# A KNOWLEDGE-BASED SYSTEM FOR PROCESS PLANNING IN A SEAMLESS STEEL TUBE PLANT

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## Summary

The thesis describes the work carried out to develop a prototype knowledge-based system "KBS-SETUPP" to generate process plans for the manufacture of seamless tubes. The work is specifically related to a plant in which hollows are made from solid billets using a rotary piercing process and then reduced to required size and finished properties using the fixed plug cold drawing process.

The thesis first discusses various methods of tube production in order to give a general background of tube manufacture. Then a review of the automation of the process planning function is presented in terms of its basic sub-tasks and the techniques and suitability of a knowledge-based system is established. In the light of such a review and a case study, the process planning problem is formulated in the domain of seamless tube manufacture, its basic sub-tasks are identified and capabilities and constraints of the available equipment in the specific plant are established.

The task of collecting and collating the process planning knowledge in seamless tube manufacture is discussed and is mostly fulfilled from domain experts, analysing of existing manufacturing records specific to plant, textbooks and applicable Standards.

For the cold drawing mill, tube-drawing schedules have been rationalised to correspond with practice. The validation of such schedules has been achieved by computing the process parameters and then comparing these with the drawbench capacity to avoid over-loading. The existing models cannot be simulated in the computer program as such, therefore a mathematical model has been proposed which estimates the process parameters which are in close agreement with experimental values established by other researchers.

To implement the concepts, a Knowledge-Based System "KBS-SETUPP" has been developed on Personal Computer using Turbo-Prolog. The system is capable of generating process plans, production schedules and some additional capabilities to supplement process planning. The system generated process plans have been compared with the actual plans of the company and it has been shown that the results are satisfactory and encouraging and that the system has the capabilities which are useful.

## Key words

Knowledge-Based System, process planning, seamless tube manufacture, rotary piercing processes, fixed plug cold drawing

Dedicated to my wife and children

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# CHAPTER 1

## INTRODUCTION

### 1.1 INTRODUCTION

The technology of manufacturing is changing rapidly to meet the ever-increasing demands for quality products and high productivity. The increased domestic and international competition has forced firms to scrutinise their manufacturing strategies to produce their products at competitive prices for the survival and stabilisation of their businesses.

The rapid change in the technology is brought about by the increased computer applications in every function associated with manufacturing. The ever-increasing computer applications are due partly to the enhanced capabilities of computers and partly to a steady fall in the prices of computer hardware ( 1) in relation to the capacity and range of features offered. The emergence of micro-computers with increased computational power at low costs has made the use of computers possible within the reach of small- and medium-sized manufacturing industries (2,3).The ability of the computer to store and process a vast amount of data has made a major contribution to the reduction of cost of products and quality improvement and now businesses can react more rapidly to fluctuating demands for their products in the market.

The above factors have motivated businessmen to utilise the powerful tools including Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM), Computer-Aided Process Planning (CAPP), Computer-Aided Production Management (CAPM), Computerised Numerical Control Machines (CNC), Material Requirement Planning (MRP) and, now, Computer-Integrated Manufacturing (CIM) to increase productivity and maintain flexibility in their manufacturing concerns.

One area of manufacturing industry which is beginning to witness the increased applications of such tools, and has not been paid due attention in the past, is seamless tube manufacturing. The present study is focused on the identification of the problem(s) related to process planning in a seamless tube manufacture plant and makes use of recent advances in computing technology for the solution of such problems.

## 1.2 SEAMLESS TUBE MANUFACTURE

Tube are manufactured without any discontinuity in the wall in any stage of manufacture by the use of rotary or non-rotary processes and have diversified applications in the modern technological world.

The rotary tube manufacturing technique basically uses cross- and longitudinal rolling operations upon heated material. The heated billet is pierced between a pair of rolls over a piercing plug in the first stage to form a shell, known as a "bloom". The bloom is rolled by any of the processes such as pilgering, plug rolling or the Diescher process to impart required elongation. The Diescher process has another advantage in that it improves the concentricity of the hollow. The hollow of any particular size is then fed into the stretch-reducer which is capable of producing a number of smaller sizes therefrom. These tubes termed as "hollows" can be made to any sizes by cold drawing operations, many of which cannot be made by rotary processes. The cold drawing of tubes gives high dimensional accuracy, required surface finish and mechanical properties.

The non-rotary tube manufacturing technique involves such operations as extrusion piercing for hole initiation in the billet, tube extrusion and drawing for breaking down the shell to the required tube size.

The configuration of the tube mill varies according to the type of the tube manufacturing technique adopted. A non-rotary mill, for instance, may consist of non rotary plants such as extrusion presses and drawbench in addition to heating and reheating furnaces. On the other hand, a rotary tube mill may contain a heating furnace, rotary piercing plant, cross-rolling plant for pierced bloom such as Diescher mill, stretch-reducer and cold drawing plants with all other associated facilities such as cutting, pickling and lubricating. Such a rotary tube mill is the subject of the present study.

## 1.3 PROBLEM IDENTIFICATION

In order to identify the problems associated with a seamless tube manufacturing plant, a preliminary case study was carried out which revealed, among many other factors, the problem of process planning. The process planning problem is mainly related to the determination of detailed plans for the manufacture of tube and is still being performed manually by a single planner on the basis of past experience and product knowledge. The severity of this problem further increases with the presence of job shop environment, where each job is of a different specification, giving a wider variety of production. In addition, process planning in such a seamless tube plant involves a large number of operations, extensive computation of process parameters such as drawing stress, strain and loads and parameters required for setting up mill for a particular job. In such a situation, a single process planner cannot perform effectively. Moreover, it is highly advisable to capture the personal assets of the planner in terms of experience and heuristics evolved over the long period of actual planning and to document it properly.

## 1.4 PROCESS PLANNING AND SEAMLESS TUBE MANUFACTURE

In recent years, a great deal of effort has been made to automate the different manufacturing operations. One area that has received due attention has been process planning which has been described by many (4, 5) as a bottleneck or gap in overall manufacturing. A general definition of process planning which is equally applicable to all different manufacturing domains, as quoted by Weill et al (5) is as follows:

"Sub-system responsible for the conversion of design data to work instruction"

| Machining | Seamless Tube Manufacture |
|---|---|
| Blank selection | Billet selection |
| Selection of machining process such as turning, facing etc | Selection of forming processes such as piercing, drawing etc |
| Selection of operation sequence | Selection of operation sequence |
| Machine selection based on capabilities and constraints | Machine selection based on capabilities and constraints |
| Cutting tools selection | Forming tools selection |
| Machining parameters selection (speed, feed,and depth of cut) | Forming process parameters (stress, strain, drawing loads) |
| Jig and fixture selection for set-up | Determination of set-up parameters for a given job |
| Selection of production tolerance | Selection of production tolerance as specified in the standards |
| Calculation of cutting time for the product | Calculation of forming time for the tube |

Table 1.1: Comparison of process planning sub-tasks in the domains of machining and seamless tube manufacture

The process planning function consists of different sub-tasks, which have been compared for two different domains of manufacturing in table 1 namely: machining and seamless tube manufacture. One of the problems associated with process planning is the difficulty of achieving a generalised computer-aided solution (6) as opposed to Computer-Aided Design. In CAD, the engineering drawings are constructed from the basic entities of arcs, lines and text so that, whether the product is a prismatic machined component or a printed circuit board, the same system may be used to design it. The process planning function is not blessed with the same type of basic entities and, because of its specific characteristics, it is ill-defined and intuitive in nature and manufacturing-system-dependent (7,8,9), it is difficult to achieve a generalised Computer-Aided solution ready to be used in every domain of manufacturing. As a result, more specific applications are being developed to suit the individual domains with the basic principle being the same but varying in operations and details.

One of such manufacturing domain is the long-established tube manufacturing industry which tends to rely upon past experience for most of its operations. The increasing demands of better quality tubes and high productivity during the last two decades (10), and the need to meet those requirements, has highlighted the basic problems facing the industry. The complexity of these problems has suggested a wide range of research work to be carried out and requires the application of recent advances in computing technology to react more rapidly in a very highly dynamic environment. The present investigation of process planning in a seamless tube plant is one of those highlighted problems.

## 1.5 PROCESS PLANNING TECHNIQUES

The literature indicates three techniques (11) for accomplishing the task of process planning :

manual approach
variant approach
generative approach

The manual approach goes beyond our industrialised age when the verbal design of a plough given by a farmer, was accomplished by the blacksmith, having a manufacturing method in the mind, to transform the scrap material into a plough without giving the terminology of process planning to his manufacturing method as exists at the present time. In the manual approach, the engineering part drawing is examined in order to develop manufacturing instructions based upon past experience, process knowledge, operation cost and shop practice. This approach is highly subjective, labour intensive, time consuming, slow to react and unmanageable in the business of high product variety with frequent design changes, as discussed by Steudel (11). Furthermore, it has the drawback of producing inconsistent and sometimes inaccurate plans, containing personal preferences.

In order to remove the inherent limitations of the traditional manual approach, researchers tried to seek alternative methods and set out to employ the speed and consistency of computers to assist in the generation of process plans. Among them Niebal (12) was the first to suggest the application of computers and later the idea was supported by many others. As a result of these efforts the variant and generative type Computer-Aided Process Planning (CAPP) systems emerged.

In the variant approach, the parts to be manufactured are grouped into a number of part families, characterised by similarities of manufacturing methods. For each of these part families, a standard process plan is developed which includes all possible operations, their sequence and operational details. All the process plans for available 'part families' are permanently stored in the computer database with a family number as a key. The process plan for a new part can then be created by retrieving the existing process plan for a family to which the new part belongs using the associated key family number. The planner makes the necessary modifications to the standard process plan relying past experience to suit the manufacture of a new part. CAPP (13) is the best example of such a variant type process planning system. This technique helps in many ways such as consistency, accuracy and speed of preparing plans, but the biggest disadvantage is that an experienced process planner is still required to construct, modify and maintain the process plans.

To overcome the problems associated with the variant approach, the idea of the generative approach came in to play its role in bridging CAD and CAM technology. In this approach, process plans are generated from scratch by means of decision logic, formulae, technology algorithm and geometry based data (11) to uniquely determine the many processing decisions for converting a part from raw material to finished state. The technique employs the storing of rules of manufacture, processes and machine capabilities and operations precedence relationships as compared with standard process plans in the variant approach. The generative approach has the potential to eliminate the process planner and plays the vital role in bridging the technologies of CAD and CAM towards the unmanned factories of the future. The system AUTAP (14) developed by Eversheim et al uses the generative approach to process planning.

The recent developments in the field of Artificial Intelligence (AI) and Knowledge-Based Systems (KBS) and the encouraging success of their application in problems such as process planning, has shown the generative approach to be most promising solution in Computer-Integrated Manufacturing (CIM).

## 1.6 KNOWLEDGE-BASED SYSTEMS AND PROCESS PLANNING

The generative CAPP systems based on conventional programming techniques (algorithmic) were inflexible and rigid (7) because of the intermixing the flow of control and utilisation of data. Those programs consist of hundreds of interlinked program units and modification to such a system was severely limited. This technique of programming became unsuitable where the expertise of the expert was needed to be incorporated to enhance the performance of the system or any change in the process planning knowledge became necessary to include in the system.

The developments in AI and KBS provided the opportunity to capture such expertise and changes because of the separation of knowledge from the control. Such expertise can be represented in the KBS in the form that would allow the system to come closer to emulating the decision making processes of the experts and give flexibility to modify or extend the knowledge source. The use of Knowledge-Based Systems in the field of process planning will be elaborated later, but an overview at this stage is useful. In Knowledge-Based Systems, the 'knowledge' is organised in a way that separates knowledge about the problem domain from problem-solving knowledge. The collection of domain-specific knowledge is called 'knowledge-base' while problem-solving knowledge is an 'inference engine'. The knowledge-based systems are intended to solve real problems intelligently in a narrow domain. The problem solving power in these systems come from the knowledge they possess as stated by Waterman (15).

Following the initial success of KBS in medical diagnostic and mineral exploration, interest has expanded to other areas including manufacturing and its subfields such as process planning where many Knowledge-Based Systems have been developed and their potential has been established, EXCAP (16) being one example.

This research work is intended to extend the horizon of such systems from the above cited traditional application to the manufacture of seamless tube manufacture.

## 1.7 OBJECTIVES OF THE RESEARCH

Preliminary study in a seamless tube mill identified the process planning problem which needed the computer application to put it into its right perspective as discussed in section 1.4. The main objective of this research work is thus to develop a computer aided solution using the established potential of knowledge-based systems as mentioned in section 1.6 to generate and optimise process plans for the manufacture of seamless tubes in a plant employing rotary processes. However, the generation of process plans for individual orders may not be enough because of the requirement of 'product mix' to reduce the setup time. To run a plant efficiently on the basis of the product mix necessitates the preparation of production schedules. Therefore, in addition to the generation of process plans, specific objectives are:

1. To identify and gather the process planning knowledge associated with seamless tube manufacture and to represent it in a formal way in the system.
2. To optimise the hollow manufacture in the rotary piercing mill. The possible strategies may include optimisation of resources utilisation and development of production schedules based on the grouping of orders requiring similar settings of the mill. The elimination of frequent set-ups of the mill will reduce overall set-up time resulting in an increase of production time.
3. To include some optional capabilities in the system such as material requirement, inquiry handling and the latest available manufacturing capacity status of the mill.
4. To rationalise the tube-drawing schedules in the cold drawing mill based on the availability of the tools. A possible strategy may be to generate alternative tube-drawing schedules and then to select a best schedule based upon some criteria.
5. To investigate whether the existing mathematical models of fixed plug tube drawing can be simulated in the system in order to validate the tube drawing schedules or not. In tube drawing the mechanical properties of material are changed and are usually determined experimentally while a computer-based solution requires a mathematical model which can predict the material properties and process parameters analytically. If the existing model cannot be simulated then can a new mathematical model be proposed which can predict mechanical properties and process parameters analytically with the results being comparable to existing model.

# CHAPTER 2

## TUBE MANUFACTURE - A REVIEW

### 2.1 INTRODUCTION

Both seamed and seamless tubes have gained a wider application in the modern technological world being extensively used in nuclear and conventional power plants, refineries, machine tools and hydraulic equipment, specialised telescopic applications and pipelines for conveying gases, oil and other fluids. An increasing demand for steel tubes can be visualised from the production forecast of 90 million tonne/year by 2000, given by Neuhoff (10). This forecast contains a significant proportion of tubes produced by seamless processes.

In this chapter, general tube manufacturing processes and the type of tube mills that may be available, are discussed as a general background. The work is mainly concerned with the rotary process, due attention being given to the layout and description of the different units of a tube mill. This discussion is intended not only ensure a clear understanding of the activities of a tube mill, but also to provide an indication of the complexity of the process planning functions which are the main objectives of this research work.

### 2.2 TUBE MANUFACTURING PROCESSES

Tube manufacturing processes can be classified according to the types of the tube they produce:

Seamed or welded

Seamless

In a seam or welded tube manufacture, a continuous sheet or a strip is gradually formed into a circular open seam tube and the edges are then welded together by any welding process.

Seamless tube, on the other hand, is a tube without discontinuity at any stage of its manufacture or "weldless" as defined by Jenkin (17). Seamless tubes are manufactured by using either rotary or non-rotary processes followed by some secondary process.

## 2.3 SEAMED OR WELDED TUBE MANUFACTURING PROCESS

The origin of the use of welded pipes on a limited scale goes back to the Egyptians and more extensively by Romans who produced the first pipeline (18), using a very elementary welding process. The process of welded tube manufacture had undergone through extensive refinement and, at the present state of development, the process involves the following steps:

- Preparation of sheets for forming
- Forming the sheets into tubing
- Welding process
- Finishing process

In order to make a satisfactory piece of pipe, it is necessary that the edges be sheared cleanly and that the accurate width is maintained longitudinally to ensure the production of perfect cylinders. Slitting and cleaning operations are carried out to achieve this objective.

The principle of forming the tube is the same as that for cold roll forming of sheets and strips into wide variety of shapes. The different techniques used for forming tube include: hot and cold rolling and rotary bending. Basically, the sheet or strip is fed longitudinally through successive pairs of rolls, each pair progressively forming the strip into finished tube shape, as discussed by Morehead (19). The detailed on these techniques is described in the work of Morgan (20), Anderson (21) and Middleton (22), giving prime importance to the design of rolls and their adjustment to avoid poorly formed tubes.

The process of welding can be accomplished from a variety of techniques as reviewed by Blazynski (23), in outlining the basic manufacturing system for welded tubes. The established welding processes include: helical welding, continuous welding, electric resistance welding with low and high frequency current and medium and high frequency induction welding, argon and submerged arc welding.

The finishing processes may include weld annealing or normalising, cold drawing, straightening and cutting to required lengths.

## 2.4 SEAMLESS TUBE MANUFACTURING PROCESSES

The seamless tube manufacturing processes can be broadly classified into three groups:

(1) Rotary processes

(2) Non-rotary processes

(3) Secondary processes

## 2.5 ROTARY PROCESSES

One of the traditional methods of seamless tube manufacture is by the use of rotary processes. These are basically cross rolling operations and include:

(1) Rotary piercing

(2) Pilger or rotary forging

(3) Plug rolling

(4) Diescher process or elongation by oblique rolling

(5) Stretch-reducing

(6) Reeling or straightening

### 2.5.1 ROTARY PIERCING

The solid billets are converted into blooms (shells) by the rotary piercing process. Three main types of rotary piercing mill which have been commercially successfully are as follows:

(1) Mannesmann process

(2) Cone or 60 deg piercing process

(3) Disc or Stiefel process

Detailed descriptions and design features of the above main three types piercing mill are given by Jenkin (17), Hamilton (24) and Evans(25). In all the rotary piercing processes, the formation of the hollow is achieved by peripherally rolling a cylindrical billet over a conical plug or a mandrel by driven rolls which are set an angle to horizontal plane.

#### 2.5.1.1 MANNESMANN PROCESS

In the Mannesmann piercing process, a forward motion is imparted to the incoming heated billet by means of two barrel rolls with their axes lying parallel to one another in the plan view, but intersecting each other in the lateral plane at an angle of 5 deg as shown in figure 2.1. Both rolls turn in the same direction, thus driving the workpiece in the opposite direction. The essential feature is the rotation of the billet as it is pulled forward by a cross-rolling operation due to the longitudinal component of the force and the weakening of the centre as in flat anvil forging due to the tensile effect.

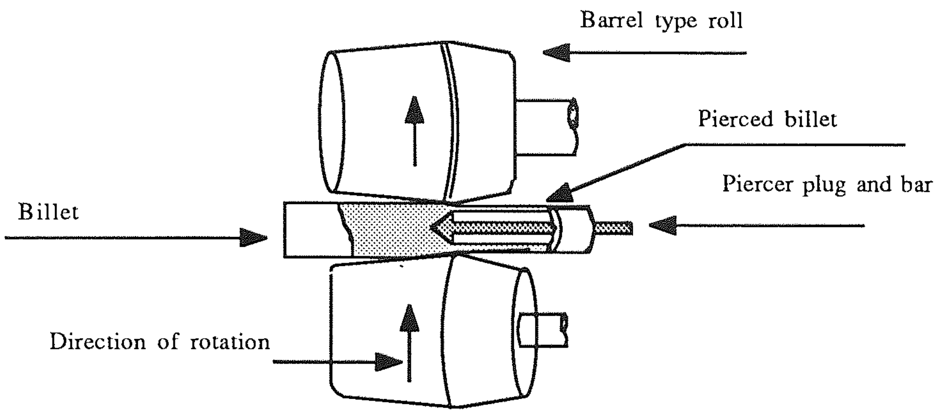



Figure 2.1: Mannesmann rotary piercing mill

The piercing plug, which is supported at the front end of the piercing bar, may revolve or remain stationary. When this plug is held against the forward motion of the billet in the weakened central region, the billet passes over it and the plug serves to ensure that the centre opens out into a round hole, more or less concentric with the outside diameter. In this way the hot billet passing over the piercing plug emerges as a rough thick-walled pierced bloom. More detail about theory of piercing, billet guide mechanism and roll design can be found in the articles by McLaren (26) and Rodder (27).

2.5.1.2 CONE OR 60 DEGREE PIERCING PROCESS

In the cone or 60 deg piercing mill, two conical rolls are set an angle of 60 deg, each being driven by individual motor drive as shown in figure 2.2 below. This type of mill can also be used to expand very large diameter tubes. The cone piercing mill has a relative advantage of small power requirement per unit volume of displacement and smooth and uniform hollows are obtained after piercing. In order to control the outside diameter of the hollows, guide shoes or discs are used while the wall thickness can be controlled by the relative position of the piercing plug and the main piercer rolls.

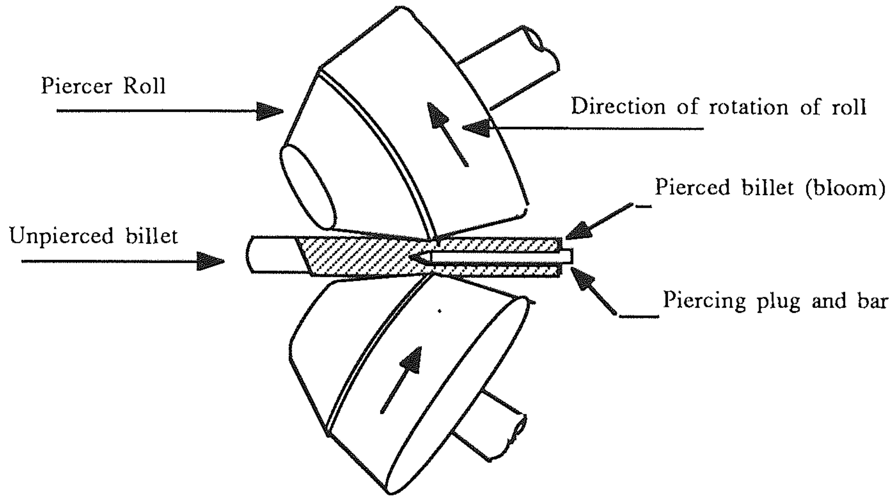



Figure 2.2: Cone type piercing mill

### 2.5.1.3 DISC OR STIEFEL PROCESS

In the disc piercer, the billets are rolled between two main discs set on parallel but

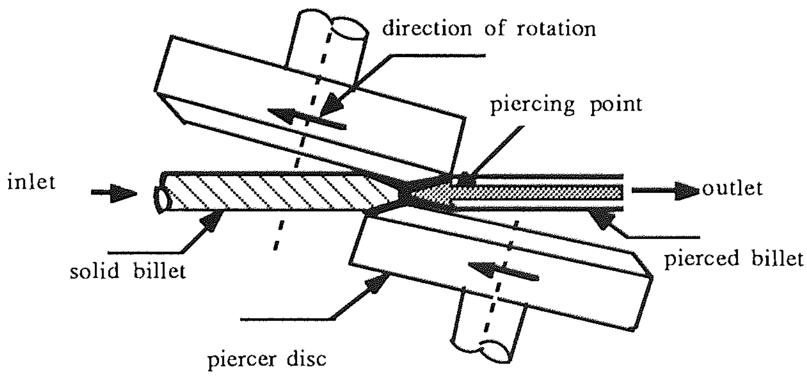



Figure 2.3 : Disc type or Stiefel mill

offset axes as shown in figure 2.3 . The billet enters the tapering space between two rolls which are rotating in the same direction, imparting rotation to the billet.

### 2.5.2 PILGER PROCESS: ROTARY FORGING

In this process, the action of the pilger rolls is described by the Evans (25) as similar to that of the blacksmith in drawing out a piece of round steel to a smaller diameter under a hammer action. Jenkin (17) explains this action as that of pilgrims approaching a shrine by taking three steps forward and two back. The pilger process works on the pilgrim principle of causing the bloom to pass through the rolls step by step making a certain amount of progress at each stroke.

The pilger process is used to reduce the outside diameter and the wall thickness of the tube by elongating it. The maximum elongation in the pilger process is of the order of 15:1 as quoted by Cole (28).

### 2.5.3 PLUG ROLLING

As with the pilger process, the plug rolling process is used for reducing the outside diameter and the wall thickness of the pierced blooms. The plug rolling process is widely used in United States as a follow-up operation to rotary piercing to elongate a pierced bloom by passing it through grooved rolls over a stationary blunt nosed plug. The bloom is rotated at 90 deg between the successive passes. The disadvantage of this process being that wall thickness of the elongated bloom is usually not uniform.

### 2.5.4 DIESCHER PROCESS

In the Diescher process, the cross-rolling principle of the primary stage of piercing is used to secondary stage of elongating the pierced blooms. For instance, a long bloom which has been pierced by Mannesmann barrel rolls, is given a second pass through similar rolls after having a long bar loosely inserted in to it. Support above and below is provided by large rotating discs, some 900 mm diameter and 50 - 75 mm thick, the periphery of which is of such a contour as to assist the forward motion of the bloom. The resulting tube has an enviable reputation for concentricity, close tolerance with a good standard of internal and external finish as described by Cole (28).

### 2.5.5 STRETCH-REDUCING

Repeated diameter reduction of hot tubes, passing through multiple roll passes arranged in series, by the pull or stretching action, is termed the stretch-reducing operation. The tension or pull is applied to the tubes by increasing the relative speeds of rolls in successive stands. The average reduction in the diameter per stand of the stretch-reducing mill is in the range of 3 - 7 % as quoted by Rumrich (29). Stretch-reducing mills have been utilised in conjunction with seamless tube mills of any kind and d/t ratios down to 2.5 have been rolled with good results. Stretch-reducing is commonly applied to:

- Improve tonnage output, since the production of small diameter pipes can be produced more quickly on a stretch-reducer as compared with a basic mill which requires frequent changes of setting.
- Expand the size range by manufacturing many different sizes of tubes from one size of the entry tube made by the basic mill.
- Substantially reduce the number of tools changeovers in the basic tube manufacturing mill, since the basic tube manufacturing mill is assigned to produce one particular size which can be fed to a stretch-reducer to make many different size of tube therefrom.

The design features of two and three roll stretch-reducing mills are described in a detail in article by Stoffer (30).

2.5.6 STRAIGHTENING

During the tube manufacturing processes, stresses are produced which are usually unbalanced, causing bends in the tubes. These bends can be eliminated by straightening processes. In this process the tubes are bent in opposite direction of the original bend by an amount of load which exceeds the elastic limit in the outer fibres of the cross-section, to correct the original bend.

A common method applied to all kind of tubes is to pass them through a reeling machine; a cross-rolling process between concave rolls set at an angle causes the tube to rotate and imparts forward motion. The use of concave rolls provides line contact between the rolls and the tube. Several concave rolls may thus be used in succession, causing the tube to rotate as it travels forward, bearing against each successive roll one side or the other and subjecting it to a continuous straightening action.

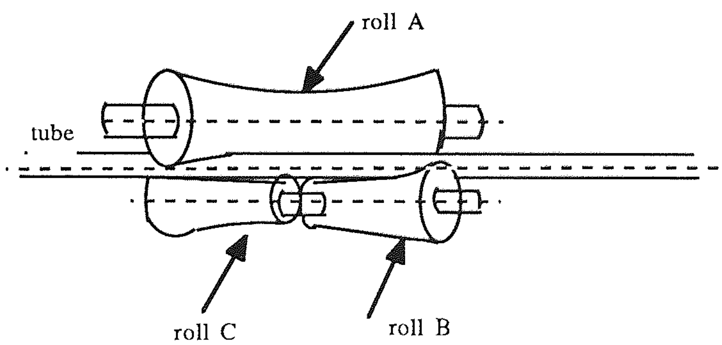



Figure 2.4: 3-roll straightening machine

Reeling machines have different configurations of rolls and number of roll stands, as described by Siegrest (31) and Fangmeier (32). A three-roll straightening machine is shown in figure 2.4; rolls B and C act as support points and lie in one plane with their parallel axes while roll A applies the straightening load and is at an angle to rolls B and C. All three rolls are driven by individual motors.

## 2.6 NON-ROTARY PROCESSES

Non-rotary processes for the manufacture of seamless tubes do not require any form of rolling and can generally be classified as:

(1) Extrusion processes

(2) Cold drawing process

### 2.6.1 EXTRUSION PROCESSES

In the extrusion process for the manufacture of tubing a billet is converted into a continuous length of uniform cross-section by forcing it to flow, under high pressure, through a die orifice which is shaped to impart the required form to the product. In the main it is hot working operation but it can also, in some instances, be carried out in the cold condition depending upon the composition of the material, pressure requirement and other conditions. A full account of modern extrusion practices can be found in the book by Pearson and Parkins (33); it can be either direct or indirect extrusion according to the direction of movement of piercing punch. The process as applied to the manufacture of tubing can also further classified into:

(1) Extrusion piercing

(2) Tube extrusion

(3) Combined piercing and extrusion

A brief outline of the above process is as follows.

### 2.6.1.1 EXTRUSON PIERCING

This method is used to manufacture shells from solid billets and is essentially a hot-working operation. The billet is preheated to give a suitable degree of plasticity and placed in a strong-walled enclosure (container) and caused to be pierced by a mandrel under pressure.

A simple diagram of the arrangement figure 2.5 for this process from Loewy (34) is shown below. For the extrusion of tubing from solid billets, the heated billet is confined in the container by the advancing motion of ram and piercing mandrel as shown in figure 2.5A.

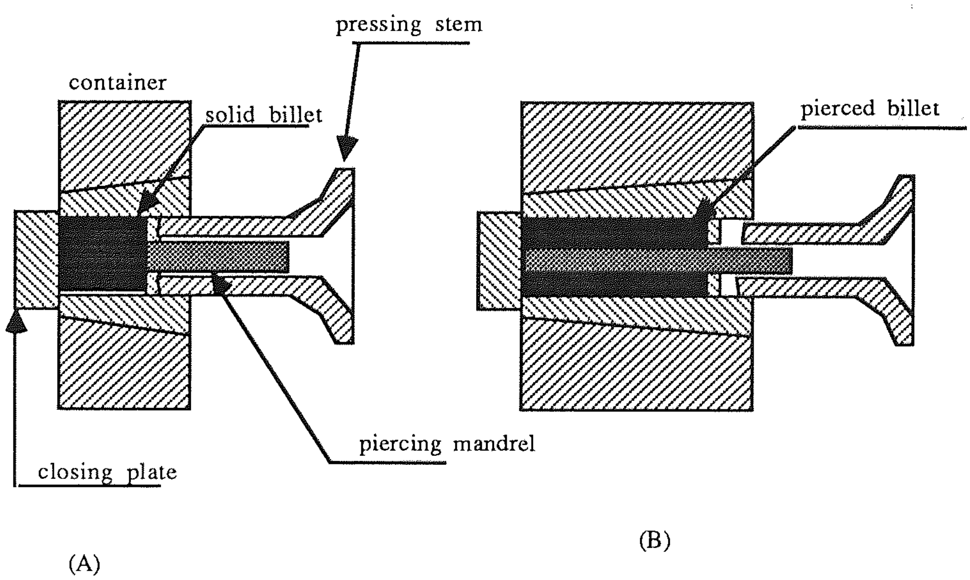



Figure 2.5: Extrusion piercing

The ram or pressing stem is then withdrawn to allow the back flow of material as shown in figure 2.5B while the piercing mandrel is advanced until the completion of the piercing operation. The design of the press usually provides for compression of the billet to make it fill the container prior to piercing. This prevents the eccentric piercing resulting from the billet lying to one side of the container.

Extrusion piercing has the disadvantage of increased pressure requirement and more rigidity of tools to attain better concentricity (35) compared with rotary piercing. This disadvantage is sometimes outweighed by the fact that extrusion is a compressive operation which often means that material which cannot be pierced by the rotary process can be extruded easily.

2.6.1.2 TUBE EXTRUSION

In the tube extrusion process, a pierced billet (shell) is confined in the container between the ram of extrusion press and the die. A mandrel extending from the ram passes through the shell and the die as shown in the figure 2.6 below. The forward motion of the ram squeezes out the metal between the die and the mandrel. The outside diameter is controlled by the die size while the mandrel size determines the inside diameter of the tube.

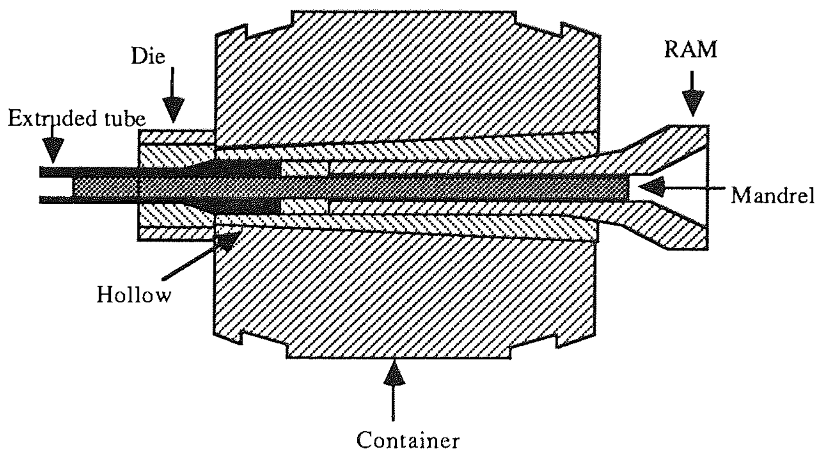



Figure 2.6: Tube extrusion

For the extrusion of tubes, the mandrel of the press can move in the direction of the extrusion with the speed of the ram or it can be stationary or it can move independently of the extruding ram. The detailed design of presses using these three principles are fully described by Evans (25).

### 2.6.1.3 COMBINED PIERCING AND EXTRUSION

The two aforementioned processes of extrusion piercing and tube extrusion are combined into a single operation which is called the combined piercing and extrusion process and can be used for the extrusion of large diameter tubes.

Briefly, in this process the billet is heated to extruding temperature and transferred into the extrusion press container rapidly. The billet is pierced by advancing the piercing mandrel which pushes the slug from the centre and allows the material to flow in the opposite direction round the mandrel. The shell produced is then forced through the die by the action of the pressing stem with the piercing mandrel advancing simultaneously and acting as a guide. The steps involved are explained by Loewy (34) in discussing developments in the extrusion of metal.

### 2.6.2 COLD DRAWING PROCESSES

With tube drawing, it is the inside surface, rather than the outside, that requires the greatest attention and dictates the quality of the cold-drawn tube. Cold drawing is a process where there is no metal removal, and the initial hot-worked surface is stretched to obtain a smoother one. There are four main methods available for tube drawing:

(1) Sinking
(2) Mandrel
(3) Fixed plug
(4) Floating plug

These methods are fully explained by Lardge (36), but a brief description to understand the principle is as follows:

### 2.6.2.1 SINKING

Sinking is the simplest form of the tube drawing and is shown diagrammatically in figure 2.7.

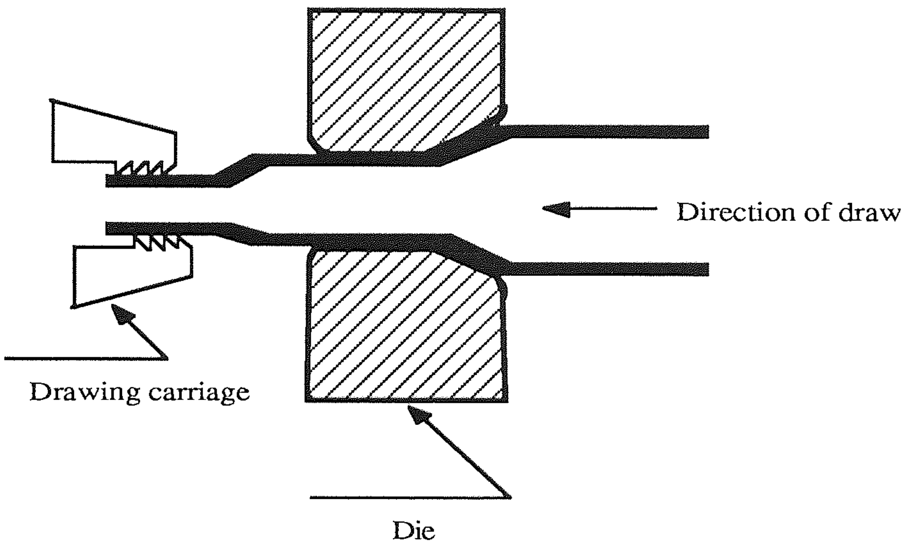



Figure 2.7: Tube drawing by sinking method

With no plug or mandrel in the bore, the tube is drawn through the die and there is no control over the bore size and surface condition. This process is used when the bore of the tube is not critical in its specification. The diameter reduction through the die causes some changes in the wall thickness i.e. the walls thicken slightly. For heavy wall thicknesses (d/t ratio 5:1), this thickening becomes a thinning operation, because of the uncontrolled flow of metal in the bore which causes a deterioration of the bore surface. The advantage of the sinking process is related to the absence of the plug in very small bore tubes in which it is not possible to insert any kind of plug or mandrel.

### 2.6.2.2 MANDREL DRAWING

Mandrel drawing is a far less popular process, but its main advantage is the greater reduction of wall thickness compared with fixed or floating plug drawing. In this process the bore clearance is just sufficient to allow the mandrel bar to be pushed into the tube before drawing as shown in figure 2.8. The diameter decrease can be kept

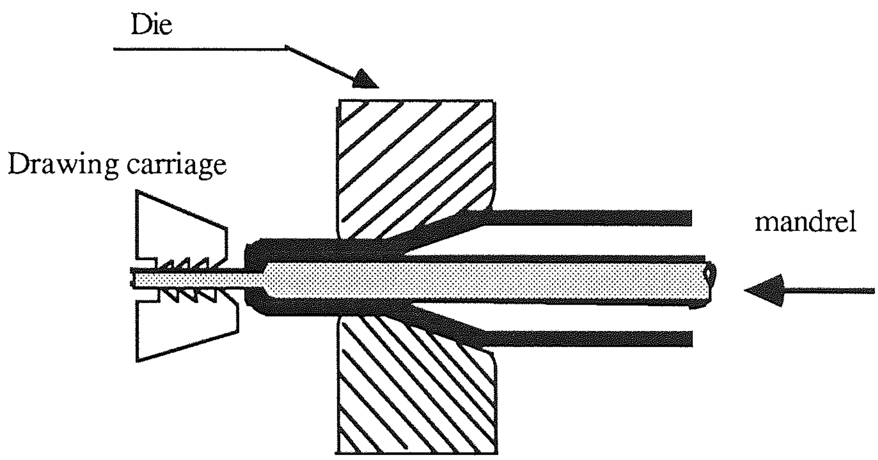



Figure 2.8: Mandrel drawing

small and the mandrel bar can be removed by expanding of the tube after drawing. In this process the finished bore size usually remains very close to the size before drawing. The end of the mandrel is reduced in diameter and may be shaped in such a way that it can be picked up easily by the drawbench carriage.

### 2.6.2.3 FIXED PLUG DRAWING

This is most versatile and best known method of drawing steel tubes. The parallel plug, when pushed into the deformation area, is acted upon by the axial forces required to reduce the wall thickness and to overcome the friction created by the forward sliding movement of the tube over the plug. A plug bar is required to hold the plug in the correct position in the throat of the die, the arrangement of fixed plug drawing is shown in figure 2.9. Excessive vibration of the bar and plug with poor lubrication may result in unstable drawing condition. The diameter of the plug determines the bore of the drawn tubes.

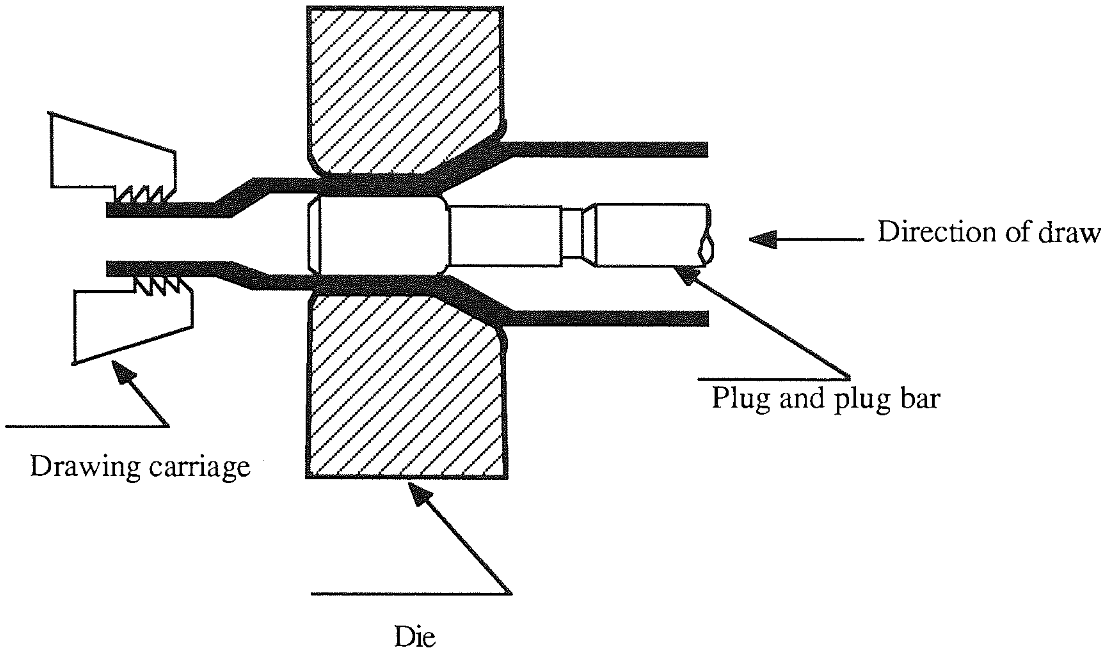



Figure 2.9: Fixed plug drawing

### 2.6.2.4 FLOATING PLUG DRAWING

In floating plug drawing, the plug remains in the correct position unsupported and the system is used for quantity production. The advantage of the process is the higher speed of drawing.

The floating plug has a parallel section and a cone section as shown in figure 2.10. The parallel section of the plug gives the final size to the tube and produces the forward pull while the cone section, does the initial thinning of the tube and produces the backward reaction to balance the forward pull to achieve the self-centering or floating action. In order to achieve the best drawing condition, it has been suggested that the difference between the die entry angle and plug angle should be between 3 and 7 deg.

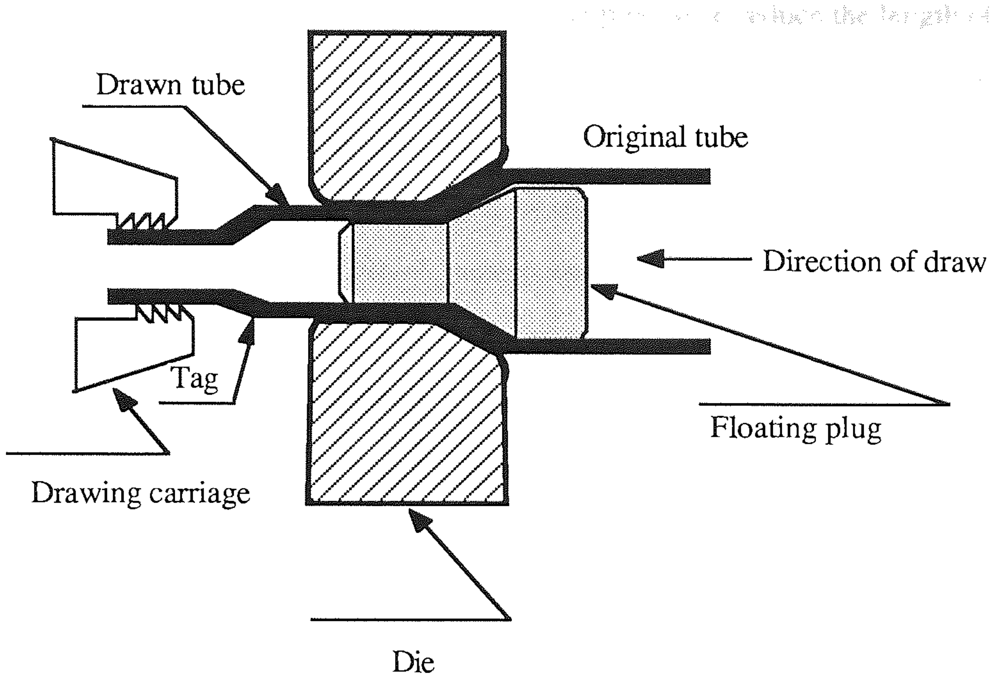



Figure 2.10: Floating plug drawing

## 2.7 SECONDARY PROCESSES

To enable the tube manufacturing process to be carried out efficiently, some other secondary processes are also used in the tube manufacture which include:

(1) Cutting

(2) Tagging and swaging

(3) Pickling

(4) Lubricating

(5) Annealing

(6) Normalising

(7) Tempering

(8) Finishing

### 2.7.1 CUTTING

The cutting process is used either as an intermediate process to reduce the length of the tubes to their required dimension or as a finishing process to cut the finished tubes to their required lengths. In cutting to length in the finishing department, circular-type saws are generally used. For cutting the raw material (round stock) into billets of the required length, oxy-acetylene or oxy-propane cutters are used.

### 2.7.2 TAGGING AND SWAGING

The tagging process, basically, involves reduction of the end of a tube, to a smaller diameter than the body so that the tube can pass through the throat of the die and can be gripped by the drawing carriage, as discussed by Evans (25). The reduction of the end of the tube is required to be achieved in such a way that the reduced end (tag) may not result in breakage. During the actual tube drawing operation, the tagged portion may fail, if the tube material is too hard or the reduction of area per pass is too heavy.

The swaging process usually adopted for the tapering or fine pointing operation necessary on the larger diameter tubes to a predetermined diameter and length. The length should be just sufficient to be gripped by the drawing carriage and should be kept to a minimum in order to reduce metal loss.

### 2.7.3 PICKLING

The pickling process is used to remove the oxide scale which is formed during hot working and to prepare the surface of the tube for lubrication. Tubes that are to have a second or subsequent passes, and have therefore to be annealed for redrawing, must have annealing scale removed in similar way.

Either hydrochloric acid or sulphuric acid is used for the pickling operation. Hydrochloric acid has the advantage of higher reactivity at normal temperatures and this can be increased by heating the acid. For practical purposes, it is not heated because of the evaporation of acid makes hazardous fumes.

Pickling is usually done in tanks, called vats or boshes, containing 5 - 10 % sulphuric acid at $65^0$ C as described by Mulcathy (37).The action of the sulphuric acid is to dissolve the inner layer of iron oxide while the outer layer is broken off by the evolution of hydrogen. The pickling time is very much dependent upon the type of the scale and condition of the acid solution, including the build up of iron in it, but can be decreased by raising the temperature of the bosh. In order to get an adequate flow of acid through the bore, the bundle of the tubes is dipped in and lifted up clear of the solution a number of times during the pickling cycle. In this way the tubes are emptied and replenished with fresh acid and adjacent tubes are moved in relation to each other to prevent unprocessed contact lines.

### 2.7.4 LUBRICATING

Lubrication is a governing factor in the cold drawing of tubes. Prior to lubrication a zinc phosphate coating is applied which acts as a carrier for the lubricant, behaving like a sponge because of its open crystalline structure. It soaks up the lubricant and also gives a non-metallic barrier to the surface of the tube. With a phosphate coating it is possible to re-lubricate the drawn tubes for a second pass without anneal.

The tube bundle is dipped into 10 % soap (sodium stearate) solution at a 60 $^0$C and allowed to drain. Normal atmospheric drying takes place and results in a soap film hardening on the tube surface. The soap film must be dry, otherwise its film strength will be so low that it readily breaks when tube and die are in intimate contact at a high pressure and siezure or "pick up" occurs. Other types of soap and oil lubricants are also used as discussed by Rowe (38).

### 2.7.5 ANNEALING

The tube material during cold or hot working processes becomes hard and difficult to re-draw. Annealing is the heat treatment process to soften such tubes before any further cold drawing process is carried out. For low carbon steel, which forms the bulk of the tonnage in the seamless steel tube industry, this is a sub-critical anneal between temperature range of 650 - 700$^0$ C in the furnace. The tubes must be held at this temperature for between 20 - 30 min, after which they are taken out and allowed to cool. The annealing restores the structure of the steel tubes and become soft enough for subsequent drawing.

### 2.7.6 NORMALISING

In the normalising process, low carbon steel tubes are heated to between 810$^0$ C and 950$^0$ C for 20 - 30 min and then taken out for air cooling. The normalising process completely restores the steel to its initial condition before drawing. Sometimes tubes of alloy steel, which become hardened because of rapid cooling, are allowed to cool within the furnace by heating them to normalising temperature and then shutting off the furnace and allowing the tubes and the furnace to cool down together. The tubes can be taken out from the furnace at any temperature below 700$^0$ C. This process is very slow and hence becomes expensive.

### 2.7.7 TEMPERING

Some specifications for tubes require tempering after cold drawing. This is done by heating the tubes in the furnace to within the temperature range 650$^0$ C - 720$^0$ C for one to four hours.

## 2.8 FINISHING PROCESSES

There are certain other processes which are used to achieve the required finish of the tubes. These processes include :

(1) Electro-plating

(2) Galvanising

(3) Honing

(4) Grinding and polishing

### 2.8.1 ELECTRO-PLATING

Electro-plating is the process of depositing a coating by means of electrolysis to alter the characteristics of the tube surface so as to provide improved appearance, protection from corrosion and ability to resist abrasion or other desired properties. The electrolysis is carried out in a solution of fused salts.

### 2.8.2 GALVANISING

Galvanising is the process of zinc coating, in which the article to be coated is thoroughly cleaned and, then completely immersed in the molten metal and, when withdrawn, enough of the molten metal adheres to the surface to give the desired coating. Sometimes an addition of aluminium in the molten zinc gives rise to the formation of a bright zinc coating and increases the corrosion resistance property.

### 2.8.3 HONING

Honing is the process of the finished machining of cylindrical surfaces (internal and external) with the objective of improving size, geometric shape and surface quality.

Grinding strips with various grain sizes are used to abrade the surface to attain a certain smoothness either manually or by mechanical methods.

### 2.8.4 GRINDING AND POLISHING

For external grinding and polishing, the tube is placed between the abrasive surface and feed roll and is supported by a suitably adjusted rest . Internal grinding of the tube is a difficult operation except where the bore is large enough to permit the free access of abrading tool. Tubes are usually polished and ground on centreless machines.

## 2.9 TUBE MILLS

Basically, the different types of tube mills which emerge by the combination of the various manufacturing processes previously described, can be classified into the following three categories:

(1) Welded tube mills
(2) Non-rotary tube mills
(3) Rotary tube mills

The first two types of tube mills will be described briefly, while detailed description is required for the rotary tube mill to highlight the process planning problems associated with such an installation.

### 2.5.1 WELDED TUBE MILLS

There are a large number of welding and forming processes which give a considerable variation in welded tube mills depending upon the process being used. Generally, a welded tube mill will have the following facilities according to sequence of operations in the manufacture of welded tube:

- Machines for the preparation and handling of raw material in the form of coils and strips.
- Cold forming units for progressively forming the strips into "O" shaped open seam tubes.
- Welding equipment to weld the open ends of the "O" shaped tube.
- Sizing mill to provide close control over the dimensions
- Finishing section comprising straightening machines, heat-treating furnaces, sawing machines for cutting to length and testing and inspection equipment.

Detailed descriptions of such tube mills can be found in the works by Middleton (22), Rodder (27) and Donaldson and Etherington(18).

### 4.9.2 NON-ROTARY TUBE MILLS

The non-rotary tube mills may consist of:

- Furnaces to heat the billets to required temperatures
- Extrusion presses for piercing and extruding billets into shells.
- Sizing plant which may consist of drawbenches, heat-treating furnaces and other facilities. The extruded shell can be sized on the drawbench by inter-pass annealing to restore ductility to the tubes that have been work-hardened during previous cold working operations.

Some non-rotary tube mills may have their own facilities for melting the material and casting the billets in the foundries.

### 2.9.3 ROTARY TUBE MILLS

The configuration of a rotary tube mill may depend upon the equipment it employs and generally consists of:

- Billet heating equipment
- Rotary piercing mill to for initiating the hole in the heated billet to form into blooms
- A cross-rolling mill to elongate the bloom and to give it concentricity with additional equipment such as mandrel bar handling, strippers etc.
- Reheating furnaces
- Stretch reducing or sizing mill.

The capabilities and constraints of such a rotary tube mill are described in Chapter 4 together with the formulation of the process planning problems.

# CHAPTER 3

## PROCESS PLANNING - A REVIEW

### 3.1 INTRODUCTION

Process planning has been defined as preparing the detailed plan of actions to transform raw material into required finished shapes. Traditionally, the process planning function was carried out manually by a human planner, but since Niebal (12) first discussed the use of the computer to assist the process planning tasks, there has been a trend towards the automation of this function. Over the last two decades, the central role of process planning in production flow and in the definition of the global strategy of a manufacturing concern has been more and more recognised. Many researchers, both in academia and industry have worked towards the automation of this function in order to bridge the advanced and matured technologies of Computer Aided Design and Computer Aided Manufacturing. This can be a step forward towards the unmanned factories of the future.

The first part of the chapter discusses the sub-tasks of process planning, manual approach and the need of computer assistance in process planning. Then the variant and generative approaches of process planning are reviewed and their merits and demerits evaluated. The second part of the chapter is devoted to the generative approach based on the Knowledge-Based technique. In this part, a review of Knowledge-Based Systems is presented; their structure, knowledge representation techniques and the application of such systems for generative process planning in different domains of manufacturing are discussed.

## 3.2 PROCESS PLANNING SUB-TASKS

The function of process planning, whether it is manual or automatic, includes the following sub-tasks as mentioned by Weill et al (5) and Houten and Van't Erve (39):

- Selection of blank and material
- Selection of machining processes
- Selection of machine tools
- Selection of cutting tools
- Selection of operation sequence
- Determination of cutting conditions (speed, feed and depth of cut)
- Selection of jig and fixture and determination of set-ups
- Calculation of standard times and costs for operations
- Calculation of tool paths and NC generation

The above sub-tasks of process planning are particularly concerned with the machining domain but can be used for other domains of manufacturing such as forming, assembly, welding and printed circuit board by modifying their detail appropriately.

## 3.3 MANUAL PROCESS PLANNING

Manual process planning is an experience-based method of developing process plans. In this approach, the engineering drawings are examined by the human planner and the processes are selected on the basis of the product and process knowledge, machine tool capabilities, tooling, material, related costs and shop practice (11). This requires a considerable amount of shop floor experience and familiarity with shop capabilities on the part of the planner. In order to develop the new plan, the manufacturing methods for similar parts produced in the past are recalled and modified accordingly. This approach is suitable in companies where the number of processing alternatives is small.

According to Steudel (11), Allen (40) and Austin (41), the manual approach to process planning is highly subjective, labour intensive, time consuming and tedious. The notable disadvantage of this approach is the difficulty for a human to recall past experience, cope with too many alternatives and several revisions. Wysk et al (42) has pointed out that manual process planning nearly always results in non-standard process plans and tooling, resulting in higher than necessary production costs. This has been confirmed in a study to develop process plans manually for a family of spur gears as quoted by Al-Qattan and Sundaram (43). For a sample of 425 of process plans, there were 377 different plans for operation sequence, 54 different types of machine selection and 15 different materials used. Clearly, all of these process plans cannot be cost effective and many reflect the degree of personal experience, preference and even prejudice of process planner. Furthermore, the task of process planning in companies with a wider variety of products becomes unmanageable for a human planner.

## 3.4 NEED OF COMPUTER ASSISTED PROCESS PLANNING

The process planning function is preparatory work for manufacturing and can take as much as 40 % of the time as mentioned by Rehman and Narayanan (44). Experience planners are rapidly diminishing in numbers and the rate of change of design is so rapid that the life time for older models of household appliance is less than the delivery time (45). The limitation of manual process planning and increased rate of design changes on the other hand demand an alternative way of performing process planning to react more rapidly in developing process plans. The only alternative is the use of the speed and consistency of computers and due attention has been paid to exploiting it for the standardisation of process planning and to capturing the manufacturing logic (46). As a result of these efforts two approaches have been evolved, namely:

1. Variant approach
2. Generative approach

These two techniques will be discussed in the remainder of this chapter.

## 3.5 VARIANT APPROACH TO PROCESS PLANNING

The variant approach is based on the Group Technology (GT) concept (47), in which the individual parts are assigned codes, using a coding and classification scheme and are grouped into part families based on certain similar design and manufacturing characteristics. For each part family, a standard process plan is developed and stored permanently in the database making a library of standard process plans for different part families. This step is termed as the preparatory stage of variant process planning as described by Chang and Wysk (9).

The process planning tasks for a new part starts with giving a proper code number to it based on design and manufacturing attributes. Using this information, a search is carried out for a part family number to which the new part belongs and associated standard process plan is retrieved. This plan is then modified to reflect the specific characteristics of the new part creating a "variant" to the basic plan. If the standard plan does not exist, then a new plan is created and stored in the database system for future use. According to many researchers (9, 11, 47), this approach is merely a computer-assisted extension of the traditional manual approach, where the computer assists by providing an efficient system of data management, retrieval, editing and high speed printing.

In order to visualise the development and working of the variant approach, an over-simplified example can be devised. Suppose that the three parts shown in figure 3.1 are to be manufactured in a workshop containing the following facilities.

1. S01 - a sawing machine to cut the blanks for the finished part from raw material

2. L01 - a CNC lathe

3. M01 - a coordinate measuring machine to inspect the part

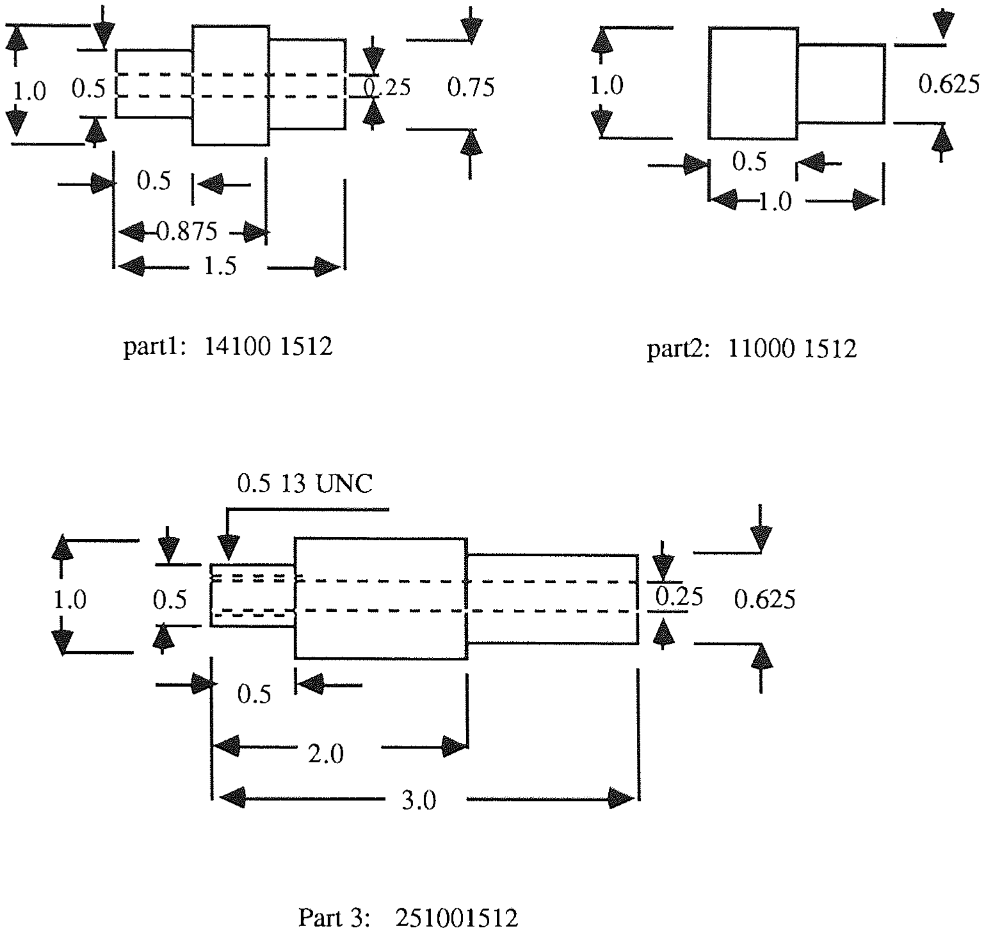



Figure 3.1: Three components and their associated OPTIZ code (not to scale)

The steps required to develop a variant process planning system for such a shop are as follows:

1. Classification and coding
2. Preparation of process summary table
3. Part family formation
4. Database structure
5. Searching
6. Editing

### 3.5.1 CLASSIFICATION AND CODING

The British Institute of Management (48) has defined the classification as "the systematic arrangement of similar items into suitably selected categories". Coding is the process of allocation of meaningful symbols to components based on the presence or absence of design and manufacturing attributes. Associated with the growing practice of GT, there has been the development of new classification and coding systems to identify the parts according to the features they contain, such as OPTIZ, MICLASS and CODE etc. Groover and Zimmers (49) has divided these systems into three categories based upon:

- Part design attributes
- Part manufacturing attributes
- Both design and manufacturing attributes

The systems based upon the manufacturing attributes have many other applications and are well suited to process planning functions. The structure of the coding system may vary and can be hierarchical, chain type, or a combination of hierarchical and chain type referred to as hybrid. In hierarchical code, each succeeding symbol depends upon the value of the preceding symbol, giving a relatively compact structure. In the chain type structure, the interpretation of each symbol in the sequence is fixed and these codes tend to be relatively longer. The OPTIZ code has been chosen for the example and is a chain type. The code for example parts are shown in figure 3.1.

### 3.5.2 PREPARATION OF PROCESS SUMMARY TABLE

The process summary table represents the information concerning the design and processing of existing components and helps in the formation of part family matrices in the next stage (9). The table represents the code number allocated to each part and operation plan (OP) code sequence. In the example the OP code sequence for all the three components is the same i.e., S01, L01, M01. The summary table is shown in table 3.1 below. Where OP code e.g. (L01) represents a series of operations to be performed on one machine such as turning, facing and threading on lathe.

| part No. | code | OP code sequence |
|---|---|---|
| 1 | 14100 1512 | S01, L01, Inspect |
| 2 | 11000 1512 | S01, L01, Inspect |
| 3 | 2500 1512 | S01, L01, Inspect |

Table 3.1: Process Summary table for example parts

### 3.5.3 PART FAMILY FORMATION

In the example, there are only three components having the same sequence, forming one part family matrix. However, in actual practice, there are thousands of components in a workshop which cannot be grouped into part families merely by observation. Special techniques, such as Production Flow Analysis (PFA), are used to construct a large matrix whose rows and columns represent the OP code and components respectively. The elements of such a matrix represent the presence or absence of OP code for that particular component. The special algorithm as discussed by Kusiak (50) can be used to rearrange the matrix in such a way that the components requiring a similar operation sequence are grouped to form a family of components.

The families thus obtained are represented in a manner consistent with the coding scheme to form a part family matrix. A part family matrix is a binary matrix (Fig. 3.2 for example components) with a rank I x J, where I represents the possible values in

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| 0 | | | 1 | 1 | 1 | | | | |
| 1 | 1 | 1 | 1 | | | 1 | | 1 | |
| 2 | 1 | | | | | | | | 1 |
| 3 | | | | | | | | | |
| 4 | | 1 | | | | | | | |
| 5 | | 1 | | | | | 1 | | |
| 6 | | | | | | | | | |
| 7 | | | | | | | | | |
| 8 | | | | | | | | | |
| 9 | | | | | | | | | |

Figure 3.2: Part family matrix for example components

each code position (usually 0-9 as in OPTIZ code) and J is the code length (9 in OPTIZ). The element of such a Matrix ($P_{IJ}$) is 1 when code position J is allowed to have a value I otherwise it is zero.

### 3.5.4 DATABASE STRUCTURE

Database is a group of cross-referenced data files containing information regarding part family matrix, associated standard plans, operation plans, operation parameters and other necessary data. These files should be arranged in such a way that access to any information is easy and efficient. These files may be arranged in relational or hierarchical format.

### 3.5.5 SEARCHING FOR STANDARD PROCESS PLAN

The searching for the standard process plans and parameters begins with assigning a code number to the new part. The system allows the input of the code number to execute a search for the part family matrix. The search is based upon matching the presence or absence of attributes in a part family matrix for the values of every position in the code. A successful search means that all the attributes of the new part are present in the family number and the part family has been found. The associated standard process plan is retrieved and the parameters are selected.

### 3.5.6 EDITING THE STANDARD PROCESS PLAN

Since the standard process plan may not be suitable for the manufacture of new part, the system usually allows the planner to edit the process plan to suit the manufacture of the part. For editing the standard process plan, the planner relies on past experience, which is a drawback of variant system.

### 3.5.7 ADVANTAGES AND DISADVANTAGES OF VARIANT THE APPROACH

The variant approach has many advantages over the traditional manual approach as discussed by Steudel (11), Alexander and Jaganathan (51), Eskicioglu and Cebeci (52) and Atling and Zhang (53). The main advantage being the simplicity of this approach requiring less investment and shorter development time. In the operational stage, the variant approach firstly promises less time consumption in developing process plans because of the efficient data retrieval and editing facilities of the computer. Secondly, it helps in preparing accurate and consistent process plans and helps in eliminating the clerical work from the planner.

The biggest disadvantage of this approach is the need of a experienced planner to construct the plans for a new part family and to modify the existing plans to suit the requirements. This implies that the variant approach is unsuitable for Computer Integrated Manufacturing (CIM) and cannot play its vital role in bridging the CAD and CAM technologies.

### 3.5.8 VARIANT TYPE SYSTEMS

A number of systems using the variant approach have been developed by different organisations. Examples of such systems include MITURN (20), MIPLAN and MIAPP (55) and CAPP (13). Other Systems which have been developed using the variant approach can be found in the survey given by Weill et al (5), Eversheim and Schulz (56), Chang and Wysk (9) and, more recently, by Atling and Zhang (53).

## 3.6 GENERATIVE APPROACH TO PROCESS PLANNING

The generative approach to process planning involves the automatic generation of a unique plan for each component as opposed to the variant approach which requires the storage of standard plans. According to Steudal (11), the generative approach makes use of manufacturing decision logic, formulae, technological algorithms and geometry based data in order to determine the alternative decisions for converting a part from rough to finished state uniquely . This approach, on the one hand requires the detailed part description in terms of geometrical features ( a feature is a distinctive part of a workpiece, defining a geometric shape such as holes, slots etc.) and their attributes (size, location) and technological characteristics (surface finish, tolerance etc.). On the other hand, it requires the incorporation of manufacturing decision logic in terms of the experience and skills of the planner in order to mimic his decision-making process.

The essential components of a generative process planning system, thus, are as follows as mentioned by Chang and Wysk (9).

- Part description
- Process capabilities and limitations
- Manufacturing decision logic

### 3.6.1 PART DESCRIPTION

A fundamental requirement in a generative process planning system is the ability to describe the shape of the component. The part description techniques are varied from system to system but the three techniques which have been in use are:

- Group Technology code
- Part description languages
- CAD model

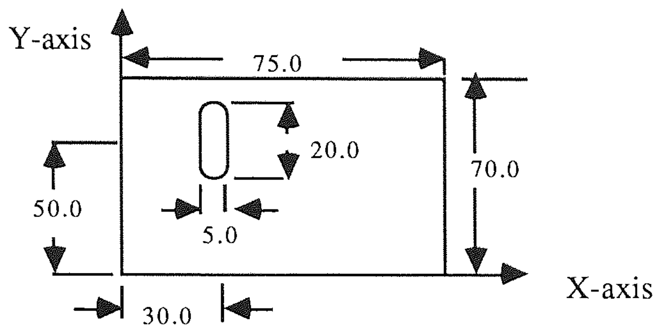
#### 3.6.1.1 GROUP TECHNOLOGY CODES

The GT code, based on design and manufacturing attributes have been used in the generative systems. In such codes, it is necessary to record detailed information including the method of manufacture as well as design attributes, as discussed by Love (57). APPAS (42) and Micro-GEPPS (58) are two examples of such systems using GT code as input.

Micro-GEPPS is a code-driven system using 21-digit KK-3 code which represents the external and/or internal geometry, basic dimensions, material and other information.

#### 3.6.1.2 PART DESCRIPTION LANGUAGES

Part description languages are specially designed to describe a part in terms of their geometric feature, size, location and other characteristics which are used for decision-making at later stage. The system AUTAP (59) for sheet metal parts, uses a language containing a special code to represent the features and related attributes. The use of such a language for a part and associated description code taken from the original example is shown in figure 3.3. The first code "BLANK" describes the work piece blank by dimension (length, width and thickness) values. The next element defined by a code "HOLELONG" describes a long hole with length, width, shape definition and position of the hole at xx = 30 and yy = 50. Similar codes are used to describe the full part.




| WZL | Part description |
|---|---|
| BLANK | /75,70,2/ |
| HOLELONG /20,5,0,xx=30,yy=50/ | |

Figure 3.3: A sheet metal part and its description code (Evershiem)

Another way to describe a part is a combination of graphical vectors and alphabetical symbols. This approach is interactive and has been discussed by Liu and Allen (60). In the knowledge-based systems, components can be described by the Artificial Intelligence languages as discussed in the second part of the chapter.

#### 3.6.1.3 CAD MODEL

The CAD model or, more specifically, geometrical model, is concerned with the computer-compatible mathematical description of the geometry of an object. It contains all the necessary design information represented by solid modelling or other techniques. Solid modelling uses solid geometry shapes called primitives to construct an object by the use of Boolean operators as discussed by Groover and Zimmers (49). The most prominent techniques in solid modelling are Constructive Solid Geometry (CSG) or Boundary-representation (B-rep). In CSG, the complex solids are defined by the use of

Boolean operators (union, difference or intersection) on primitive solids (cylinder, cone etc.) which are called as the building blocks for CSG.

The CAD model as such cannot be used as an input to the process planning system because of the different representation scheme employed in CAD and CAPP as discussed by Houten and Van't Erve (39), Graves et al (61) and Chang and Wysk (62). The representation of parts in a CAD model is in terms of 'coordinates', 'faces' and 'edges' without mentioning technological information for manufacture. On the other hand, the CAPP systems require inputs in terms of manufacturing-specific features such as 'grooves', 'holes' etc and their technological information. There have been many research efforts to integrate CAD and CAPP by identifying the form features from a CAD model as discussed by Grave et al (61) and Henderson (63). Examples of such integrated systems include CADCAM (62) for hole making and TIPPS (9).

### 3.6.2 PROCESS CAPABILITIES AND LIMITATIONS

It is well known that different processes can be used to attain different tolerances and surface finish. For example, a twist drilling process cannot be used to make a hole of an accuracy attainable by the boring process (62). Every process has different capabilities in term of producing shapes, surface finish and tolerances. There are also physical limitations and constraints associated with the process; a boring process cannot be selected until a hole is drilled first.

In generative process planning systems, the processes and parameters, machine capabilities and their constraints and associated tooling information are required to be stored in appropriate files. This information is required at a later stage in order to select the processes, machines and tooling.

### 3.6.3 MANUFACTURING DECISION LOGIC

The manufacturing decision logic is the major component of a generative process planning system. The prime function of manufacturing decision logic is to compare the geometrical and technological description of the part to be manufactured with the process capabilities, in order to select the appropriate machining process. It also determines the sequence of the selected processes on the basis of their precedence relationship and operation planning parameters as discussed by Weill et al (5), Steudel (11), Wysk et al (42) and Chang and Wysk (9).

Allen (40) and Groppeti and Semeraro (64) have quoted three manufacturing decision logic techniques namely:

- Decision tree logic
- Decision table logic
- Artificial Intelligence (AI) techniques

The first two categories will be briefly discussed and illustrated here, while AI techniques will be elaborated in the second part of this chapter.

#### 3.6.3.1 DECISION TREE LOGIC

A decision tree is composed of branches and their junctions; the conditions are set on the branches of the tree while the actions are at the junction of each branch. During the search, if the conditions become true, a pre-determined action stored at the junction is taken. Examples of generative process planning systems using this logic include Micro-GEPPS (58), APPAS (42), DCLASS (65) and CADCAM (62).

An example of such a decision tree to select the process, taken from Micro-GEPPS system, is shown in Figure 3.4 which shows how the logical checks are made for the given conditions of a coded part (KK-3 coding system) to be manufactured in order to select appropriate process.

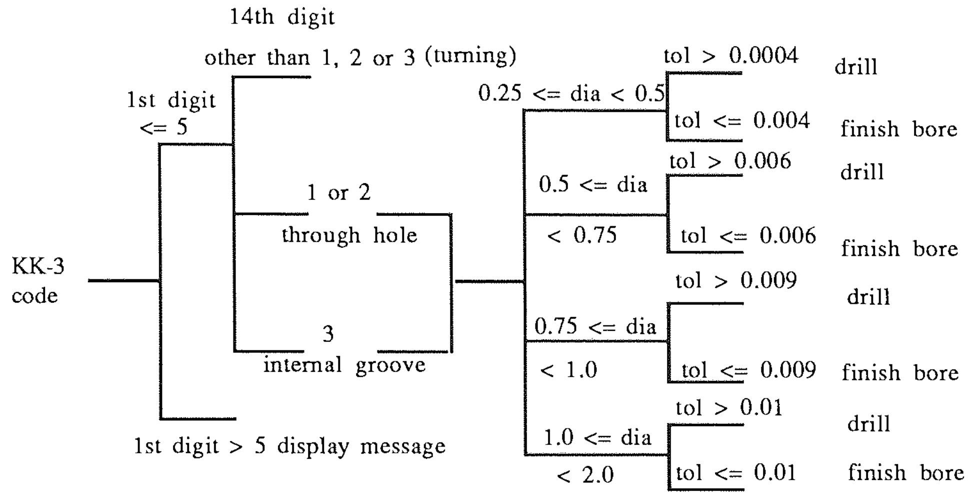



Figure 3.4: Decision tree for process selection after Wang and Wysk (58)

### 3.6.3.2 DECISION TABLE LOGIC

The structure of a decision table is in the form IF <conditions> THEN <actions> statements. The conditions and actions statements have their corresponding entries

| | | |
|---|---|---|
| Hole | * | * |
| 6.35<= dia < 12.7 | * | * |
| tol > 0.1 | * | |
| tol < = 0.1 | | * |
| drill | * | |
| finish bore | | * |

Figure 3.5: A decision table for the selection of first two processes shown in figure 3.4

which are either true or false. In order to execute an action/s, the set of condition entries must be satisfied, as discussed by Milner (66). A partial decision table in figure 3.5 represents some of the conditions and associated actions from the decision tree shown in figure 3.4 . For example, the table shows that a drilling process should be selected for a hole of diameter in the range 6.4 and 12.7 mm and tolerance greater than 0.1 mm. Examples of generative systems using decision table logic include AUTAP (59) and TIPPS (9) which uses a special language for storage and access of the tables.

### 3.6.4 GENERATIVE CAPP SYSTEMS

Many examples of generative type CAPP systems have been mentioned in the preceding sections. These systems are mainly developed for machining domains such as rotational, prismatic, sheet metal parts and assembly operations. Some more examples of such systems may include XPS-1 (64), CMPP (41), ACAPPS (52) etc. AUTOPASS (67) and CAPP-ASS (68) are the two examples of assembly process planning. More examples of generative process planning systems can be found in surveys by Weill et al (5), Chang and Wysk (9) and Atling and Zhang (53).

It may be useful to point out at this stage that some systems are reported to have a hybrid structure (i.e. a combination of variant and generative approach) such as ICAPP(69) and TOJICAPP (70).

### 3.6.5 MERITS AND DEMERITS OF GENERATIVE APPROACH

The generative approach to process planning has advantages over the manual and variant approach as discussed by Steudel (11) and Groppeti and Semeraro (64) namely:

- Process plans can be generated without a skilled planner.
- New parts can be planned as easily as the existing components.
- Process plans are more accurate and consistent because of the same logic.

- Generative approach has a scope in CIM.

The disadvantages of this approach is related to the use of conventional programming techniques where the software is composed of hundreds of interlinked units making a "spaghetti type" structure. Modification to such a system is severely limited, as discussed by (40), and this structure makes the system rigid and inflexible. The disadvantage of rigidity really becomes obvious when a company wants to incorporate major design changes or new facilities. As quoted by Atling and Zhang (53), some have taken the view that the generative system will not be possible using conventional techniques of programming. It is the AI technique which opened the new opportunity for the development of such systems.

## 3.7 ARTIFICIAL INTELLIGENCE

Feigenbaum (71) describes Artificial Intelligence as 'a sub-field of computer science concerned with the concepts and methods of symbolic inference by a computer and the symbolic representation of knowledge to be used in making inferences. A computer can be made to behave in ways that humans recognise as "intelligent" behaviour in each other'. The AI is thus concerned with devising of intelligent computer programs that exhibit the characteristics which are associated with intelligence in human behaviour. These programs make the computer 'smarter' in solving problems by imitating the basic human reasoning process.

The field of Artificial Intelligence consists of several areas of study as described by Schildt (72) namely:

- Searching for solutions
- Knowledge-Based Systems (KBS)
- Pattern matching and recognition

- Natural language processing
- Logic and fuzzy logic

Some of the above areas such as searching for solutions and natural language processing are AI building blocks which are added to other programs to enhance their performance. Knowledge-Based Systems are the first viable product of AI and represent a final application. The following sections give an overview of searching for solutions, knowledge-based systems and their architecture, knowledge representation schemes and application of these systems in the field of process planning.

## 3.8 SEARCHING FOR SOLUTIONS

There are many ways to search for a possible solution, the most common techniques are (72):

- Depth-first search
- Breadth-first search
- Heuristic search (least-cost search)

Only the Depth-first search and Heuristic-search will be described because of the application of these techniques in the present work. The description of other techniques may be found elsewhere (72, 73).

In Depth-first search, the inference engine takes every opportunity to produce sub-goals by digging deeper and deeper into the knowledge-base until it finds a solution or finishes the search space. This strategy is similar to that of an expert who tends to focus on specific aspects of the problem. In Depth-first search, each possible path to the goal is explored to its conclusion before another path is tried. As an example, consider a tree structure of different processes available for machining as shown in figure below. The goal is to select a 'straight turning operation' marked as 'F'.

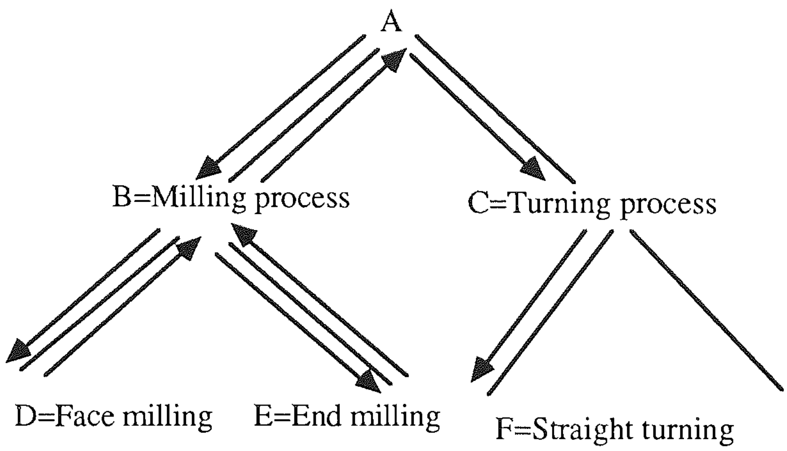



Figure 3.6: Depth-first strategy

A Depth-first search will traverse this tree in order of 'ABDECF', where A is the start point and every other letter represents a machining operation. In this type of traversal, the search is executed towards the left side until a terminal node is reached or a goal is found. If a terminal node is reached, then it backs up one level, goes right, and then left until encounters either the goal or examines the last node in the search path. The turbo prolog language ( a PC version of prolog) which has been used for present work, uses Depth-first search strategy in finding the goals.

Depth-first search is a blind routine and relies solely upon moving from one goal to another without the use of heuristic rules, which results in an inefficient search. There must be some strategy to optimised this type of search and this is where the Heuristic-search comes in. These methods are based upon maximising or minimising some aspects of the problem. In the above example, the search time can be minimised by providing a heuristic rule or a predicate which differentiates the paths leading to milling and turning processes and the path is taken which leads to the desired goal. Heuristic rules of this nature will lead more closely to the solution in less time or in a cost effective manner.

## 3.9 EXPERT SYSTEMS AND KNOWLEDGE-BASED SYSTEMS

It is necessary to clarify, first, the dual usage of the terms 'Expert System' and 'Knowledge-based systems'. According to Waterman (15), an expert system is that which applies 'expert' knowledge to solve difficult and real problems and every expert system is a knowledge-based system. He stresses that a knowledge-based system for a simple problem cannot be called an expert system. Feigenbaum and McCorduk (71) describe expert systems as speicies of knowledge-based systems and add that these two terms are often used interchangeably.

Harmon and King (74) argued that at first the systems were developed by interviewing a recognised human expert in the field and capturing his knowledge, hence the term 'expert system' was used. Now, systems are being build using knowledge engineering techniques that contain the knowledge of a difficult decision-making situation but hardly equivalent to a human expert. Since it cannot be said that a system build by this technique captures the knowledge of human experts, 'Knowledge-based system' is becoming the preferred name. They conclude that the two terms are synonyms, the view shared by Feigenbaum and McCorduck (71).

## 3.10 KNOWLEDGE-BASED SYSTEM DEFINED

A knowledge-based system has been defined by Feigenbaum and quoted by Harmon and King (74) as 'an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require human expertise for their solution. Knowledge necessary to perform at such a level, plus the inference procedures used, can be thought of as a model of the expertise of the best practitioners in the field'.

It might be interesting to give a brief history of knowledge-based systems. The early AI efforts were concentrated on the development of a generalised problem-solver using search algorithms, as discussed by Waterman (15). It soon become apparent that the general problem-solving programs are not the answer, because of the difficulty of handling broad classes of problems. Efforts were focused on very selective approaches by developing powerful inferring techniques (75). This technique had very little success and scientists soon realised that the intelligence performance of a program comes from the quality and the quantity of domain-specific knowledge and not simply from the reasoning capability. This was referred to as knowledge principle (75) and termed as a significant breakthrough in the technology.

The knowledge-based systems are high performance and special purpose programs, as mentioned by Allain (76), that facilitate the mental work of a human being by providing decision support based on the conclusions drawn from stored knowledge, which may be the skills of an expert in his domain of expertise or knowledge collected from text books and journals. The skill of an expert is the personal range of information or the familiarity gained by experience as discussed by Beerel (77). This knowledge is organised by the knowledge engineer in a way that separates the knowledge about the problem domain from the general knowledge of problem solving. The collection of domain knowledge is called the 'knowledge-base' while the general problem-solving knowledge is called the 'inference engine'. Thus the inference engine performs logical inferences and deduces new knowledge from the knowledge base until the posed problem is solved.

## 3.11 COMPONENTS OF A KNOWLEDGE-BASED SYSTEMS

As discussed by Kriz (78) and Harmon and King (74), a knowledge-based system consists of at least two components, as shown in figure 3.7, namely:

1. A knowledge-base with working memory

2. An inference engine and other subsystems

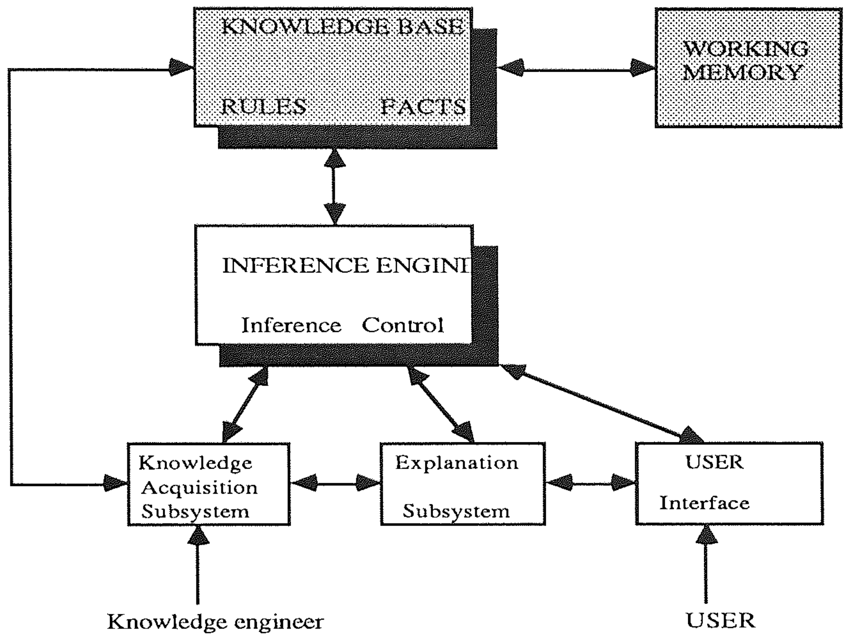



Figure 3.7: Components of a knowledge-based system (74)

The subsystems may include user-interface, knowledge acquisition, and explanation modules. In the following sections, these components will be described in detail.

### 3.11.1 KNOWLEDGE BASE AND WORKING MEMORY

The performance of a knowledge-based system depends upon the knowledge it possesses. The slogan "knowledge is power" is equally applied to society and knowledge-based systems. Feigenbaum (79) describes knowledge as an essential commodity for the success of society and adds that a knowledgeable worker who work smarter will have an upper hand over those who work harder, and the same is true for knowledge-based systems.

The knowledge-base consists of two types of knowledge; the facts and the heuristics.

The facts are widely shared, publicly available in text books and journals and usually agreed upon by the experts. Heuristics knowledge consists of little discussed rules of good judgement (71, 74) and is mostly acquired by the years of work experience in the field.

The knowledge base is different from the database as in conventional programs. The difference between these two can be made clear by considering an example in the domain of process planning. Supposing the manufacture of a component which contains a manufacturing feature, say, a slot. The data values describing the dimensions (length, width, depth), location of the slot with reference to some datum, surface finish and tolerance specified will constitute a 'database'. On the other hand, the data in form of facts and manufacturing rules are used to process the facts in order to select the machine, tool and fixture will constitute a knowledge-base.

### 3.11.2 INFERENCE ENGINE AND SUBSYSTEMS

The inference engine is the method of reasoning used to understand and act upon the combination of knowledge and the problem data in order to solve the given problem, as mentioned by Feigenbaum and McCorduck (71). It contains the general knowledge about the solution of problems in the form of rules and involves several different process that must work together. These processes, as discussed by Keller (80), may include:

- Identifying the sets of rules which are relevant to the problem situation
- Resolving the conflict between competing rules and selecting a best rule which is the most appropriate
- Execution of the selected rule by matching the conditional part to the available facts to reach a conclusion

There are two important strategies used in making inferences; the first being "forward chaining" and the second "backward chaining" .

In forward chaining, the search for new information proceeds from the left hand side to the right hand side of the rule in the forward direction (15). The system starts with the IF part of the rule and searches the knowledge base to satisfy the conditions in the IF part. Satisfaction of the conditions causes the THEN part of the rule to be invoked and the associated action is taken. Forward chaining systems are also called "data driven" systems.

In backward chaining, the process of inferring starts from a goal which is assumed to be true and works backward through sub-goals. In order to prove the given goal (THEN part), the system first tries to prove sub goals (IF part). When all the sub-goals are shown to be true, the goal itself is proved. Systems using this strategy are sometimes called "goal driven" systems. Prolog has the inference engine based on the backward chaining strategy and is the major advantage of its use. The use of prolog means that inferencing procedures do not have to be developed.

With reference to figure 3.7 the other subsystems in a knowledge-based system may include User interface, Explanation module and Knowledge acquisition module.

The user interface accepts the information from the user in a user-friendly manner and communicates the inferred results back to the user. In addition, the user interface is responsible for handling keyboard and screen input/output, supporting the dialogue between the user and the system, recognising the cognitive mismatch and providing user-friendly features such as menu systems, as discussed by Yin and David (81).

An explanation subsystem is required for answering the questions such as 'how' a certain conclusion is drawn or 'why' the systems needs a piece of information. This is achieved by displaying the recorded inference chain to the user or printing the rule associated with the situation.

A knowledge acquisition subsystem deals with the automatic or semi-automatic transfer of expertise from human experts to symbolic data structures that constitute the knowledge-base.

## 3.12 KNOWLEDGE REPRESENTATION

The purpose of the knowledge representation is to organise the required information into such a form that a program can access it readily for making decisions. This activity becomes central to knowledge-based system because of the argument (74,76,79) that the power of the problem solver lies in the explicit representation of knowledge that a program can access, rather than in the sophisticated mechanism of drawing inferences. The term "knowledge engineering" is used for extracting and organising knowledge. The task of the knowledge engineer is to extract the knowledge, represent it in the system and devise the method for inferring. There are a number of ways of representing knowledge and many books are available on the subject. The following techniques will be briefly reviewed:-

1. Semantic networks
2. Rule-based representation
3. Frames
4. Logic-based method

### 3.12.1 SEMANTIC NETWORKS

The idea of using semantic network is usually attributed to Quinlan as quoted by Alain (76). The semantic network is a collection of objects (physical or conceptual) called nodes which are connected together by arcs or links representing the relationship of objects. The description of the objects provides additional information. The best feature associated with semantic networks is the inheritance (15, 74).This means that a lower node in the hierarchy will automatically inherit the properties of higher level node.

As an example, the statements "twist drill is a hole-making tool" and "hole-making tools used on machining centre" can be presented in a simple network as shown in figure 3.8 below. Another statement can be concluded from this network which is not explicitly stated, that, "twist drill used on machining centre", because of the inheritance property.

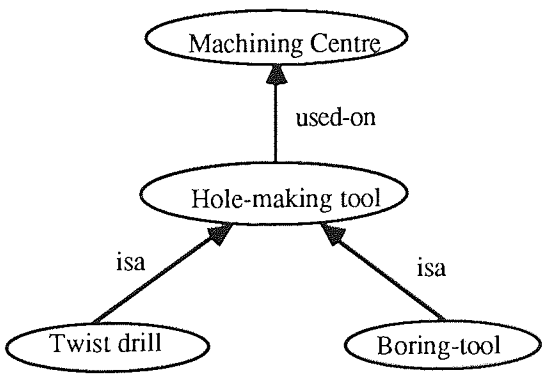



Figure 3.8: A simple semantic network

### 3.12.2 RULE-BASED REPRESENTATION

Rule-based representation is the most popular form of knowledge representation, where rules are expressed in the form of IF<conditions> THEN <actions>. As an example, the rule for selecting a tool to drill a hole as appeared in PROPLAN (82) can be of the form:

IF <OPERATION is DRILLING>

and<PARTMATERIAL is HIGH_CARBON_STEEL>

and<DIAMETER of HOLE is less than 2 inches>

and<HARDNESS of PARTMATERIAL is between 200 and 240 BHN>

THEN

<recommend DRILL with HELLIX 240 deg.>

The IF part of the rule defines a pattern to be matched against the available facts while the THEN part of the rule recommends an action to be taken. The action taken may modify the contents of the working memory and the new facts are added which can be used for further inferences. This process continues until the problem is solved.

Production rules are different from the conventional conditional statements as discussed by Ringland and Duce (83). In a production rule, the conditional part is expressed as a pattern rather than a Boolean operation (as in conditional statements). The second difference is that the flow of the control does not pass from one rule to another but is determined by the interpreter, allowing the separation of knowledge from the control.

Since the rule-based representation technique is very popular, it has been applied to a number of knowledge-based systems for process planning. Example of these systems include RUPPS (84), XCUT (85) and EXCAP (16).

### 3.12.3 FRAMES-BASED REPRESENTATION

A frame is a data structure that includes declarative and procedural information in a pre-defined internal relationship (86). A frame describing an object may contain many slots, which in turn, contains the attributes, default values, pointer to other frames, or set of rules or procedures by which the values may be calculated to fill the slots (74). A frame-based knowledge representation is best suited to hierarchical problems which require both procedural and declarative strategies. This strategy has been used in a process planning expert system called SIPP (87). For example, a flat surface has been defined by a frame in SIPP as:

```
type(flate-surface, surface).
slots(flat-surface,[
    [norm,[X,Y,Z],number(X),number(Y),number(Z)],
    [flatness,X,number(X)],
    [angularity,X,number(X)],
    [parallelism,X,number(X)],
    [boundries,X,list_of_atoms(X)]
]).
```

In this frame, there are five slots for a flat surface and the slot "[flatness,X,number(X)]" describes the flatness tolerance and expects a number (not symbol) to fill this slot. The frame-based knowledge representation scheme has been used in other process planning expert systems such as SIPS (88), a successor of SIPP and APP (89).

### 3.12.4 LOGIC - BASED REPRESENTATION

The logical method of representing knowledge employs first order predicate logic. In this approach, a knowledge-base can be viewed as a collection of logical assertions and rules (90). The logical rules are usually of the form :-

$$P_0 = P_1, P_2, \ldots\ldots\ldots, P_n$$

Where $P_0$ is a consequent predicate and $P_1$, $P_2$,.....$P_n$ are ancedent predicates connected by 'AND' connector (commas represents 'AND' in prolog). The ancedents can be tested for their truth value and, if they are true, the consequent is concluded as true. A program using logical rules takes a goal and compares it with the consequent of the stored clauses in the rule base. After finding a match, it tries to prove the subgoal (antecedents) of that rule in order to prove the original goal. When all the sub-goals are proved to be true, the main goal is concluded as true, as discussed by Waterman (15).

As an example, a logical rule for selecting the billet diameter for the manufacture of seamless tube can be written in prolog as under

```
select_billet_diameter (Outside_dia_of_hollow, Thickness_of_hollow, Billet_dia):-
        Outside_dia_of_hollow < = 80,
        Thickness_of_hollow<=6,
        Billet_dia=80,!.
```

This rule says that if the outside diameter of the hollow (shell) is less than or equal to 80 mm and the wall thickness of hollow is less than or equal to 6 mm then select a billet of diameter 80 mm.

## 3.13 CONVENTIONAL PROGRAM VERSUS KNOWLEDGE-BASED SYSTEM

Knowledge-based systems differ in many ways from the conventional program, as quoted by Milner and Vasiliou (91), Hunt (92) and many other researchers. Conventional programs have been used for deterministic problems by processing numerical data and complex algorithms, i.e. step by step instructions to compute the right answers. In these programs, the information and control are intermixed which makes it very difficult to modify the code in order to incorporate changes.

According to Feigenbaum and McCorduck(71), most of the world problems are non-mathematical in nature and require symbolic inferences. The knowledge-based system deals mainly with symbolic processing but there is no reason that these programs should not perform calculations where necessary, as mentioned by Kriz (78). Knowledge-based systems are most suited to ill-defined and difficult problems which do not have well-defined patterns of solution. In knowledge-based systems, the mechanism for inferring (inference engine) is separated from the knowledge-base, which helps in modifying the knowledge according to the requirements, without affecting the control structure. The knowledge-based system requires the instructions as "what" should be solved rather than "how" to be solved as in a conventional program.

## 3.14 ADVANTAGES OF KNOWLEDGE-BASED SYSTEMS

Knowledge-based systems as compared with human expertise have many advantages, as described by Waterman (15), Kreshner and Lorenz (93) and Taylor (94). According to Waterman, human expertise is perishable, difficult to transfer and document, unpredictable and expensive. On the other hand, knowledge-based systems can retain their expertise for ever and can be transferred from one system to another simply by copying. The expertise in these systems can easily be documented and furthermore it is consistent and affordable.

Knowledge-based systems are free from emotional sentiments and their performance is not affected by fatigue, tiredness or crisis situations. These systems are free from biased judgement, do not forget relevant factors due to a large volume of information and are available at any time. They offer reduced response time in decision-making and less variation in the decisions. Knowledge-based systems have a modular structure, where every module contains a chunk of knowledge independent of others, which provides the facility for easy addition, deletion and modification of knowledge. These characteristics help in the refinement of expertise, providing better maintainability and adaptability to dynamic situations. The company which uses an expert system is less likely to depend wholly on the specialist, which can be more beneficial in certain cases.

## 3.15 APPLICATION OF KNOWLEDGE-BASED SYSTEMS

Knowledge-based systems have a diversified range of applications start from agriculture to space technology. Initially, most of these systems were developed in the field of medical diagnostics i.e. MYCIN, as quoted by Waterman (15). The success of these systems expanded the interest of researchers into other fields such as chemistry, mineral exploration and engineering. Now, the subfields of engineering such as design, scheduling, manufacturing, and specially process planning are benefitting from such systems.

### 3.15.1 SUITABILITY OF KBS FOR PROCESS PLANNING

The problem of process planning is usually ill-defined, intuitive (8) and requires experience and intelligence for its solutions. Usually, there are number of alternative courses of action available in producing process plans and selection of the best depends upon the expertise and judgement of the process planner. These characteristics of process planning make it an ideal candidate for a knowledge-based system. According to Tsang (95), process planning is typically an AI problem and he formulated it in the framework of AI as " given the initial state which is the raw material, the goal state which is the manufactured part, the repertory of permissible actions (operations) and available resources (machine, tools...), the problem is to determine the sequence of actions (process plan) which enables the goal state to be reached from the initial state.

### 3.15.2 KNOWLEDGE-BASED SYSTEMS FOR PROCESS PLANNING

To keep the goal of research on target, it is necessary to update information about the state of the art in process planning. At present, the knowledge-based technique is being employed in the development of generative process planning systems and, according to many researchers, the results are encouraging. Efforts of some of the researchers, and systems which emerged, in the last decade are reviewed briefly.

Probably, the first use of a knowledge-based technique in process planning is due to

Descotte and Latombe (96) in a development of a system called GARI. It was developed using MACLISP in 1981. The parts to be machined are described as sets of interrelated features (faces, bores, grooves etc.) which convey an operational meaning with respect to cutting processes and are exploited by the manufacturing rules of the system in generating a process plan.

In 1982, Matsushima et al (97) developed a system called TOM using a production rule representation of knowledge. This system allow the integration of a CAD system (COMPAC) with a NC generation module (EXAPT). The system was developed using PASCAL language and can automatically generate the optimum machining sequence for the given hole geometry of the part.

In 1984, Wolfe and Kung (98) described an automated process planning system which uses PADL-1 (Part and Assembly Description language) as a solid modeller. The system extracts form features from the boundary representation of the part and uses these data and manufacturing rules in the knowledge base to generate the process plans. In the same year another system XPS-E was reported by Latombe and Dunn (99).

EXCAP, is an automated process planning system for rotational components developed at UMIST. The original version EXCAP A was developed by Darbyshire and Davies (100), using a commercially available expert system tool called AL/X. The second version called EXCAP Y was developed by using York Portable prolog, as mentioned by Davies et al (16). The third version of EXCAP uses POPLOG shell (45). As reported by Joseph et al (101), EXCAP knowledge-base can be configured by the user with company-specific knowledge. EXCAP uses backward planning strategy in which planning starts from the finished component and the metal is added to a recognised feature which converts it to an intermediate workpiece. This process of adding metal is continued for all the features present on a component until a blank configuration is achieved i.e. no more features left. The play back of this planning gives the operation sequence.

In 1985, Phillips and Mouleeswaran (82) described the development of a system called PROPLAN for rotational parts. PROPLAN can select machines, tools, feeds and speeds and generates the manufacturing instructions. The system derives the part geometry and other related information from a computer-aided design database in the form of descriptive language and produces detailed process plans. The other systems which emerged in the same year include MICROPLAN (102), FORMEX (103) and SIPP (87). MICROPLAN is a micro-computer based expert system for generative process planning for rotational parts. It integrates the CAD and CAM system and CAD data is transferred to a symbolic representation with solid primitives which can be used for process planning. It is written in LISP and uses manufacturing rules for the generation of process plans. FORMEX determines the forming sequence for multi-stage forging machines and is written in prolog. SIPP (Semi-Intelligent Process Planner) uses a frame-based approach for knowledge representation and contains about 55 frames. It is written in prolog and can be used for machined parts process planning.

In 1986, the efforts to apply knowledge-base techniques for process planning resulted in systems such as CUTTECH (104), XPLANE (105), HI-mapp (106), OPEX (107), Machinist (108), SIPS (88), SAPT (109) and X-MAPP (110). CUTTECH was developed by Metcut Research Associates for rotational parts. The system uses machinability, tooling, fixture, machines databases and manufacturing rules for process plan generation. XPLANE is a knowledge-base driven expert system and takes care of prismatic parts. HI-mapp was developed using inter-LISP for rotational parts and OPEX is written in prolog. OPEX generates all possible machining sequences and uses heuristics to select the best sequence. Machinist is designed for integrating future CAD CAM systems and can generate process plans for prismatic parts. Its main task is to group the features on a component into different set-ups and order those set-ups using heuristic rules. It is written in OPS5 and contains about 130 rules. SIPS is a successor to SIPP mentioned earlier and LISP has been used for its development. SAPT is designed to generate process plans for both prismatic and rotational parts and is written in PASCAL and LISP language. X-MAPP has been developed in LISP and runs on LISP machine. It simulates the series of operations which can modify the product model from initial blank to final product.

Some of the knowledge-based systems which have been described in the literature during 1987 are Turbo-CAPP (111), DOPS (112), XCUT (85), PWA-planner (113) and RUPPS (84). Turbo-CAPP uses AIMSI (An Intelligent Machine Surface Identifier) to extract surface features from a CAD database. It contains five supplementary modules in order to generate process plans for rotational parts. The system is implemented in prolog and runs on IBM PCs. DOPS is a Drilling Operation Planning System, written in INTER-LISP version D and recommends optimised hole operation sequence by eliminating unnecessary tool changes. Expert Assistant generates process plans for producing finished holes in manufactured parts. XCUT is written in LISP and is integrated to a solid modelling system. It contains about 300 rules to plan the manufacture of prismatic parts. PWA-planner is written in prolog and prepares the assembly plans for the manufacture of printed circuit boards by automatic components mounting machines.

The year 1988 has seen the emergence of a few more process planning expert systems such as APP (89), WELEXP (114) and TOLTEC (7) etc. However it must be emphasised that this is not the complete list of knowledge-based system for process planning. Atling and Zhang (53) have given a comprehensive survey of process planning systems but even then some of the above listed systems do not appear.

## 3.17 CONCLUSION

In this chapter, the function of process planning and the different techniques used to perform this task have been reviewed. These techniques include manual planning, variant approach and generative approach based upon conventional programming and AI techniques. It has been observed in reviewing these techniques, that the manual approach and variant approach to process planning is not the answer, because of the large volume of data, variety of components and dynamic changes in the design. The concept of CIM emphasises the need of the generative approach to bridge the gape between CAD and CAM. The generative approach, based on the conventional programming, has the drawback of system rigidity and inflexibility to incorporate necessary changes. However, the AI techniques is proved to be most suitable.

The survey on the existing process planning systems indicated that such systems have been developed mainly for machining domains for rotational, prismatic, sheet metal parts, drilling, boring and welding operations. There is a very little evidence of such a system for the manufacture of seamless tubes. On this basis, it can be concluded that there is clearly a need for a knowledge-based system for the manufacture of seamless tube manufacture which will extend the horizon of these new computational techniques beyond the machining domain.

# CHAPTER 4

## PROCESS PLANNING IN A TUBE MILL
## (PROBLEM FORMULATION)

### 4.1 INTRODUCTION

In the last two chapters, a general apparisal was given of tube manufacturing processes, the tube mills which are generally available, process planning and the techniques used in developing process planning solutions. Process planning is a decision-making process for the manufacture of the products. The decisions to be made depend upon the type and quantity of products, the available production facilities and the technology being employed. The pre-requisite to develop a process planning solution in any manufacturing concern is, therefore, to gain detailed knowledge of the technology, production facilities available, their capabilities, limitations and constraints.

In this chapter, based on a case study, the layout of the tube mill for which the process planning solution is intended is described and the existing facilities in terms of their capabilities and constraints are reviewed. The present methods of process planning being practised in the mill, and the associated disadvantages are outlined. Finally, attention is focused on the identification of the sub-tasks generally experienced in the manufacture of seamless tube related to process planning.

### 4.2 A CASE STUDY OF SEAMLESS TUBE MANUFACTURE

The present research work is restricted to a seamless tube manufacturing facility which consists of two different plants at separate sites namely:

(1) A rotary tube mill or hot mill

(2) A cold drawing mill

The rotary tube mill is used for the production of hot finish seamless (HFS) tubes or shells (hollows) from solid billets. These shells may be used as raw material for the cold drawing mill for the manufacture of cold finish seamless (CFS) tubes.

## 4.3 LAYOUT OF ROTARY TUBE MILL

Figure 4.1 shows the layout of the rotary tube mill which uses steel bars cut into

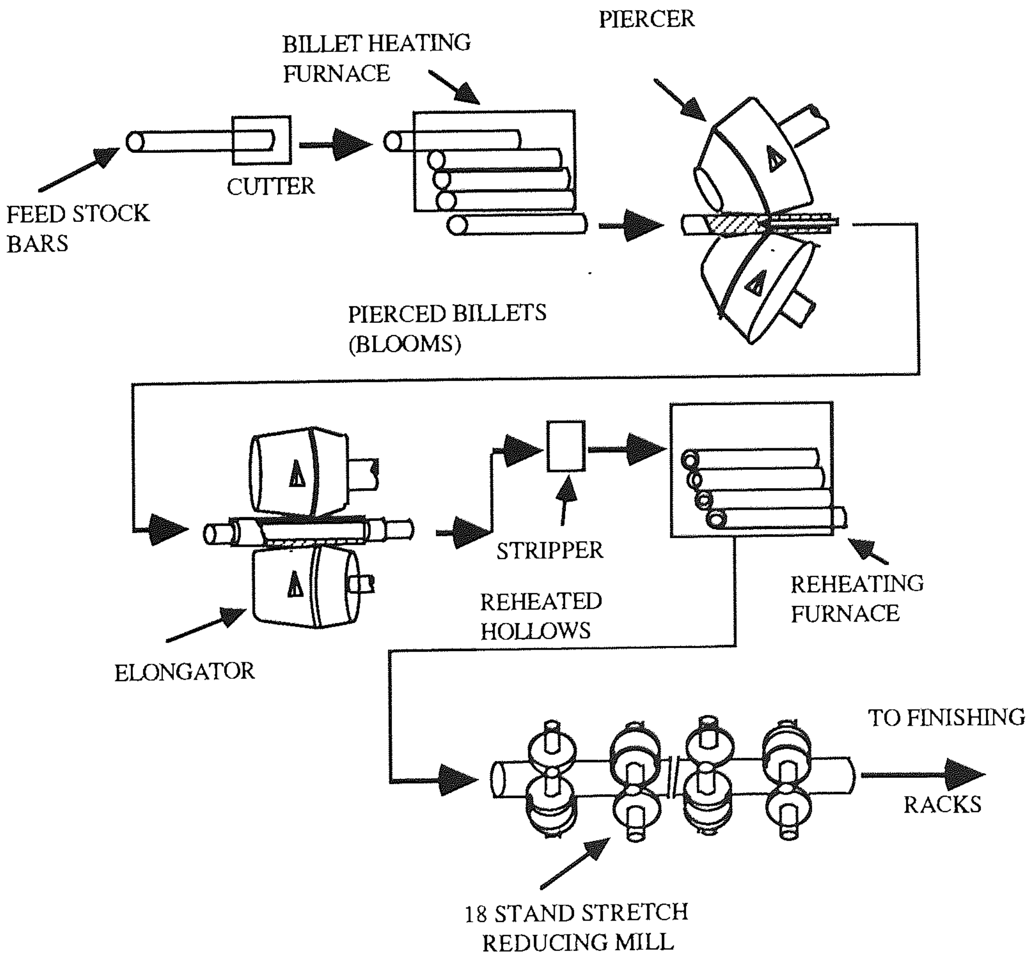



Figure 4.1: Layout of rotary tube mill

required billet lengths depending upon the required dimensions of the tube. The billets are heated in the furnace to rolling temperature and passed through a piercing mill, where they are pierced over a plug and converted into hollow blooms. In the next stage, the blooms are cross-rolled over a long mandrel in a Diescher elongator to convert into hollows. The Diescher mill reduces the outside diameter and wall thickness and improves the concentricity. The hollows, after the Diescher mill, have different routes i.e. they either go to the stretch reducing mill if the size is equal to or less than the maximum size for which it is designed, or are finished to required size off the Diescher mill. Hollows below a certain diameter, which go to stretch-reducing mill, are of two sizes. These hollows are reheated to require temperature and passed on to the stretch reducing mill, from where a number of different standard sizes are made. At this stage, the HFS tubes go to the finishing department while the CFS tubes require subsequent cold drawing.

## 4.4 PRODUCTION FACILITIES IN THE ROTARY TUBE MILL

Referring to figure 4.1, the rotary tube mill consists of:

(1) An oxy-propane cutter

(2) A billet heating furnace

(3) A piercer

(4) A Diescher mill with stripper

(5) A reheating furnace

(6) A stretch-reducing mill

These facilities are described briefly in order to identify the problems relating to process planning.

### 4.4.1 OXY-PROPANE CUTTER

The first process in the production of seamless tube is to cut the billets from the bar stock for which an oxy-propane cutter is used. The selection of the billet diameter and length depends upon many factors such as finished tube dimensions, the workpiece handling capacity of machines, the material optimisation and maximum possible utilisation of each piece of equipment in the mill. These factors will be fully discussed in a later stage.

### 4.4.2 BILLET HEATING FURNACE

The billet heating furnace is of gas-firing walking-beam type with the following specifications:

- Output/h: 3 tonne
- Inside length: 12.2 m (40 ft)
- Inside width: 1.65 m (65 in)
- Walking beam width : 0.84 m (33 in)
- Operating temperature: $1300^0$ C

The specification of the furnace imposes a restriction with regard to selection of billet length which must be in the range of 1.65 m - 0.84 m, otherwise the billet will not lie correctly on the walking beam or will damage the side wall. The maximum number of billets held at any time depends upon the furnace inside length and the billet diameter, while the number of billets output/h depends upon the capacity of the furnace.

### 4.4.3 PIERCER

The piercer is of the rotary cone type, in which two cone rolls inclined at 60 deg to each other are driven independently by two 134 kW motors. Two disc rolls are used, one on each side, to control the outside diameter of the bloom. The following constraints must be consider on the piercer in formulating the process planning solution.

- The maximum bloom length should be less than 3.05 m (10 ft) to accommodate it on the piercer discharge trough.
- The maximum diameter of bloom after piercing the billet must not increase above 165 mm on the largest disc roll.

Other process planning problems on the piercer mill to be considered are:

- Selection of piercer plug size
- Selection of piercer bar size
- Selection of disc roll size
- Selection of piercer roll gorge
- Selection of disc roll gorge
- Determination of bloom dimensions in order to check the satisfaction of piercer mill constraints

### 4.4.4 DIESCHER MILL AND STRIPPER

The Diescher mill consists of two barrel-type main rolls mounted in the horizontal plane and two profiled rotating discs mounted in the vertical plane. The disc rolls are used to control the outside diameter of the hollow while the main rolls control the wall thickness of the tube. The elongator is used to reduce the wall thickness and the outside diameter of the hollow and improves the concentricity and surface finish. The stripper unit is mainly responsible for stripping out the mandrel bar from the tube. The main constraints to be consider on the Diescher mill are:

- The length of the tube after the mill should be less than or equal to 6.1 m (20 ft) in order to fit on the discharge trough.
- There should be sufficient of material left in the wall of the tube to be worked on.

The process planning related problems on the Diescher mill may include:

- Selection of appropriate mandrel bar to support the inside diameter of the hollow.
- Selection of appropriate size of elongator discs
- Selection of disc gorge to control the outside diameter
- Selection of the main rolls gorge to control the wall thickness
- Determination of maximum reduction in the wall thickness
- Determination of elongated tube (hollow) dimensions in order to check that the Diescher mill constraints are being satisfied.

### 4.4.5 REHEATING FURNACE

A gas-fired reheating furnace is used to reheat the tubes which require further processing on the stretch-reducing mill. The rate of the discharge of the tubes from the furnace depends upon the rate of output from the Diescher mill but can be altered to suite the production rate of stretch-reducing mill. When the production line is working smoothly, tubes reach the furnace at approximately $1050^0$ C and hence only a short period is required in order to attain the required temperature.

### 4.4.6 STRETCH-REDUCING MILL (SRM)

The stretch reducing mill is an 18-stand 3-roll mill with a mechanical differential drive, which gives a variable speed curve through the mill from stands 1 to 18. The rolls are at 120 degrees to each other in a closed housing and the speed of each roll cluster is set individually to enable the stretching action to take place between stands.

Tubes below certain diameter goes to the stretch-reducing mill for the last operation. The SRM is capable of producing fourteen different sizes from two entry sizes by selecting the correct combination of roll stands. The main constraint upon the SRM is its handling capacity of output tubes with length less than or equal to 15.85 m (52 ft).

The process planning problem associated with SRM is to select the number and the appropriate combination of roll clusters to reduce the given size to required one and to compute the length of the tube after the stretch-reducing operation in order to satisfy the length constraint.

## 4.5 COLD DRAWING MILL LAYOUT

Figure 4.2 represents a lay out for the cold drawing plant and it consists of the following facilities:

- Tagging/swaging machines
- Pickling bosh
- Lubricating bosh
- A chain bench
- A Farmer Norton bench
- A Platt bench
- Two hydraulic benches
- A straightening machine
- A heat treatment furnace
- Cutting facilities
- Testing and Inspection Department

The tagging and swaging operations are required to reduce the end of the tube to a smaller diameter from the main body of the tube in order to allow the reduced end to pass through the throat of the die. The tagged semi-finish hollows are then pickled to remove the scale which is formed during the hot working operations and to prepare the surface for lubrication. After lubrication, the hollows go to the appropriate bench for cold drawing. The tubes are produced to required dimensions and surface finish by one or many passes depending upon many factors which will be discussed later.

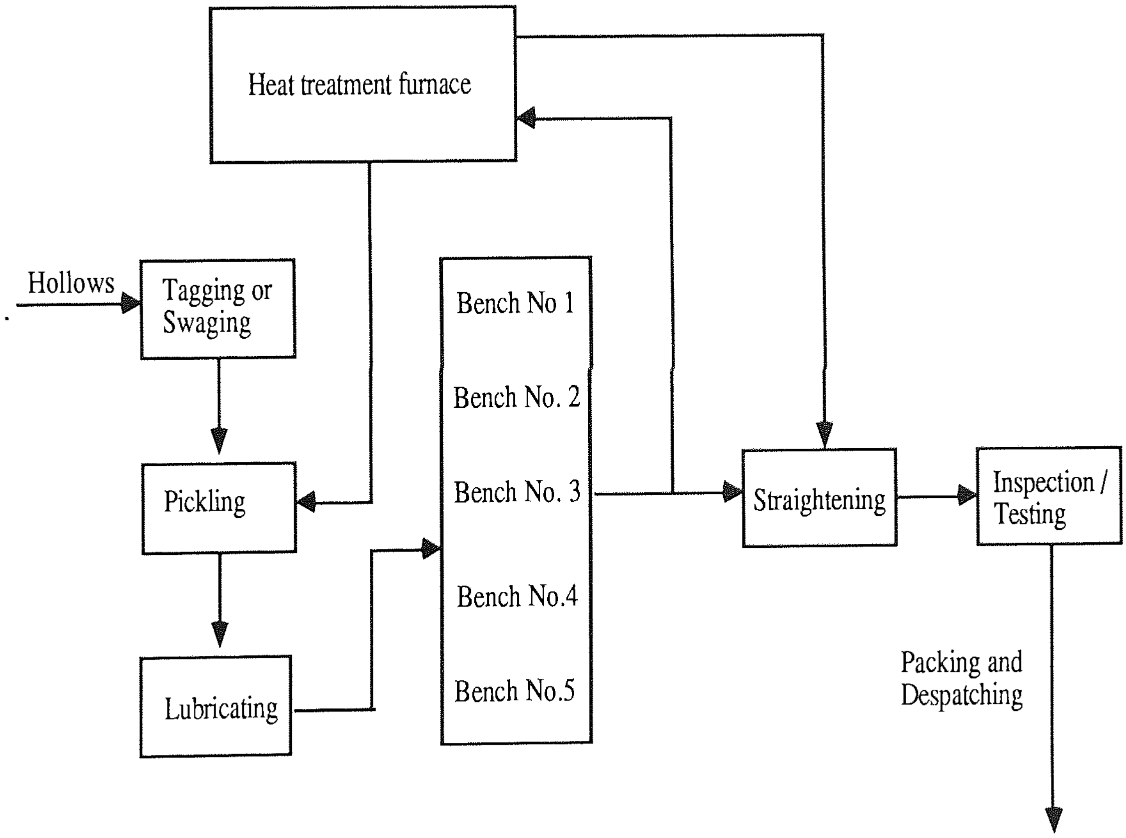



Figure 4.2 Cold drawing mill layout

After attaining the required dimensions, the tubes are then go to heat treatment, are cut to length, straightened and inspected, from where they are ready for despatch to the customer.

The selection of the appropriate bench for any job depends upon the drawing capability of the bench in terms of the maximum pull it can apply, the length constraints before and after drawing and the range of tube outside diameter. For process planning, the knowledge of these capabilities is necessary and is given below.

### 4.5.1 CHAIN BENCH

The following capabilities and constraints are required to be consider in developing the process planning solution:

- The drawing load should not increase above 280 kN
- The input length of hollow should be less than or equal to 6.4 m
- The planned length of drawn tube should not increase above 8.84 m.
- The bench has a constant drawing speed of 9.15 m /min (30 ft/ min).
- Range of outside diameters which can be drawn is 19 - 82.6 mm.
- Prevailing policy to draw tubes of outside diameter less than or equal to 51 mm

### 4.5.2 FARMER NORTON BENCH

The Farmer Norton bench has the following specification:

- Maximum drawing load = 250 kN
- Maximum input length = 6.1 m
- Maximum output length = 10.67 m
- Drawing speed = 13.7 m /min
- Drawn tube sizes range = 19 - 57.15 mm
- Prevailing policy of drawing tubes= 51 mm and below

### 4.5.3 PLATT BENCH

The capability and constraints on this bench are as follows:

- Maximum drawing load = 400 kN
- Maximum input length = 8.84 m
- Maximum output length = 15.24 m
- Drawn tube size range = 25.4 - 95.25 mm
- Prevailing policy = 51.0 - 76.2 mm

### 4.5.4 HYDRAULIC BENCHES

Process planning solution requires the following constraints and capabilities to consider on the hydraulic benches:

- Maximum drawing load = 1000 kN
- Maximum input length = 4.27 m
- Maximum output length = 5.18 m
- Drawn tube sizes = 76.2 mm - 152.4 mm

## 4.6 PRESENT METHOD OF PROCESS PLANNING AND DISADVANTAGES

At present, the process planning task is performed manually based upon technical planning sheets which contain the detailed manufacturing data for a particular job manufactured in the past. The sequence of manual process planning prevailing in the mill can be summarised as follows:-

- On receipt of customer's firm orders, a master record card is created which contains the customer name and address, tube dimensions, finish required, total quantity and the price detail.

- The master record card is sent to the Technical Department for entering other details such as material and tube specification, tolerances on the dimensions, stencilling and colour coding and the tests requirement to be carried out under the specification on the manufactured product.
- After completion by the staff of Technical Department, the master record card is sent to the production planner, who in turn uses his experience and technical planning sheets :

  - to determine the shell (hollow) dimensions to be manufactured in the hot mill in case of CFS tubes by giving appropriate allowances for tagging, cutting and scrap in thickening of ends in stretch-reducing .
  - to determine the billet dimensions
  - to estimate the week number in which the job can be rolled using available hot mill capacity in terms of number of ton/shift.
  - to select the appropriate bench and number of passes by which the job can be reduced to the required size and surface finish.
  - knowing the estimated week number for rolling, he estimates the week number for completion of the job in cold the drawing plant using the available capacity for the benches and giving certain allowances to time periods for servicing operations such as tagging, pickling, lubricating and annealing.

All these data are then entered into the computer database and, after each week, modified rolling programs are prepared. The production planner then raises the works order one week prior to actual rolling and issues to mill supervisor. The mill supervisor, in response to these work orders, determines the operation planning details using experience and familiarity with the production facilities. The operation detail may include selection of appropriate tools and selection of set-up parameters of the unit. After completion, the job is sent to the Inspection Department for testing and inspection and, if it qualifies, it can be despatched after stencilling and colour coding.

The present method of process planning is manual and being slow is less reactive to the dynamic situation of the factory floor status resulting in delays to prepare or revised the process plan. The task of process planning is performed by individuals using work experience, familiarity with the production facilities and the product knowledge. Reliance on individual expertise may not be helpful in the case of his absence or non-availability. Sometimes, it becomes difficult to optimise all the parameters for the economical manufacture of the product manually and requires the advance computational technologies to overcome such problems. In order to achieve this, details of the formulation of process planning problem in such a mill are given below.

## 4.7 PROCESS PLANNING FORMULATION IN A SEAMLESS TUBE MILL

The basic sub-tasks of process planning for machining as outlined in section 3.2 can generally be applied to process planning in a seamless tube mill by arranging them in such a way as to suit the flow of production. The process planning in such a mill can be divided (115) into:

(1) Process planning for the manufacture of hollows or HFS tubes

(2) Process planning for the manufacture of CFS tubes

In the following sections, the sub-tasks needed in the manufacture of HFS and CFS tube are discussed.

## 4.8 PROCESS PLANNING FOR THE MANUFACTURE OF HOLLOWS

To prepare the process planning solution for the manufacture of hollows or HFS tube, it is necessary to consider the following sub-tasks:-

(1) Tube specification

(2) Hollow size selection

(3) Billet selection

(4) Process and machine selection

(5) Tools selection

(6) Machine parameter selection

(7) Operation sequencing

(8) Time estimating

(9) Optimisation of hollow manufacture and material

(10) Preparation of production schedules and additional requirement

### 4.8.1 TUBE SPECIFICATION

The input for process planning in any domain is the design of a product with some technological and manufacturing specifications. Seamless tube can be specified in terms of:

- Dimensions, such as outside diameter, wall thickness, bore and length
- The specification number under any Standards such as BS, DIN etc
- The material grade used
- Heat treatment specification other than that specified in the applied Standard
- Special requirements such as special finish (i.e. polishing,

grinding), special test according to customer requirement not specified in the relevant Standard.

As an example, BS 6323/4 CFS 7 BKW (116) designates a cold finished seamless tube made from CFS 7 carbon-manganese steel (0.2/0.3% carbon) in cold finished/soft condition. The specifications greatly effect the selection of the process for the manufacture of tube. In this case, after the manufacture of the tube it has to go through a light pass and annealing to attain the required soft finished condition. Therefore, the process planning solution requires the inclusion of detailed knowledge as specified in these Standards in order to recommend the tolerances to be achieved and the standard tests to be performed in addition to process selection.

### 4.8.2 HOLLOW SIZE SELECTION

In order to reduce the time lost in setting up the mill for every order, the prevailing policy at the plant is to manufacture standard sizes of hollows. The range of such standard products manufactured is given in Appendix A1. For the production of CFS tubes by the cold drawing process, the appropriate hollow size must be selected by giving the appropriate allowances for tagging and cutting etc. Ideally, the hollow should be selected in such a way that the finished tube can be manufactured in one pass (i.e. least operations to reduce the costs). In practice, it may not be possible because of the limitation of hollow sizes which can be manufactured in the hot mill or the standardisation of product range to reduce the set-up time as mentioned above. In such a case, an appropriate decision policy is needed to plan the manufacture of hollow sizes which can be economically reduced to the required size in subsequent cold drawing as well as falling in with the standard product range. In the case of HFS tubes, the task of hollow size selection does not exist because HFS tubes are the same size as hollows.

### 4.8.3 BILLET SELECTION

After selection of the hollow size to be manufactured, the next step is the selection of the billet. The appropriate billet selection is the crucial factor in the economical manufacture of hollows since it depends upon many factors. The following decisions are necessary in the selection of a billet:

- Material grade to be used
- Diameter of the billet
- Length and/or weight of the billet

The knowledge as to which material grades are available under the relevant Standards together with customer's requirement is necessary in order to decide the material grade, composition and mechanical properties. The selection of the billet diameter depends upon the outside diameter of the bloom, the piercer gorge (the distance between the rolls to grip the billet), the availability of the feed stock and wall thickness of the tube (whether it is light wall or heavy wall). In deciding the length of the billet, it is necessary to give due consideration to:-

- The dimensions of the finish tube
- Tagging and cutting allowances in case of CFS tubes
- Minimisation of scrap resulted from cutting billet lengths from the bars
- The maximum utilisation of hot mill production facilities
- The constraints imposed by the production facilities in terms of minimum and maximum workpiece handling capacities.

Any conflict resulting from interaction of the above factors must be resolved for the economic manufacture of the tubes.

### 4.8.4 PROCESSES AND MACHINE SELECTION

The selection of the manufacturing processes and machines to transform the raw material (billets) into hollows or HFS tubes largely depends upon the processes and facilities available in the mill. As stated in chapter 2, there are many alternative processes for the manufacture of tubes; for instance, rotary piercing and cross-rolling processes, non-rotary piercing such as extrusion processes and combined piercing and extrusion. The selection among the alternative processes is decided at the design stage of a tube mill. Thus, for an existing mill, the task of selection a manufacturing process among the alternatives does not apply.

However, selection among the available processes depends upon the tube specification and capabilities of the machines. In case of HFS tubes, the finishing processes such as heat treatment, cutting the ends and stencilling may be selected, while in case of hollows production these processes are not needed at this stage. Similarly, the stretch-reducing process cannot be applied to hollows or HFS tubes when the outside diameter off the Diescher mill exceeds the design intake range of stretch-reducer.

### 4.8.5 TOOL SELECTION

The production of hollows requires the selection of appropriate tools in the piercing, cross-rolling and stretch-reducing processes. During the piercing process, the tools to be selected are piercer plug, piercer bar and piercer discs. Usually, there are a number of tool sizes available and choice depends upon a number of factors such as billet size, bloom dimensions and finished hollow dimensions off the Diescher mill. A given combination of piercer and elongator disc rolls is capable of producing a range of hollow sizes and should be selected according to that range. Selection of one tool, for example a piercer plug, may affect the selection of another such as piercer bar.

Selection of mandrel bar and elongator discs in the cross-rolling operation depends upon the hollow dimensions and tolerances (in case the hollow is not going to the stretch-reducing operation) and other factors such as the easy withdrawal of the mandrel bar from the tube. Similarly, selection of the number and combination of roll clusters in the stretch-reducer depends upon the finished hollow size and the tolerances to be achieved.

The process planning solution in the hot mill, therefore, must possess knowledge of the available tools and the expertise for their selection. In a case where the strategy applied results in a tool size which is not available, proper action must be taken to select a tool among the available tools without affecting the manufacture of the product.

### 4.8.6 SELECTION OF MACHINE PARAMETERS

Each batch of hollows or HFS tubes may be different in dimensions, requiring a different setting of the facilities in the mill through which it goes. Minor adjustments are required within a given combination of piercer and elongator discs to suit the manufacture of a particular size. These adjustments may include the set-up parameters such as piercer disc gorge, piercer main roll gorge, elongator disc gorge and elongator main roll gorge.

### 4.8.7 OPERATION SEQUENCING

The selected manufacturing processes must be arranged in succession to produce an operation sequence sheet which specifies the order of operations for transformation of billet into hollows or HFS tubes. The operation sequence in a hot mill depends upon the precedence relationship of operations i.e., a billet cannot be cross-rolled on the Diescher mill until it is pierced. In other words, the operation sequence depends upon the basic manufacturing technology for seamless tubes which specifies:

- Cut the feed stock bars into required billet length
- Heat the billets into required temperature
- Pierce the billets into blooms
- Cross-roll the blooms to improve concentricity and to elongate them.
- Reheat the hollows to required temperature
- Perform the stretch-reducing operation to reduce the hollow to the required size.

### 4.8.8 TIME ESTIMATION

In the machining domain, the standard time for a process can be estimated by the summation of time taken in the machining operation, loading/unloading time and the machine set-up. The process standard time can then be summed for all operations in the sequence sheet to find the total time required for the manufacture of that component. Although this technique can be used in the tube mill, it is not usually practical because, on one hand, the estimation of time for a batch of tube is the more significant factor and can be estimated by the design capacity in terms of tonne/hr, rather than the time required for the manufacture of one tube. On the other hand, the operation time in processes such as annealing and normalising depends to a large extent on factors such as heating and cooling rate and the amount of deformation that the material has undergone. Since the above factors are not known in advance, the precise calculation of operation time is often difficult.

Usually, the operation time is estimated for the manufacture of a batch of tubes, as discussed earlier, based on measures such as the number of tubes produced per shift or the number of tonne of tube produced per shift. The mills are initially designed for a production capacity in terms of tonne of tubes per hr but the output usually deteriorates with the ageing of the plant, giving production difficulties. In such a case, production capacity in terms of these measures must be established for an existing plant. This measure can then be used for the estimation of the time required to manufacture a batch of tubes. The next chapter, contains a study carried out in the mill to establish the output capacity in terms of tonne of tubes per shift.

### 4.8.9 OPTIMISATION OF HOLLOW MANUFACTURE AND MATERIAL

The prime importance in any manufacturing environment is not always given merely to the manufacture of the products but to economical production by eliminating the under-utilisation of resources and scrap. Similarly, for the optimum or economical production of hollows in the hot mill under investigation, the questions to be answered are:

- What is the maximum possible length of workpiece which can be manufactured within the design limitation of each production facility in order to achieve the maximum utilisation.
- How can the incoming orders be grouped (product mix) in order to reduce the non-productive time in major changes of mill set-up and run the mill for longer span of time.
- How the orders within a group can be arranged to reduce the time lost in minor adjustments in order to attain required parameters such as piercer and elongator gorges.

The raw material for the mill is purchased in the form of different diameter steel bars with three length sizes which are multiple of 1295 mm. In addition to considering the other factors in selection of billet length as discussed in section 4.8.3, due consideration must be given to the minimisation of scrap.

### 4.8.10 PRODUCTION SCHEDULES AND ADDITIONAL REQUIREMENTS

Production schedules or rolling programmes determine the start and finish dates of a job, based upon the forward work load summary over the planning horizon. It is a production control problem, but in order to implement the strategy for the optimisation of hollows manufacture, to group the orders requiring similar setting of piercer-elongator discs and thus reduce the overall set-up time, it becomes necessary to include the preparation of production schedules in the process planning stage.

In order to include new orders in the preparation of hot mill production schedules, computation of available and used capacity over the planning horizon is required. This, in turn, needs the development of a factory-based calendar to incorporate holidays or non working-days in the year, total manufacturing capacity in terms of tons of tube per week and periodic total of previously scheduled orders. In addition to implementing the optimisation strategy for hollow manufacture, other useful information such as periodic material requirement, enquiries about the status of scheduled orders and latest situation of capacity in form of bar charts, are also required. This information provides a basis for the management to be able to foresee the available capacity situation for the planning horizon and further actions and strategies can be planned.

## 4.9 PROCESS PLANNING FOR THE MANUFACTURE OF CFS TUBES

Once the manufacture of a hollow is planned, the next step is to determine the process plan to transform the hollows into required CFS tubes by the fixed plug cold drawing process. The planning tasks involved are:-

(1) Selection of a drawbench

(2) Selection of number of passes

(3) Determining of alternative and optimum tube-drawing schedules

(4) Selection of secondary processes

(5) Validation of optimum schedule

(6) Operation sequencing

Other sub-tasks, such as time estimating and preparation of bench programmes are also required, but are not included in this current work because of the large volume of work. The following sections will discuss how each of the above-mentioned tasks can be formulated in the cold drawing mill.

### 4.9.1 SELECTION OF DRAWBENCH

Although the decision on the selection of drawbench must be taken during the hollow planning stage in order to give suitable tagging and end thickening allowances, it is appropriate to discuss it under the heading of process planning in the cold drawing mill. The selection of the drawbench depends upon its production capabilities such as the input and output workpiece handling capacity, the diameter of the tube, the prevailing policy of the range of tubes to be manufactured and the drawing capacity in terms of drawing load.

### 4.9.2 DETERMINATION OF NUMBER OF PASSES

In the cold drawing process, initial dimensions of hollow (wall thickness and outside diameter) are reduced to a pre-determined dimensions and the tube is said to undergone a pass. Usually, a hollow can be reduced to the required dimensions by one or more passes depending upon the total deformation required and the allowable strain per pass. The allowable strain per pass depends upon the material composition, prior work-hardening and drawing capability of selected bench. The number of passes to be selected is also dependent upon the final delivery condition i.e. some specifications of tube require a light finishing pass in order to achieve a soft condition. For the process planning solution, it is necessary to determine the number of passes either by using the expertise and shop practice or by using a mathematical analysis.

### 4.9.3 ALTERNATIVE AND OPTIMUM MANUFACTURING SCHEDULE

Once the total number of passes is decided, the next step is to establish a detailed tube-drawing schedule which determines what should be the appropriate dimensions of tube in the intermediate passes in order to obtain the required dimensions in the final pass. The dimensions of the tube in the intermediate passes depend upon the selected tool sizes i.e. die and plug size to control the outside diameter and bore of the tube respectively and the wall thickness is controlled by the combination of die and plug together. Usually, a number of tool sizes are available in the range between initial hollow and final tube size and selection of the different combinations, from the available tools list, gives a number of possible alternative tube-drawing schedules. In a case where the number of available tools in the range is large, the number of alternative schedules, generated by combining each die and plug sizes may exhaust the limited memory space of a PC. In such a case, the tube drawing schedules which do not lie in the actual production range must be discarded before they are saved in the memory.

Every drawing schedule thus generated will achieve different dimensions in the intermediate passes and hence different amounts of drawing load, stress/strain and deformation work will be required. There must be a strategy to select an optimum schedule from the available alternatives based on some criteria. These criteria may be the economics of the drawing, the even distribution of area reduction over total passes or the constraints on the benches in terms of process parameters such as drawing load and power requirement. Therefore process planning must have the strategy to generate the alternative manufacturing schedules and to select the optimum.

### 4.9.4 SELECTION OF SECONDARY PROCESSES

The secondary processes may include the hollow or tube preparing processes prior to drawing such as tagging, pickling and lubricating; inter-pass annealing; finish heat treatment such as annealing, normalising and tempering and other tube finishing processes including straightening, cutting to length, electro-plating, galvanising, grinding, polishing and honing etc. Prior to the first pass a tube must be tagged, pickled and lubricated, but in subsequent passes the selection of hollow or tube preparing process depends upon the selection of inter-pass annealing. The selection of annealing depends upon material composition and deformation history. The selection of finish heat treatment and other processes depends upon the tube specification, material used and the special customer requirement. The process planning solution, therefore, must have the knowledge of the interactive behaviour of these processes and a strategy to select them when and where necessary.

### 4.9.5 VALIDATION OF OPTIMUM SCHEDULE

The decision to pick an optimum schedule from the alternatives was based upon certain criteria as discussed in section 4.9.3 and little attention was given to process parameters such as stress/strain, drawing load. The process parameters depend upon the inter-pass heat treatment and their computation is not possible until the annealing between the passes is decided. The drawing schedule cannot be valid until the process parameters in every pass satisfy the constraints imposed by the selected work station. The computation of process parameters requires a vigorous mathematical treatment depending upon the tool geometry, condition of drawing, frictional conditions, given deformation, material mechanical properties and the change of these properties during processing.

The change in material properties (yield stress) due to work-hardening is usually determined experimentally. The computer solution requires the development of a mathematical model to predict these changes analytically in advance for use in the determination of process parameters. The process parameters can then be compared with limiting parameters of the selected work station in order to validate or reject a given manufacturing schedule. Therefore, the problem related to the validation of a schedule is to develop a model which not merely estimates the parameters, but their estimation should be in accordance with the experimental results as represented by other researchers.

### 4.9.6 OPERATION SEQUENCE

The selected manufacturing processes in the cold drawing mill may include hollow preparation processes, heat treatment, finishing processes and tube drawing schedules. Every pass in a tube drawing schedule is a separate process as it is carried out separately to achieve different dimensions. As discussed in section 4.8.4, the selected processes must be arranged in succession depending upon the precedence relationship, forming an operation sequence to transform a given hollow to required CFS tubes. The related problem for the process planning solution is the development of a strategy which contains the knowledge of precedence relationships and the initial and transformed state of the tube after a process in order to apply the precedence relationships in determining the operation sequence.

# CHAPTER 5

## PROCESS PLANNING IN A ROTARY PIERCING MILL (CONCEPTUALISATION)

### 5.1 INTRODUCTION

The identification of problems is the first phase in the development of knowledge-based systems and Chapter 4 was devoted to pinpointing the problems related to the domain of seamless tube manufacture for process planning. The next phase is the conceptualisation i.e. what concepts, relations, knowledge and expertise are required in order to solve the identified problems in the selected domain and how this can be achieved. The expert's knowledge has to be extracted and other knowledge sources need to be researched in order to gather and collate the knowledge.

In this chapter, a brief review of the methods used for knowledge acquisition will be presented first. Then the strategies, concepts and relations will be discussed in order to solve the process planning tasks for the manufacture of hollows. It may be useful to point out here that knowledge regarding process planning in the seamless tube manufacture is hard to find in the literature compared with the machining domain. This claim can be supported by the fact that no research paper has been found by an on-line computer search through the available publication databases. This chapter is therefore focused towards gathering and collating process planning knowledge in the domain of seamless tube manufacture.

### 5.2 KNOWLEDGE ACQUISITION

The purpose of knowledge acquisition is to obtain a complete and correct description of the expert knowledge , i.e. the way in which different situations in the specific area of expertise are handled as well as related knowledge from the other sources. These sources of knowledge may include textbooks, reports, databases, case studies, empirical data and shop manuals. The most common methods of extracting expertise from the domain experts as discussed by Welbank (117) and Waterman (15) are: interviewing the experts; group discussions; observation; questionnaires and sampling from existing records. The general principles to be observed in the knowledge acquisition process and other related topics has been extensively discussed by Hart (118). The methods which have been tried in this present work for the purpose of knowledge acquisition are as follows:

(1) Interviewing
(2) Observing
(3) Analysis of existing manufacturing records

In the interviewing process, the responses of the experts regarding the method of solution, short cuts and tricks (heuristics) can be recorded and then translated to a set of rules. The drawbacks of this method which have been observed are:

- All possible problems and situations in the given domain cannot be dreamed of in advance
- The responses of the expert sometimes cannot be fully understood by the interviewer
- The expert may not be able to support his expertise by the reasoning process
- The expert may hesitate to give a full account of his expertise for a multitude of reasons

The second method of knowledge acquisition is by observing experts solving real problems. In this method the knowledge engineer is not allowed to ask questions, in order that the experts may be allowed to think uninterruptedly. This method has the drawback that the observer may not be able to comprehend the expertise and it is not very practicable because of the scale of time involved.

The acquisition of knowledge by the method of analysing existing manufacturing records is the most suitable and effective but is only possible when such records exist. Manufacturing records are the historical cases showing the detailed history of the successful manufacture of jobs. By analogy, the manufacturing records in a seamless tube manufacture are similar as the results of successful experiments in the machining domain to select the best tools and optimum feed and speed in order to obtain the best surface finish. The manufacturing records usually contain discrete information and must be analysed for the interaction of the attributes in order to group them in such a way that a set of rules can be induced to describe the whole set of raw data. There are many techniques available for the analysis of discrete raw data in order to form such groups and they will be discussed later. If the results from such an analysis support the rules induced by other methods (interviewing and observing) then the acquired expertise can be represented in the knowledge-base with much confidence.

## 5.3 SOLUTION METHODOLOGY FOR PROCESS PLANNING TASKS

In the following sections, the solution methodology for each process planning task in the rotary piercing tube mill will be discussed.

### 5.3.1 TUBE SPECIFICATION

A tube can be specified by its dimensions, Standard under which it is being made, material grade to be used and other special requirements specified by the customer. Standards such as BS, DIN and ASTM etc further specify the method of manufacture (seamless or welded), the tolerances and finish to be achieved, the material grades and recommend tests and inspection procedures.

Two strategies can be used for specifying the tube attributes i.e. either having a question-answer session or the use of a code. The second strategy is preferable so that a simple alpha-numeric code can be used to communicate the tube specification to the system. This strategy eliminates the lengthy and boring question-answer session regarding the input of tube specification. The code is a string of the form shown in figure 5.1 where every piece of discrete information is separated by a slash "/".

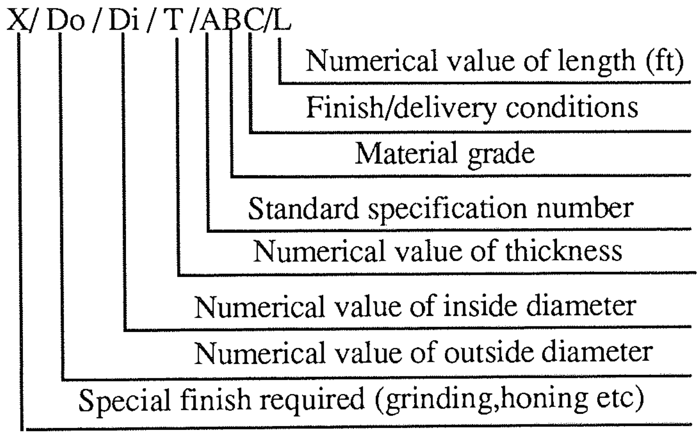



Figure 5.1: A simple alpha-numeric code for product specification

A tube can be specified by critical dimensions (design surfaces) on which the recommended tolerances are to be achieved, i.e. either outside diameter and wall thickness or inside diameter and wall thickness or outside diameter and inside diameter with null or zero value for third dimension.

Once an appropriate code is given to a incoming order and fed into the system, it needs to be checked and interpreted to prepare the order detail. The checking of the code is required in order to prevent the user from feeding in a wrong code i.e. a code with missing characters or some extra characters is uncomplete and the related information cannot be retrieved. The interchange of numerical values at a position where characters are expected or vice versa also makes the code meaningless. After checking the validity of the code, it is necessary to interpret symbols as what information they communicate. This requires the storing of all related information in the knowledge base in the form of facts which can be used to retrieve the code-related information. The retrieved information is the new knowledge containing all necessary information in an appropriate format and can be used for developing the process plan.

### 5.3.2 SELECTION OF HOLLOW SIZE

Cold finish seamless tubes are manufactured from a hollow which is a semi-finished product of the rotary piercing process. Such hollows must be bigger in outside diameter and wall thickness than the required dimensions of the finished tube in order to allow the deformation to take place in the cold drawing process. In addition, the hollow size must be such that it can be reduced to the finished size, ideally, in a minimum number of passes and available in the standard products range of the rotary piercing mill.

The following strategy can be used for the selection of appropriate hollow size and to achieve the above mentioned objectives:

- Storing the standard products range of rotary piercing mill in the knowledge- base
- Computing the ideal hollow size by adding the minimum cold drawing margin in the finished tube dimensions. Cold drawing margin is the allowance to be added in the outside diameter and wall thickness of the finished tube in order to plan the manufacture of hollow.
- Checking whether the ideal size computed in step 2 is available in the standard product range. If it is not available then appropriate action is necessary.

In order to store the available product sizes, the concept of "lists" can be used. A list is an ordered set of objects in which the objects are linked internally so that they can be accessed as a group (list as a whole) or as individual objects i.e. the elements of the list. A small example is needed at this stage to give an overview of the concept of list and list processing. The standard diameters and thicknesses produced in the mill can be stored in the knowledge-base in form of facts of the kind:

standard_product("standard_diameters", [$D_1$,$D_2$,$D_3$,......................$D_n$])

standard_product("standard_thicknesses", [$T_1$,$T_2$,$T_3$,......................$T_n$])

where [$D_1$,$D_2$,$D_3$,......................$D_n$] is a list of standard diameters, "standard_product" is the database predicate to access the list. The elements of the list $D_1$,$D_2$,$D_3$ etc can be accessed by list processing, a concept which will be discussed in the chapter on knowledge representation.

The ideal size of hollow can be computed by allowing a minimum material margin to be deformed in subsequent cold drawing operations. The amount of this margin depends upon the outside diameter and wall thickness of the finished tube and has been quantified by analysing the manufacturing records. The prevailing practice is that, in case of thin-walled tube, a hollow is manufactured of thickness at least 2 gauges lower than the required thickness gauge of the finished tube where a gauge represents a certain thickness of the tube and being a higher gauge number means a smaller thickness. The amount of margin required to be added in a thick-walled tube is equivalent to a tube of thickness whose gauge number is 16. The cold drawing material margin in the outside diameter, ranges between 0/3 to 3 gauge to be added in the outside diameter of finished tube depending on its value.

Once the ideal size is computed by adding the minimum margin, it is necessary to check whether this size is available in the standard product range. The ideal size can be compared with each element of list and a match results in a conclusion that the ideal size is a member of the list. If there is no match available, then the next larger size from the list must be selected which can be achieved by list processing. A possible strategy in this case is as follows:

- Arrange the elements of the list in ascending order
- Split the list into two sub-lists in such a way that the elements of the first sub-list are less than the ideal size and the elements of the second sub-list are greater than the ideal size.
- The first element (head) of the second sub-list is the required next larger size.

### 5.3.3 BILLET SELECTION

For the selection of billet, decisions are necessary regarding the billet diameter, length and grade to be used. Under a given Standard, there are a number of material grades available having different composition and mechanical properties. The selection of a particular grade depends upon the customer requirement as specified in the code. This requires the storing of material grade, composition and mechanical properties in the knowledge-base so that it can be accessed when required.

The decision regarding the billet diameter depends upon the dimensions of the hollow to be achieved and the extent of expansion during piercing process i.e. whether it rises over plug or not. The strategy adopted for the selection of billet diameter for a given job is to compile a set of rules by analysing the existing manufacturing records of the mill and by grouping the jobs which require the same billet size. There are many methods available such as cluster analysis (119), Quinlan's algorithm (120) and a modified form of Quinlan's algorithm presented by Cendrowska (121) etc to form groups according to similarities of the attributes. Quinlan's algorithm produces an output in the form of a decisions tree on the basis of given raw data. Such decision trees, however, are difficult to manipulate and, in addition, usually contain redundant information. Decision trees having redundant information cannot be translated into independent rules to be incorporated in knowledge-based systems. In this present work, the modified form of Quinlan's algorithm as presented by Cendrowska (121) has been used to analyse the manufacturing records in order to produce modular rules and is discussed below.

### 5.3.3.1 MODIFIED FORM OF QUINLAN'S ALGORITHM

Before describing the algorithm, it is necessary to define the terms used such as "training set", "information gain", "classification" , " probability of instances belonging to a class" and " probability of occurrence of a class based on the attribute-value pair". A training set can be thought of as a discrete information system i.e. it contains a number of discrete messages (value of attributes) which impart some information about a classification. The information gain is the amount of information contributed by knowing the value of an attribute to the determination of a specific classification. The amount of information about a classification in a message *i* is thus:

$$I(i) = \log_2 \left( \frac{\text{Probability of classification after the message is received}}{\text{Probability of classification before the message is received}} \right)$$

For example, a training set containing 20 messages out of which 4 belong to a class, $\delta_1$.

The probability of an instance $p(\delta_1)$ belonging to a class $\delta_1$ is therefore 4/20 and thus if

the message $(i)$ was $\delta_1$ then the amount of information gain in this message is (121):

$$I(\delta_1) = \log_2 \left( \frac{1}{p(\delta_1)} \right) \tag{5.1}$$

where probability of classification after the message is received is 1. The lower the probability of occurrence of an event, the more information is received if the event has occurred.

Classification means a group of instances in the training set leading to the same decision and the probability of occurrence of a class $\delta$ based on attribute -value pair, $a_x$ is $p(\delta/a_x)$. Having defined the terms, the task of the algorithm must be to find the attribute-value pair, $a_x$ , which contributes the most information about a specific classification, $\delta_n$, i.e. for which $I( \delta_n / a_x )$ is maximum i.e.

$$I\left(\frac{\delta_n}{a_x}\right) = \log_2 \left(\frac{p\left(\frac{\delta_n}{a_x}\right)}{p(\delta_n)}\right) \text{ bits} \tag{5.2}$$

Since $p( \delta_n)$ is the same for all $a_x$, it is only to necessary to find the $a_x$ for which $p( \delta_n / a_x )$ is maximum.

The basic induction algorithm can thus be described as follows:

If the training set contains instances of more than one classification, then, for each classification $\delta_n$ in turn:

Step 1: Calculate the probability of occurrence, $P( \delta_n / a_x )$, of the classification $\delta_n$ for each attribute-value pair, $a_x$ .

Step 2: Select the $a_x$ for which $P( \delta_n / a_x )$ is a maximum and create a sub-set of the training set comprising all the instances which contain the selected $a_x$ .

Step 3: Repeat steps 1 and 2 for this sub-set until it contains only instances of class $\delta_n$. The induced rule is a conjunction of all the attribute-value pairs used in creating the homogeneous sub-set.

Step 4: Remove all the instances covered by this rule from the training set.

Step 5: Repeat step 1 to 4 until all instances of class $\delta_n$ have been removed.

When the rules for one classification have been induced, restore the training set to its original state and apply the algorithm again in order to induce the rules covering other classes.

In order to illustrate the working of the algorithm for the selection of the billet diameter, a training set (which is a small sub-set of the whole manufacturing records) is shown in Table 5.1. The attribute a's ($a_1$ - $a_7$) denote the diameter of the hollow, b's ($b_1$ - $b_{13}$) denote the thickness of the hollow and the δ's ( $\delta_1$ - $\delta_3$) is the billet diameter to be selected. The training set contains a total of 91 instances with 20 that of classification $\delta_1$.

TABLE 5.1

Decision table for selecting the billet diameter (training set)

| | a | b | δ | | a | b | δ | | a | b | δ | | a | b | δ | | a | b | δ | | a | b | δ | | a | b | δ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 14 | 2 | 1 | 1 | 27 | 3 | 1 | 1 | 40 | 4 | 1 | 1 | 53 | 5 | 1 | 1 | 66 | 6 | 1 | 1 | 79 | 7 | 1 | 1 |
| 2 | 1 | 2 | 1 | 15 | 2 | 2 | 1 | 28 | 3 | 2 | 1 | 41 | 4 | 2 | 1 | 54 | 5 | 2 | 1 | 67 | 6 | 2 | 1 | 80 | 7 | 2 | 1 |
| 3 | 1 | 3 | 1 | 16 | 2 | 3 | 1 | 29 | 3 | 3 | 1 | 42 | 4 | 3 | 1 | 55 | 5 | 3 | 2 | 68 | 6 | 3 | 2 | 81 | 7 | 3 | 2 |
| 4 | 1 | 4 | 1 | 17 | 2 | 4 | 1 | 30 | 3 | 4 | 2 | 43 | 4 | 4 | 2 | 56 | 5 | 4 | 2 | 69 | 6 | 4 | 2 | 82 | 7 | 4 | 2 |
| 5 | 1 | 5 | 2 | 18 | 2 | 5 | 2 | 31 | 3 | 5 | 2 | 44 | 4 | 5 | 2 | 57 | 5 | 5 | 2 | 70 | 6 | 5 | 2 | 83 | 7 | 5 | 2 |
| 6 | 1 | 6 | 2 | 19 | 2 | 6 | 2 | 32 | 3 | 6 | 2 | 45 | 4 | 6 | 2 | 58 | 5 | 6 | 2 | 71 | 6 | 6 | 2 | 84 | 7 | 6 | 2 |
| 7 | 1 | 7 | 2 | 20 | 2 | 7 | 2 | 33 | 3 | 7 | 2 | 46 | 4 | 7 | 2 | 59 | 5 | 7 | 2 | 72 | 6 | 7 | 2 | 85 | 7 | 7 | 2 |
| 8 | 1 | 8 | 2 | 21 | 2 | 8 | 2 | 34 | 3 | 8 | 2 | 47 | 4 | 8 | 2 | 60 | 5 | 8 | 2 | 73 | 6 | 8 | 2 | 86 | 7 | 8 | 2 |
| 9 | 1 | 9 | 2 | 22 | 2 | 9 | 2 | 35 | 3 | 9 | 2 | 48 | 4 | 9 | 2 | 61 | 5 | 9 | 2 | 74 | 6 | 9 | 2 | 87 | 7 | 9 | 2 |
| 10 | 1 | 10 | 2 | 23 | 2 | 10 | 2 | 36 | 3 | 10 | 2 | 49 | 4 | 10 | 2 | 62 | 5 | 10 | 3 | 75 | 6 | 10 | 3 | 88 | 7 | 10 | 3 |
| 11 | 1 | 11 | 3 | 24 | 2 | 11 | 3 | 37 | 3 | 11 | 3 | 50 | 4 | 11 | 3 | 63 | 5 | 11 | 3 | 76 | 6 | 11 | 3 | 89 | 7 | 11 | 3 |
| 12 | 1 | 12 | 3 | 25 | 2 | 12 | 3 | 38 | 3 | 12 | 3 | 51 | 4 | 12 | 3 | 64 | 5 | 12 | 3 | 77 | 6 | 12 | 3 | 90 | 7 | 12 | 3 |
| 13 | 1 | 13 | 3 | 26 | 2 | 13 | 3 | 39 | 3 | 13 | 3 | 52 | 4 | 13 | 3 | 65 | 5 | 13 | 3 | 78 | 6 | 13 | 3 | 91 | 7 | 13 | 3 |

The probability of occurrence of class $\delta_1$ is p( $\delta_1$) = 20/91 and the information provided by the message $\delta_1$ before any attributes are known by equation 5.1 is:

$$I(\delta_1) = \log_2\left(\frac{1}{p(\delta_1)}\right) = 2.1863 \text{ bits} \tag{5.3}$$

To find the information gain using equation 5.2, $p(\delta_n/a_x)$ is required, for which the frequency table such as Tables 5.2 and Table 5.3 can be used which give the frequency of occurrence in the training set for attributes a's and b's. From Table 5.2 and Table 5.3, the value of $p(\delta_n/a_x)$ can be determined as specified in step 1 of the algorithm and is tabulated in Table 5.4 for n = 1. Now, according to step 2, there are two candidates for best $a_x$ having maximum $p(\delta_n/a_x)$ equal to 1. Selecting arbitrarily $b_1$ and using equation 5.2, the information gain for $b_1$ is:

$$I\left(\frac{\delta_1}{b_1}\right) = I\left(\frac{\delta_1}{b_2}\right) = \log_2\left(\frac{p(\frac{\delta_1}{b_1})}{p(\delta_1)}\right) = \log_2\left(\frac{1}{\frac{20}{91}}\right) = 2.1863 \text{ bits} \tag{5.4}$$

The message $b_1$ is the same as the message $\delta_1$ from equation 5.3 and if $b_2$ had been selected the information gain would have been the same. The sub-set of the training set comprising all the instances having $b_1$ and $b_2$ as shown in Table 5.5 contains the same class $\delta_1$, and therefore step 3 of algorithm cannot be applied. The induced rule for this subset can be written as:

IF( $a_1$ - $a_7$) AND ( $b_1$ - $b_2$) THEN select billet diameter of class $\delta_1$ (5.5)

Now, removing all the instances given in Table 5.5 as specified in step 4 from the training set (Table 5.1) and repeating step 1 for the rest of the training set will ultimately result in Table 5.6. Using equation 5.1, the information provided by the

TABLE 5.2

Frequency table for attribute 'a'

| No. of instances referencing | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | $a_6$ | $a_7$ | Total |
|---|---|---|---|---|---|---|---|---|
| $\delta_1$ | 4 | 4 | 3 | 3 | 2 | 2 | 2 | 20 |
| $\delta_2$ | 6 | 6 | 7 | 7 | 8 | 7 | 7 | 48 |
| $\delta_3$ | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 23 |
| Total | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 91 |

TABLE 5.3

Frequency table for attribute 'b'

| No. of instances referencing | $b_1$ | $b_2$ | $b_3$ | $b_4$ | $b_5$ | $b_6$ | $b_7$ | $b_8$ | $b_9$ | $b_{10}$ | $b_{11}$ | $b_{12}$ | $b_{13}$ | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $\delta_1$ | 7 | 7 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 |
| $\delta_2$ | 0 | 0 | 3 | 5 | 7 | 7 | 7 | 7 | 7 | 5 | 0 | 0 | 0 | 48 |
| $\delta_3$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 7 | 7 | 7 | 23 |
| Total | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 91 |

TABLE 5. 4

probability of occurrence for attributes 'a' and 'b'

| $a_x$ | | $p(\delta_1 / a_x)$ |
|---|---|---|
| $a_1$ | = 4/13 | 0.3077 |
| $a_2$ | = 4/13 | 0.3077 |
| $a_3$ | = 3/13 | 0.2308 |
| $a_4$ | = 3/13 | 0.2308 |
| $a_5$ | = 2/13 | 0.1538 |
| $a_6$ | = 2/13 | 0.1538 |
| $a_7$ | = 2/13 | 0.1538 |
| $b_1$ | = 7/7 | 1 |
| $b_2$ | = 7/7 | 1 |
| $b_3$ | = 4/7 | 0.5714 |
| $b_4$ | = 2/7 | 0.2857 |
| $b_5$ - $b_{13}$ | = 0 | 0 |

TABLE 5.5

Subset of training set comprising attributes $b_1$ and $b_2$

| a | b | $\delta$ |
|---|---|---|
| 1 | 1 | 1 |
| 1 | 2 | 1 |
| 2 | 1 | 1 |
| 2 | 2 | 1 |
| 3 | 1 | 1 |
| 3 | 2 | 1 |
| 4 | 1 | 1 |
| 4 | 2 | 1 |
| 5 | 1 | 1 |
| 5 | 2 | 1 |
| 6 | 1 | 1 |
| 6 | 2 | 1 |
| 7 | 1 | 1 |
| 7 | 2 | 1 |

TABLE 5.6

Probability table for attributes 'a' and 'b'

| $a_x$ | | $p(\delta_1 / a_x)$ |
|---|---|---|
| $a_1$ | = 2/11 | 0.1818 |
| $a_2$ | = 2/11 | 0.1818 |
| $a_3$ | = 1/11 | 0.0909 |
| $a_4$ | = 1/11 | 0.0909 |
| $a_5$ - $a_7$ | = 0 | 0 |
| $b_3$ | = 4/7 | 0.571 |
| $b_4$ | = 2/7 | 0.2857 |
| $b_5$ - $b_{13}$ | = 0 | 0 |

message $\delta_1$ before any attribute is known is:

$$I(\delta_1) = \log_2 \left(\frac{1}{p(\delta_1)}\right) = 3.6826 \text{ bits} \qquad (5.6)$$

where $p(\delta_1) = 6/77$ i.e.( 6 instances of $\delta_1$ in total of 77 instances)

From the Table 5.6, the best candidate for which $p(\delta_1/a_x)$ is maximum is $b_3$ and the information gain is:

$$I(\frac{\delta_1}{b_3}) = \log_2 (\frac{p(\frac{\delta_1}{b_3})}{p(\delta_1)} = \log_2 (\frac{\frac{4}{7}}{\frac{6}{77}}) = 2.8751 \text{ bits} \tag{5.7}$$

From equation (5.6) and (5.7) it is obvious that the information gain by knowing $b_3$ is not the same as provided by $\delta_1$. Therefore the creation of a sub-set is required containing all the instances of $b_3$ as shown in Table 5.7. Repeating step 1 for this subset, Table 5.8 can be formed which gives the frequency of occurrence for attribute-value pair.

TABLE 5.7

Subset of training set comprising $b_3$

| a | b | δ |
|---|---|---|
| 1 | 3 | 1 |
| 2 | 3 | 1 |
| 3 | 3 | 1 |
| 4 | 3 | 1 |
| 5 | 3 | 2 |
| 6 | 3 | 2 |
| 7 | 3 | 2 |

From table 5.8, the best candidate for which $p(\delta_1/ a_x)$is maximum are $a_1$ - $a_4$. Selecting $a_1$ arbitrarily the information gain is:

$$I(\frac{\delta_1}{a_1}) = \log_2 (\frac{p(\frac{\delta_1}{a_1})}{p(\delta_1)} = \log_2 (\frac{1}{\frac{4}{7}}) = 0.8075 \text{ bits} \tag{5.8}$$

The total information gain by knowing $b_3$ and $a_1$ by equations (5.7) and (5.8) is:

TABLE 5.8

Probability table for training set given in table 5.7

| $a_x$ | | $p(\delta_1/a_x)$ |
|---|---|---|
| $a_1$ | = 1/1 | 1 |
| $a_2$ | = 1/1 | 1 |
| $a_3$ | = 1/1 | 1 |
| $a_4$ | = 1/1 | 1 |
| $a_5$ - $a_7$ | = 0 | 0 |
| $b_3$ | = 4/7 | 0.571 |

$$I(\frac{\delta_1}{a_1}) + I(\frac{\delta_1}{b_3}) = 3.6826 \text{ bits} \tag{5.9}$$

The information provided by message $\delta_1$ by equation 5.6 before any attributes are known and the information gain by knowing $b_3$ and $a_1$ are equal. Since $p(\delta_1/a_x)$ is equal for $a_1$-$a_4$, another rule can be induced as:

IF ($a_1$ - $a_4$) and $b_3$ THEN select billet diameter of class $\delta_1$ (5.10)

Removing the instances containing $a_1$ - $a_4$ and $b_3$ will result in a sub-set for which the information provided by the message $\delta_1$ before any attribute is known is:

$$I(\delta_1) = \log_2(\frac{1}{p(\delta_1)}) = \log_2(\frac{1}{p(\frac{2}{70})}) = 5.1303 \text{ bits} \tag{5.11}$$

Again repeating the step 1 for this subset Table 5.9 is formed having the maximum value of $p(\delta_1/a_x)$ for $b_4$. The information gain by this message is:

TABLE 5.9

Probability for the training set

| $a_x$ | | $p(\delta_1/a_x)$ |
|---|---|---|
| $a_1$ | = 1/10 | 0.1 |
| $a_2$ | = 1/10 | 0.1 |
| $a_3$ - $a_7$ | = 0 | 0 |
| $b_4$ | = 2/7 | 0.2857 |
| $b_5$ - $b_{13}$ | = 0 | 0 |

$$I\left(\frac{\delta_1}{b_4}\right) = \log_2\left(\frac{p\left(\frac{\delta_1}{b_4}\right)}{p(\delta_1)}\right) = \log_2\left(\frac{\frac{2}{7}}{\frac{2}{70}}\right) = 3.3226 \text{ bits} \tag{5.12}$$

From equations (5.11) and (5.12) it is obvious that the information gain by knowing $b_4$ is not the same as provided by $\delta_1$, therefore a sub-set containing all the instances of $b_4$ is required to be formed as shown in Table 5.10. Applying the step 1 of algorithm on this sub-set will result in Table 5.11, having maximum $p(\delta_1/a_x)$ for $a_1$ or $a_2$. The information gain by knowing $b_4$ and $a_1$ is thus:

$$I\left(\frac{\delta_1}{a_1}\right) = \log_2\left(\frac{p\left(\frac{\delta_1}{a_1}\right)}{p(\delta_1)}\right) = \log_2\left(\frac{\frac{1}{2}}{\frac{2}{7}}\right) = 1.8077 \text{ bits} \tag{5.13}$$

Therefore, the total information gain by knowing $b_4$ and $a_1$ from equation (5.12) and (5.13) is:

$$I\left(\frac{\delta_1}{a_1}\right) + I\left(\frac{\delta_1}{b_4}\right) = 5.1303 \text{ bits} \tag{5.14}$$

TABLE 5.10

Subset of training set when instances of $b_4$ are removed

| a | b | $\delta$ |
|---|---|---|
| 1 | 4 | 1 |
| 2 | 4 | 1 |
| 3 | 4 | 2 |
| 4 | 4 | 2 |
| 5 | 4 | 2 |
| 6 | 4 | 2 |
| 7 | 4 | 2 |

TABLE 5.11

probability table for training set in Table 5.10

| $a_x$ | | $p(\delta_1/a_x)$ |
|---|---|---|
| $a_1$ | = 1 | 1 |
| $a_2$ | = 1 | 1 |
| $a_3$ - $a_7$ | = 0 | 0 |
| $b_4$ | = 2/7 | 0.2857 |

which is the same amount as provided by message $\delta_1$ in equation 5.11. Therefore another rule can be induced as:

IF ($a_1$ - $a_2$) and $b_4$ THEN select billet diameter of class $\delta_1$ (5.15)

Now, there are no more instances of class $\delta_1$ in the training set and it should be restored to its original shape. Then the algorithm should be repeated to induce the rules for classification $\delta_2$ and $\delta_3$. The induced rule for classification $\delta_1$ from (5.5), (5.10) and (5.15) can be rewritten as:

Rule 1:

IF the diameter of the hollow lies between value $a_1$ - $a_7$

and the thickness of the hollow lies between value $b_1$ - $b_2$

THEN select a billet diameter belonging to class $\delta_1$

Rule 2:

IF the diameter of the hollow lies between value $a_1$ - $a_4$

and the thickness of the hollow is $b_3$

THEN select a billet diameter belonging to class $\delta_1$

Rule 3:

IF the diameter of the hollow lies between value $a_1$ - $a_2$

and the thickness of the hollow is $b_4$

THEN select a billet diameter belonging to class $\delta_1$

These rules can be obtained by observation of the training set, without the use of any algorithm, due to the fact, that in this case, there are few parameters and the purpose was to illustrate the working of algorithm. The algorithm is more useful when the training set and number of parameters is large. In that case, simple observation cannot be used to imagine the interaction of those parameters.

### 5.3.4 PROCESS AND MACHINE SELECTION

In the machining domain, a single machine e.g. a lathe, can perform a number of operations such as straight turning, taper turning, facing, threading, chamfering etc. In such a case, the capabilities and limitations of available machines are stored in the knowledge-base and then the selection of a machine can be accomplished by comparing the requirements on the job with stored capabilities. Similarly, the processes are selected on the basis of their capabilities and constraints.

In case of hollow manufacture, every machine is , usually, a single purpose one which is capable of performing only one operation (piercing, elongating etc). Therefore, the selection of a machine is equivalent to the selection of a process. The hollow manufacturing process is a multi-production one and it is necessary to select all the processes. However, if the tube diameter is bigger than the intake capacity of stretch-reducer, then reheating and stretch-reducing operations should be omitted in the selection.

### 5.3.5 TOOL SELECTION

The appropriate tools need to be selected for various processes such as piercing, elongating and stretch-reducing. The piercing and elongating operations require tools which include the piercer plug, piercer bar, piercer disc rolls, mandrel bar and elongator disc rolls while that on the stretch-reducer the proper combination of roll cluster is needed.

The selection of most of these tools depends upon the size of the workpiece being manufactured, the billet diameter selected and, most important, is the availability of the tools. The piercer plug size is usually smaller than the bore of the hollow from the elongator depending upon whether bloom rises over plug or not i.e. the tube is of light or heavy wall thickness. The plug size also depends upon the selected mandrel bar and is usually 3 - 4 mm bigger than it so that it can be threaded easily in the bloom. The piercer bar diameter should be less than the plug size by a minimum amount in order to attain rigidity. The selection of piercer disc and elongator disc is inter-dependent and a particular combination can be used for a range of hollow sizes. The selection of mandrel bar size should be such that it can be withdrawn easily by the stripper i.e. the size should be less than the bore of the hollow. The rolls on the stretch-reducer are selected according to the finished hollow dimensions and the entry size.

The following strategy can be used for the selection of the tools:

- The available tools need to be represented in the knowledge-base in form of a list structure. This structure has the advantage of accommodating new tools as they become available.
- Knowing the hollow dimensions and plant practice, the ideal size of the tool can be computed.
- The availability of the ideal tools can be checked from the stored lists of the tools
- If the availability is confirmed, the tools are selected otherwise, a decision is required for selection among the available tools. Usually , such decisions are to select the tools which are in close proximity to the ideal size.

### 5.3.6 MACHINE PARAMETERS

The machine parameters may include the piercer disc and main roll gorge, elongator discs and main rolls gorge as discussed in section 4.8.6. The gorge between the piercer roll is determined by the billet diameter being used and is increased as the billet diameter increases. This implies that each size of the billet requires a different amount of draft or pinch so that it can be pulled through the main rolls. The amount of this pinch varies between 12 - 21 mm and must be subtracted from the billet size. The amount of the piercer disc gorge is usually set by adding a certain allowance to the billet diameter size.

The amount of the elongator main roll gorge is determined by the selected mandrel bar size and the thickness of the tube off the elongator. A small allowance is also necessary for the springback of the main rolls during the rolling process. The elongator disc rolls gorge is determined by adding an amount of allowance in the outside diameter of the hollow to be manufactured which varies between 3 - 8 mm.

### 5.3.7 OPERATION SEQUENCE

The operation sequence in the rotary piercing mill is dictated by the seamless tube manufacturing technology where operations are to be performed in a fixed order as discussed in section 4.8.7. For the generation of an operation sequence sheet, the precedence relationships can be used. The following two statements of precedence relationship, for example, completely specify the order of piercing operations.

operation_preced_relat (piercing, follows, billet heating)

operation_precd_relat (piercing, before,reducing on elongator)

Similar statements can be used for other operations including finishing operations to be carried out in case of HFS tubes. Once the operations are arranged according to the order in which they are required, they can be accessed in that order where necessary.

### 5.3.8 TIME ESTIMATION

The strategy used for time estimation is based upon the output capacity of the mill. The initial design capacity of the mill cannot be used for realistic time estimation due to ageing of the plant giving production difficulties. It has been observed from the actual production records of the mill that, due to the time lost in breakdown and other production difficulties, the mill usually runs at about 60 % of the design capacity.

A study was carried out to establish the actual output of the mill by analysing the parameters such as average billet weight, number of tons of tube and number of tubes produced per shift. The production data were taken for similar shifts i.e. equal time of running of the mill per shift. Figure 5.2 of such an analysis shows that as the average

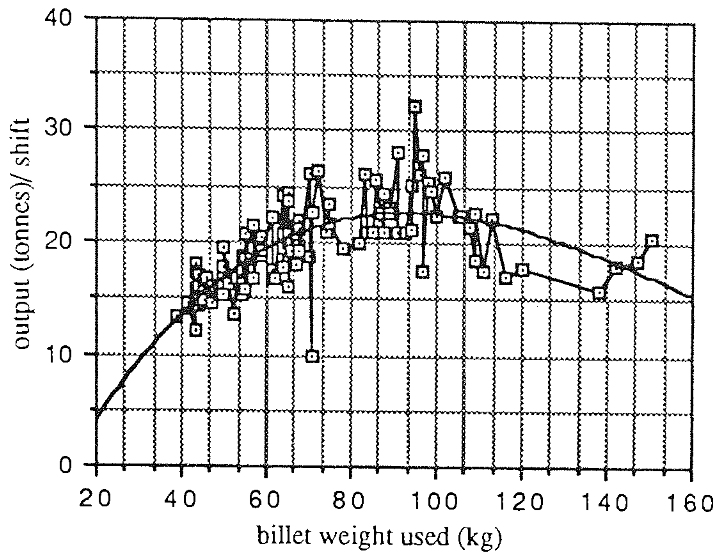



Figure 5.2: Actual production capacity (tonnes of tube/shift)

billet weight increases the mill output increases to a certain extent, beyond which the output starts decreasing. The reason is that as the billet weight increases beyond 100 kg, the system starts malfunctioning due to high forces of deformation and production time is wasted in maintenance resulting in lower output.

The average value of output is approximately 20 tons/shift or 200 tons/week on a two shift basis. Since the production data taken from the mill record is widely spread over the whole year production, it can be safely used for the estimation of production time for a given batch of tube.

### 5.3.9 OPTIMISATION OF HOLLOW MANUFACTURE AND MATERIAL

The manufacture of hollows can be optimised at two levels i.e. optimising the individual orders and optimising a group of orders. The first strategy of optimisation is discussed in this section:-

There are two possible techniques which can be used for optimising individual orders:

- Determining the maximum possible length of hollow which can be manufactured in the rotary mill so that the plant as a whole can be utilised to its maximum capacity.
- Determining the maximum length of hollow by taking into consideration the required length of the finished tube and the maximum utilisation of the mill.

In the first strategy, the maximum possible length can be computed by taking into consideration the workpiece handling constraints of furnace, piercer, elongator and stretch-reducer, on the basis of which optimal billet length can be computed. This technique can be used for finished tubes of random length. In the case of fixed length finished tubes, the maximum length may not be an exact multiple of the required lengths and therefore to cut exact required length may result in the scrap of manufactured hollow.

In the second technique, the billet length is iteratively increased by an amount from which the required finished tube can be manufactured, and lengths after piercing, elongating and stretch-reducing are computed to check the mill constraints. The process is repeated until the mill constraints are satisfied and maximum possible utilisation is achieved. The result will be an optimal billet length from which a maximum hollow length can be manufactured and is an exact multiple of the required length of the tube. This ensures that there is no scrap of tube, but there are chances that the equipment is not being used to maximum capacity.

Once the optimal billet length has been computed, the next step is to determine from what bar stock the billet should be cut in order to minimise material loss. To achieve this , a possible strategy may be:-

- To determine the number of billets of required length from every type of available bar
- To record the material loss for every type of bar i.e. the remaining length from which the billets of required length cannot be made.
- To select a bar with the minimum material loss from which to cut the billets

### 5.3.10 PRODUCTION SCHEDULES

The preparation of production schedules or rolling programmes is necessary for the implementation of the optimisation strategy of hollow manufacture by the method of grouping similar orders i.e. the orders which require similar settings of the mill. It is important to give a brief account of the setting of the mill on the basis of which the orders are grouped. Each combination of piercer-elongator disc rolls is capable of making a certain range of hollow sizes, forming a group. Setting of the mill requires a significant amount of time which is non-productive and should be minimised. This can be achieved by running the mill on a particular setting for as long as possible, depending on the availability of orders in that group. Having sufficient orders, the usual practice is to make a particular combination operational for one week at the most and any remaining orders which can not be manufactured in that week are then postponed for the next turn which comes when all the remaining combinations have been operational at the most for one week each or depending on the availability of orders. The production is, therefore, achieved in a sequence-wise fashion as shown in the figure 5.3.

The planning horizon is usually for the next 12 weeks which is the approximate delivery time of the mill. This means that the planning horizon depends upon the available orders. In order to fully automate the preparation of production schedules on the basis of orders grouping, the following strategies can be used.

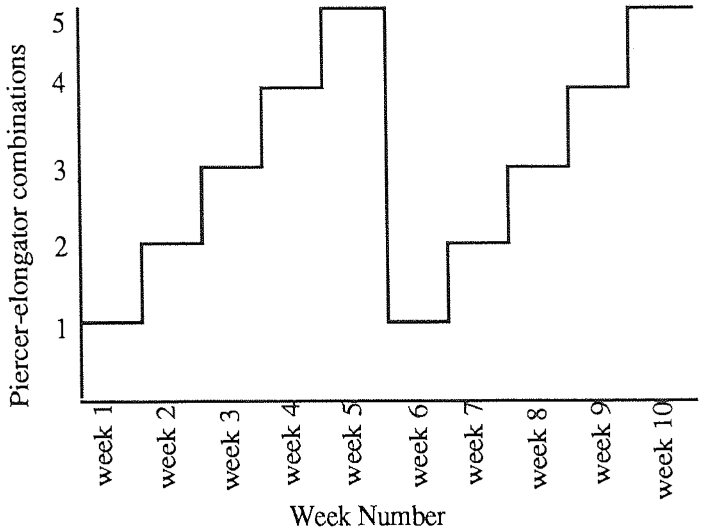



Figure 5.3: Ascending order of piercer-elongator disc rolls combination

### 5.3.10.1 CASE 1: FRESH START

When a new order is planned by the process planning system, it should be written in the "new order file" of unscheduled orders. Whenever scheduling of these orders is required, then the following strategy can be used:

1. Group the new orders according to piercer-elongator disc roll combination and write into " file of grouped orders"
2. Set a particular piercer-elongator disc rolls combination as anticipated by the user and establish a sequence in which it can be changed.
3. Find the current week number, its start and finish date and total output manufacturing capacity for the working days by excluding the non-working days
4. Based on the available manufacturing capacity of the current week find the orders of a group belonging to prevailing piercer-elongator combination which can be scheduled, arrange them in an economical way of manufacture and record them in a "master file" of orders. Eliminate the newly scheduled orders from the "grouped order file" so that they cannot be consider again

for scheduling.

5. Update the time period of present week to next week and present combination to next combination according to the established sequence.
6. repeat process 4-5 until no more orders are available in the "file of grouped orders" i.e. all new orders are scheduled and recorded in the master file.
7. Estimate the start and completion date for each order in the "master file" by determining the completion time in terms of fraction of a day per order and then translating it into real time indicated by expected completion date and record them in the production schedules file.

5.3.10.2 CASE 2: WHEN PREVIOUSLY SCHEDULED ORDERS EXIST

After the initial start, the previously scheduled orders must be taken into account for scheduling the new orders. The following strategy can be used:

1. Group the new orders according to piercer-elongator disc roll combination and write into " file of grouped orders"
2. Eliminate the completed orders from the master fiie as anticipated by the user so that they should not be considered for rescheduling
3. Find the current week number, its start and finish date and the total manufacturing capacity and the remaining capacity (total capacity - capacity used up by the previous orders)
4. Knowing the remaining capacity and associated group number of previously scheduled orders find orders of this group from the " file of grouped orders" which can be scheduled. The old orders from the master file and the new orders which can be manufactured in the remaining capacity are to be arranged in a way of economical manufacture and the master file needs to be updated accordingly.

5. Update the time period from the present week to next week and the present combination to next combination. Determine the total manufacturing capacity and the remaining capacity for this week.

6 repeat the process 4- 5 until no orders remain in the "file of grouped orders" and all the new orders are scheduled and recorded in the master file.

7. Estimate the start and completion dates for each order in the master file and write into the production schedules file.

5.3.10.3 CASE 3: BREAKDOWN

In case of breakdown, the previous estimates of start and finish dates are no longer valid. In this case, before rescheduling to estimate start and finish dates, the completed orders should be eliminated from the master file. The same procedure as mentioned in CASE 2 can be used except that new orders are not taken into account and rescheduling is done only for the orders in the master file.

5.3.10.4 CASE 4: CONTINUOUS SCHEDULING

The scheduling procedure in CASE 2 is done on a weekly basis in which the sequence of piercer-elongator disc rolls is repeated. There may arise a case where the available orders for one or more groups are less than the available capacity in the week. In this case , the procedure will generate a schedule allotting the whole week to the orders which can be made in less time. For example, supposing that available orders for four groups A, B, C and D require 9.5 weeks of production. The orders of group A and D require 3 weeks each, B requires 2 week sand C requires 1.5 weeks. The rolling programme as generated by the procedure on the weekly basis will result as shown in figure 5.4.

The figure 5.4 shows that although capacity in weeks 7, 10 and 11 is available, the orders for group D have been scheduled in week 12 and the capacity in weeks 7, 10 and

11 has not been used. This is a result of implementing the policy of one full week for every type of orders and in practice this schedule is unrealistic beyond week 7 and needs to be rectified.

| Week No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Group | A | B | C | D | A | B | C | D | A | B | C | D |
| Cap. used | | | | | | | | | | | | |

Figure 5.4: Production schedule based on allotting one week capacity for each group

In order to overcome such a problem, the orders which follow the week 7 -9 are required to be shifted 0.5 week and orders in week 12 by 2.5 weeks earlier for actual production. Figure 5.5 shows the actual production schedule which is realistic. This strategy has been applied in the system in order to generate realistic schedules.

| Week No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Groups | A | B | C | D | A | B | C+D | D+A | A+D | D |
| Cap. used | | | | | | | | | | |

Figure 5.5: Improving production schedule by moving the orders to fill unused capacity

5.3.10.5 OTHER REQUIREMENTS

Once the orders are scheduled and start and finish dates are estimated, there are some additional requirements which becomes necessary , including:-

- Listing of available orders in the system
- Listing of scheduled orders in the system
- Listing of a particular order i.e. order enquiry
- Listing of material requirement on a weekly basis. This includes material of different grades and different sizes.
- The listing of weekly status of total, used and unused capacity of the mill. This is the most important aspect on which future planning is based therefore graphical representations such as bar charts are most suitable.

## 5.4 SUMMARY

The process planning concepts for the manufacture of hollows have been discussed. The knowledge and the expertise required to solve the every sub-task of process planning have been presented. In some cases the expertise has been acquired by analysing the existing manufacturing record by the utilising the concept of Quinlan's algorithm in its modified form. The algorithm can be used to induce modular rules to be represented in the knowledge-base. In other cases, the expertise of the expert can be directly translated into rules. Two techniques have been identified in order to optimise the manufacture of hollows, one being the optimisation of individual orders and other being the optimisation of a group of orders. After capturing the expertise for the manufacture of hollows, knowledge is required to convert the hollows into required finished seamless tubes by the process of cold drawing which will be discussed in the next chapter.

# CHAPTER 6

## PROCESS PLANNING IN A COLD DRAWING PLANT (CONCEPTUALISATION)

### 6.1 INTRODUCTION

In this chapter, the concepts for process planning in the cold drawing plant will be presented. These concepts are related to the selection of drawbench, number of passes, secondary processes, generation of alternative tube-drawing schedules, selection of best schedule and validation of selected schedule. The validation of a selected schedule requires the computation of the process parameters such as stress/strain and total drawing load and then to compare them with the capacity of the drawbench.

The computation of these parameters requires an understanding of the mechanics of tube drawing. The existing models for the prediction of the drawing load and power requirement cannot be used as such in the computer programs because they require some parameters to be determined experimentally. To overcome this, an analytical approach has been proposed to predict the required parameters and will be discussed. It will be shown that the results predicted by the proposed model are valid and therefore it can be used safely in the computer software.

In the following sections the solution methodology for process planning tasks in the cold drawing mill are presented.

### 6.2 SELECTION OF DRAWBENCH

A number of drawbenches available in the cold drawing plant and selection is based on the capacity in terms of drawing load or power requirement and workpiece handling. This requires the computation of stress/strain, the drawing load and hence the power requirement for a tube drawing schedule.

The strategy, however, cannot be used because the selection of drawbench needs to be made at a much earlier stage of the planning of hollow manufacture, since appropriate allowances are necessary, the amount of which varies for different drawbenches. These allowances may include the tagging and cutting margin and thick end scrap in the stretch-reducing process (where the wall of the hollow is thickened at the ends due to less stretching action compared with the centre portion (122)). The thick end portions are not suitable for cold drawing operations due to the fact that the standard plug cannot be accommodated in the bore and it is necessary to be cut as scrap. The amount of thick end scrap varies being more on smaller diameter. To accommodate these allowances, therefore, the selection of drawbench must be carried out in the hollow planning stage.

The strategy used is based upon the prevailing policy of experience that a particular drawbench is more suitable for a group of orders. The groups are made according to the dimensions of the hollows and the finished length of tube required. This policy ensures the utilisation of all the available drawbenchs whereas the optimum selection of drawbench on the basis of power requirement may result in the overloading of a particular bench with others remaining idle.

However, the selection of a drawbench on the basis of this strategy must be validated at a later stage in order to eliminate the risk of particular tube-drawing schedule requiring power which is beyond the design capacity.

## 6.3 NUMBER OF PASSES

It is common practice to reduce a hollow to the required dimensions of CFS tubes by one or more passes. The number of passes can be determined by the knowledge of the total reduction of area (total strain to be imparted to the tube) and the maximum allowable reduction of area per pass i.e. allowable strain per pass. The maximum allowable reduction of area per pass is limited by the tensile fracture of the drawn tube which is equivalent to the yield stress if there is no appreciable strain hardening is assumed, as discussed by Rowe (38). The amount of maximum allowable reduction for a close pass (defined later) has been estimated by Rowe as 51 % for a straight plug (with plug semi-angle $\beta = 0$) and a die semi-angle of $15^0$ using coefficients of friction for plug and die of 0.05 . On this basis, he determines the number of passes by the use of total strain and allowable strain. The diameter and thickness after every pass is then adjusted to standard values.

The classical theories of tube drawing take account of one of two extremes of close pass tube drawing and sinking. In close pass (pure draft condition) as shown in figure 6.1b,

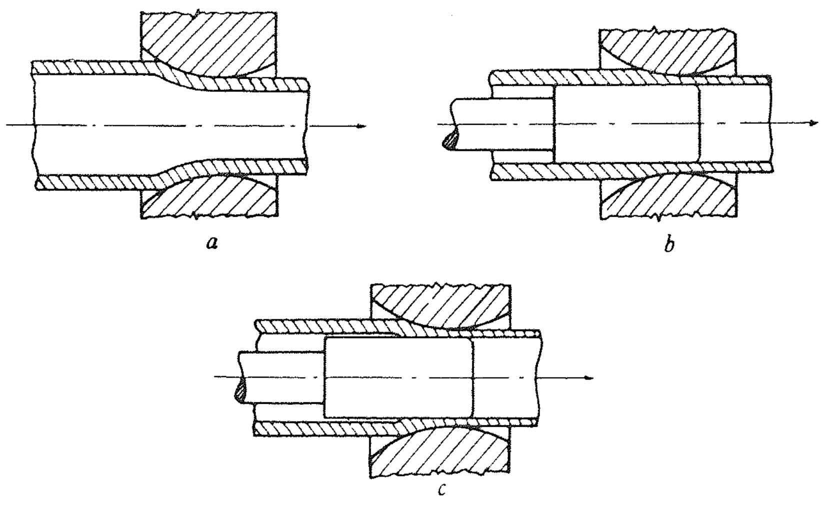



Figure 6.1: Diagrammatic representation of the modes of drawing( Blazynski and Cole)

6.1a Pure sink 6.1b: Pure draft or close pass 6.1c:Mixed mode

there is no reduction in the inside diameter of the tube and all the reduction is achieved at the expense of wall thickness as discussed by Young and Meadows (123) and Blazynski and Cole (124). On the other hand, during the sinking process figure 6.1a, both inside and inside diameters are reduced and wall tends to thicken because of lack of internal support. However, in industrial practice tubes are commonly drawn by a combination of sink and draft reduction and the expressions of classical theories as such cannot be used.

Based on the mixed mode of deformation figure 6.1c, Meadows and Lawarence (125) have suggested a model which is based upon the criterion of zero circumferential tensile residual stress in the drawn tube to predict the limiting value of reduction of area per pass. In this model, the equation of drawing stress based on the Sachs approximate theory has been modified to account for stress/strain characteristic of material and redundant work. The redundant work is the amount of additional work required for deformations which are not essential to the required changes in the shape of workpiece (126) and is mostly due to the tool geometry which causes the metal to flow in a more complex manner than necessary to achieve the desire change of shape. In the model, it is assumed that the maximum allowable reduction per pass is limited by the tag strength i.e. the modified equation should predict a stress lower than the tag strength and outside this condition tag failure will occur. The tag strength was obtained from the stress/strain characteristics of the material, i.e. $\sigma = c\varepsilon^n$ was used and the strain, $\varepsilon$, was defined in terms of wall thickening as a result of tagging operation. Thus, if the wall thickens by 10 % then $\varepsilon = \log(1.10)$. However the extent of wall thickening cannot be determined before the tagging operation is actually performed.

It has been observed (115) that the determination of the number of passes on the basis of maximum allowable reduction of area per pass by the use of above mentioned model, does not correspond with practice in the plant. The possible reasons may be the different actual dimensions of the hollow as compared with planned dimensions ( in this case more overall reduction is required than the planed reduction), the prevailing frictional condition in the shop and non-standard tooling etc. In order to determine the realistic number of passes which corresponds to the prevailing practice, experienced-based strategy is needed. Such a strategy, therefore, requires the capturing of the experience of plant personnel and analysis of the existing manufacturing records. A similar analysis as described in 5.3.3.1 has been used on the existing manufacturing records and it has been observed that factors such as total reduction of area, selected drawbench, material composition and tube finish are taken into account and there exists a pattern for the selection of the number of passes for a given job. This pattern has been reduced to a set of heuristic rules to be represented in the knowledge-base.

## 6.4 ALTERNATIVES AND BEST TUBE DRAWING SCHEDULE

The determination of the number of passes does not specify the die and plug sizes required in carrying out the number of passes by cold drawing operation. A tube drawing schedule determines what tools should be selected in the intermediate passes to obtain the required dimensions in the final pass. Meadows and Lawrence(125) in their work on a 'Theoretical Approach to Rationalising Tube-drawing Schedules" have mentioned the nomographs used by some companies to assist the selection of die and plug sizes using

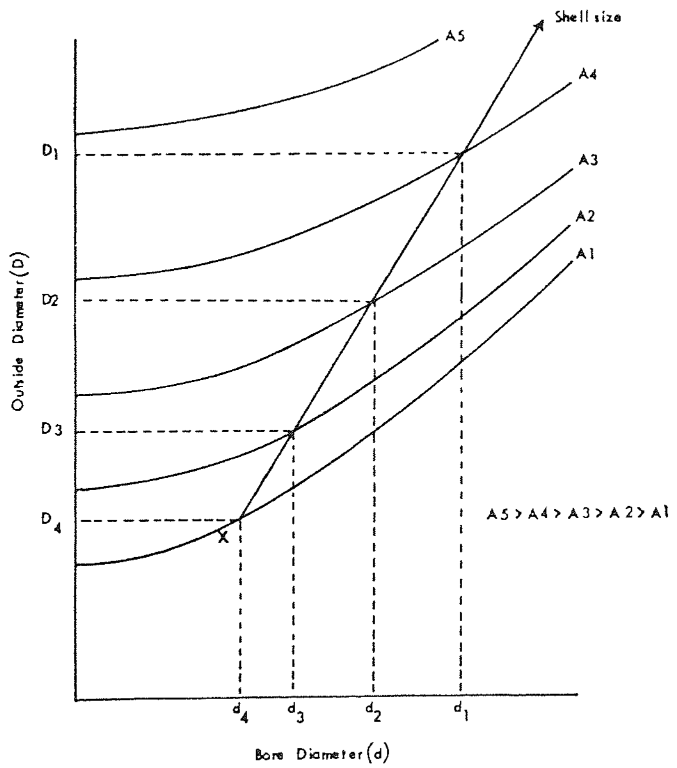



Figure 6.2: Iso-area curves relating outside and inside diameter after Meadows and Lawrence (125)

zero residual stress criteria. The nomographs as shown in figure 6.2 consists of iso-area curves relating the outside and inside diameter, spaced in such a way that the distance between two curves represents the maximum practicable reduction of area. Given a customer size of tube, the required hollow, die and plug sizes can be selected by the use of these graphs. The approach presupposes the availability of an infinite number of hollows, die and plug sizes whereas in practice only a limited number of such sizes is usually available. The available, not the ideal, sizes need to be selected even though the zero residual stress criterion may not be achieved. It was suggested by Meadows and Lawrence (125) that the available die/plug combination can be selected by deviating from the zero residual stress criterion and allowing a certain amount of residual stresses which can be tolerated in the drawn tube. The permissible amount of residual stress in the drawn tube may not be known when selecting a die/plug combination from the available tools.

Another disadvantage of this type of nomograph is associated with thin wall tubing where

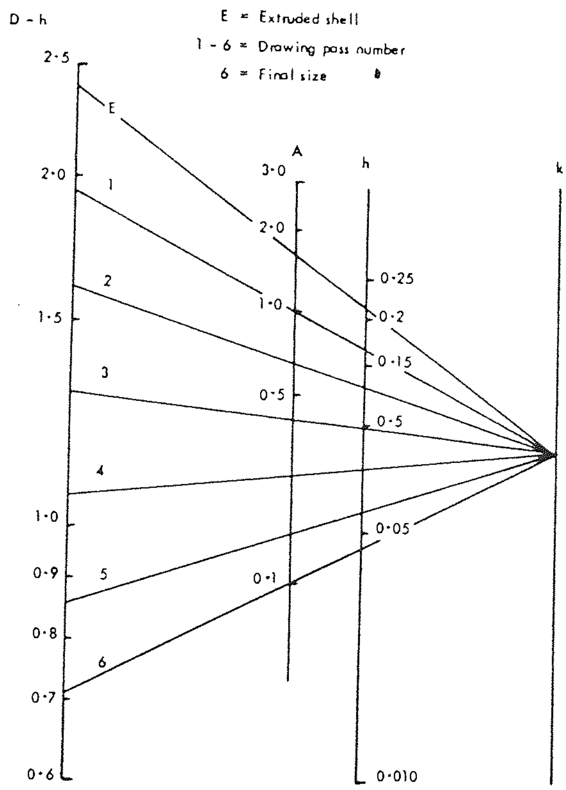



Figure 6.3: Nomograph relating D-h, A, h and K.Pass sequence from extruded shell to final size using 6 passes of equal reduction after Meadows and Lawrence (125)

iso-area curves are very closely spaced, restricting the usefulness of these curves. To overcome such problems a parallel-scale nomograph as shown in the figure 6.3 was suggested. Such nomograph can be developed by using the area formula of the tube in logarithmic form and imposing the zero residual stress concept that the ratio of the diameter, thickness and hence the mean diameters are constant throughout the schedule. To establish the intermediate passes and tool sizes, a linear unit of length is selected on the log area scale that is equivalent to maximum reduction allowable. The lines connecting these areas to a point on K scale, which is determined by the required customer size, are drawn and the values of the average diameter and thickness can be read off.

The nomographs discussed above were of great help for developing tube drawing schedules manually for the operation of a plant at optimum condition. However they may not be very useful when the optimum reduction of area per pass is not required (e.g. to obtain the required properties, sometimes very light passes are required), optimum reduction cannot be achieved due to non-standard tooling, the tools sizes as predicted by the nomograph are not available, the level of residual stress tolerated by the drawn tube is not known or simply the schedule does not correspond to plant practice.

As required by the knowledge-based systems, the strategy to produce a tube drawing schedule is based upon expertise, i.e. shop practice, the planned dimensions of hollows and, most importantly, the availability of the tools. Given the initial dimensions of the hollow, the final dimensions of the tube required and the lists of available die and plug sizes represented in the knowledge-base, the range of usable tools can be determined. A given hollow can be reduced to the required tube size in many different ways depending upon the combination of die and plug sizes used. On the basis of the number of passes decided and the usable tools combinations, all possible alternatives tube drawing schedules then can be generated, the number of such schedules depending upon the number of possible die and plug sizes in the range. For each schedule, the reduction of area is computed for every pass and schedules which lie outside the actual production criteria are discarded. For example, a schedule having a reduction of area more than 50 % or less than 5 % is obviously not desirable.

Once all the alternative schedules are generated and sorted out, the best schedule can be selected by using heuristic rules such as minimum variation in reduction of area over the selected passes. This ensures that the selected schedule is more even and the drawing forces required are similar in every pass of the drawing schedule on the basis of annealed material. In case where the tube is required in the soft condition and a light (10 -15 % reduction of area) in final pass has to be carried out, the schedule is selected accordingly.

## 6.5 SELECTION OF SECONDARY PROCESSES

In cold drawing plant, a variety of tubes are manufactured requiring other secondary processes either to prepare and soften the hollow for cold drawing operations or to obtain the required properties and finish in the drawn tube. For a given schedule, these processes are repeated in a sequence as shown in figure 6.4. Before giving the first pass to the tube, the hollows are always tagged, pickled and lubricated. The tagging operation

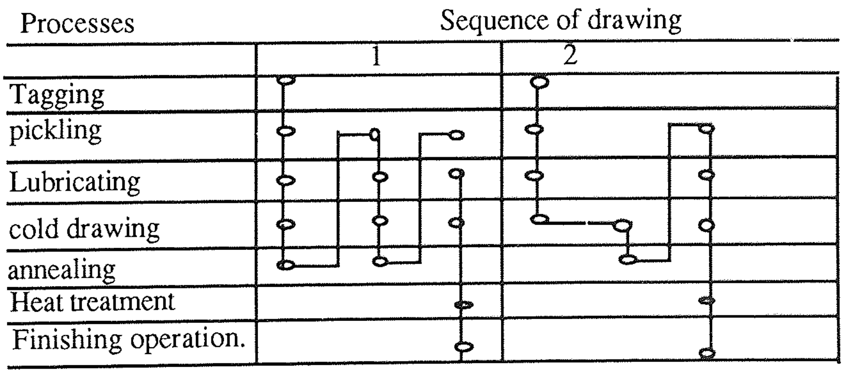



Figure 6.4: Repetition of secondary process for a 3 pass job

is performed according to the finished tube dimensions so that it is done only once. However, the tubes are pickled to remove the scale after the annealing process and then lubricated to reduce the friction.

The selection of the inter-pass annealing depends upon the condition of the tube. The technicians who have been in the business for a long time, based on their experience, can suggest when inter-pass annealing is require, simply by looking at the surface texture of the drawn tube. Such experience cannot be programmed in off-line computer software.

It has been observed from the manufacturing records that the selection of inter-pass annealing is mainly dependent upon the material composition and grade. For more hard-to-draw materials such as high carbon and alloy steels, inter-pass annealing should be selected after every pass while for easy-to-draw materials such as mild steel, after every two passes.

The implementation of this strategy requires that the every material type and composition (carbon content) must be stored in the knowledge-base. Then, knowing the material designation, the compiled rules can be used for the selection of inter-pass annealing or otherwise.

The finish heat treatment operations and other finishing process can be selected either from relevant Standard or as specified by the customer.

## 6.6 VALIDATION OF TUBE-DRAWING SCHEDULE

The determination of the number of passes and the selection of the best schedule amongst the generated alternatives was based upon plant practice as discussed earlier. No attention was paid to the cold drawing process parameters such as stress/strain, drawing load and power requirement for a selected tube drawing schedule. The estimation of the process parameters was not possible because of their dependency on inter-pass annealing. The power requirement for a pass in the given schedule will be less for an annealed batch of tube compared with an unannealed batch.

Although it is less likely, it may be possible that for the selected tube-drawing schedule the power requirement may exceed the capacity of the drawbench. It is, therefore, necessary to check the validity of tube-drawing schedule by computing the process parameters and checking against the capability of the available drawbench. Such an extra safeguard is necessary in order to eliminate the minimal chances that a selected tube-drawing schedule based on shop practice is beyond the drawbench capacity.

The determination of these parameters requires an understanding of the mechanics of the tube drawing. This has been investigated by a number of researchers using both theoretical and experimental approaches. The main contribution for plug drawing is the Sachs approximate theory which is the basis of further investigations (123 - 125). Bramley and Smith (127) have used the upper bound technique to investigate the importance of various parameters in floating plug drawing.

The application of Sachs theoretical expressions to practice encounters major difficulties (124). This is because of the pre-supposition of the knowledge of the mean yield stress of the material, coefficient of friction between the working surfaces and not accounting the strain hardening of the material. To overcome this, the work of Blazynski and Cole (124) was aimed towards determining experimentally the mean yield stress of the metal being drawn so that the Sachs expression can be used with the experimental value of mean yield stress.

For the determination of these parameters, the model based upon the work of Blazynski and Cole (124) has been chosen. In this model, the experimental determination of mean yield stress is based on the concept of equivalent strain as first defined by Hill and Tupper (128). In order to simulate the model in a computer program, provision must be made for finding the equivalent strain and hence the true mean yield stress of the metal analytically. The values of equivalent strain and the true mean yield stress thus determined must be in agreement with the experimental values. The model can then be used for determining the drawing load and power requirement in order to validate the drawing schedule.

In the following sections, first the Sachs general expression for drawing load and its solution leading to the determination of true mean yield stress on the basis of the equivalent strain concept is presented. Then the proposed analytical approach for determining the equivalent strain and the true mean yield stress is discussed. Taking the original tube drawing schedules as a basis, the equivalent strain and the true mean yield stress are computed. On the basis of values of the true mean yield stress, the drawing load and its components such as total deformation, useful deformation and frictional component can be computed. The values of these parameters, are then compared with the original experimental values (124), in order to establish the usefulness of the proposed analytical approach.

### 6.6.1 DRAWING STRESS

The general expression for drawing stress based on the von Mises criterion under conditions of plane strain, due to Sachs, is given by:

$$\frac{dt}{t} = \frac{d\sigma}{c\sigma - \sigma_0\,(1+c)} \qquad (6.1)$$

where

$\sigma_0$ = true mean yield stress;

$c = 2\mu/\tan\alpha$;

t = thickness of the tube during drawing

$\sigma$ = drawing stress during the process

$\alpha$ = die semi-angle

$\mu$ = coefficient of friction.

Rearranging equation (6.1) and knowing that the thickness t varies from $t_1$ to $t_2$ and $\sigma$ varies from $\sigma_1$ to $\sigma_2$ and integrating :

$$\left[\frac{t_1}{t_2}\right]^c = \frac{\sigma_1 c - a}{\sigma_2 c - a} \qquad (6.2)$$

where

$t_1$ = initial tube thickness

$t_2$ = final tube thickness

$\sigma_2$ = drawing stress at the exit from the die;

$\sigma_1$ = back pull stress;

$c = 2\mu/\tan\alpha$;

$a = \sigma_0(1+c)$

For frictionless drawing the coefficient of friction is zero and equation 6.1 reduces to:

$$-\frac{dt}{t} = \frac{d\sigma}{\sigma_0}$$

which after integrating yields:

$$\frac{\sigma_2}{\sigma_0} = \frac{\sigma_1}{\sigma_0} + \ln\frac{t_1}{t_2} \qquad (6.3)$$

Equation (6.3) gives the load of deformation and the frictional component of drawing load then can be obtained by taking the difference between total drawing load and deformation load computed from equations (6.2) and (6.3) respectively. Values of $\sigma_1$ and $\sigma_0$ are required in order to be able to determine the load components. In industrial practice, tubes are commonly drawn by a combination of sink and draft reduction in a single pass and unless the tube is drawn in a pure draft condition in which case $\sigma_1 = 0$, the value of back pull ($\sigma_1$) for the sinking condition can be obtained by empirical relations, quoted in (124), for different die geometry as follows:

for a radius die

$$\sigma_1 = 9.0\ R\ MN/m^2 \tag{6.4}$$

and for a straight taper die of angle $15^0$

$$\sigma_1 = (15.5 + 8.8\ R)\ MN/m^2 \tag{6.5}$$

Where R = Percentage reduction in area during sinking

### 6.6.2 ESTIMATION OF TRUE MEAN YIELD STRESS

To solve equations (6.2) and (6.3), the true mean yield stress ( $\sigma_0$) can be determined experimentally by obtaining the basic stress-strain curve for the material and true stress-strain curve for the drawn material by plane compression indentation tests.

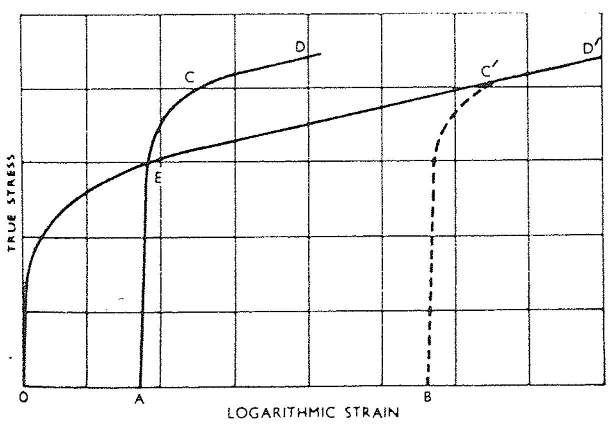



Figure 6. 5: Illustration of the concept of "Equivalent strain" after Blazynski and Cole

In theory, the basic stress-strain curve for the material and the true stress-strain curve for the drawn tube should coincide. It is not the case and the values of actual stress in the drawn material (curve ACD) are higher than those given in the basic stress-strain curve due to work-hardening as shown in figure 6.5 (curve AEC'D') after Blazynski and Cole (124). The increase in the strain due to work-hardening is equivalent to shifting the curve ACD to position B'C'D' and the intercept OB is defined as equivalent strain which is higher than the actual strain (intercept OA). Therefore, the true or effective mean yield stress is the average value of area under the curve and can be found numerically by:

$$\sigma_0 = \frac{1}{\varepsilon_f - \varepsilon_i} \int_{\varepsilon_i}^{\varepsilon_f} \sigma \, d\varepsilon \tag{6.6}$$

where

$\varepsilon_f$ = final value of strain

$\varepsilon_i$ = initial value of strain

$\sigma$ = is a function describing the stress in the stress-strain curve

Equation (6.6), gives two values of true mean yield stress i.e. one for actual strain OA and other for equivalent strain OB. The actual total strain (OA) can be determined by using the following equation by assuming that the thickness before and after the sinking remains constant as discussed by Blazynski and Cole (124).

$$\varepsilon = \frac{\sqrt{3}}{2} \ln \frac{A_0}{A_1} + \ln \frac{t_0}{t_2} \tag{6.7}$$

where

$\varepsilon$ = total strain;

$A_0$ and $A_1$ = cross-sectional areas of tube before and after the sinking portion;

$t_0$ and $t_1$ = tube thickness after sinking

The equivalent strain can be determined experimentally by:

- Obtaining the basic stress-strain curve for the metal and true stress-strain curve for the specimen from the drawn tube by plane compression indentation tests.
- Shifting the actual curve to a position where it coincides with the basic curve to approximate the condition of farmer.
- Reading the value of intercept which is the required equivalent strain.

The difference between the two values of true mean yield stress based on the actual strain and the equivalent strain is due to the additional work-hardening and can be related to the redundant work in the process. In order to simulate the plug drawing process and to determine the process parameters, the model as such cannot be used because it requires the values of equivalent strain to be determined experimentally. In order to overcome this an analytical model has been proposed as discussed below.

### 6.6.3 DETERMINATION OF EQUIVALENT STRAIN BY ANALYTICAL MODEL

The mathematical model (129) predicts the values of the equivalent strain which are in close agreement with the experimental value published by Blazynski and Cole (124). The model is based upon the similar analysis given by Bramley and Smith (127) for floating plug drawing and has been modified to simulate the process of fixed plug drawing.

Material behaviour, i.e. the stress-strain curve can be expressed in different ways (38) as shown graphically in figure 6.6. The simple form of the material behaviour can be assumed as a constant straight line as shown in figure 6.6d. The constant straight line expression assumes that there is no work-hardening and the yield stress remains constant and independent of the strain if the elastic effect is ignored. This simple approach cannot be used for real metals and a better approximation is, therefore, to assume a uniform rate of strain-hardening as shown in figure 6.6c. Although, it is a better approximation for heavily worked metals but over estimates the stresses in annealed material. For annealed

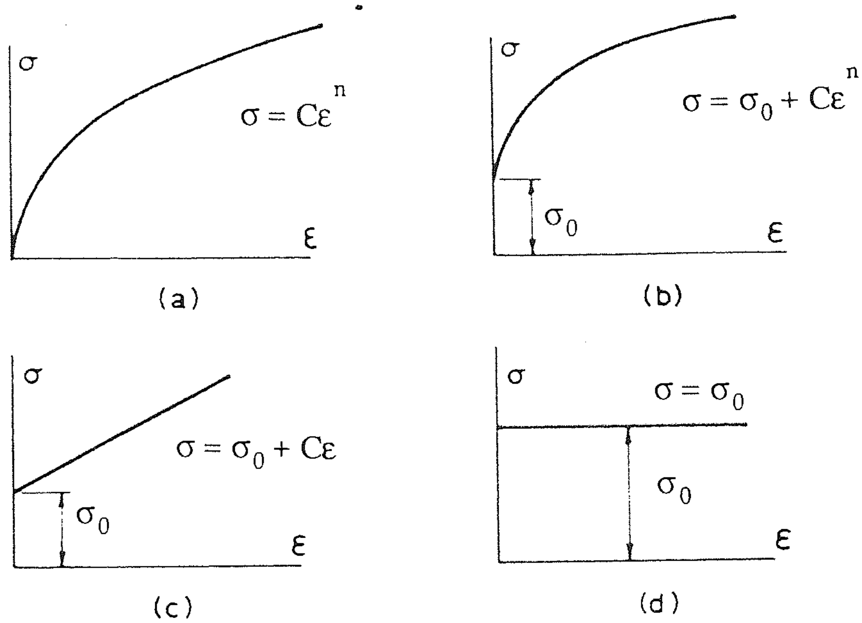



Figure 6.6: Approximate form of stress-strain curve after Rowe (38)

materials, the stress-strain curve can be represented with fair accuracy by simple power law as shown in figure 6.6a which is of the form:

$\sigma = C\,\varepsilon^n$

where

C = constant

n = strain hardening exponent

The material approximation for previously cold worked material with an initial yield stress can be represented as shown in figure 6.6b. For annealed material using the material behaviour represented by above mentioned power law, equation (6.6) can be rewritten as:

$$\sigma_0 = \frac{1}{(\varepsilon_f - \varepsilon_i)} \int_{\varepsilon_i}^{\varepsilon_f} C\,\varepsilon^{\,n}\, d\varepsilon \tag{6.8}$$

The process of plug drawing can be modelled as shown in Figure 6.7. Referring to figure 6.7, AB and CD are the discontinuity lines where the material changes course during operation. AD, DM and CN are the tube/die and tube plug frictional interfaces. During the

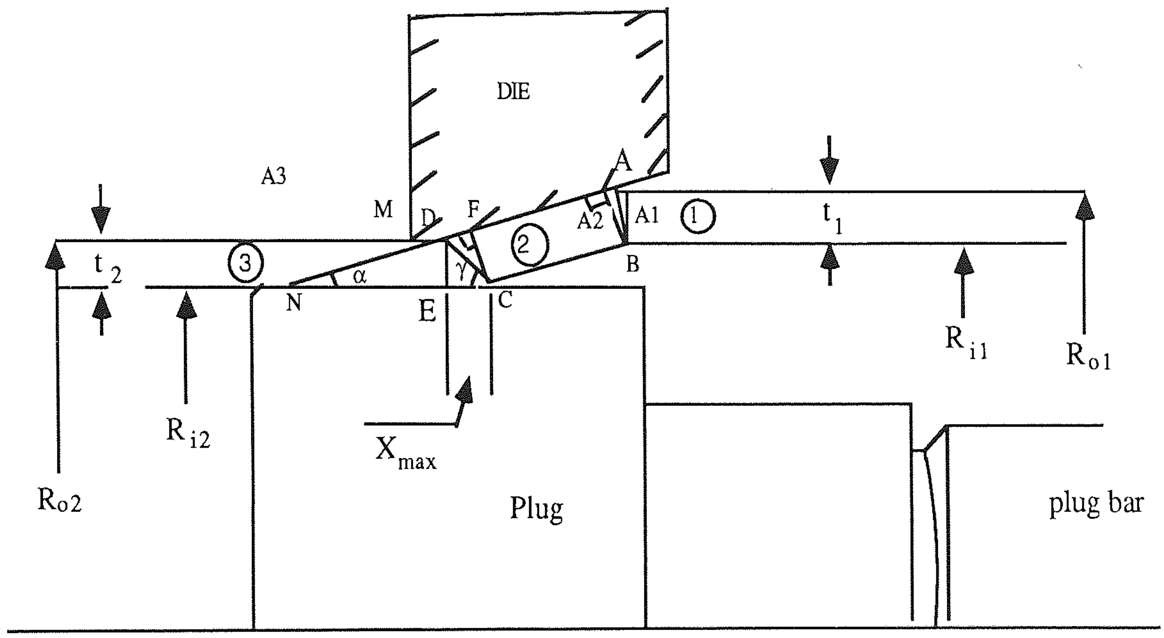



Figure 6.7: Pass geometry and assumed pattern of velocity discontinuities for fixed plug drawing

sinking portion, i.e. before the tube makes contact with the plug, it is assumed that the wall thickness remains constant. In the region 1, the tube material travels with a unit velocity, $U_{r1}$ while in region 2 the material velocity is $U_{r21}$ with respect to region 1 and $U_{r23}$ with respect to region 3 and parallel to die interface AD. The material velocity in region 3 is $U_{r3}$ parallel to interface DM. The hodograph for the assumed pattern of velocities at all the discontinuities is shown in figure 6. 8.

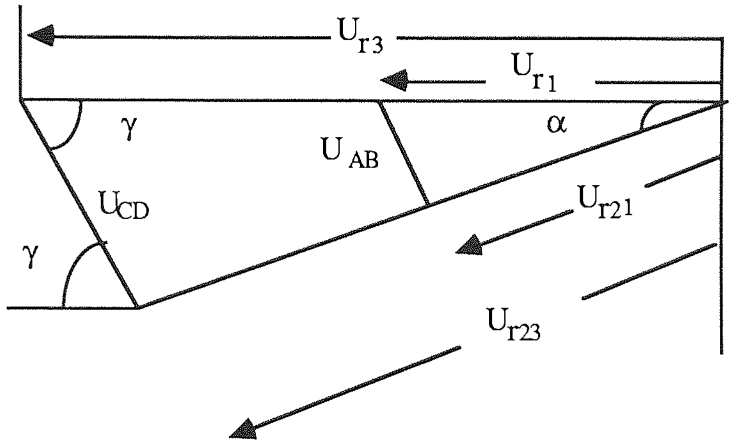



Figure 6.8: Hodograph for pattern of discontinuities

The rate of energy dissipation i.e. rate of plastic work done across a velocity discontinuity line is given by:

$$\frac{dW}{dt} = \dot{W} = K_d A_d U_d \tag{6.9}$$

where

$K_d$ = shear yield stress

$A_d$ = area of velocity discontinuity

$U_d$ = tangential velocity of discontinuity

At any discontinuity, plastic work is done which changes the equivalent strain of the material from an initial value $\varepsilon_1$ to a final value $\varepsilon_2$. Thus the total plastic work done in crossing the any discontinuity line is given by:

$$\dot{W} = \int_{\varepsilon 1}^{\varepsilon 2} \sigma \, d\varepsilon \, A \, . \, U \tag{6.10}$$

Integrating equation (6.10) the total plastic work done is:

$$\dot{W} = \sigma (\varepsilon_2 - \varepsilon_1) \, A.U \tag{6.11}$$

The von Mises yield criterion is given by

$$\sigma = \sqrt{3}\, K_d$$

Substituting in equation (6.11) the total plastic work done is:

$$\dot{W} = \sqrt{3}\, K_d\, (\varepsilon_2 - \varepsilon_1)\, A\, U \qquad (6.12)$$

From equation (6.9) and (6.12), the increase in equivalent strain across a velocity discontinuity line cab be found which is:

$$\varepsilon_2 - \varepsilon_1 = \frac{A_d}{\sqrt{3}} \frac{U_d}{A\, U} \qquad (6.13)$$

where

U = velocity of material after discontinuity

A = area after discontinuity in direction normal of velocity U

$A_d$ = area of discontinuity

$U_d$ = velocity of material at discontinuity

The equation (6.13) can be used to find the change in equivalent strain due to plastic work done at any discontinuity line i.e. AB and CD.

#### 6.6.3.1 CHANGE IN EQUIVALENT STRAIN AT DISCONTINUITY AB

At discontinuity line AB, due to the plastic work done the initial stain $\varepsilon_1$ increases to a new higher value $\varepsilon_{2AB}$. Due to the assumption that the thickness remains constant before and after the sinking the material velocity will remain the same. In other words

$$U_{r1} = U_{r21}$$

$$A_{r1} = A_{r2}$$

The various parameters in equation (6.13) as applied to discontinuity AB are

$U_d = U_{AB}$

$A_d = A_{AB}$

$U = U_{r1} = U_{r21}$

$\varepsilon_1$ = state of hardening of undrawn material

$\varepsilon_2$ = state of hardening after discontinuity AB = $\varepsilon_{2AB}$

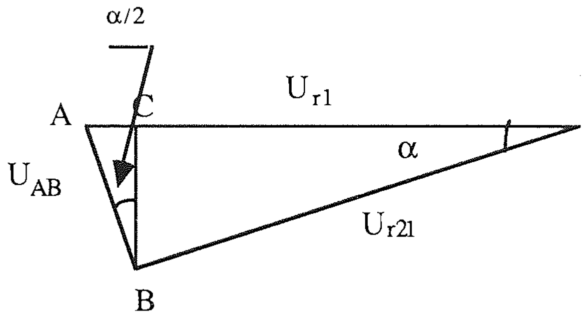



Figure 6.9: Velocity diagram for discontinuity AB

$U_{AB}$ and $A_{AB}$ can be found by considering the hodograph in figure 6.9

From triangle BCD

$$\frac{BC}{U_{r21}} = \sin\alpha \qquad \text{or } BC = U_{r21}\sin\alpha \tag{6.14}$$

And from triangle ABC

$$\frac{U_{AB}}{BC} = \frac{1}{\cos\frac{\alpha}{2}} \qquad \text{or} \qquad U_{AB} = \frac{BC}{\cos\frac{\alpha}{2}}$$

Substituting the value of BC from equation (6.14) the velocity $U_{AB}$ is:

$$U_{AB} = \frac{U_{r21}\sin\alpha}{\cos\dfrac{\alpha}{2}} \tag{6.15}$$

In terms of cross-sectional area

$$\frac{BC}{AB} = \cos\frac{\alpha}{2} \quad \text{or } AB = \frac{BC}{\cos\frac{\alpha}{2}}$$

but $\quad BC = A_{r2} = A_{r1} \quad$ and $\quad A_{AB} = AB$

The value of area $A_{AB}$ will be changed by same amount i.e.

$$A_{AB} = \frac{A_{r2}}{\cos\frac{\alpha}{2}} \tag{6.16}$$

Substituting the values of $U_{AB}$ and $A_{AB}$ from equation (6.15) and (6.16) in equation (6.13) , the higher value of the equivalent strain is:

$$\varepsilon_{2AB} = \varepsilon_1 + \frac{\dfrac{A_{r2}}{\cos\frac{\alpha}{2}} \; \dfrac{U_{r21}\sin\alpha}{\cos\frac{\alpha}{2}}}{\sqrt{3}\,A_{r2}\,U_{r21}} = \varepsilon_1 + \frac{\sin\alpha}{\sqrt{3}\cos^2\frac{\alpha}{2}} \tag{6.17}$$

6.6.3.2 CHANGE IN EQUIVALENT STRAIN AT DISCONTINUITY CD

At the discontinuity line CD the equivalent strain increases from an initial value $\varepsilon_{2CD}$ to a new higher value $\varepsilon_3$. The various parameters of equation (6.13) as applied to discontinuity line CD are:

$$\varepsilon_1 = \varepsilon_{2CD} = \varepsilon_{2AB} + \varepsilon_{2r}$$

where $\varepsilon_{2AB}$ can be found by equation (6.17) and $\varepsilon_{2r}$ is the sum of the radial and circomfrential strain in region 2

$\varepsilon_2 = \varepsilon_{3CD} = \varepsilon_3$

$U = U_{r3}$

$U_d = U_{CD}$

$A_d = A_{CD}$

$A = A_{r3}$

To find $A_{CD}$ and $U_{CD}$ figure 6.10 can be used. Referring to figure 6.10 and from the triangle BCD

$$CD = \frac{BC}{\sin\gamma}$$

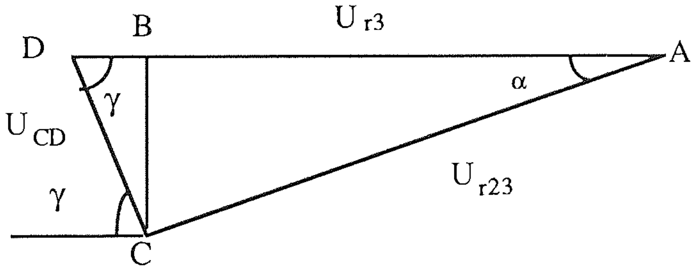



Figure 6.10: Velocity diagram for discontinuity CD

But CD represents $A_{CD}$ and BC is area of the tube in region 3 i.e. $A_{r3}$, Substituting these values in the above result area $A_{CD}$ is given by:

$$A_{CD} = \frac{A_{r3}}{\sin\gamma} \tag{6.18}$$

To find $U_{CD}$ consider the triangle ACD and, using the sine rule,

$$\frac{U_{CD}}{\sin\alpha} = \frac{U_{r3}}{\sin(180 - (\alpha + \gamma))}$$

Since $\sin(180 - (\alpha + \gamma) = \sin(\alpha + \gamma)$ and substituting this above equation becomes:

$$\frac{U_{CD}}{\sin\alpha} = \frac{U_{r3}}{\sin(\alpha + \gamma)}$$

Therefore the velocity $U_{CD}$ will be

$$U_{CD} = \frac{U_{r3}\sin\alpha}{\sin(\alpha + \gamma)} \tag{6.19}$$

The strain in region 2 can be found by using the von Mises criterion as follows:

$$\varepsilon_{2r} = \frac{2}{\sqrt{3}}(\varepsilon_\theta + \varepsilon_r)$$

Since there is no thickness straining in region 2, the thickness strain $\varepsilon_r = 0$ and the above result reduces to:

$$\varepsilon_{r2} = \frac{2}{\sqrt{3}}\varepsilon_\theta \tag{6.20}$$

The radial strain $\varepsilon_\theta$ is given by

$$\varepsilon_\theta = \ln\frac{R_{o1}R_{i1}}{R_{o2}R_{i2}}$$

Substituting the value in equation (6.20) and taking the average value, the strain in region 2 becomes:

$$\varepsilon_{r2} = \frac{1}{\sqrt{3}}\ln\frac{R_{o1}R_{i1}}{R_{o2}R_{i2}} \tag{6.21}$$

Since $\varepsilon_{2CD} = \varepsilon_{2AB} + \varepsilon_{r2}$, therefore from equation (6.17) and (6.21) we have

$$\varepsilon_{2CD} = \varepsilon_1 + \frac{\sin\alpha}{\sqrt{3}\cos^2\frac{\alpha}{2}} + \frac{1}{\sqrt{3}}\ln\frac{R_{o1}R_{i1}}{R_{o2}R_{i2}} \tag{6.22}$$

Substituting the values of $U_{CD}$, $A_{CD}$ from equation (6.19) and (6.18) into (6.13), the change in equivalent strain will be:

$$\varepsilon_3 - \varepsilon_{2CD} = \frac{\dfrac{U_{r3}\sin\alpha}{\sin(\gamma+\alpha)}\,\dfrac{A_{r3}}{\sin\gamma}}{\sqrt{3}\;U_{r3}A_{r3}}$$

$$\varepsilon_3 - \varepsilon_{2CD} = \frac{\sin\alpha}{\sqrt{3}\sin\gamma\;\sin(\alpha+\gamma)} \tag{6.23}$$

Substituting the value of $\varepsilon_{2CD}$ from equation (6.22) and rearranging, the value of equivalent strain $\varepsilon_3$ will be:

$$\varepsilon_3 = \varepsilon_1 + \frac{\sin\alpha}{\sqrt{3}\cos^2\frac{\alpha}{2}} + \frac{1}{\sqrt{3}}\ln\frac{R_{o1}R_{i1}}{R_{o2}R_{i2}} + \frac{\sin\alpha}{\sqrt{3}\sin\gamma\;\sin(\alpha+\gamma)} \tag{6.24}$$

Where $\varepsilon_3$ gives the total value of equivalent strain for the operation. In case of annealed material the value of $\varepsilon_1$ can be taken as zero while in case of previously cold worked material the value of $\varepsilon_1$ can be computed by using the same equation. Since the hollows are hot-worked, therefore, the annealed condition can be assumed at the start and $\varepsilon_1$ can be taken as zero. In equation (6.24), the angle $\gamma$ can be determined by referring to figure 6.7. The distance $X_{max}$ which is the distance of deformation zone is given by:

$X_{max} = CN - EN$

From triangle CFN

$$\frac{CF}{CN} = \sin\alpha \quad \text{or} \quad CN = \frac{CF}{\sin\alpha}$$

But $CF = R_{o1} - R_{i1} = t_1$ since the thickness remains constant in region 2, therefore CN is:

$$CN = \frac{t_1}{\sin\alpha} \tag{6.25}$$

Similarly from triangle DEN

$$\frac{EN}{ED} = \frac{1}{\tan\alpha} \quad \text{or} \quad EN = \frac{ED}{\tan\alpha}$$

Since $ED = R_{o2} - R_{i2} = t_2$ therefore

$$EN = \frac{t_2}{\tan\alpha} \tag{6.26}$$

By substituting from equations (6.25) and (6.26) the distance $X_{max}$ is therefore

$$X_{max} = \frac{t_1}{\sin\alpha} - \frac{t_2}{\tan\alpha} \tag{6.27}$$

from triangle CDE

$$\frac{ED}{CE} = \tan\gamma \quad \text{or} \quad \frac{t_2}{Xmax} = \tan\gamma$$

$$\gamma = \tan^{-1}\left[\frac{t_2}{X_{max}}\right] \tag{6.28}$$

Therefore using equations (6.28) in (6.24), the equivalent strain for the operation can be determined. Once the equivalent strain is known, the equation (6.8) can be used to estimate the true mean yield stress ( $\sigma_0$). The total drawing stress and the total deformation stress and hence the load components then can be found by the use of equations (6.1) and (6.2) by substituting the value of $\sigma_0$ based upon the equivalent strain. The difference between the values obtained from equations (6.1) and (6.2) is the measure of the frictional load component . The difference between the values obtained by equation (6.2) based on higher and lower (based on actual strain as determined by equation (6.7)) values of the mean yield stress will give the measure of useful deformation and redundant deformation.

## 6.7 COMPARISON OF RESULTS

The basis for comparison of results obtained from proposed analytical approach is that of experimental results published by Blazynski and Cole. Table 6.1 gives the initial and final

TABLE 6.1

Tube dimension before and after drawing (Blazynski and Cole)

| Number | Initial dimensions | | Final dimensions | | Reduction |
|---|---|---|---|---|---|
| | outside diameter (mm) | Thickness (mm) | outside diameter (mm) | Thickness (mm) | Total percent |
| 1 | 54.91 | 3.66 | 50.34 | 4.22 | 25.50 |
| 2 | 55.50 | 3.94 | 50.34 | 4.22 | 31.50 |
| 3 | 56.00 | 4.22 | 50.32 | 4.22 | 35.90 |
| 4 | 56.75 | 4.52 | 50.29 | 4.22 | 41.10 |
| 5 | 57.33 | 4.83 | 50.29 | 4.22 | 45.00 |
| 6 | 58.24 | 5.31 | 50.27 | 4.22 | 50.40 |

dimensions of the tubes and total reduction of area for six different schedules as measured in the initial investigation. The values of equivalent strain and true mean yield stress as obtained from equations (6.23) and (6.8) are compared with the measured values in Table 6.2. The discrepancy in equivalent strain varies from -11.3 to 18.4 % while the discrepancy in true mean yield stress varies from -2.1 to 2.2 %. Table 6.3 compares the total drawing load and its components such as total deformation load, useful deformation load and frictional load. The discrepancy in the total drawing load

Table 6.2

Comparison of equivalent strain and true mean yield stress

| Number | Equivalent strain | | | True mean yield stress | | |
|---|---|---|---|---|---|---|
| | Blazynski and Cole | Proposed Model | Discrepency % | Blazynski and Cole (N/mm2) | Proposed Model (N/mm2) | Discrepency % |
| 1 | 0.53 | 0.47 | -11.30 | 628.56 | 615.13 | -2.14 |
| 2 | 0.66 | 0.63 | -4.50 | 652.19 | 647.86 | -0.06 |
| 3 | 0.80 | 0.80 | 0.00 | 676.74 | 673.03 | -0.55 |
| 4 | 0.97 | 0.97 | 0.00 | 700.36 | 696.34 | -0.57 |
| 5 | 1.03 | 1.15 | 11.60 | 706.53 | 715.64 | 1.29 |
| 6 | 1.19 | 1.41 | 18.50 | 726.45 | 742.36 | 2.19 |

Table 6.3

Comparison of total drawing load and its components

| No. | Total drawing load | | | Total deformation load | | Useful deformation load | |
|---|---|---|---|---|---|---|---|
| | Blazynski and Cole (kN) | Proposed Model (kN) | Discrepency % | Blazynski and Cole (kN) | Proposed Model (kN) | Blazynski and Cole (kN) | Proposed Model (kN) |
| 1 | 116.58 | 122.16 | 4.80 | 86.29 | 82.32 | 76.12 | 77.12 |
| 2 | 145.47 | 150.85 | 3.70 | 109.90 | 106.22 | 97.55 | 98.15 |
| 3 | 165.40 | 177.76 | 7.50 | 130.33 | 129.73 | 116.58 | 118.67 |
| 4 | 188.32 | 204.06 | 8.50 | 156.04 | 154.34 | 140.79 | 139.69 |
| 5 | 214.23 | 229.67 | 7.20 | 177.16 | 178.65 | 161.62 | 158.13 |
| 6 | 246.11 | 266.34 | 8.20 | 209.04 | 214.62 | 191.41 | 190.71 |

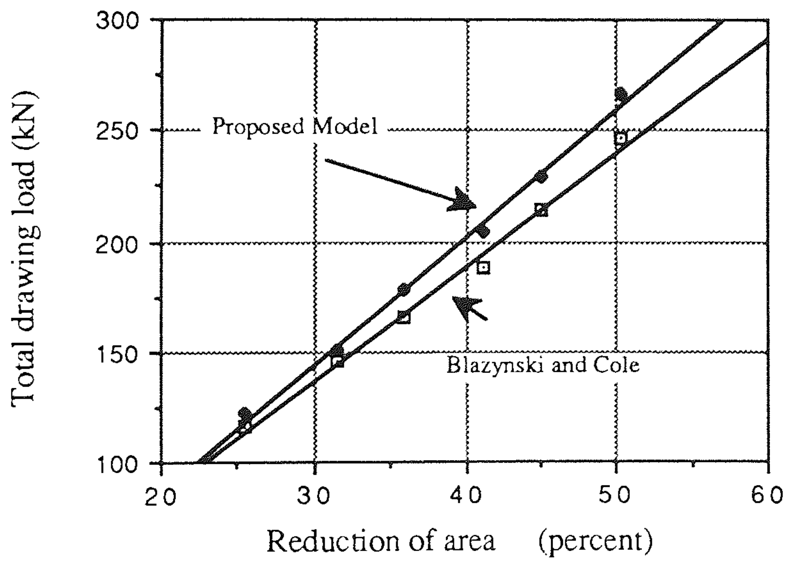



Figure 6.11: Graphical comparison of total drawing load

which is the basis for computation of power requirement and to validate the schedules varies between 3.7 to 8.5 %. The total drawing load is compared graphically in the figure 6.11.

It can be concluded from the comparison of the results that the computed values of total drawing load are an over-estimate compared with the measured values. The extent of over -estimate varies between 3.7 to 8.5 % which means that the computed value of the total drawing load eliminates the risk of overloading a particular drawbench and is desirable for safe validation of tube-drawing schedules. Thus the proposed analytical approach can be used in the software safely.

## 6.8 OPERATION SEQUENCE

The selected process must be arranged in succession depending upon the precedence relationships of operations to form an operation sequence sheet. The sequencing of operation is achieved by checking the present state of the tube (initially in the semi-finished hollow) and adding the necessary selected operations to be performed in order to convert it from its present state to next required state. The process is continued until the required state is reached.

## 6.9 SUMMARY

In this chapter, in addition to discussing the solution methodology for selecting the appropriate drawbench, number of passes, secondary processes and generation of alternative schedules and selection of best schedule, the proposed analytical approach to determine the equivalent strain and true mean yield stress has been presented. The comparison of the results computed by the proposed approach and the existing experimental results by the other researchers has shown that the former over-estimates the drawing load. Since over estimation is on conservative side i.e. it includes a factor of safety for the plug drawing operations, it can be used safely in the computer program to validate the drawing schedules.

Having established the solution methodology for the process planning tasks in the rotary piercing mill (chapter 5) and cold drawing plant, the next step in the development of knowledge-based system is to represent the acquired knowledge.

# CHAPTER 7

## SYSTEM STRUCTURE AND KNOWLEDGE REPRESENTATION

### 7.1 INTRODUCTION

In the previous two chapters , concepts, principles, theories and methods were presented that how the process planning tasks can be accomplished in the domain of seamless tube manufacture. The next step is to decide that how the sub-tasks of process planning can be structured to form a system which can generate process plans for the manufacture of finished tubes from the raw material and the related concepts can be formally represented in the knowledge-base.

Before presenting an overall structure of such a system and knowledge representation scheme, it is necessary to give the restrictions under which the system can be applied. Furthermore, a decision must be made regarding the choice of the hardware and software for the implementation of the system. An overall structure of the system is presented and, finally, an attempt is made to show that how the gathered knowledge can be represented formally in the knowledge-base within the framework of selected software.

### 7.2 SCOPE OF THE SYSTEM

The system will have the following restrictions:

- It is intended for the generation of process plans for the manufacture of seamless tubes only

- Hollow manufacture is restricted to rotary piercing process only
- It can be applied for the manufacture of seamless tubes specified under British Standard (BS) which are BS 6323:part 3, BS 6323:part 4, BS 980, BS 3601,BS 3602:part1, BS 3603, BS3604, BS 3059:part1 and 2, BS 970, BS 5242:part 1, 3 and 4, BS 6258 and BS 3606 etc. The materials which have been included in the knowledge-base are only those which are specified by BS. However, the system can be used for other standards such as DIN and ASTM if the previous two conditions are satisfied and the necessary data are provided.
- The material properties such as index of hardening and constant c are not the actual values. These properties must be compiled by experimentation or from the published literature.
- Production schedules can be prepared for rotary piercing mill only.

## 7.3 HARDWARE CONSIDERATION

The prime consideration in the selection of hardware is the price which must be in the range of affordability of the business for which the system is being developed. The present research work is intended for a small-to-medium sized company which dictates the selection of a microcomputer.

There are a number of other reasons for the selection of a micro-computer for the current work. Firstly, they are inexpensive, widely available and general purpose machines. As a result, individuals and small companies can afford such machines and do not have to purchase special purpose workstations. In addition, the dedication of a micro-computer to a knowledge-based project is feasible, whereas dedicating a more costly machine would raise major problems in small companies. Micro-computers are so inexpensive that they can be distributed over a wide range and rare expertise can be delivered to a place where it is needed in a cost-effective manner as discussed by Assad and Golden (130). The easy transportability of hardware and software from one location to another and availability are other considerations to support the selection of a micro-computer.

## 7.4 SOFTWARE SELECTION

The development of the knowledge-base system can be speeded up by the use of system building tools. The tools which are currently available can be categorised into following (15,130,131):

(1) Expert system shells

(2) Programming environment or knowledge engineering tools

(3) Programming languages

To select an appropriate tool for developing the knowledge-based system, the factors which need to be considered include hardware i.e. whether it is available on a micro-computer or mainframe, knowledge representation formalism (rules, frame or logic), control strategies supported (backward or forward chaining), and the role of procedural programming, database technology and advance interfaces as discussed by Graham (131). The development of an application on the micro-computer will eliminate the choices of those tools which require special purpose or main frame computer. The knowledge representation formalism such as production rules can be used where the knowledge is available in form of independent chunk of knowledge while frame-based formalism is suitable for hierarchical knowledge. In the business and commercial world where numeric computations are involved extensively, software with capabilities of numeric computation is needed.

Keeping in view the selection criteria, a review on the feasibility of a selection amongst three different categories is represented . The first type of such tools, shells, are usually constructed by taking out the domain specific knowledge from an existing expert system. A shell, consists of an inference engine and empty knowledge-base with support facilities such as mean of encoding domain specific knowledge as discussed by Keen and Williams (132).The expert systems such as PROSPECTOR, MYCIN and CASNET were converted into shells KAS, EMYCIN and EXPERT by stripping out the domain-specific knowledge (15). These shells can then, theoretically, be used for developing other expert systems by plugging in the new knowledge, which makes the development easy and fast.

Selection of those shells need to be investigated which are designed for a micro-computer. This is because the implementation of the system is decided on the micro-computer as discussed in section 7.3. There are many commercially available PC based shells and their comparison being not straight forward due to variation in costs, applications, documentations, size of the knowledge-base they can handle as discussed by Assad and Golden(130). In a study to evaluate PC-based shells for building expert systems Assad and Golden concluded with the recommendation of two shells, TIMM-PC and M.1, suitable for use in research work. The feasibility of selection for the current work can be evaluated for only TIMM-PC, because of its availability.

TIMM, The Intelligent Machine Model (133) is an interactive tool that performs the function of the knowledge engineer by questioning the domain expert, constructing and interpreting the knowledge-base. TIMM uses a frame-like method of knowledge representation and decisions are made using a pattern directed inference engine. To use TIMM, the system is first trained by specifying the factors and their possible values and appropriate choices of decisions associated with the combination of factor values. The knowledge gathered from the expert during the training session is stored in the knowledge-base. The system, then can be used for a specific situation to check its ability to reach at a proper decision.

TIMM-PC has very impressive functions on one hand such as consistency checking, compression of knowledge-base to remove redundant information, generalisation of rules from the training set and provision of decisions in response to imprecise information by "near match" algorithm (133). On the other hand, the capability to have a limited number of rules and non-availability of numeric computation methods restricts its use to small and symbolic processing applications. In tube manufacturing technology, where rigorous numeric computation of process parameters is involved, TIMM-PC will have little success. Moreover, a large number of people have expressed the dissatisfaction with shells. Two complaints (i) that an inference engine which was successful in one application will not necessarily be successful in another and (ii) that the knowledge representation scheme suitable for original domain often makes the expression of knowledge in another more difficult, have been reported by Jackson et al (134). The conclusion can be drawn that the real flexible shell to be used in all domains is still not available.

The decision of unavailability of appropriate shell for the present work opens the next choice of knowledge engineering tools. In such tools, on the top of the languages, special features such as graphics , icon, knowledge representation scheme and some form of built-in inference engine are provided. The degree of flexibility in these tools is much greater and a wide variety of problems can be tackled as discussed by Graham (131). He further argues that the price to be paid for additional flexibility is that the systems are much more expensive and require special hardware. This means that the applications developed on the systems are difficult to deliver to a wide class of the end user i.e. either to rewrite the programme to match the existing hardware or persuade the end user to invest in a new type of work station. Again small companies are not usually in a position to afford the purchase of such special purpose hardware and software, therefore, the selection of such programming environment is restricted to large concerns.

The third obvious choice is to select an appropriate programming language which offers great flexibility in the development of knowledge-based systems. The most commonly used AI programming languages include LISP and PROLOG. LISP, LISt Processing is a symbol manipulation language developed by McCarthy as quoted by Anderson et al (135) and is one of the oldest programming languages in use today. There are many version of LISP (15) such as MACLISP, ZETALISP, InterLisp etc and they differ greatly both in underlying concepts and specific details as discussed by Tatar (136). He further argues that the choice from different implementation becomes very difficult even to experienced programmer. The drawbacks of LISP may include hard-to-read and difficult syntax and requirement of special purpose machines. Moreover, unavailability has eliminated its choice for the present work.

PROLOG, PROgramming in LOGic, was originally developed in France and became very popular in Europe for AI applications. Its popularity has been enhanced by the Japanese announcement of using Prolog in their Fifth Generation Computer Project. Prolog has three distinctive features that gives it key advantage over the LISP as described by Rowe (137). Firstly, prolog syntax is much closer to formal logic, the most common ways of reasoning method used in AI applications. Secondly, prolog provides a built-in backtracking and pattern matching mechanisms which make the search, a fundamental to most AI techniques, much easier. This is also a drawback of prolog according to many researchers. Thirdly, the arguments in a procedure can be freely designated in different ways to achieve required output so that the same procedure definition can be used for many different kinds of reasoning.

Prolog implements the simplified version of predicate calculus and is designed for symbolic manipulation and is capable of list processing. In prolog, the programmer does not specify "how" the computer perform its tasks but rather specifies a description of tasks as a sequence of constraints to be satisfied. This approach is advantageous because it frees the programmer from worrying about details of the algorithm of searching and making inferences.

There are many commercial versions of prolog such as SD prolog (138), microprolog (139), Quantus prolog (140) and Turbo prolog(141) to name a few. For the present research work Turbo-Prolog a PC version of prolog has been chosen. The availability of Turbo-Prolog and its implementation on the micro-computer were the main reasons for its selection. However, the following reasons further support the selection of Turbo-prolog.

Turbo-Prolog supports modular programming i.e. breaking down the application into smaller components so that they can be developed separately and independently. The implementation of independent modules has a number of advantages (142) such as testing in isolation, ease of debugging and maintenance. The creation of a single executable program in the Turbo-prolog linking individual modules is a powerful feature in supporting its selection.

In the domain of seamless tube manufacture process planning, there is rigorous mathematical computation of process parameters involved. Turbo-prolog unlike other versions of prolog has a full range of built-in mathematical functions and predicates that operate on integer as well as on real values. The availability of these functions make it more suitable for the development of such an application. Turbo -Prolog like any other version provides an exploratory style of programming and the programs can be modified and extended easily (107).

Turbo-prolog tool box (143) which is a collection of software tools increases the efficiency with which the application can be constructed. This tool box includes user interface design and construction, screen layout design, business graphics images and importing files from other systems such as databases. Moreover, turbo-prolog supports the compilation of stand-alone programs that will execute on a machine not running on turbo-prolog, provides interfaces to other languages and includes the integrated editor to make program development, compilation and debugging easier. The aforementioned reasons made the choice of turbo-prolog most suitable for the intended research work.

## 7.5 OVERALL STRUCTURE OF THE SYSTEM

With reference to figure 7.1, the knowledge-based system for process planning is composed of four main modules:

(1) The user interface

(2) Data acquisition module

(3) Discrete order process planner

(4) Production schedules generator

The user interface is designed to provide the user-friendly features such as menu systems showing the tasks that a user can select for the preparation of process plans for the individual orders and production schedules for a batch of orders. The selected task is communicated to the control modules to accomplish it and the inferred decisions and actions are communicated by the interface back to the user for verification and then saved in appropriate files.

The data acquisition module is responsible for appending, editing and displaying the files of declarative knowledge in the form of facts about a specific domain of application. These facilities are to be provided to assist the user in adding new facts into knowledge or editing the existing facts due to changes.

With reference to figure 7.2, Discrete order Process Planner has two major components, in addition to user interface and data acquisition modules :

(1) Knowledge-base

(2) Inference modules

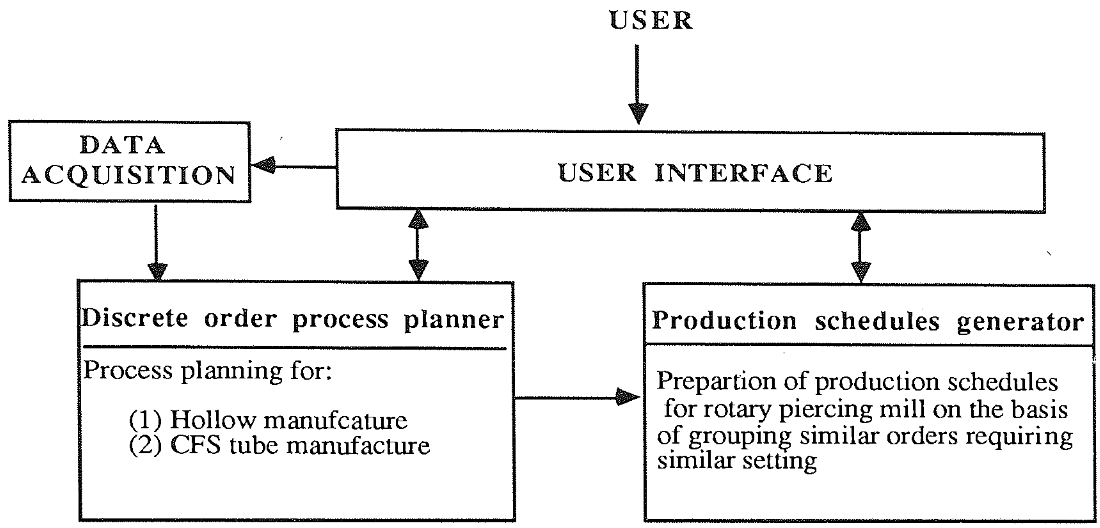



Figure 7.1: Overall structure of Knowledge-based system for process planning

The knowledge-base is central part of any knowledge-based system and contains the collection of knowledge in form of facts and rules. The control modules are responsible for selecting and controlling the required rule bases and specify the logic to be taken to arrive at a conclusion in solving different tasks of process planning. The Control modules mainly control the execution of the rules on the basis of certain pre-conditions. The Turbo-prolog built-in inference engine (internal unification routines), backtracking mechanism and control predicates can be used for performing the inferences.

The Discrete order process planner module Figure 7.2 generates the process plan sheet for individual order and the generated details are written into a file in the form of facts. This file serves as an input to Production schedules generator as shown in figure 7.3. This module prepares the production schedules or rolling programme to implement the optimisation strategy of hollow manufacture by the method of grouping the similar orders requiring similar setting of the mill as discussed in section 5.3.10. The main

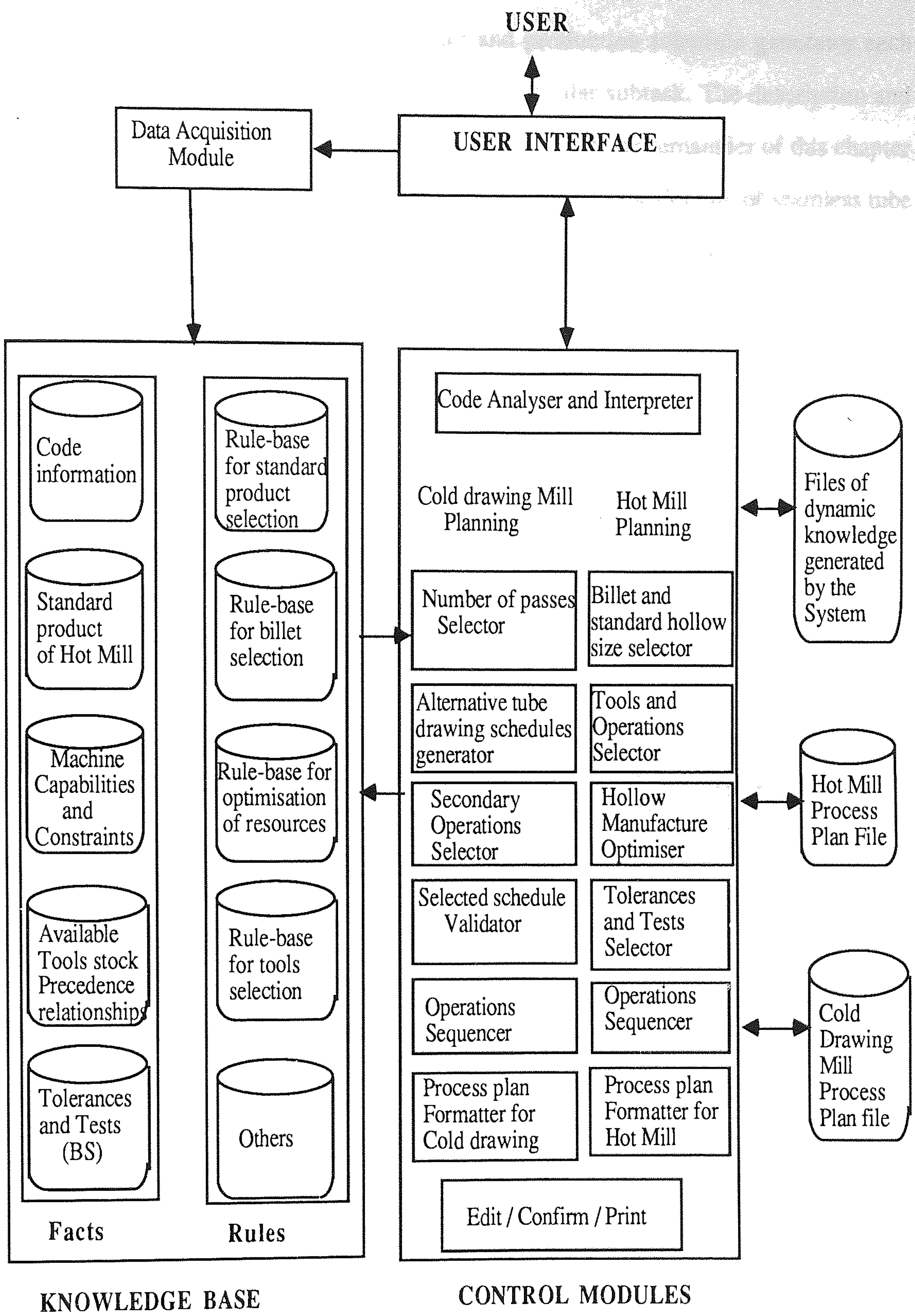



Figure 7.2: Components of Discrete order Process Planner

modules of Discrete order process planner and production schedule generator each consists of several sub-modules performing a particular subtask. The description and functions of these sub-modules will be discussed later. In the remainder of this chapter a discussion will be presented that how the key concepts in the domain of seamless tube manufacture can be formalised within the framework of Turbo-prolog.

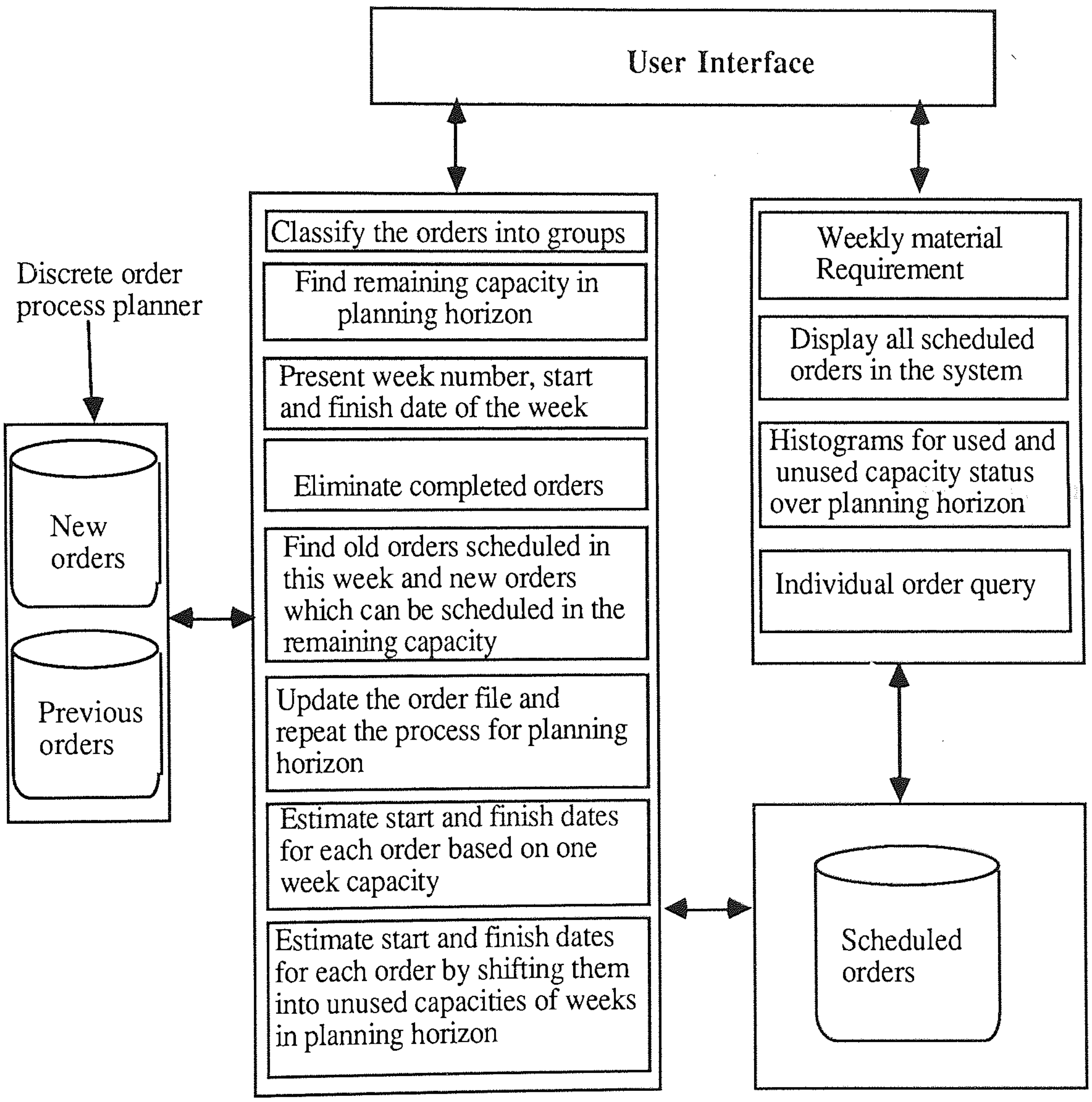



Figure 7.3: Structure of production schedules generator for rotary piercing mill

The concepts have been organised in the knowledge-base at three different levels i.e:

(1) The first level is declarative knowledge in the form of facts about the problem domain such as information related to specification, tolerances, machine capabilities and constraints etc. This level also contains the current state of affairs in an attempt to solve any particular task, the dynamic database. This level is analogous to data in an ordinary program.

(2) The second level are the rule-bases containing the problem-solving knowledge specific to a given task of the problem to be solved by the system. The conditions of the rules are satisfied against the facts in first level and corresponding action is written into memory. These rules can be computational rules which use the built-in mathematical functions etc.

(3) The third levels contains the rules to control the second level rules . At this level the decisions are made on how to use the problem-specific knowledge in the knowledge-base. It also includes the rules for input and output handling, windows handling etc.

Representation of knowledge in the form of facts and rules is illustrated in the following sections.

### 7.5.1 REPRESENTING FACTS

A fact is a statement to be consider as true, and describes many things such as relationships between two objects, property or properties of an object and function mapping as described by Rowe (137). In prolog, a relationship is called a "predicate" and the objects which are related are called arguments or parameters of the predicate. These arguments can be of different data type such as characters, integer and real numbers, string, symbols or list.

In the domain of seamless tube manufacture, such facts may include all possible information being conveyed by product code, such as special requirement, tube specifications, material to be used and the delivery conditions. The material properties, the tolerances to be achieved on outside and inside diameters, wall thickness and length, required straightness of the tube as specified and tests to be carried out on the tube can also be represented in form of facts. In addition, the statements of available tools in the cold drawing mill and hot mill, standard product range also form facts. Similarly, the machine capabilities, precedence relationships for operations are the other example of such statements.

The characters in the product code convey different messages as discussed in section 5.3.1. For example the first character represents the special requirement on the tube as specified by the customer which does not include in the specification of the tube. Special requirements such as grinding, polishing, plating, galvanising can be represented in the knowledge base in form of facts such as:

special_requirement ('A', "tubes to be delivered with ground outside diameter")
special_requirement ('B', " tubes to be delivered with bevel ends")

The first statement can be read off as " Character 'A' in the code indicates a special requirement that tubes to be delivered with ground outside diameter". The character position in the code is not taken into account in the above statement because the code interpreter takes care of it.

Similarly, following are the examples of other messages in the code which have been represented in the knowledge base :

specification ('A', "BS 6323: Part 4")
material_designation ('A',"BS 6323: Part 4","CFS 3")

material_designation('A',"BS 5424: Part 3","HP 8")

delivery_condition ('A',"BK")

The first statement says that "character 'A' indicates the specification of the tube to be BS 6323: Part 3. Since the materials to be used for the manufacture of a tube depends upon the given specification and no other material can be used for that specification, therefore in the material_designation statements the BS specification have been included. The material designation statements show that the character 'A' indicates different material designations for different specifications. "BK" delivery condition has been specified in the standard as to deliver the tube as drawn without any heat treatment.

The general format for stating the tolerances for a given job is as follows:

tolerances(Dimension_type,Specification_number,Tube_type,Tol_category,Method of_specification,[String_list], [Min,Max,Pos_tol,Neg_Tol]).

The "Dimension_type" contains one of the dimension such as outside diameter, inside diameter, thickness, length, straightness or recommended test. This follows with the specification number and the type of the tube whether it is HFS or CFS. A given specification can have different categories ("Tol_category") of the tolerances which has to be specified by the customer. The tolerances on the dimensions can be specified for their range or computed by a formula stated in the specification. The string list can be used in association with straightness and tests to store the specified straightness or the test recommended by the specification. If the tolerances are specified on the range of dimension then the last list can be used for positive and negative tolerance with the specified range of dimension. Following examples will illustrate these statements

tolerances("outside dia","BS 6323: Part 4","CFS","","R",[],[0,30,0.1,0.1])

tolerances("outside dia","BS 5242: Part 3","CFS","H8","F5",[],[])
tolerances("straightness","BS 5242: Part 3","CFS","A","",[1:600],[])
tolerances("tests","BS 6323: Part 4","CFS","","",["Tensile test","Visual test",
"Flatten test","Hydraulic test"],[]).

The material properties can be stated in the knowledge-base as:

mat_properties(Steel_grade,Steel_type,A_string_describing_carbon_%age,
[Min_carbon_%age,Max_carbon_%age,Index_of_hardening,Constant C]).

mat_properties ("CFS 3", "carbon steel",[0.0,0.2,0.2,315]).
mat_properties("HP 8","alloy steel", 0.4 - 0.45 % carbon",[0.4,0.45,0.2,850]).

The general format for storing the tools available in the hot mill, cold drawing mill and the standard product of the company takes the form:

hot_mill_tools(Tool_type,[List of available tools])
cdm_tools(Tool_type,[List of available tools])
standard_hollow_sizes(Dimension_type, [list of standard dimensions]).

For examples

hot_mill_tools("plug_sizes",[Size1, Size2,Size3,.............Sizen])
cdm_tools("die_sizes",[Size1,Siz2,Size3,..........Sizen])
standard_hollow_sizes("outside_diameter",[Size1,Size2,Size3,...........Sizen]).

The constraints and machining capabilities can be stated as:

constraints("piercer",Value_of_max_length_of_workpiece) constraints("stretch_reducing_mill",Value_of_max_length_of_workpieces)

bench_capabilities(Bench_name,Maximum_diameter_policy,
Maximum_length_of_workpiece,Maximum_drawing_load)

Similarly the precedence relationships for sequencing selected operations in hot mill can be stated as:

operation_preced_relation(billet_cutting,follows,none)

operation__preced_relation (billet_cutting,before, heating)

operation__preced_relation (billet_heating,follows,billet_cutting)

operation_preced_relation(billet_heating,before,piercing)

Similar operation precedence relationships are represented for the cold drawing plant.

During the execution of the system, new data are generated which can be stored in the form of facts which are used at a later stage for further processing. A few examples of facts generated by the system are as follows:

outside_dia(X)

billet_diameter(BD)

optimum_billet_length(L)

new_orders(outside_dia,Wall,Billet_weight,Works_order_No,Customer,Quantity,
Total_weight_of_order,Steel_grade,Billet_dia,Finish)

grouped_orders(group,outside_dia,Wall,Billet_weight,Works_order_No,Customer,
Quantity, Total_weight_of_order,Steel_grade,Billet_dia,Finish )

scheduled_orders(outside_dia,Wall,Billet_weight,Works_order_No,Customer,
Quantiy,Total_weight_of_order,Steel_grade,Billet_dia,Finish,
Week_number,Start_date, Finish_date)

### 7.5.2 REPRESENTATION OF RULES

A rule is an expression that infers the truthfulness or falseness of a conclusion based on one or more other facts in the antecedents. The turbo-prolog rule format is different from the production rules in a way that the conclusion is stated first and is followed by the word *if*. The conditions upon which the conclusion is based are stated next and can be connected by *and* connectives. For example

```
select_billet_diameter(OUTSIDE_DIA,THICKNESS,80) IF
        OUTSIDE-DIA<=80 and
        THICKNESS<=6 and!.
```

The portion before *if* in the above rule is called the head while the antecedents after if is called the body of the rule. The arguments in the body of the rule can be constant or variables. The sub-goals in the antecedent must be satisfied for the conclusion to be true, on the other hand rule will fail.

The rules can be divided mainly into two categories:

- Procedural rules
- Control rules

Procedural rules are the domain specific problem solving rules to draw inferences or conclusions based upon the available facts in the knowledge-base. These rules can be categorised according to the nature of their use for a particular task such as:

- Recursive rules
- Non-recursive rules
- Generalised rules
- Computational rules

The above mentioned categories of rules can be illustrated by a segment of prolog code used for sequencing selected operations for the manufacture of hollows in the rotary piecing mill. Given a random list of selected processes as given below:

SP=[stretch_reducing,piercing,billet_heating,billet_cutting,elongating,reheating]

The following program make use of the rules and precedence relationships to converts the random list of selected processes to a list of sequenced processes.

```
/* CONTROL OR META LEVEL RULE*/
sequence_list(SP):-
        length(SP,Length1),
        operate_on_pr(SP,SP),
        for_given_process_seq_is(SEQGP),!,
        sequence_processes(Length1,1,SEQGP,SEQUENCED_LIST),
        clear,assertz(operation_seq_hm(SEQUENCED_LIST)),
        save("seqhm.dat"),retract(operation_seq_hm(_)).

/*RECURSIVE RULES WHERE A TASK IS REPEATED MANY TIMES*/


operate_on_pr([],L1).
operate_on_pr([H|T],L1):-
        operation_preced_relation(H,follows,X),
        operation_preced_relation(H,before,Y),
```

```
        make_list(H,X,Y,L1,L),
        assertz(for_given_process_seq_is(L)),operate_on(T,L1).

sequence_process(N,N,Sequenced,Sequenced).
sequence_process(N,_,[H|T],L4):-
        for_given_process_seq_is(L1),
        last(Element,L1),Element=H,!,
        append(L1,T,L2),length(L2,Length2),
        sequence_process(N,Length2,L2,L4).

sequence_process(N,N,Sequenced,Sequenced).
sequence_process(N,_,L1,L5):-
        last(Element,L1),find_rest_list(Element,L1,L2),
        for_given_process_seq_is(L3),
        for_first_element(L3,H,_),Element=H,!,
        append(L2,L3,L4),length(L4,Length2),
        sequence_process(N,Length2,L4,L5).

length([],0).
length([_|T],LL):-
        length(T,LL1),
        LL=LL1+1.

append([],L,L).
append([H1|L1],L2,[H1|L3]):-
        append(L1,L2,L3).
last(ELEMENT,[ELEMENT]).
last(ELEMENT,[_|T]):-
        last(ELEMENT,T).
```

```
/* NON-RECURSIVE RULES*/

make_list(H,X,Y,L1,L):-
        not(member(X,L1),L=[H,Y].
make_list(H,X,Y,L1,L):-
        not(member(Y,L1),L=[X,H].
make_list(H,X,Y,_,L):-
        L=[X,H,Y].
```

The recursive rules are used where the same procedure is repeated many times and require a condition which has to be satisfied in order to terminate the recursion and avoid infinite recursion. In the program segment the first rule of this type "operate_on_pr" uses the list of selected processes(SP) to find the sequence for every process in the list using operation precedence relationship. It accomplishes the task by taking the first process in the list (H|T where H being first process and the remaining processes forms tail T) and finds the process which is to be performed before and after it. The sequence for this process is converted into a list structure and saved into working memory under the clause "for_given_process_seq_is(L)". It repeats the procedure with the first process in the tail (T) until the whole list becomes empty which is the exit condition at the top of the rule (operate_on_pr([],L1). When this condition is satisfied the working memory will have the sequence of individual process as:

```
for_given_process_seq_is(billet_heating,piercing,elongating)
for_given_process_seq_is (reheating,stretch_reducing)
for_given_process_seq_is (billet_cutting,billet_heating)
for_given_process_seq_is (billet_cutting,billet_heating,piercing)
for_given_process_seq_is (piercing,elongating,reheating)
for_given_process_seq_is (elongating,reheating,stretch_reducing)
```

The sequenc_process rules will operate on the above sequence of the individual orders to generate an overall sequenced list of the selected process which will be as follows:

[billet_cutting,billet_heating,piercing,elongating,reheating,stretch_reducing)

The rules for process sequencing, finding the length of the given list, finding last element in the list and appending the given two lists into a third single list as shown in the program segment are all of recursive type.

The non-recursive rules can be used at the places where the task is to infer the conclusion by satisfying certain conditions and the rule can not be generalised. For example, the last "make_list" rule in the program segment take the given process (H), preceding process (X) and following process (Y), and convert them into a list structure [X,H,Y]. If there is no process which precedes or follows the given process then action is taken accordingly.

The generalised rules can be used when there is a general pattern exists to infer a conclusion from the given facts. For example, a draw bench can be selected for a given job by a general rule of the form:

```
draw_bench(DiaFinTube,LenFinTube,Bench):-
        bench_capabilities(Bname,Xmax,Lmax,_),
        DiaFinTube<=Xmax,
        LenFinTube<=Lmax,!,
        Bench=Bname.
```

The same rule can be used for selection of all drawbenches and rule says that given the diameter and the length of the finished tube, find a drawbench of capabilities which can be used to manufacture the job.

The computational rules have been used for computing the different parameters required for accomplishing the process planning tasks. For example, given the outside and inside radius of the tube, angle of the die and the strain in previous pass, the following rule can be used to find the value of equivalent strain (see equation 6.24):

```
find_strain(Ro1,Ri1,Ro2,Ri2,Angle,Prev_strain,New_strain):-
        equ_strain_ab(Angle,Prev_strain,Str_ab),
        Str_2=(1/sqrt(3))*(ln((Ro1*Ri1)/(Ro2*Ri2)),
        Str_2cd=Str_ab+Str_2,
        find_angle_gamma(Ro1,Ri1,Ro2,Ri2,Angle,Gamma),
        Str_def=sin(Angle)/(sqrt*3)*(sin(Gamma)*sin(Angle+Gamma)),
        New_strain=Str_2cd+Str_def.
```

The control rules determine that how the rules in the knowledge-base can be used for solving a given problem and direct the control to execute one or more than one rules to accomplish it. The general format of control rules can be as follows:

```
predicate1 IF
        <condition 1> THEN predicate2 OR
        <condition 2> THEN predicate3 OR
        <condition 3> THEN predicate4.
```

The "predicates" in the body of the rule can be connected by "AND" or "OR" connectives and the lower level predicates then can be called accordingly. Referring to program segment to sequence the selected process, the control clauses are connected with "," which is equivalent to "AND". The first clause "length(SP,Length1) is used to find the total number of processes in the selected process list (SP) which can be used to terminate the recursive rule when all the processes have been sequenced. The 2nd, 3rd and fourth clauses have been used to determine the sequence of individual process which is taken as a basis for determining the overall sequence of selected processes. The control or meta level rule also contains the clauses for pushing and poping the databases and saving the generated facts into files.

## 7.6 CONCLUSION

The selection of hardware and software for the development of knowledge-based system has been discussed. The choice of turbo-prolog from the different tools such as shells, knowledge engineering and AI programming languages, was mainly based upon its availability and the constraint of using a micro-computer for the development of a knowledge-based system.

The overall structure of the knowledge-based system for process planning in a seamless tube manufacture consists of four main modules ,as described in section 7.5. The modules for discrete order process planning and production schedule generating are further divided into sub-modules to accomplish a particular task. The knowledge in these modules have been represented at three levels; facts at lower level, procedural rules in the middle level and control rules at upper level. The procedural rules at the middle level have been categorised according to their nature of application.

The next chapter is devoted to discussion of the main modules such as user interface and data acquisition module and the functions of sub-modules in discrete order process planner and production schedule generator.

# CHAPTER 8

## DESCRIPTION OF PROCESS PLANNING MODULES

### 8.1 INTRODUCTION

This chapter describes the different modules which have been implemented for the generation of process plans for the manufacture of HFS hollows and CFS tubes and is divided into four sections which are as follows:

(1) Supportive modules

(2) Process planning modules for hot mill

(3) Process planning modules for cold drawing mill

(4) Modules for preparation of production schedules

The supportive modules are designed to help the user to develop the process plan and include User Interface and Knowledge-acquisition subsystems. The process planning modules develop the process plan either for HFS tubes or CFS tubes. In order to develop a process plan for CFS tubes, the user has to develop a process plan for the manufacture of hollows described in section 8.3 and then the plan for CFS tubes which is described in section 8.4. Section 8.5 deals with the preparation of production schedules or rolling programs for the manufacture of hollows. The modules of this section are based upon the optimisation strategy of hollow manufacture discussed in Chapter 5, section 5.3.10.

### 8.2 SUPPORTIVE MODULES

Supportive modules include two main programs i.e. user interface and the knowledge acquisition module. The user interface is designed to help the user to select a task from the menu systems while the knowledge acquisition program is used to update the facts in the knowledge-base according to changing requirements. These modules are described below.

### 8.2.1 USER INTERFACE (UIFACE.PRO)

The User Interface is the part of knowledge-based system that communicates with the user. Usually, the users of the system have very little information of the organisation of the knowledge-bases and working with the system without User Interface becomes very difficult.

The program "UIFACE.PRO", is designed on the basis of Menu selection. Menu selection systems are very attractive because they eliminate training and memorisation of the complex commands for the execution of the system. In these systems the user can select an item or a task easily and indicates choice by the single stroke of a key. This simplified interaction style reduces the probability of errors and guides the novice.

There are many designs of the menu systems but the tree structure with the cyclic network has been chosen for the present work as shown in Figure 8.1. Such a structure is beneficial because it has the power to accommodate a large collection of choices for the user.

The main menu of the system has four different choices as shown in Appendix A2, figure A2.1. The first choice invokes the knowledge acquisition menu which has a depth (number of levels) of 2 and a breadth (number of choices per level) of 4 and 9 for level 1 and 2 respectively. Therefore, an untrained user can select a right choice out of a collection of 36 different tasks used to perform various operations on the knowledge-base files. The phrasing of knowledge acquisition menus of level 1 and 2 is shown in Appendix A2 figures A2.2 and A2.3 respectively.

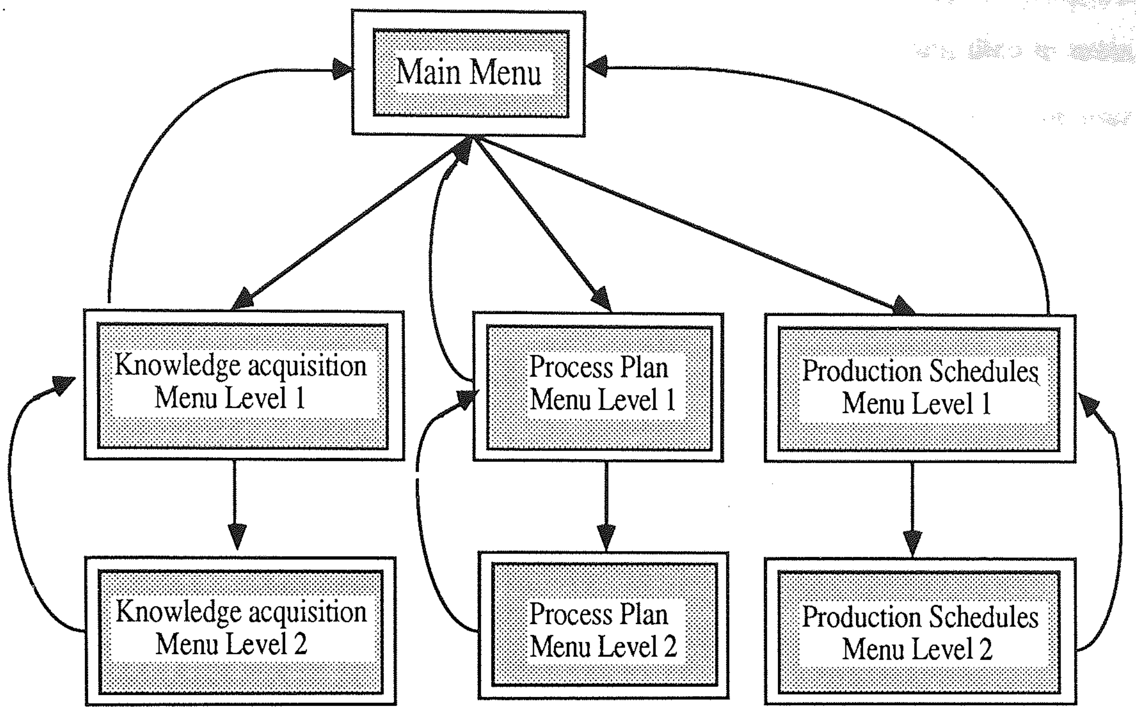



Figure 8.1: User Interface Menu System

On the selection of second and third choice from the main menu, the program first controls the execution of various sub-modules for the preparation of process plan for the manufacture of HFS or CFS tubes and acts as a main program as in the conventional systems. When the process plan and its sub-details are prepared, the module then displays the first level process plan menu shown in Appendix A2, figure A2.4. The selection of a particular choice from this menu, invokes the level 2 menus shown in Figures A2.5 and A2.6 depending upon the finish of the tube (HFS or CFS). From these menus a choice can be made to perform the operation selected from the first level menu. Level 1 menus are mostly consist of operators required to be performed at next lower levels.

The last choice in the main menu is the preparation of production schedules and selection of this choice displays the menu of level 1 and 2, the available choices in the menu are shown in Appendix A2, figure A2.7 and A2.8.

The User Interface is designed in such a way that the menu traversal can be accomplished by the user in a cyclic manner. The user can go from the main menu to level 1 and then to level 2 or traverse back from level 2 to level 1 and then to main menu. The cyclic traversal is shown in figure 8.1 by curved arrows and helps the user to comprehend quickly that what is being looking for without getting lost in the menu system.

### 8.2.2 KNOWLEDGE ACQUISITION MODULE (KNACQUIS.PRO)

This module is designed to perform the selected tasks from the knowledge acquisition menu (Appendix A2 figure A2.2) on the knowledge-base files to update the facts for a particular domain. The selection of any task from the menu invokes a lower level menu as described in section 8.2.1 giving the opportunity to the user to select a choice with which he intends to work. The position of these choices in the menu is linked with corresponding knowledge-base files and selection of any choice opens up the corresponding file to perform the previously selected operation. The choices of level 1 menu i.e. addition of facts, deleting a file, displaying or editing the contents of a file are provided to help the user to update the knowledge according to the changing requirements of the factory process planning function and to view it.

The module guides the user in the performance of every operation. For example, in order to add the tolerances on the outside diameter of the tube as specified by the corresponding standard, the user can select the choice 1 from a lower level tolerance menu shown in Appendix A2, figure A2.9.

The outside diameter tolerances can be specified either for a range (min - max) of diameter value or can be computed by a formula depending upon the method of tolerance specification in the relevant Standard. In addition, the tolerances may have different categories (very fine or fine or coarse) depending upon the final application of the tube. In updating the tolerance knowledge, the user has to go through a dialogue session shown in figure A2.10 to give responses to the questions being asked. If the user gives the response that the tolerances are to be computed by the formula ('F' answer), the system displays a range of formulas compiled from the British Standard as shown in Figure A2.11. The user can then select a formula which is required for the computation of tolerances.

At the end of this dialogue session, the user is prompted whether to continue(C) or end the session by typing "SAVE" and according to user response, the process is repeated or the data collected in the session is saved in the tolerance file in appropriate format of facts related to outside diameter tolerances. Similar process has been programed in this module for other option available in menu A2.3.

The knowledge acquisition module is limited only to acquire new knowledge in form of facts and can not provide the facility for adding new rules. Although this can be achieved by structuring the rules in the rule bases into object-attributes-values triplet but these types of rules sometimes cannot be used for the computation requiring many arguments.

## 8.3 PROCESS PLANNING MODULES FOR HOLLOW/HFS TUBES

To generate a process plan for the manufacture of hollow or a HFS tubes, the following modules have been implemented:

(1) CODINTERP.PRO

(2) HOLBILSEL.PRO

(3) PRSASEQH.PRO

(4) TSAOPTIM.PRO

(5) TOLERAN.PRO

(6) A series of process plan formatting programs

These modules are also used for the preparation of process plans for the manufacture of CFS tubes together with some other specific modules. In the following sections, each module is described.

### 8.3.1 CODE ANALYSER AND INTERPRETER (CODAINTP.PRO)

This module takes the part code from the user, checks its validity and then interprets the code symbols as what they communicate to prepare the order detail as shown in figure 8.2. The user can enter the code in upper or lower case and the module converts them into upper case. To avoid the wrong entry of the part code it is checked character by character. This makes sure that the positions where characters are expected should not be replaced by integers and vice versa. The module also checks that the slashes "/" are at right places and the total number of characters in the code i.e. code length is valid.

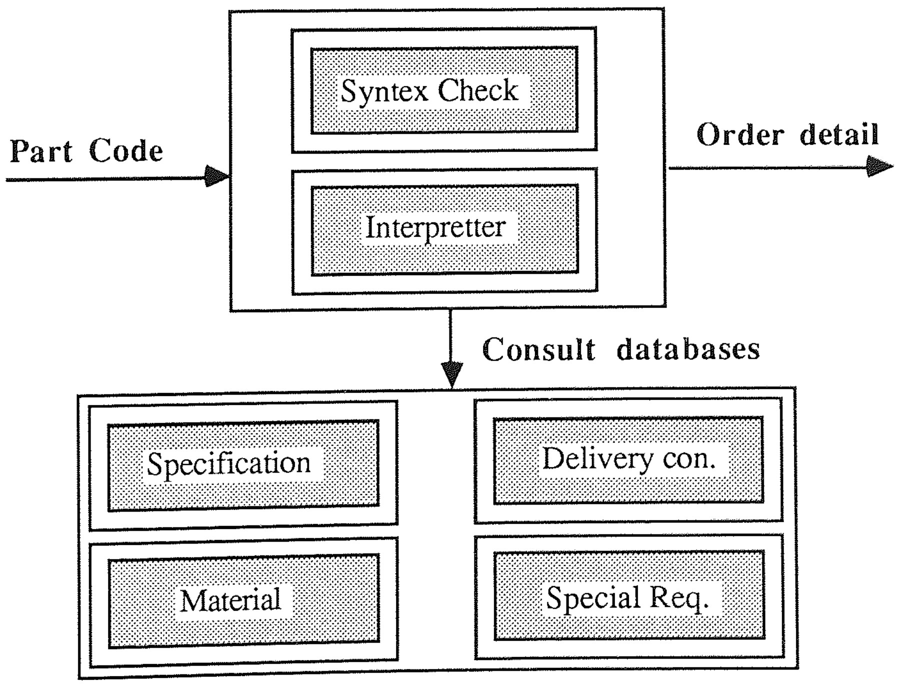



Figure 8.2: Sub-modules called and knowledge-bases of code Interpreter

A loop has been provided so that if the code is found invalid, the user is warned with a beep sound and prompted to enter it again.

Once the code has been checked for its length, character positions and their type and found valid, it is interpreted by using the facts in the knowledge-base to assign the meanings to the characters as well as the dimensions are converted to metric values. The availability of facts in the knowledge-base files determines that the code can be interpreted or not. In case of successful interpretation, the messages received in the code are converted into appropriate format of facts and saved into order file. These facts include the dimensions of the tube, special requirement, delivery condition, specification and material to be used.

In case the code can not be interpreted by the available information in the knowledge base, the user is prompted to enter the meanings of those characters as what information they communicate. The user response then can be saved in the appropriate file and can be used if a similar situation occurs again. In this way the facts in the knowledge-base can be increased and the system becomes more and more experienced. The format of output of this program is shown in Appendix A4, figure A4.1.

### 8.3.2 HOLLOW AND BILLET SIZE SELECTOR (HOLBILSEL.PRO)

This module is designed to select the standard hollow sizes which can be manufactured economically, entry size of the tube for stretch-reducing mill, billet diameter and to compute the billet weight and length for required finished tube dimensions. The input to this module is the order detail prepared by the previous module.

The various sub-modules called by this program to perform a specific task are shown in figure 8.3. The functions of these sub-modules are briefly described below.

(1) RBHOLLOW.PRO

Determines the ideal hollow size by adding the appropriate cold drawing margin as discussed in section 5.3.2 in outside diameter and wall thickness of the finished dimensions of the CFS tubes. In case of HFS tubes this module is not required to be executed.

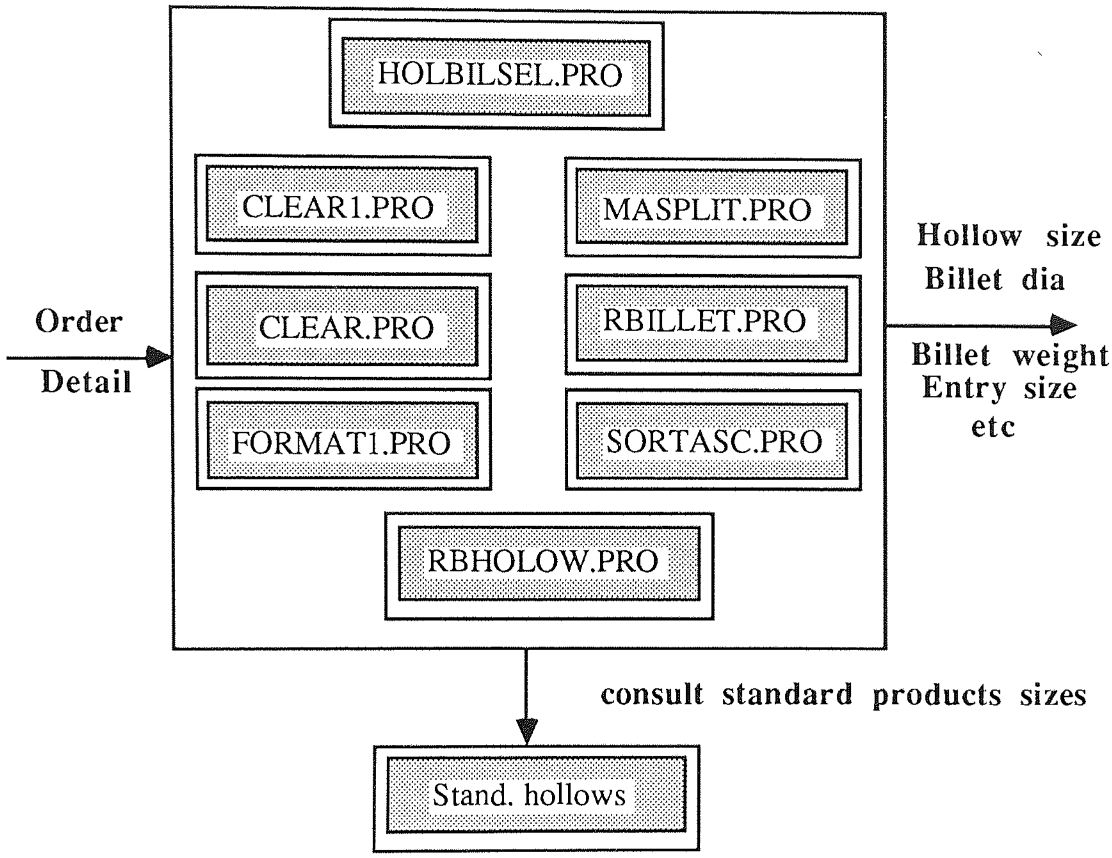



Figure 8.3: The sub-modules called by HOLBILSEL.PRO

(2) SORTASC.PRO

The standard hollow sizes are kept in a list structure which can not retain its ordered form due to addition of new sizes. This module arranges the list in ascending order required by the next module.

(3) MASPLIT.PRO

This module takes the list arranged in ascending order of standard hollow sizes and determines whether the ideal size belongs to this list or not. In case the ideal size is the member of this list then it is selected for the manufacture. On the other hand if the ideal size is not available, then it splits the arranged list into two sub-lists with the elements of first and second sub-list being less than and greater than the ideal size respectively. The first element of the second list which is within close proximity and is bigger than the ideal size is then chosen for the manufacture.

(4) RBILLET.PRO

Once the standard hollow size is decided, it can be used for the selection of billet diameter by firing the rules provided in this module.

(5) FORMAT1.PRO

Formats the data into three decimal places by rounding of the next digit.

(6) CLEAR.PRO

Retracts the facts of order detail from the memory.

(7) CLEAR1.PRO

Retracts the facts generated by "HOLBILSEL.PRO" module from the memory.

In addition, the module communicates all the decision taken during the execution to the user for approval. In case the user is not satisfied with the decision taken, then he is prompted to overwrite the decisions by providing his own decision and new responses will be saved. The output of the program is shown in Appendix A4, figure A4.2.

### 8.3.3 SELECTION AND SEQUENCING PROCESSES (PRSASEQH.PRO)

This module is designed to select the required processes for the manufacture of hollow or HFS tubes and to arrange them in succession i.e. the order in which they are to be performed. The input to this module are operations precedence relationships, order detail and entry size while the output is the sequenced list of selected processes as shown in figure 8.4.

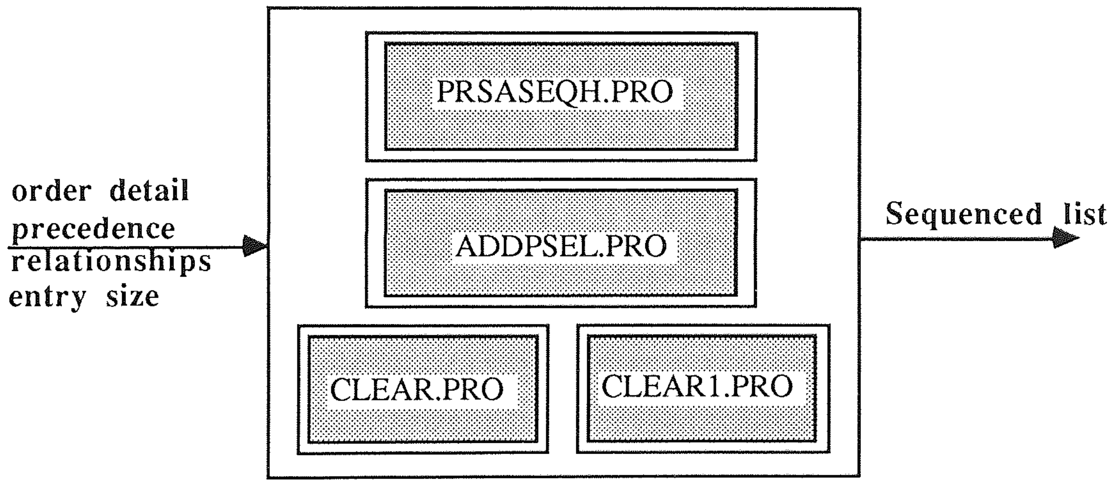



Figure 8.4: Sub-modules of PRSASEQH.PRO

The hollow manufacturing processes are selected on the basis of the entry size whether the tube goes to stretch-reducer or not and kept randomly as selected process list. Every process in this list is taken turn by turn in order to find its place by using the operation precedence relationships discussed in section 5.3.7 and placed in another list called "list of sequenced processes". When the first list becomes null i.e. no more processes left for sequencing, the resultant list i.e. the list of sequenced processes then can be saved. In case of HFS tubes, there are some secondary processes to be carried out to attain special requirement of surface finish or mechanical properties. In such a case, the sub-module "ADDPSEL.PRO" is called to select the additional processes and placed at the appropriate place in the sequenced processes list. This list of processes can be used to convert the billets (raw material) into hollows (finished product).The list of sequenced processes is shown in Appendix A4, figure A4.3.

### 8.3.4 TOOLS SELECTION AND RESOURCES OPTIMISATION FOR HOLLOW MANUFACTURE (TSAOPTIM.PRO)

This module is designed to select drawbench for CFS tubes, tools and machine parameters for the manufacture of hollow, the maximum possible length of hollow that can be manufactured within the design constraints and limitation of hot mill resources, the optimum billet length and the economical feed stock bar size to cut the billets of required length with minimum material loss. The input to this module are the order detail, hollow size and billet diameter and it consults the knowledge bases such as available tools and the bench capabilities to perform its functions as shown in fig. 8.5.

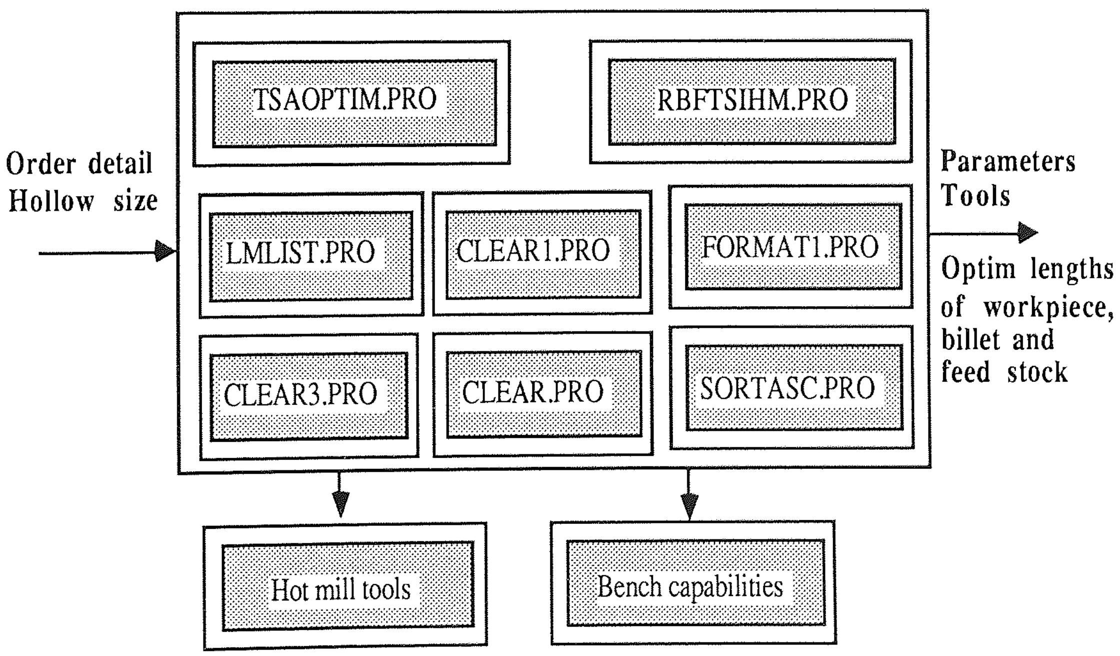



Figure 8.5: Sub-modules called in TSAOPTIM.PRO

In the case of CFS tubes, the module first selects an appropriate drawbench on the basis of capability in terms of maximum diameter and length of workpiece it can accommodate and then finds the length margins (cutting and thick ends) to be added so that the exact lengths of finished tubes can be manufactured.

It then calls the sub-module "RBFTSIHM.PRO" to select the required tools and machine parameters for the manufacture of hollows. In this module the rules are provided to determine the ideally required tools, but in case such tool(s)are not available then list of available tools is arranged in ascending order (SORTASC.PRO) and a tool is selected which is within close proximity and smaller than the ideal size by a sub-module (LMLIST.PRO) as discussed in section 5.3.5. The module also contains the rules for selecting machine parameters. After selection of tools and machine parameters the user is asked whether these decisions are acceptable or not. In case the user is not satisfied, he can give his own responses and those are then saved.

The module "TSAOPTIM.PRO" then determines the maximum possible length of hollow that can be manufactured by utilising the hot mill resources to their maximum capability by using a strategy as discussed in section 5.3.9 and determines the equivalent length of billets. During this process, the dimensions of the workpiece after each operation of the hot mill are computed and saved.

Using the optimum length of billet as the basis, the module computes the loss of material which can possibly goes to scrap by cutting the required billet lengths from various feedstock bars of different sizes. Then material losses are compared and a bar size with minimum material loss is selected for billet cutting.

The generated data is formatted (FORMAT.PRO) and stored in a file in form of facts as shown in Appendix A4 figure A4.4. These facts then retracted from the memory by the module CLEAR3.PRO.

8.3.5 TOLERANCES AND TESTS SELECTION (TOLERAN.PRO)

The inputs to this module are the tube dimensions, specification number and the finish (HFS/CFS) of the tube. It recommends the specified tolerances on the dimensions and tests to be carried out by consulting the tolerance knowledge-base as shown in figure 8.6 below.

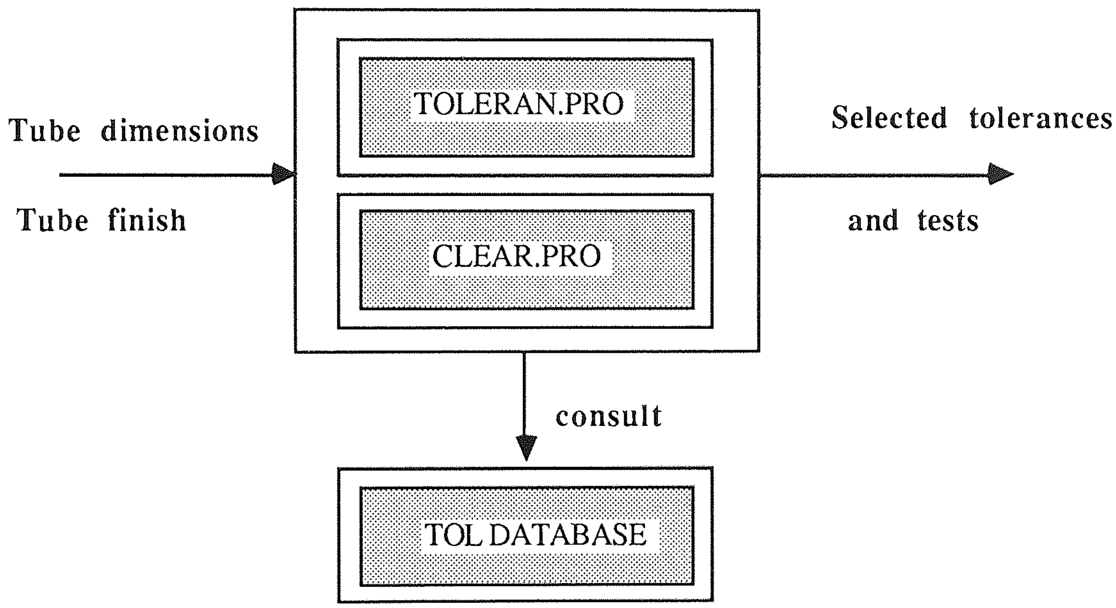



Figure 8.6: The module for selection of Tolerance and Tests

The tolerance module first determines the specification number, tube finish and specified dimensions i.e. (OD/ID, or OD/W, or ID/W) from the order detail file on which the tolerances are required. Then it determines whether this specification number has any categories of tolerances on the specified dimensions by consulting the tolerance database. In case the specification number has different categories, it asks the user to specify the category. On the basis of the known information, it finds from the tolerance database that whether the tolerances are specified for a range of dimension values or to be computed by a formula. In cases in which the tolerances are specified for a range of dimension values, it finds the range in which the value of dimension lies and retrieves the corresponding tolerance values. On the other hand, if the tolerances are to be computed by a formula, it retrieves the formula number and invokes the rule associated with that formula to compute the tolerance. Approximately all the formulas available in BS for computing the tolerances on seamless tube dimensions have been incorporated in this module as an individual rule. The whole process is repeated for other specified dimensions such as ID, WALL, LENGTH etc. Similarly, the required straightness on the finished tube can be retrieved by knowing the straightness category.

Using the specification number, the associated tests required can be retrieved. In cases in which the customer has requested for special tests, those tests are appended to the list of recommended tests. These tests are separate operations but not included in the manufacturing operation sequence because of their association with testing and not manufacturing.

If the tolerances are not available in the database for the given specification number, the user is requested to enter the values in a dialogue session. The format of facts related to selected tolerances for a job is shown in Appendix A4 figure A4.5.

### 8.3.6 PROCESS PLAN FORMATTING PROGRAMS

At this stage, the process plan for the manufacture of hollows or HFS tubes is ready and its details are available in different files in the form of generated facts. In order to convert these facts to a user-readable format, a series of small modules has been written as follows:

| | | |
|---|---|---|
| (1) | Order detail formatter | (ORDERD.PRO) |
| (2) | Tolerance detail formatter | (TOLD.PRO) |
| (3) | Material detail formatter | (MAD.PRO) |
| (4) | Hollow detail formatter | (HOLLOWD.PRO) |

| | | |
|---|---|---|
| (5) | Tools detail formatter | (TOOLD.PRO) |
| (6) | Operation sequence formatter | (OPERSH.PRO) |
| (7) | Hot mill process plan Formatter | (PPLAN.PRO) |

These modules have been briefly described below.

(1) ORDERD.PRO

The module ORDERD.PRO writes the header section of the process plan and the order detail in a user readable format. The header section of the process plan includes the planner name, the date and the time when the plan was generated. The order detail includes the part code number, works order number, tube dimensions, specification number, finish of the tube and quantity of the tubes ordered by the customer. The formatted detail for an order is shown in Appendix A3 figure A3.1.

(2) TOLD.PRO

This module converts the selected tolerances and the tests to be carried out in a format as shown in Appendix A3 figure A3.2. For each specified dimension positive and negative tolerances and recommended tests are written into a file.

(3) MAD.PRO

This module gathers the information related to material such as material designation number, material type with carbon content, size, quantity and weight of billet, number of finished tubes per billet and the total weight of the order and writes in an appropriate format as shown in Appendix A3 figure A3.3.

(4) TOOLD.PRO

This module is designed to format the selected tools and machines set up parameters as shown in Appendix A3 figure A3.4.

(5) HOLLOWD.PRO

The selected standard hollow and the entry size of the tube for stretch-reducing mill are communicated by this module as shown in Appendix A3 figure A3.5.

(6) OPERSH.PRO

The module OPERSH.PRO is designed to gather the selected information regarding the operation sequence in the hot mill, the tube dimensions after each operation, the economical feedstock bar size and to prepare the hot mill operation sequence sheet as shown in Appendix A3 figure A3.6. This module also gives the number for each operation according to their selected sequence.

(7) PPLAN.PRO

The previous module save the formatted information in the individual files. This module reads the information in all of those files and combines them into one file called the hot mill process plan file.

## 8.4 PROCESS PLANNING MODULES SPECIFIC TO CFS TUBES

Once the process plan for the manufacture of hollow is generated, next step is to develop a process plan for the CFS tubes manufactured from hollows. The following modules have been implemented for this purpose:

(1) PASSN.PRO

(2) UPLDIES.PRO

(3) ALTSCH.PRO

(4) BESTSCH.PRO

(5) ANNEAL.PRO

(6) STADLP.PRO

(7) CDMOPERS.PRO

(8) Process plan formatting programs

### 8.4.1 SELECTION OF NUMBER OF PASSES (PASSN.PRO)

This module is designed to select the number of passes in which a given hollow size

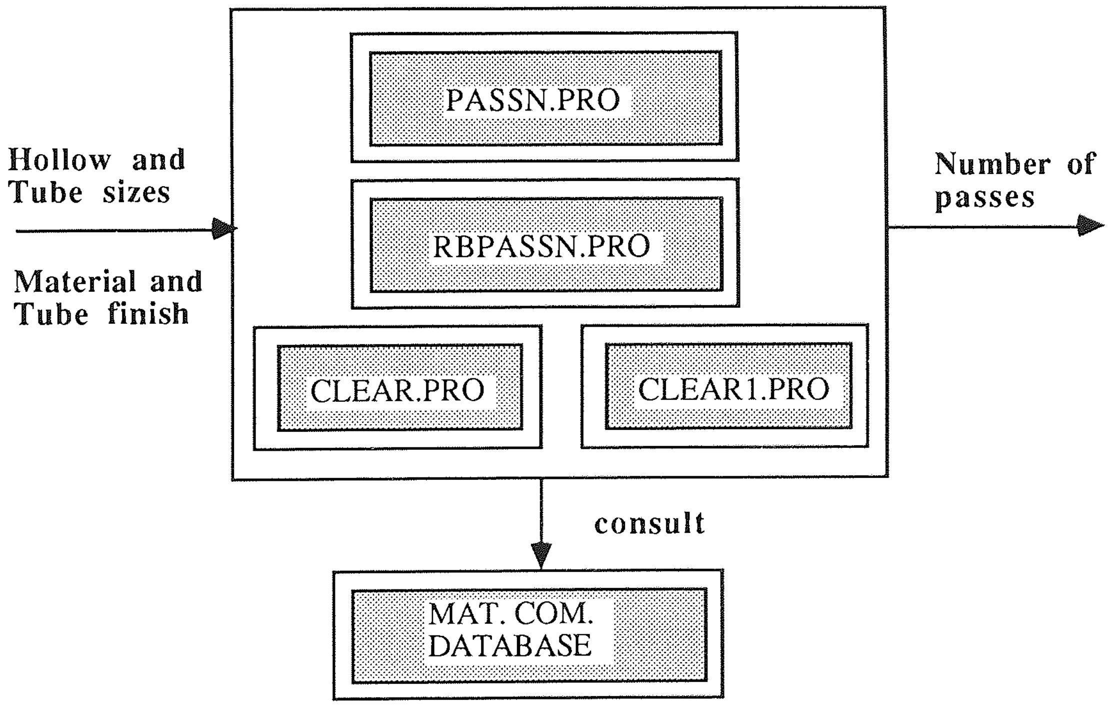



Figure 8.7: Sub-modules for Number of Passes Selector

can be reduced to finished tube size. The sub-modules called within this program are shown in figure 8.7 and it requires the hollow and finished tube size as input.

It determines the overall reduction of area, finds whether the finish tube has any special requirement and consults the material composition database in order to find the material carbon content to establish its measure of ductility which can influence the selection of the number of passes.

The information is passed to the sub-module "RBPASSN.PRO", where the rules are provided to select the number of passes for a given job by considering and satisfying the associated conditions. The number of passes selected are thus based upon the prevailing policy but the user can overwrite the decision taken and this ensures the system flexibility. The output format from this program is shown in Appendix A4, figure A4.6.

### 8.4.2 SELECTION OF PLUG AND DIE SIZES (UPLDIES.PRO)

The module "UPLDIES.PRO" determines the plug and die sizes which can possibly be used to reduce the given hollow to the required size by calling the various sub-modules as shown in figure 8.8. It consults the database and passes the list of available tools and initial and final dimensions of the tube to sub-module "SPLIT.PRO". The functions of various sub-modules are described below.

#### (1) SPLIT.PRO

This module picks up the usable die and plug sizes within the range of hollow and finished tube dimensions from the lists of available tools.

#### (2) REMUNTO.PRO

The number of tools in the lists of usable die and plug sizes may be very large and the consecutive tools may have dimensions which are very close to each other i.e. use of such tools may result in a small and unrealistic reduction of area in a pass. Since lists of usable tools are required at a later stage for generating alternative tube drawing schedules based on trying all possible combinations of die and plug sizes, therefore, a large number of tools in the lists means many combinations which sometimes exhausts the limited memory of Personal Computer (PC).

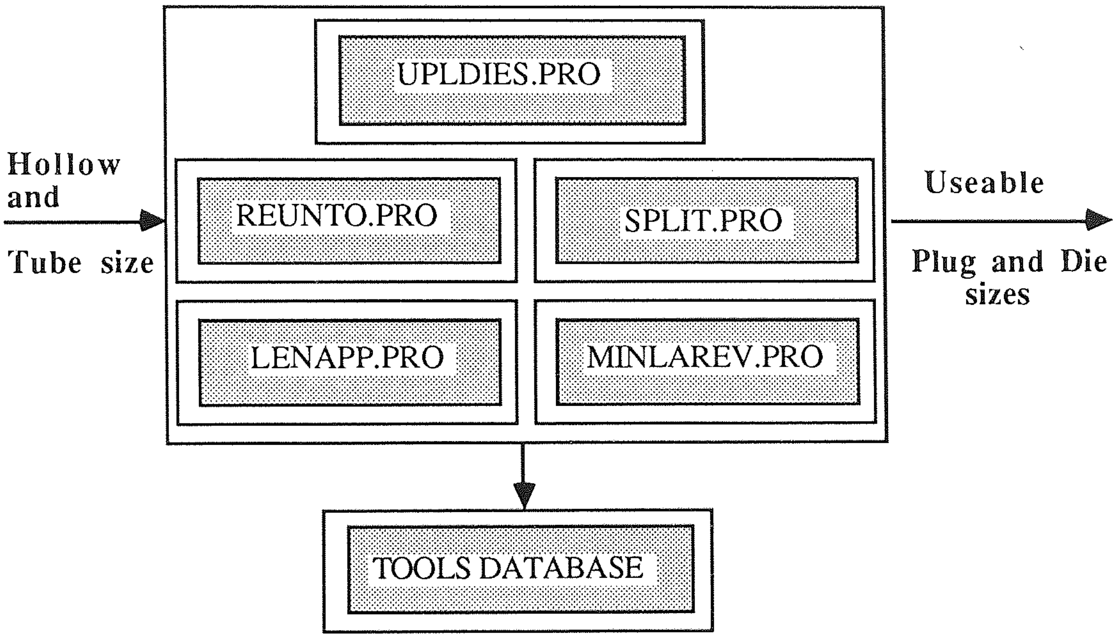



Figure 8.8: The sub-modules called for the selection of die and plug sizes

In order to overcome this difficulty, this module is designed to remove unnecessary tools from the usable tools list, at the same time ensuring that a reasonable number of tools is still available to generate the alternative schedules.

Removal of unnecessary tools is based upon finding the difference between two consecutive tools for the whole list and then determining the minimum value from the resultant difference list. Then one of the tools associated with minimum difference is removed from the list. The process is repeated for the new list until the number of tools left in the final list is reasonably sufficient which is decided by the number of passes.

(3) LENAPP.PRO

This module finds the length of a given list or to append the two given lists into a third list.

(4) MINLAREV.PRO

This module has three different predicates to finds:

- Minimum number in a given list or
- Last element of a list or
- Reverse the order of a list

The format of output from this program is shown in appendix A4, figure A4.7.

### 8.4.3 ALTERNATIVE TUBE DRAWING SCHEDULES (ALTSCH.PRO)

This module is designed to control the lower level modules for generation of alternative tube drawing schedules and to eliminate the unwanted schedules among the alternatives. It gathers the required information from the different files and calls the sub-modules to perform a specific task as shown in figure 8.9 .

Depending upon the selected number of passes for the job, the sub-module GENSCH.PRO is executed repeatedly to generate alternative schedules. It then scans the alternatives schedules in order to remove those which contain the last set of plug and die sizes i.e. they can not be further broken down to generate a schedule which satisfies the number of passes. The other sub-modules are briefly described below.

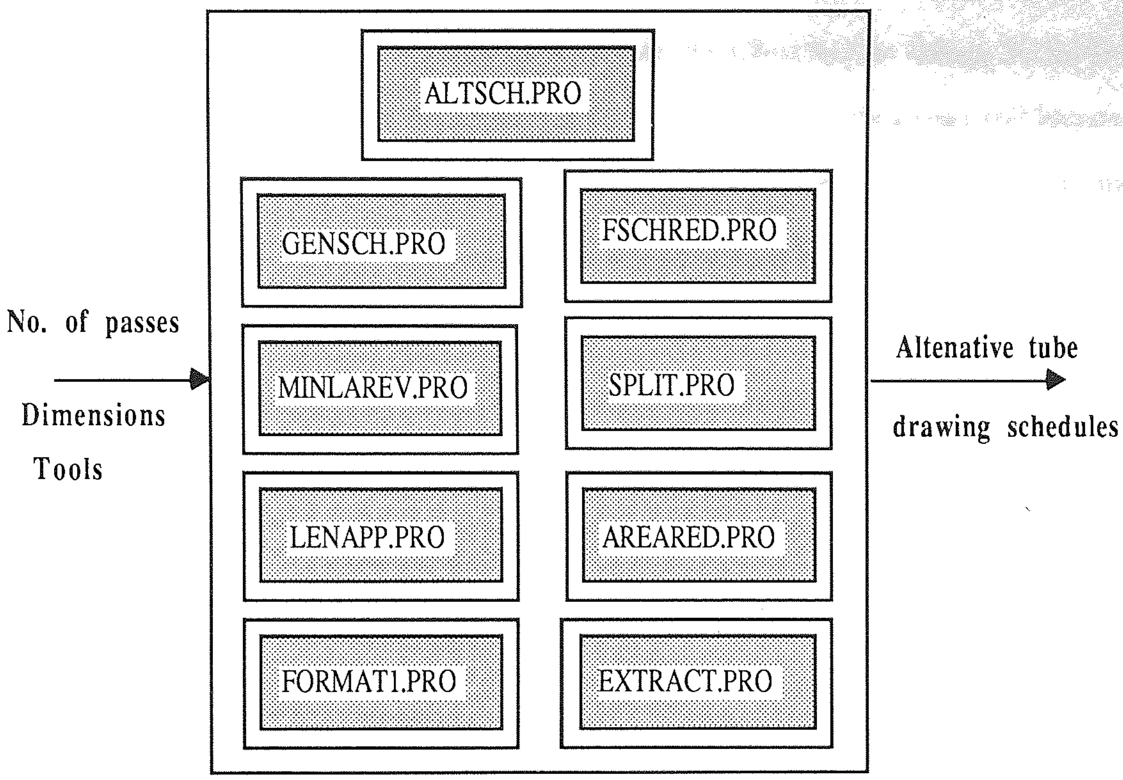



Figure 8.9: Sub-modules called for the generation of Alternative Schedules

(1) GENSCH.PRO

This module works on the basis of generate and test i.e. it first generates a tube drawing schedule and then tests whether the reduction of area per pass is within the production range or not. The schedules with unrealistic reduction of area per pass are discarded and only those schedules are saved which lie within actual production range. Supposing that a tube requires two passes to be reduced from initial hollow dimensions of $X_o$ and $X_i$ to a final dimension of $D_4$ and $P_4$ (outside and inside diameter respectively) and the selected die and plug sizes are:

usable_die_sizes($D_2$, $D_3$, $D_4$)

usable_plug_sizes($P_2$, $P_3$, $P_4$)

In order to generate the alternative tube drawing schedule for the manufacture of tube of this example, the module is executed to generates the schedules by taking the hollow size prior to first pass or final dimension of the tube in the previous pass and locating the tools which can be used after those dimensions to add another pass. The first time when module is executed it takes the initial dimension of hollow ( $X_o$ and $X_i$ ) and every combination of plug and die size is tried to generate a schedule containing one pass. Such schedules are shown below in figure 8.10 and it is supposed that all the schedules are realistic i.e. within the actual production range.

(1) $X_o X_i$ --------> $D_2 P_2$
(2) $X_o X_i$ --------> $D_2 P_3$
(3) $X_o X_i$ --------> $D_2 P_4$
(4) $X_o X_i$ --------> $D_3 P_2$
(5) $X_o X_i$ --------> $D_3 P_3$
(6) $X_o X_i$ --------> $D_3 P_4$
(7) $X_o X_i$ --------> $D_4 P_2$
(8) $X_o X_i$ --------> $D_4 P_3$
(9) $X_o X_i$ --------> $D_4 P_4$

Figure 8.10: Alternative tube drawing schedules after first call of GENSCH.PRO

In case of one pass job the schedules in figure 8.10 are complete and can be scanned to eliminate those which do not attain the required dimensions. In this example the job requires two passes so that the program ALTSCH.PRO will eliminate those schedules (3, 6, 7, 8 and 9) which contain the final set of plug and die because they can not be used for second pass. After elimination of unwanted schedules the module GENSCH.PRO is called again which in turn will take the final dimensions of the tubes after first pass for remaining schedules and generate the schedules for 2nd pass as shown in figure 8.11.

The schedules in figure 8.11 represent two passes as required and control goes back to the module ALTSCH.PRO. This time the program will save those schedules in which the final required dimensions of the tubes are attained by discarding others (1, 2, 3, 5 and 7). Therefore, the remaining schedules (4, 6, 8 and 9) will be saved as alternative tube drawing schedules for this example.

(1) $X_o\ X_i$ --------> $D_2\ P_2$ ------------> $D_3\ P_3$
(2) $X_o\ X_i$ --------> $D_2\ P_2$ ------------> $D_3\ P_4$
(3) $X_o\ X_i$ --------> $D_2\ P_2$ ------------> $D_4\ P_3$
(4) $X_o\ X_i$ --------> $D_2\ P_2$ ------------> $D_4\ P_4$
(5) $X_o\ X_i$ --------> $D_2\ P_3$ ------------> $D_3\ P_4$
(6) $X_o\ X_i$ --------> $D_2\ P_3$ ------------> $D_4\ P_4$
(7) $X_o\ X_i$ --------> $D_3\ P_2$ ------------> $D_4\ P_3$
(8) $X_o\ X_i$ --------> $D_3\ P_2$ ------------> $D_4\ P_4$
(9) $X_o\ X_i$ --------> $D_3\ P_3$ ------------> $D_4\ P_4$

Figure 8.11: Alternative tube drawing schedules after second call of GENSCH.PRO

(2) FSCHRED.PRO

Once the possible alternative tube drawing schedules are generated, the reduction of area per pass is required to be added after the final dimensions of every pass. This module takes the dimensions before and after every pass, calculates the area and reduction (AREARED.PRO) and places the value at the required position in the every alternative tube drawing schedule.

(3) AREARED.PRO

During the process of generation of alternative tube drawing schedules the area of the tube and reduction of area is required to be calculated many times. This module performs the calculation for area of tube and reduction of area in percent.

(4) EXTRACT.PRO

This predicate is designed to extract an element from a list at a given position. The alternative schedules generated for an actual examples are shown in Appendix A4, figure A4.8.

8.4.4 SELECTION OF BEST SCHEDULE (BESTSCH.PRO)

The program "BESTSCH.PRO" is designed to select the best schedule from the alternatives. The input to this module being the delivery condition and the alternative schedules as shown in figure 8.12.

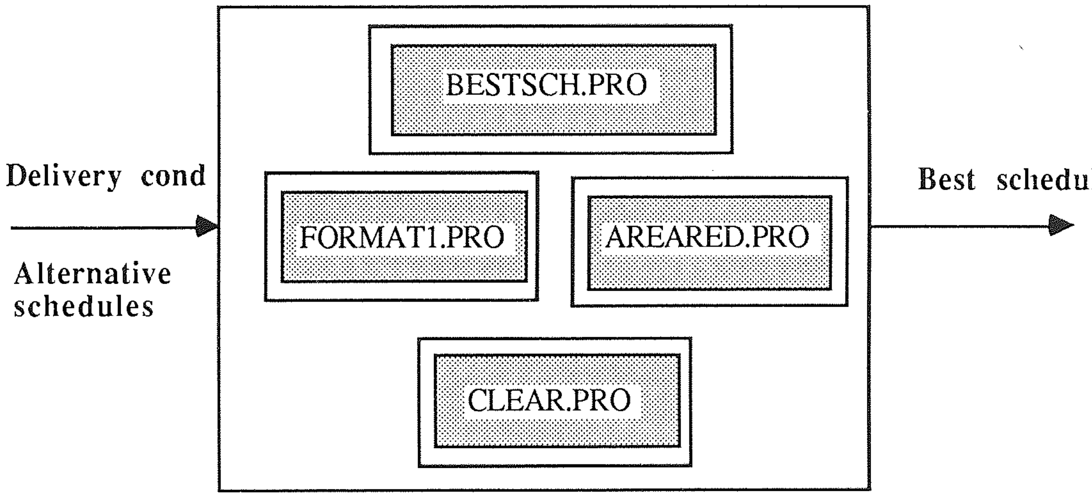



Figure 8.12: Selection of Best Schedule from alternatives

This program first determines the variation in reduction of area between every two consecutive passes for a given schedule and sums up the variation for the whole schedule. The process is repeated for all the alternative schedules available and a schedule corresponding to minimum variation is selected as a best schedule. This ensures that the reduction of area over all the passes is evenly distributed.

In some cases, however, the delivery condition of the tube dictates a light final pass to attain the required properties in the tube. In such a case a schedule is selected with less than 15 percent reduction of area in the final pass. If such a schedule is not available in the alternatives, then the schedule selected on the basis of minimum variation in reduction of area is modified by introducing new die and plug sizes in such a way that the required reduction of area in the final pass is attainable. The format of best schedule as selected is shown in Appendix A4, figure A4.9.

### 8.4.5 SELECTION OF INTER-PASS ANNEALING (ANNEAL.PRO)

This module selects the annealing requirement between the different passes of the selected tube drawing schedule. The input to this module is the number of passes and the material designation number is shown in figure 8.13.

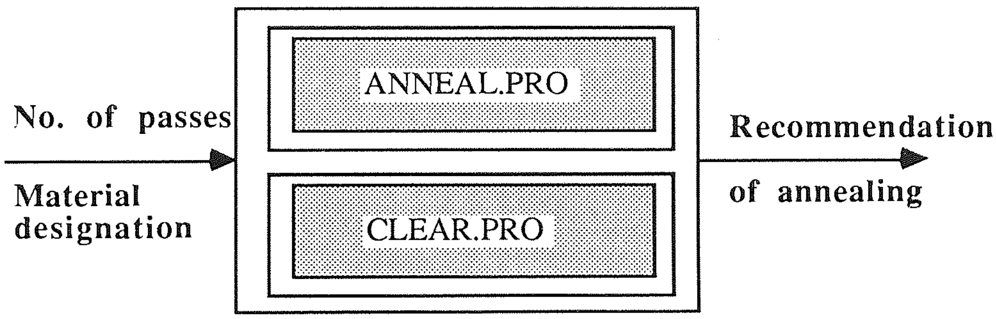



Figure 8.13: Module for Selection of Inter-pass annealing

The main criteria for selecting the inter-pass annealing is the carbon contents in the material being used as discussed in section 6.5. Annealing is usually recommended after every pass for alloy steel or a material which are hard-to-draw. The materials, which are easy-to-draw are annealed after every two passes. The format of output is shown in Appendix A4, figure A4.10.

### 8.4.6 STRESS/STRAIN, DRAWING LOAD AND POWER CALCULATION (STADLP.PRO)

This module is designed to calculate first the strain, on the basis of which drawing stress, drawing load and power requirement are then computed for the tube drawing schedule. The computation of these parameters is carried out on the basis of the proposed theory described in Chapter 6. The drawing load for every pass in the schedule is then checked against the drawing capability of the selected drawbench. If the drawing load for any pass in the schedule exceeds the bench capability, the user is warned and advised to develop a new process plan. Such a possibility is very remote as the schedules are developed on prevailing policy and experience.

This module uses the selected number of passes, the tube dimensions in the schedule and the recommended inter-pass annealing requirement to compute the process parameters as shown in figure 8.14 below.

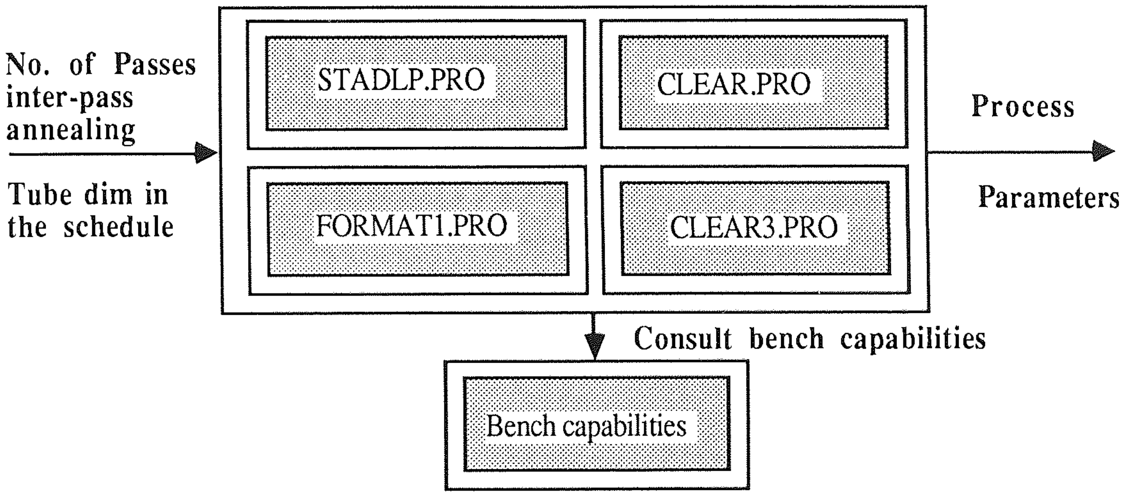



Figure 8.14: Computation of process parameters by module STADLP.PRO

The strain is computed by the use of equations (6.24) and (6.28) given in Chapter 6. Initially, the hollow material is assumed to be in the annealed condition i.e. zero initial strain. During the subsequent passes, the initial strain is taken either zero or the strain imparted in the previous pass depending on whether annealing is recommended or not. Other required information such as effective die semi-angle and speed of drawing are supplied by the user.

The computation of the strain together with other information allows the program to compute drawing stress, drawing load and power requirement. These parameters are then displayed to the user and saved for inclusion in the process plan. The format of the contents of process parameters file is shown in Appendix A4, figure A4.11.

### 8.4.7 OPERATION SEQUENCE FOR CFS TUBES (CDMOPERS.PRO)

This module requires tube drawing schedule and inter-pass annealing as input and selects the necessary secondary processes for the manufacture of CFS tubes. The selected processes are then sequenced by the use of cold drawing mill operation precedence relationships and the sequence sheet is prepared according to required format. The sub-modules which are called to perform specific tasks are shown in figure 8.15.

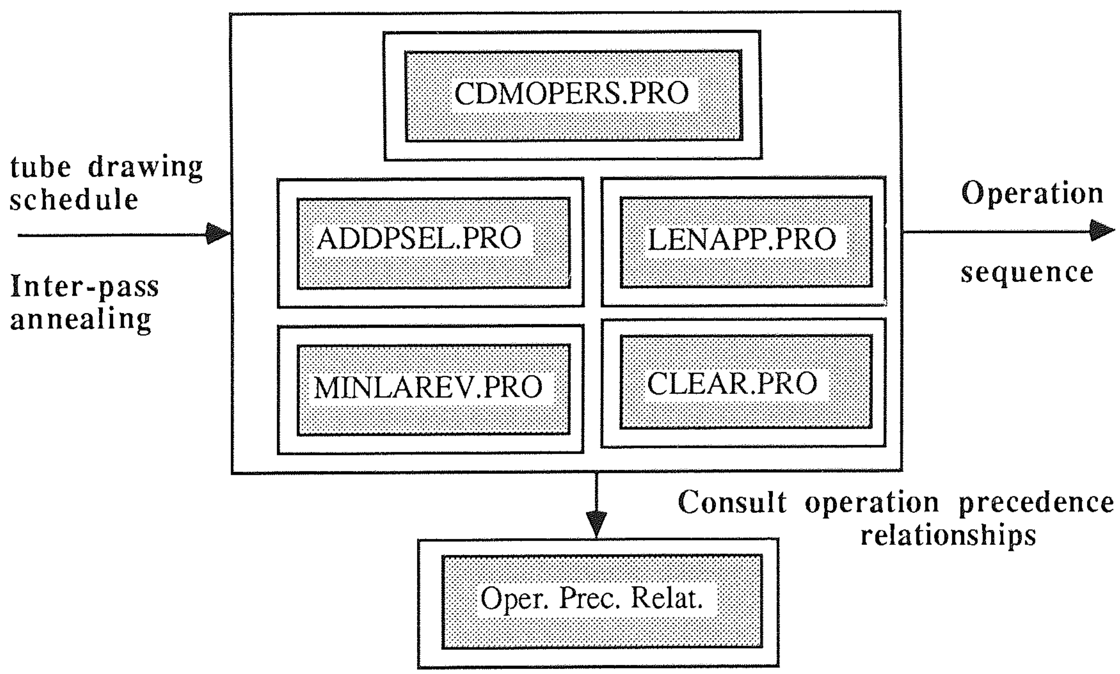



Figure 8.15: The sub-modules called by CDMOPERS.PRO for operation sequence

The secondary processes which are required to be selected include tube preparation processes (tagging, pickling and lubricating), final heat treatment to attain required properties and other tube finishing processes as required by the customer. The tube preparation processes are kept in the operation precedence-relationships in the sequence and selected if the precondition of their selection is satisfied. Prior to the first pass, they are selected but their selection before subsequent passes depends upon whether inter-pass annealing is required, as discussed earlier.

The other type of secondary processes such as final heat treatment and tube finishing are related to customer order (specification and special requirement) and are selected by the sub-module "ADDPSEL.PRO" mentioned in section 8.6.

In order to prepare the operation sequence sheet for the manufacture of CFS tubes, initially, the first pass and its related details (dimensions of tube before and after the pass and percent reduction of area) are added to the selected sequence of tube preparation processes. The addition of the first or any pass to the sequence transforms the present state of the tube to the next state which is checked against the final required state. In case of mismatch with the final required state, a further check is made using the precedence relationships and, if required inter-pass annealing and related tube preparation processes are added to the sequence which prepares the tubes for next pass. The process is repeated till the final required state is reached.

The selected heat treatment and tube finishing processes required are then placed at the appropriate place to complete the operation sequence and all processes are numbered. Such an operation sequence sheet for an example part is shown in Appendix A3 figure A3.7.

### 8.4.8 PROCESS PLAN FORMATTING PROGRAMS

The process planning information for the CFS tube manufacture are in the forms of generated facts and required to be converted in a user-readable format. The following modules convert those details into required format.

(1) CDMTOOL.PRO

(2) STRESSHP.PRO

(3) CDMPLAN.PRO

The module "CDMTOOL.PRO" writes and saves in an appropriate file the selected plug and die sizes for every pass in the schedule as shown in Appendix A3 figure A3.8. Similarly, the process parameters such as drawing load, stress and power requirement details are prepared by the module "STRESSHP.PRO' and shown in Appendix A3 figure A3.9. The module "CDMPLAN.PRO" combines the formatted details for hollow and CFS tube manufacture into a single file which contains the full process plan for the manufacture of CFS tubes.

## 8.5 PREPARATION OF PRODUCTION SCHEDULES

The modules to prepare production schedules or rolling programs are designed to achieve the optimisation of hollow manufacture by the method of grouping those orders which require similar setting of the hot mill, as discussed in section 5.3.10. The programs can be executed according to the objectives to be achieved such as:

(1) To prepare production schedules as fresh start

(2) Revising the production schedules

- (i) To include new unscheduled orders
- (ii) After a breakdown
- (iii) For fully utilisation of manufacturing capacity in each week

(3) To determine material requirement for each week

(4) For graphical display of total and used capacity in form of bar charts

(5) To list the scheduled orders and their weekly total

(6) For order query

## 8.5.1 FRESH START OF THE SYSTEM FOR PRODUCTION SCHEDULES

This procedure is designed to prepare the production schedules for the first time and to create different files required for saving the temporary data and production schedules. The various sub-modules for this procedures are shown in figure 8.16 and their functions are described briefly.

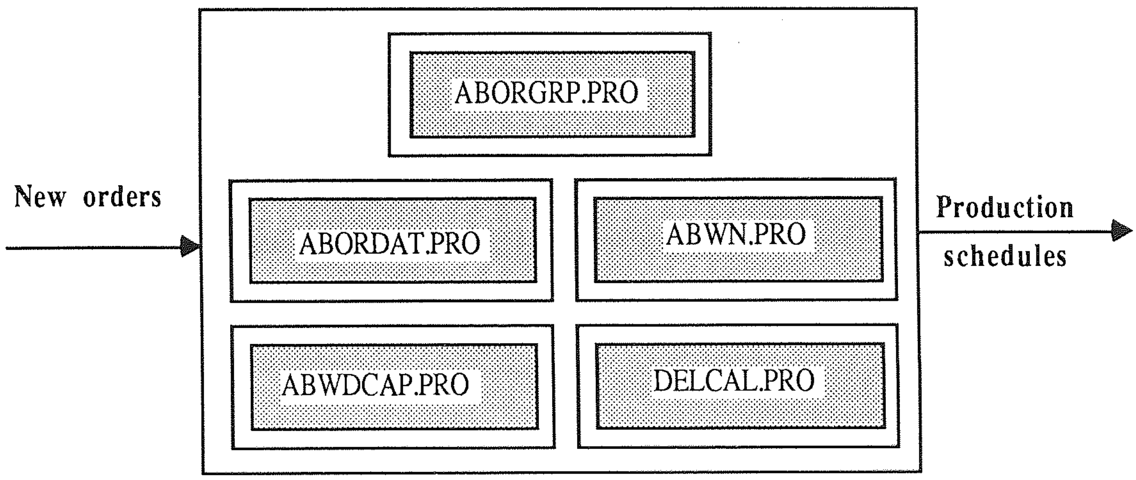



Figure 8.16: Modules used for fresh start to prepare production schedules

### (1) ABORGRP.PRO

This is the only module specific for the fresh start of the system which creates a master file of orders to be used by other modules for preparing production schedules or rolling programmes. This module sorts the new orders from a file, prepared by the process planning modules on confirmation of each order, into different groups. The grouping of orders is based on a range of outside diameter of hollow which can be manufactured in a particular piercer-elongator disc combination.

The orders which contain details such as outside diameter, wall thickness, works order number, customer detail, billet weight, quantity, size, required finish and total weight of the tubes in the order, are then arranged first in ascending order of outside diameter and then of wall thickness. This arrangement is required in order to reduce the overall setting time for the group, since the time required to change the setting of the machines from one order to another is less if the values of outside diameter for both the orders are closed to each other. The arranged orders for every group are then saved in the master file. The master file, therefore, contains the orders of different groups sorted in ascending order of outside diameter and wall thickness.

(2) ABORDAT.PRO

This is the main module to estimate the start and finish dates for every order, available in the master file based on the policy of allowing a manufacturing capacity equivalent to one week to each group of orders.

The strategy for the estimation of the starting and completion dates for each order can be summarised as follows:

The module reads the current date known to the system, and executes the lower level modules ABWN.PRO and ABWDCAP.PRO (described later) to determine the current week number and the list of working days in the current week. By comparing the current date with the first working date of the week it determines the remaining working days and hence the remaining manufacturing capacity in terms of tonnes of tubes. Knowing the prevailing setting of piercer-elongator disc combination from the user, a cycle in which the orders of different groups are to be scheduled is established.

The orders in the first group are retrieved and total weight of tubes in the first order is compared against the remaining manufacturing capacity of the week. If the remaining capacity allows the manufacturing of tubes in that order, then the finishing time in terms of fractions of a day is estimated and the remaining capacity for that week is reduced by an equivalent amount. A set of rules is used to translate the estimated finishing time into "real time" indicated by the expected completion date, which is then set as the expected starting date for next job. The setting time for the next job is not included in the computation because the manufacturing capacity includes allowances for setting time and production difficulties (see section 5.3.8).

The process is repeated for every job until every order in that group is scheduled or the remaining manufacturing capacity for that week is exhausted. If some of the orders of that group cannot be scheduled in the current week because of lack of capacity, they are left for scheduling in the next combination of piercer-elongator setting.

The time period is then changed to the next week and the available working days and equivalent capacity are determined. The orders of the next group in the cycle are then retrieved and the expected starting and completion dates are estimated.

The process is repeated for the orders of every group until the expected starting and completion dates for all the orders in the master file are estimated. Every scheduled order, in addition to its original detail, contains the week number in which rolling is required and the expected start and completion dates. The scheduled orders are then saved in the production schedule file, a partial view of which is shown in Appendix A5, figure A5.1.

(3) ABWN.PRO

This module is designed to find the week number from which the production schedules are to be prepared. Knowing the current date from the computer system, it consults the factory-based calendar file where information such as starting date of first week of a year, number of days in a year, number of days in a month and holidays in a week, are stored in form of facts.

The module progressively determines the starting date of the next week from the starting date of the current week and increments the week counter. The starting date of the next week is compared with the total number of days in that month and starting date and month counters are reset accordingly. A set of rules in the module compares the content of the month counter and starting date of a week being processed with the current month and date. These rules stop the execution of the program when the conditions are met and the content of the week counter is saved as current week number.

(4) ABWDCAP.PRO

This module is designed to determine the number of working days and corresponding dates. Given a week number, it executes a lower level module ABCAL.PRO to determine the starting and finishing dates of that week.

Based on the information of the week number and its start and finish dates, the module consults the factory-based calendar file to determine any holiday (s) in the week. If there are any non-working days, it eliminates those dates from the week number and returns the number of working days and corresponding dates to the main module.

(5) ABCAL.PRO

This module determines the starting and finishing dates of a given week number by consulting the calendar file; it begins from the first week of the year and its execution is stopped when the content of the week counter is equal to the given week number.

## 8.5.2 REVISING PRODUCTION SCHEDULES TO INCLUDE NEW ORDERS

Production schedules need to be revised every week, or whenever necessary, in order to eliminate completed orders from the system and to include new orders in the schedule. The revision of the production schedule to include new orders is achieved by the execution of various sub-modules in a fixed order as shown in figure 8.17. Each module in turn executes various sub-modules to perform a specific task. These modules are briefly described below.

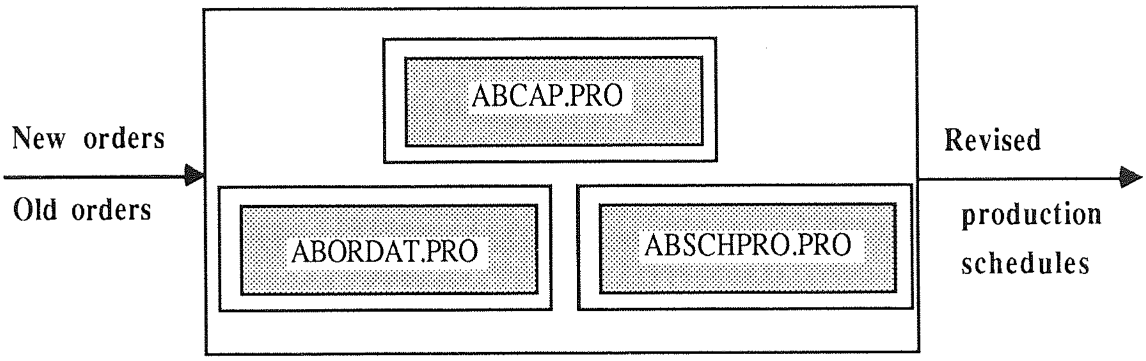



Figure 8.17: Modules used for revision of production schedules to include new orders

(1) ABCAP.PRO

This module is designed to determine the total and remaining manufacturing capacity in terms of tonnes of tubes for each of the production schedules. The various sub-modules which are executed to achieve the overall task are shown in figure 8.18.

The list of week numbers can be found from the production schedules. In such a list each week number is repeated as many times as the number of orders in that week. Multiple entry of a week number is eliminated by module ABMUNIQ.PRO and the list is arranged in ascending order of week number (ABLISTP.PRO).

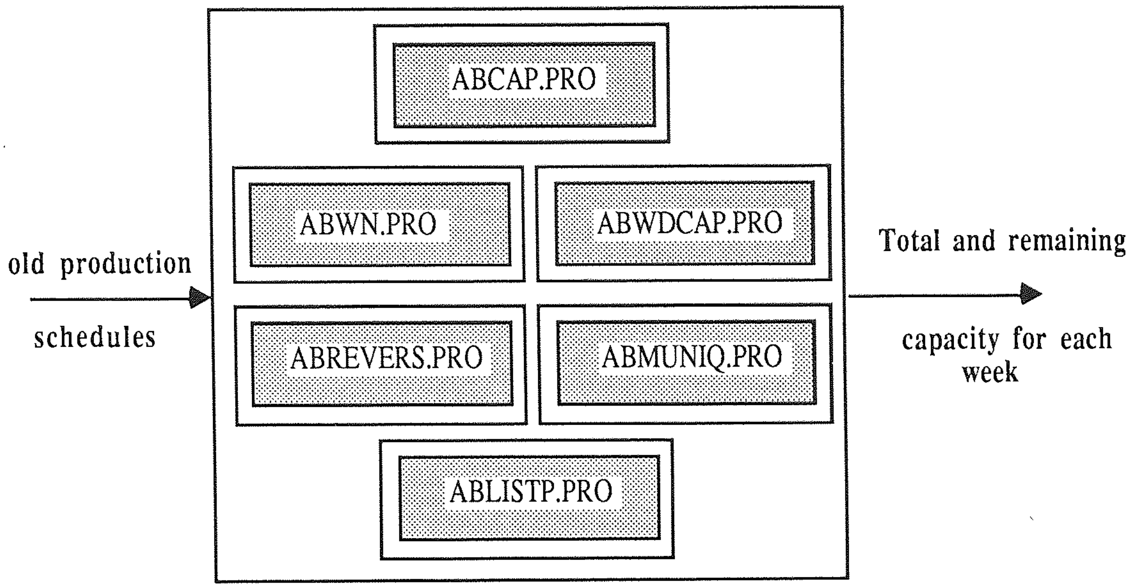



Figure 8.18: The modules used to find remaining capacity

Once the list of week numbers for scheduled orders exists, the total capacity for each week is then determined by finding the number of working days by executing module ABWDCAP.PRO. The used capacity is then determined by computing the total weight of scheduled orders in a given week. The difference between the total and used capacity is then saved as the remaining capacity for that week. The format of output from this module is shown in Appendix 5, figure A5.2.

(2) ABSCHPRO.PRO

This module is designed to include new orders for manufacture in the production schedule based on the availability of manufacturing capacity. Knowing the total and remaining manufacturing capacity it executes the various sub-modules as shown in figure 8.19 to update the master file of orders which can be used to revise the production schedules. The functions of various sub-modules are described briefly below.

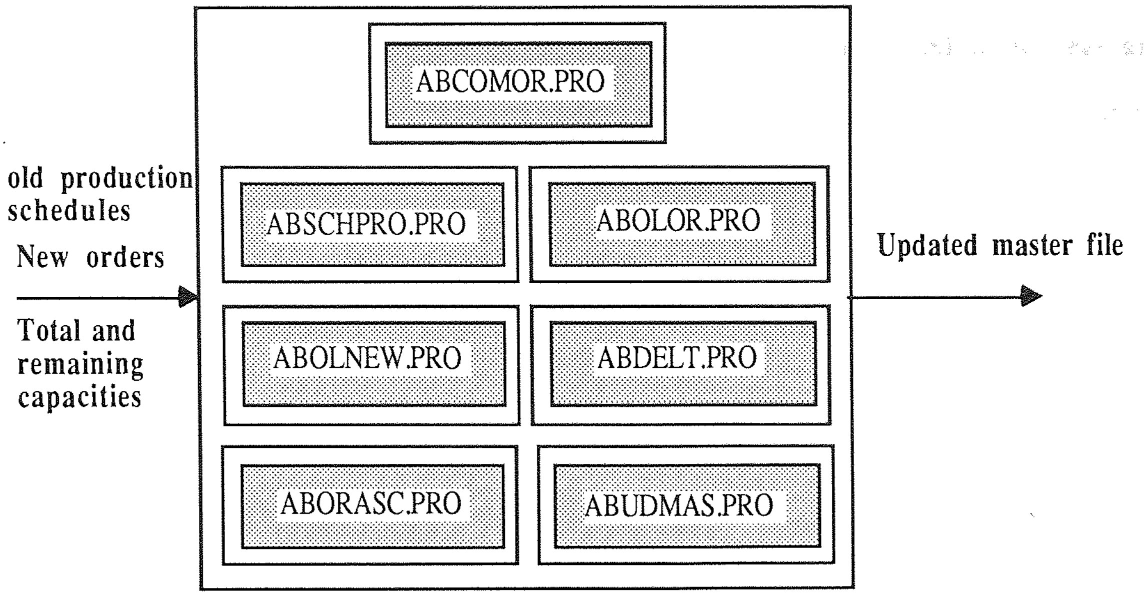



Figure 8.19: Various sub-modules called by ABSCHPRO.PRO to include new orders

(1) ABCOMOR.PRO

In order to exclude the revision of completed orders from the production schedule, this module takes the works order number of completed orders and eliminates them from the system.

(2) ABOLOR.PRO

This module copies the old orders from the production schedules for a particular week number and saves them in a temporary file 1. It reads the group number for those orders and communicates to the next module so that the new orders of that group can be included in that week.

(3) ABOLNEW.PRO

Knowing the group number, week number and the remaining capacity of that week, this module decides how many new orders of that group can be included in the week to utilise the remaining capacity. The new orders which can be included are copied and saved together with old orders in the temporary file 2.

(4) ABDELT.PRO

New orders which are included to utilise the remaining capacity are deleted from the new order file so that they cannot be considered again.

(5) ABORASC.PRO

The inclusion of new orders in the old orders may disturb the ascending arrangement. This modules arranges the old and new orders from temporary file 2 into temporary file 3.

(6) ABUDMAS.PRO

This module first eliminates the old orders of that week from the master file and modifies the master file by including the contents of temporary file 3. Therefore, the master file now contains the old and the new orders which can be manufactured in that week.

The main module ABSCHPRO.PRO repeatedly executes the sub-modules (2-6) for every week number for which the old orders exist in the production schedules and every time new orders are included and master file is updated. This file then can be used by the module ABORDAT.PRO to estimate the starting and completion dates and the result is saved as a revised production schedule.

### 8.5.3 REVISION OF PRODUCTION SCHEDULES AFTER A BREAKDOWN

In case of a breakdown the expected starting and completion dates in the schedule are no longer valid and the schedule has to be revised. In this procedure, first the completed orders are eliminated from the master file and then module ABORDAT.PRO is executed which estimates the starting and completion dates for the remaining orders in the master file.

### 8.5.4 REVISING THE SCHEDULE TO UTILISE FULL CAPACITY

The module ABORDAT.PRO estimates the starting and completion dates based on the policy of allowing manufacturing capacity of one week to each group, as discussed in section 8.5.1. The drawback of preparing production schedules based on such a policy (discussed in section 5.3.10.4) is that the schedules are unrealistic because the orders for a particular group may not be sufficient to utilise the full week capacity. It was suggested that, in such a case, the orders of the next week should be moved backward in order to utilise the available capacity.

The module ABCDAT.PRO is designed on the basis of such a policy. The working of this module is similar as that of ABORDAT.PRO described in section 8.5.1. The difference is that if the capacity is available, and no more orders of a group exist to fill this capacity, then it moves the orders of the next group to utilise the remaining capacity. It estimates the new expected starting and completion dates and repeats the process for every order in the production schedules prepared on the policy of allowing one week capacity. The revised schedules do not then contain any unused capacity gap and are more realistic. The difference can be seen by comparing the original with the revised schedule as shown in Appendix A5 figure A5.1 and A5.3.

### 8.5.5 MATERIAL REQUIREMENT

Every record in the production schedule contains the material designation number and billet size. The production schedules can be used to find the actual material requirement in order to place the purchase orders for the material.

The module ABMAT.PRO is designed to find the material requirement from the production schedules and is able to convey the following useful information to the user:

- The requirement of each material type per week
- The requirement for each size of every material type per week
- The grand total of all the material type and sizes per week.

The format of a partial output from this module is shown in Appendix A5 figure A5.4.

### 8.5.6 GRAPHICAL VIEW OF OVERALL CAPACITY STATUS

In order to visualise the overall status of manufacturing capacity in the mill, the module ABBARGRAPH.PRO has been implemented. The module first executes ABCAP.PRO which determines the total and used capacity for the weeks in which the orders have been scheduled. Using the numerical values of the capacities, it constructs 3-dimensional bar charts showing the proportion of total and used capacity. Such bar charts are shown in Appendix A5 figure A5.5.

### 8.5.7 DISPLAYING SCHEDULED ORDERS

The module ABWSOR.PRO is designed to display the orders which have been scheduled in a week and also gives the grand total of those orders.

### 8.5.8 ORDER ENQUIRY

Sometimes it is necessary to display the details of a particular order, such as expected starting and completion dates. The module ABQUERY.PRO prompts the user to enter the works order number and displays the required detail. A screen of order enquiry request is shown in Appendix A5, figure A5.6.

# CHAPTER 9

## APPLICATION AND VALIDATION OF THE SYSTEM

### 9.1 INTRODUCTION

KBS-SETUPP (Knowledge-Based System for SEamless TUbe Process Planning) is the generic name given to the system which is a collection of sub-modules described in Chapter 8. The coherent application of KBS-SETUPP to generate process plans, production schedules or rolling programme and its optional capabilities remain to be shown and validated.

In this chapter, the test runs of the system KBS-SETUPP are presented to accomplish the tasks of discrete and batch orders process planning for the manufacture of seamless tubes. These test runs are based upon the knowledge which the system possesses and are compared with their equivalent actual records obtained from the company. Such a comparison is a basis for the demonstration of the logical correctness of the system as well as the verification and validation of the system generated outputs. Other optional capabilities of the system are then demonstrated and their usefulness is discussed. Finally, the way in which the system can be used for the generation of process plans for cases in which the necessary domain-specific knowledge does not exist is demonstrated together with the method of extending and modifying the knowledge-base. Such a facility is of the utmost importance in giving the system flexibility so that it can be adapted with changing requirements.

## 9.2 SYSTEM APPLICATION FOR CFS TUBES PROCESS PLAN

The executable version of the system KBS-SETUPP is installed on a hard disk and can be started by going into the directory and typing the word "SETUPP" at the DOS prompt "C:\prolog>". After going through the introductory screen, the system displays the main menu (Appendix A2 figure A2.1) from which a task can be selected.

The selection of a task from the main menu invokes the execution of related modules to perform the overall task. The order of the execution of modules depends upon the selected task which is controlled by the User Interface. Each module, when executed, informs the user by displaying a message as to which task is being performed and prompts the input of additional information.

During the execution of each module, a line menu (the last line of the screen) is displayed, from which the user can select a choice of either continuing or aborting the session. In case the user wants to continue the session, the next related module is called which performs its sub-task and at the same time, the line menu is refreshed with a message giving the detail of that task. However, if the user wants to abort the session, after giving a warning of an uncompleted task, the session is terminated and the system displays the main menu. The screen above the line menu enclosed in a window can be used for the system-user dialogue where the decisions taken by the system are communicated to the user and their validity is confirmed. If system decisions are to be changed because the user does not agree with them, the system prompts the user for his version of decisions and instead of the system's decisions, the user responses are saved.

In order to demonstrate that how KBS-SETUPP generates process plans, an example for the manufacture of CFS tubes is considered. Since the generation of a process plan for CFS tubes also contains a process plan for hollow manufacture, such an example will be sufficient to demonstrate the system capability in the generation of a process plan for CFS as well as HFS tubes. Suppose that a quantity of 100 tubes is to be manufactured to BS 6323: Part 4. The material to be used is CFS 3A and the tubes are required "AS DRAWN" termed as "BK" under the specification number which does not require any finishing heat treatment. The finished tubes dimensions are to be 19.05 mm diameter, 2.02 mm thick and 3.04 m long. It is further supposed that there is no additional requirement for such tubes. These tubes can be given a part code number "A/0750/0000/080/aba/10" to represent the required dimensions and characteristics.

Selection of a choice of "process planning for CFS tube" from the main menu invokes the first module "CODINTERP.EXE" which displays the line menu to obtain the user's response for continuing or aborting the session. In the case of continuing the session, the line menu is refreshed with a message "interpreting part code" to give the user an idea of the sub-task being performed. Then in the dialogue area of the screen the user is asked to input the part code number, works order number and the quantity of tubes to be manufactured. The module checks the validity of the part code number, interprets the information being communicated and prepares the order detail. After completion of the sub-task for "preparation of order detail" the next module is called and in the case of the user response to continue the session, the second sub-task is performed. The required order of execution of sub-modules (function of sub-modules are described in chapter 8) for preparation of the process plan for the manufacture of CFS tubes is as follows:-

(1) CODINTERP.EXE
(2) HOLBILSEL.EXE
(3) PRSASEQH.EXE
(4) TSAOPTIM.EXE
(5) TOLERAN.EXE
(6) PASSN.EXE

(7) UPLDIES.EXE

(8) ALTSCH.EXE

(9) BESTSCH.EXE

(10) ANNEAL.EXE

(12) STADL.EXE

(13) CDMOPERS.EXE

(14) The process plan formatting programs as discussed in sections 8.3.6 and 8.4.8

During the generation of the process plan for the above example, the system-user dialogue strung together is shown in appendix A6 figure A6.1. It can be seen that the dialogue is mostly concerned with communicating the decisions taken by the system to obtain the user response about their acceptability.

The details of process plan generated by this session are shown in appendix A3, figure A3.1 to A3.9.

## 9.3 VERIFICATION/VALIDATION OF PROCESS PLAN

The capability of the system KBS-SETUPP to generate the process plan for an example part was demonstrated in section 9.2 while its validity is remain to be shown. Such a plan can be validated either by an expert in the field, or from published work or by comparing with manually prepared plans for the actual production in a company in which the system will eventually run. The availability of company-based plans (Appendix A6, figure A6.2 and A6.3) which are manually prepared using past experience and knowledge of products and machine capabilities, provides a sound basis for the validation of the KBS-SETUPP generated process plan.

Figure A6.2 shows a "plan form" for the manufacture of hollows which contains two sections. Section 1 contains the customer order details such as Customer Part No. (part code), tube dimensions, specification number and the price details to be filled in by the Order Processing and Sales Departments which is similar to the order detail (figure A3.1) prepared by KBS-SETUPP where the price detail is not included.

The process planning details are mainly in section 2 of the "plan form" which is to be completed by the production planner and the technical staff concerned based on experience. In section 2 of the "plan form" a provision is available for completion with the required tool sizes and left for the decision of the mill supervisor. In the same section, blanks are provided for the week number in which the job can be rolled to be filled in by the production planner based upon the available manufacturing capacity of the mill. The 'plan form' does not contain any provision for the operation sequence and inter-operation workpiece details, optimal billet length, optimal bar size from which the billets are to be cut to minimise the scrap and maximise resources utilisation. All these important decisions are taken by the mill supervisor on ad hoc basis which may or may not be optimal.

Comparison of available entries in the "plan form" (figure A6.2) with the KBS-SETUPP generated details (figures A3.1-A3.6) on hollow manufacture (such as material detail, hot mill set-up and tools, standard hollow size and the operation sequence for hot mill) shows that:

- decisions taken by the system regarding hollow size, billet size, number of passes required to reduce the hollow to finished size and the selected bench are valid and exactly the same as provided in the company-based plan.
- the system maximises the resources utilisation by planning an optimal length of 12.3 m as compared to 9.6 m in the company-based plan, a decision not only valid but improved.

- the material details generated by the system gives full details of billet length and weight, material type, number of tubes per billet and total weight of the job, while these details have to be worked out manually in the company-based plan.
- the system selects the necessary tools and machine parameters which are valid because the rules for the selection are compiled from actual practice, while in the company-based plans these decisions are left to the mill supervisor. In the case of his unavailability, inexperienced people may not be able to select appropriately.
- the system provides full details of billet cutting in order to minimise the material scrap, and the operation sequence with inter-operation workpiece detail. The validity of the operation sequence can be proved from basic tube manufacturing technology. In the company-based plan these decisions are to be taken by the people concerned during the actual production.

Figure A6.3 shows a company-based "plan form" for the manufacture of CFS tubes in which the tolerance and test details are filled in by the Test/Inspection Department by consulting the tolerance manual, while the tube drawing schedule i.e. the die and plug size for four different passes, are filled in by the production planner based on the knowledge of available tools. The "plan form" does not contain any provision for the operation sequence which is to be decided in actual production by the Foreman.

The comparison of the company-based plan (figure A6.3) with the system-generated process plan (operation sequence, tool sizes and process parameters in figures A3.7 - A3.9) shows that:

- the tube drawing schedule, i.e. die and plug sizes selected for the passes, are valid and exactly the same as those given in the company-based plan form. The tolerances and tests ought to be same because of the same specification number.

- the system capability of generating alternative schedules and then selecting a best schedule based on an even distribution of area of reduction over the available passes always ensures a best schedule. In the company-based plan, the combination of plug and die sizes to be used, depends upon the production planner, therefore the tube drawing schedule may not be as consistent as that generated by the system.
- the company-based plan does not contain any operation sequence which is decided by the foreman, while the system generates an operation sequence by selecting the appropriate tube preparation, inter-pass annealing and other finishing processes and sequencing them by using the operation precedence relationships.
- the system is also capable of validating the tube-drawing schedule by computing the process parameters and then comparing them with the drawbench capability. The computation of these process parameters has already been validated by comparing with published work in section 6.7.

The above comparison has not only demonstrated the validity of the system-generated process plan but has also shown that such plans are more detailed, containing full information on the operation sequence, clear instructions and set-up procedures. In addition, the system validates the tube-drawing schedule by computing the process parameters and comparing with the drawbench capacity which means that a drawbench cannot be over loaded.

Moreover, KBS-SETUP, being a generative system, prepares process plans from scratch for every job, which is more consistent because of the same logic being applied each time. The preparation of process plans by the system has the additional advantage of speed compared with manual preparation.

## 9.4 SYSTEM APPLICATION FOR PRODUCTION SCHEDULES

The preparation of production schedules is closely linked with process planning in order to implement the optimisation strategy of hollow manufacture, as discussed in section 5.3, which reduces mill set-up time. Production schedules can be prepared by first selecting the task " production schedules for hot mill " from the main menu which invokes a lower level menu from which a desired task can be selected. These sub-tasks have been discussed in sections 8.5.1-8.5.8. The production schedules generated by the system for dummy orders (assumed for the demonstration) are shown in Appendix A5, figures A5.1 and A5.3.

The company-based rolling programmes are prepared by the strategy, as discussed in section 4.6, where a week number, in which the tubes are to be rolled, is allotted for every order and then all the orders and related information are stored. Orders are then sorted using a relational database program and rolling programmes are prepared as shown in Appendix A6, figure A6.4. Comparison of company-based and system-generated production schedules shows that:

- the system, in addition to giving a rolling week number, automatically estimates the starting and completion dates for every order while the company-based program contains only the week number allotted manually by production planner. The validity of estimated start and completion dates is not doubtful because the estimation is carried out on the basis of actual manufacturing capacity.
- in the case of a breakdown, the system can revise the production schedules automatically in less time (in a matter of minutes) while the revision of company-based schedules is difficult since each order has to

be given a new week number in which it is to be rolled.

- the system can automatically include new (unscheduled) orders while the production planner has to compute the forward load summary to include new orders.
- the system automatically retrieves the holidays and reduces the available capacity accordingly. Moreover, every time the schedules are generated, it revises the capacity status and updated information is available.

Comparison shows that the system KBS-SETUPP is automatic, a more flexible and powerful tool and can react more rapidly to dynamic changes in the preparation of production schedules.

## 9.5 PRODUCTION SCHEDULE RELATED OPTIONAL CAPABILITIES

The optional capabilities, although not directly related to the process planning function, are used to complement the system and consist of:

- to estimating the material requirement
- giving a graphical view of the capacity status
- listing the schedule orders
- order enquiry

These facilities have been provided to enable the user to plan the purchase of material needed against orders, view the used and available capacity status for further planning and help in tracing a particular order or listing of the production schedules. Any of the above facilities, which have been elaborated in chapter 8, can be accessed from the production schedule menu.

## 9.6 EXTENSION OF DECLARATIVE KNOWLEDGE-BASE OF THE SYSTEM

In section 7.2, it was discussed that the system can be used for the generation of process plans for the manufacture of seamless tubes under British Standard because only such related information has been included in the knowledge-base. The manufacture of seamless tubes under other Standards such as ASTM and DIN require similar processes, the only differences being in the information related to specified tolerances, tests to be carried out, materials to be used and their properties, special requirements and the tube mechanical properties to be achieved by heat treatment. Since the organisation of knowledge in the system is such that information is always required in the form of facts as a declarative knowledge (section 7.5) and the system allows the extension of declarative knowledge-bases with the help of the knowledge-acquisition module, therefore such information can be represented without disrupting the existing knowledge related to British Standard. Moreover, since the problem-specific and control knowledge are the same ( i.e. method of manufacture is same) the system can be used for the generation of process plans for the manufacture to other Standards.

In order to demonstrate the extendibility of declarative knowledge and the preparation of a process plan on the basis of this new knowledge, an ASTM specification, ASTM 210/A 210M-88 (144, 145), has been chosen. The information related to dimensional tolerances, tests, materials to be used and properties can be written in the form of facts into the associated knowledge-base files. The knowledge-acquisition module takes the information from the user and appends the associated selected file with the facts in a form shown partially below.

Tube specification knowledge-base file

```
specification('K',"ASTM 210/A 210M-88")
```

Material designation knowledge-base file

material_designation("ASTM 210/A 210M-88",'A',"GRADE A-1")

material_designation("ASTM 210/A 210M-88",'A',"GRADE C")

Material properties knowledge-base file

mat_properties("GRADE A-1","Medium-carbon steel","0.27% carbon max",
[0,0.27,255,0.2,415])

mat_properties("GRADE C","Medium-carbon steel","0.35% carbon max",
[0,0.35,275,0.2,485])

Tolerances and tests knowledge-base file

tolerances("odtol","ASTM 210/A 210M-88","CFS","_","R",[],[0,25.4,0.1,0.1])

tolerances("odtol","ASTM210/A 210M-88","CFS","_","R",[],[25.4,38.1,0.15,0.15])

tolerances("odtol","ASTM 210/A 210M-88","CFS","_","R",[],[38.1,50.8,0.2,0.2])

tolerances("odtol","ASTM210/A 210M-88","CFS","_","R",[],[50.8,63.5,0.25,0.25])

tolerances("odtol","ASTM 210/A 210M-88","CFS","_","R",[],[63.5,76.2,0.3,0.3])

tolerances("wall","ASTM 210/A 210M-88","CFS","_","OD/W",[],[0.1,0.1])

tolerances("straightness","ASTM 210/A 210M-88","CFS","_","_",["1:666"],[])

olerances("test","ASTM 210/A 210M-88","CFS","_","_",
["TENSILE 415 N/mm$^2$ MAX","YIELD 255 N/mm$^2$ MIN", "ELONG 30% MIN IN 50.8 mm gauge length"],[])

The manufacture of any tubes under ASTM 210/A 210M-88 can then be given an appropriate code number and the system can be used for the generation of a process plan as discussed in section 9.2 using the new information in the knowledge base. A print-out of the process plan generated by the system based on new knowledge is shown in Appendix 6 figure A6.5 and demonstrates the capability of the system KBS-SETUPP to extend its knowledge for seamless tube manufacture under the Standards other than BS.

It might be useful to add that individual modules in the system can also be used to obtain advice in a certain context. For example, the question of how many passes are required to reduce a given hollow to a required size can be answered by the execution of module PASSN.EXE. The user has to know the input file to the module in order to change its data according to requirement and the function of each module.

# CHAPTER 10

## DISCUSSION, CONCLUSION AND FUTURE WORK

### 10.1 GENERAL DISCUSSION

Manufacture of seamless tubes is a multi-stage production process and, in the initial stage of hollow manufacture, either rotary or non-rotary processes can be used. Although the present work is specifically related to rotary processes, it was thought to be necessary at the initial stages of the work to discuss briefly other methods such as welded and non-rotary processes, in order to give a background of tube manufacture in general.

The function of process planning is central to any manufacturing concern and there have been concrete efforts to automate it. The reasons for automating the process planning functions are two-fold, i.e. on one hand the aim is to link other technologies such as CAD and CAM to fully automate the whole process and on the other to speed up the preparatory work of the generation and revision of process plans for actual production. New approaches, such as variant and generative, have emerged to automate the process planning function and recently the application of knowledge-based systems and their potential have been established in the field. However, these efforts have been mostly in the area of machining and little attention has been paid to other manufacturing fields. The present work was intended to exploit the established potential of knowledge-based systems for the generation of process plans for seamless tube manufacture.

The decision to select the knowledge-based technique for the development of KBS-SETUPP was made on the basis of several factors. Seamless tube manufacturing is a long-established industry and relies heavily on experienced personnel who possess experience through long association with the industry. Experienced-based skill is usually non-algorithmic and can be better represented in the form of independent rules for which knowledge-based systems are most suitable. Secondly, the current application was intended for a job shop environment, where each job of a different variety requires different raw material, tooling, set-ups, tolerances to be achieved and process parameters. This means that there is always a need to incorporate additional knowledge in the system as it become available. Conventional systems have the drawback that modification to those programmes is severely limited while knowledge-based systems allow the extension of knowledge very easily. Therefore the choice of a knowledge-based technique for the development of a system for process planning was thought to be good.

The knowledge required for process planning in the domain of seamless tube manufacture is hardly available as such. The reason for unavailability of such knowledge is due to the fact that, firstly, there has probably been no attempt to automate the process planning function and, secondly, most of the domain-specific knowledge in form of heuristic rules which apply to a particular installation is unpublished and remains to be as a personal asset with the associated people. Therefore the collection of such knowledge relied heavily upon the domain expert, the analysis of the existing manufacturing records and relevant Standards for seamless tube manufacture. The capturing of an expert's skills is mostly done by interviewing and/ or observing the expert solving real problems. The captured skills were then translated in the form of facts and rules to be represented in the knowledge-base. The other method of knowledge-acquisition which has been extensively used in the present work is to analyse the existing manufacturing records in order to compile the knowledge in the form of facts and rules. Two techniques; visual observation and a modified form of Quinlan algorithm, have been used for the compilation of rules from the manufacturing records data. The inclusion of expert skill and the knowledge compiled from the existing records have made it possible that the system-generated process plans mostly correspond with the actual plant practice and that the level of system performance is mostly comparable with the expert.

The system-generated process plans do not merely correspond with practice, but an attempt has been made to optimise the manufacture of seamless tube wherever possible. The strategies for the optimisation of discrete orders for hollow manufacture based upon maximum utilisation of resources and materials aim to best output within the prevailing constraints.

There have been some attempts to rationalise tube-drawing schedules based on an optimum area of reduction per pass. Such attempts were mostly in the pre-computer era based upon developing a nomograph from which an optimum tube-drawing schedule and associated tools can be selected. It has been observed that such optimum schedules, sometimes, do not correspond with the actual plant practice due to a multitude of reasons. First, these nomographs require the availability of an infinite number of hollow sizes and die and plug sizes which are not available in the practice. Secondly, the optimum area of reduction per pass may not be achievable due to inadequate tools, lubricant or it is not desirable due to the final properties to be attained. The strategy used in the present work to create tube-drawing schedule is based upon the actually available hollow, die and plug sizes and, on the basis of available resources, a number of alternative schedules can be generated. Then the best schedule can be selected from the alternatives which, on the one hand, is based on the available resources in practice and, on the other hand, ensures that reduction of area per available pass is evenly distributed.

The best schedule thus selected had to be validated in terms of drawing load so that the required load would not be beyond the drawbench capability. The existing mathematical models require some parameters (coefficient friction or effective mean yield stress for the drawn tube) to be determined experimentally. These models, therefore, can only be simulated in the program if the user of the system provides these values. However, these parameters are difficult to obtain in practice and therefore, the user may be unable to provide them to the system. In such a case, the performance of a program based on such models would be of little use. Therefore, there was a significant need to propose a mathematical model which can predict the process parameters which are comparable with the experimentally determined values and can be programmed directly in the system.

A mathematical model has been proposed to predict the equivalent strain from which the effective mean yield stress can be determined. The model requires the material properties such as the constant "c" and the index of hardening "n" for the undrawn material which are available for most of the materials involved. The comparison of predicted values of critical process parameters, such as drawing load, by the model with experimental values published by other researchers has shown not only an acceptable level of discrepancy (3.7 % - 8.5 %) but also that the actual values of drawing load are over-estimated. Such over-estimates eliminate the risk of any overloading of a particular drawbench and is desirable for the safe validation of a selected tube-drawing schedule. Thus the model ensures a factor of safety in validating the tube-drawing schedule.

## 10.2 DISCUSSION ON KBS-SETUPP

The development of KBS-SETUPP has been of an incremental and exploratory nature. The system consists of many modules as described in Chapter 8, each being designed for a specific task and tested against the actual data. The modular structure of the system helped in debugging and testing the individual module and successive refinements were carried out to achieve a better performance each time. All the modules were than linked together using the Turbo-Prolog concept of "project" to form a single executable system. However, it was soon realised that although each module is being executed perfectly well, the linked system, when loaded, exhausts the limited memory of the Personal Computer (640K RAM) and causes malfunctioning. In order to overcome this difficulty, each module was compiled separately and the order of execution was left to be controlled by user interface program. In this way the individual module was called whenever needed to perform a specific task rather than having all the modules available in the memory all the time.

The user interface program of KBS-SETUPP, apart from controlling the order of execution, serves the purpose of communication between user and system through pop-up menus as discussed in section 8.2.1. Although of a simple and elementary type, it serves the purpose for the present application by reducing the probability of errors and being user-friendly.

The knowledge-acquisition module of KBS-SETUPP, being operative only on lower level declarative knowledge, can be used for the automatic transfer of knowledge in the form of facts. The usefulness of this module in the transfer of new knowledge into the knowledge-base which was then used for process planning has been demonstrated in section 9.6.

One characteristic associated with the knowledge-based system which many regard as essential is to explain its line of reasoning by displaying the comprehensive account of its action taken during the execution. The explanation facility, usually, gives the novice user a response to "why" and "how" questions. However, such a facility has not been developed for KBS-SETUPP because of the following :

- the explanation facility may reduce the response time of the system because of keeping track of triggered rules and this may effect the usefulness of the system.

- the explanation facility is required either for debugging or to assure the that the system decisions are logical, or to educate novice user. However, the current system was intended to support the expert in the decision-making process, therefore, such a facility was thought to be unnecessary.
- in KBS-SETUPP many decisions are to be taken on the basis of the result of numerical computations, therefore it is difficult to record and play back the events of numeric computations.
- due attention was given to the development of a useful utility to be used in practice but this involves a large volume of work and there was therefore a little time remaining to develop the explanation facility.

Some observations need to be discussed in the context of the use of Turbo-Prolog for the development of KBS-SETUPP. The language, being user-friendly, can be learned and applied to actual situations more quickly than conventional languages. The characteristics of Prolog, such as rapid prototyping and ability to extend the prototype, provide an incremental and exploratory approach which was very helpful at the start of the project. The availability of Prolog's own inference engine which performs unification by pattern matching, determines the order in which to scan the rule relieves the programmer from worries that how the inference mechanism and search technique should be developed and this might be the reason that the Prolog code tends to be shorter as compared to conventional languages. The provision of database, control and arithmetic predicates, list structures, graphic routines and the tool box with the new version, ease the tasks of knowledge engineer in developing a specific application. Although the opponents of Prolog criticise the depth-first search mechanism which is rigidly controlled by the interpreter leaving a limited control for the programmer, its advantages, however, outweigh any such disadvantages.

The usefulness of KBS-SETUPP depends upon many parameters such as the validity of its decisions, the speed of solution of a given problem, the quality of its knowledge, the user-friendliness and, most importantly, the level of performance in the domain of application. The level of performance of a system can be tested either by an expert, who must devise some examples for the system and then compare the system's recommendation against his own, or, most importantly it must be evaluated for capability by the end user.

The performance evaluation of KBS-SETUPP, discussed in Chapter 9, which performed on the basis of company-based plans and it was stated that those plans provide a sound basis for such a comparison. It was shown that the system-generated plans are not merely valid but are more comprehensive, consistent and complete. Moreover, the system recommendation gives useful instructions to the user regarding operation sequence, set-up details, tooling requirement and inter-operational details. The system also optimises the decisions regarding maximum utilisation of available resources, minimisation of scrap and reduction of overall set-up time. The production schedules, in addition to estimation of start and completion time for each order, can be revised automatically either after a breakdown or to include new orders. The optional capabilities of the system such as material requirement, order enquiry and latest manufacturing capacity status are the important factors required at the plant.

## 10.4 CONCLUSION

The work reported in this thesis shows that the established objectives have been achieved successfully and the following conclusions can be drawn:

1. KBS-SETUPP being a generative prototype system is the result of current research and is capable of generating process plans for the manufacture of seamless steel tubes in the specific plant for which it is designed.

2. The process plans generated by the systems are valid, consistent, comprehensive and moreover corresponds to actual practice in the plant. The comparison of the system's output against manually prepared process plans for the actual production provides reasonably good results and gives the desired confidence in the practicability of the system.
3. The speed at which process plans are generated by the system has the additional advantage of time-saving and the automatic generation of plans, based on coded knowledge, requires minimum intervention so that an unskilled user can use the system easily .
4. System capability for overwriting its own decisions with the responses provided by the expert make it more flexible. The built-in facility for editing the process plan is a further help whenever necessary.
5. The inclusion of optimisation strategies in discrete order process planning such as maximum utilisation of manufacturing resources and minimisation of material scrap during the billet cutting process promotes the economical tube production.
6. The system is capable of preparing and revising the production schedules for hollow manufacture automatically. The strategy of grouping the orders requiring a similar setting of the mill and rearranging the orders of a particular group in the most economical way of manufacture reduces the overall set-up times of the mill. In addition, the system estimates the start and completion dates of individual orders for hollow manufacture based on available manufacturing capacity, which can be of great help in the planning of the drawing programmes, since the availability date of hollows has been established.
7. The supportive facilities of the system, such as user-interface and knowledge-acquisition modules, although of an elementary type, facilitate the execution of the system and the updating of the declarative knowledge in the form of facts.

8. The strategy of first generating the alternative tube-drawing schedules based on the available tools and then selecting the best schedules achieves an even distribution of reduction of area.
9. The optional capabilities related to production schedules such as estimation of material requirement and the latest manufacturing capacity complement the process planning function and provide valuable information to the user.
10. The organisation of knowledge at different levels (i.e. declarative knowledge in form of facts at lower level, procedural in middle and control at top), the modular structure of the system and the transparency of the rules (i.e. easy-to-read syntax of the rules) ensure the easier modification and extension of the knowledge.

Some complementary conclusions can be drawn, such as:

1. The current research has made it possible to gather and collate knowledge in the context of process planning for the manufacture of seamless tubes from diversified sources such as domain experts, existing manufacturing records and mill practice and relevant Standards etc. The collection of the knowledge in form of knowledge-base of KBS-SETUPP can be used as a reference book and the system as a whole can be used as "knowledge delivery system" for the plant.
2. A significant contribution has been made to the study of the mechanics of fixed plug tube drawing by proposing a mathematical model and then simulating it in the system in order to predict the equivalent strain and the effective mean yield stress, on the basis of which, other parameters such as drawing stress, drawing load and its different components such as load required for useful deformation, redundant deformation and frictional load, and the power requirement can be established for a tube-drawing schedule. The estimated process parameters values by the proposed model are in close

agreement with the experimentally determined values by other researchers,at least for the same material (0.12 % carbon steel). Moreover, the model is on the conservative side by over-estimating the drawing load, thus giving a factor of safety for the process. The estimated value of drawing load, therefore, can be used for validating a selected tube-drawing schedule , eliminating the risk of over-loading a drawbench. Another advantage of the proposed model is the elimination of an experimental step for the determination of effective mean yield stress. However, generality of the model for other materials cannot be concluded without experimental evidence but it can be said that it can be used for a rough estimation of loads.

The system KBS-SETUPP can be used for generating process plans for actual production at least in a plant for which it is designed and it is probably a first step in extending the knowledge-based technique for process planning from the main stream of machining to seamless tube manufacture.

## 10.5 SUGGESTION FOR FUTURE WORK

KBS-SETUPP is a prototype system in which process planning problem associated with seamless tube manufacture based on rotary processes, a small field in tube manufacture in general, has been addressed. There are a number of other methods used for tube production such as non-rotary and welding processes, as discussed in Chapter 2. These other processes present enormous opportunities for further research in the application of advanced computational techniques for their automation in general. The fact that tube-manufacturing industries relied heavily upon personal experience in the past suggests a need for the application of knowledge-based techniques in particular so that the specific knowledge which varies from installation to installation can be gathered and represented in these systems. In the following section, first a few suggestions have been made for further research to extend the present version of KBS-SETUPP to make its usefulness more effective and then other areas of tube manufacture in general which require research are discussed.

KBS-SETUPP requires further extension of knowledge-base in the following areas:

- The present version of the system includes the BS specification and the relevant knowledge. A initiative is needed to gather and collate the knowledge related to other Standards such as DIN and ASTM. The inclusion of such knowledge will broaden the scope and usefulness of the system.
- KBS-SETUPP, at its present version contains a facility to create production schedules for hollows and establish the date of manufacture. Based on the availability date of hollows, similar facility is required to be developed to generate the tube-drawing programmes. This will make the system more complete and its usefulness will increase.
- The system generates the operation sequence for the cold drawing plant but the operation details have not been included. There is scope for further research to enhance the performance so that the system can answer questions such as which lubricant is economical and gives better results, what should be the length of the tagged end, how the pickling, annealing and other finishing process must be carried out etc.
- The system is capable of recommending a tool size but since the tool material, its composition and geometry effect the hot and cold working operations, an effort is needed to gather knowledge regarding the effect of tool parameters on manufacture. The inclusion of such knowledge will enable the system to recommend tools associated with best performance.
- Seamless tube mills employ different processes i.e. some mills may have a Mannesmann piercer while others may use a cone type piercer. Similarly,

cold drawing plants may use different process of drawing such as fixed plug, mandrel or sinking. Modules for such processes need to be developed and the user should be able to select those processes which are to be used in a particular installation. Such a system may then be a comprehensive and can be used in any seamless tube manufacturing installation.

The above discussion of future work was directly related to seamless tube manufacture using rotary processes. Similar systems are required for:

- Process planning for the manufacture of seamless tubes using non-rotary processes
- process planning for welded tube manufacture

The welded tube manufacture can be further subdivided to provide specific applications for different techniques. Welded tube manufacture mills usually contain their own facilities of strip making and cold forming into tubes, therefore it can be said that there are many opportunities for the research.

Finally, all these modules grouped together will result in a "Knowledge-Based System for Tube Manufacture Process Planning" and individual companies may have a choice of selection of a module specific to their applications. Such a system may serve as an "Electronic Library of the Future" in the domain of tube manufacture for process planning knowledge.

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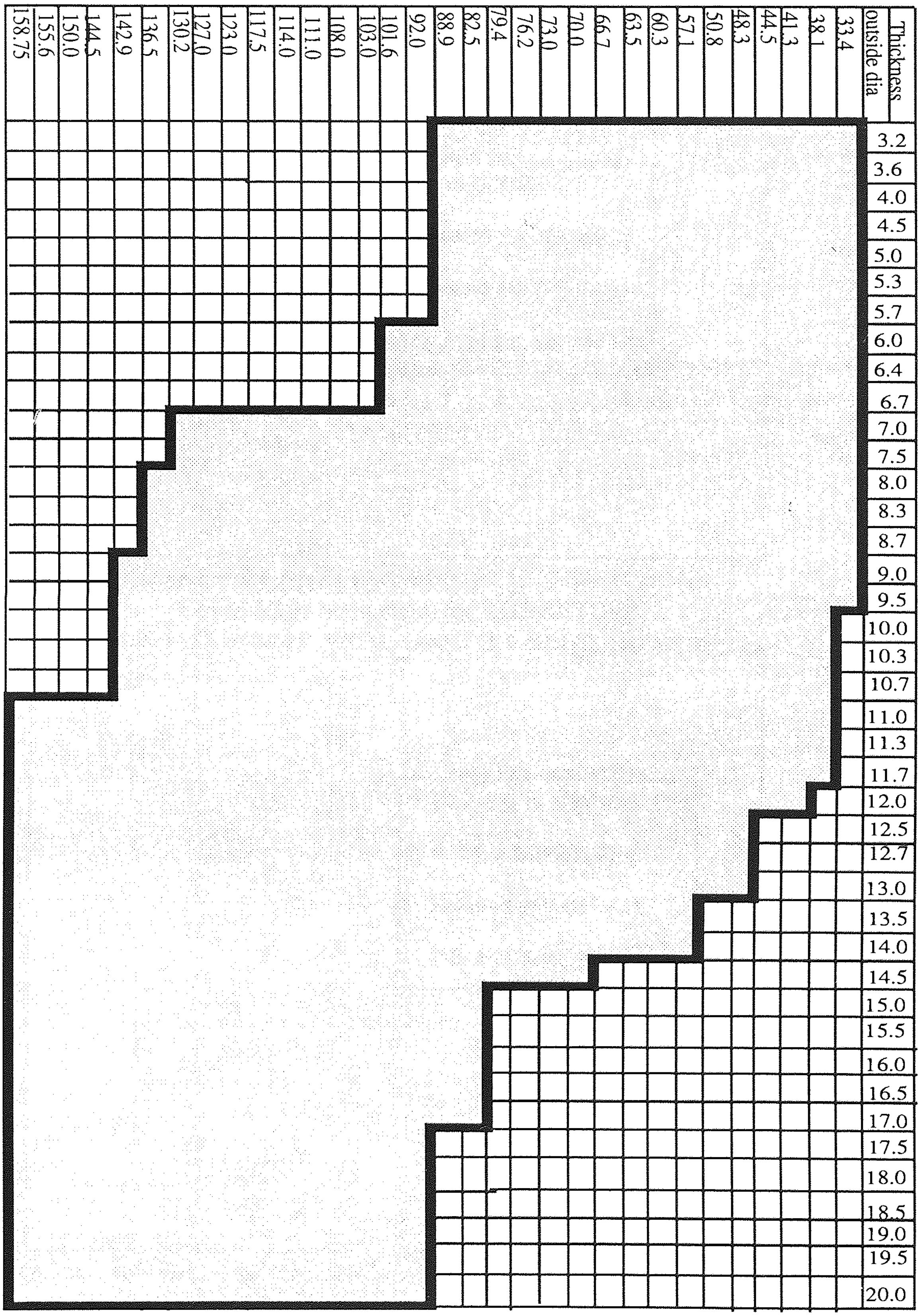
## Appendix A1: Standard products (hollow sizes)



## Appendix A2 - User Interface menu system

KNOWLEDGE-BASED SYSTEM FOR PROCESS PLANNING IN A SEAMLESS TUBE FACTORY

Main menu

1: DATA ENTRY TO DATABASE

2: PROCESS PLANNING FOR HFS TUBES

3: PROCESS PLANNING FOR CFS TUBES

4: PRODUCTION SCHEDULES FOR HOT MILL

ESC: Quit this menu -- Use arrow keys to select and hit RETURN to activate.

Figure A2.1: Main menu for KBS-SETUPP

KNOWLEDGE-BASED SYSTEM FOR PROCESS PLANNING IN A SEAMLESS TUBE FACTORY

KNOWLEDGE-ACQUISITION

1: ADD FACTS TO A DATABASE FILE

2: DELETE A DATABASE FILE

3: DISPLAY A DATABASE FILE

4: EDIT A DATABASE FILE

ESC: Quit this menu -- Use arrow keys to select and hit RETURN to activate.

Figure A2.2: Knowledge-acquisition menu of level 1

## Appendix A2 - User Interface menu system

```
KNOWLEDGE-BASED SYSTEM FOR PROCESS PLANNING IN A SEAMLESS TUBE FACTORY

                                   KNOWLEDGE-BASE FILES
                                   1: SPECIAL REQUIREMENTS
                                   2: TUBE SPECIFICATION
                                   3: DELIVERY CONDITIONS
                                   4: MATERIAL DESIGNATION
                                   5: TOLERANCES AND TESTS
                                   6: MATERIAL PROPERTIES
                                   7: TOOLS IN COLD DRAWING
                                   8: STANDARD PRODUCTS
                                   9: TOOLS IN HOT MILL

ESC: Quit this menu -- Use arrow keys to select and hit RETURN to activate.
```

Figure A2.3: Menu for selection of knowledge-base files for modification

```
KNOWLEDGE-BASED SYSTEM FOR PROCESS PLANNING IN A SEAMLESS TUBE FACTORY

                                   PROCESS PLAN OPERATOR
                                   1: PRINT PROCESS PLAN/DETAILS
                                   2: DISPLAY PROCESS PLAN/DETAILS
                                   3: EDIT PROCESS PLAN/DETAIL

ESC: Quit this menu -- Use arrow keys to select and hit RETURN to activate.
```

Figure A2.4: Menu for selection of print, display and edit commands

## Appendix A2- User Interface menu system

```
KNOWLEDGE-BASED SYSTEM FOR PROCESS PLANNING IN A SEAMLESS TUBE FACTORY

                    PROCESS PLAN/DETAIL
                    1: PROCESS PLAN FOR HOT MILL
                    2: ORDER DETAIL
                    3: TOLERANCES DETAIL
                    4: MATERIAL DETAIL
                    5: HOLLOW DETAIL
                    6: TOOLS DETAIL
                    7: OPERATION SEQUENCE DETAIL

ESC: Quit this menu -- Use arrow keys to select and hit RETURN to activate.
```

Figure A2.5: Menu to select process plan details for hollows

```
KNOWLEDGE-BASED SYSTEM FOR PROCESS PLANNING IN A SEAMLESS TUBE FACTORY

                    PROCESS PLAN/DETAIL
                    1: PROCESS PLAN FULL
                    2: ORDER DETAIL
                    3: TOLERANCES DETAIL
                    4: MATERIAL DETAIL
                    5: HOLLOW DETAIL
                    6: TOOLS DETAIL FOR HM
                    7: TOOLS DETAIL FOR CDM
                    8: OPERATION SEQUENCE HM
                    9: OPERATION SEQUENCE CDM
                    10:STRESS/POWER DETAIL

ESC: Quit this menu -- Use arrow keys to select and hit RETURN to activate.
```

Figure A2.6: Menu to select process plan details for CFS tubes

## Appendix A2 - User Interface menu system

```
KNOWLEDGE-BASED SYSTEM FOR PROCESS PLANNING IN A SEAMLESS TUBE FACTORY

                         PRODUCTION SCHEDULES
                   1: FRESH START OF THE SYSTEM

                   2:REVISION OF PRODUCTION SCHEDULES

                   3: LISTING OF SCHEDULED ORDERS

                   4: BAR DIAGRAMS OF CAPACITY STATUS

                   5: MATERIAL REQUIREMENT

                   6: ORDER ENQUIRY

ESC: Quit this menu -- Use arrow keys to select and hit RETURN to activate.
```

Figure A2.7: Production schedule menu of level 1

```
KNOWLEDGE-BASED SYSTEM FOR PROCESS PLANNING IN A SEAMLESS TUBE FACTORY

            PREPARE OR REVISE SCHEDULES
      1: ELIMINATION OF COMPLETED ORDERS

      2: ALLOW A WEEK CAPACITY FOR EACH GROUP

      3: SHIFT ORDERS TO UTILISE FULL CAPACITY

      4: RESCHEDULE USING POLICY (2)

      5: RESCHEDULE USING POLICY (3)

ESC: Quit this menu -- Use arrow keys to select and hit RETURN to activate.
```

Figure A2.8: Production schedules menu of level 2

```
KNOWLEDGE/DATA ACQUISITION

‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡
‡                                     ‡
‡ 1. To enter outside dia tolerance   ‡
‡ 2. To enter inside dia tolerance    ‡
‡ 3. To enter thickness tolerance     ‡
‡ 4. To enter straightness            ‡
‡ 5. To enter length tolerance        ‡
‡ 6. To enter test required           ‡
‡                                     ‡
‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡
Enter your choice? :

TO FINISH THE SESSION AND SAVE THE FACTS TYPE 'SAVE
```

Figure A2.9: Menu to select the desired dimension for adding tolerance information

```
KNOWLEDGE/DATA ACQUISITION

Enter your choice? : 1
Enter the spec:part no? 'BS6323:part3' : BS 6323:PART 4

Enter the finish? 'CFS/HFS' : cfs

Enter the catagory? (N.A enter'_') : _

Tolerance range or formula? 'F/R' : R

Enter the range 'min dia','max dia','+ Tol','- Tol'
Min dia: 30

Max dia:

TO FINISH THE SESSION AND SAVE THE FACTS TYPE 'SAVE
```

Figure A2.10: A dialogue to enter tolerances on outside diameter

## Appendix A2 - User Interface menu system

```
                          KNOWLEDGE/DATA ACQUISITION

****************************************************************
*      FOR NOMINAL DIMENSION X FORMULAE ARE:                   *

* 1: 1% (MAX=0.5MM)               2: 0.75% (MAX=0.5MM)         *
* 3: 0.5% (MAX=0.1MM)                                          *
* 4: 0.75% (MAX=0.1MM)                                         *
* 5: 25*I (I=0.45*CUBEROOT(X)=0.001X                           *
* 6: 40*I                         7: 100*I                     *
* 8: 160*I                        9: 250*I                     *
*10: pos:-Es/1000,neg:Es+25*I where Es=-5.5*X^0.41             *
*11: pos:-Es/1000,neg:Es+40*I   12: pos:-Es/100,neg:Es+64*I    *
*13: pos:-Es/1000,neg:Es+100*I  14: pos:-Es/100,neg:Es+160*I   *
*15: 1% (MAX=0.3)               16: 2% (MAX=1MM)               *
****************************************************************

 Enter the formula number:


TO FINISH THE SESSION AND SAVE THE FACTS TYPE 'SAVE
```

Figure 2.11: A menu to select a desired formula for the computation of tolerances

# Appendix A3 - Formatted process plan

```
      KNOWLEDGE-BASED SYSTEM FOR PROCESS PLANNING  SEAMLESS TUBE

PLANNER NAME: SIDDIQUE, M.             date: 13/8/1990      at: 12:53:6

                               PROCESS PLAN
********************************************************************************

              PLEASE NOTE: ALL DIMENSIONS EXCEPT LENGTH ARE IN MILIMETRE
                             LENGTH IS IN METRE
              ******************************************************


                               ****************
                               * ORDER DETAIL *
                               ****************


customer part number: A/0750/0000/080/ABA/10
works order number: 1234

outside diameter    : 19.050          inside diameter    : 14.986
wall thickness      : 2.032           tube length        : 3.048
specification       : BS6323          finish required    : BK CFS
total quantity      : 100
```

Figure A3.1: Order detail generated by KBS-SETUPP

```
                                     *********************
                                     * TOLERANCES DETAIL *
                                     *********************

Outside diameter:
*****************
Positive tolerance: 0.100      Negative tolerance: 0.100
Wall thickness:
***************
Positve tolerance: 0.203      Negative tolerance: 0.203
Eccentricity     : ["incl.ecc."]
Length :
********
Positive tolerance: 5.000      Negative tolerance: 0.000
Straightness:
*************
Straightness: ["1:666"]
Tests requirement:
*****************
1: Visual
2: Tensile
3: Flatten
4: Hydraulic (if required)
5: Test certificates (if required)
```

Figure A3.2: Tolerance detail generated by KBS-SETUPP

## Appendix A3 - Formatted process plan

```
‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡

        PLEASE NOTE: billet length in metre and billet dia in mm
        ‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡

                        ‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡
                        ‡ MATERIAL DETAIL  ‡
                        ‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡


Material specification       : CFS 3A carbon steel 0.2 % carbon max
Billet diameter              : 80
Billet length                : 0.824
Number of billets            : 15
Weight/billet                : 32.290  kg
Number of finished tube/bil  : 7
total weight of the job      : 484.354  kg

‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡
```

Figure A3.3: Material detail generated by KBS-SETUPP

```
‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡
                     PLEASE NOTE: all sizes are in mm
                     ‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡

                          ‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡
                          ‡  HOT MILL SETUP AND TOOLS ‡
                          ‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡

Piercer disc size  : 61.91          Piercer disc gorge   : 83.17
Piercer gorge      : 67.30
Plug size          : 64.00          Piercer bar size     : 57.20

Elongator disc size: 66.00          Elongator disc gorge : 76.17
Elongator gorge    : 68.30          Mandrel bar size     : 61.91
SRM roll combination: A4A5A6A7A8A9A10A11A12A13A14A15A16A17A18A19B20

‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡
```

Figure A3.4: Tools and hot mill set-up generated by KBS-SETUPP

## Appendix A3 - Formatted process plan

```
################################################################################

                     PLEASE NOTE: all sizes are in mm
                     ################################

                            ###################
                            # Standard hollow #
                            ###################


outside diameter   : 33.401
wall thickness     : 3.6
Entry size for SRM : 73

################################################################################
```

Figure A3.5: Standard hollow size selected by KBS-SETUPP

```
##################################################################################

                     #######################
                     #  OPERATION SEQUENCE #
                     #######################


op.No.  oper. name                  OPERATION DETAIL
##################################################################################
op#1    billet_cutting      cut: 0.824 metre billets from a bar of
                            length: 5.18 metere and diameter: 80 mm
op#2    billet_heating      heat the billets in the furnace to 1300 deg C

                                INITIAL DIMENSION       FINAL DIMENSIONS
##################################################################################
op#3    piercing              80.000  ######   0.824  74.800   5.400   3.519
op#4    elongating            74.800   5.400   3.519  73.000   3.600   5.279
op#5    reheating             73.000   3.600   5.279  73.000   3.600   5.279
op#6    stretch_reducing      73.000   3.600   5.279  33.401   3.600  12.294
op#7    cut the hollow into equal length of: 1.756 Metre
##########################################################################
```

Figure 3.6 : Operation sequence for hollows manufacture as generated by KBS-SETUPP

## Appendix A3 - Formatted process plan

```
!                    OPERATION SEQUENCE IN COLD DRAWING MILL
!                    !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

!OPER NO:  OPER NAME :                OPERATION DETAIL
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
         PLEASE NOTE: ALL DIMENSIONS ARE IN mm
         !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
! OPER #1 : TAG THE HOLLOWS
! OPER #2 : PICKLE/BONDERISE
! OPER #3 : SOAP
!                 OD       WALL      X-AREA      OD       WALL       %R
!               !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
! OPER #4 : DRAW 1: 33.401    3.600    336.871  ::>28.575   3.251    23.261
! OPER #5 : DRAW 2: 28.575    3.251    258.511  ::>23.800   2.946    25.377
! OPER #6 : ANNEAL AT 660 - 720 deg C
! OPER #7 : PICKLE/BONDERISE
! OPER #8 : SOAP
! OPER #9 : DRAW 3: 23.800    2.946    192.909  ::>22.225   2.337    24.347
! OPER #10: ANNEAL AT 660 - 720 deg C
! OPER #11: PICKLE/BONDERISE
! OPER #12: SOAP
! OPER #13: DRAW 4: 22.225    2.337    145.942  ::>19.050   2.032    25.598
! OPER #14: REEL
! OPER #15: CUT TO LENGTH
```

Figure A3.7: Operation sequence in cold drawing mill as generated by KBS-SETUPP

```
PLEASE NOTE DIMENSIONS: LOAD(KN),STRESS(N/MM2),POWER(KW)
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

                   !!!!!!!!!!!!!!!!!!!!!!!!!!
                   !   STRESS/LOAD/POWER    !
                   !!!!!!!!!!!!!!!!!!!!!!!!!!


DRAWING LOADS (KN)
!!!!!!!!!!!!!!!!!!

1st PASS     : 39.04                  2nd PASS     : 9.45
3rd PASS     : 12.11                  4th PASS     : 16.60

DRAWING STRESSES (N/mm2)
!!!!!!!!!!!!!!!!!!!!!!!!

1st PASS     : 151.01                 2nd PASS     : 49.00
3rd PASS     : 82.98                  4th PASS     : 152.85

POWER REQUIREMENT (KW)
!!!!!!!!!!!!!!!!!!!!!!

1st PASS     : 5.86                   2nd PASS     : 1.42
3rd PASS     : 1.82                   4th PASS     : 2.49
```

Figure A3.8: Selected tools (die and plug) sizes by KBS-SETUPP

```
        PLEASE NOTE: ALL PLUG AND DIE SIZES ARE IN mm
        *********************************************

               *****************************
               *     DIE AND PLUG SIZES    *
               *****************************

DIE SIZES (mm)
**************

1st PASS : 28.575               2nd PASS : 23.8
3rd PASS : 22.225               4th PASS : 19.05

PLUG SIZES (mm)
***************

1st PASS     : 22.073              2nd PASS     : 17.908
3rd PASS     : 17.551              4th PASS     : 14.986

****************************************************************************
```

Figure A3.9: Process parameters computed by KBS-SETUPP

## Appendix A4 - Format of Dynamic knowledge-base during execution

```
outside_dia(19.05)
inside_dia(0)
wall_thickness(2.032)
length_is(3.048)
tube_type("standard")
specification_of_tube("BS6323")
material_is("CFS 3A")
finish_required("BK")
quantity_required(100)
works_order_number(1234)
part_number("A/0750/0000/080/ABA/10")
tube_finish("CFS")
```

Figure A4.1: Output format of CODINTERP program

```
billet_dia(80)
entry_size(73)
hollow_size(33.401,3.6,0.982)
billet_length(0.066)
billet_weight(2.586)
```

Figure A4.2: Output format of HOLBILSEL program

```
sequenced_processes_hotmill(["billet_cutting","billet_heating","piercing",
"elongating","reheating","stretch_reducing"])
```

Figure A4.3: Output of module PRSASEQH

```
bench_type("Chain or Farmer Norton")
bloom_dim(74.8,64,5.4)
piercer_disc_size(61.913)
elong_disc_size(66)
mandrel_bar_size(61.91)
plug_dia(64)
piercer_bar_size(57.2)
op_bi_dim(80,0.824)
no_of_cut(6)
bloom_length(3.519)
elong_tube_dim(73,3.6,5.279)
sra_tube_dim(33.401,3.6,12.294)
sra_roll_combination("A4A5A6A7A8A9A10A11A12A13A14A15A16A17A18A19B20")
optimum_bar(5.18)
piercer_gorge(67.3)
piercer_disc_gorge(83.175)
elongator_gorge(68.3)
elongator_disc_gorge(76.175)
```

Figure A4.4: Output format of TSAOPTIM program

## Appendix A4 - Format of dynamic knowledge-base during execution

```
o_dia_tol(0.1,0.1)
wall_tolerance(0.2032,0.2032,["incl.ecc."])
length_tolerance(5,0)
straight_tolerance(["1:666"])
test_requirement(["Visual","Tensile","Flatten","Hydraulic (if required)","Test certificates (if required)"])
```

Figure A4.5: Output format of TOLERAN program

```
no_of_passes(4)
init_final_dia(33.401,3.6,19.05,2.032)
```

Figure A4.6: Output format PASSN program

```
usable_die_sizes([31.75,28.575,27,25.4,23.8,22.225,19.05])
usable_plug_sizes([3.251,2.946,2.642,2.337,2.032])
```

Figure A4.7: Output format of UPLDIES program

```
poss_tdsched_red([33.401,3.6,28.575,3.251,23.261,27,2.946,13.926,23.8,2.337,29.217,19.05,2.032,31.058])
poss_tdsched_red([33.401,3.6,28.575,3.251,23.261,27,2.946,13.926,22.225,2.642,26.988,19.05,2.032,33.163])
poss_tdsched_red([33.401,3.6,28.575,3.251,23.261,27,2.946,13.926,22.225,2.337,34.411,19.05,2.032,25.598])
poss_tdsched_red([33.401,3.6,28.575,3.251,23.261,27,2.642,21.833,25.4,2.337,16.247,19.05,2.032,35.841])
poss_tdsched_red([33.401,3.6,28.575,3.251,23.261,27,2.642,21.833,23.8,2.337,22.057,19.05,2.032,31.058])
poss_tdsched_red([33.401,3.6,28.575,3.251,23.261,27,2.642,21.833,22.225,2.337,27.777,19.05,2.032,25.598])
poss_tdsched_red([33.401,3.6,28.575,3.251,23.261,25.4,2.946,19.652,23.8,2.337,24.173,19.05,2.032,31.058])
poss_tdsched_red([33.401,3.6,28.575,3.251,23.261,25.4,2.946,19.652,22.225,2.642,21.786,19.05,2.032,33.163])
poss_tdsched_red([33.401,3.6,28.575,3.251,23.261,25.4,2.946,19.652,22.225,2.337,29.738,19.05,2.032,25.598])
poss_tdsched_red([33.401,3.6,28.575,3.251,23.261,25.4,2.642,26.967,23.8,2.337,16.578,19.05,2.032,31.058])
poss_tdsched_red([33.401,3.6,28.575,3.251,23.261,25.4,2.642,26.967,22.225,2.337,22.699,19.05,2.032,25.598])
poss_tdsched_red([33.401,3.6,28.575,3.251,23.261,23.8,2.946,25.377,22.225,2.642,15.785,19.05,2.032,33.163])
poss_tdsched_red([33.401,3.6,28.575,3.251,23.261,23.8,2.946,25.377,22.225,2.337,24.347,19.05,2.032,25.598])
poss_tdsched_red([33.401,3.6,28.575,3.251,23.261,23.8,2.642,32.102,22.225,2.337,16.854,19.05,2.032,25.598])
poss_tdsched_red([33.401,3.6,28.575,2.946,29.623,27,2.642,14.767,25.4,2.337,16.247,19.05,2.032,35.841])
poss_tdsched_red([33.401,3.6,28.575,2.946,29.623,27,2.642,14.767,23.8,2.337,22.057,19.05,2.032,31.058])
poss_tdsched_red([33.401,3.6,28.575,2.946,29.623,27,2.642,14.767,22.225,2.337,27.777,19.05,2.032,25.598])
poss_tdsched_red([33.401,3.6,28.575,2.946,29.623,25.4,2.642,20.365,23.8,2.337,16.578,19.05,2.032,31.058])
poss_tdsched_red([33.401,3.6,28.575,2.946,29.623,25.4,2.642,20.365,22.225,2.337,22.699,19.05,2.032,25.598])
poss_tdsched_red([33.401,3.6,28.575,2.946,29.623,23.8,2.642,25.964,22.225,2.337,16.854,19.05,2.032,25.598])
```

Figure A4.8: Alternative tube drawing schedules generated by module ALTSCH (shown partially)

```
best_schedule([33.401,3.6,28.575,3.251,23.261,23.8,2.946,25.377,22.225,2.337,24.347,19.05,2.032,25.598])
```

Figure A4.9: Output format of best schedule as selected by BESTSCH

```
die_sizes_for_four_passes(28.575,23.8,22.225,19.05)
plug_sizes_for_four_passes(22.073,17.908,17.551,14.986)
isa4("no anneal","anneal after 2nd pass","anneal after 3rd pass")
```

Figure A4.10 Output format of ANNEAL program

```
drawing_stress1(151.015)
drawing_stress2(49.001)
drawing_stress3(82.985)
drawing_stress4(152.851)
drawing_load1(39.039)
drawing_load2(9.453)
drawing_load3(12.111)
drawing_load4(16.597)
hp1(7.853)
hp2(1.901)
hp3(2.436)
hp4(3.339)
```

Figure A4.11: Output Format of STADL program

# Appendix A5 - production schedules

| W.O | CUSTOMER | WEIGHT | WEEK | START DATE | COMPL DATE | FINISH |
|---|---|---|---|---|---|---|
| 100 | ASSOCIATE | 12.440 | 41 | 10/10/1990 | 10/10/1990 | HFS |
| 105 | ASSOCIATE | 12.440 | 41 | 10/10/1990 | 10/10/1990 | CFS |
| 109 | ASSOCIATE | 7.480 | 41 | 10/10/1990 | 10/10/1990 | CFS |
| 112 | prod steel | 4.980 | 41 | 10/10/1990 | 10/10/1990 | HFS |
| 114 | prod steel | 19.950 | 41 | 10/10/1990 | 11/10/1990 | CFS |
| 122 | prod steel | 2.490 | 41 | 11/10/1990 | 11/10/1990 | CFS |
| 122 | prod steel | 27.390 | 41 | 11/10/1990 | 12/10/1990 | CFS |
| week total= 87.17 | | CFS: 69.75 | | HFS: 17.42 | | |
| 9980 | ABC | 24.940 | 42 | 15/10/1990 | 15/10/1990 | CFS |
| 6 | ABC | 19.900 | 42 | 15/10/1990 | 16/10/1990 | CFS |
| 9982 | BCD | 21.500 | 42 | 16/10/1990 | 16/10/1990 | CFS |
| 7 | prod steel | 11.090 | 42 | 16/10/1990 | 16/10/1990 | CFS |
| 9983 | CDE | 8.600 | 42 | 16/10/1990 | 17/10/1990 | CFS |
| 8 | prod steel | 17.460 | 42 | 17/10/1990 | 17/10/1990 | CFS |
| 14 | CDE | 49.600 | 42 | 17/10/1990 | 18/10/1990 | CFS |
| 9985 | DEF | 24.800 | 42 | 18/10/1990 | 19/10/1990 | CFS |
| week total= 177.89 | | CFS: 177.89 | | HFS: 0 | | |

Figure A5.1: A partial view of production schedules file (schedule is generated by allowing one week capacity to each group of orders)

```
rremaining_capacity_of_a_week(1,41,120,84,36,32.83,14.25,18.58)
remaining_capacity_of_a_week(2,42,200,140,60,22.11,-37.89,60)
remaining_capacity_of_a_week(3,43,200,140,60,145.39,85.39,60)
remaining_capacity_of_a_week(4,44,200,140,60,29.4,-15.64,45.04)
remaining_capacity_of_a_week(4,48,200,140,60,88.2,64.08,24.12)
```

Figure A5.2: Output format of ABCAP program

## Appendix A5 - Production schedules

| W.O | CUSTOMER | WEIGHT | WEEK | START DATE | COMPL DATE | FINISH |
|---|---|---|---|---|---|---|
| 112 | prod steel | 4.980 | 41 | 10/10/1990 | 10/10/1990 | HFS |
| 114 | prod steel | 19.950 | 41 | 10/10/1990 | 11/10/1990 | CFS |
| 122 | prod steel | 2.490 | 41 | 11/10/1990 | 11/10/1990 | CFS |
| 122 | prod steel | 27.390 | 41 | 11/10/1990 | 12/10/1990 | CFS |
| 9980 | ABC | 24.940 | 41 | 12/10/1990 | 12/10/1990 | CFS |
| week total= 112.11 | | CFS: 94.69 | | HFS: 17.42 | | |
| 6 | ABC | 19.900 | 42 | 15/10/1990 | 15/10/1990 | CFS |
| 9982 | BCD | 21.500 | 42 | 15/10/1990 | 16/10/1990 | CFS |
| 7 | prod steel | 11.090 | 42 | 16/10/1990 | 16/10/1990 | CFS |
| 9983 | CDE | 8.600 | 42 | 16/10/1990 | 16/10/1990 | CFS |
| 8 | prod steel | 17.460 | 42 | 16/10/1990 | 16/10/1990 | CFS |
| 14 | CDE | 49.600 | 42 | 16/10/1990 | 17/10/1990 | CFS |
| 9985 | DEF | 24.800 | 42 | 17/10/1990 | 18/10/1990 | CFS |
| 9986 | DEF | 9.280 | 42 | 18/10/1990 | 19/10/1990 | CFS |
| 18 | prod steel | 7.480 | 42 | 19/10/1990 | 19/10/1990 | CFS |
| 9987 | EFG | 7.480 | 42 | 19/10/1990 | 19/10/1990 | CFS |
| 9988 | GHI | 17.900 | 42 | 19/10/1990 | 19/10/1990 | CFS |
| week total= 195.09 | | CFS: 195.09 | | HFS: 0 | | |

Figure A5.3: Format of revised schedules by shifting orders to utilise full capacity of each week

```
WEEK NUMBER: 41
---------------
                MATERIAL: CDS11          SIZE: 80          87.193
                -------------------------------------------------
                WEEK TOTAL                               = 87.193


WEEK NUMBER: 42
---------------
                MATERIAL: CDS 2          SIZE: 80          24.8
                MATERIAL: CDS 13         SIZE: 100         49.6
                MATERIAL: HFS 3          SIZE: 80           8.6
                MATERIAL: CDS11          SIZE: 80          28.55
                MATERIAL: CFS 4          SIZE: 80          21.5
                MATERIAL: CDS 11         SIZE: 80          44.85
                -------------------------------------------------

                WEEK TOTAL                              = 177.901
```

Figure A5.4: A partial report of material requirement by program ABMAT

## Appendix A5 - Production schedules

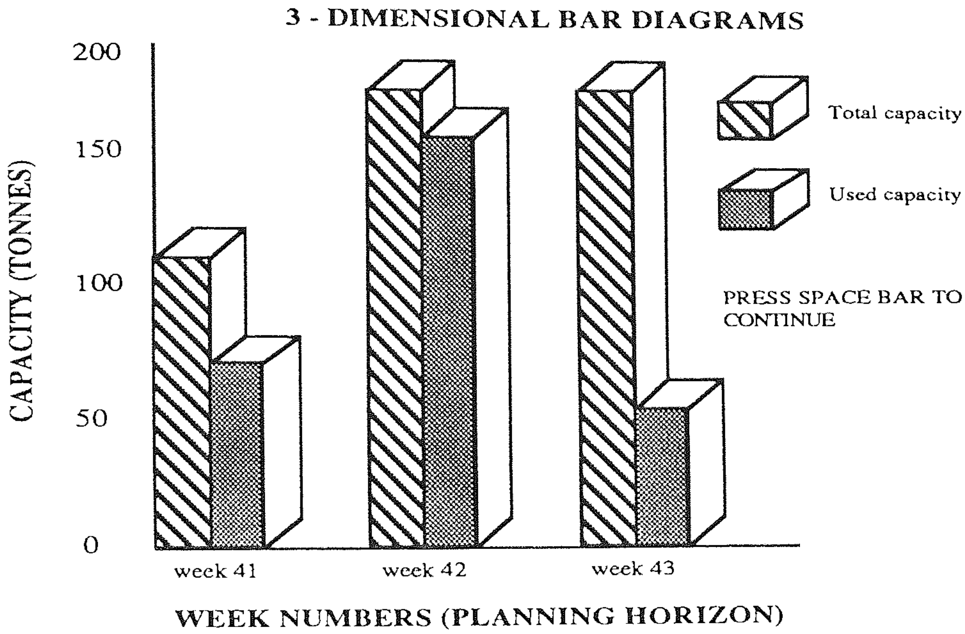



Figure A5.5: Bar diagrams showing total and used capacity

ENQUIRY

| | | | |
|---|---|---|---|
| WORKS ORDER NO: | 6 | CUSTOMER NAME: | ABC |
| SIZE | 57[illegible]6 | FINISH | CFS |
| BILLET WEIGHT | 43 | NO. OF BILLETS | 463 |
| BILLET SIZE | 80 | ROLL WEEK: | 42 |
| START DATE | 15/10/1990 | FINISH DATE | 16/10/1990 |

Figure A5.6: A screen of order enquiry

## Appendix A6 - System application

After loading KBS-SETUPP and selecting the process planning task for CFS tubes from the main menu , the following is a typical system-user dialogue. System's query are written in *italic* words while user responses are in **bold** letters.

*part code format is : A/1234/0000/123/AAA/20*

*Enter the part code number:* **a/0750/000/080/aba/10**

*Enter the quantity required:* **100**

*Enter the works order number:* **10**

*Outside dia of selected hollow is : 33.401*

*Wall thickness of selected hollow is: 3.6*

*Do you accept the selected hollow size (y/n):* **y**

*Selected billet diameter for this job is: 80 mm*

*Billet diameter is acceptable (y/n):* **y**

*Specification BS 6323 has any applicable part number (y/n) :* **y**

*Enter part number for BS 6323:* **4**

*Tolerances has been selected for this job*

*Press any key to continue*

*Required processes for hollow manufacture have been selected and sequenced*

*Press any key to continue*

*Recommended mandrel bar dia: 61.91 mm*

*Do you accept the selected mandrel bar size (y/n):* **y**

*Recommended piercer plug dia: 64 mm*

*Do you accept the selected piercer plug size (y/n):* **y**

**Appendix A6 - System application**

*Recommended piercer bar dia: 57.2 mm*

*Do you accept selected piercer bar size (y/n):* **y**

*Recommended piercer disc size: 61.913 mm*

*Do you accept the selected piercer disc size (y/n):* **y**

*Recommended elongator disc size: 66 mm*

*Do you accept the selected elongator disc size (y/n):* **y**

*Recommended elongator gorge: 68.31 mm*

*Do you accept the selected elongator gorge (y/n):* **n**

*Enter the value of elongator gorge which you recommend:* **68.31**

*Optimum billet length for this job is computed to be: 0.824 m*

*Do you accept this optimum billet length (y/n):* **y**

*Press any key to continue*

*X-sectional area of hollow: 336.871 mm2*

*X-sectional area of required tube is: 108.583 mm2*

*Total reduction required (%): 67.76*

*Recommended number of passes for this job are: 4*

*Recommended number of passes are acceptable (y/n):* **y**

*press any key to continue*

*Usable plug and die sizes for this job has been determined from the available tools list*

*Press any key to continue*

*Alternative tube drawing schedules have been generated for this job*

*Do you want to display the alternative tube-drawing schedules (y/n):* **n**

*Press any key to continue*

## Appendix A6 - System application

*The best tube-drawing schedule amongst the alternatives is as follows*

| *pass* | *Dia* | *Thick* | *X-area* | *Dia* | *Thick* | *X-area* | *% Red* |
|---|---|---|---|---|---|---|---|
| *1* | *33.401* | *3.600* | *336.9* | *28.575* | *3.251* | *258.511* | *23.261* |
| *2* | *28.575* | *3.251* | *258.5* | *23.800* | *2.946* | *192.909* | *25.377* |
| *3* | *23.800* | *2.946* | *192.9* | *22.225* | *2.337* | *145.942* | *24.347* |
| *4* | *22.225* | *2.337* | *145.942* | *19.05* | *2.032* | *108.583* | *25.598* |

*Is this tube-drawing schedule acceptable (y/n):* **y**

*Press any key to continue*

*No anneal is decided after first pass*

*Is it acceptable (y/n):* **y**

*Anneal after 2nd pass is decided*

*Is it acceptable (y/n):* **y**

*No anneal is decided after 3rd pass*

*Is it acceptable (y/n):* **y**

*Press any key to continue*

*Please enter the semi-effective angle of die:* **15**

*Please enter the drawing speed for first pass (m/min) :* **9**

*Drawing load for fist pass:is computed to be : 39.039 kN*

*Drawing stress for first pass is computed to be : 151.015 N/mm2*

*Power requirement for first pass is: 7.853 kW*

*Please enter the drawing speed for 2nd pass (m/min) :* **9**

*Drawing load for 2nd pass:is computed to be : 9.453 kN*

*Drawing stress for 2nd pass is computed to be : 49.00 N/mm2*

*Power requirement for 2nd pass is: 1.42 kW*

*Please enter the drawing speed for 3rd pass (m/min) :* **9**

*Drawing load for 3rd pass:is computed to be : 12.11 kN*

*Drawing stress for 3rd pass is computed to be : 82.98 N/mm2*

*Power requirement for 3rd pass is: 1.82 kW*

*Please enter the drawing speed for fourth pass (m/min) :* **9**

*Drawing load for 4th pass:is computed to be : 6.77 kN*

*Drawing stress for 4th pass is computed to be : 62.4 N/mm2*

*Power requirement for 4th pass is: 1.02 kW*

After this the system executes the formatting programs and asks the user for header section of the process plan such as planner name etc. At the end the system displays the menu to print or display or edit the process plan which is then saved.

Figure A6.1: A system-user dialogue during generation of process plan

***** Record 580 in ORDER *****

WORKS ORDER No. 1234 CUSTOMER J.C.BAMFORD
ACC.NO. BAMF ALT'DEST'1 REP 05

CUSTOMER ORDER DETAILS:

1. CUSTOMER ORDER No. A192 2. CUSTOMER PART No. A07500000080ABA
3. DESTINATION UTTOXETER 4. SCHEDULED (Y/N) no S/H no
5. SPECIFICATION BS.6323 Pt4 1982 CSF 3 A
6. DIMENSIONS 3/4" od x 14g x R/ls
7. PRICE/Mtr (Tonne) 1.023 (1,199) 8. SCRAP SURCHARGE 0 /INCL'
9. PRICE/UNIT # 1.023 (METRE) 10. DATE LAST INCR. 1/ 2/90
11. COMMENTS

PRODUCTION DETAILS:

1. BENCH TYPE CHAIN BENCHS (3) 2. WGT. KG/Ft & Mtr 0.260 0.853
3. HOLLOW SIZE(OD/WT) 33.40x 3.60 4. HOLLOW WEIGHT(KG) 36
5. STEEL SIZE (MM) 80 6. CARBON % 10/15/
7. NUMBER of PASSES 4 8. BAR SIZE 29/32
9. NUMBER of CUTS 6 10. WEIGHT per CUT 5.000
11. FIN DRAWN LEN(Mtr) 31.512 12. ALCESTER St. WGT 30.000
13. CUTTING INSTRUCTIONS END & CUT 5 Kgs off 6 TIMES
14. TAG SIZE (ins) 15. FIN'BORE SIZE

W/O 1234 CUSTOMER J.C.BAMFORD ISSUE WEEK FACTOR 5

PIERCER DISC SIZE(IN.) ELONG. DISC SIZE(mm)
BULLET SIZE(IN.) PIERCER BAR SIZE(IN.) ENTRY
MANDRELL BAR SIZE(mm) PIERCER PLUG SIZE(mm) SIZE(mm)

| QTY REQ (MTRS.) | DATE REQ. | PLAN ISS | ROLL WEEK | ROLLING NO. | ACT ISS | LEFT S/RD | TOT PASS | NO HLWS | QTY DEL (MTRS.) | DATE DEL. |
|---|---|---|---|---|---|---|---|---|---|---|
| 100 | 32/89 | 26/89 | 25/89 | / / | / | | 72 | 3 | | / |
| | / | / | / | / / | / | | 0 | 0 | | / |
| | / | / | / | / / | / | | 0 | 0 | | / |
| | / | / | / | / / | / | | 0 | 0 | | / |
| | / | / | / | / / | / | | 0 | 0 | | / |
| | / | / | / | / / | / | | 0 | 0 | | / |
| | / | / | / | / / | / | | 0 | 0 | | / |

LATEST DELIVERY: QTY.DEL. DATE / / ORDER COMPLETE
DATE TYPED 15/08/90 ORDER LAST MODIFIED 31/90

Figure A6.2: A company-based plan form for hollow manufacture (courtesy of Universal)

# Appendix A6 - System application

| Order Date | Customer Part No. | Customer Order No. | Extract No. | Works Order No. | Batch |
|---|---|---|---|---|---|
| 01/07/89 | A07500000080ABA | A192 | | 1234 | |

| Date Received | Customer Name |
|---|---|
| / / | J.C.BAMFORD |

| Date Typed | 05 | Addresses |
|---|---|---|
| 15/08/90 | Invoice | ROCESTER<br>UTTOXETER<br>STAFFS. ST14 5JP |
| Tech. Vet | | |
| Comm. Vet | Delivery | AS ABOVE |

| | Tolerances | Finished Tube Size Imperial | Finished Tube Size Metric |
|---|---|---|---|
| O.D. | 0.754"<br>0.746" | 0.750" | |
| Bore | | | |
| Wall | 0.088"<br>0.072" | 14g | |
| Length | | R/ls | |

**TEST AND CERTIFICATION REQUIREMENTS**

1. TENSILE 450 N/mm2 MIN
2. 0.5% PS 360 N/mm2 MIN
3. ELONG 6% MIN 5.65/So
4.
5. 3
6.
7.
8.

TEST CERTIFICATES - WITH GOODS

| | |
|---|---|
| Specification | BS. 6323 Pt4 1982 CFS 3 A |
| Eccentricity | |
| Steel | 0.20% CARBON MAX |
| Ovality | |
| Finish | AS DRAWN |
| Straightness | 1/666 |
| Weight Factor | 0.260 |

[redacted]

**ORDER QUANTITY AND DELIVERY INSTRUCTIONS**

| Customer Delivery | Estimated Delivery | Quantity Required | Unit | Weight Tonnes |
|---|---|---|---|---|
| A.S.A.P | BEG JULY | 100 | MTR | 0.085 |
| | | | | 0.000 |
| | | | | 0.000 |
| | | | | 0.000 |

**SPECIAL REQUIREMENTS:**

| Cast No. | FORWARD PLAN | | |
|---|---|---|---|
| Start Date | Passes | | Draw Bench: CHAIN BENCHS |
| Finish Date | Bar Size: 29/32 | | |

**SIZING PROCEDURE**

| No. | Weight | | O.D. | Wall |
|---|---|---|---|---|
| | | Steel | 80 | |
| | | Hollow | 33.4 | 3.6 |

| | Die | Plug | Est. Wall |
|---|---|---|---|
| Draw No. 1 | 1.137 | 0.881 | 0.128 |
| Draw No. 2 | 0.937 | 0.705 | 0.116 |
| Draw No. 3 | 0.875 | 0.691 | 0.092 |
| Draw No. 4 | 0.750 | 0.590 | 0.08 |

Comments

**PRODUCT YIELD**

| | Estimated | Actual |
|---|---|---|
| Pieces | | |
| Units | | |
| Bundles/Bins | | |
| Weight | | |

Figure A6.3: A company-based plan for CFS tube manufacture (courtesy of Universal )

HOLLOW SIZE LIST BY ROLL WEEK up to WEEK 32/90

REPORT RUN 15/08/90

| HOLLOW SIZE | | | WORKS O/N | CUSTOMER | ROLL WEEK | No of TUBES | TONNES | CARBON | STEEL SIZE | BAR SIZE |
|---|---|---|---|---|---|---|---|---|---|---|
| 33.40 | 3.29 | 36 | 9302 | G.E.C CANNON INDUSTRIES | 32 | 179 | 6.44 | 18/21 V6675 | 80 | HOT FIN |
| | 4.55 | 33 | 7693 | LANCASHIRE TUBE | | 164 | 5.41 | 18/21 V6675 | 80 | 0 |
| | 4.90 | 43 | 5371 | C.C.L. SYSTEMS | | 16 | 0.69 | 12/16 | 80 | 13/16" |
| | 5.30 | 43 | 5322 | GULLICK DOBSON | | 57 | 2.45 | 10/15 | 80 | 7/8" |
| | 5.30 | 43 | 5179 | GULLICK DOBSON | | 29 | 1.25 | 10/15 | 80 | 7/8" |
| | 5.40 | 43 | 5325 | INTERPIPE (UK) LTD | | 69 | 2.97 | 11/16 | 80 | 3/4" |
| | | | | 6 | | 514 | 19.21 | | | |
| 38.00 | 6.00 | 51 | 5370 | C.C.L. SYSTEMS | | 37 | 1.89 | 12/16 | 80 | 29/32" |
| | 6.00 | 51 | 5370 | C.C.L. SYSTEMS | | 37 | 1.89 | 12/16 | 80 | 29/32" |
| | 11.10 | 58 | 5361 | EUROTUBE LIMITED | | 24 | 1.39 | 11/16 | 100 | 1/2 |
| | | | | 3 | | 98 | 5.17 | | | |
| 48.30 | 5.00 | 51 | 5313 | INTERPIPE (UK) LTD | | 216 | 11.02 | 16/21 E4642 | 80 | 1.15/32 |
| | 5.00 | 43 | 5260 | W.W.GREW & CO LTD | | 22 | 0.95 | 10/15 E4653 | 80 | 1.3/8 |
| | | | | 2 | | 238 | 11.96 | | | |
| 50.00 | 7.00 | 68 | 9474 | G.K.N.AXLES(K) | | 8 | 0.54 | 18/21 Mn | 100 | HOT FIN |
| | 7.00 | 65 | 9478 | G.K.N.AXLES(K) | | 25 | 1.62 | 18/21 Mn | 100 | HOT FIN |
| | | | | 2 | | 33 | 2.17 | | | |
| 51.00 | 5.00 | 59 | 5334 | R.F LUKE (S.M.E) LTD | | 8 | 0.47 | 12/16 | 100 | 2" |
| | 5.00 | 53 | 5336 | INTERPIPE (UK) LTD | | 49 | 2.60 | 18/22 ST52 | 100 | 1.1/2" |
| | 5.00 | 59 | 5304 | EUROPEAN TUBES LIMITED | | 24 | 1.42 | 10/15 | 100 | 1.1/2" |
| | 7.00 | 53 | 9558 | K.A.MACLAINE LTD (RECEIVERSHIP) | | 131 | 6.94 | 45/50 | 100 | 1.5/16 |
| | | | | 4 | | 212 | 11.43 | | | |
| 57.00 | 5.60 | 68 | 5312 | BRITISH AND GENERAL(S) | | 16 | 1.09 | 45/50 | 100 | 1.21/32 |
| | 6.00 | 68 | 5307 | EUROPEAN TUBES LIMITED | | 19 | 1.29 | 10/15 | 100 | 1.5/8" |
| | | | | 2 | | 35 | 2.38 | | | |
| 63.50 | 6.30 | 68 | 7739 | MARKLAND TUBES LTD. | | 101 | 6.87 | 16/21 HF430 | 100 | 0 |
| | | | | 1 | | 101 | 6.87 | | | |
| 76.00 | 7.90 | 90 | 9344 | G.K.N.AXLES(B) | | 1 | 0.09 | 35/40 | 115 | 2.1/16" |
| | 7.90 | 90 | 9345 | G.K.N.AXLES(B) | | 3 | 0.27 | 35/40 | 115 | 2.1/16" |
| | 7.90 | 90 | 9333 | G.K.N.AXLES(B) | | 82 | 7.38 | 35/40 | 115 | 2.1/4" |
| | | | | 3 | | 86 | 7.74 | | | |
| 76.10 | 5.40 | 68 | 7679 | MARKLAND TUBES LTD. | | 39 | 2.65 | 16/21 HF430 | 100 | 0 |
| | | | | 1 | | 39 | 2.65 | | | |
| 79.40 | 12.00 | 105 | 7544 | ANCON STAINLESS STEEL | | 187 | 19.64 | 30/35 E4898 | 115 | |
| | | | | 1 | | 187 | 19.64 | | | |
| 110.00 | 23.50 | 116 | 9488 | J.C.BAMFORD | | 17 | 1.97 | 10/15 | 120 | 2" |
| | | | | 1 | | 17 | 1.97 | | | |

No of ITEMS for WEEK 26 No of TUBES for WEEK 1560 91.18 WEEKS TONNES

TOTAL No of ITEMS 26 TOTAL No of TUBES 1560 91.18 TOTAL TONNES

Figure A6.4: Format of company-based production schedules(courtesy of Universal)

KNOWLEDGE-BASED SYSTEM FOR PROCESS PLANNING SEAMLESS TUBE
PLANNER NAME: SIDDIQUE,M. date: 15/9/1990 at: 6:39:11

PROCESS PLAN

---

ALL DIMENSIONS EXCEPT LENGTH ARE IN MILIMETRE

ORDER DETAIL

customer part number: A/2000/0000/250/KAA/10 works order number: 20
outside diameter : 50.800 inside diameter : 38.100
wall thickness : 6.350 tube length : 3.048
specification : ASTM 210/A 210M-88 finish required : BK CFS
total quantity : 100

---

PLEASE NOTE: ALL TOLERANCES ARE IN mm

TOLERANCES DETAIL

Outside diameter: Pos tolerance: 0.200 Neg tolerance: 0.200
Wall thickness : Pos tolerance: 0.635 Neg tolerance: 0.635
Eccentricity : ["incl.ecc."]
Length : Pos tolerance: 3.000 Neg tolerance: 0.000
Straightness : ["1:666"]
Tests required : 1: TENSILE 415 N/mm2 MAX 2: YIELD 255 N/mm2 MIN 3: ELONG 30%

---

PLEASE NOTE: billet length in metre and billet dia in mm

MATERIAL DETAIL

Material specification : GRADE A-1 Medium carbon steel 0.27 % carbon max
Billet diameter : 100 Billet length : 0.995
Number of billets : 50 Weight/billet : 60.924 kg
Number of finished tube/bil : 2 total weight : 3046.193 kg

---

PLEASE NOTE: all sizes are in mm

HOT MILL SETUP AND TOOLS

Piercer disc size : 61.91 Piercer disc gorge : 103.17
Piercer gorge : 81.00
Plug size : 64.00 Piercer bar size : 57.20
Elongator disc size: 73.00 Elongator disc gorge : 85.67
Elongator gorge : 77.70 Mandrel bar size : 63.50
SRM roll combination: A1A2A3A4A5A6A7B8

---

PLEASE NOTE: all sizes are in mm

Standard hollow

outside diameter: 60.3 wall thickness: 7.5 Entry size for SRM : 82.5

Figure A6.5: A printout of process plan generated on the basis of new knowledge related to ASTM specification *(continued to next page)*

*(Figure A6.5 continued)*

```
                         HOT MILL OPERATION SEQUENCE
                         ---------------------------

op.No.  oper. name                   OPERATION DETAIL
--------------------------------------------------------------------------------
op#1   billet_cutting       cut: 0.995 metre billets from a bar of
                            length: 5.18 metere and diameter: 100 mm
op#2   billet_heating       heat the billets in the furnace to 1300 deg C

                                 INITIAL DIMENSION       FINAL DIMENSIONS
--------------------------------------------------------------------------------
op#3   piercing             100.000  ######    0.995   86.500  11.250   2.938
op#4   elongating            86.500  11.250    2.938   82.500   7.500   4.422
op#5   reheating             82.500   7.500    4.422   82.500   7.500   4.422
op#6   stretch_reducing      82.500   7.500    4.422   60.300   7.500   6.281
op#7   cut the hollow into equal length of: 3.14 Metre
--------------------------------------------------------------------------------
                    OPERATION SEQUENCE IN COLD DRAWING MILL
                    ---------------------------------------

# OPER NO:  OPER NAME :                OPERATION DETAIL
#-------------------------------------------------------------------------------
          PLEASE NOTE: ALL DIMENSIONS ARE IN mm
#         -------------------------------------

# OPER #1 : TAG THE HOLLOWS
# OPER #2 : PICKLE
# OPER #3 : LUBRICATE
#                     OD       WALL      X-AREA        OD       WALL      %R
#                     -------------------------------------------------------
# OPER #4 : DRAW 1: 60.300    7.500    1243.440 ::> 53.975    7.112    15.836
# OPER #5 : DRAW 2: 53.975    7.112    1046.530 ::> 50.800    6.350    15.312
# OPER #6 : REEL
# OPER #7 : CUT TO LENGTH
--------------------------------------------------------------------------------
              PLEASE NOTE: ALL PLUG AND DIE SIZES ARE IN mm
              ---------------------------------------------

DIE SIZES (mm)            1st PASS : 53.975        2nd PASS : 50.8
PLUG SIZES (mm)           1st PASS : 39.751        2nd PASS : 38.1
--------------------------------------------------------------------------------
          PLEASE NOTE DIMENSIONS: LOAD(KN),STRESS(N/MM2),POWER(KW)
          --------------------------------------------------------

DRAWING LOADS (KN)          1st PASS : 118.84      2nd PASS : 52.96
DRAWING STRESSES (N/mm2)    1st PASS : 113.56      2nd PASS : 59.76
POWER REQUIREMENT (KW)      1st PASS : 17.83       2nd PASS : 7.94
--------------------------------------------------------------------------------
```