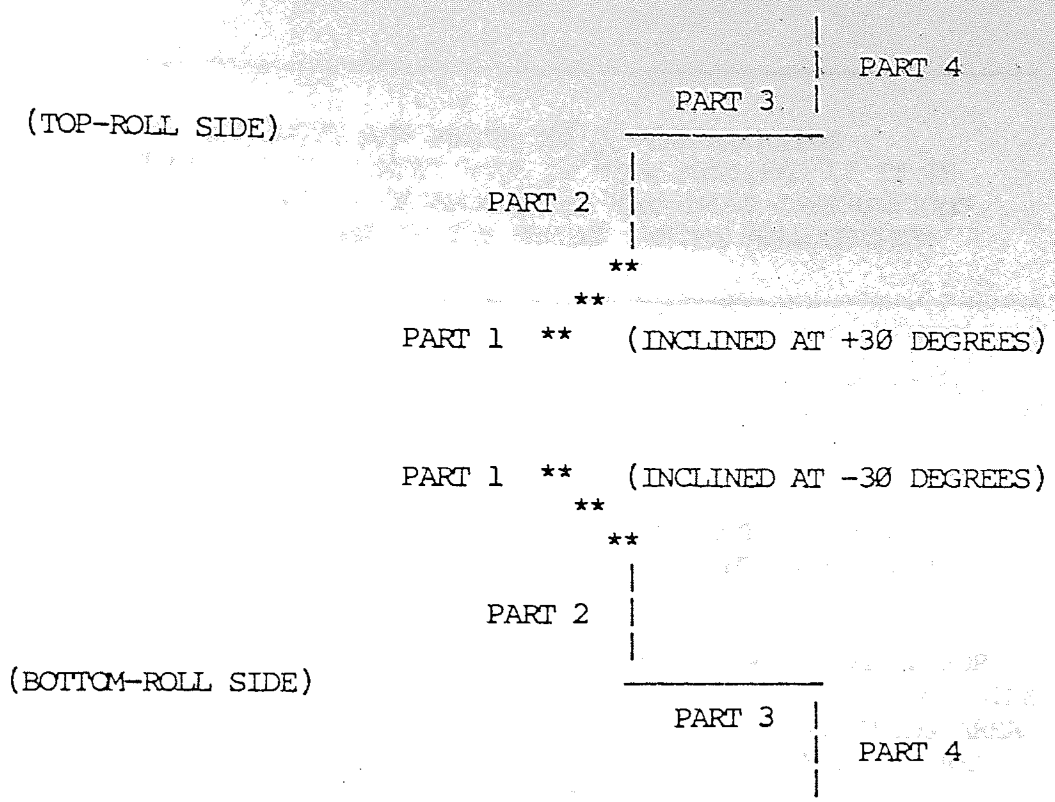


(2) ELEMENT FACES FOR DEFINING SIDE-ROLL CONTOURS

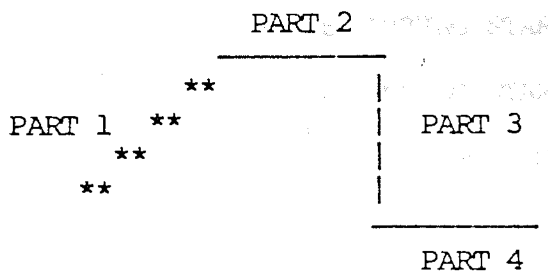


WHERE FACE 1 IS BOTTOM FACE,
FACE 2 IS TOP FACE,
FACE 3 IS LEADING FACE AND
FACE 4 IS TRAILING FACE.

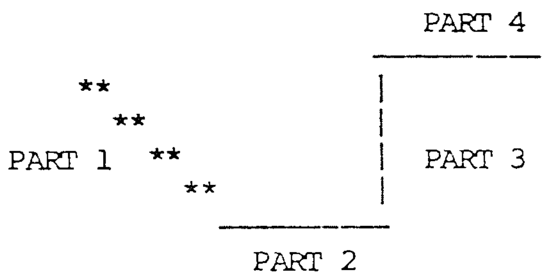
TYPE 1 :- SIDE-ROLL EXTENSION-CONTOURS



TYPE 2 :- SPIGOT TYPE A



TYPE 3 :- SPIGOT TYPE B



(N.B. :- THE IRRELEVANT PARTS OF THE EXTENSION-CONTOURS MAY HAVE THEIR LENGTH MADE ZERO)

D. EXPERT SYSTEM ROLL MACHINING PROCESSOR

THIS PROGRAM GENERATES AND PLOTS THE CUTTER LOCATION POINTS AUTOMATICALLY (INPUT DATA IS ONLY REQUIRED IF IT IS INTENDED BY THE USER TO DETERMINE THE MACHINING INSTRUCTIONS MANUALLY WITHOUT THE USE OF THE EXPERT SYSTEM SUBROUTINES)

INPUT DATA SEQUENCE
****

C1. NSTAGE = STAGE NO. OF ROLL
ICON = ROLLER NO. (1 FOR TOP ROLL, 2 FOR BOTTOM ROLL, 3 FOR LEFT SIDE ROLL, AND 4 FOR RIGHT SIDE ROLL)

C2. ICYCLE = TYPE OF CUTTING CYCLE CHOSEN (1 FOR ROUGHING, 2 FOR GROOVING, 3 FOR FINISH PROFILING, AND 4 FOR RIGHT SIDE ROLL)
ISEL = THE NO. OF THE STARTING ELEMENT OF THE MACHINING AREA
IEEL = THE NO. OF THE ENDING ELEMENT OF THE MACHINING AREA
TOL = MATERIAL TOLERANCE LEFT (MM)

N.B. :- TERMINATE INPUT TO THIS PROGRAM BY TYPING 4 Ø'S
IF ICYCLE = 1 OR 2, THEN PROCEED TO SECTION C3.

C2A. (FOR ICYCLE 3 OR 4)
ZP = THE Z-COORDINATE OF THE CUTTING START POINT ON THE DESIGNATED CUT-IN-LINE
XP = THE X-COORDINATE OF THE CUTTING START POINT ON THE DESIGNATED CUT-IN-LINE
ANG = ANGLE OF THE CUT-IN-LINE (+VE FOR CCW)

C3. NTOOL = THE TOOL NO. (TURRET POSITION). IF THE TOOL IS NOT CURRENTLY IN THE TOOL LIBRARY, ENTER NTOOL = Ø, AND ENTER DETAILS OF THE TOOL IN SUBGROUP C4
DCUT = DEPTH OF CUT (MM), FOR ICYCLE = 2 OR 3, ENTER DCUT = Ø.Ø
SPEED = CUTTING SPEED IN M/MIN
FEED = FEEDRATE IN MM/REV

N.B. :- IF NTOOL = Ø, PROCEED TO SECTION C4, OTHERWISE GO TO C2.

C4. (FOR DEFINING TOOL GEOMETRY OF NON-STANDARD CUTTING TOOL)

NTOOL	=	TURRET POSITION (DEPENDING ON THE SELECTED CNC LATHE)
RAD	=	TOOL TIP CIRCLE RADIUS
RZ	=	Z-COORDINATE OF THE TOOL TIP CIRCLE CENTRE
RX	=	X-COORDINATE OF THE TOOL TIP CIRCLE CENTRE
WID	=	WIDTH OF THE PARTING-OFF TOOL, ENTER Ø.Ø FOR OTHER TOOLS
ZREF	=	Z-COORDINATE OF THE TOOL OFFSET POSITION
XREF	=	X-COORDINATE OF THE TOOL OFFSET POSITION

APPENDIX 3

FILES FOR THE INTEGRATED MANUFACTURING SOFTWARE SYSTEM

List of all files containing all source programs, compiled files and execution files.

FILES FOR THE INTEGRATED MANUFACTURING SOFTWARE SYSTEM

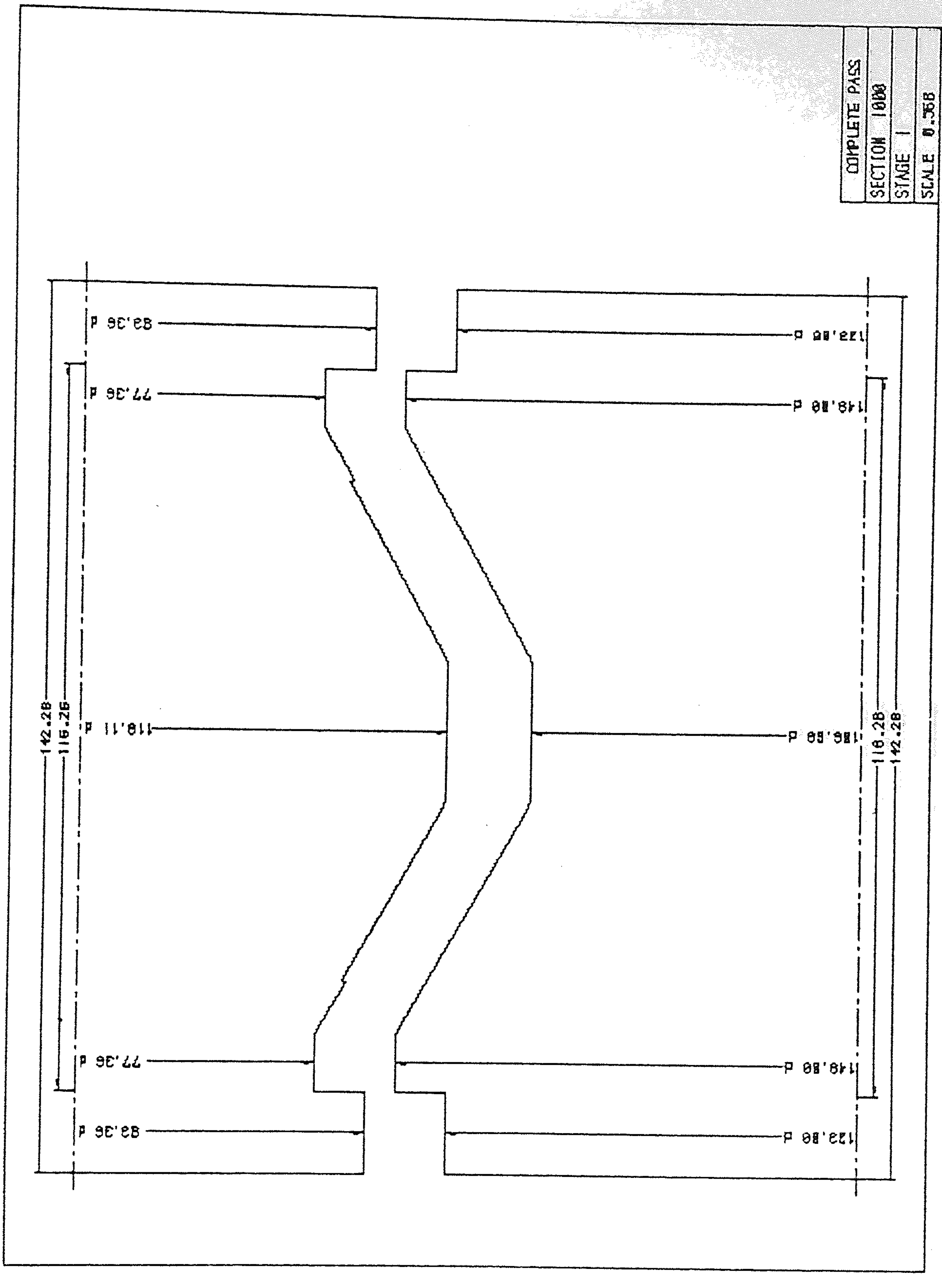
EXECUTION FILE	COMPILED OBJECT FILE	FORTRAN SOURCE FILE
SECTION.EXE	SECTION.OBJ SECT1.OBJ FRAME.OBJ	SECTION.FOR SECT1.FOR FRAME.OBJ
NSECTION.EXE	NSECTION.OBJ NSECT1.OBJ NFRAME.OBJ	NSECTION.FOR NSECT1.FOR NFRAME.FOR
FLOWER.EXE	FLOWER.OBJ FLO1.OBJ FRAME.OBJ	FLOWER.FOR FLO1.FOR FRAME.FOR
SFLOWER.EXE	SFLOWER.OBJ SFLO1.OBJ FRAME.OBJ	SFLOWER.FOR SFLO1.FOR FRAME.FOR
NFLOWER.EXE	NFLOWER.OBJ NFLO1.OBJ FRAME.OBJ	NFLOWER.FOR NFLO1.FOR FRAME.FOR
TEMPLATE.EXE	TEMPLATE.OBJ TEMP1.OBJ TEMP2.OBJ	TEMPLATE.FOR TEMP1.FOR TEMP2.FOR

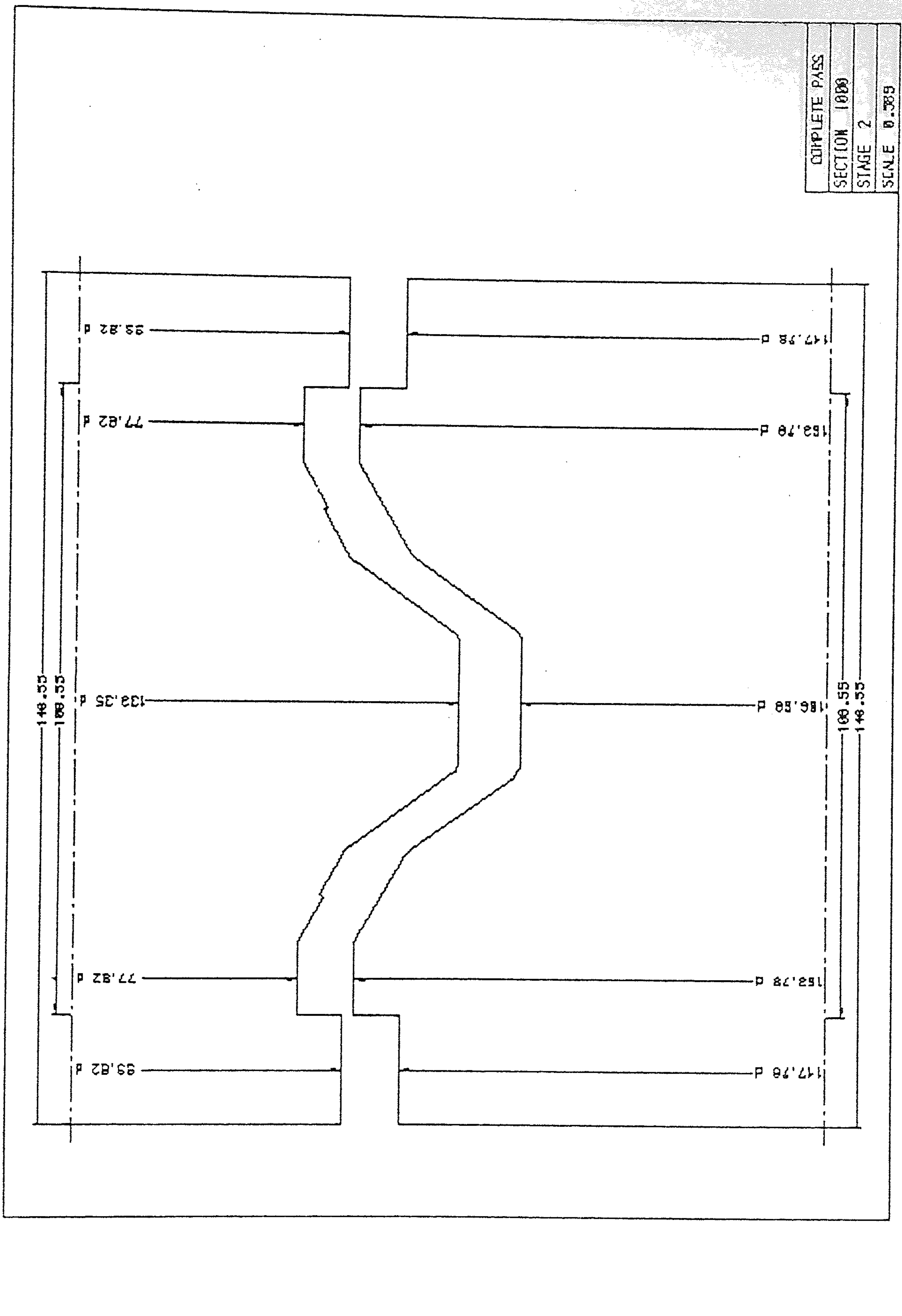
EXECUTION FILE	COMPILED OBJECT FILE	FORTRAN SOURCE FILE
DESIGN.EXE	DESIGN.OBJ DESR1.OBJ DESR2.OBJ DESR3.OBJ DESR4.OBJ DESR5.OBJ DESR6.OBJ DESR7.OBJ DESR8.OBJ	DESIGN.FOR DESR1.FOR DESR2.FOR DESR3.FOR DESR4.FOR DESR5.FOR DESR6.FOR DESR7.FOR DESR8.FOR
SDESIGN.EXE	SDESIGN.OBJ SDESR1.OBJ DESR2.OBJ DESR3.OBJ DESR4.OBJ DESR5.OBJ DESR6.OBJ DESR7.OBJ DESR8.OBJ	SDESIGN.FOR SDESR1.FOR DESR2.FOR DESR3.FOR DESR4.FOR DESR5.FOR DESR6.FOR DESR7.FOR DESR8.FOR
NDESIGN.EXE	NDESIGN.OBJ DESR1.OBJ DESR2.OBJ DESR3.OBJ DESR4.OBJ DESR5.OBJ DESR6.OBJ DESR7.OBJ DESR8.OBJ	NDESIGN.FOR DESR1.FOR DESR2.FOR DESR3.FOR DESR4.FOR DESR5.FOR DESR6.FOR DESR7.FOR DESR8.FOR
EDITOR.EXE	EDITOR.OBJ STAGE.OBJ ROEDA.OBJ ROEDB.OBJ ROEDC.OBJ ROEDD.OBJ	EDITOR.FOR STAGE.FOR ROEDA.FOR ROEDB.FOR ROEDC.FOR ROEDD.FOR

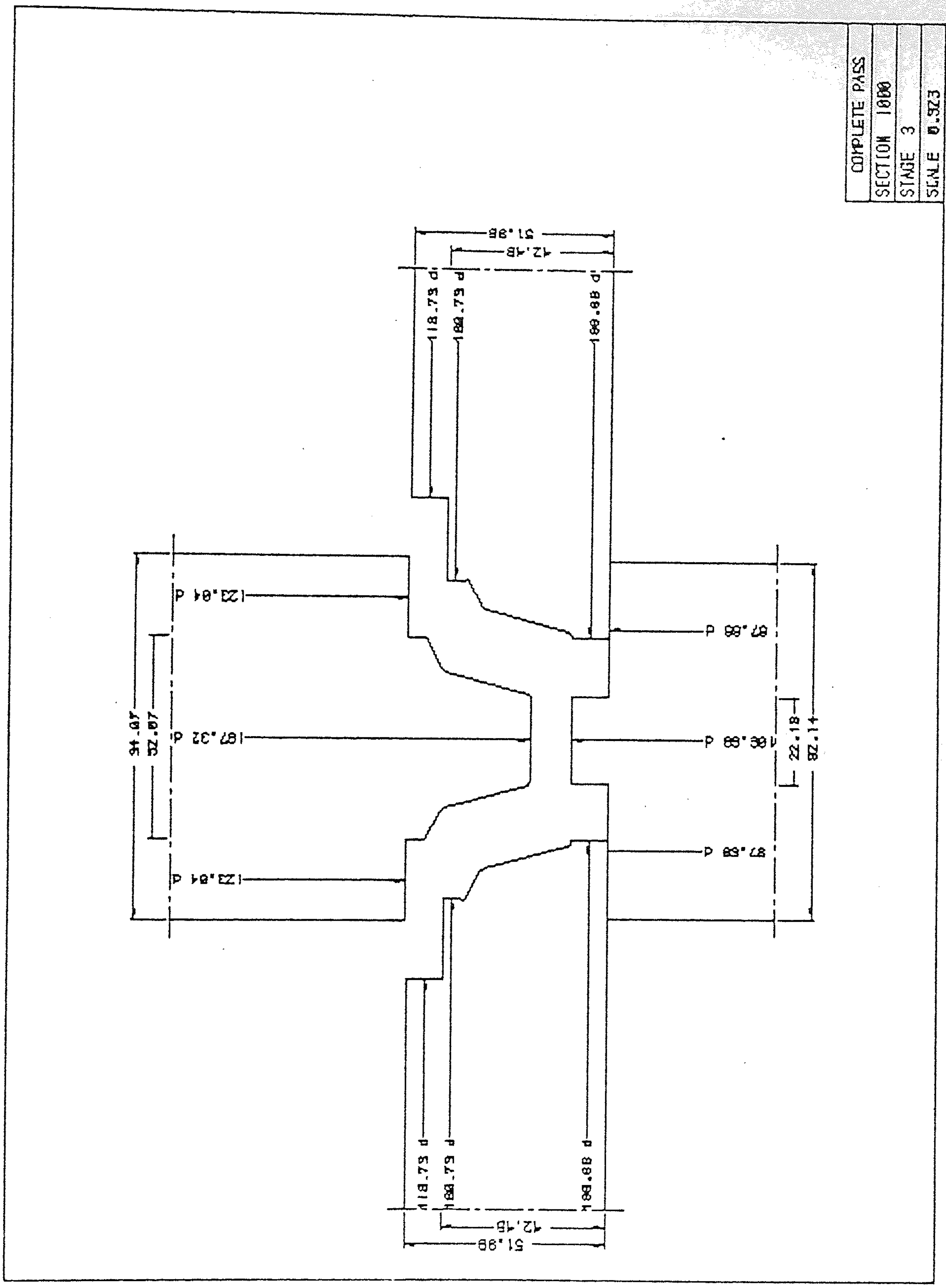
EXECUTION FILE	COMPILED OBJECT FILE	FORTRAN SOURCE CODE
EXPSYS.EXE	EXPSYS.OBJ EXP1EX.OBJ EXP2EX.OBJ TLIBM.OBJ TLIBS.OBJ	EXPSYS.FOR EXP1EX.FOR EXP2EX.FOR TLIBM.FOR TLIBS.FOR
NCUTPL.EXE	NCUTPL.OBJ CUT1PL.OBJ NCUT2P.OBJ TLIB.OBJ	NCUTPL.FOR CUT1PL.FOR NCUT2P.FOR TLIB.FOR
GNPOST.EXE	GNPOST.OBJ GNAPOS.OBJ	GNPOST.FOR GNAPOS.FOR
MFPOST.EXE	MFPOST.OBJ MFAPOS.OBJ	MFPOST.FOR MFAPOS.FOR
SBPOST.EXE	SBPOST.OBJ SBAPOS.OBJ	SBPOST.FOR SBAPOS.FOR
TAPCHK.EXE	TAPCHK.OBJ	TAPCHK.FOR
CACE.EXE	CACE.OBJ	CACE.FOR
TOOL.EXE	TOOL.OBJ	TOOL.FOR

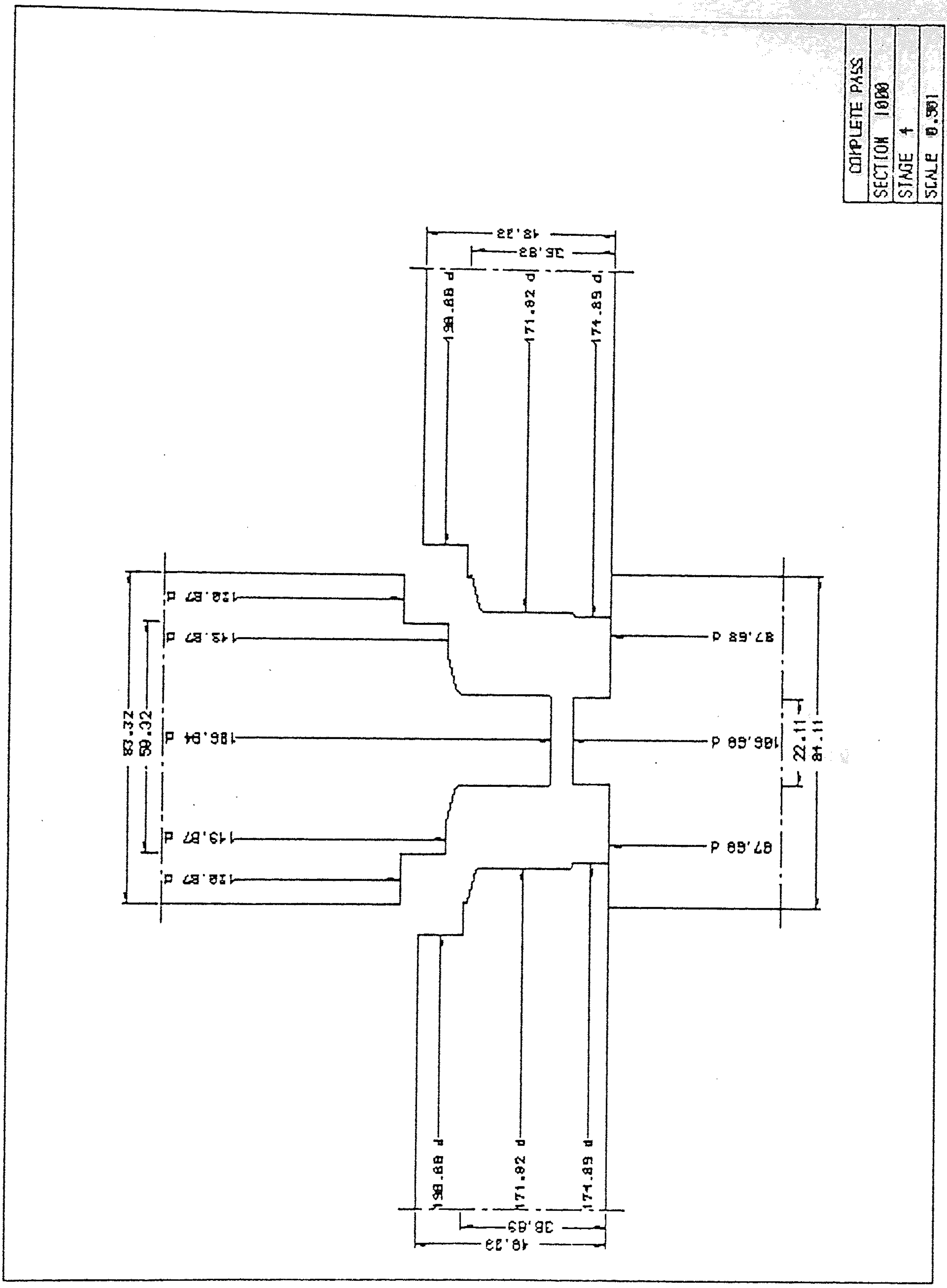
APPENDIX 4

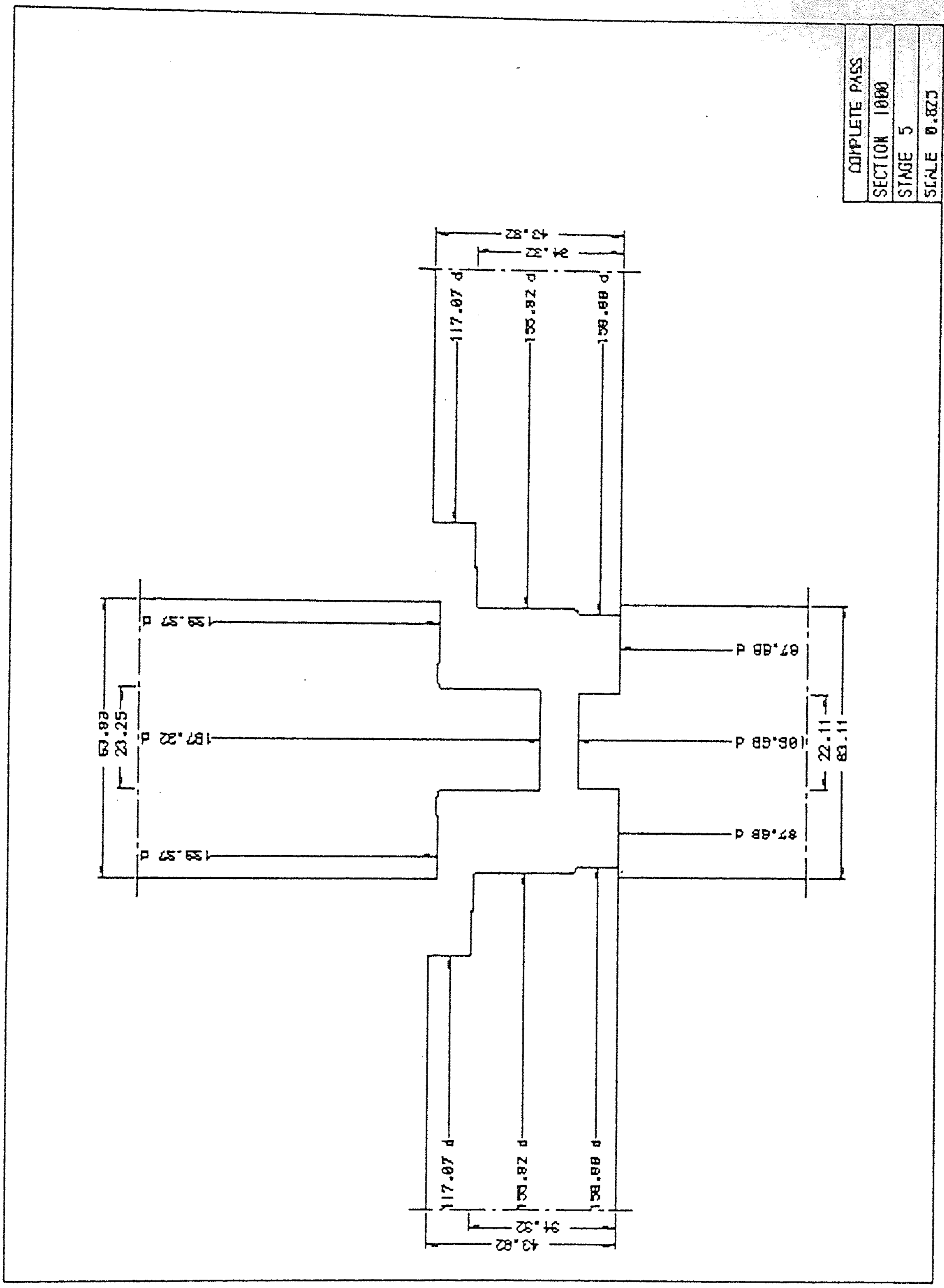
A SET OF ROLL PROFILE DRAWINGS GENERATED DURING OPERATION OF THE INTERACTIVE ROLL EDITOR PROGRAM

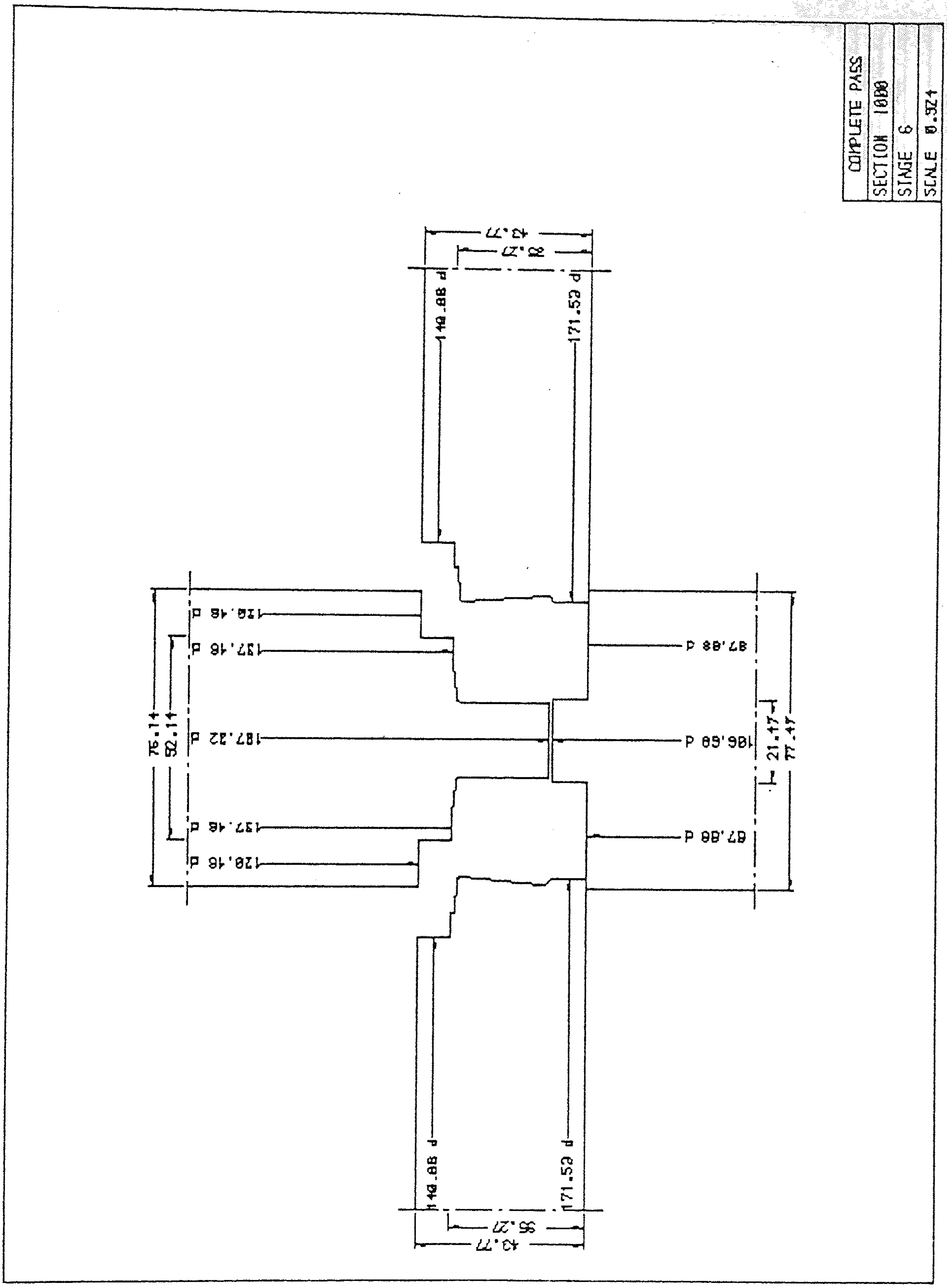

COMPLETE PASS
SECTION 1000
STAGE 1
SCALE 0.368
83.36 d
77.36 d
118.11 d
142.28
116.28
123.80 d


COMPLETE PASS
SECTION 1000
STAGE 2
SCALE 0.389
148.55
108.55

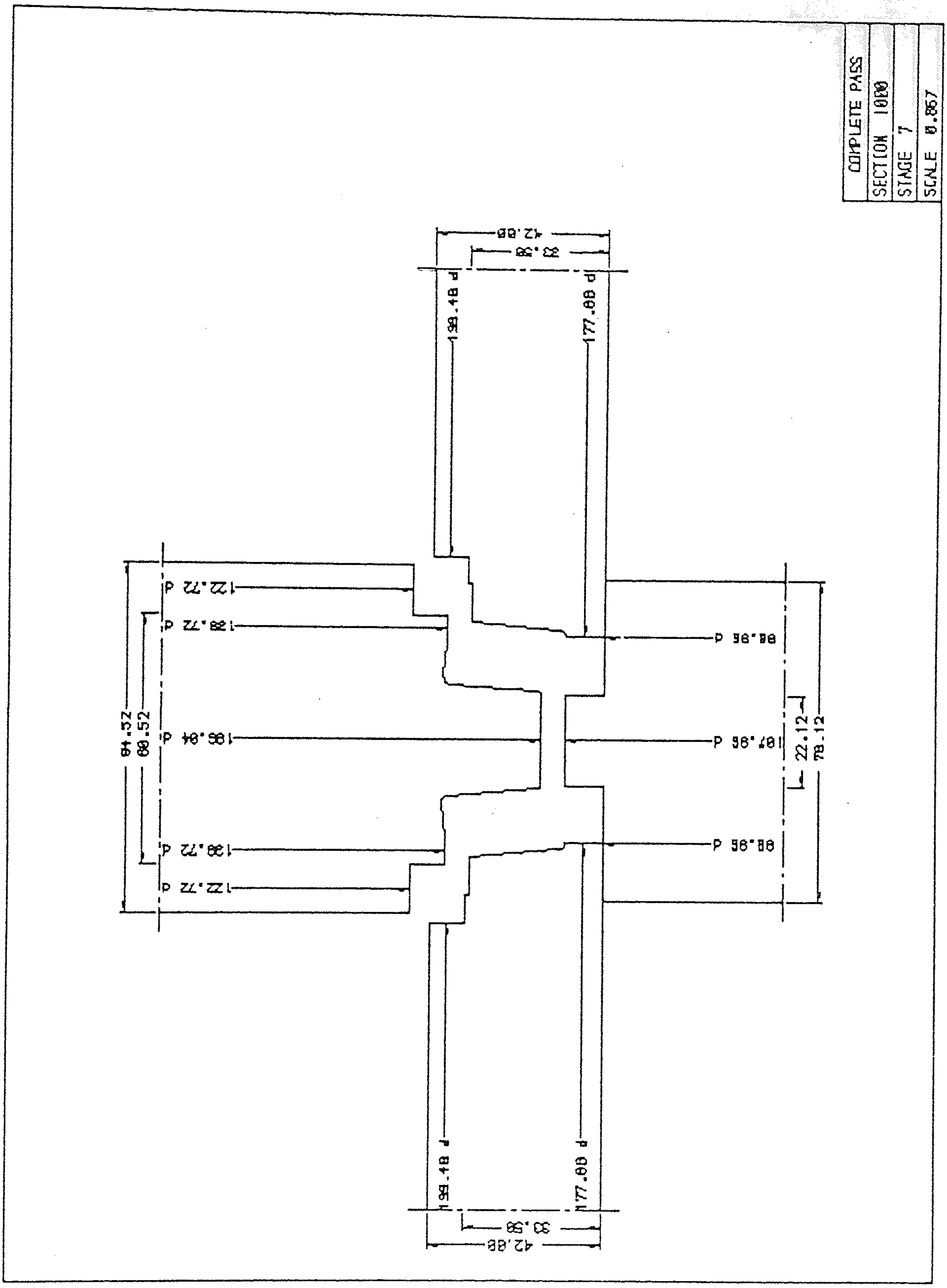

COMPLETE PASS
SECTION 1000
STAGE 3
SCALE 0.923

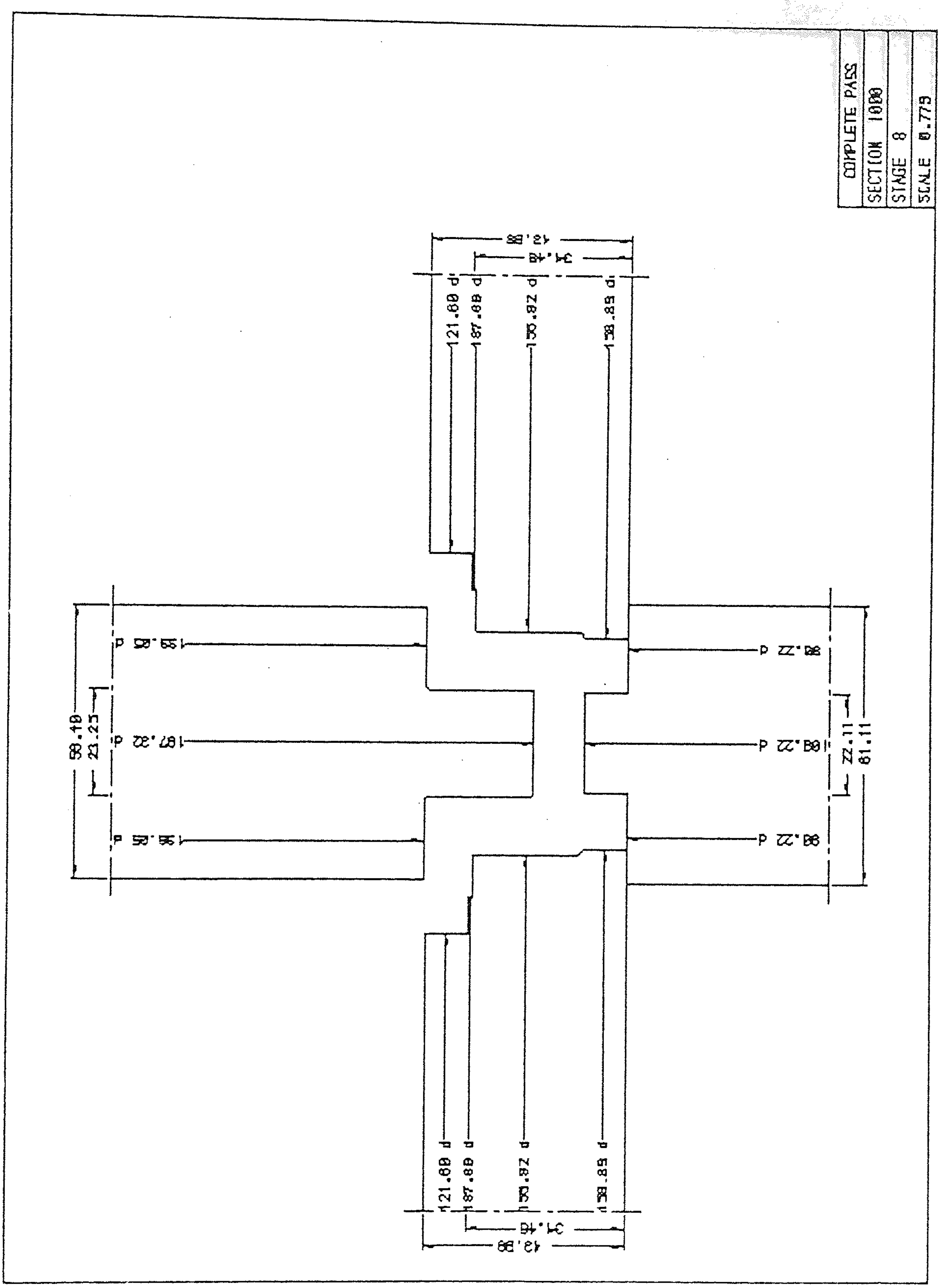

COMPLETE PASS
SECTION 1000
STAGE 4
SCALE
171.82 d
174.89 d
83.32
59.32
22.11
84.11

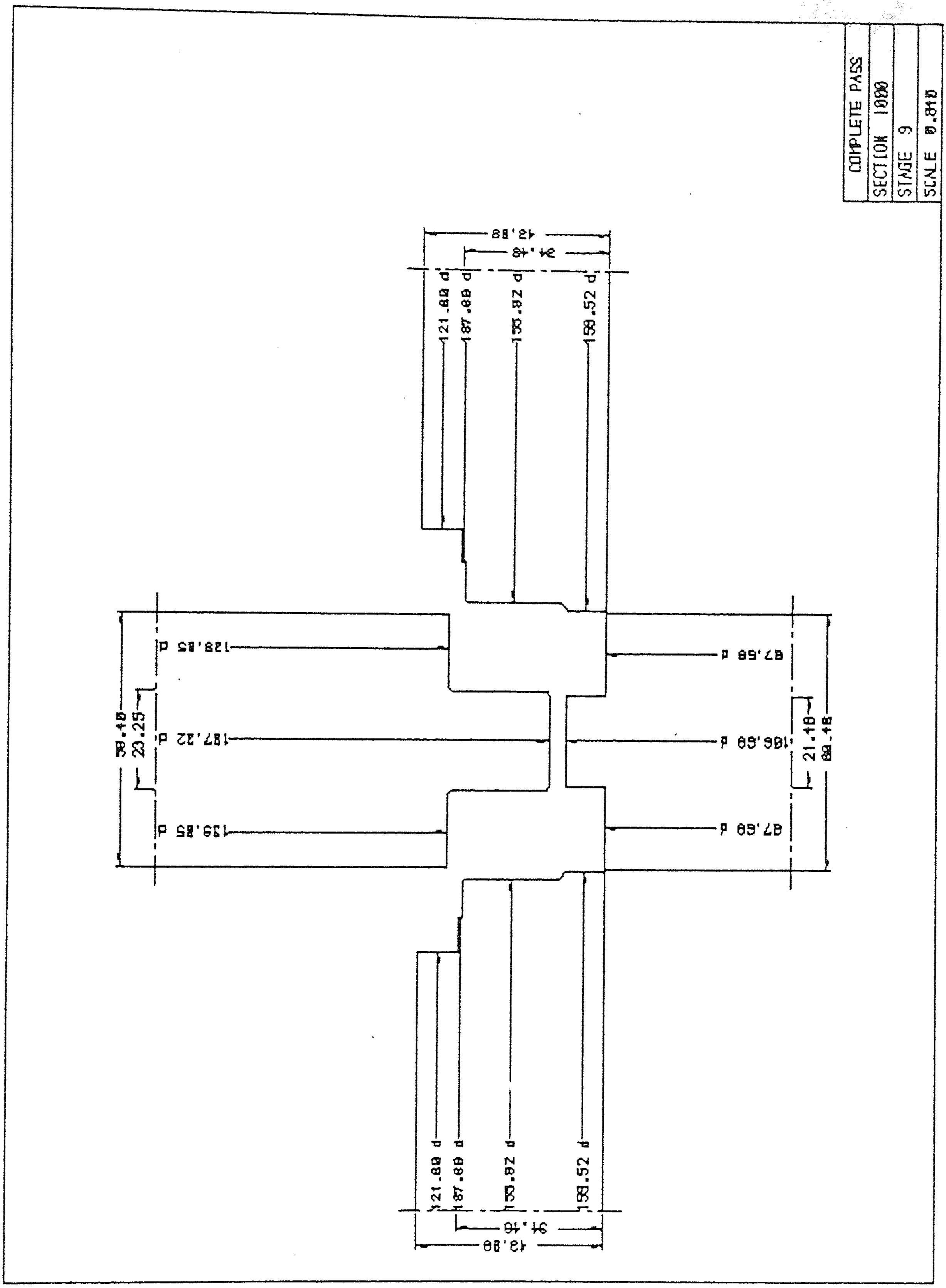

COMPLETE PASS
SECTION 1000
STAGE 5
SCALE 0.823



COMPLETE PASS
SECTION 1000
STAGE 6
SCALE 0.524

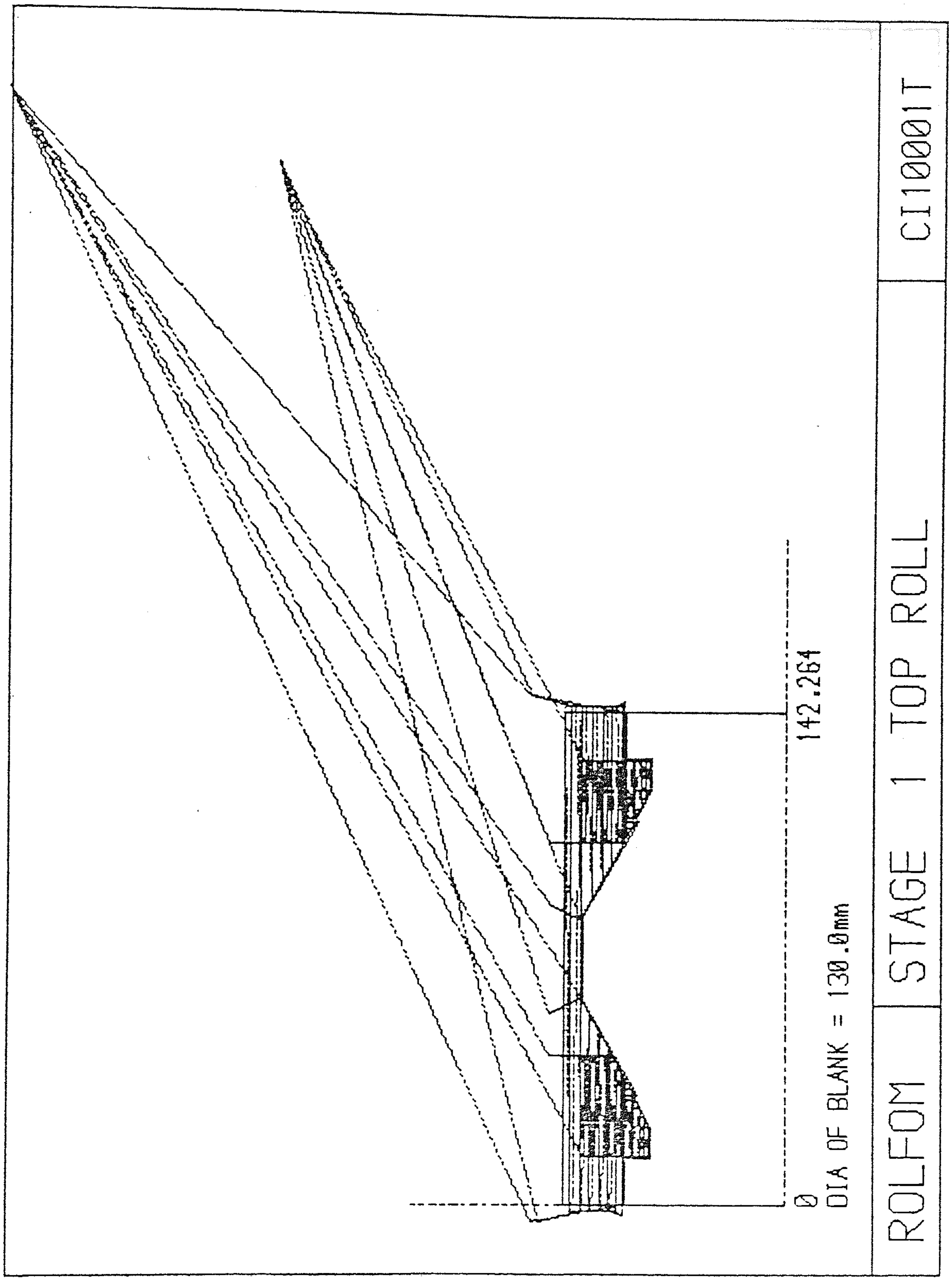

COMPLETE PASS
SECTION 1000
STAGE 7
SCALE 0.067

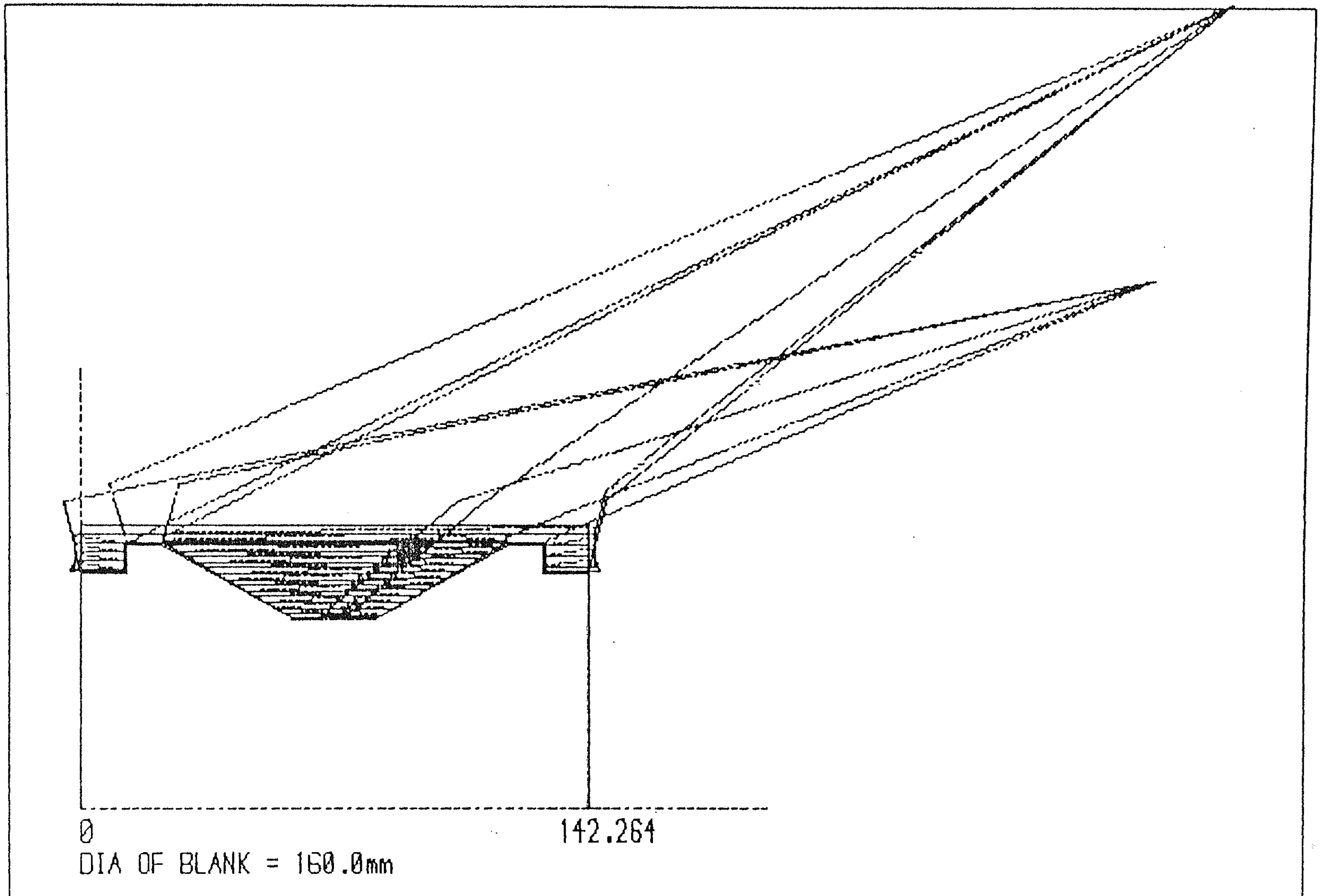

COMPLETE PASS
SECTION 1000
STAGE 8
SCALE 0.779
121.80 d


COMPLETE PASS
SECTION 1000
STAGE 9
SCALE 0.010

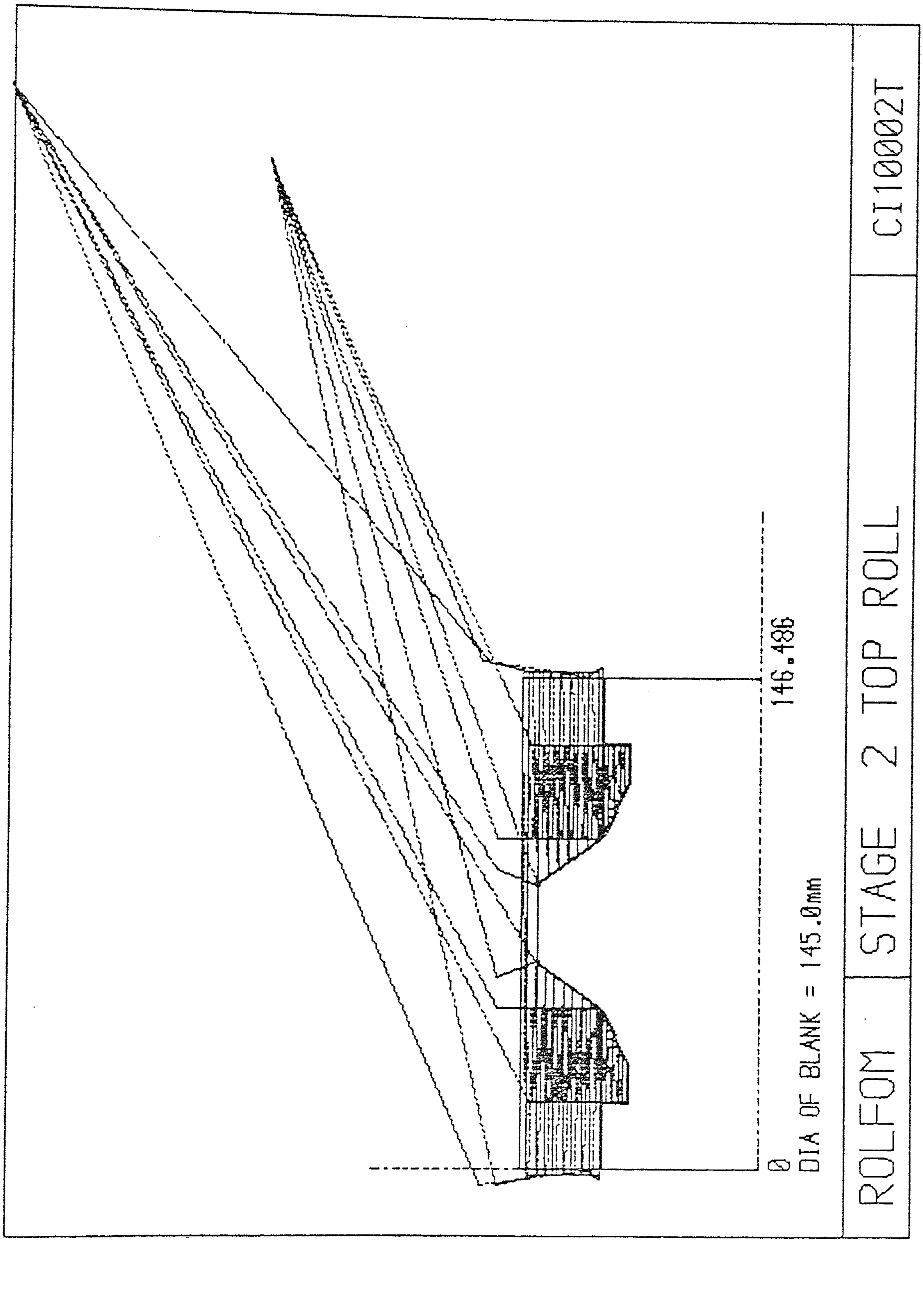
APPENDIX 5

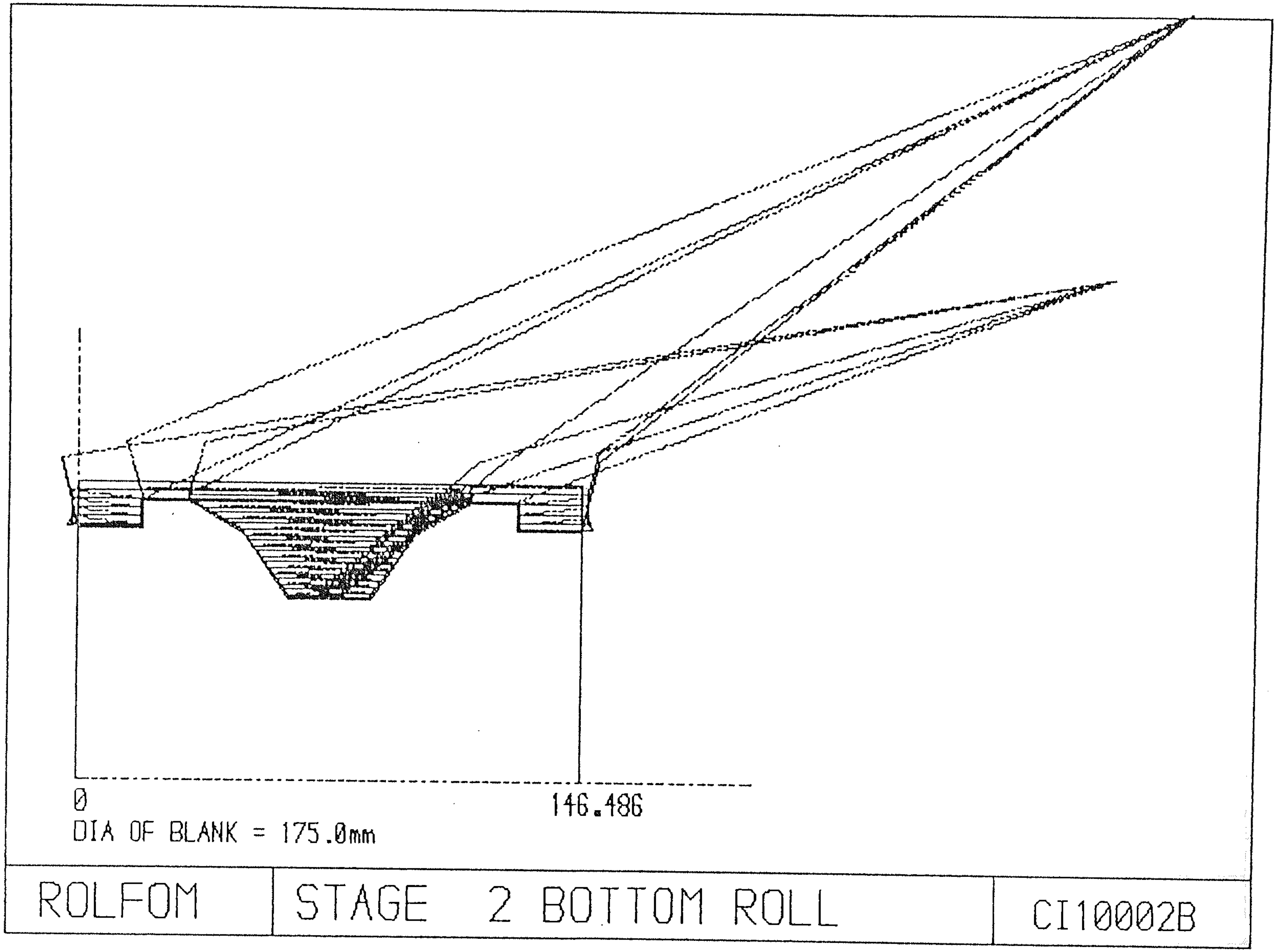
A SET OF CUTTER PATH DRAWINGS GENERATED DURING OPERATION OF THE EXPERT SYSTEM ROLL MACHINING PROCESSOR

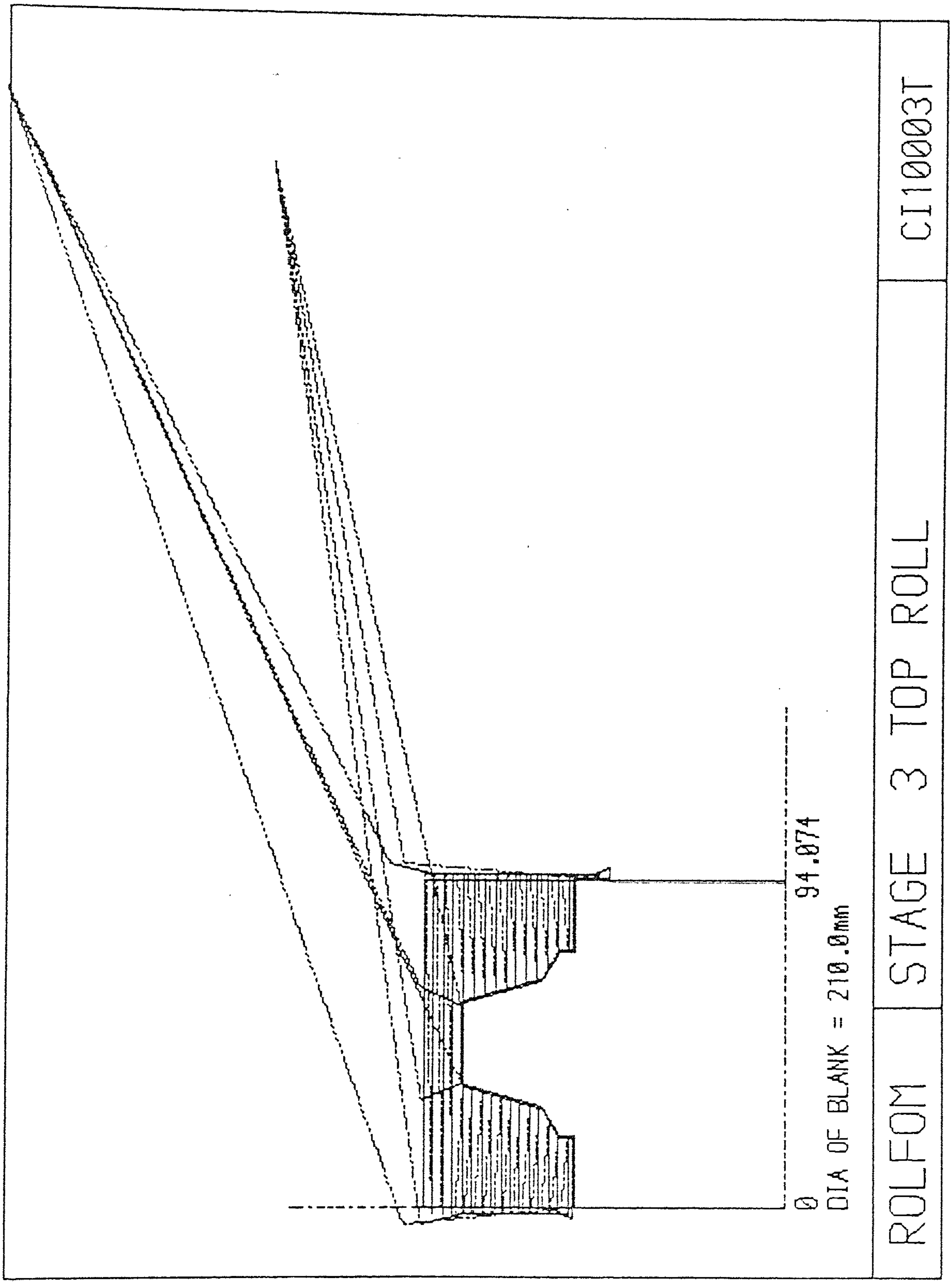

ROLFOM
STAGE 1 TOP ROLL
CI10001T
DIA OF BLANK = 130.0mm
0
142.264

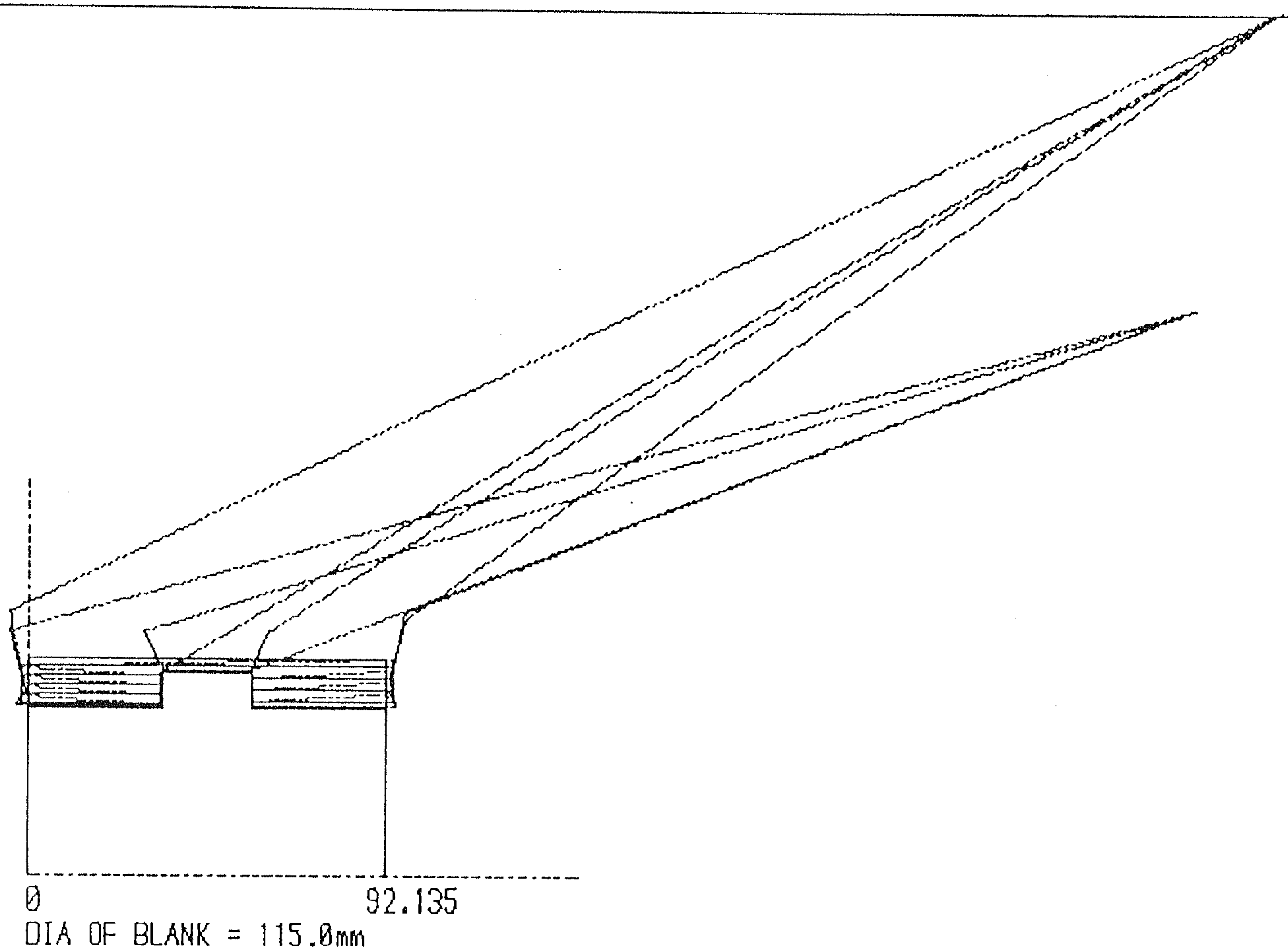


ROLFOM	STAGE 1 BOTTOM ROLL	CI10001B

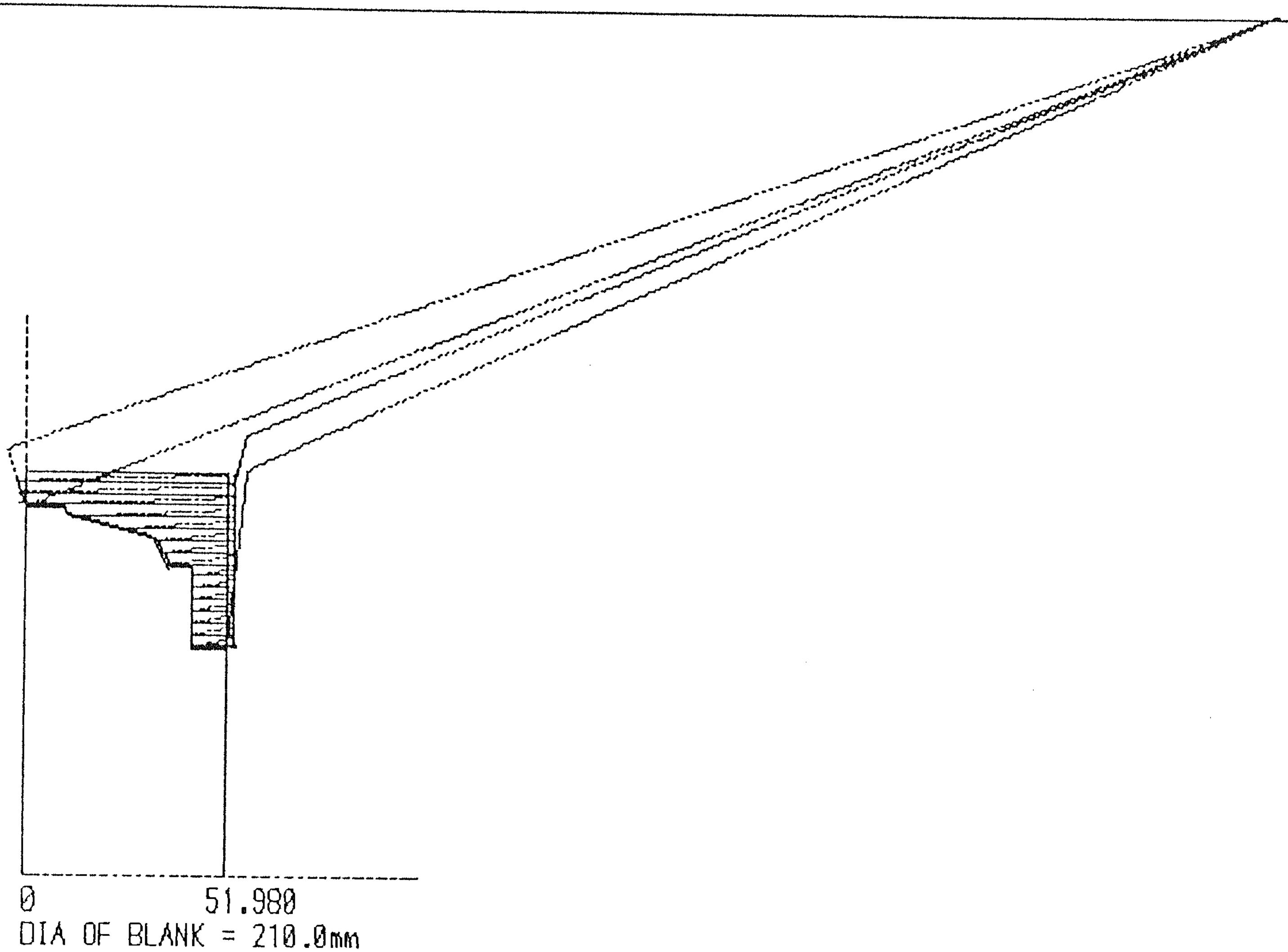

146.486
0
DIA OF BLANK = 145.0mm
ROLFOM
STAGE 2 TOP ROLL
CI10002T


0
146.486
DIA OF BLANK = 175.0mm
ROLFOM
STAGE 2 BOTTOM ROLL
CI10002B

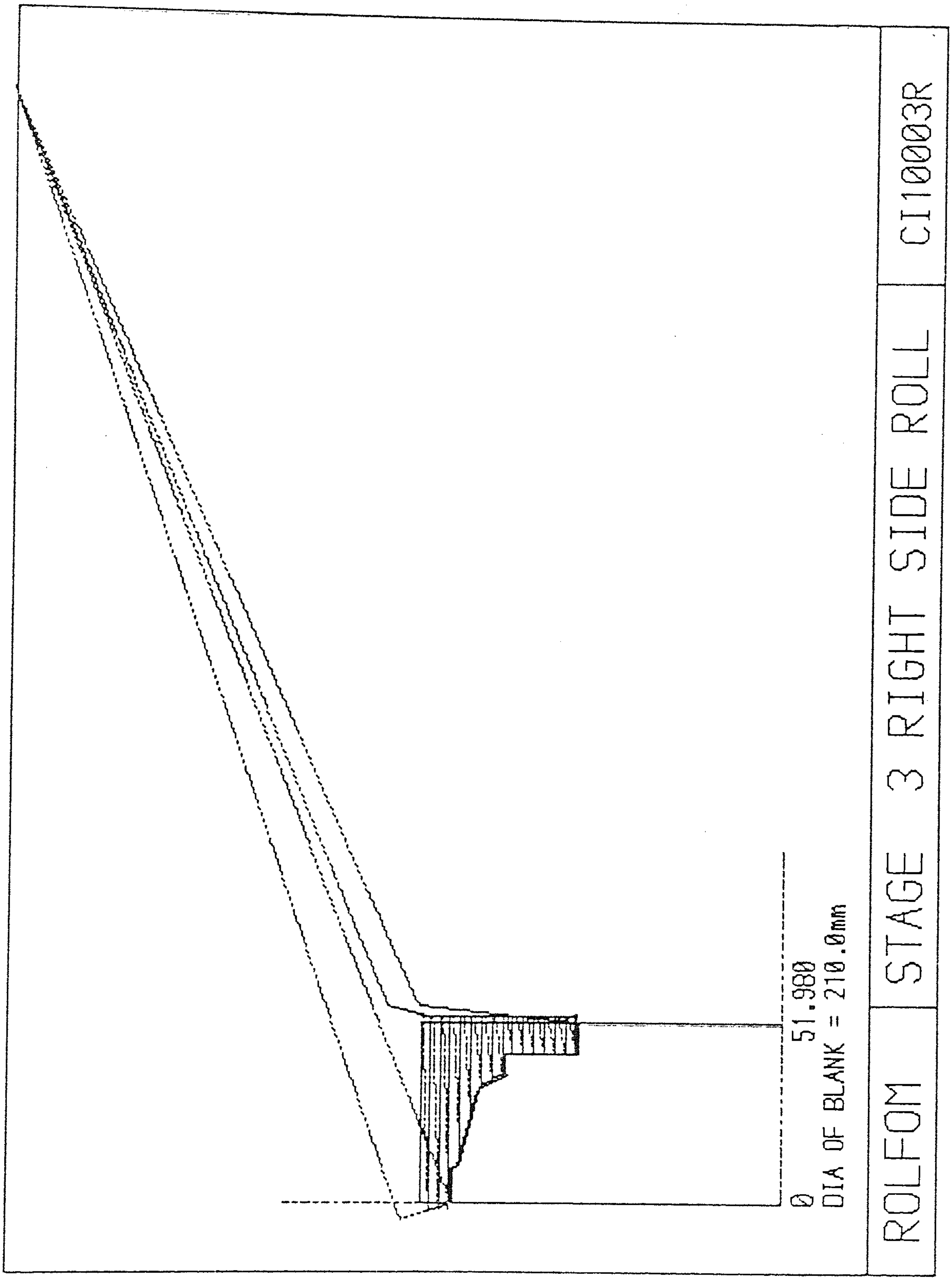

ROLFOM
STAGE 3 TOP ROLL
CI10003T
DIA OF BLANK = 210.0mm
0
94.074

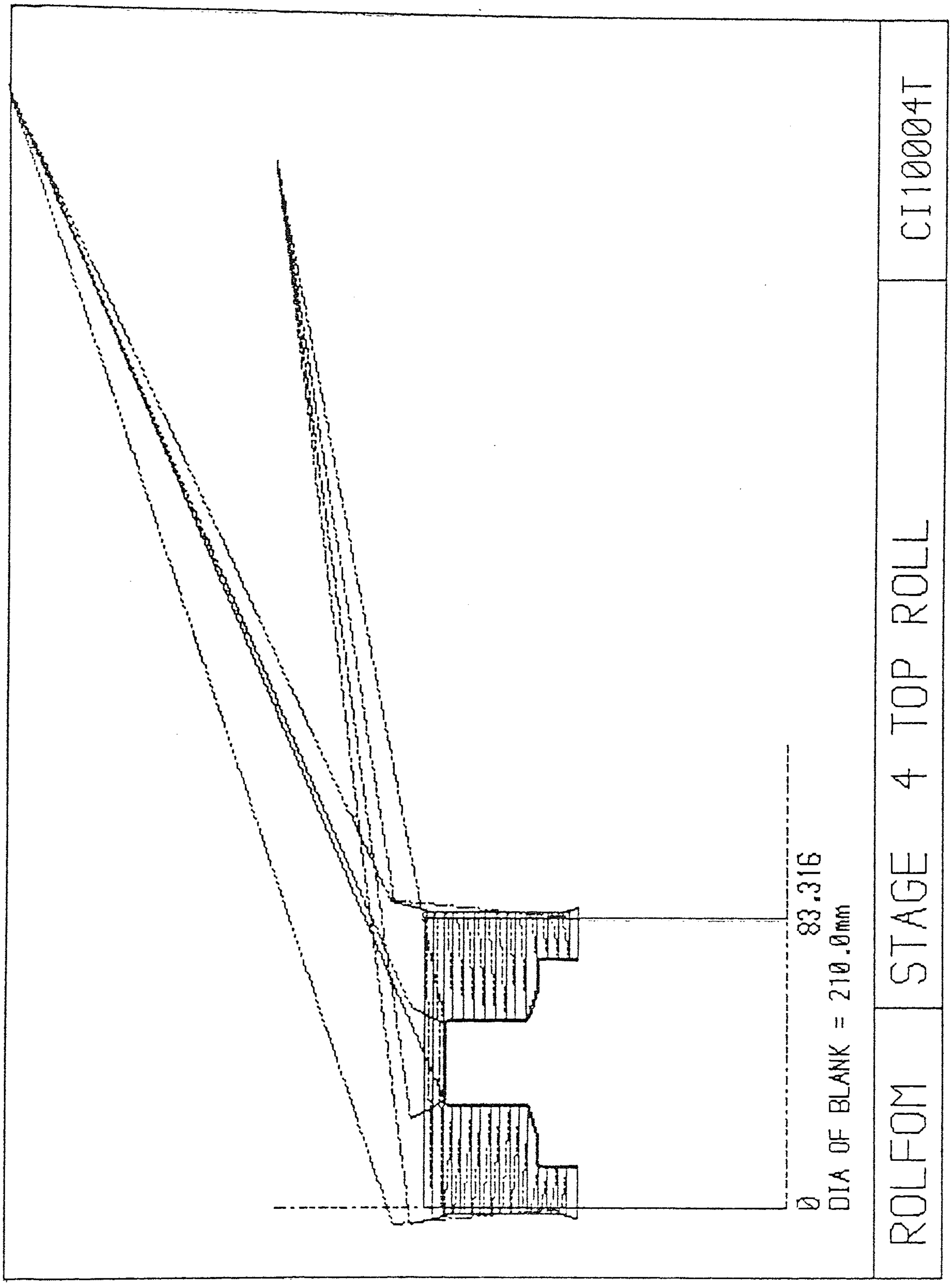


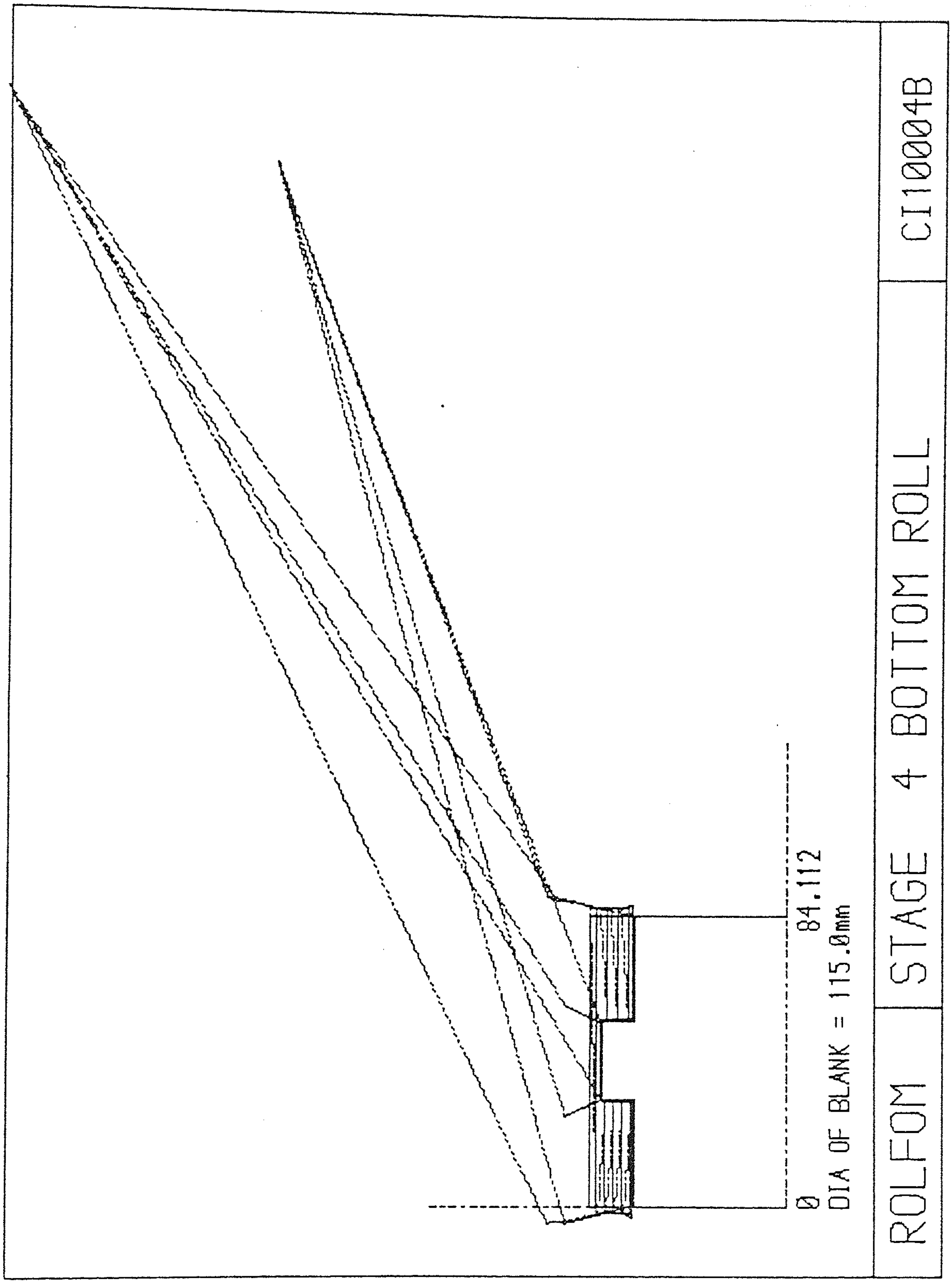
ROLFOM	STAGE 3 BOTTOM ROLL	CI10003B

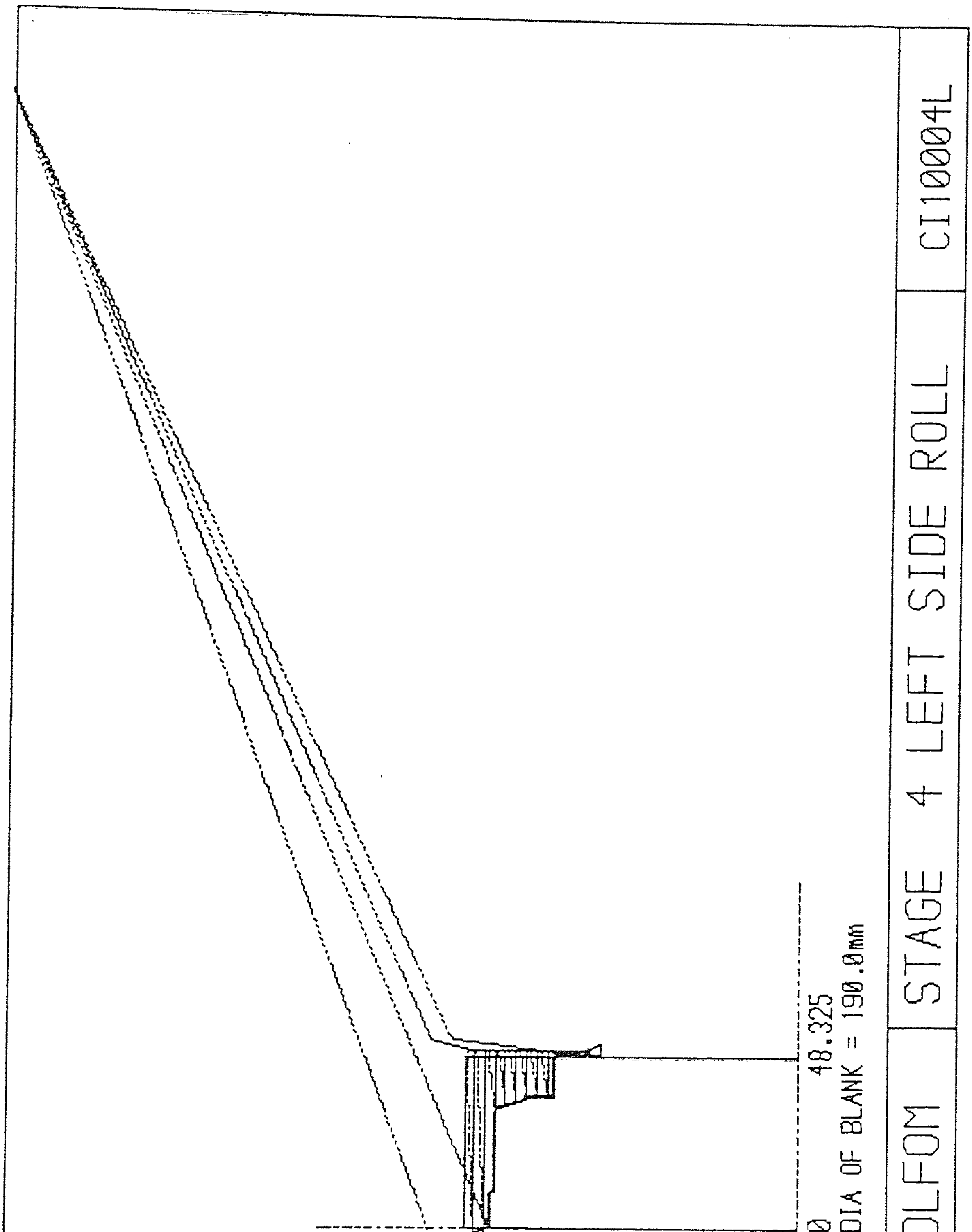


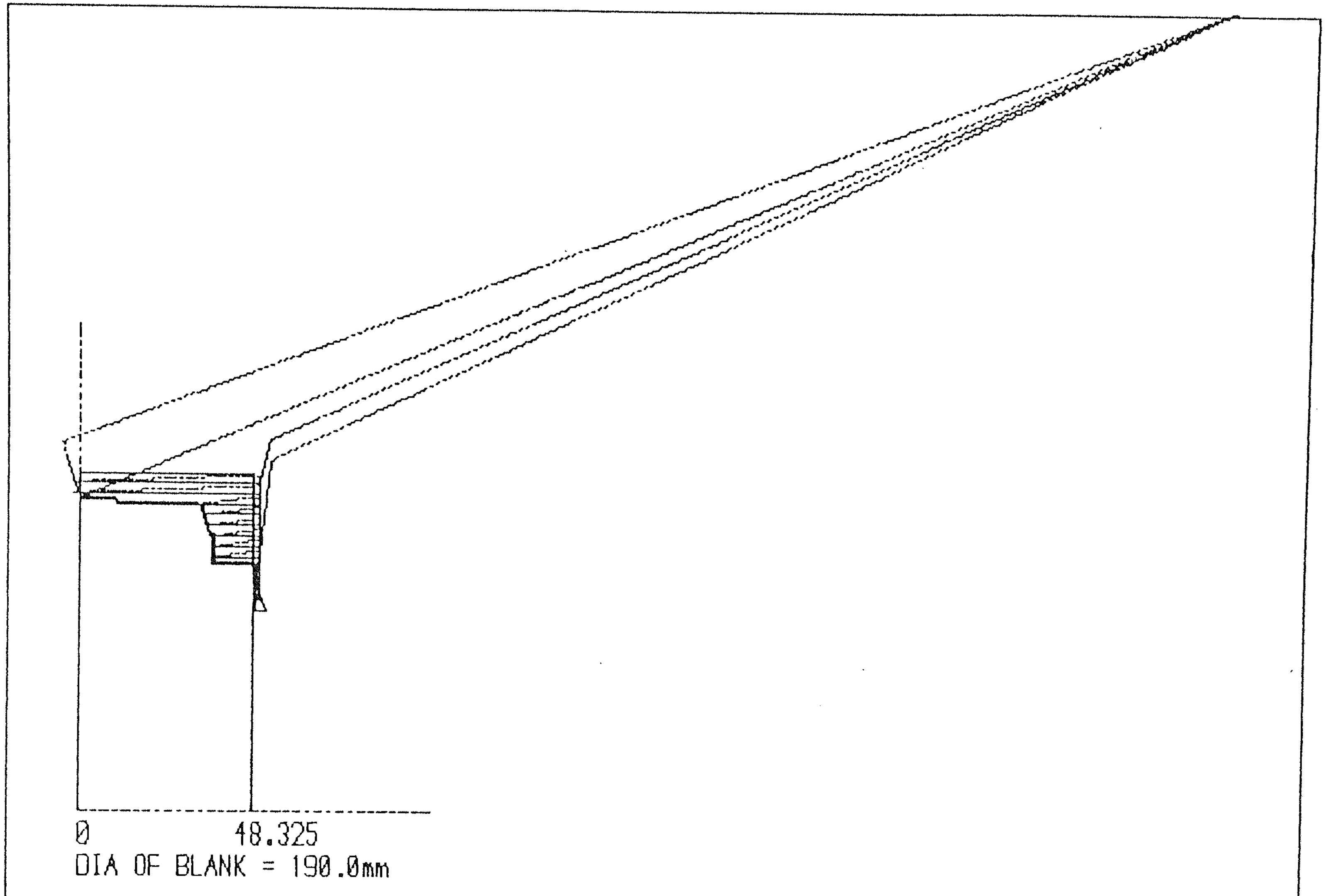
ROLFOM	STAGE 3 LEFT SIDE ROLL	CI10003L


0
51.980
DIA OF BLANK = 210.0mm
ROLFOM
STAGE 3 RIGHT SIDE ROLL
CI10003R

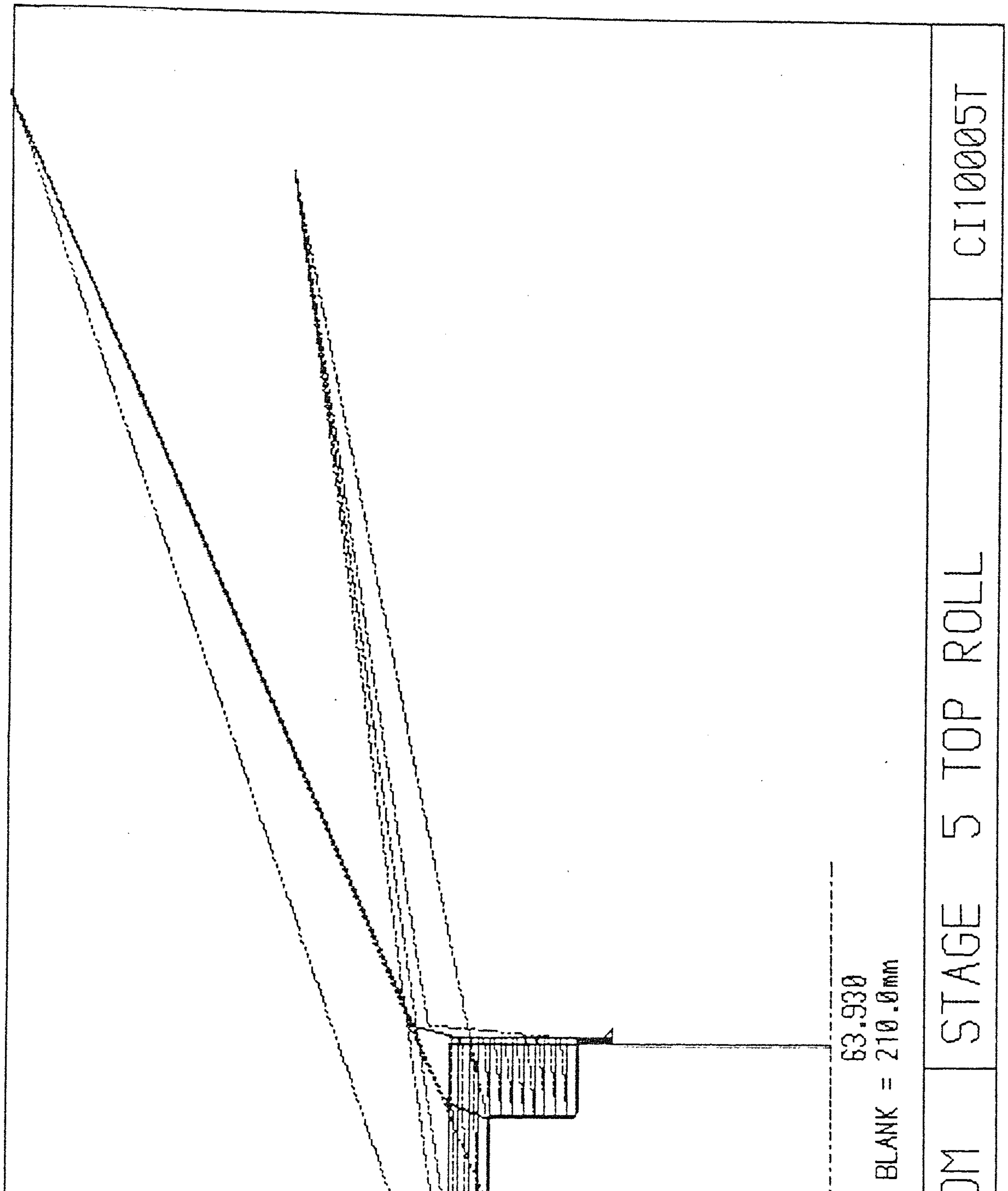

0
83.316
DIA OF BLANK = 210.0mm
ROLFOM
STAGE 4 TOP ROLL
CI10004T

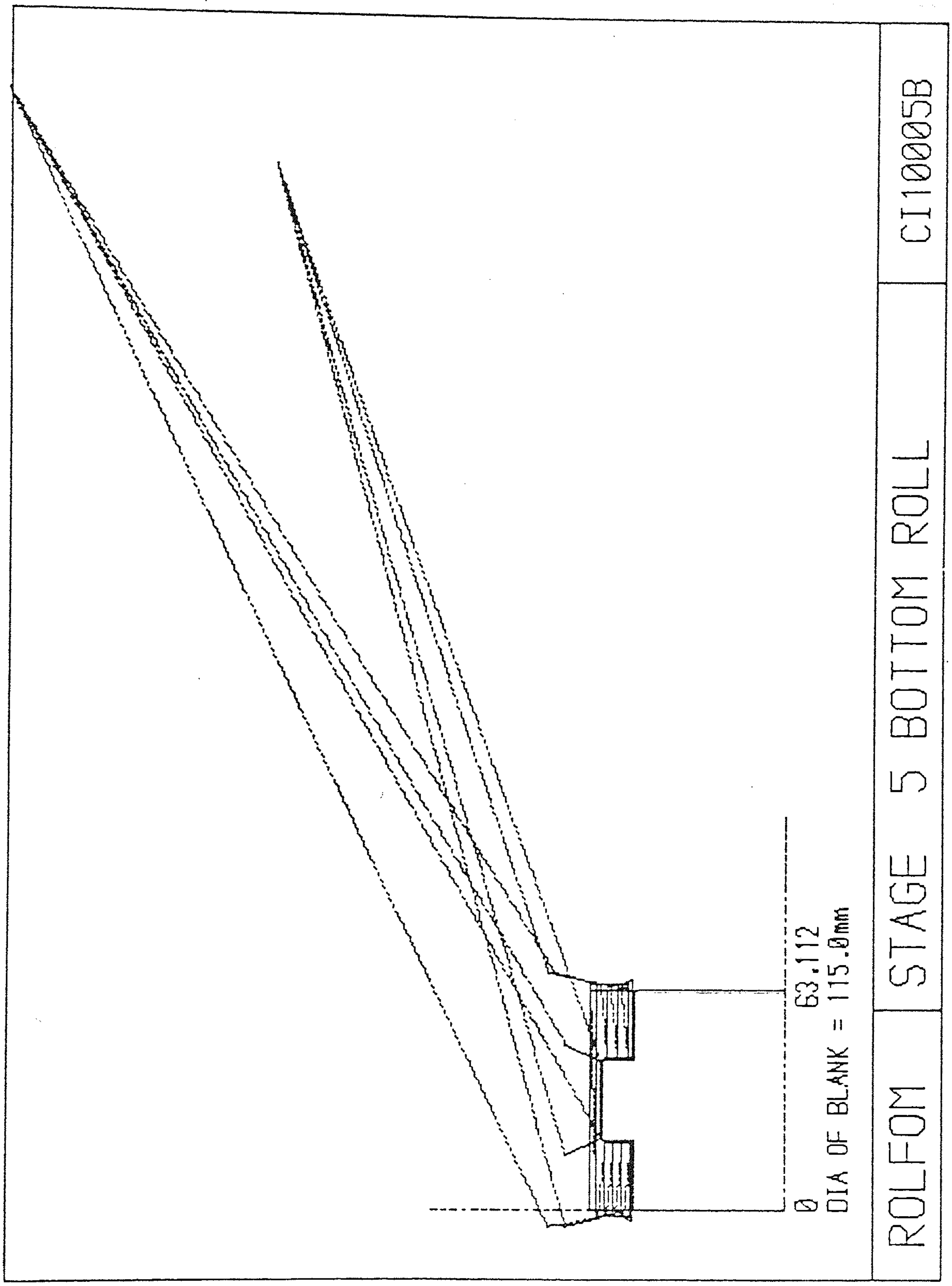

Ø
84.112
DIA OF BLANK = 115.Ømm
ROLFOM
STAGE 4 BOTTOM ROLL
CI1ØØØ4B


ROLFOM
STAGE 4 LEFT SIDE ROLL
CI10004L
0
48.325
DIA OF BLANK = 190.0mm



ROLFOM	STAGE 4 RIGHT SIDE ROLL	CI10004R


63.930
0
DIA OF BLANK = 210.0mm
ROLFOM
STAGE 5 TOP ROLL
CI10005T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63.112
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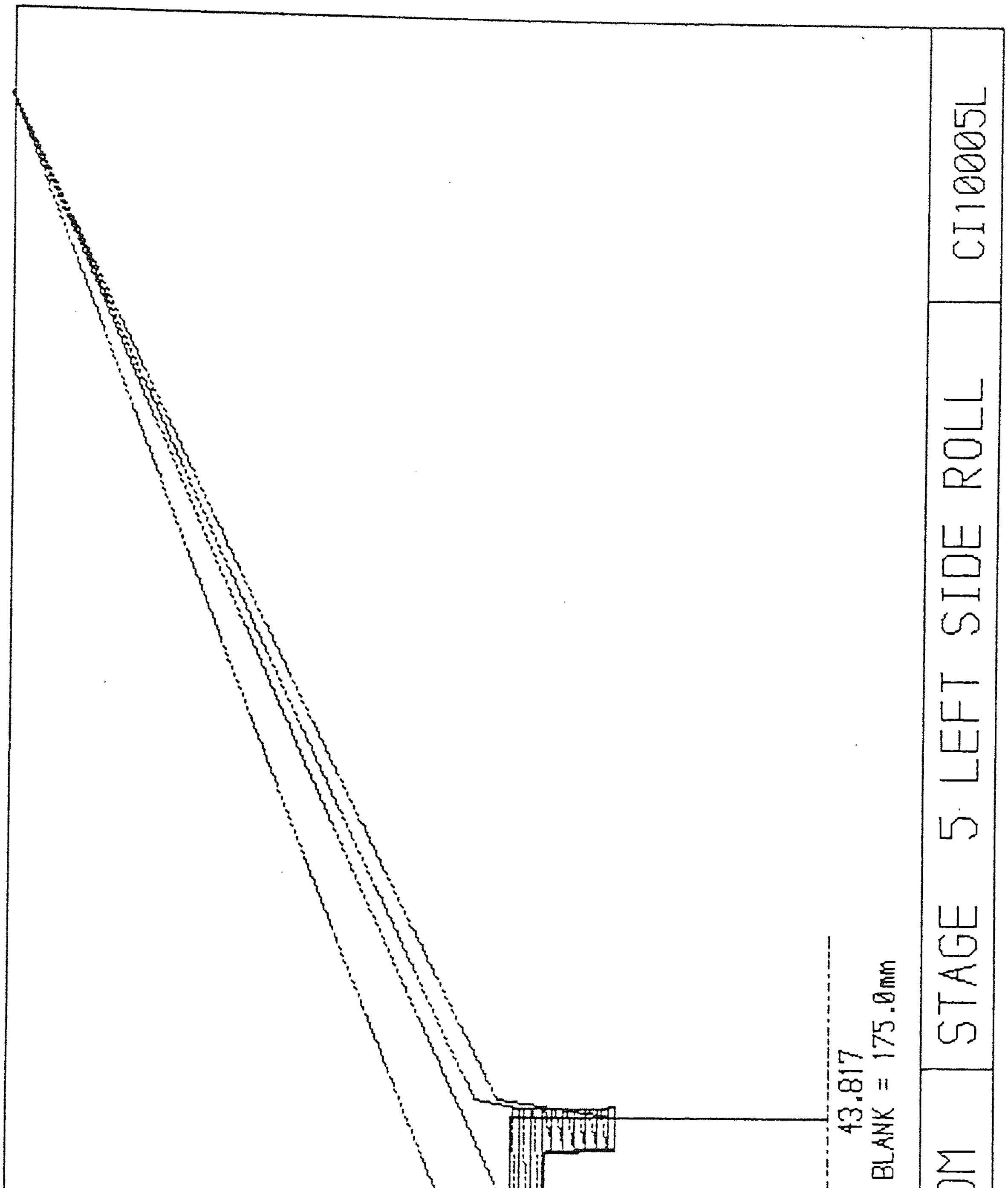
ROLFOM
STAGE 5 BOTTOM ROLL
CI10005B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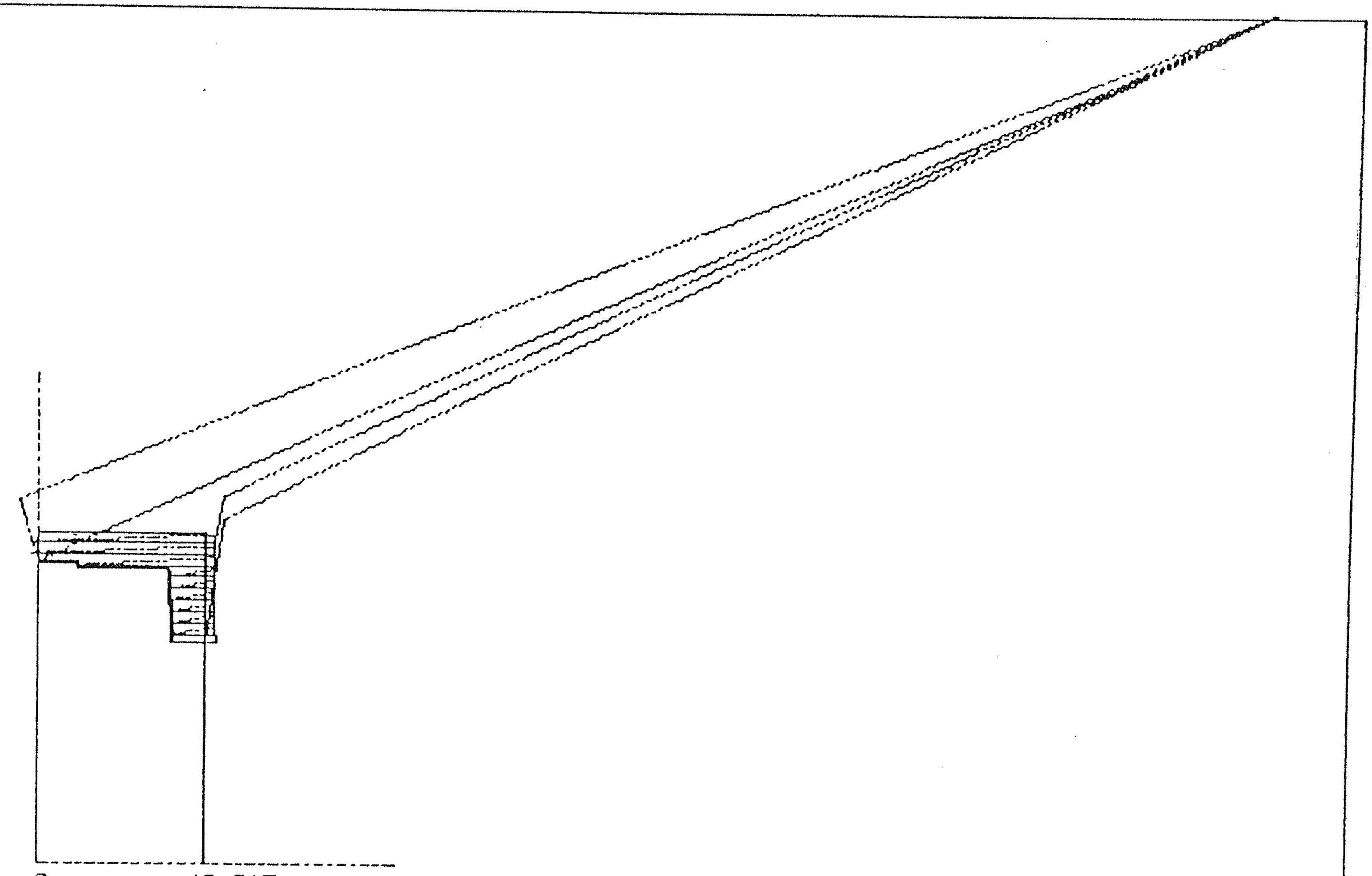
43.817
DIA OF BLANK = 175.Ømm
ROLFOM
STAGE 5 LEFT SIDE ROLL
CI1ØØØ5L



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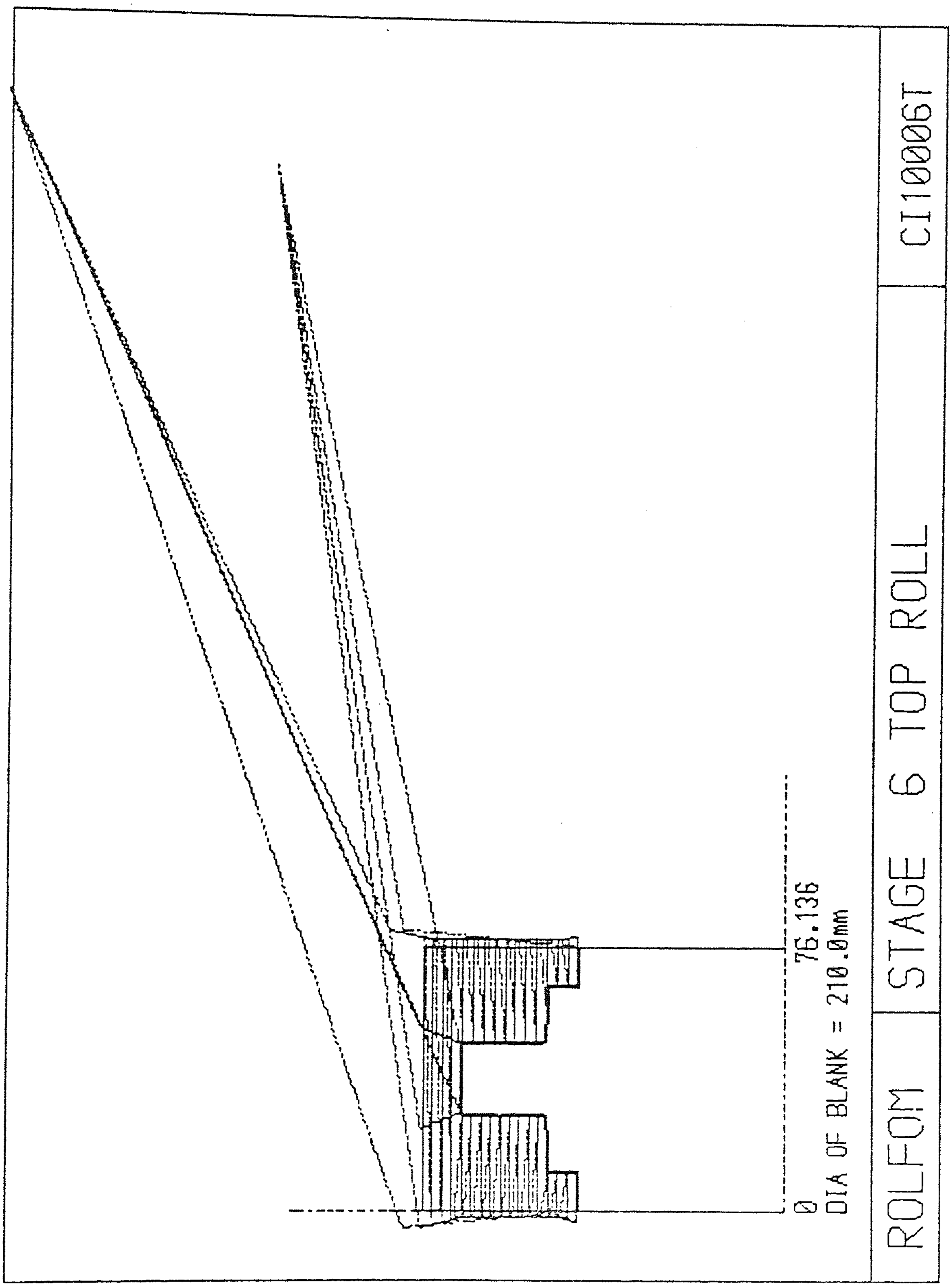
76.136
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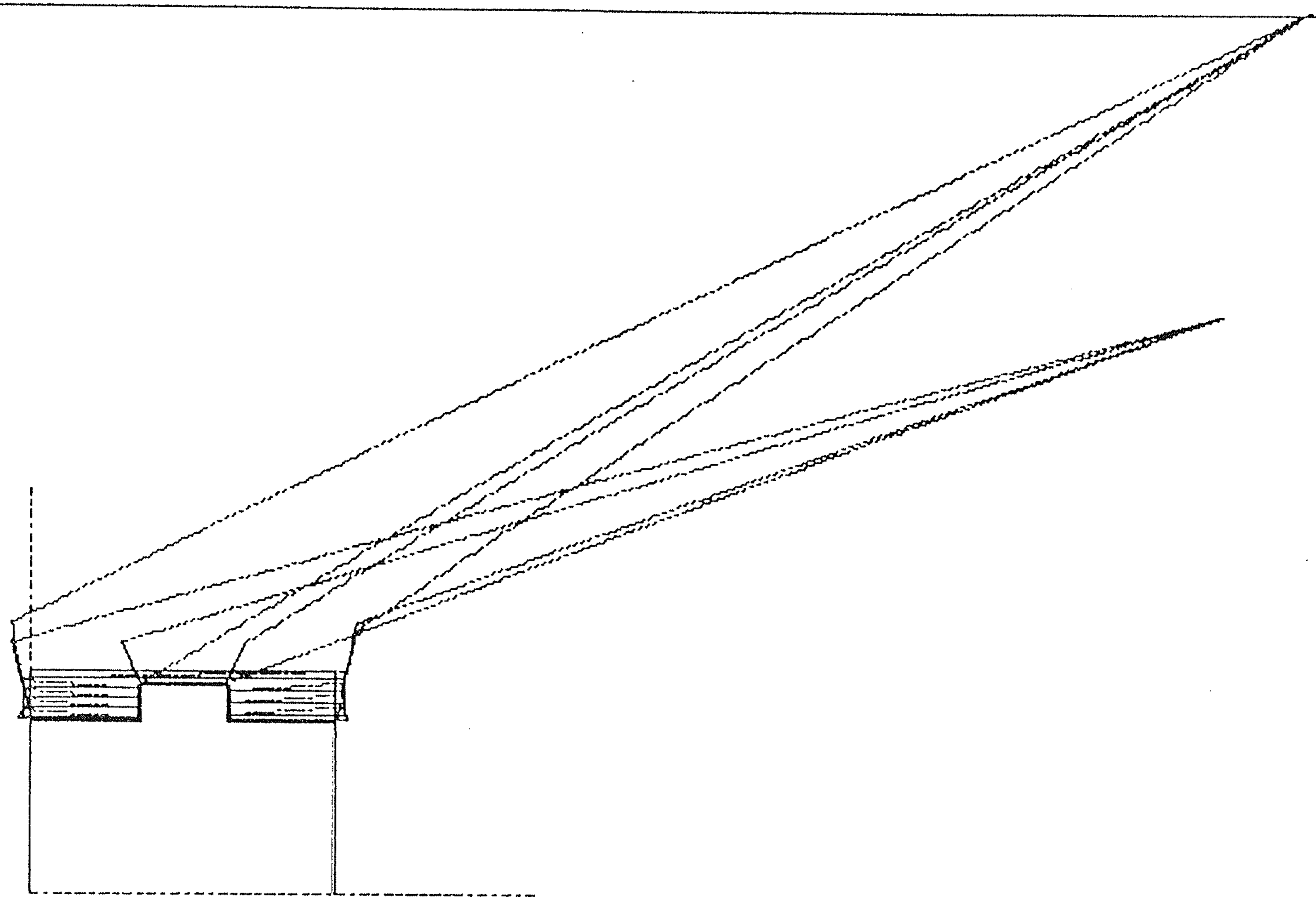
STAGE 6 TOP ROLL
CI1000GT



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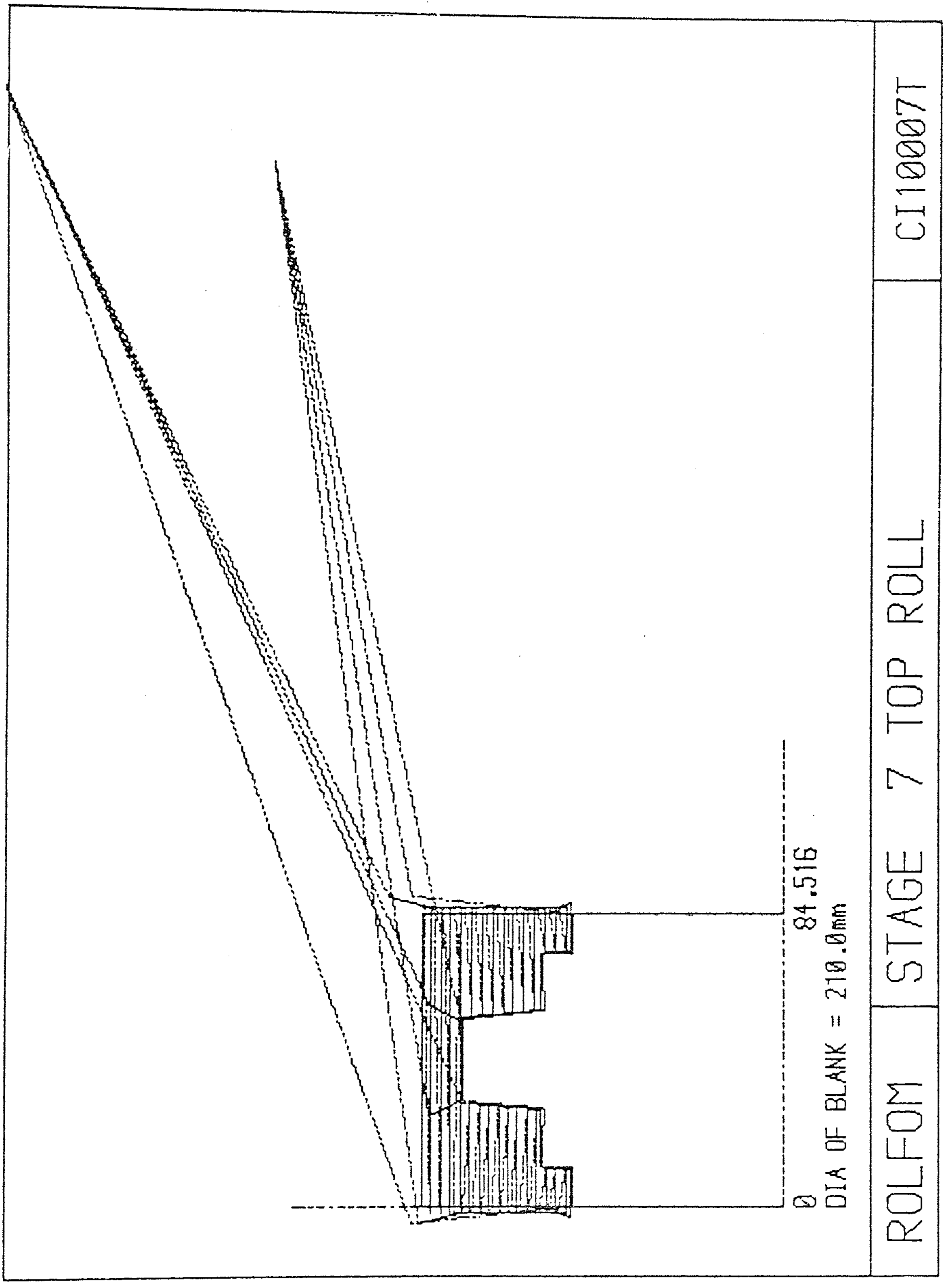
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84.516
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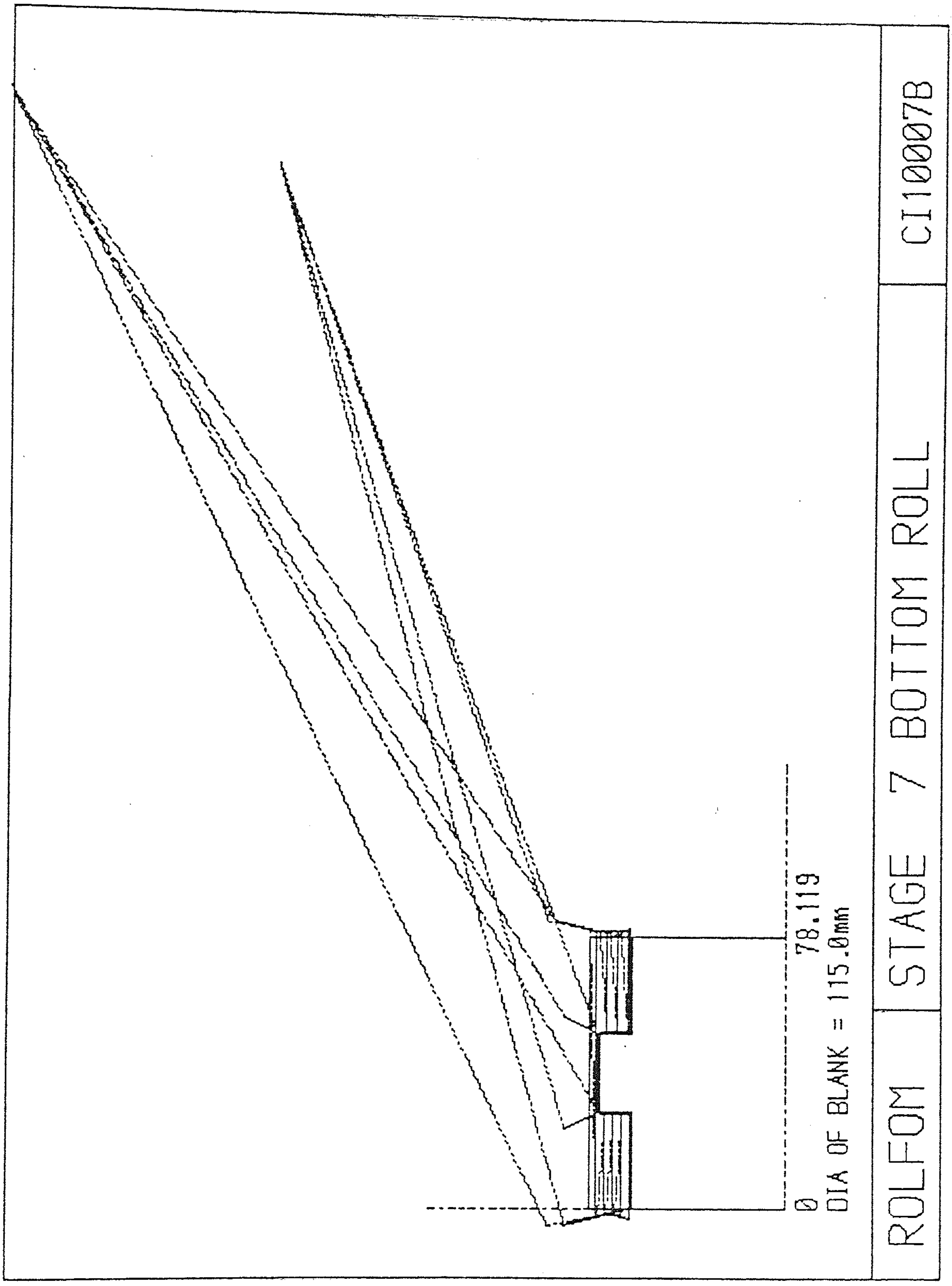
ROLFOM
STAGE 7 TOP ROLL
CI10007T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STAGE 7 BOTTOM ROLL
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Ø
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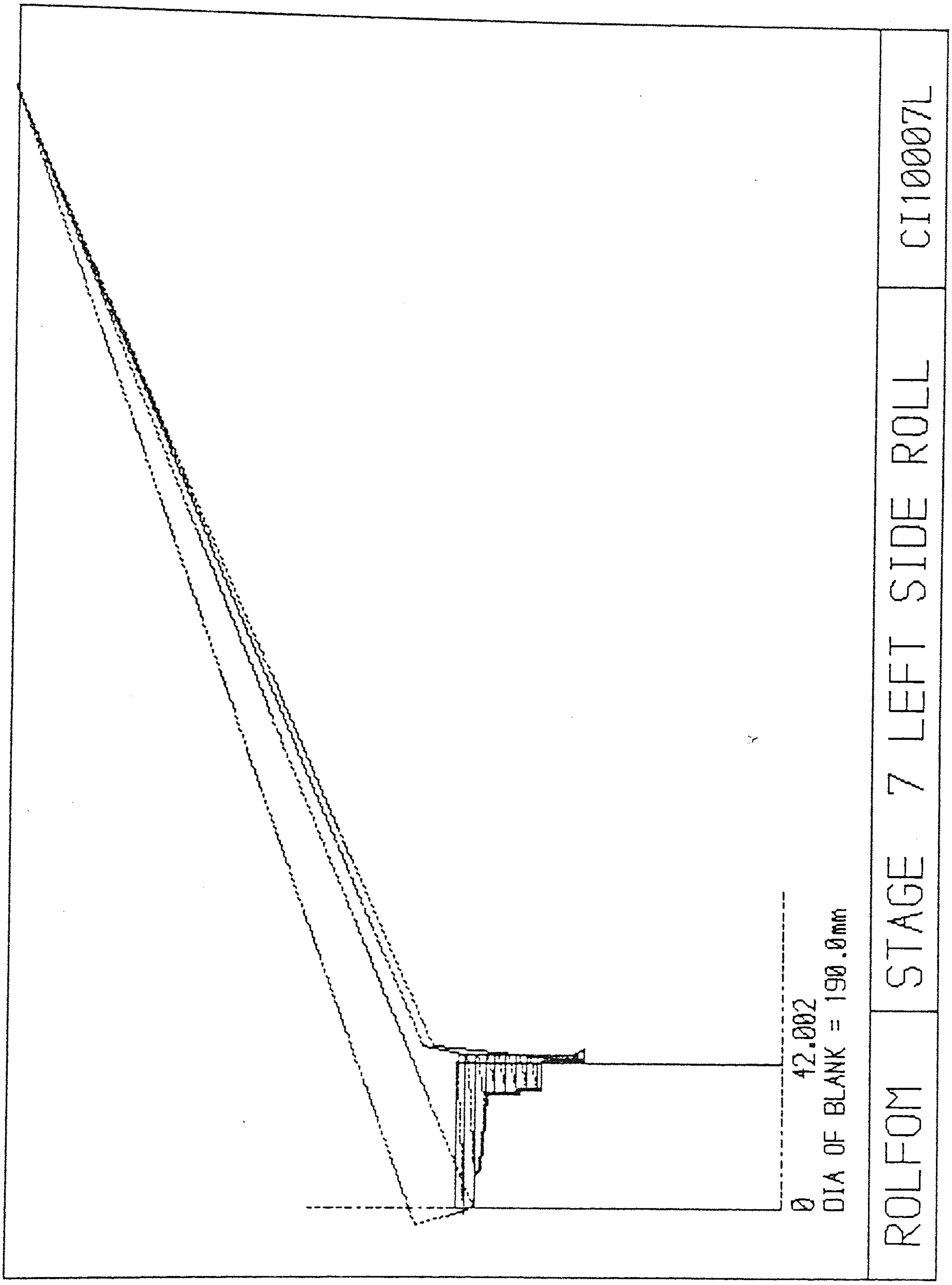
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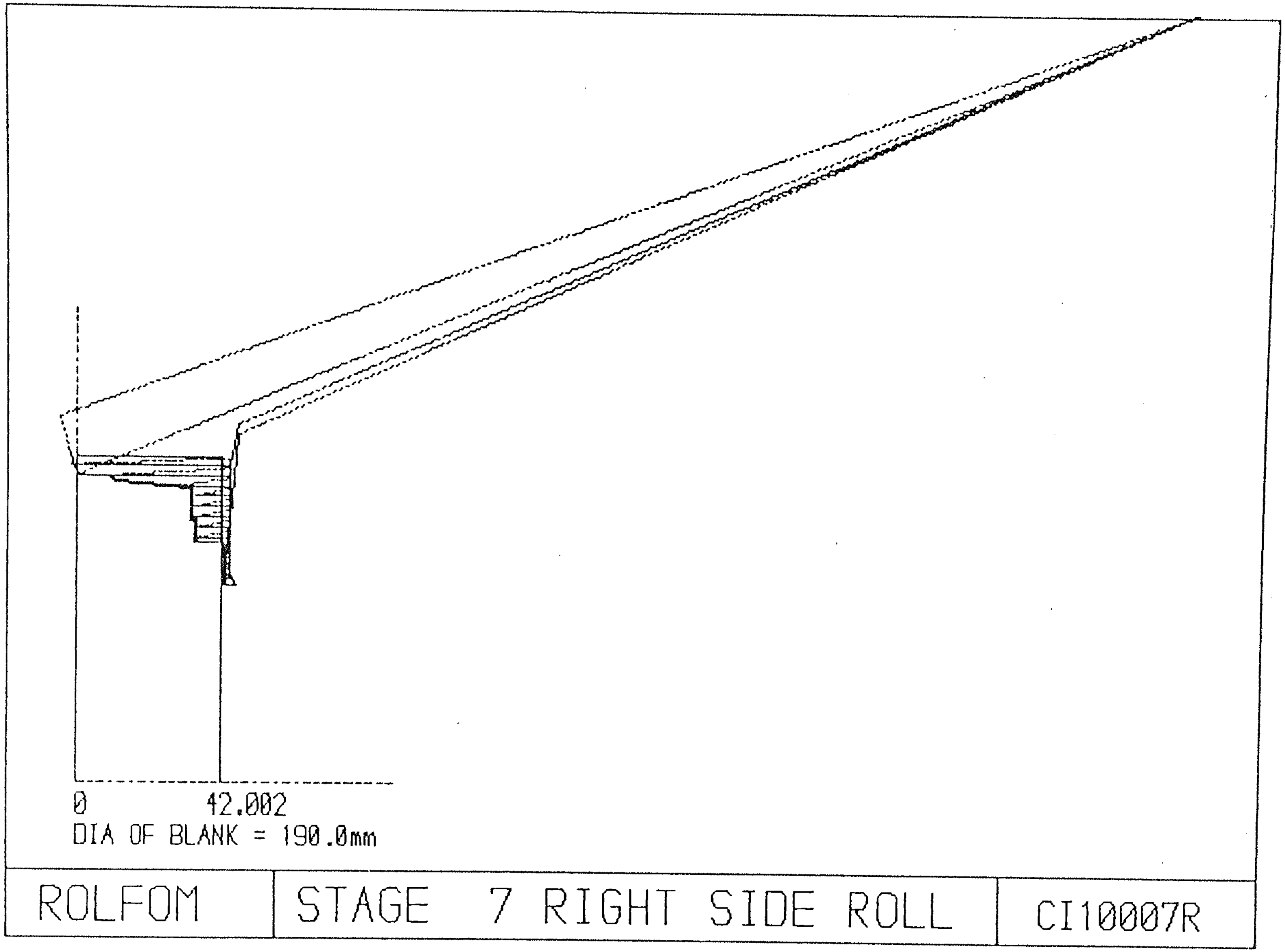
ROLFOM
STAGE 7 LEFT SIDE ROLL
CI10007L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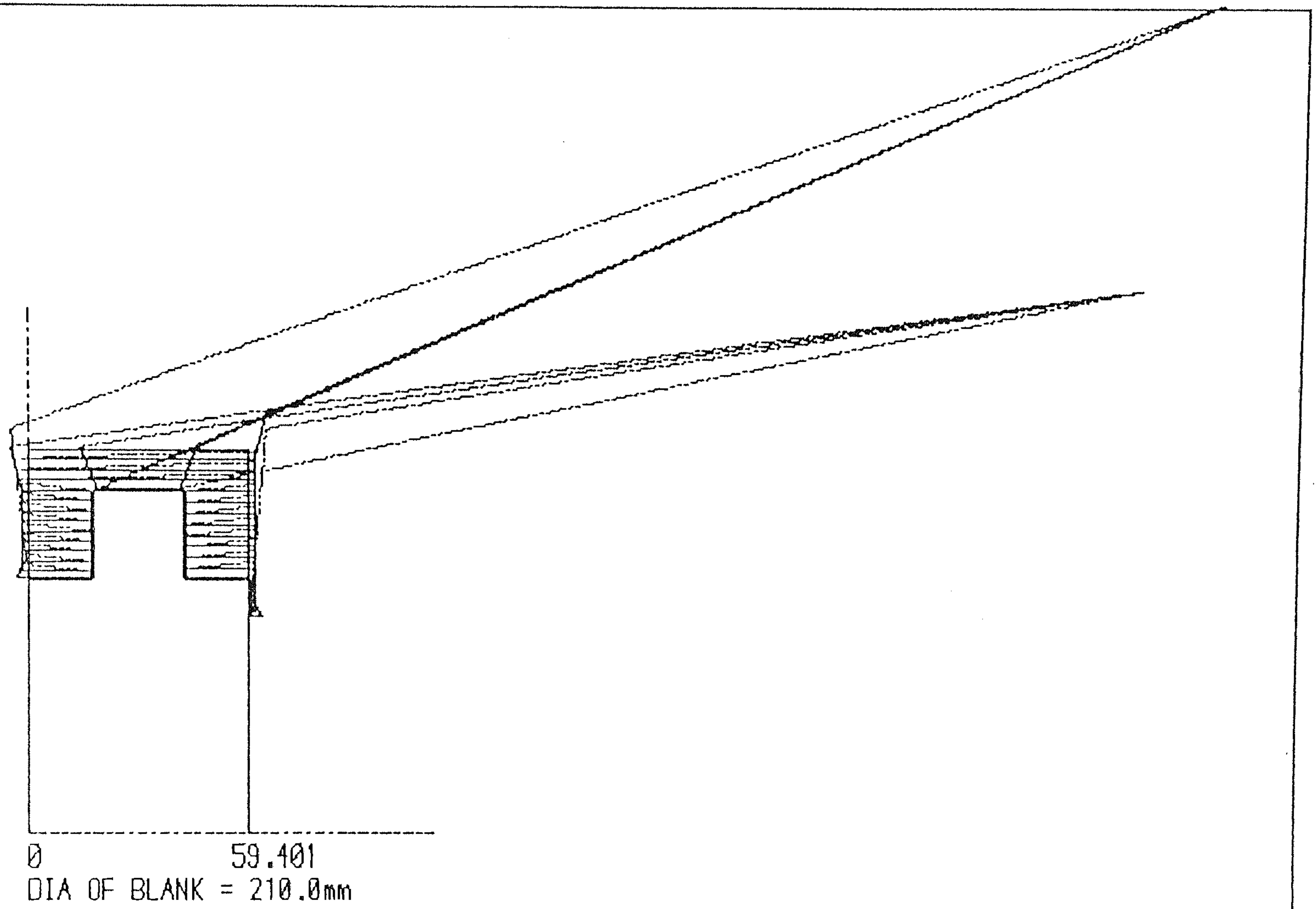
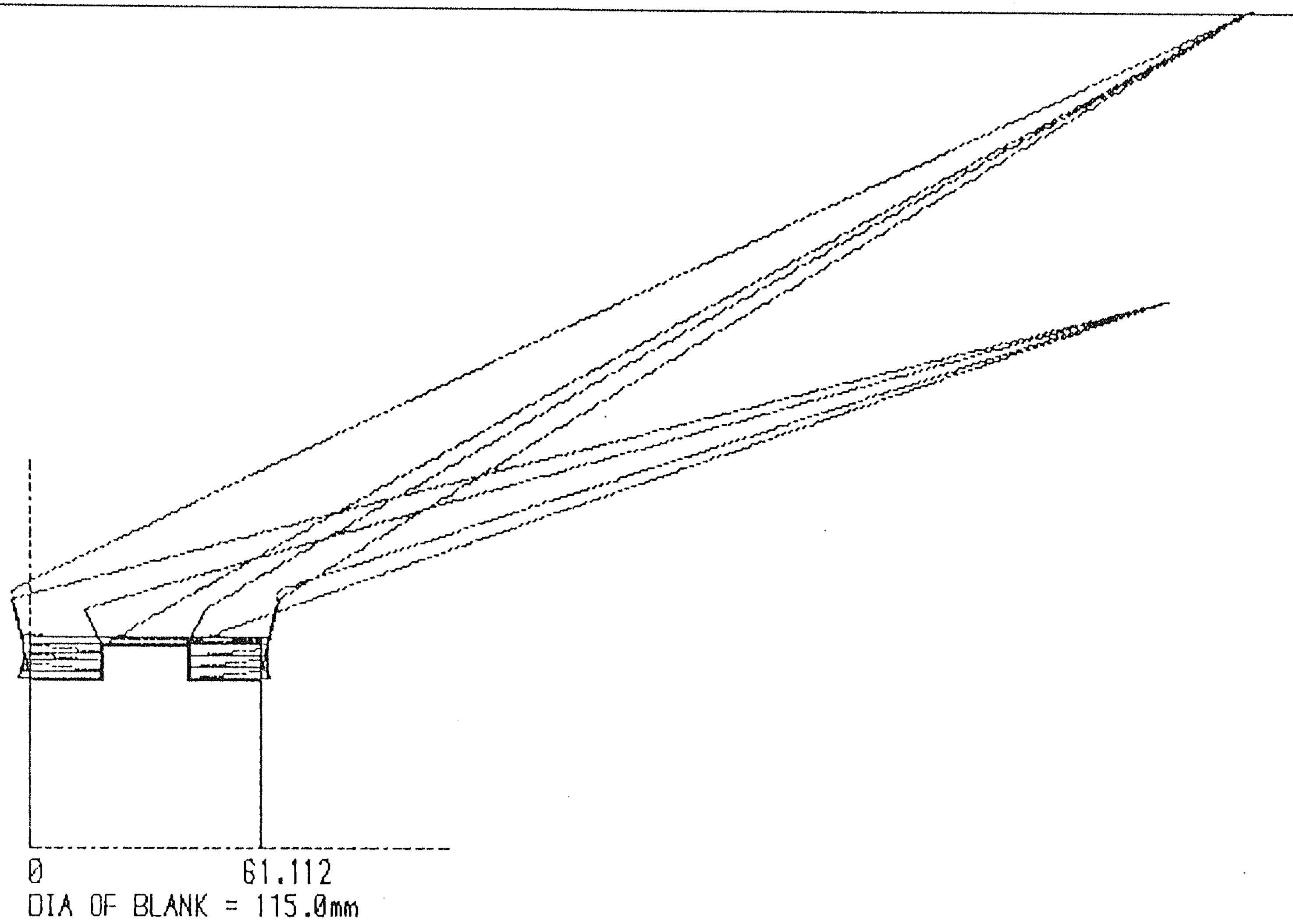
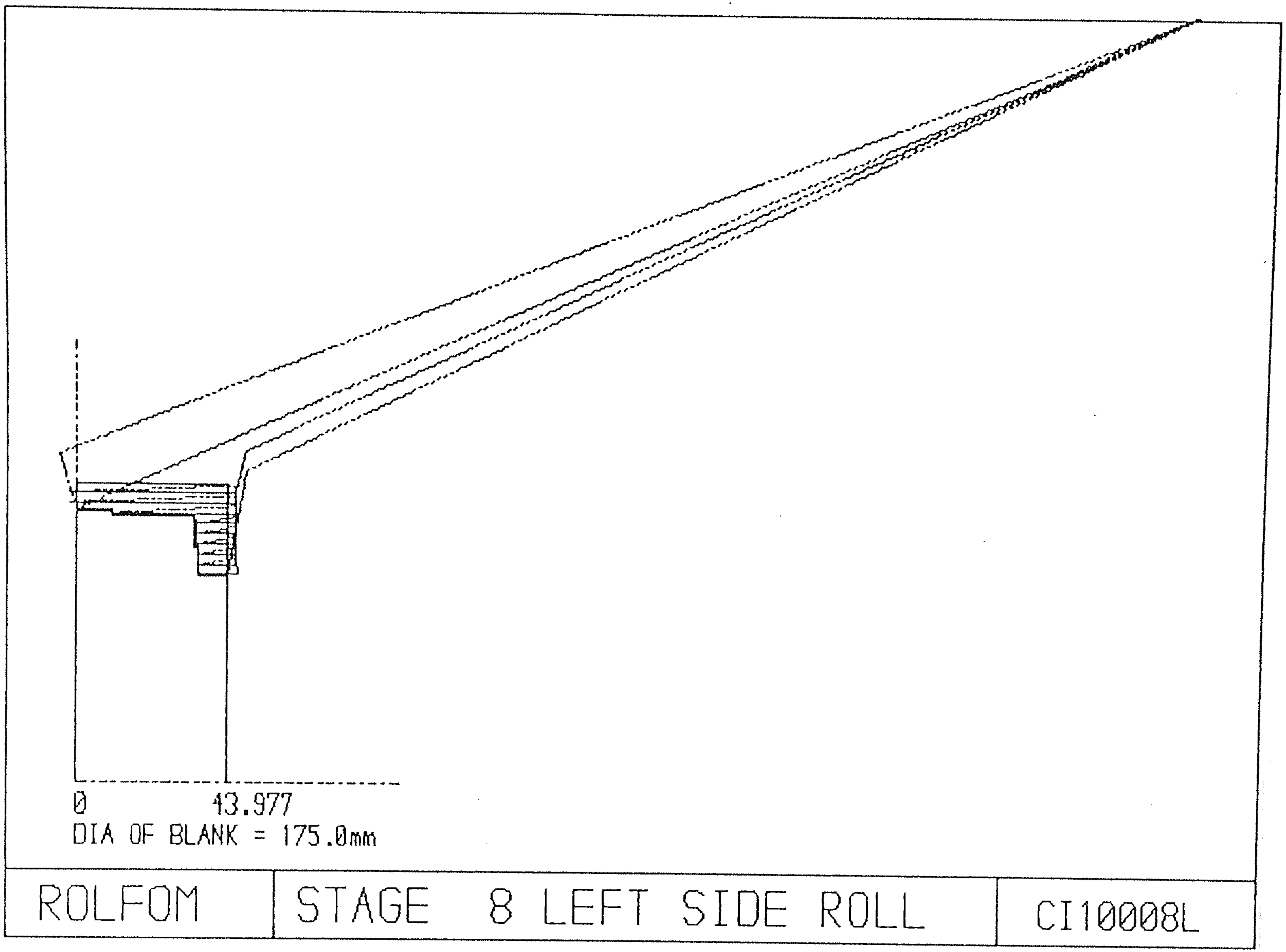
ROLFOM
STAGE 7 RIGHT SIDE ROLL
CI10007R



ROLFOM	STAGE 8 TOP ROLL	CI10008T



ROLFOM	STAGE 8 BOTTOM ROLL	CI10008B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43.977
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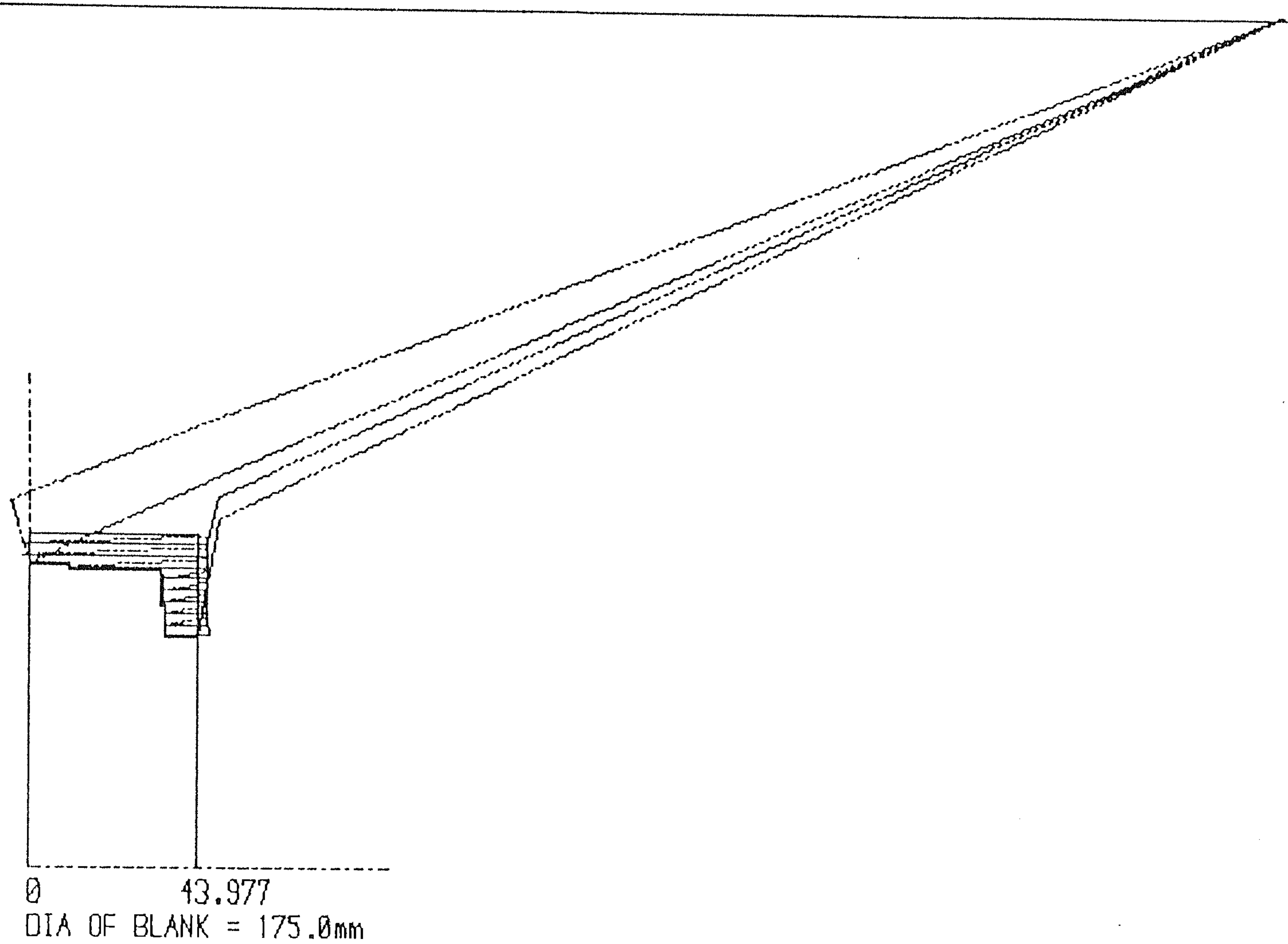
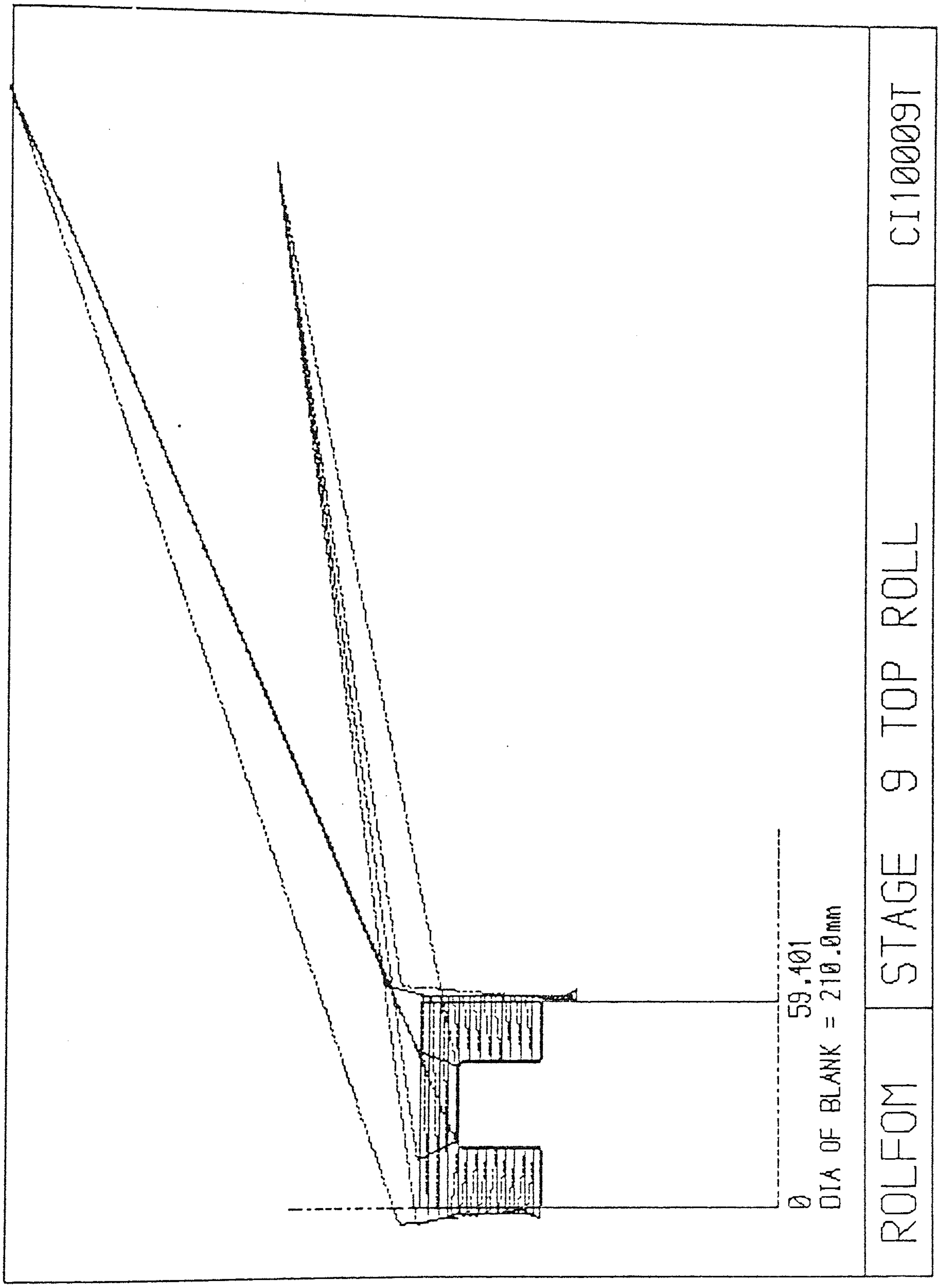
ROLFOM
STAGE 8 LEFT SIDE ROLL
CI10008L



ROLFOM	STAGE 8 RIGHT SIDE ROLL	CI10008R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59.401
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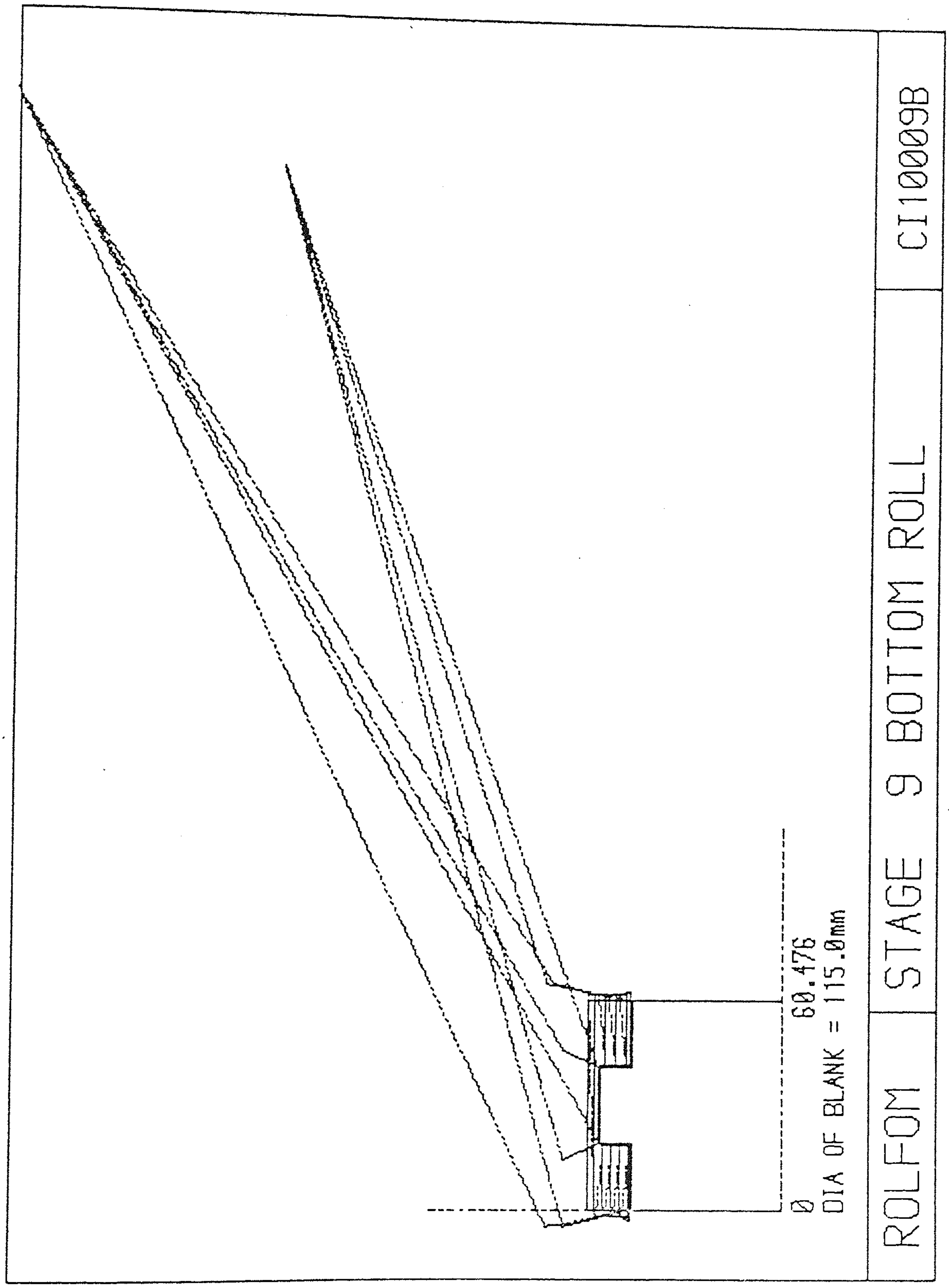
ROLFOM
STAGE 9 TOP ROLL
CI10009T



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60.476
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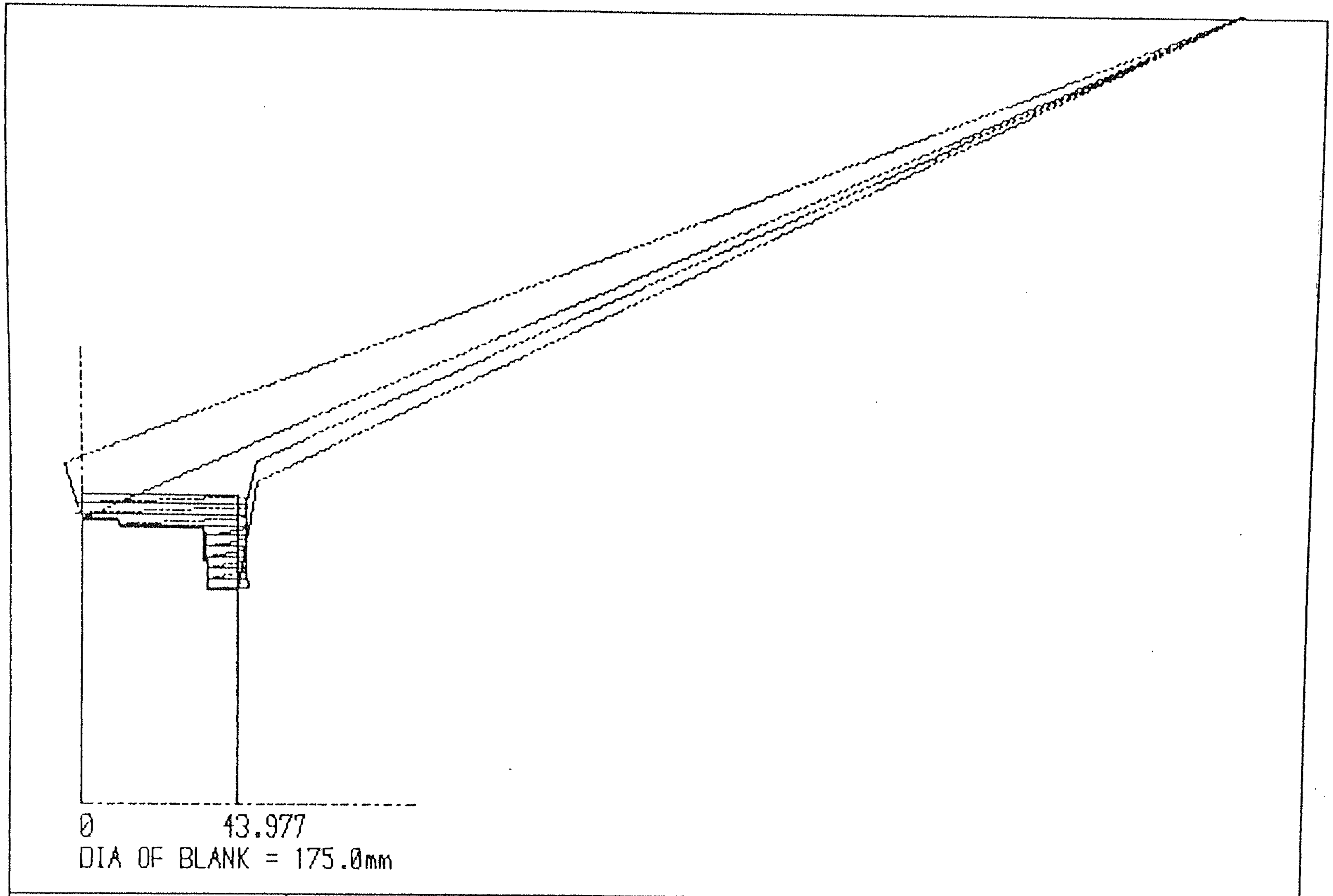
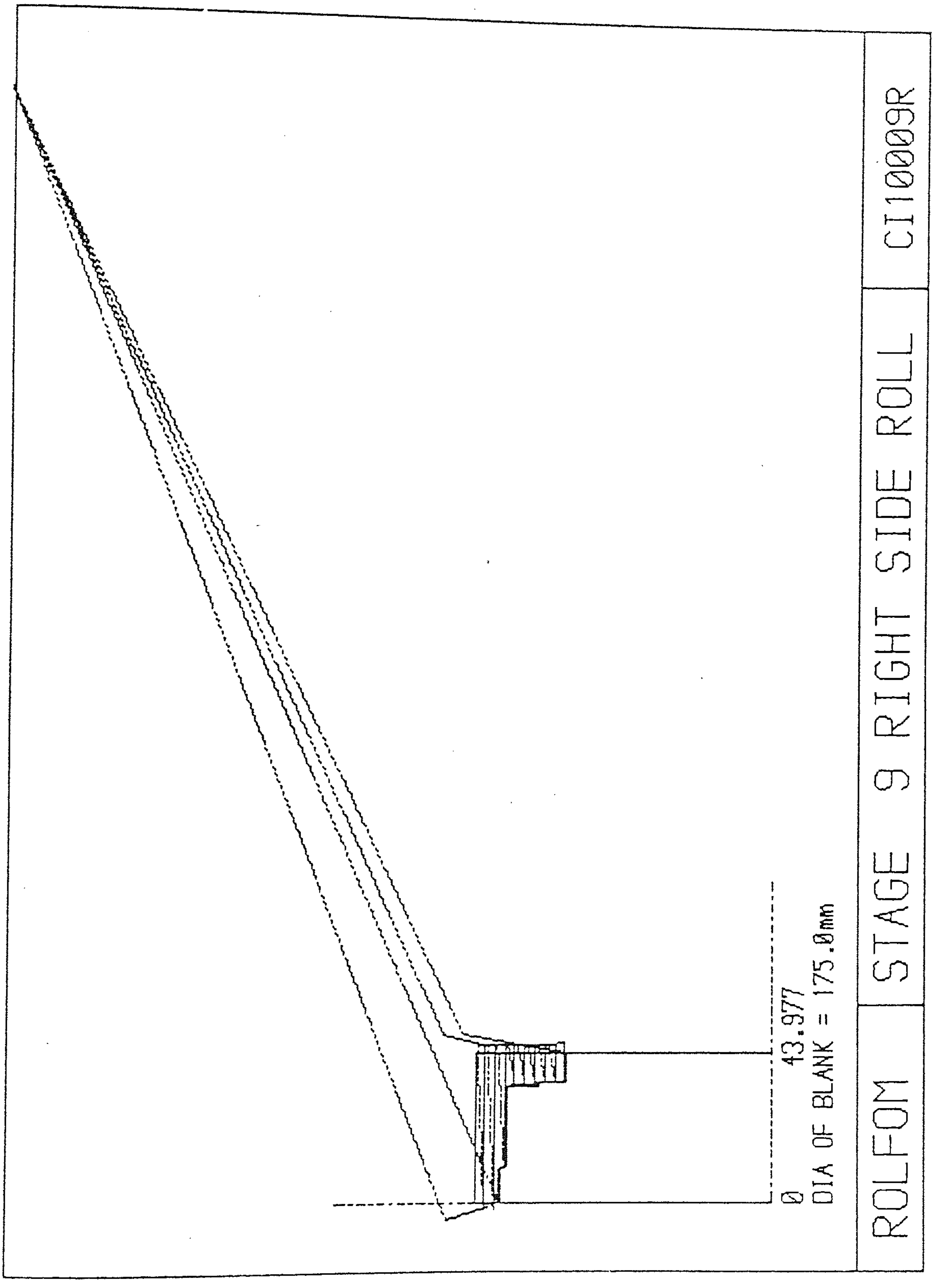
STAGE 9 BOTTOM ROLL
CI10009B



ROLFOM	STAGE 9 LEFT SIDE ROLL	CI10009L



Ø
43.977
DIA OF BLANK = 175.Ømm
ROLFOM
STAGE 9 RIGHT SIDE ROLL
CI1ØØØ9R

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REFERENCES

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