# AUTOMATIC TOOL SELECTION AND PRODUCTION ROUTING GENERATION FOR ROTATIONAL PARTS

A Master's Thesis

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for Prof. Dr. Ismail TOSUN

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I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Prof. Dr. Rüknettin OSKAY

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We certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Mechanical Engineering

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## ABSTRACT

## AUTOMATIC TOOL SELECTION AND PRODUCTION ROUTING GENERATION FOR ROTATIONAL PARTS

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The aim of the present study is to develop a system for automatic tool selection and production routing generation for the manufacture of turned components. Tool considered herein consists of a holder and an insert. The profile for the workpiece may be stepped, contain a recess/shoulder or have any type of basic external profile. The system developed for this purpose includes four main modules. These are part definition module, tool database, tool selection module and production routing sheet.

Data files prepared by part definition module and ISO codes of the tools from tool database are used as input to tool selection module. After analyzing the machining profile for tool collision, the system selects and recommends tools suitable to machine the given part geometry. Selected tools for a given workpiece are arranged in an order such that tools with greater plan angle (angle defined on an insert) are given higher priority. The system also selects tools for grooved and threaded portions.

Tool recommended by the system and other machining data are required by the user to enter manually on a form called route sheet. Route sheets for different samples of workpieces can be stored and retrieved as required.

Keywords: Automatic Tool Selection, CAPP, Production Routing

Science Code: 625.02.07

# ÖZ

## SİLİNDİRİK PARÇALAR İÇİN OTOMATİK KESİCİ TAKIM SEÇİMİ VE ÜRETİM PLANI YARATILMASI

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Bu çalışmanın amacı, tornalama işlemlerinde kullanılmak üzere otomatik olarak kesicitakım seçimi ve üretim planı yapabilen bir sistem geliştirmektir.Burada kullanılan kesici takım terimi, kesici ucu ve kesici ucun bağlandığı kateri ifade etmek için kullanılmıştır. İş parçası basamaklı, faturalı veya herhangi değişik tipte temel bir dış yüzey profilini içeriyor olabilir. Bu amaçla geliştirilen sistem dört ana modülden oluşmaktadır. Bunlar parça tanımlama, kesici takım veritabanı, kesici takım seçme ve üretim planlama modülleridir.

ISO standartlarına uygun kesici takım veritabanındaki verileri ve parçanın dış profil özellikleri kesici takım seçme modülüne gönderilir. İşlenecek olan profile uygun kesici takım veya takımlar, işlem sırasında kesici takımın malzemeye çarpıp çarpmayacağı kontrol edildikten sonra belirlenir. Belirli bir iş parçası için seçilen kesici takımlara plan açılarının -kesici uçta tanımlı açı- büyüklüğüne göre öncelik verilir. Büyük plan açılı kesici uçlar daha küçük

açılılardan önce listelenir. Kullanıcının karar vermesine yardımcı olacak bu program diş ve kanal açmada kullanılacak kesici takımları da belirler.

Daha sonra kullanıcı, seçilen kesici takımlardan bir tanesini ve diğer malzeme kesme verilerini üretim planlama tablosuna girer. Bu tablolar saklanabilir ve gerektiğinde yeniden kullanılabilir.

Anahtar Kelimeler : Otomatik Kesici Takım Seçimi, Bilgisayar Destekli Üretim Planlaması, Üretim Planlaması

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# CHAPTER I

# INTRODUCTION

Today's industry competes in a truly international market place. Efficient transportation networks have created a 'world market' in which participation is made on daily basis. An industrial country to compete in this market must have companies that provide economic high quality products to their customers in a timely manner.

Industrial automation provides a solution to achieve such competitive standards and higher efficiencies. It is a modern form of increasing productivity by reduction of production time and cost. It is concerned with the application of complex mechanical, electronic and computer based system in the operation and control of production. The use of computers in automated production systems to perform the information processing function lead to computer integrated manufacturing (CIM). At the design stage computer-aided design (CAD), and at the manufacturing stage computer-aided manufacturing (CAM) are the basic applications of computers in automation.

Computer-aided process planning (CAPP), is the application of computers to assist human process planners in the process planning function. It is an activity to determine appropriate procedures to transform a raw material into a final product in an automated environment. It is a major focus of manufacturing automation as it forms the interface between CAD and CAM by providing the necessary link between design and manufacturing. It mainly comprises determination of the available resources, sequence of operations, cutting tools selection, cutting parameters, that is cutting speed, feed rate, depth of cut and other auxiliary functions.

An automatic tool selection module that forms the basic requirement of CAPP systems is a main concern of this study. The system developed for this purpose caters for the cases where the given workpiece could be of any other complicated shapes of basic external profile.

The system developed in Turbo Pascal programming language mainly comprises four main modules. These include part definition module, tool database, tool selection module and the production routing sheet.

Part definition module include basic geometric shapes that can be combined to generate a wide range of turned parts of many different profiles. These part geometries residing in a CAD database can be retrieved and used by an automatic tool selection module for tool selection.

The tool database is designed such that all the tool holders and inserts used for rotational parts can be retrieved from data files and displayed on the screen according to their ISO codes. The user can also mark for availability of each tool in the database.

Tool selection module makes use of data files prepared by both part definition module and tool database for an automatic tool selection of rotational parts. The system recognizes the data file about the workpiece prepared by part definition and redraw it. After analyzing the machining profile, the system selects and graphically displays the tool holders suitable to machine the given part geometry. During the selection procedure the priority is given to the tools found already available in the industry. The system also selects tools for grooved and threaded portions. ISO codes of the selected tool holders along with their inserts are also displayed to the user with a mark of availability. Final selection is left to the user to select one from the recommended ones.

Part geometry analysis forms the basis of the tool selection algorithm for a given workpiece having any type of basic external part profile. It is mainly divided into four sub systems. These include the adjustment of arc segments, straight line approximation, interface checks, and angle checking. These are discussed in detail in Chapter III. On a workpiece, an angle faced by the tool moving from right to left or from left to right is given as entrance angle whereas, an angle on its trailing edge is defined as an in-copy angle. Corresponding angles on a tool holder are given as approach angle and trailing angles. To avoid any tool collision, part geometry is analyzed such that tools having approach and trailing angles greater than or equal to the entrance and in-copy angles respectively registered on machining profile are selected from the tool database. Also, tools with greater plan angle (angle defined on an insert) are given higher priorities. Priority algorithm for tools is given in detail in chapter III. During the tool selection, feed direction and clearance angles on trailing edge of the tool holder are also taken into consideration.

Tool selected for a given workpiece geometry, machining parameters i.e. cutting speed, feed rate, depth of cut and other auxiliary functions are required by the user to enter manually on a form called *route sheet*. Route sheet prepared can be modified according to the user needs. Routing plan for a given workpiece in the form of route sheets can be retrieved and printed as required.

The related literature survey about the subject is given in Chapter II. In Chapter III an implementation algorithm for tool selection along with some set of rules for different types of machining profiles of the workpiece is given. Chapter IV constitutes a session with the system. Finally in Chapter V, the conclusion drawn from this study is presented.

# CHAPTER II

# LITERATURE SURVEY

## 2.1 Computer Integrated Manufacturing

The CIM concept is that all of the firm's operations related to the production function are incorporated in an integrated computer system to assist, augment, and/or automate the operations (Groover,1987). The computer system is pervasive throughout the firm, touching all activities that support manufacturing. In this integrated computer system, the output of one activity serves as the input to the next activity, though the chain of events that starts with the sales order and culminates with shipment of the product. The components of the integrated computer system are illustrated in Figure 2.1.

Customer orders are initially entered by the company's sales force into a computerized order entry system. The specifications serve as the input to the product design department. New products are designed on a CAD system which involves any type of design activity that make use of computers to develop, analyze or modify an engineering design. Databases which are created by CAD systems can be easily transformed to many types of outputs to provide the availability of data for other elements. The components that comprise the product are designed, the bill of material is compiled, and assembly drawings are prepared using such systems.

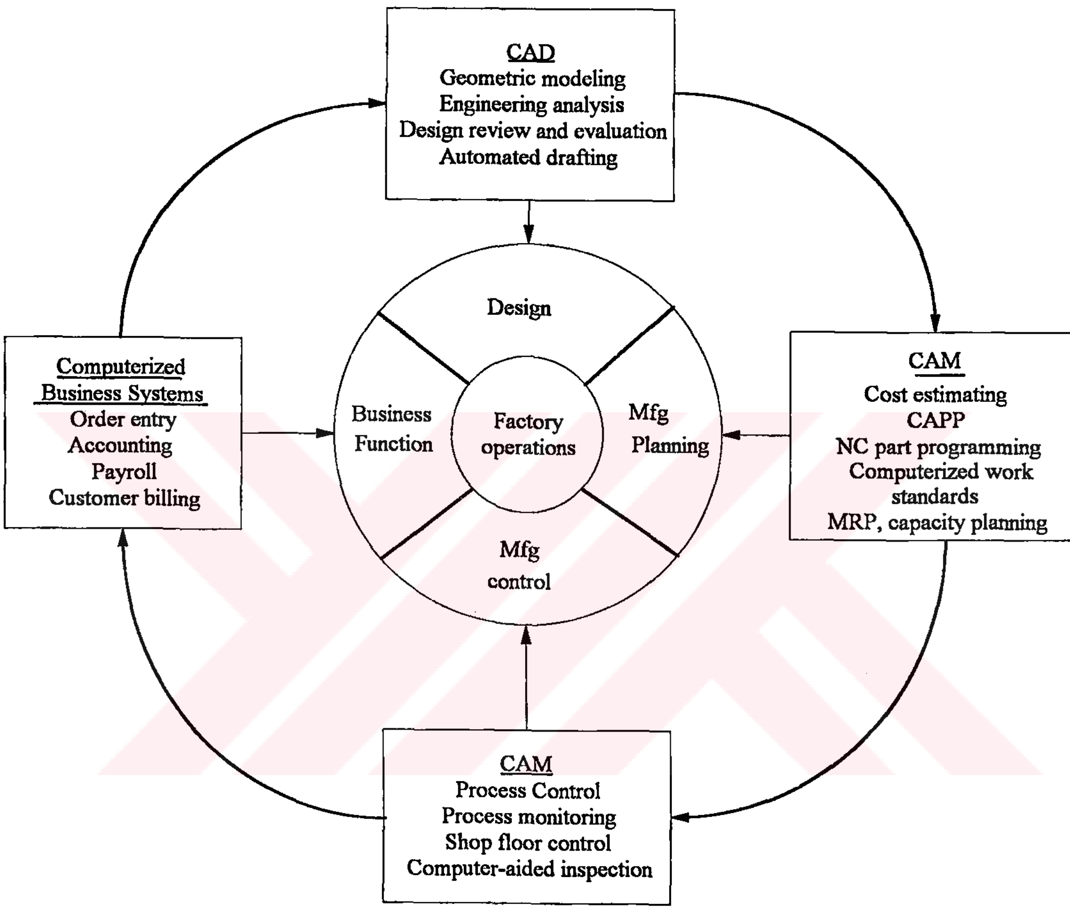



Figure 2.1 Computerized Elements of a CIM System (Groover,1987)

The information and documentation that constitute the design of the product flow into the manufacturing planning function. It is the application of Computer-aided manufacturing (CAM) in which the computer is used indirectly to support the production function, but there is no direct connection between the computer and the process. The computer is used "off-line" to provide information for the effective planning and management of production activities.

As shown in Figure 2.1, the important applications of computer-aided manufacturing for information-processing activities in manufacturing planning include cost estimation, computer-aided process planning (CAPP), computer-assisted NC part programming, development of work standards, material requirement planning, and capacity planning.

The output from manufacturing planning serves as the input to manufacturing control which is also one of the applications of CAM. It is concerned with managing and controlling the physical operations in the factory to implement the manufacturing plans. Included with the control function are shop floor control, inventory control, quality control, and various other control activities. And so it goes, through each step in the manufacturing cycle. Full implementation of CIM results in the automation of the information flow through every aspect of the company's organization.

Of the few activities that are being listed in manufacturing planning, computer-aided process planning (CAPP) forms the backbone of the planning function as it also provides the necessary link for the integration of CAD and CAM in a firm. The ultimate goal of an automated process planning system is to integrate design and production data into a system that generates usable process plans.

However, before embarking a detailed discussion on CAPP system, a brief review of process planning is presented.

## 2.2 Process Planning

Manufacturing planning, process planning, material processing, process engineering, and machine routing are only a few of the titles given to the topic referred to here as process planning (Fabrycky, 1991). Process planning is the function within a manufacturing facility that establishes which processes and parameters are to be used, as well as those machines capable of performing these processes, to convert a piece part from its initial form to a final form predetermined by a design engineer in an engineering drawing. Alternatively process planning is concerned with the sequence of processing and assembly steps that must be accomplished to make the product.

The processing sequence is documented on a form called a route sheet. The route sheet typically lists the production operations, machine cells or workstations where each operation is performed, fixtures and tooling required, and the standard time for each task. These instructions dictate the cost, quality and rate of production, therefore, process planning is of utmost importance to the production system.

There are numerous factors that affect process planning. The shape tolerance, surface finish, size, material type, quantity and the manufacturing system itself all contribute to the selection of operation and the operation sequence. To prepare a process plan the following are some steps that have to be taken (Fabrycky, 1991).

1. Study the overall shape of the part. Use this information to classify the part and determine the type of workstation needed.
2. Thoroughly study the drawing. Try to identify all manufacturing features and notes.
3. Determine the best raw material shape to use if raw stock is not given.
4. Identify datum surfaces. Use information on datum surfaces to determine the setups.
5. Select machines for each setups.
6. Determine the rough sequence of operations necessary to create all the features for each setup.
7. Sequence the operations determined in the previous step. Check whether there is any interference or dependency between operations. Use this operation to modify the sequence or operations.
8. Select tools for each operation. Try to use the same tool for several operations if possible. Keep in mind the trade-off on tool change time and estimated machining time.
9. Select or design fixtures for each setup.
10. Evaluate the plan generated thus far and make necessary modifications.
11. Prepare the final process plan document.

During each of these steps, decision is made on an evaluation of many factors. For example, tool selection is based on the feature to be created and other related features. Operations selection depends on the features as well as the machine to be used and the capability of the machine selected. Machine selection is normally determined by the operation required. All these factors contribute to the development of a process plan presenting the instruction for the production of a particular part.

However, the process plans in the industry shows inconsistency for the production of same parts with no logical reason. Overall unit production is often highly affected by the quality of the process planning function.

### 2.2.1 Manual Process Planning

In a conventional production system, a process plan is created by a process planner, who examines a new part and then determine the appropriate procedure to produce it. In industry most process plans are still prepared manually.

In order to prepare a process plan, a process planner has to have the following knowledge.

- ability to interpret an engineering drawing
- familiarity with manufacturing processes and practice
- familiarity with tooling and fixture
- know what resources are available in the shop
- know how to use reference books, such as machinability data handbooks
- ability to do computations on machining time and cost
- familiarity with the raw materials
- know the relative cost of processes, tooling and raw materials

Considering these factors into consideration it can be seen that each process plan reflect primarily the skills and experience of the individual planner concerned and hence it is extremely difficult to maintain consistency and discipline in the planning process. Process planning also requires the use of many complex disciplines including sequencing, machine selection, tool selection, time and motion study and material flow to name some of the most common. All of these skills are needed in a complex manufacturing environment making it even more difficult to produce efficient process plans.

### 2.2.2 Computer Aided Process Planning

Early attempts to automate process planning consisted primarily of building computer assisted systems for report generation, storage and retrieval of plans. A database system with a standard form editor is what many early systems encompassed. Formatting of plans was performed automatically by the system. Process planner simply filled in the details. The storage and retrieval of plans are based on part number, part name, or project ID. When used effectively these systems can save up to 40% of a process planner's time (Fabrycky, 1991).

Recent developments in computer-aided process planning have focused on eliminating the process planner from the entire function. Computer-aided process planning can reduce some of the decision making required during a planning process. It has the following advantages:

1. It can reduce the skill required of a planner.
2. It can reduce the process planning time.
3. It can reduce both process-planning and manufacturing costs.

4. It can create more consistent plans.

5. It can produce more accurate plans.

6. It can increase productivity.

Figure 2.2 represents the structure of a complete computer-aided process planning system. Although no existing turnkey system integrates all of the functions shown in the Figure (or even a goodly portion of them), it illustrates the functional dependencies of a complete process planning system. It also helps to illustrate some of the constraints imposed on a process planning system (e.g., available machines, tooling, and jigs).

In Figure 2.2, the modules are not necessarily arranged based on importance and decision sequence. The system monitor controls the execution sequence of the individual modules. Each module may require execution several times in order to obtain an "optimum" process plan. Iterations are required to reach feasibility as well as good economic balance.

### 2.2.3 Approaches of CAPP

Two approaches for computer aided process planning are currently being pursued, the variant approach and the generative approach. However, with the rapid development of new techniques, many CAPP systems do not exactly fit this classification and combine to a semi-generative approach.

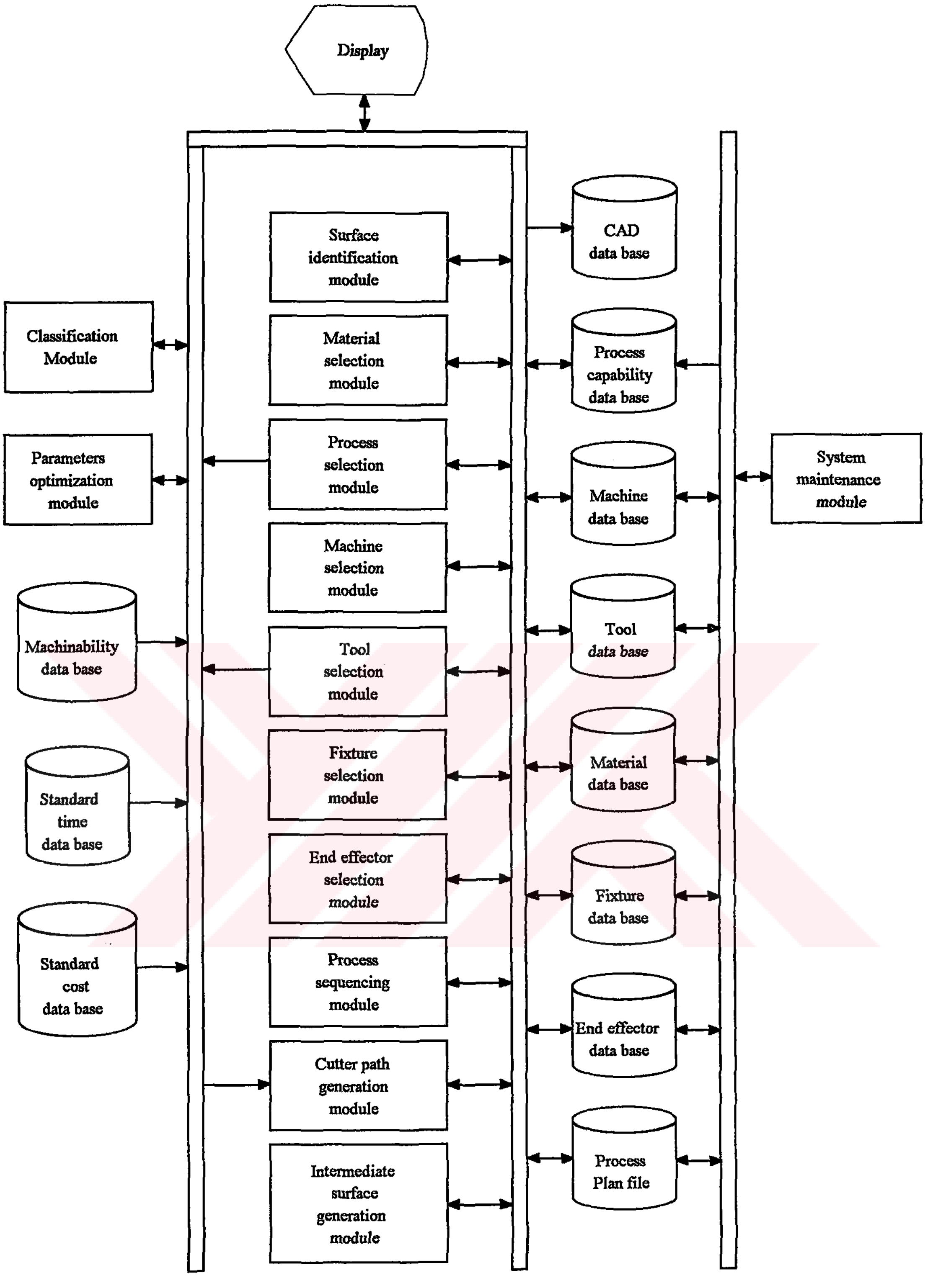



Figure 2.2 Process-planning Modules and Databases (Fabrycky, 1991)

2.2.3.1 Variant Approach

A variant process planning system uses the similarity among components to retrieve existing process plans. A process plan that can be used by a family of components is called a standard plan. A standard plan is stored permanently in the database with a family number as its key. There is no limitation to the detail that a standard plan can contain. However, it must contain at least a sequence of fabrication steps or operations. When a standard plan is retrieved, a certain degree of modification is usually necessary in order to use the plan on a new component.

The retrieval method and the logic in variant systems are predicated on the grouping of parts into families. Common manufacturing methods can then be identified for each family. Such common manufacturing methods are represented by standard plans.

2.2.3.2 Generative Approach

Generative approach is a second type of computer-aided planning. It can be concisely defined as a system that synthesizes process information in order to create a process plan for a new component automatically. In a generative planning system, process plans are created from information available in a manufacturing database without human intervention. Upon receiving the design model, the system can generate the required operations and operation sequence for the component. Knowledge of manufacturing must be captured into efficient software. By applying decision logic, a process planner's decision making process can be imitated. Other planning functions, such as machine selection, tool selection, and process optimization, can also be automated using generative planning techniques.

The generative planning approach has the following advantages:

1. It can generate consistent plans rapidly.
2. New components can be planned as easily as existent components.
3. It can potentially be interfaced with an automated manufacturing facility to provide detailed and up-to-date control information.

Decisions on process selection, process sequencing, etc., are all made by the system. However, transforming component data and decision rules into a computer readable format is still a major obstacle to be overcome before generative planning system become operational. Successful implementation of this approach requires the following key developments:

1. Process planning knowledge must be identified and captured.
2. The part to be produced must be clearly and precisely defined.
3. The captured process-planning knowledge and the part description data must be incorporated into a unified manufacturing database.

Today the term "generative process planning" is often loosely used. Systems with built-in decision logic are often called generative process planning systems. The decision logic consists of the unusual ability to check some conditional requirements of the component and select a process.

Ideally, a generative process planning system is a turnkey system with all the decision logic coded in the software. The system possesses all the necessary information for process planning; therefore, no preparatory stage is required. This is not always the case, however. In order to generate a more universal process-planning system, variables such as process limitations, process capabilities, and process cost must be defined prior to the production stage.

#### 2.2.3.3 Semi-Generative Approach

The term semi-generative approach may be defined as a combination of the generative and the variant approach, where a pre-process plan is utilized in a real production environment. The system works in the same way as in generative approach at first sight, but the final process plan has to be examined and modified to fit the real production environment. A semi-generative system may be thought as breaking a generative system down in a generative planning stage and a modifying stage to correct the plan which may be in conflict with the specific production environment. Note that modifying is small compared with the variant approach.

From a research point of view, the semi-generative system may not be the desired direction but it increases the system's competitiveness on the market. Since, it is a practical oriented system for industry, semi-generative approach may be a good candidate during the transition period. Industrial application of such current systems can be:

1. Speed up automation production.
2. Reduce the process planners participation.
3. Ensure the quality of process plan.

## 2.3 Tool Selection in CAPP

A cursory look at Figure. 2.2, which represents a complete computer-aided process planning system, indicates that if the full potential of CAPP is to be realized, selection of optimum cutting tools from tool database must be used for a given workpiece. It is a fraction of a detailed planning of a part and is performed after process selection has been done. Selecting a tool involves determining the correct material size and shape of the tool. This requires a great deal of information about both the machinable feature to be created, and the machining process to be used to create that feature.

Selecting the proper cutting tool for a given machining operation is one of the most important factors involved in obtaining high production at low cost. The need for selecting the proper tool is apparent when one recognizes that performance of an expensive n/c machine tool depends to a large measure on the capability of a very inexpensive cutting tool.

The industry provides a wide range of tool sizes and materials for use by n/c programmers in manufacturing facilities. The process engineer must decide which tool will best produce the required machining profile without frequent tool changing. This provides a need for developing such systems which could select minimum number of tools to machine the given profile. In view of this, research into automatic tool selection procedure is increasing rapidly.

## 2.4 Previous Work

While all tool selection procedures must take account of the main geometrical requirements in that the chosen tool must be able to produce the component to the desired accuracy and shape, the extent to which technological factors are taken into account varies significantly between the various systems which have been developed.

The expert module for tool selection COATS developed by Giusti et al. (1986) includes a certain amount of cutting technology since it predicts the machining behavior of a tool using a 'weight' which is based on the parameters of a tool. Tool selection by COATS is progressive, first of all choosing between external and internal, then verifying geometrical compatibilities with respect to machine and workpiece and selecting proposed insert material. Finally a fitness index which is the sum of the scores corresponding to actual value of angles, corner radius, cutting edge type and chip former geometry, is given to remaining toolholder-insert couples.

Chen et al. (1989) have proposed a tool selection method which takes into account the constraints acting during rough turning operations. The system is computationally very efficient because it does detailed calculations for only a small percentage of the tools that are feasible but it is only suitable for those cases where the entire area can be machined by one tool.

The system developed by van Houten (1986) make tool selection by finding all tools which can machine the respective areas of the given workpiece. The problem of finding the optimum set of tools is modeled as a shortest route problem in a unidirectional network which is solved by a dynamic programming technique. The method is efficient only when tools are to be selected from pre-defined tool sets, but it would be very time consuming when all the tools in the database are under consideration. The concept of pre-defined tool sets contradicts the existence and support of a complete tool database.

TECHTURN: a technologically oriented system for turned components (Hinduja, 1986) caters for most of the stages involved in the manufacturing of rotational parts. The basic structure of TECHTURN divides the module for tool selection into two sub modules. ATS, the automatic tool selection module and SITS, a semi-intelligent or manual tool selection module.

Early attempts to develop a tool selection module for TECHTURN was manual and the user had to key in the code for the toolholder as well as the insert. Later, the introduction of an automatic tool selection module (ATS) made the system to select tools automatically. ATS is again divided into two sub modules. The first one select tools for rough turning operations (Maropoulus and Hinduja, 1991) and the second system (Maropoulus and Hinduja, 1990) determine the tools for finishing operations performed on a CNC center. For both cases the system divides the procedure for the selection of tools into three stages. In the first stage, the database is searched and a list of tools which are feasible for the operation is determined. In the second stage, the cost of machining with each of these tools is determined. Finally, the system make tool collision checks for tool selection and determine the cutting conditions and cost for every tool from the selected list in order to predict the machining cost for a given workpiece.

SITS- A Semi-Intelligent Tool Selection System for Turned Components, (Hinduja, 1993) is also a tool selection module of TECHTURN which combine both manual and automatic approaches for the user to make tool selection. Automatic tool selection is made by the algorithm used for ATS module whereas for manual approach the user can override the system advice and make tool selection with intelligent advice from the system.

The knowledge-based system SIPS-Semi-Intelligent Process Selector (Nau & Luce,1987) selects tools by determining the type or family of tools which can successfully machine the part, which tool size fits the constraints of the various parts and finally which tool material must be used.

(Domazet,1990) used a somewhat hybrid approach in that both algorithms and rules were used for selecting tools. The non-algorithmic approach is implemented in the tool class and the toolholder type selection whereas other machining parameters and insert and toolholder dimensions determination use algorithmic approach for tool selection.

IRPPS-Interpreted rule based process planning system developed by (Saygin, 1992) is a rule based approach to determine selection of cutting tools and sequencing the machining operations. The logic used in the form of rules, for cutting tool selection is based on end conditions of each cutting plane defined to determine tool style, insert shape and feed direction for the given workpiece. The output of the system is a process plan including the sequencing of machining operations for external, internal and superimposed features as well as corresponding cutting tools and machinability data.

## 2.5 Deficiencies in Present Systems

Detailed literature survey in automatic tool selection in CAPP exhibit many different approaches for the selection of optimum cutting tools. Some systems use an algorithmic approach whereas the others takes the advantage of using expert system for tool selection. However, the system developed so far do not report on tool selection procedure for the case where there could be any type of basic external profile. Also the profile for the workpiece described by (Maropoulus and Hinduja, 1991) consider geometrical requirements for machining external profiles up to a certain extent. These profile could be an increasing, decreasing and/or for the cases where there is a recess or a shoulder. In case of an increasing or decreasing profiles, one tool is selected whereas a recess/shoulder case make use of two tools for machining of complete workpiece. Moreover, most current systems do not care for the availability of tools in the factory. A possible connection with workshop environment can result in a more realistic approach for making tool selection.

# CHAPTER III

# SYSTEM DESIGN

## 3.1 Introduction

The interface between CAD and CAM typically involves recognition and reinterpretation of a product definition data file in a CAD database. This is used for extracting manufacturing knowledge about the part so as to proceed with the process planning and other manufacturing activities. The system that has been developed in this study aims to recognize turned components of any type of basic external profile along with some superimposed features defined in a CAD database and make tool selection that can best machine the given part geometry without having tool collision with the workpiece.

With reference to Figure 2.2, current study is focused on five of the CAPP sub-systems.

1. CAD Database
2. Tool Database
3. Process Plan File
4. Surface Identification Module
5. Tool Selection Module

For the system these are defined in the following four main parts.

1. Part Definition Module
2. Tool Database
3. Tool Selection Module
4. Production Routing Sheet

The interface between the main parts is shown in Figure 3.1.

These modules are in fact separate executable programs. The interaction between these modules and the user interface are obtained by a separate unit that is the Main Module.

## 3.2 Part Definition Module

The basic elements to define a turned part are simple geometric shapes such as rectangles, trapezoids, convexes and concaves. A sequence of these basic elements constitutes form features, which, in turn define a turned part. These basic geometric shapes that comprise form feature on a part are called feature primitives. Therefore, with a limited number of feature primitives a wide range of turned parts can be drawn.

A part definition module that is used to process basic external profile of rotational parts includes six feature primitives. Figure 3.2 shows their name, shape, attributes, and major geometric characteristics. Each feature primitive is defined by its corresponding number of attributes. The attributes for left and right trapezoid shapes in incremental mode are defined by their right diameter, left

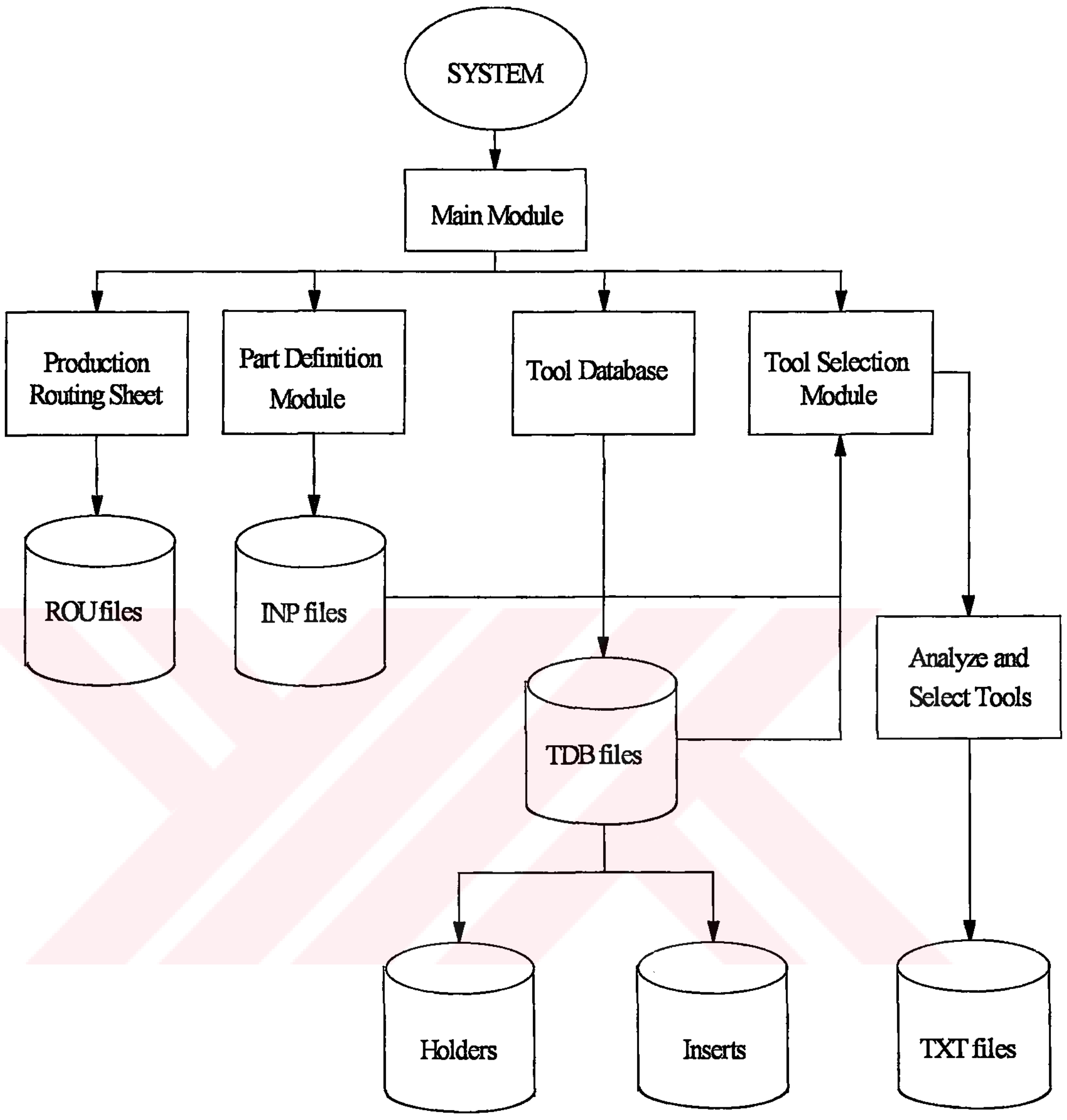



Figure 3.1 Interaction Between the Main Parts of the System

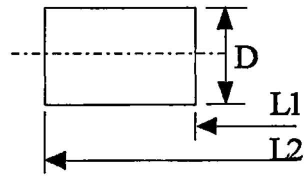
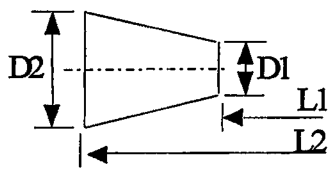
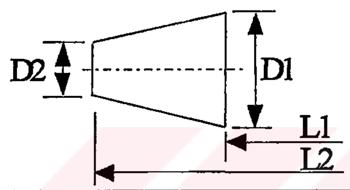
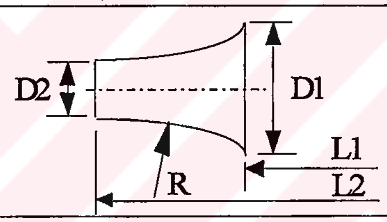
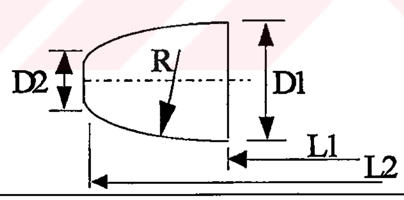
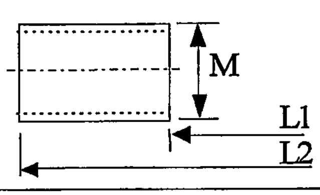
| Code | Name | Shape | Attributes |
|---|---|---|---|
| 1 | Rectangle |   | D, L1, L2 |
| 2 | Diverging Taper |   | D1, D2, L1, L2<br>D1 < D2 |
| 3 | Converging Taper |   | D1, D2, L1, L2<br>D2 < D1 |
| 4 | Concave |   | D1, D2, L1, L2, |
| 5 | Convex |   | D1, D2, L1, L2, |
| 6 | Threaded |   | L1, L2, M |

Figure 3.2 Feature Primitives

diameter, and the distance between the two ends. Whereas, in absolute mode the distance between two ends is defined from the right end of the workpiece giving an additional attribute to this shape. This is true for all the feature primitives defined in this study. Similarly, convex and concave shapes are defined by the starting point, the ending point, left end radius, right end radius and the radius of the arc. In case of rectangular and threaded feature primitives, besides diameter and length attributes, some superimposed features can also be defined. Figure 3.3 shows some of the superimposed features that can be defined. In case of chamfer, besides converging, diverging chamfer can also be defined on both ends of the cylindrical elements. Furthermore, fillets with certain fillet radius can also be superimposed on either ends of cylindrical segment.

Because a turned part is symmetric along its center line and all the shapes are orthogonal to this line, the relationships between feature primitives are straightforward. They can be arranged in the order of their X coordinate values. Therefore, a turned part can be defined with its feature primitives in the sequence of the X coordinate value of each shape comprising the part.

## 3.3 Tool Database

The system contains a turning tool database of all the tool holders mounted with inserts contained in Sandvik Turning Tool catalogue. These tools are used to machine external, internal and superimposed features.

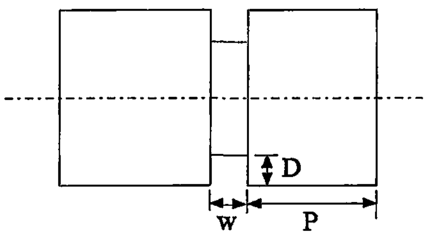
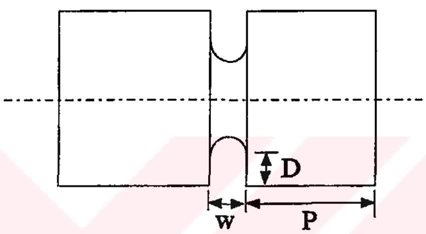
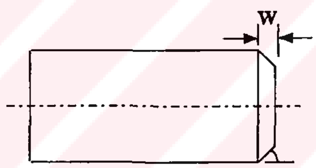
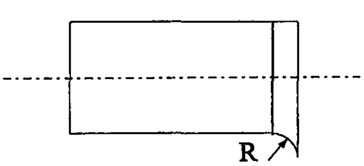
| Feature | Shape | Attributes |
|---|---|---|
| Rectangular Groove |  | P, D, W |
| Circular Groove |  | P, D, W |
| Chamfer |  | W, Angle |
| Fillet |  | R |

Figure 3.3 Superimposed Features

Following tool holders along with their inserts exist in the tool database.

1. External
2. Internal
3. Threading
4. Grooving

Detailed explanations about the use of this program are given in Appendix. Tool holders and inserts contained in tool database are entered according to their ISO codes. Also, special section is provided to the user to mark the availability of each tool in the factory. The database contains the ISO codes of about 4000 tool holders and inserts. These ISO codes provide an easy access for the system during tool selection procedure.

## 3.4 Tool Selection Module

Tool selection module mainly comprises three main sub-systems. These include

1. Feature Recognition Module
2. Part Geometry Analysis
3. Tool Selection Procedure

Main tasks accomplished by Tool Selection module are

1. Re-drawing part geometry file drawn in part definition module.

2. Analyzing part profile for tool collision with the workpiece geometry.
3. Making tool selection for rough and finish turning.
4. Graphically displaying selected tool holders for availability.
5. If not found available, displaying the first five from the selected ones.
6. Displaying also the ISO codes of the selected tool holders and inserts in a given order of priority.
7. Saving the selected tool holders and inserts as a text file for the user to observe for priority and availability.

### 3.4.1 Feature Recognition Module

Feature Recognition Module is designed to interpret and re-display the part geometry created by Part Definition Module. This module takes the files with extension .INP as input and redisplay them. The left end of the part geometry is taken as the reference point, X being the longitudinal coordinate along the axis of rotation and Y being the axial coordinate.

An example of the format of a file drawn by part definition module and used by feature recognition module is shown in Figure 3.4

### 3.4.2 Part Geometry Analysis

An algorithm for part geometry analysis is based on four steps. These are given as

```
18
 1 6   THRD        L1         0  L2        12  M      24
 1 *   Cham   end   rght  dir   down  size   2  angl   30
 2 3   CONT        L1        12  L2        14  D1     24     D2    20
 3 1   CYLN        L1        14  L2        17  D      20
 4 2   DIVT        L1        17  L2        22  D1     20     D2    30
 5 1   CYLN        L1        22  L2        26  D      30
 6 3   CONT        L1        26  L2        28  D1     30     D2    26
 7 1   CYLN        L1        28  L2        40  D      26
 8 2   DIVT        L1        40  L2        42  D1     26     D2    30
 9 1   CYLN        L1        42  L2        46  D      30
10 1   CYLN        L1        46  L2        66  D      38
11 1   CYLN        L1        66  L2        70  D      32
12 1   CYLN        L1        70  L2        74  D      38
13 3   CONT        L1        74  L2        78  D1     38     D2    30
14 1   CYLN        L1        78  L2        86  D      30
15 1   CYLN        L1        86  L2        90  D      36
16 3   CONT        L1        90  L2        92  D1     36     D2    32
17 1   CYLN        L1        92  L2       102  D      32
18 3   CONT        L1       102  L2       104  D1     32     D2    28
```

Figure 3.4 Output of a Data File

1. Adjust arc segment

2. Straight line approximation

3. Interface check

4. Calculation of entrance and in-copy angles

During the analysis, each feature primitive defined in a workpiece is designated with its left end as (x1, y1) and right end as (x2, y2).

On a workpiece, an angle faced by the tool moving from right to left or from left to right is given as entrance angle whereas, an angle on its trailing edge is defined as an in-copy angle. For a tool moving from right to left these are defined as shown in the Figure 3.5. Tool moving from left to right will have an entrance angle as in-copy angle and vice versa.

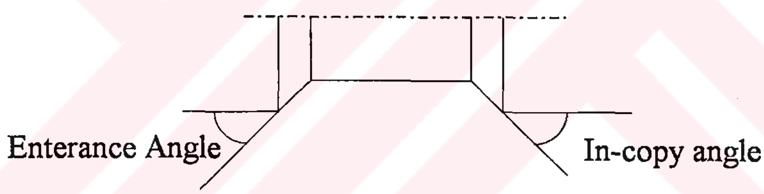



Figure 3.5 Part Geometry Angles

Rules discussed in the following sections are valid where the machining direction is from right to left. For tool moving from left to right same algorithm is applicable with the exception that y1 and y2 are interchanged throughout the analysis.

Searching through Sandvik catalogue, it was found that a copying tool is capable of machining a workpiece with a maximum in-copy angle of 50°.

Therefore, part geometries with in-copy angles greater than 50° are approximated with this maximum limit.

### 3.4.2.1 Adjust Arc Segments

The first step towards the implementation of this algorithm is the adjustment of arc segments present in the workpiece geometry. Depending on, whether the segment is a concave or convex type the system locates the center of curvature (of the arc) joining the two end points and checks if it exists between the end points of it or not. In case the center point lies between the two ends, that concave or convex segment is divided into two feature primitives such that each has one edge at the intersection of a vertical line passing through the center point. This internally increases the number of feature primitives for the system.

### 3.4.2.2 Straight Line Approximation

Second step is the straight line approximation of those concave and convex segments present in part geometry with their y1 less than y2. In case of concave segment points (x1, y1) and (x2, y2) are simply joined with each other. This converts the given feature primitive into a converging taper. It is explained as shown in the Figure 3.6.

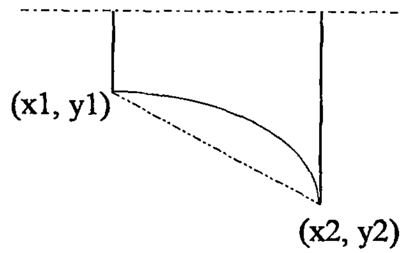



Figure 3.6 Taper Approximation of Concave Segment

In case of convex segment with its y1 less than y2, an intersection point T of the tangents drawn from points (x1, y1) and (x2, y2) is found. Joining point T with (x1, y1) and also with (x2, y2) converts this convex segment into a cylinder and taper segment or two taper segments depending on the center of curvature of the arc segment as shown in Figure 3.7. This analysis internally increases the number of feature primitives present in part geometry.

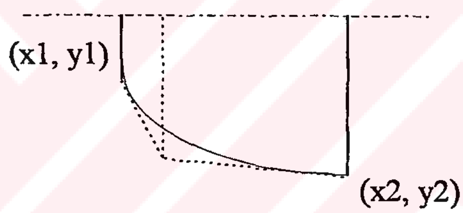



Figure 3.7 Taper Approximation of Convex Segment

3.4.2.3 Interface Checks

In third step an interface check is made for feature primitives adjacent to each other. The criterion is checked for the cases where y1 of feature primitive 2 is greater than y2 of the one prior to that as shown in Figure 3.8.

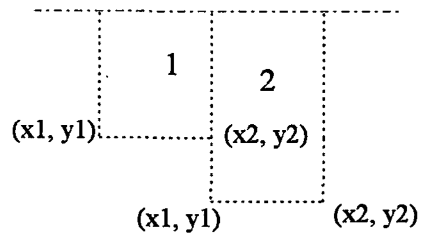



Figure 3.8 Interface Check

Dashed lines show that feature primitive 1 & 2 can be converging or diverging tapers, concave or convex segments or cylindrical segments. For each case rule, in the form of IF-THEN type of statements are defined for the system depending on the type of part profile.

Two cases exists for interface check in part geometry analysis.

3.4.2.3.1 Case I

First one is considered where the interface check does not exceed the limit for maximum in-copy angle of 50°.

Following situations may occur where the interface can be due to

1. A cylindrical segments and a diverging taper or a concave or convex segment.
2. A cylindrical segment and a converging taper
3. Two cylinders in contact with each other.

These are explained as shown in the Figure 3.9.

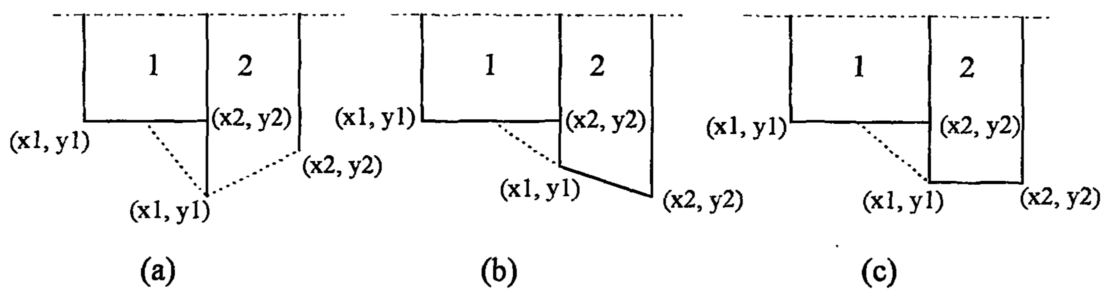



Figure 3.9 Interface Check (i)

Dashed lines for Figure 3.9 (a) show feature primitive 2 to be a concave or convex segment or a diverging taper. For the cases discussed in Figure 3.9, the given profile is approximated with a line joining the center point of the cylindrical segment 1 and point (x1, y1) of 2 forming an in-copy angle on a workpiece profile. This analysis increases the number of feature primitives present in part geometry with an addition of a converging taper.

In another situation, the interface is checked where feature primitive 1 are a converging taper and feature primitive 2 can be any one of the shapes discussed in Figure 3.9.

This is explained as shown in the Figure 3.10.

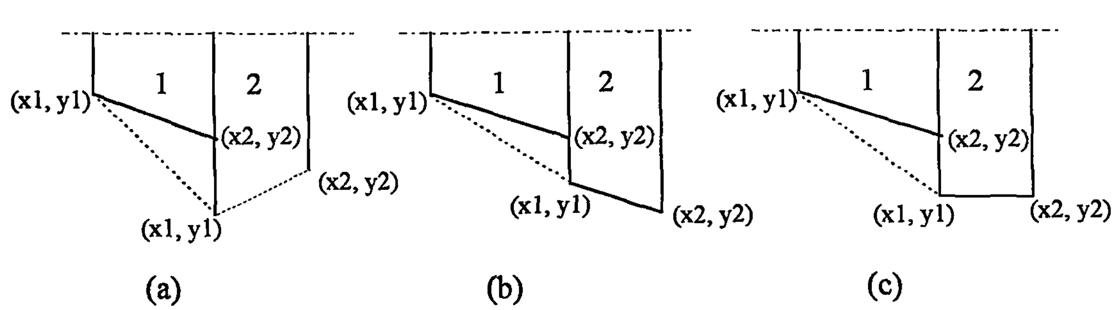



Figure 3.10 Interface Check (ii)

Again for these cases, part geometry is approximated with a line joining point (x1, y1) of feature primitive 2 with that of feature primitive 1.

Another situation can arise where the interface is due to a concave or convex segment or a diverging taper and any one of the shapes discussed for feature primitive 2 in Figure 3.9. These cases are explained as shown in the Figure 3.11.

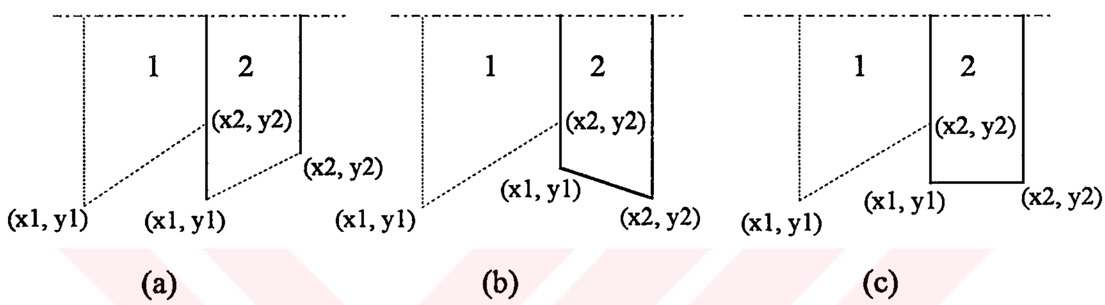



Figure 3.11 Interface Check (iii)

Dashed lines for feature primitive 1 shows feature primitive to be a concave or convex segment or a diverging taper. In this case, however, the y coordinate of the starting point of feature primitive 1 is first checked with that of feature primitive 2. If y1 of 1 is found greater than or equal to y1 of 2, the given feature is approximated with a straight horizontal line from point (x1, y1) of 2 till the point of intersection with feature primitive 1. This leaves the rest of the portion to be machined with a left hand tool. In case, point (x1, y1) of 1 is less than (x1, y1) of 2, the two points are joined with each other.

3.4.2.3.2 Case II

If the interface check exceeds the maximum limit for the in-copy angle of 50°, feature primitives prior to those under consideration are also taken care off. This is explained as shown in the Figure 3.12

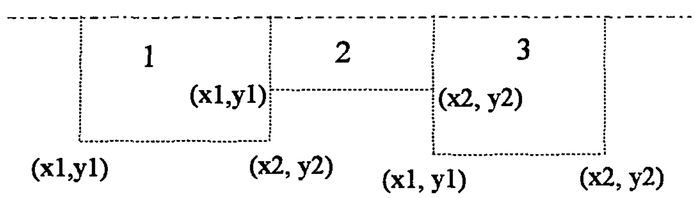



Figure 3.12 Interface Check (iv)

Dashed lines show feature primitives 2 and 3 to be a combination of any one of the shapes discussed in Figures 3.9, 3.10 and 3.11. Also, feature primitive 1 can be of any one the feature primitives defined in part definition module. In this case, y coordinate of the end point of feature primitive 1 is checked with the starting point of feature primitive 3. Following two situations may arise. Point y2 of 1 can either be greater than or equal to y1 of 3 or it could be less than y1 of 3.

For the case where y2 of 1 is greater than or equal to y1 of 3, a horizontal line is drawn from point (x1, y1) of 3 to the point of intersection of feature primitive 1 irrespective of the shape of the second feature primitive. The profile left unmachined can be machined using grooving tools recommended by the system to the user.

In another situation where y2 of 1 is less than y1 of 3 but greater than y1 of 2, a line is drawn from point (x1, y1) of 3 to point (x2, y2) of 1. If the slope of this line exceed the maximum limit for the in-copy angle of 50°, the given feature is approximated with a line having a slope of 50° and drawn from point (x1,y1) of 3 till the starting point of feature primitive 2. This is defined as Change angle for the system. The area left unmachined for feature primitive 2 can again be machined with a grooving tool. For the case where y2 of 1 is less than y1 of 2, a line is drawn from point (x1, y1) of 3 to point (x1, y1) of 2. Again, if the slope of this line exceed maximum in-copy angle limit of 50° or feature primitive 2 is the last feature primitive of the workpiece, the given feature is approximated with Change angle defined in the previous paragraph.

In case of y2 of 1 equal to y1 of 2 and point (x1, y1) of 1 greater than or equal to point (x1, y1) of 3, a horizontal line is drawn from point (x1, y1) of 3 till the point of intersection of feature primitive 1. Area left unmachined is machined using a grooving tool.

### 3.4.2.4 Calculation of Entrance and In-copy Angles

In fourth and final step, entrance and in-copy angles for all the feature primitives present in part geometry are calculated. In this case, feature primitives with their y1 less than y2 and an in-copy greater than 50° are considered.

If such a situation occur, feature primitive prior to one under consideration is also taken care off. This is explained as shown in the Figure 3.13.

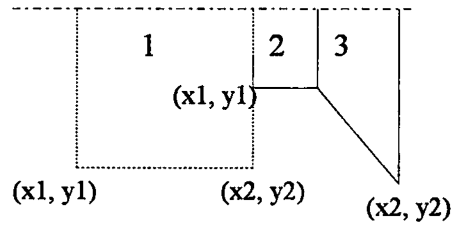



Figure 3.13 Entrance and In-Copy Angle Checks(a)

Dashed lines show feature primitive 1 to be of any shape defined in part definition module. For the case where feature primitive 2 is a cylindrical segment with (x1, y1) of 3 equal to (x2, y2) of 2, a line is joined from point (x2, y2) of converging taper to the center of cylindrical segment. This is true for the case where the joining of two points gives an in-copy angle less than or equal to 50°. However, if the angle is greater than this value, point (x2, y2) of feature primitive 1 is also considered. In this case, point (x2, y2) of 1 is checked with point (x1, y1) of 1. If the y coordinate of the end point of feature primitive 1 is greater than y1 of cylindrical segment, the given form feature is converted into cylindrical segment. This requires the rest of the machining area to be machined with the grooving tools. For the case where y2 of 1 is less than y1 of 2, the given feature is approximated with a Change angle.

In case of feature primitive other than cylindrical segment, again two cases are considered as shown in the Figure 3.14.

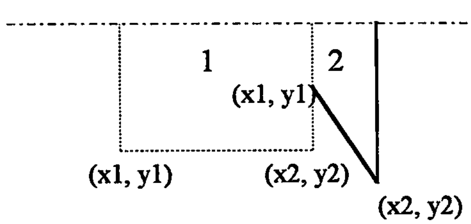



Figure 3.14 Entrance and In-Copy Angle Checks (b)

Dashed lines show feature primitive 1 to be of any shape defined in part definition module. The first case is where (x2, y2) of 1 is less than (x2, y2) of 2. In this case a line is drawn from point (x2, y2) of 2 with that of 1. However, if the joining exceeds the maximum limit for the angles the given feature is again approximated with a taper segment defined as change angle previously.

Second situation can be where (x2, y2) of 1 and (x1, y1) of 2 are equal, and (x1, y1) of 1 is greater than (x2, y2) of 1. In this case if y1 of feature primitive 1 is greater than or equal to that of 2, feature primitive 2 is approximated with a Change angle. However if y1 of 1 is less than that of 2, a line is drawn from (x2, y2) of 2 to (x1, y1) of 1. Again if the joining of line exceeds the maximum limit for the angles, the given feature is approximated with a taper segment defined as change angle.

The inference logic of part geometry analysis is shown in Figure 3.15

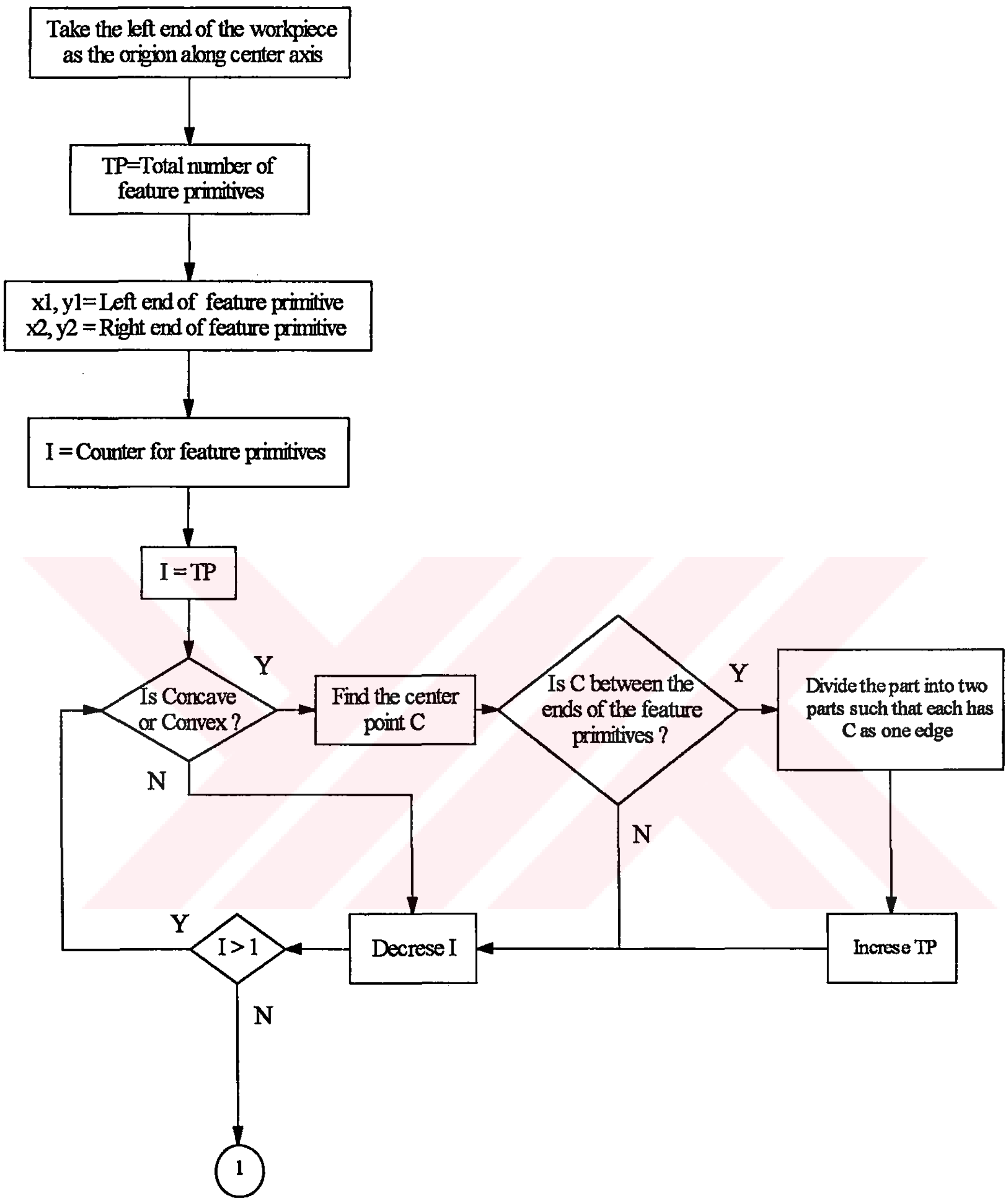



Figure 3.15 Inference Logic of Part Geometry Analysis

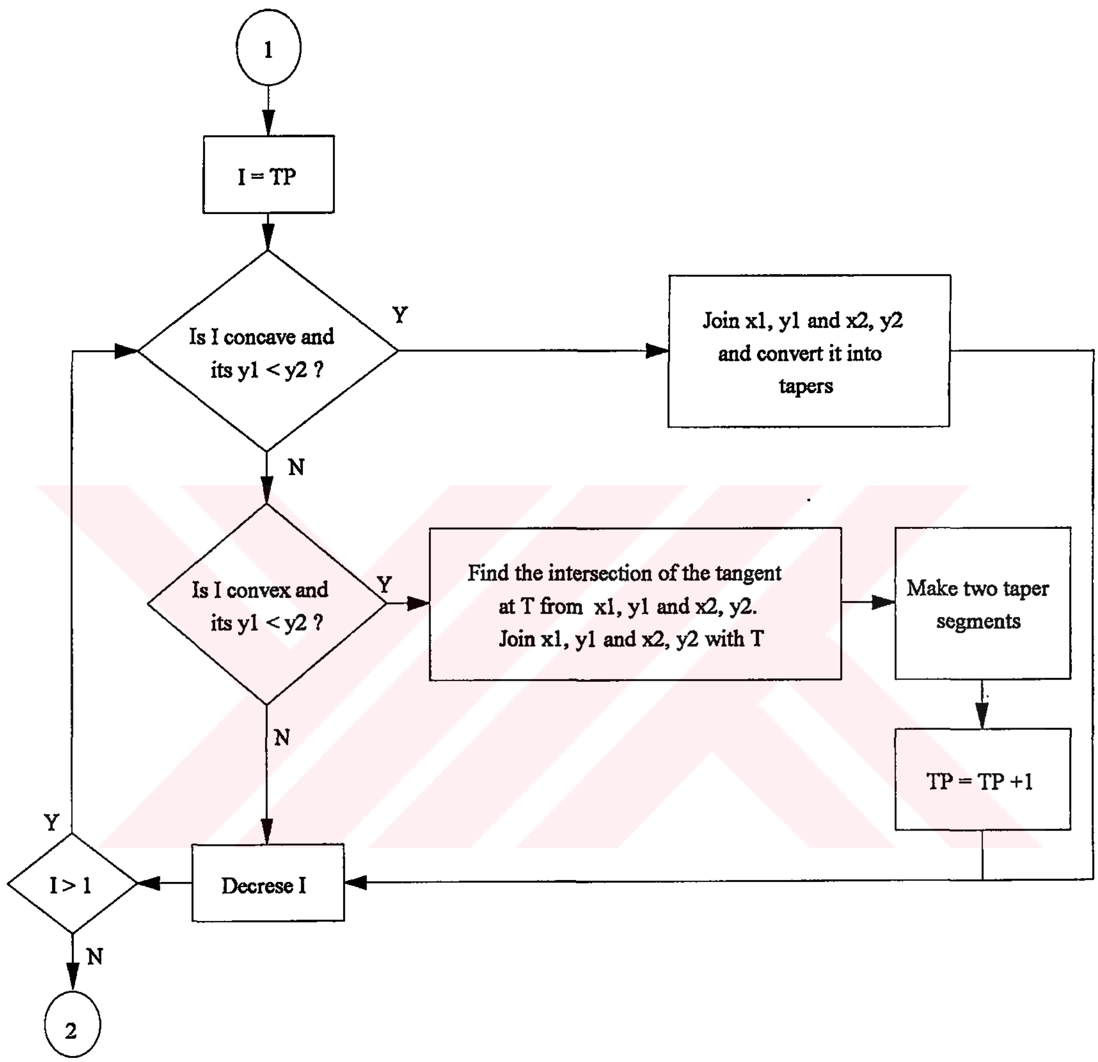



Figure 3.15 (Continued)

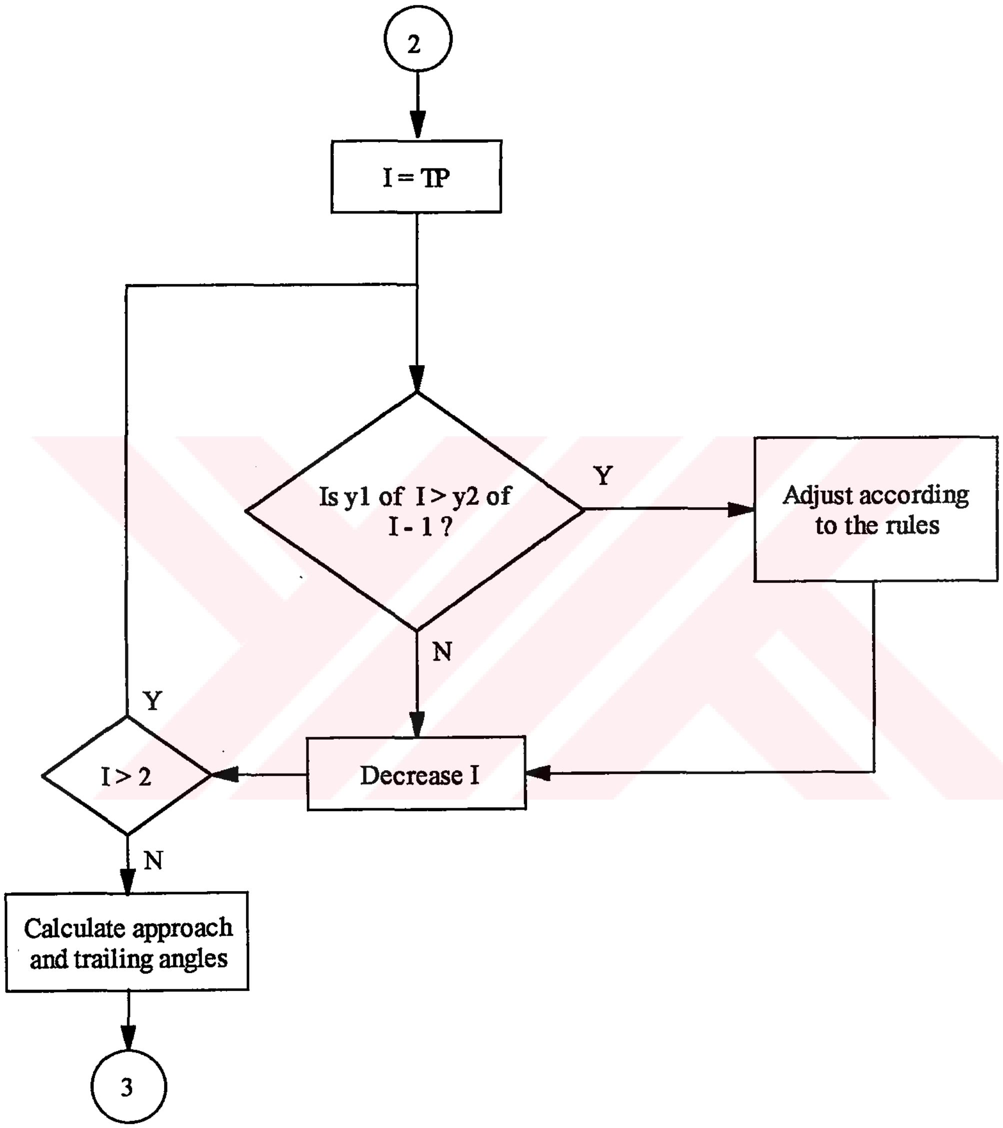



Figure 3.15 (Continued)

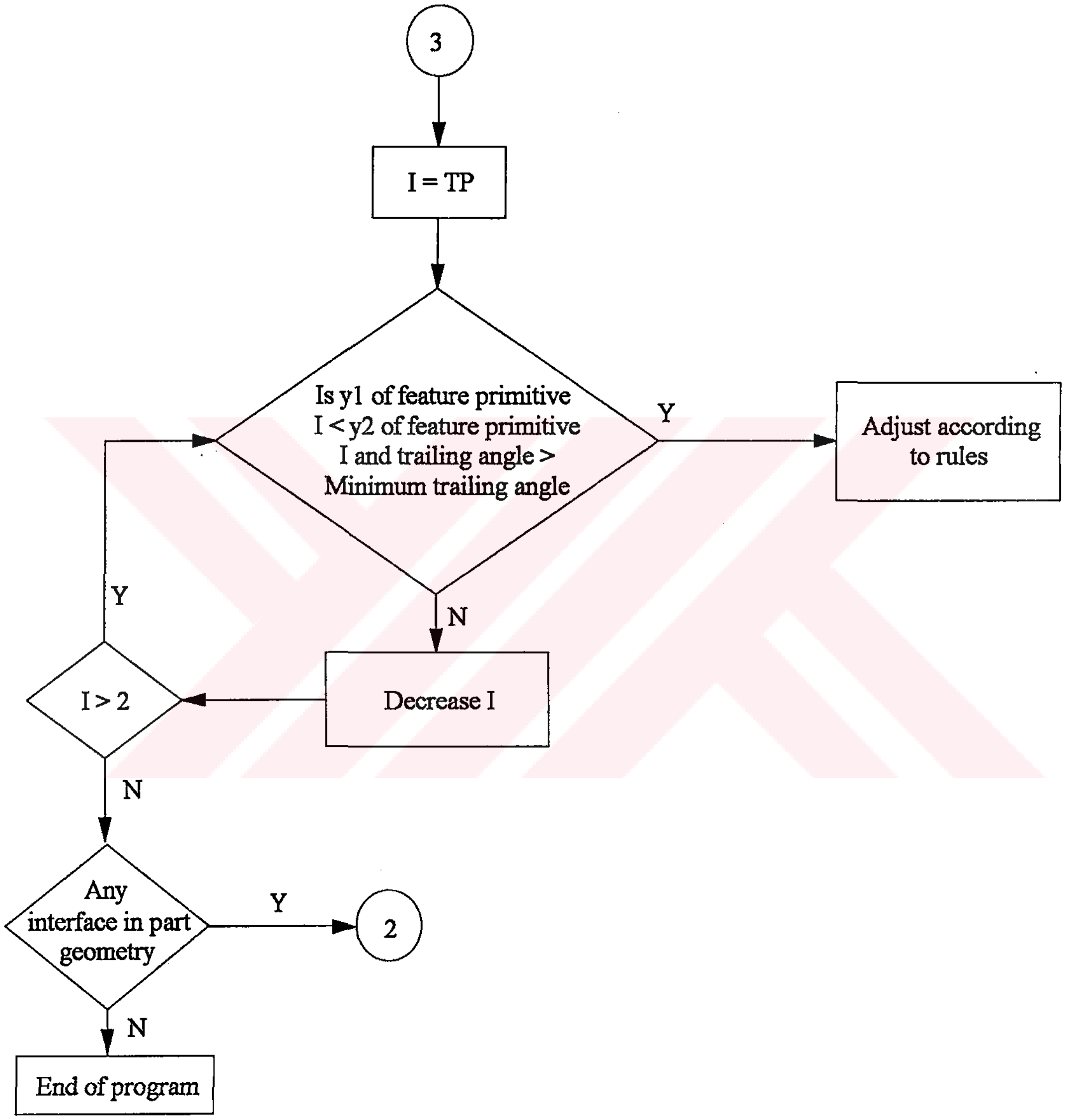



Figure 3.15 (Continued)

### 3.4.3 Tool Selection Procedure

A turning tool selection include the selection of indexable inserts and tool holders. Tool selection procedure require the selection of tool holders with an insert clamping system such that the selected tool should not have any tool collision with the workpiece profile. Tool selection is mainly divided into two parts.

1. Tool holder selection
2. Insert selection

#### 3.4.3.1 Tool Holder Selection

The algorithm for tool holder selection developed in this study is based on calculation of slopes for all the elements in the machining profile performed in part geometry analysis.

According to ISO Standards, properties of tool holders are specified with 10 parameters. Each parameter is shown either with a capital letter or a number, and the designation that is simply the combination of those parameters define the ISO Standard of tool holder. The designation include locking system, shape of the insert on the tool, tool style, insert clearance, feed direction, shank height, shank width, tool length and cutting edge length of the insert on the tool. Figure 3.16 shows the parameters in the designation of tool holders.

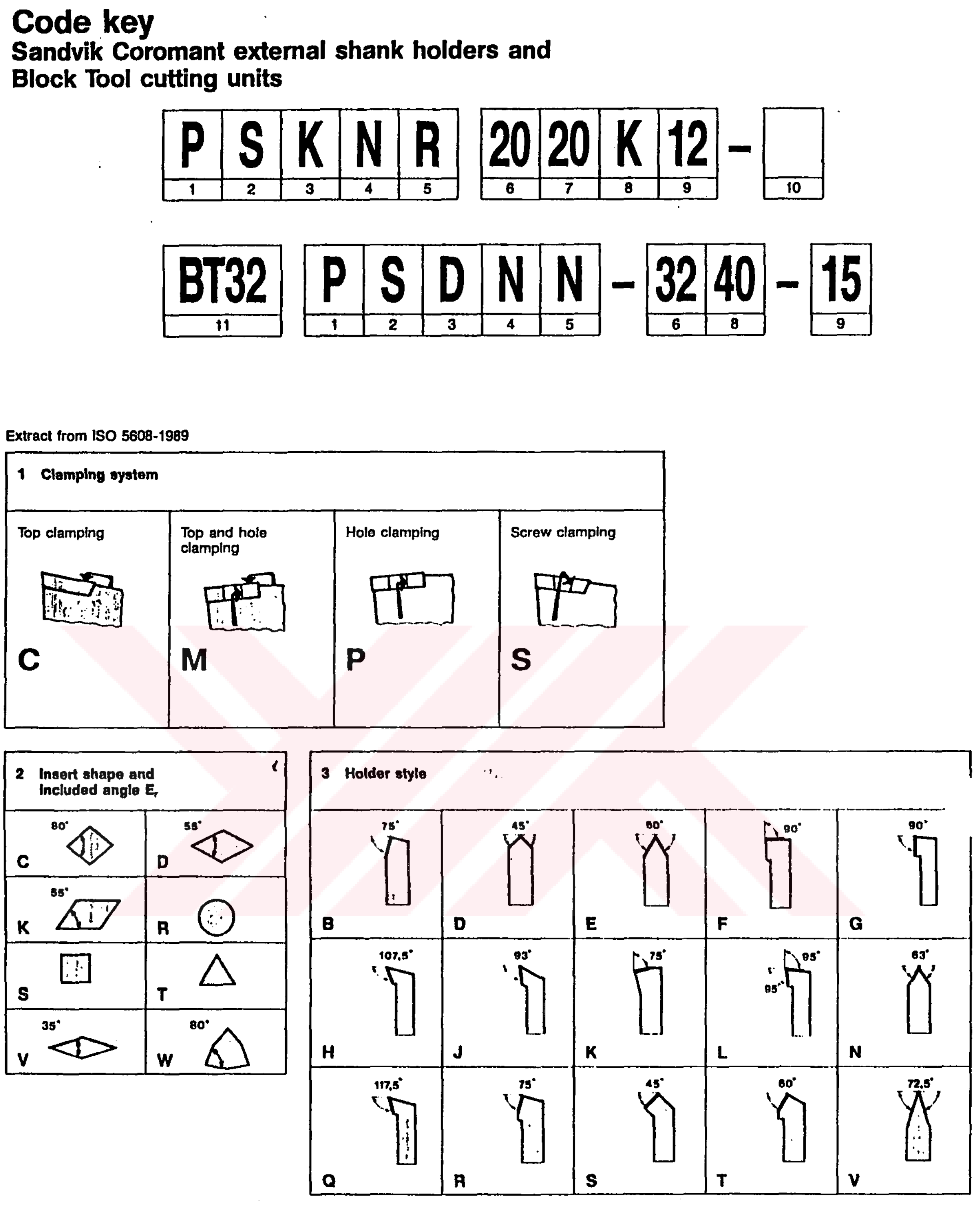



Figure 3.16 Designation of Tool Holders

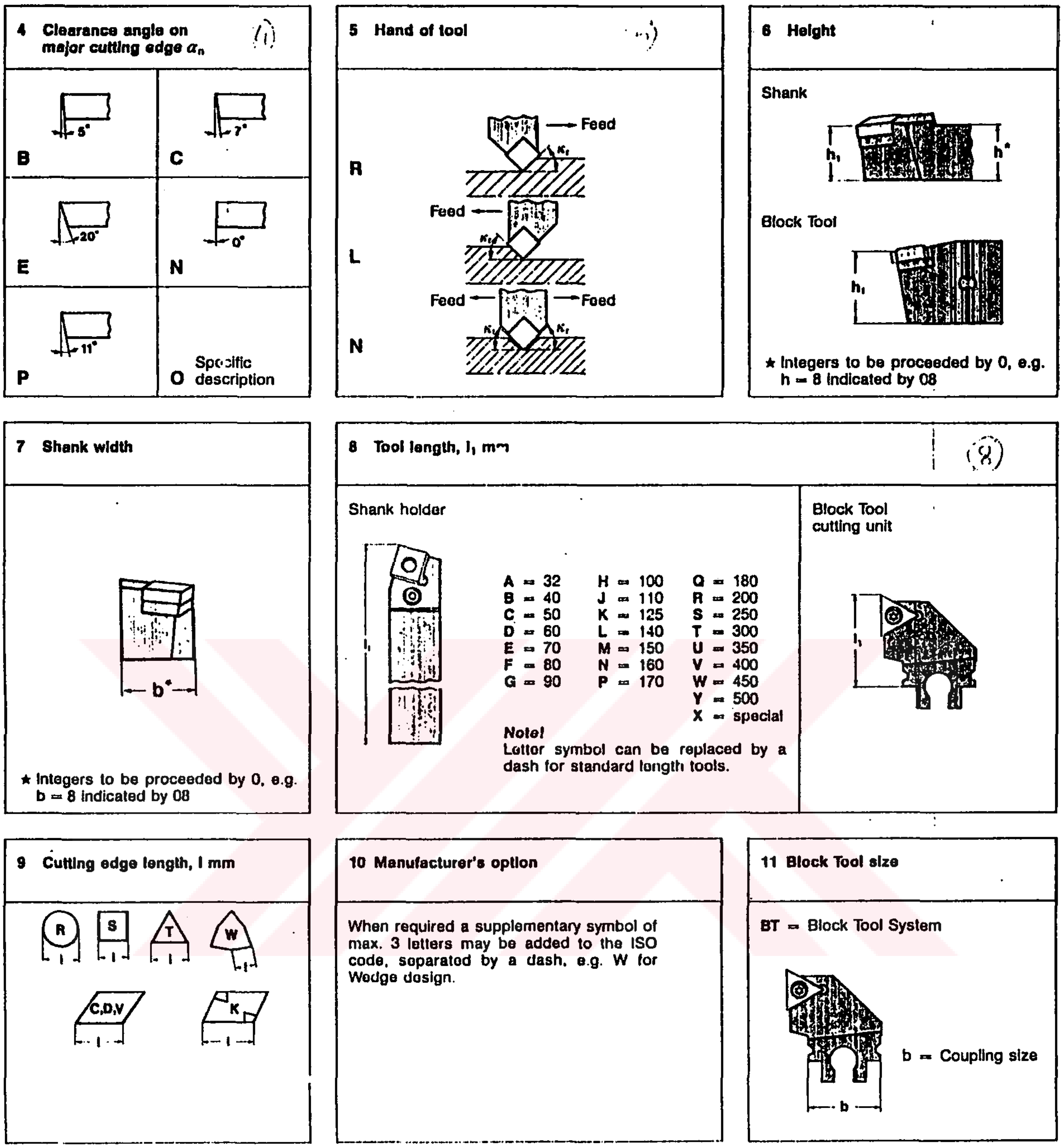



Figure 3.16 (continued)

During the selection procedure two basic tool parameters i.e. approach angle and trailing angle are considered. On a tool these are defined as shown in the Figure 3.17

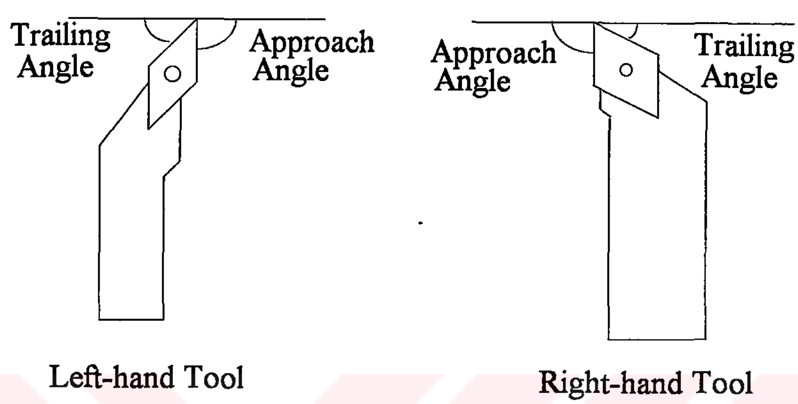



Figure 3.17 Tool Angles Designation

Approach angle is the entering angle of the type of tool holder defined in third ISO code. Since, the second ISO code define the shape and angle of the insert, summation of insert and entering angles and subtracting them from 180° determine the trailing angle of the tool holder type.

To avoid any tool collision with the workpiece, tool holder selected from the tool database are required to have greater approach and trailing angles than maximum registered entrance and in-copy angle defined on part geometry during the analysis.

Two more parameters i.e. feed direction and the clearance angle on the trailing edge of the tool holder are also considered during the selection procedure. These are important, since, a part geometry may require feed direction not suitable for a specific number of tools. Also, for a specific group of tools, the clearance angles is different depending on the manufacturer ( _______ , 1993).

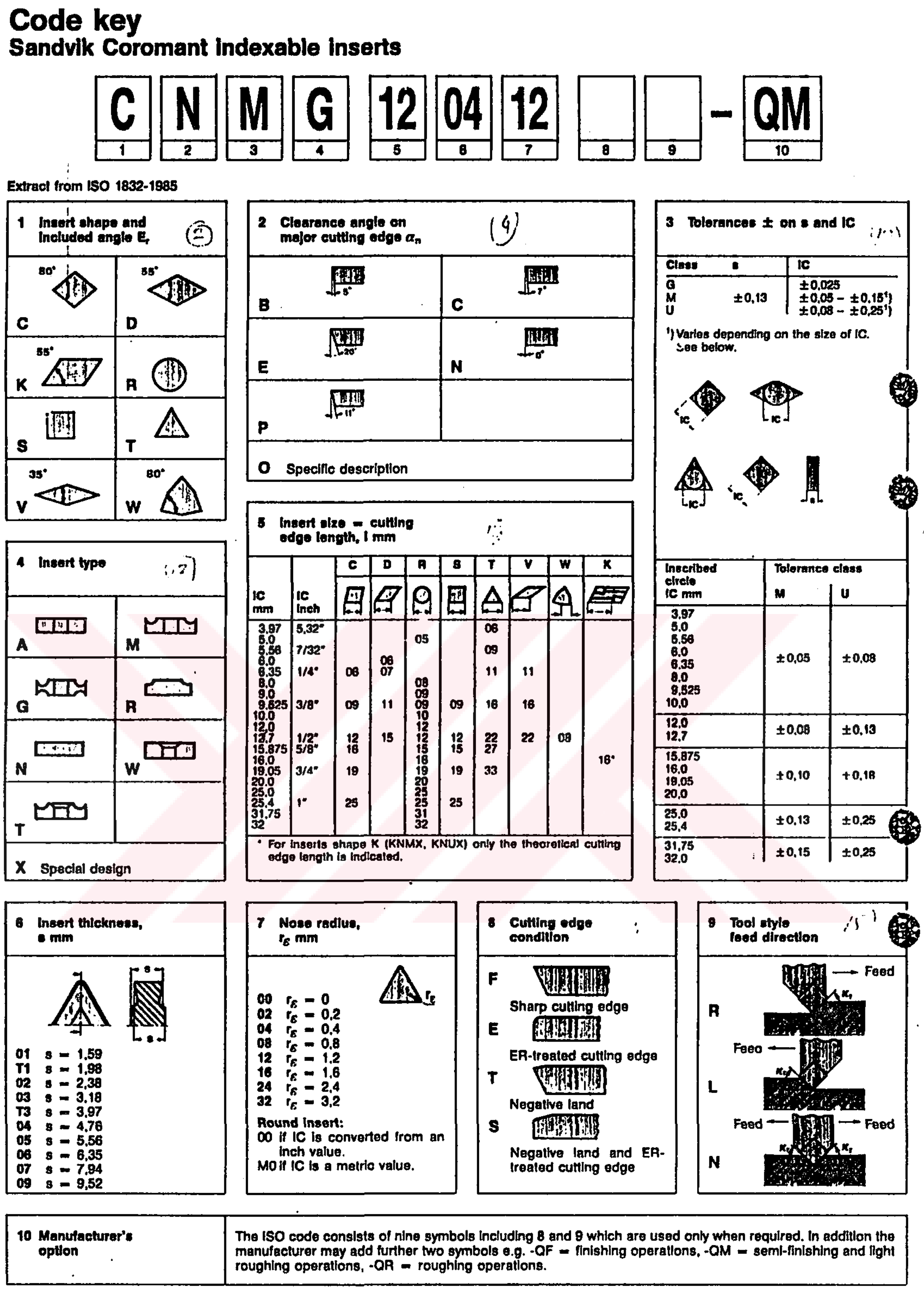
3.4.3.2 Insert Selection

Insert selection is made after the type of tool holder is selected. Depending on the type of tool holder selected for the given machining operation, the corresponding inserts are selected from tool database.

Similar to the designation of tool holders, properties of inserts are also specified with 9 parameters. Each parameter is shown with a capital letter or a number and the designation which is simply the combination of those parameters, defines the geometry of the insert. The designation include shape, clearance angle, tolerance on insert, type of insert, cutting edge length, thickness of insert, nose radius, cutting edge condition, feed direction (direction of cutting) and manufacturing option. Figure 3.18 shows the parameters in the designation of inserts.

3.4.3.3 Tool Class Selection

The tool class is defined as a group of tools for a specific turning operation, with specific design, clamping system, and feature and produced by the specific manufacturers. By grouping tools in classes, the search is focused and directed to a limited tool data area related to the selected class.



# Code key
## Sandvik Coromant indexable inserts

| C | N | M | G | 12 | 04 | 12 | | | - | QM |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | | 10 |

Extract from ISO 1832-1985

**1 Insert shape and included angle $\varepsilon_r$**

C 80°, D 55°, K 55°, R, S, T, V 35°, W 80°

**2 Clearance angle on major cutting edge $\alpha_n$**

B 5°, C 7°, E 20°, N 0°, P 11°

O Specific description

**3 Tolerances ± on s and IC**

| Class | s | IC |
|---|---|---|
| G | | ±0,025 |
| M | ±0,13 | ±0,05 – ±0,15[1] |
| U | | ±0,08 – ±0,25[1] |

[1] Varies depending on the size of IC. See below.

IC, IC, IC, IC, s

| Inscribed circle IC mm | Tolerance class M | U |
|---|---|---|
| 3,97<br>5,0<br>5,56<br>6,0<br>6,35<br>8,0<br>9,525<br>10,0 | ±0,05 | ±0,08 |
| 12,0<br>12,7 | ±0,08 | ±0,13 |
| 15,875<br>16,0<br>19,05<br>20,0 | ±0,10 | +0,18 |
| 25,0<br>25,4 | ±0,13 | ±0,25 |
| 31,75<br>32,0 | ±0,15 | ±0,25 |

**4 Insert type**

A, M, G, R, N, W, T

X Special design

**5 Insert size = cutting edge length, l mm**

| IC mm | IC inch | C | D | R | S | T | V | W | K |
|---|---|---|---|---|---|---|---|---|---|
| 3,97 | 5,32" | | | | | 06 | | | |
| 5,0 | | | | 05 | | | | | |
| 5,56 | 7/32" | | | | | 09 | | | |
| 6,0 | | | 06 | | | | | | |
| 6,35 | 1/4" | 06 | 07 | | | 11 | 11 | | |
| 8,0 | | | | 08 | | | | | |
| 9,0 | | | | 09 | | | | | |
| 9,525 | 3/8" | 09 | 11 | 09 | 09 | 16 | 16 | | |
| 10,0 | | | | 10 | | | | | |
| 12,0 | | | | 12 | | | | | |
| 12,7 | 1/2" | 12 | 15 | 12 | 12 | 22 | 22 | 08 | |
| 15,875 | 5/8" | 16 | | 15 | 15 | 27 | | | |
| 16,0 | | | | 16 | | | | | 16* |
| 19,05 | 3/4" | 19 | | 19 | 19 | 33 | | | |
| 20,0 | | | | 20 | | | | | |
| 25,0 | | | | 25 | | | | | |
| 25,4 | 1" | 25 | | 25 | 25 | | | | |
| 31,75 | | | | 31 | | | | | |
| 32 | | | | 32 | | | | | |

* For inserts shape K (KNMX, KNUX) only the theoretical cutting edge length is indicated.

**6 Insert thickness, s mm**

01 s = 1,59
T1 s = 1,98
02 s = 2,38
03 s = 3,18
T3 s = 3,97
04 s = 4,76
05 s = 5,56
06 s = 6,35
07 s = 7,94
09 s = 9,52

**7 Nose radius, $r_\varepsilon$ mm**

00 $r_\varepsilon = 0$
02 $r_\varepsilon = 0,2$
04 $r_\varepsilon = 0,4$
08 $r_\varepsilon = 0,8$
12 $r_\varepsilon = 1,2$
16 $r_\varepsilon = 1,6$
24 $r_\varepsilon = 2,4$
32 $r_\varepsilon = 3,2$

Round insert:
00 if IC is converted from an inch value.
M0 if IC is a metric value.

**8 Cutting edge condition**

F Sharp cutting edge
E ER-treated cutting edge
T Negative land
S Negative land and ER-treated cutting edge

**9 Tool style feed direction**

R Feed
L Feed
N Feed Feed

**10 Manufacturer's option**

The ISO code consists of nine symbols including 8 and 9 which are used only when required. In addition the manufacturer may add further two symbols e.g. -QF = finishing operations, -QM = semi-finishing and light roughing operations, -QR = roughing operations.

Figure 3.18 Designation of Inserts

Since the tool class that can be used to machine external and superimposed features is selected, the data files related to the tools containing external and superimposed tool holders with inserts are processed for the specific workpiece geometry. Tool class selection algorithm is based on the selection of tools in a given order of priority. Depending on the type of operation i.e. for rough and finish turning, the priority for the selection of tools is different.

3.4.3.3.1 Rough Turning

Depending on part geometry, the first priority is given to the type of clamping system on a tool ( _______ , 1993). For rough turning operation clamping systems in the order of decreasing priority is

1. T-Max P type
2. T-Max type
3. T-Max U type
4. T-Max S type

Also, the use of stronger inserts i.e. the inserts with a larger plan angle are given higher priority. Inserts in the order of decreasing priority are

1. Square Insert
2. An insert with the plan angle of 80°
3. Triangular Insert
4. An insert with the plan angle of 55°
5. An insert with the plan angle of 35°

In an algorithmic form, it is explained in Figure 3.20. Incr. in flow charts stands for increase.

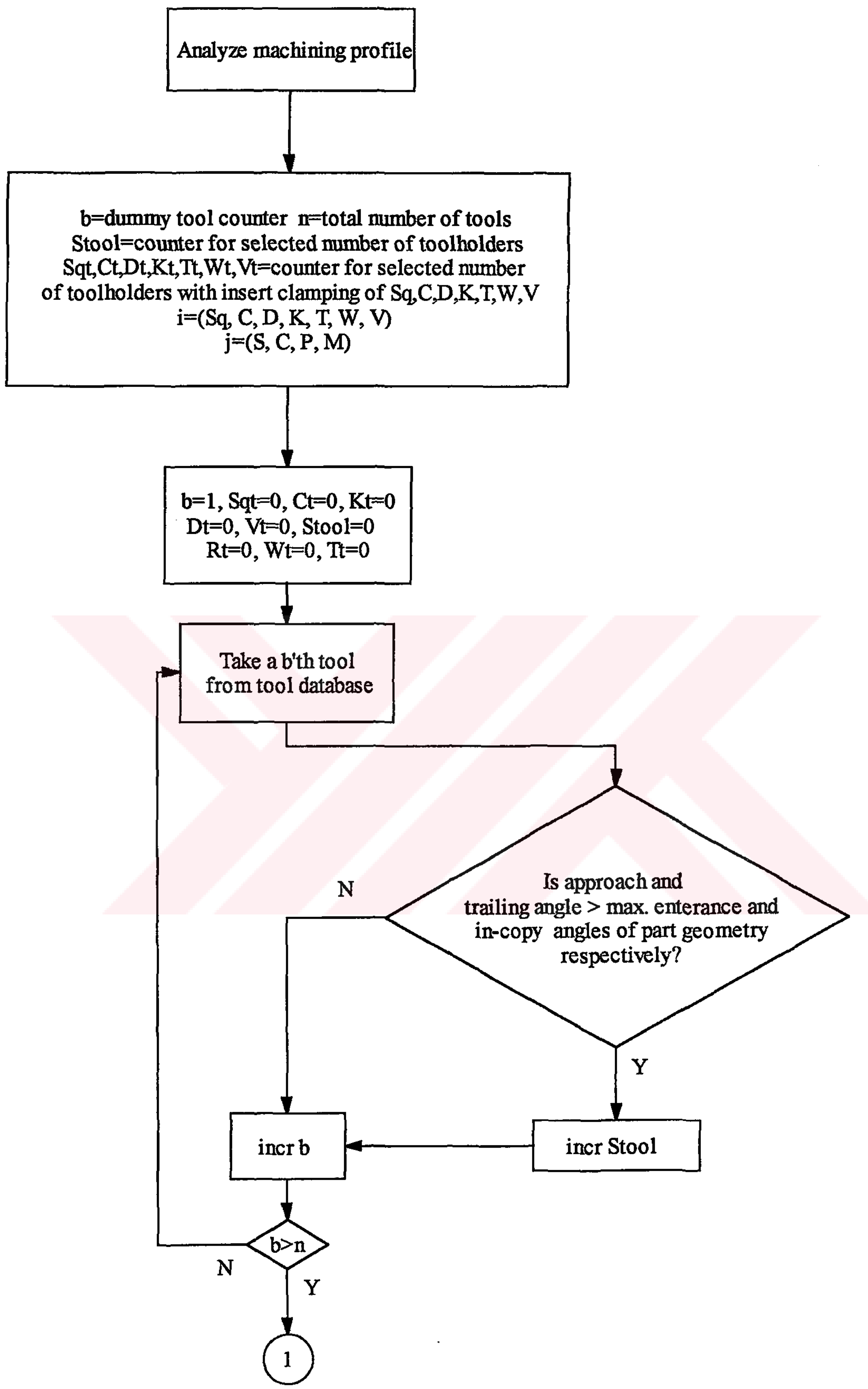



Figure 3.19 Inference Logic for Tool Selection in Rough Turning

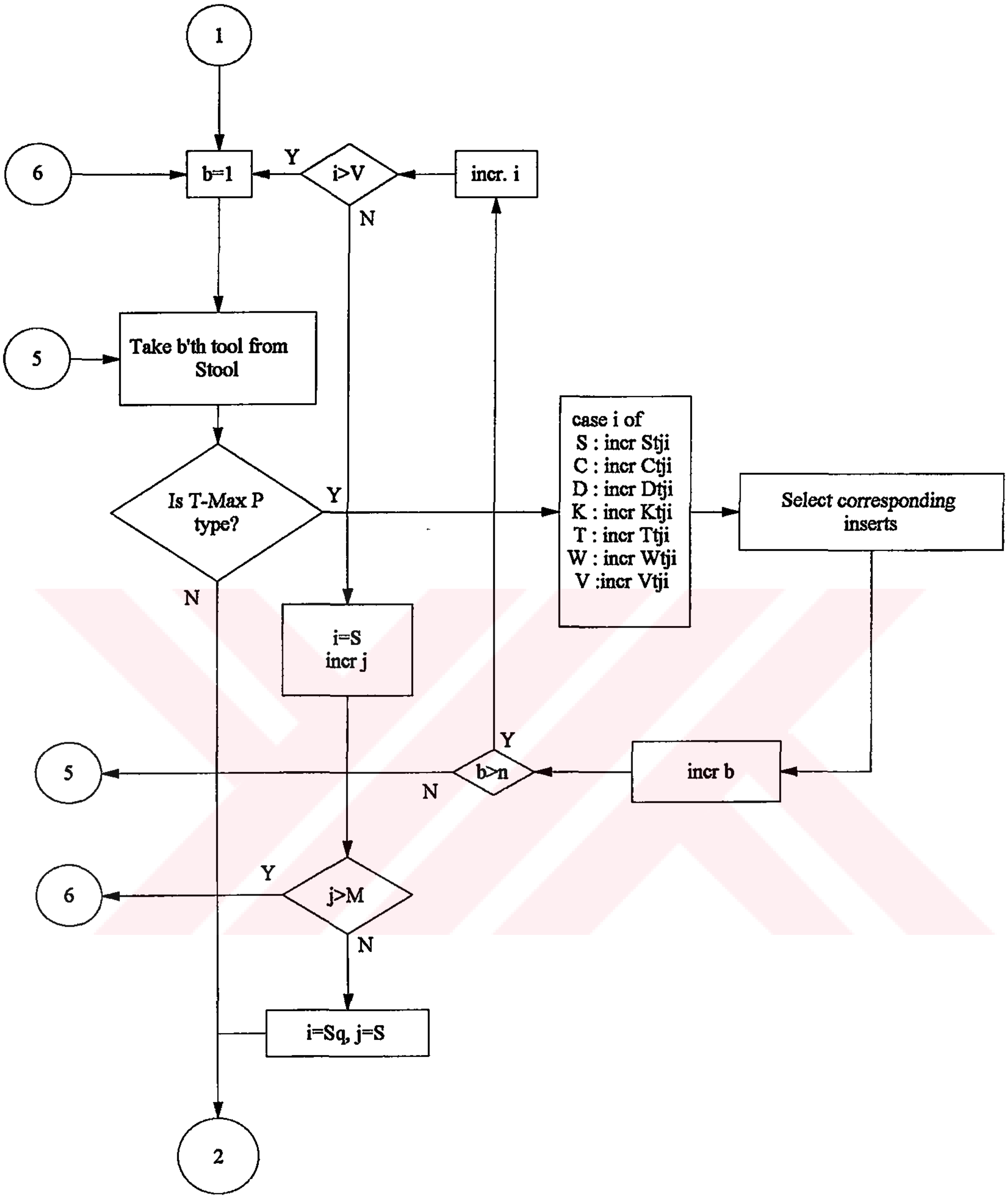



Figure 3.19 (Continued)

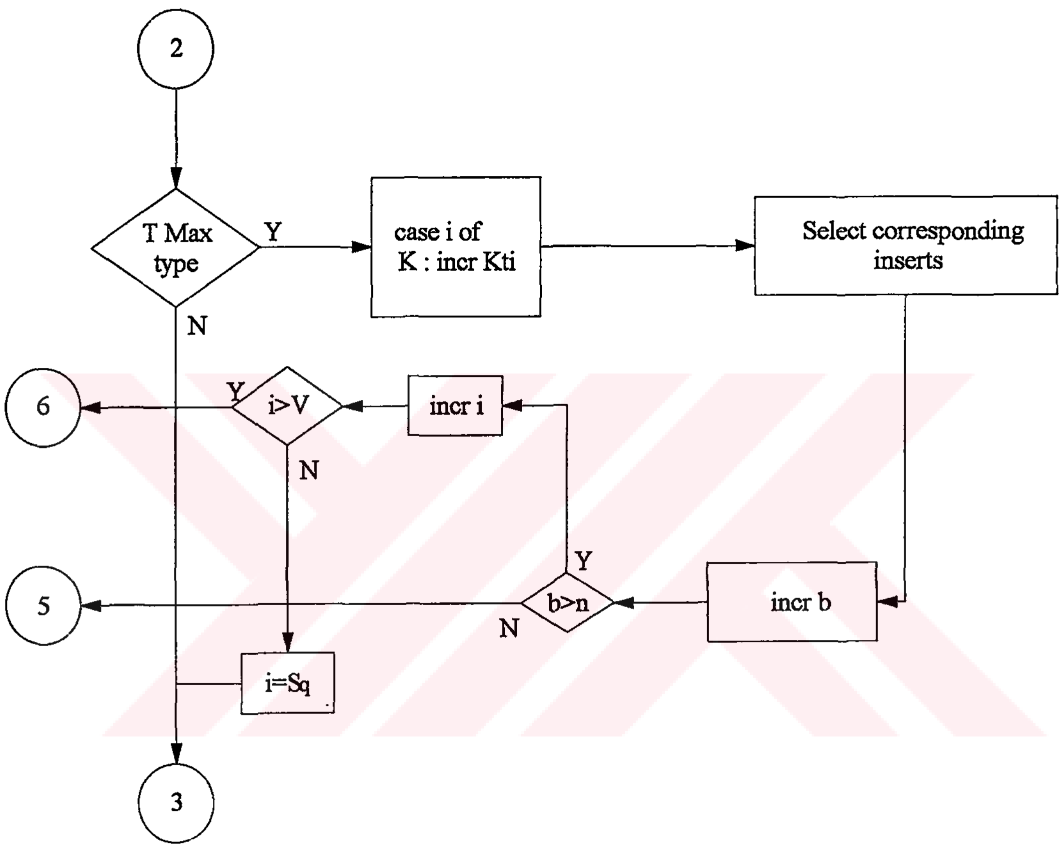



Figure 3.19 (Continued)

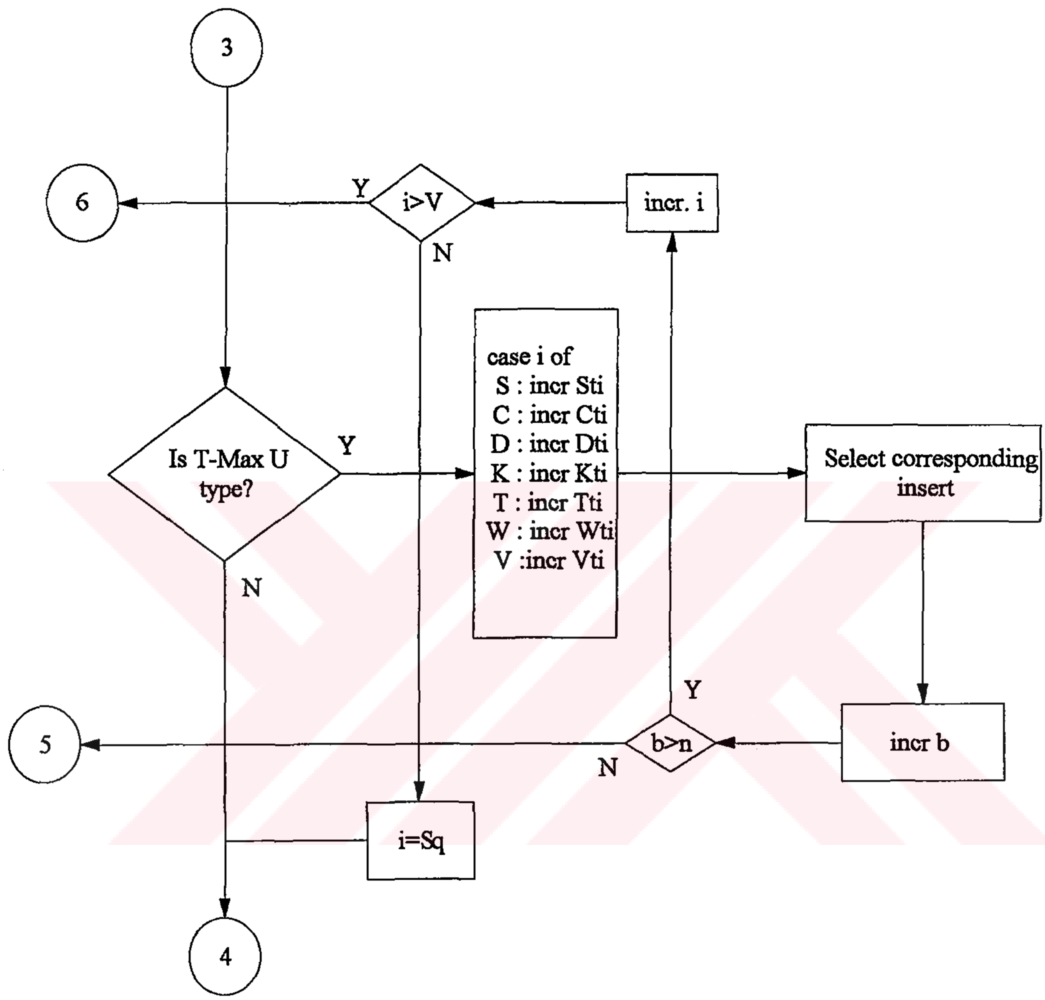



Figure 3.19 (Continued)

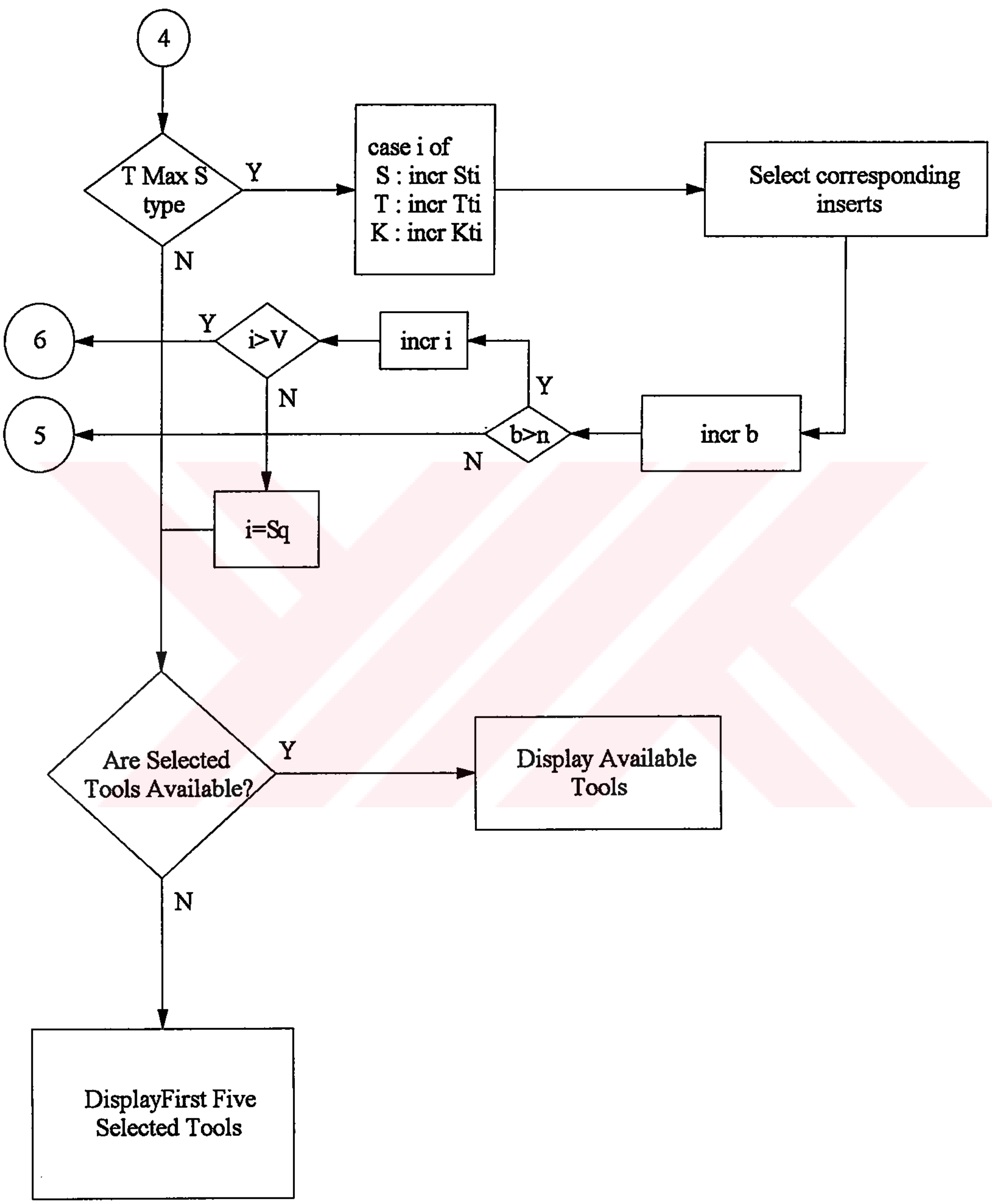



Figure 3.19 (Continued)

3.4.3.3.2 Finish Turning

Similar to rough turning, tools used for finish turning are also arranged in a given order of priority. However, the priority list for the clamping system used for finish turning is different from the one used in rough turning. For finish turning it is given as follows

1. T-Max U type
2. T-Max S type
3. T-Max P type
4. T-Max type

The insert selection priority used in finish turning operation is the same as the one used for rough turning operation. The inference logic for tool class selection for finish turning is given in Figure 3.21. In this case also, incr. in flow charts stands for increase.

The type of tool holders selected in the given order of priority for rough and finish turning for a given machining operation are first checked for availability. If tool holders selected are found available, they are displayed. However, in case of non-availability the first five selected ones are displayed to the user.

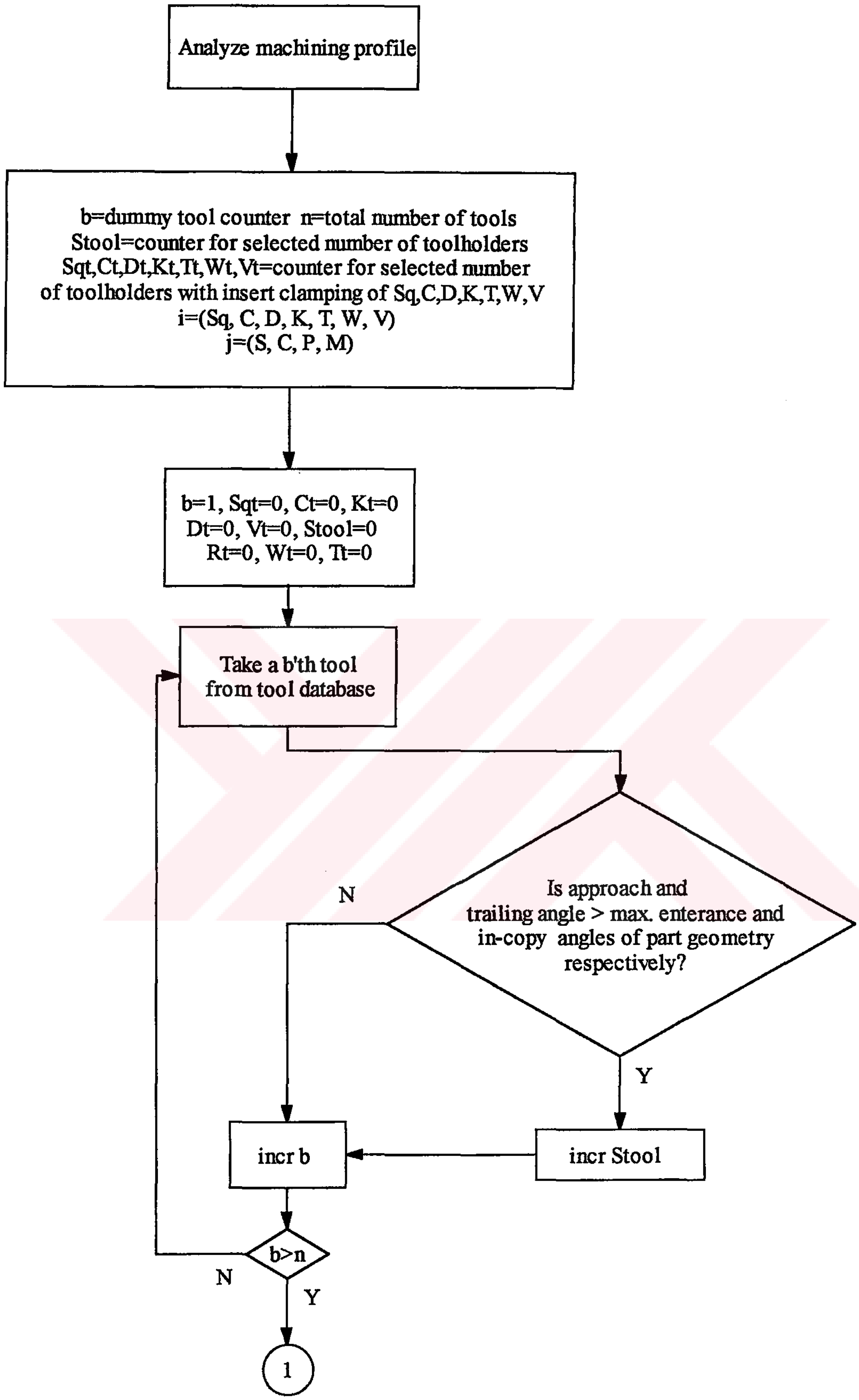



Figure 3.20 Inference Logic for Tool Selection in Finish Turning

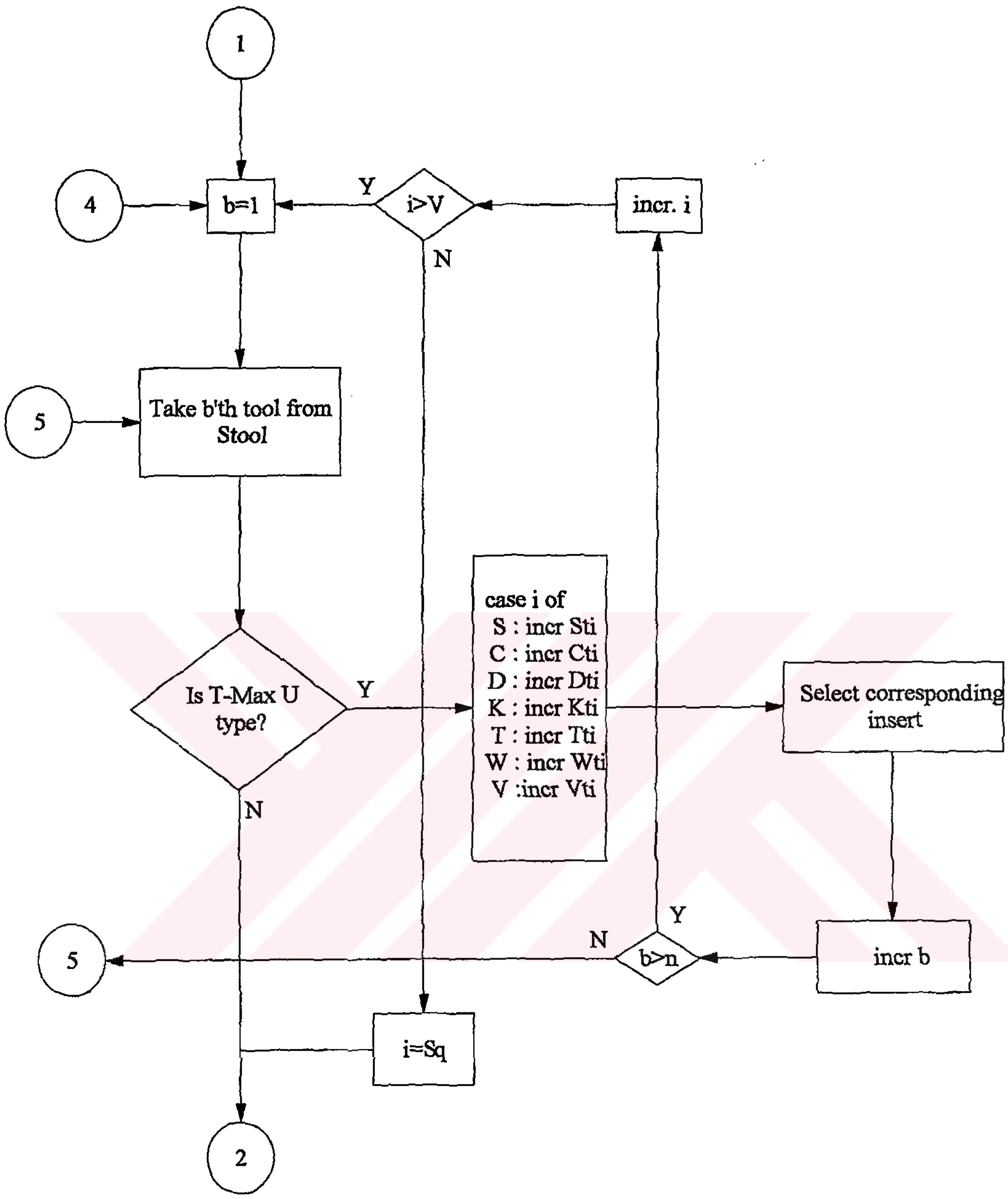



Figure 3.20 (Continued)

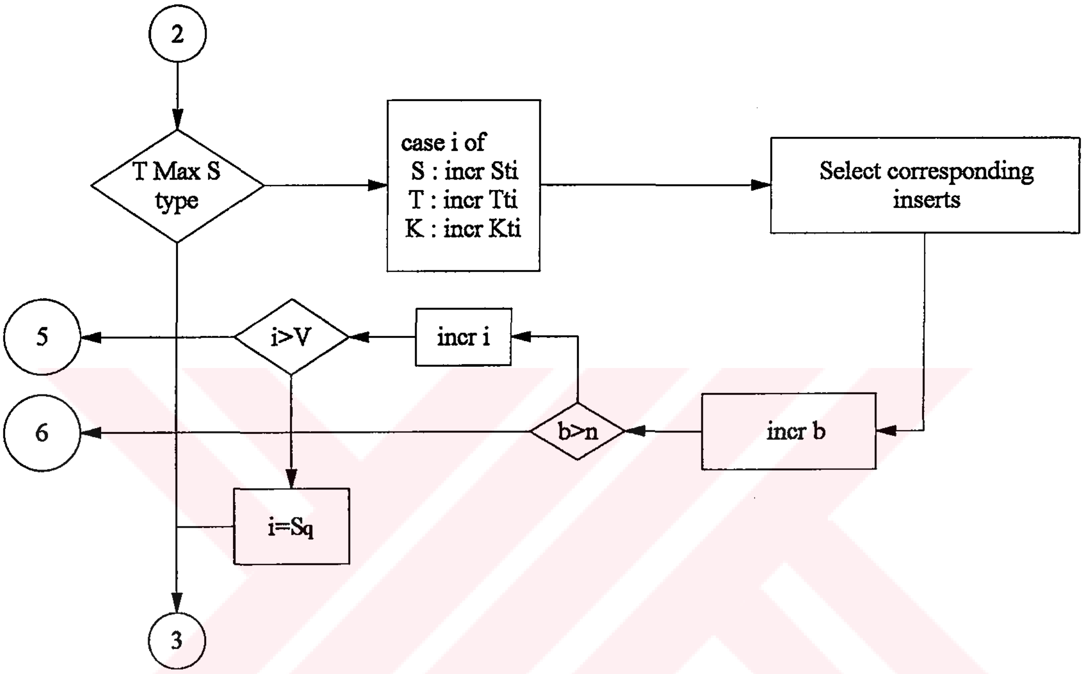



Figure 3.20 (Continued)

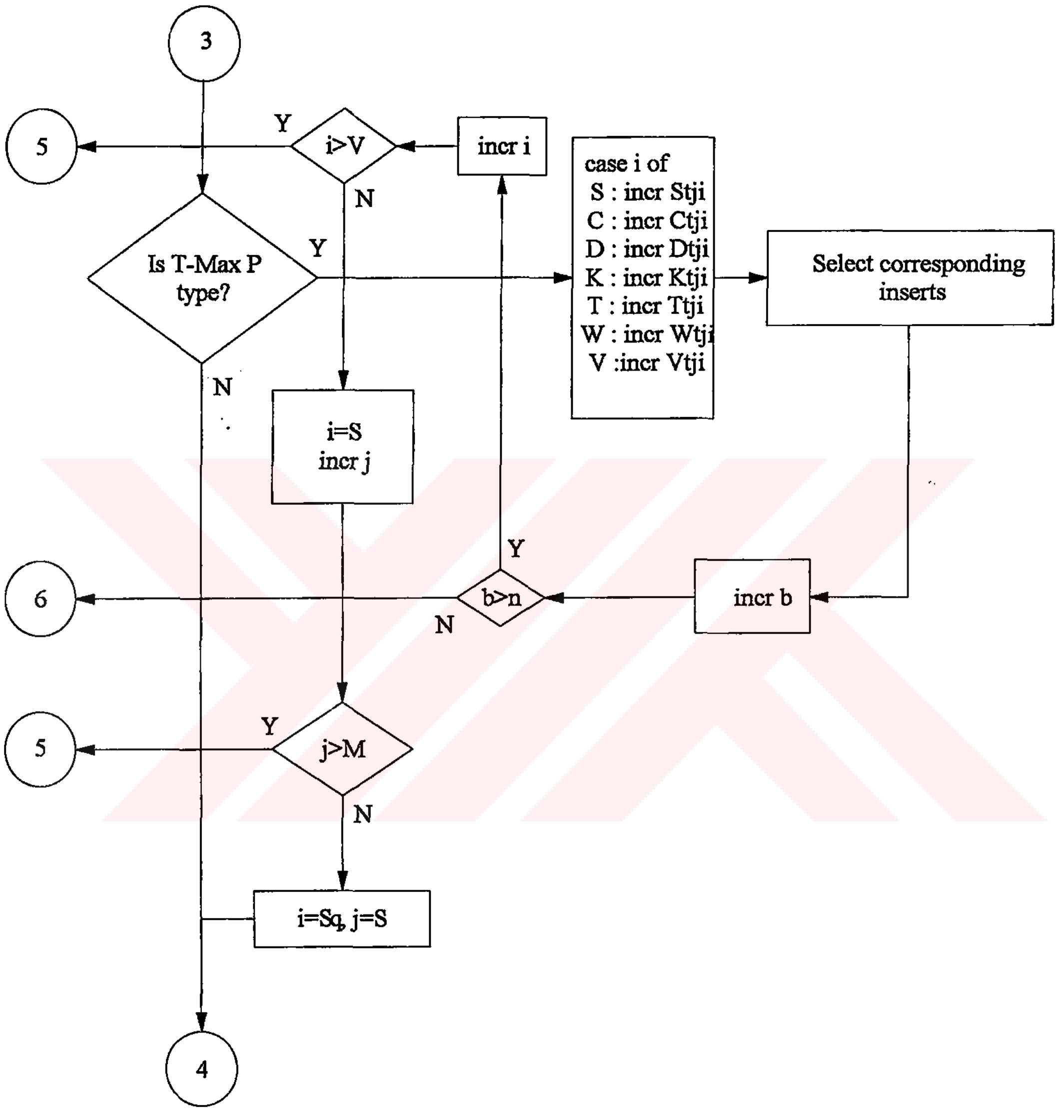



Figure 3.20 (Continued)

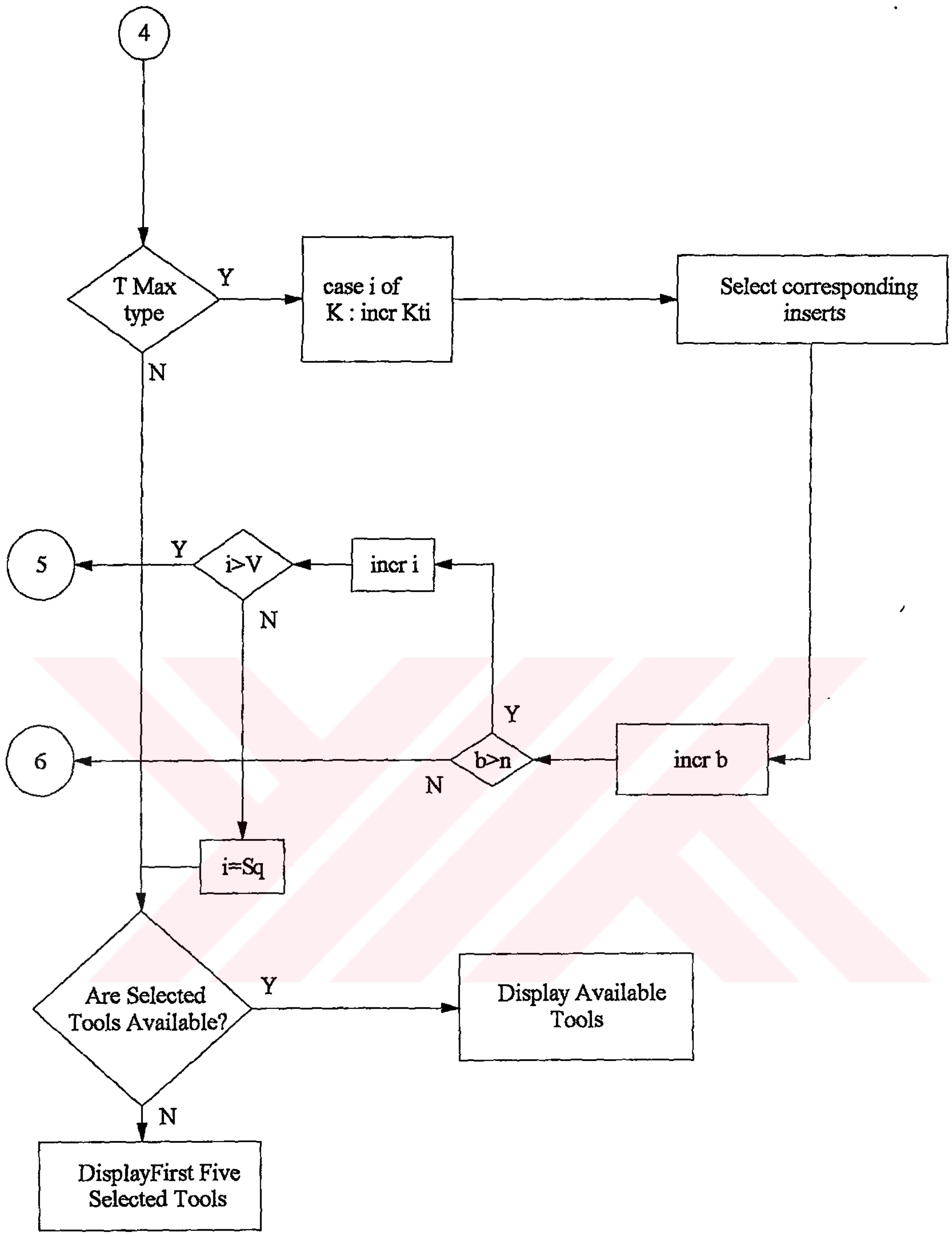



Figure 3.20 (Continued)

## 3.5 Production Routing Sheet

Information related to production of a part are written on a form called route sheet. Route sheet contains references to the name of the product or part, the order number, part material and references to drawing's specification. In addition route sheet typically list the type of machines on which each facet of the job should be done, the necessary tooling, the time required for each setup in the operation, description of the order received by the company and estimated time till which that order must be accomplished. This document is also sometimes called an operation sheet as it provides details about determination of operations through which the product must pass and the arrangement of those operations in the sequence that will require minimum production time.

A complete computer-aided process plan requires the use of these route sheets (used at the shop floor level for controlling manufacture), to be produced by the computer. This eliminates the tedious task of storage and retrieval of these documents and improve the level of service given throughout the factory.

Route sheets in industry show inconsistency with some, giving detailed information of references to the product with an overview of operations description and machining parameters, and the others, giving details about operation description but neglecting most of the information of reference to the product. The route sheet developed for the system is designed such that it contains maximum information related to a part. User is required to manually enter all the operations and technical information relevant to a part.

Editing of production routing sheet is mainly divided into two parts

1. Header Editing
2. Operation Editing

3.5.1 Header Editing

Header part of production routing sheet lists following information

- Name of organization
- Part Name
- Drawing No.
- Material
- Unit Weight
- Material Code
- Part Model and No.
- Order No.
- Blank Material Dimensions
- Actual Lot Size
- Economic Lot Size
- Lot No.
- Due date
- Issue Date
- Start Date
- Issued by

Space against each reference is provided to enter details of information about the product. Information listed above not only give details about the part to be manufactured but also about the order quantity received by the company, actual lot size, economic lot size, lot number and time till which the production should be completed.

### 3.5.2 Operation Editing

Operation editing contains the following information.

- Operation No.
- Operation Description
- Department or Production Center
- Machine
- Tool holder Type
- Insert Type
- Jig and Fixture
- Feed
- Speed
- Depth of Cut
- Set up Time
- Production Time
- Cutting Fluid

These are typical manufacturing instructions at operation level including details of time values, tooling, cutting fluid etc with details of work centers through which the manufacturing proceeds.

Route sheet for a specific workpiece is as given in chapter IV. These can be saved and retrieved as required. Detailed instructions to use this program are given in Appendix.

Tools selected for a given workpiece and other related parameters, entered manually, present a complete process plan for that part.

# CHAPTER IV

# SAMPLE TESTS

## 4.1 Introduction

In this chapter, the system is tested for three different samples of turned parts drawn with the help of part definition module. For a given workpiece the type of tool holders and inserts selected for rough and finish turning operations are analyzed and discussed in light of the algorithm developed in this study. Moreover, each tool holder selected for a given sample is also discussed for its feed direction and tool clearance angle at its trailing edge. Since, some simple geometric shapes may not require tools to be selected from one of the machining direction, a discussion of these cases is also made.

During the selection procedure standard shank height and width of tool holder is taken as 25X25 mm. However, the value can be changed considering the turret height of CNC machine. Also default settings for nose radius of the insert for rough and finish turning operations are taken as 1.2 mm and 0.4 mm respectively. These values can be changed depending on user needs. ISO codes of the selected inserts (with a mark of availability) can also be displayed if required.

Machining profiles considered in this chapter are arranged from simple ones to more complicated ones exhibiting different tool styles selected for a given sample. These are discussed as follows.

4.2 Sample 1

Drawing and output datafile of sample 1 is given in Figure 4.1 and 4.2 respectively. A tool moving from right to left has zero in-copy angle for the given profile. Therefore, for a right handed tool only entrance angle is calculated for all the feature primitives present in part profile.

Part geometry analysis of sample 1 is as given in Figure 4.3. For a tool moving from right to left, profile analysis exhibits maximum entrance angle of 90° at concave segments. Hence, tool holders having approach angle greater than or equal to 90° are selected for machining of this part. Also, from part geometry analysis, it can be seen that the given profile can be machined from tools moving from right to left. Therefore only right handed tool holders are recommended by the system. Figure 4.4 and 4.5 shows recommended tool holders for rough and finish machining of this part. System recommends five tool holders for machining of this workpiece from the list available in the factory. So final selection is left up to the user to select one from the recommended ones.. Route sheet that dictates typical manufacturing instructions for this part is as given in Figure 4.6.

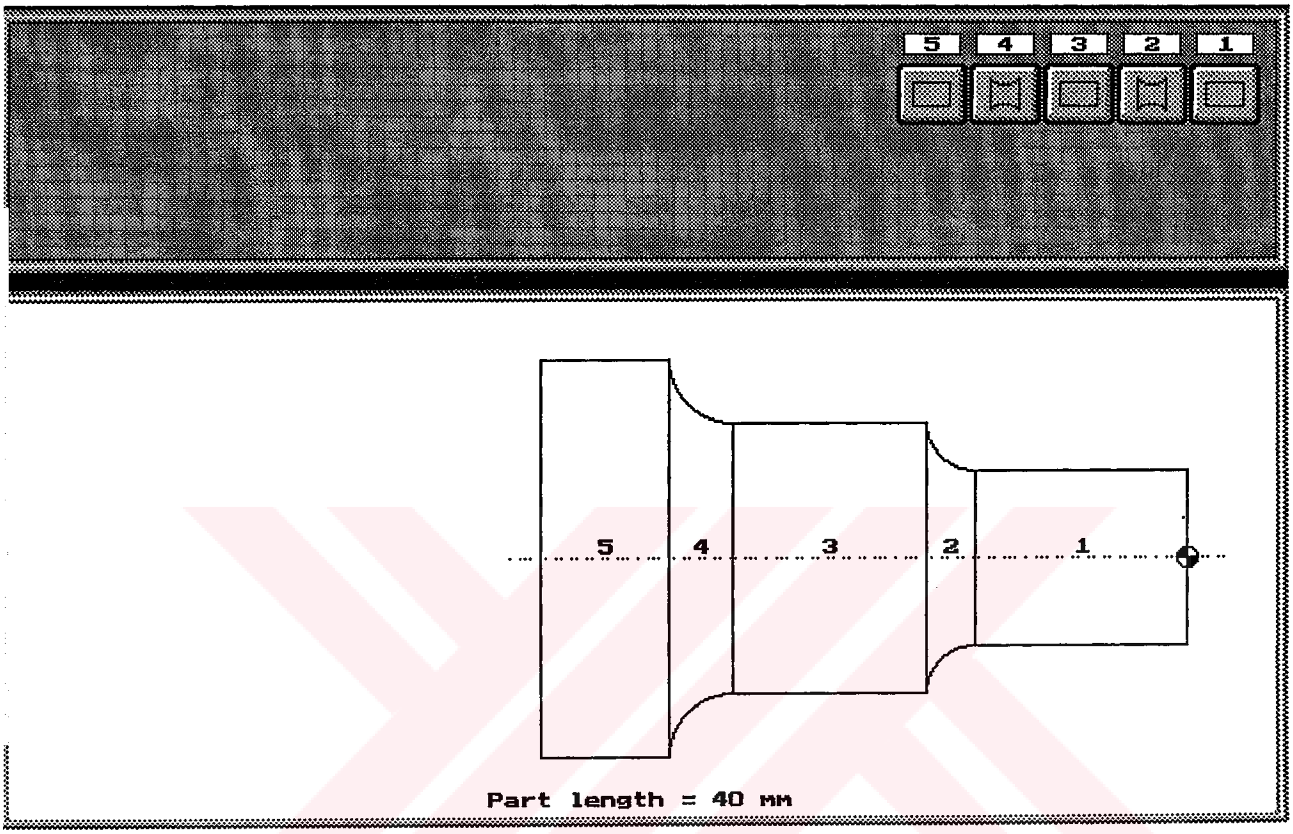



Figure 4.1 Drawing of Sample 1

5

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | CYLN | L1 | 0.0 | L2 | 13.0 | D | 11.0 | | | | |
| 2 | 4 | INCR | L1 | 13.0 | L2 | 16.0 | D1 | 11.0 | D2 | 17.0 | R | 3.0 |
| 3 | 1 | CYLN | L1 | 16.0 | L2 | 28.0 | D | 17.0 | | | | |
| 4 | 4 | INCR | L1 | 28.0 | L2 | 32.0 | D1 | 17.0 | D2 | 25.0 | R | 4.0 |
| 5 | 1 | CYLN | L1 | 32.0 | L2 | 40.0 | D | 25.0 | | | | |

Figure 4.2 Output Datafile of Sample 1

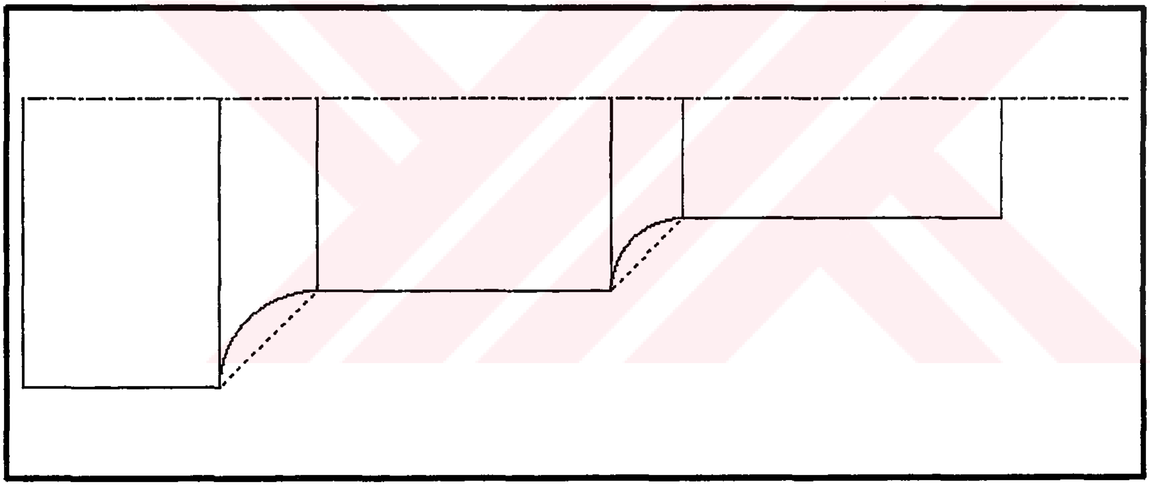


Figure 4.3 Part Geometry Analysis of Sample 1

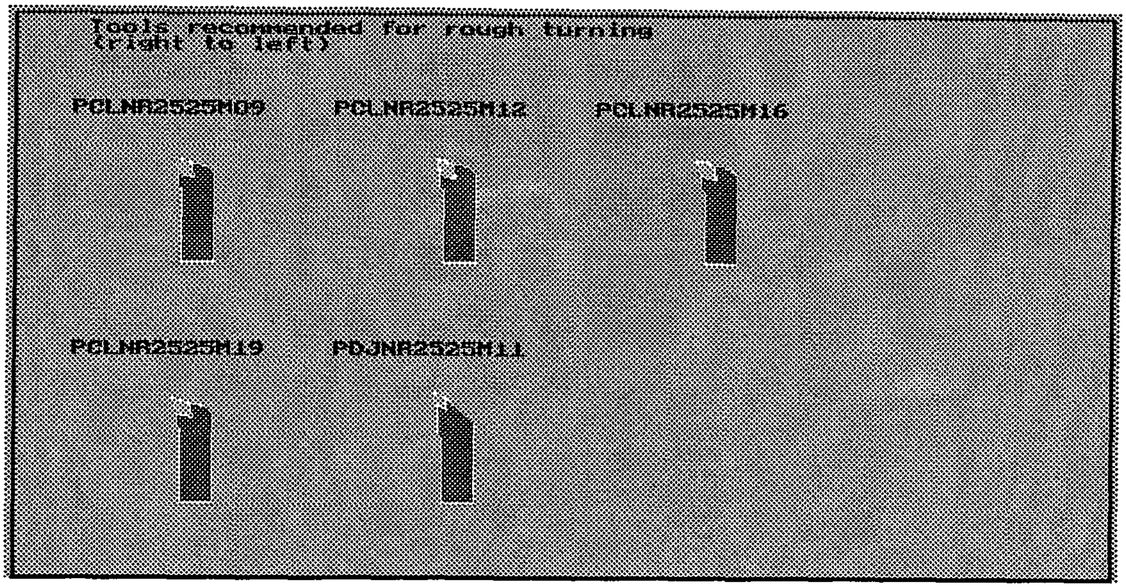



Figure 4.4 Roughing Tool Hoders for Sample 1

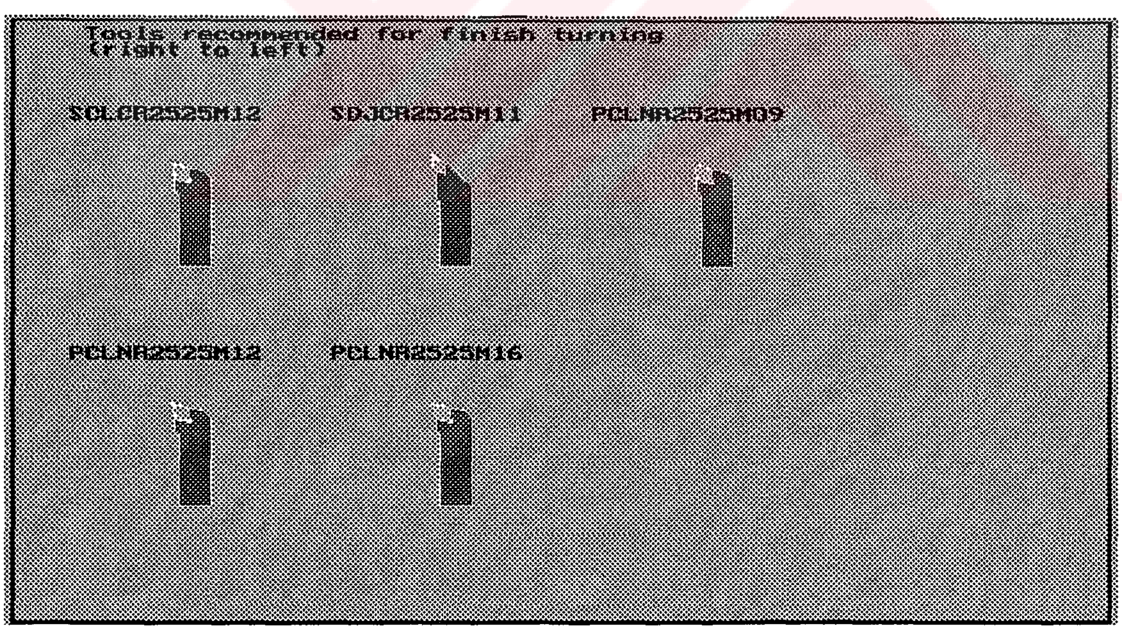



Figure 4.5 Finishing Tool Holders for Sample 1

ROUTE SHEET

Mechanical Engg. Dept.

| | | |
|---|---|---|
| Part Name :Sample 1 | Part Model & No. :ME-1 | Blank Material Dimensions (mm):25X40 |
| Drawing No. :01 | Order Quantity :1000 | Actual Lot Size :1000 |
| Material :Mild Steel | Material Code :Mete-1 | Econ. Lot Size :1000 / Lot Number :1 |
| Unit Weight (kg) :0.5 | Order No. :1 | Due Date :10-04-1995 / Start Date :10-05-1994 |
| | | Issue Date :10-04-1994 / Issued by :Nabeel Ashraf |

| Oper. No. | Operation Description | Prod. Centre | Machine | Tools | | Jig & Fixture | Feed (mm/min) | Speed (rpm) | Depth of Cut (mm) | Set up Time (min) | Prod. Time (min) | Cutting Fluid |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Holder Type | Insert Type | | | | | | | |
| 1 | Adjust Workpiece to machine tool | CNC Lathe | 150 TCL | - | - | Chuck | - | - | - | 2 | - | - |
| 2 | Turn dia 23X31.4 | " | " | PCLNR2525 M15 | CNMG120312 MF 425 | " | 70 | 2500 | 1 | - | 0.2 | Oil |
| 3 | Turn dia 21X31.4 | " | " | " | " | " | " | " | " | - | " | " |
| 4 | Turn dia 19X30.4 | " | " | " | " | " | " | " | " | - | " | " |
| 5 | Turn dia 17X28.4 | " | " | " | " | " | " | " | " | - | " | " |
| 6 | Turn radius 4 to dia 25 | " | " | " | " | " | " | " | " | - | " | " |
| 7 | Turn dia 15X15 | " | " | " | " | " | " | " | " | - | " | " |
| 8 | Turn dia 13X15 | " | " | " | " | " | " | " | " | - | " | " |
| 9 | Turn dia 11X15 | " | " | " | " | " | " | " | " | - | " | " |
| 10 | Turn radius 3 to dia 17 | " | " | " | " | " | " | " | " | - | " | " |
| 11 | Change tool | " | " | SCLNR2525 M16 | CNMG090304 QM 425 | " | - | - | - | 1 | - | - |
| 12 | Finish turn | " | " | " | " | " | 50 | 2500 | 0.5 | - | 0.2 | Oil |
| 13 | Change tool | " | " | RF151.20 252520 | R 151.2200 055F 235 | " | - | - | - | 1 | - | - |
| 14 | Part off to Length | " | " | " | " | " | 50 | 2500 | - | - | 0.1 | Oil |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |

Figure 4.6 Route Sheet of Sample 1

4.3 Sample 2

Sample 2 considered here is an adjusting screw. The drawing of this part is as shown in Figure 4.7. Figure 4.8 gives output datafile of this sample. A tool moving from right to left face enterance angles at feature primitives 1, 4, 8, 10 and 15. The maximum of these is calculated as 90°. Similarly, feature primitives 2, 6, 13, 16 and 18 exhibit in-copy angles on workpiece profile with a maximum in-copy of 45° at feature primitive 2 and 6. Therefore tool holders selected from tool database are required to have approach angles greater than or equal to 90° and trailing angles greater than or equal to 45° for machining of this part.

Since joining of point (x1, y1) of feature primitive 10 with center point of feature primitive 11 gives an in-copy angle greater than 50°, a line from point (x1, y1) of feature primitive 10 to point (x2, y2) of feature primitive 12 is drawn in accordance with the rules discussed in Chapter III. This requires the given portion to be machined with a grooving tool. Furthermore, from part geometry analysis given in Figure 4.9, it can be seen that the whole profile can be machined with a tool moving from right to left and with a grooving tool. Therefore, only right hand tool for rough and finish machining of this workpiece are recommended to the user along with some grooving tools. Recommended tool holders for roughing, finishing, grooving and threaded portions are as shown in Figure 4.10, 4.11 and 4.12. Tool holders for rough and finish turning are found as not available in the industry. Therefore user is required to buy one of these for machining of this part. Route sheet for sample 2 is given in Figure 4.13.

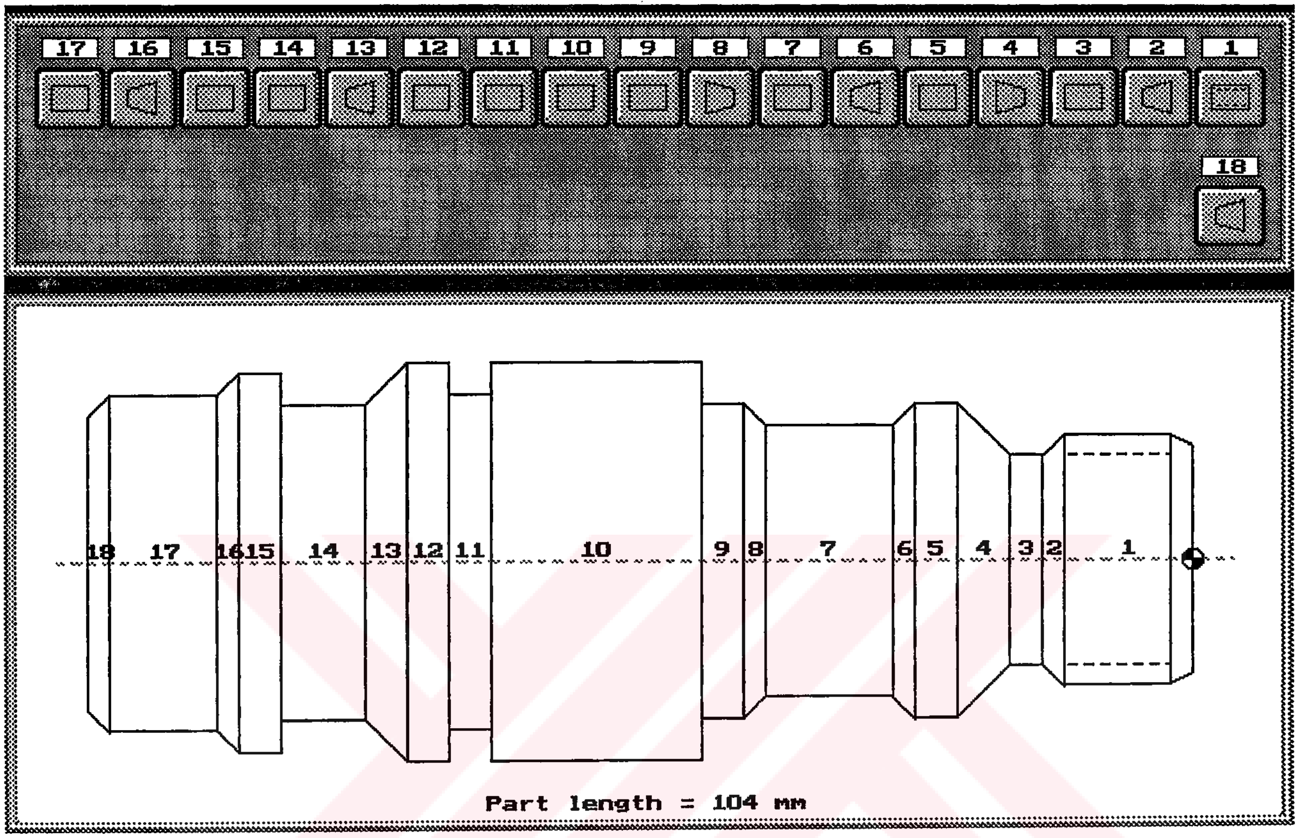



Figure 4.7 Drawing of Sample 2

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 18 | | | | | | | | | | | |
| 1 | 6 | THRD | | L1 | 0 | L2 | 12 | M | 24 | | |
| 1 | * | Cham | end | rght | dir | down | size | 2 angl | 30 | | |
| 2 | 3 | CONT | | L1 | 12 | L2 | 14 | D1 | 24 | D2 | 20 |
| 3 | 1 | CYLN | | L1 | 14 | L2 | 17 | D | 20 | | |
| 4 | 2 | DIVT | | L1 | 17 | L2 | 22 | D1 | 20 | D2 | 30 |
| 5 | 1 | CYLN | | L1 | 22 | L2 | 26 | D | 30 | | |
| 6 | 3 | CONT | | L1 | 26 | L2 | 28 | D1 | 30 | D2 | 26 |
| 7 | 1 | CYLN | | L1 | 28 | L2 | 40 | D | 26 | | |
| 8 | 2 | DIVT | | L1 | 40 | L2 | 42 | D1 | 26 | D2 | 30 |
| 9 | 1 | CYLN | | L1 | 42 | L2 | 46 | D | 30 | | |
| 10 | 1 | CYLN | | L1 | 46 | L2 | 66 | D | 38 | | |
| 11 | 1 | CYLN | | L1 | 66 | L2 | 70 | D | 32 | | |
| 12 | 1 | CYLN | | L1 | 70 | L2 | 74 | D | 38 | | |
| 13 | 3 | CONT | | L1 | 74 | L2 | 78 | D1 | 38 | D2 | 30 |
| 14 | 1 | CYLN | | L1 | 78 | L2 | 86 | D | 30 | | |
| 15 | 1 | CYLN | | L1 | 86 | L2 | 90 | D | 36 | | |
| 16 | 3 | CONT | | L1 | 90 | L2 | 92 | D1 | 36 | D2 | 32 |
| 17 | 1 | CYLN | | L1 | 92 | L2 | 102 | D | 32 | | |
| 18 | 3 | CONT | | L1 | 102 | L2 | 104 | D | 132 | D | 228 |

Figure 4.8 Output Datafile of Sample 2

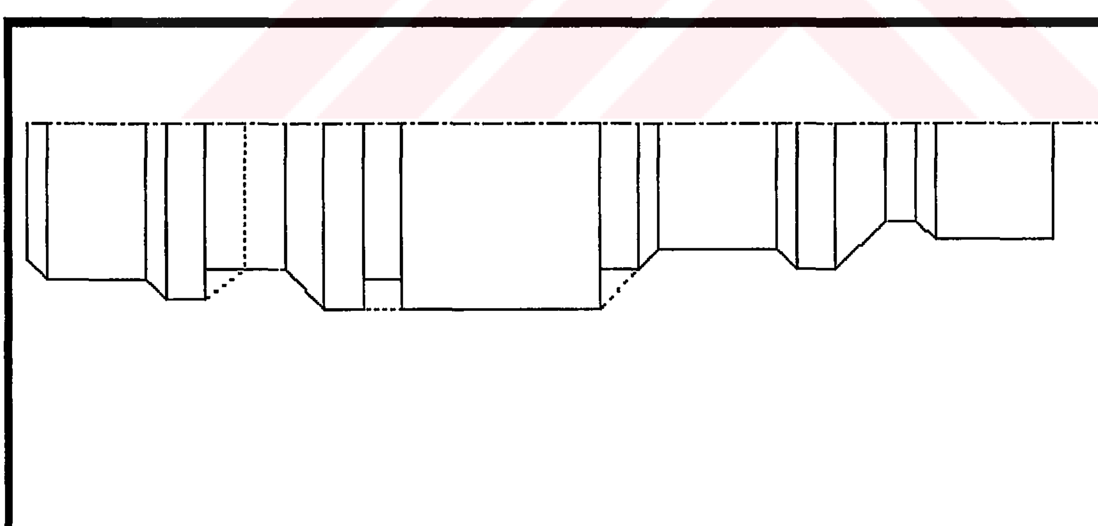
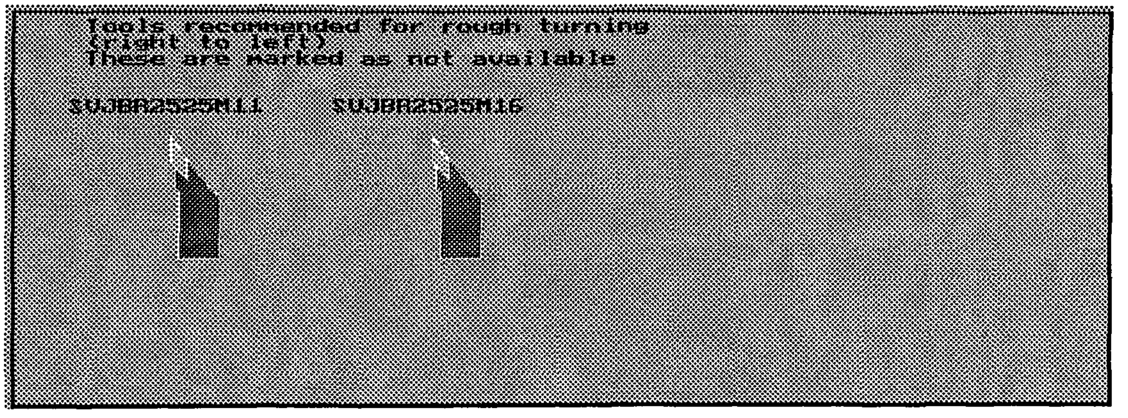


Figure 4.9 Part Geometry Analysis of Sample 2




Fgiure 4.10 Roughing Tool Holders for Sample 2

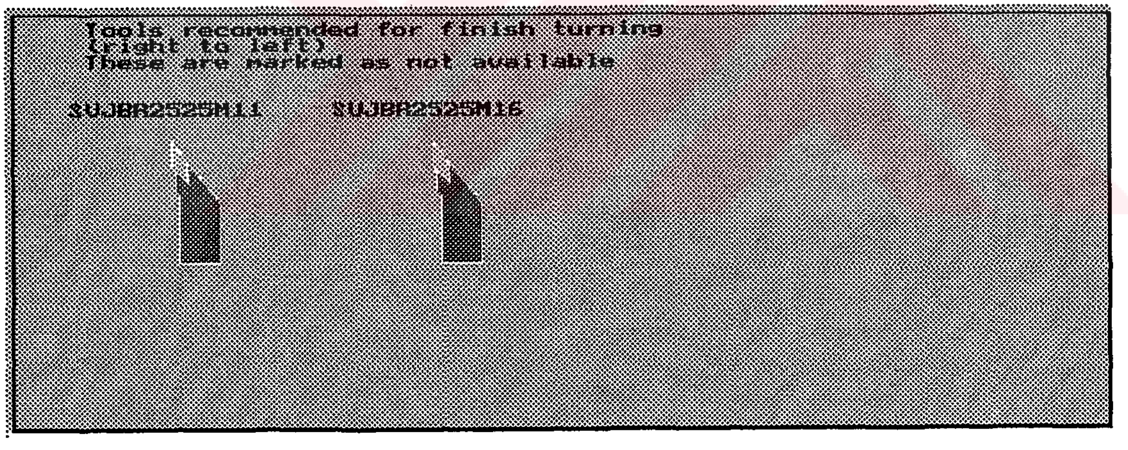



Figure 4.11 Finishing Tool Holders for Sample 2

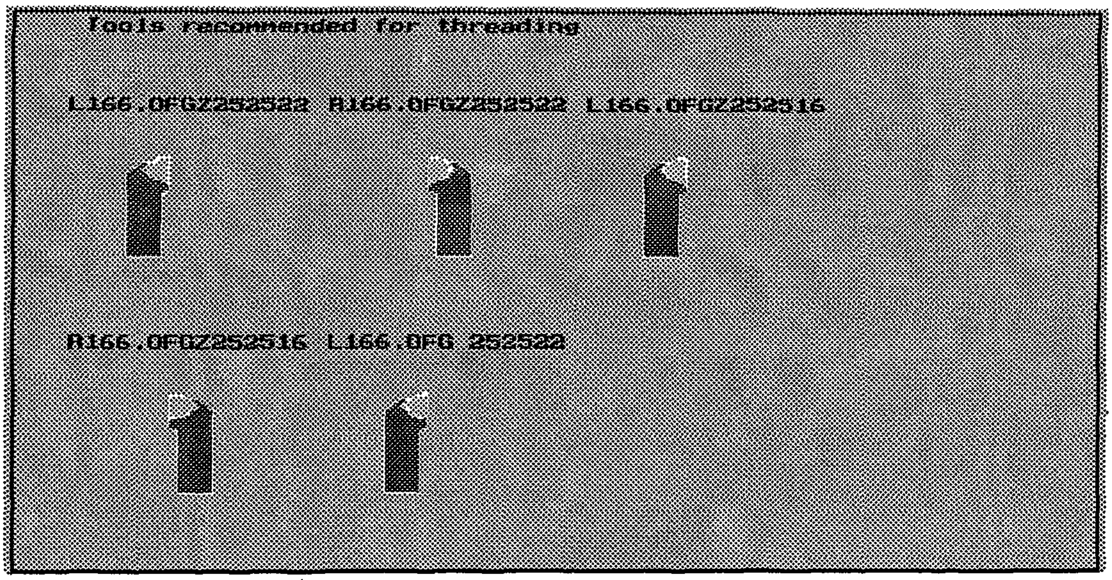



Figure 4.12 Threading Tool Holders for Sample 2

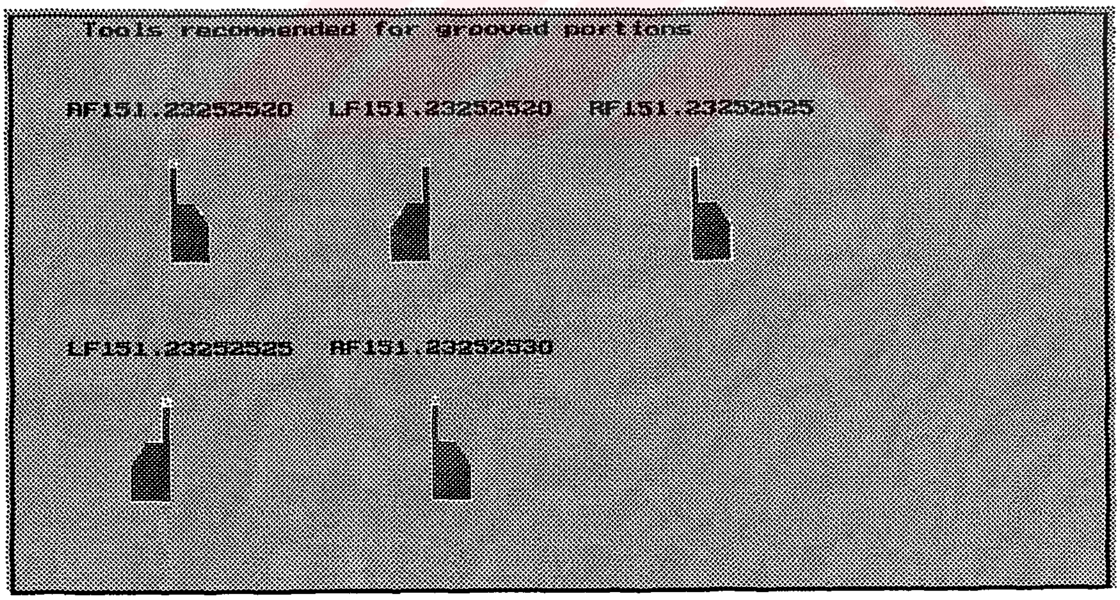



Figure 4.13 Grooving Tool Holders for Sample 2

ROUTE SHEET

| Mechanical Engg. Dept. | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Part Name :Sample 2 | | | Part Model & No. :ME-2 | | | Blank Material Dimensions (mm):40X104 | | | | | | |
| Drawing No. :02 | | | Order Quantity :1000 | | | Actual Lot Size :1000 | | | | | | |
| Material :Mild Steel | | | Material Code :Mete-2 | | | Econ. Lot Size :1000 | | | | Lot Number :2 | | |
| Unit Weight (kg) :0.8 | | | Order No. :2 | | | Due Date :10-04-1995 | | | | Start Date :10-04-1994 | | |
| | | | | | | Issue Date :10-04-1994 | | | | Issued by :Nabeel Ashraf | | |
| Oper. No. | Operation Description | Prod. Centre | Machine | Tools | | Jig & Fixture | Feed (mm/min) | Speed (rpm) | Depth of Cut (mm) | Set up Time (min) | Prod. Time (min) | Cutting Fluid |
| | | | | Holder Type | Insert Type | | | | | | | |
| 1 | Adjust workpiece to machine tool | CNC Lathe | 160 TCL | - | - | Chuck | - | - | - | 2 | - | - |
| 2 | Turn dia 39X104 | " | " | SUJBR2525 M16 | UBMT160412 UM 425 | " | 70 | 2500 | 1 | - | 0.5 | Oil |
| 3 | Turn dia 37X45.5 | " | " | " | " | " | " | " | " | - | " | " |
| 4 | Turn dia 35X45.5 | " | " | " | " | " | " | " | " | - | " | " |
| 5 | Turn dia 33X45.5 | " | " | " | " | " | " | " | " | - | " | " |
| 6 | Turn dia 31X45.5 | " | " | " | " | " | " | " | " | - | " | " |
| 7 | Turn dia 29X20.5 | " | " | " | " | " | " | " | " | - | " | " |
| 8 | Turn dia 27X19.5 | " | " | " | " | " | " | " | " | - | " | " |
| 9 | Turn dia 25X18.5 | " | " | " | " | " | " | " | " | - | " | " |
| 10 | Turn dia 23 from l=13.5 to 16.5 | " | " | " | " | " | " | " | " | - | " | " |
| 11 | Turn dia 21 from l=14.5 to 16.5 | " | " | " | " | " | " | " | " | - | " | " |
| 12 | Turn dia 29 from l=27.5 to 40.5 | " | " | " | " | " | " | " | " | - | " | " |
| 13 | Turn dia 27 from l=28.5 to 39.5 | " | " | " | " | " | " | " | " | - | " | " |
| 14 | Turn dia 37 from l=75.5 to 104 | " | " | " | " | " | " | " | " | - | " | " |
| 15 | Turn dia 35 from l=76.5 to 85.5 | " | " | " | " | " | " | " | " | - | " | " |
| 16 | Turn dia 33 from l=77.5 to 85.5 | " | " | " | " | " | " | " | " | - | " | " |
| 17 | Turn dia 31 from l=78.5 to 85.5 | " | " | " | " | " | " | " | " | - | " | " |
| 18 | Turn dia 35 from l=91 to 104 | " | " | " | " | " | " | " | " | - | " | " |

Figure 4.14 Route Sheet of Sample 2

ROUTE SHEET

| Mechanical Engg. Dept. | | |
|---|---|---|
| Part Name :Sample 2 | Part Model & No. :ME-2 | Blank Material Dimensions (mm):40X104 |
| Drawing No. :02 | Order Quantity :1000 | Actual Lot Size :1000 |
| Material :Mild Steel | Material Code :Mete-2 | Econ. Lot Size :1000 / Lot Number :2 |
| Unit Weight (kg) :0.8 | Order No. :2 | Due Date :10-04-1995 / Start Date :10-04-1994 |
| | | Issue Date :10-04-1994 / Issued by :Nabeel Ashraf |

| Oper. No. | Operation Description | Prod. Centre | Machine | Tools: Holder Type | Tools: Insert Type | Jig & Fixture | Feed (mm/min) | Speed (rpm) | Depth of Cut (mm) | Set up Time (min) | Prod. Time (min) | Cutting Fluid |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19 | Turn dia 33 from l=32 to 104 | " | " | " | " | " | " | " | " | - | " | " |
| 20 | Finish turn | " | " | " | " | " | 50 | " | 0.5 | - | 0.3 | " |
| 21 | Change tool | " | " | RF151.23 252520 | R151.220005 SF 235 | " | - | - | - | 1 | - | - |
| 22 | Make groove from l=58 to 70 | " | " | " | " | " | - | 2500 | 3 | - | 0.3 | Oil |
| 23 | Change tool | " | " | R166.OFGZ 252522 | R166.0G16MM 01-050 1020 | " | - | - | - | 1 | - | - |
| 24 | Make thread dia 12X12 | " | " | " | " | " | 50 | 2500 | - | - | 0.3 | Oil |
| 25 | Change tool | " | " | RF151.20 252520 | R151.220005 5E 235 | " | - | - | - | 1 | - | - |
| 26 | Part off to length | " | " | " | " | " | 50 | 2500 | - | - | 0.3 | Oil |

Figure 4.14 (Continued)

## 4.4 Sample 3

Drawing and output datafile of sample 3 is as given in Figure 4.15 and 4.15 respectively. Since diamaters of feature primitives 4, 5 and 6 are different, tool moving from right to left requires an interface check to be made for these feature primitives. Hence, a line is drawn from point (x1, y1) of 4 to center point of feature primitive 5 and also from point (x1, y1) of 5 to center point of feature primitive 6. Next, enterance and in-copy angles for all the feature primitives present in part geometry are calculated. This analysis gives a maximum enterance angle of 90° and an in-copy angle of 14°. Therefore right hand tool holders having approach angles greater than or equal to 90° and trailing angle greater than or equal to 14° are selected for machining of this workpiece.

Similarly, for a tool moving from left to right, rules discussed for part geometry analysis in Chapter III first convert feature primitive 10 into two converging tapers. Furthermore, concave segemnt is joined with a line from its end points. Secondly, an interface check is made and a line is drawn from point (x2, y2) of feature primitive 7 to the center point of feature primitive 6. Part geometry analysis of sample 3 is as given in Figure 4.16. Finally, enterance and in-copy angles for all the feature primitives present in part geometry are caculated. This analysis gives maximum enterance angle of 90° and an in-copy angle of 45°. Therefore, selected tools are required to have an approach angle greater than or equal to 90° and trailing angle greater than or equal to 45°.

Tools selected for rough and finish machining of this workpiece are as shown in the Figure 4.17, 4.18, 4.19, 4.20. These tools are marked as available in the factory. Therefore, final selection is left upto the user to select one from the recommended ones. Figure 4.21 gives the route sheet of sample 3.

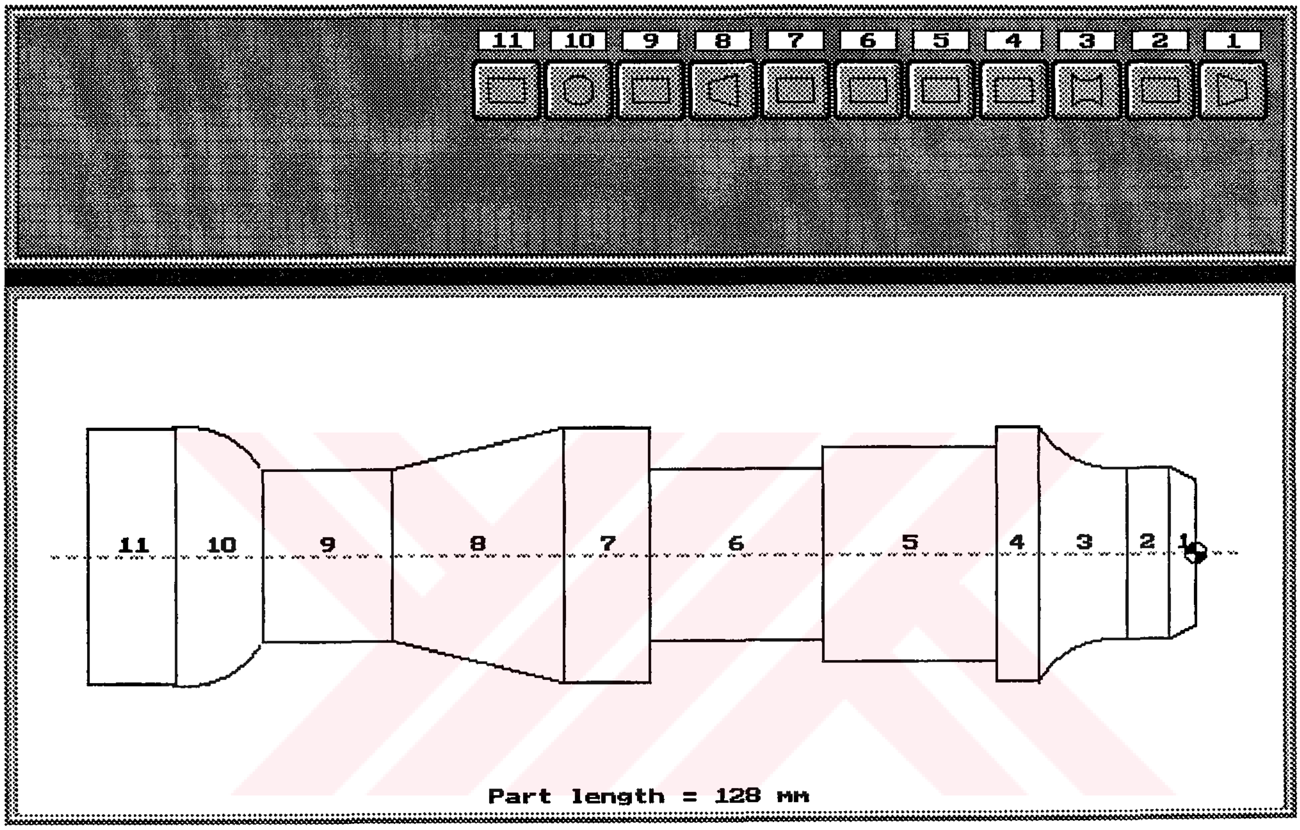



Figure 4.15 Drawing of Sample 3

11

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | DIVT | L1 | 0 | L2 | 3 | D1 | 17 | D2 | 20 | | |
| 2 | 1 | CYLN | L1 | 3 | L2 | 8 | D | 20 | | | | |
| 3 | 4 | INCR | L1 | 8 | L2 | 18 | D1 | 20 | D2 | 30 | R | 10 |
| 4 | 1 | CYLN | L1 | 18 | L2 | 23 | D | 30 | | | | |
| 5 | 1 | CYLN | L1 | 23 | L2 | 43 | D | 25 | | | | |
| 6 | 1 | CYLN | L1 | 43 | L2 | 63 | D | 20 | | | | |
| 7 | 1 | CYLN | L1 | 63 | L2 | 73 | D | 30 | | | | |
| 8 | 3 | CONT | L1 | 73 | L2 | 93 | D1 | 30 | D2 | 20 | | |
| 9 | 1 | CYLN | L1 | 93 | L2 | 108 | D | 20 | | | | |
| 10 | 5 | OUTC | L1 | 108 | L2 | 118 | D1 | 20 | D2 | 30 | R | 10 |
| 11 | 1 | CYLN | L1 | 118 | L2 | 128 | D | 30 | | | | |

Figure 4.16 Output Datafile of Sample 3

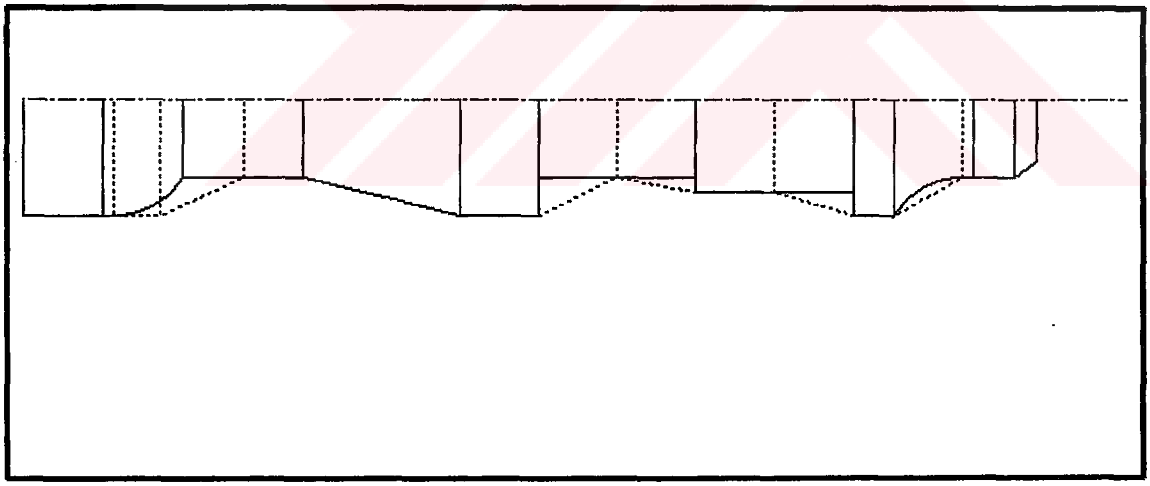


Figure 4.17 Part Geometry Analysis of Sample 3

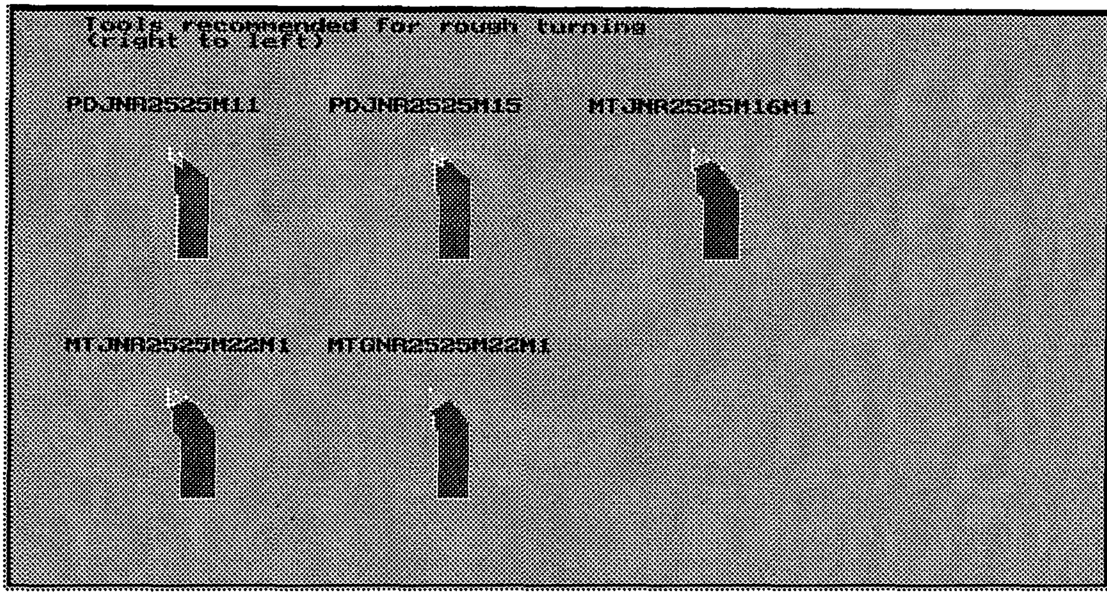



Figure 4.18 Right Handed Roughing Tools for Sample 3

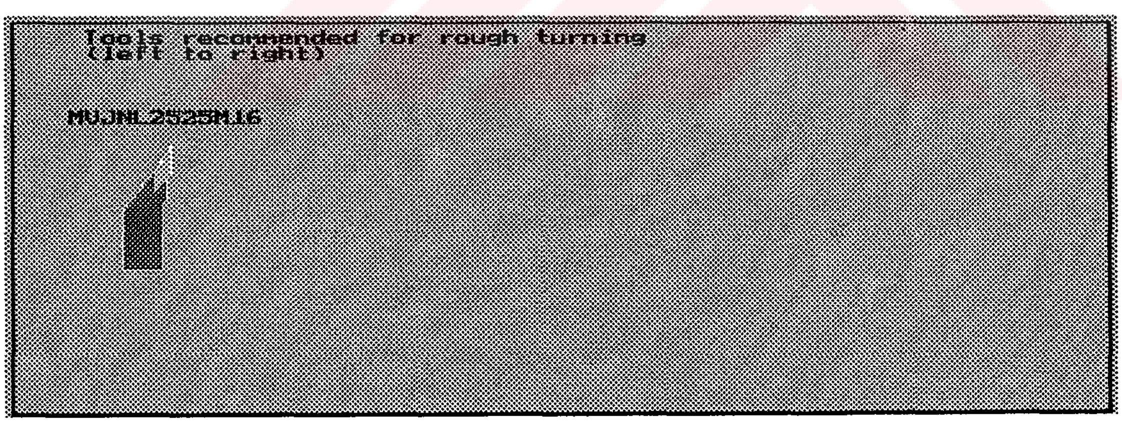



Figure 4.19 Left Handed Roughing Tool Holder for Sample 3

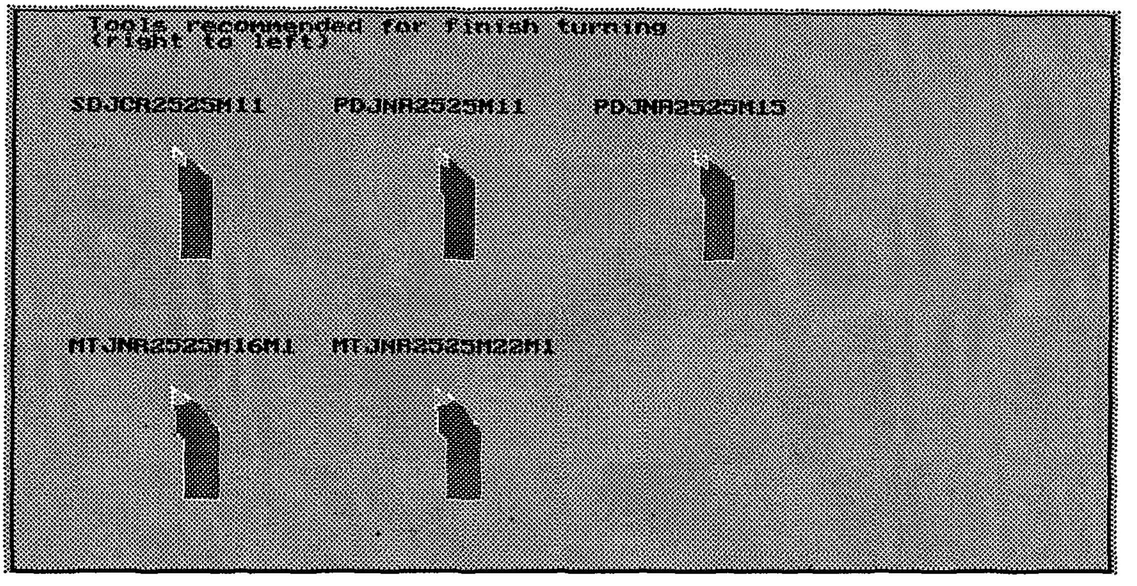



Figure 4.20 Right Handed Finishing Tools for Sample 3

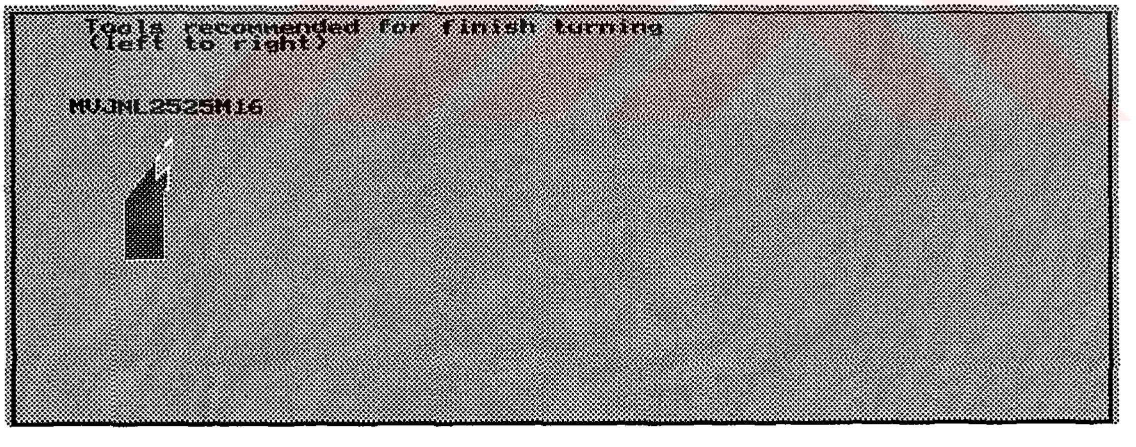



Figure 4.21 Left Handed Finishing Tool Holder for Sample3

ROUTE SHEET

| | | |
|---|---|---|
| Mecanical Engg. Dept. | | |
| Part Name :Sample 3 | Part Model & No. :ME-3 | Blank Material Dimensions (mm):145X32 |
| Drawing No. :03 | Order Quantity :1000 | Actual Lot Size :1000 |
| Material :Mild Steel | Material Code :Mete-3 | Econ. Lot Size :1000 ; Lot Number :3 |
| Unit Weight (kg) :0.8 | Order No. :3 | Due Date :10-04-1995 ; Start Date :10-05-1994 |
| | | Issue Date :10-04-1994 ; Issued by :Nabeel Ashraf |

| Oper. No. | Operation Description | Prod. Centre | Machine | Tools: Holder Type | Tools: Insert Type | Jig & Fixture | Feed (mm/min) | Speed (rpm) | Depth of Cut (mm) | Set up Time (min) | Prod. Time (min) | Cutting Fluid |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Adjust workpiece to machine tool | CNC Lathe | 160 TCL | - | - | Chuck | - | - | - | 2 | - | - |
| 2 | Turn dia 31X128 | " | " | PDJNR2525 M15 | DNMG150412 MF 425 | " | 70 | 2500 | 1 | - | 0.3 | Oil |
| 3 | Turn dia 29X17 | " | " | " | " | " | " | " | " | - | " | " |
| 4 | Turn dia 27X15 | " | " | " | " | " | " | " | " | - | " | " |
| 5 | Turn dia 25X15 | " | " | " | " | " | " | " | " | - | " | " |
| 6 | Turn dia 23X13.5 | " | " | " | " | " | " | " | " | - | " | " |
| 7 | Turn dia 21X10.5 | " | " | " | " | " | " | " | " | - | " | " |
| 8 | Turn dia 19X1.5 | " | " | " | " | " | " | " | " | - | " | " |
| 9 | Turn dia 29 from l=27 to 112 | " | " | " | " | " | " | " | " | - | " | " |
| 10 | Turn dia 27 from l=31 to 110.5 | " | " | " | " | " | " | " | " | - | " | " |
| 11 | Turn dia 26 from l=34 to 110 | " | " | " | " | " | " | " | " | - | " | " |
| 12 | Turn dia 24 from l=47 to 62.5 | " | " | " | " | " | " | " | " | - | " | " |
| 13 | Turn dia 22 from l=52 to 62.5 | " | " | " | " | " | " | " | " | - | " | " |
| 14 | Turn dia 21 from l=53 to 62.5 | " | " | " | " | " | " | " | 0.5 | - | " | " |
| 15 | Turn dia 24 from l=82 to 108.5 | " | " | " | " | " | " | " | 1 | - | " | " |
| 16 | Turn dia 22 from l=90 to 108 | " | " | " | " | " | " | " | " | - | " | " |
| 17 | Turn dia 21 from l=93 to 107 | " | " | " | " | " | " | " | 0.5 | - | " | " |
| 18 | Change tool | " | " | MVJNL2525 M16 | VNMG160412 MF 425 | " | - | - | - | 0.5 | - | - |

Figure 4.22 Route Sheet of Sample 3

## ROUTE SHEET

Mecanical Engg. Dept.

| | | |
|---|---|---|
| Part Name :Sample 3 | Part Model & No. :ME-3 | Blank Material Dimensions (mm):145X32 |
| Drawing No. :03 | Order Quantity :1000 | Actual Lot Size :1000 |
| Material :Mild Steel | Material Code :Mete-3 | Econ. Lot Size :1000 — Lot Number :3 |
| Unit Weight (kg) :0.8 | Order No. :3 | Due Date :10-04-1995 — Start Date :10-05-1994 |
| | | Issue Date :10-04-1994 — Issued by :Nabeel Ashraf |

| Oper. No. | Operation Description | Prod. Centre | Machine | Tools: Holder Type | Tools: Insert Type | Jig & Fixture | Feed (mm/min) | Speed (rpm) | Depth of Cut (mm) | Set up Time (min) | Prod. Time (min) | Cutting Fluid |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19 | Turn dia 28 from l=26 to 23.5 | " | " | " | " | " | 70 | 2500 | 1 | - | 0.3 | Oil |
| 20 | Turn dia 26 from l=32 to 23.5 | " | " | " | " | " | " | " | " | - | " | " |
| 21 | Turn dia 23 from l=47 to 43.5 | " | " | " | " | " | " | " | " | - | " | " |
| 22 | Turn dia 21 from l=52 to 43.5 | " | " | " | " | " | " | " | " | - | " | " |
| 23 | Change tool | " | " | SDJCR2525 M11 | DNMG110404 QF 425 | " | - | - | - | 1 | - | - |
| 24 | Finish turn | " | " | " | " | " | 50 | 2500 | 0.5 | - | 0.4 | Oil |
| 25 | Change tool | " | " | MUJNR2525 M16 | UNMG 160404 MF425 | " | - | - | - | 1 | - | - |
| 26 | Finish turn | " | " | " | " | " | 50 | 2500 | 0.5 | - | 0.3 | Oil |
| 27 | Change tool | " | " | RF151.20 252520 | R151.220005 SE235 | " | - | - | - | 1 | - | - |
| 28 | Part off to length | " | " | " | " | " | 50 | 2500 | - | - | 0.2 | Oil |

Figure 4.22 (Continued)

# CHAPTER V

# CONCLUSION

The aim of this study was to develop a process planning package concentrating on an automatic tool selection program which helps the user in finding correct tools for rough and finish machining of rotational parts. The given profile was analysed such that a tool moving from right to left would machine the maximum portion of the workpiece without having tool collision with the part profile. The same methodology is applied for tools moving from left to right. Tools for external part profiles with grooves and threaded portions are also selected in this study. Moreover, a production routing sheet is designed such that the selected tool along with other parameters can be written in an electronic media. Routing sheets developed for the system for each part can be stored and retrieved as required. These route sheets contribute to the development of a process plan presenting the instruction for the production of a particular part.

The use of this system gives the user an opportunity to make tool selection on a computer for a wide verity of turned components manufactured in the industry. Furthermore, the system provides a facility to the user to mark tools as available in the tool database. Therefore, during the selection procedure the system gives priority to the tools found already available in the industry.

During part geometry analysis the system calculates enterance and in-copy angles in accordance with the rules discussed in Chapter III. Considering the enterance and in-copy angles on a workpiece profile, the system selects and recommends tools from the available list having approach and trailing angles greater than or equal to the enterance and in-copy angles, respectively. At this stage the system is limited to the selection of tools without determining the cutting conditions and cost for each tool. However development of the structure for tool selection also provide greater worker participation during tool selection procedure. Therefore, a list of toolholder satisfying the above criteria is also presented to the user to by pass the recommended tools and select one from that list.

The system also provides the user with a list of inserts satisfying the selected toolholders for a given part profile. Since the selection of insert also depends on the workpiece material, the development of the structure for the system leave final selection to the user to select one insert from the list considering the type of toolholder selected.

Furthermore, the system is limited to the selection of tools for a given part profile from the tools available in the tool database. For areas of parts requiring special tools for machining, the user should use the generated results during part geometry analysis as a guide for the selection of special tools.

For further development of the program and in order to produce a complete process planning package for rotational parts the followings are recommended:

1. More powerful Part Drawing Editor is to be designed with a facility to draw complex external and internal part profiles including tolerances and detailed information about superimposed features.

2. An algorithm for machining internal profiles is to be developed for a complete Tool Selection Module for rotational parts.

3. An additional G-code Generation Module is to be adopted to the system, so that each tool motion will be represented with a G-Code.

4. A Process Demonstration Module is to be designed, so that the machining sequence in the process plan including G-code will be demonstrated on graphics screen and each tool motion will be displayed.

5. An interface module is to be developed that combine different modules and databases referred in Figure 2.2 to automatically select and display the corresponding parameters of a given part on a production routing sheet.

6. A possible link with the Machinability Database is to be made for a more precise selection of insert to be made for a toolholder selected for a given workpiece.

7. The system developed in this study select tool suitable to machine the given part profile after having tool collision with the workpiece. However, determination of cutting conditions and cost also play an important role during the selection of an optimum cutting tool. Therefore, a module is to be developed to recommend the user, the best tool, from the ones selected by the system according to these conditions.

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# APPENDIX

APPENDIX

USER'S GUIDE

## A.1 Main Menu

The program is developed by using Turbo Pascal programming language and runs on IBM personal computers and their compatibles. In order to run the program, type main, such as:

C:\>main

Program has a main menu that provides a link for four different programs developed in this study. Following items appear in the main menu.

1- Tool database
2- Drawing editor
3- Tool selector
4- Production Routing Sheet
5- Exit

### A.1.1 Tool Database

Choosing the first option executes the program for tool database. The menu bar for this program contains

- File
- Edit
- Option
- Help

A.1.1.1 File

This section provides a sub-menu for

- New TDB
- Load File F3
- Save file F2
- Save as
- Save data as text
- Print
- Exit

In New TDB, it is possible to enter new tools in accordance with the ISO codes given in Sandvik Catalog. Selecting this option ask the user to choose from the type of tool holder or insert for which the database is to be made. Following choices are given

- External Holder ( * )
- Internal Holder ( )
- Special Holder ( )
- External Threading ( )
- Internal Threading ( )
- Normal Insert ( )

- Special Insert ( )
- Threading Insert ( )

The user can make a choice among these by bringing the bar menu to the item to be chosen and pressing the space bar. Pressing enter key completes the selection.

Tools available in Sandvik Catalog have already been stored in the files with an extension .TDB. Therefore, using Load file option it is possible for the user to retrieve a file that already exists. Tab key can be used to switch between the edit line and the files' list.

Save file is related to the user option where a new file can be stored with a specific name. To change the name of the file that already exist in the tool database Save as option is used. The program also provides a facility to the user to store an existing .TDB file in text form with an extension .TXT. This is done with Save as text option. It is used to facilitate other programs to easily read the data files stored in the tool database. Text files can also be printed using print option. Last option Exit returns to main menu page. Hot keys for sub menus are written against each option.

A 1.1.2 Edit

This selection provides a sub-menu for

- Edit
- Mark available tools
- Exit from marking / editing

Edit option allows the user to edit new tools or tools existing in the tool database. Tools stored in the tool data files can be marked for availability in the factory. This is done using the second option. In order to switch to a new file or load an existing file the user must exit from marking / editing using the third option.

A 1.1.3 Option

The following options appear under the menu Option

- Make all tools available
- Unmark all tools
- Mark tools (default)

First option makes all tools as available in the factory for a file existing in the tool database whereas the second one unmark them. Mark tools (default) provide three options to the user. These are given as

- User dependent ( * )
- Always as available (   )
- Always as not available (   )

Default setting to mark the availability of tools is user dependent. However the option can be changed by bringing the selection bar to the appropriate choice and pressing space bar. Enter key complete the selection to Mark tools (default)

A 1.1.4 Help

Help menu is given for the fields defined in the ISO code of a tool. During editing help can be obtained about certain fields by pressing F1.

Short cut letter for menu bar and sub menus are given in red. Therefore, pressing Alt key simultaneously with the short cut key makes use of menu bar. Menu bar can also be activated using hot key of F10 allowing menus and menu items to be selected using cursor keys.

Since the ISO codes of the tools available in Sandvik Catalog already exists as data files, the user should not edit new files or make changes in the existing one's unless new tools become available in the market. However, the user can mark for the availability of tools in the factory with the help of this tool database.

A 1.2 Drawing Editor

When this program is run, following menu appears

Part File Help Quit

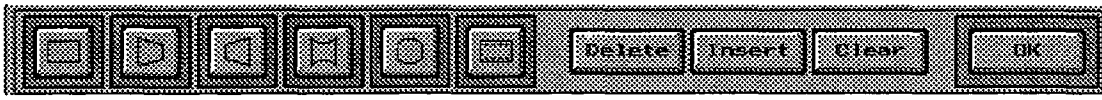
A 1.2.1 Part

This section provides a sub menu for

Sketch Data View Main

A 1.2.1.1 Sketch

Menu appearing under the option Sketch allows the user to generate new workpiece drawing with given feature primitives. Sub-menu for this option is given as




A feature primitive can be inserted into the workpiece using insert option. Clear option allows the user to clear all feature primitives defined for a workpiece whereas delete option erase only single feature primitive from the workpiece. OK makes the final selection and returns to the main menu.

A 1.2.1.2 Data

Data input to feature primitives defining a workpiece is done using the option Data. Following sub menu appears under this option

| | | | |
|---|---|---|---|
| Input | Mode | Set | OK |

To input the data, two modes are defined. These are absolute mode and incremental mode. In absolute mode, length dimensions of a feature primitive are always measured from an absolute point on the right side of the workpiece whereas in incremental mode length of each feature primitive is separately defined. Third option Set allows the user to set the number of decimal digits to which the data will be entered. Default value for this option is 0. However, these values can be entered up to five decimal digits. Also, workpiece dimension limits can be fixed using this option. In this case default value is 1000 mm that can be altered as required. Maximum limit to which the workpiece dimension can be entered is 9999 mm. Fourth and the final option returns to the main menu.

#### A 1.2.1.3 View

View option facilitates the user to have an appearance of the workpiece drawn using the given dimensions.

#### A 1.2.1.4 Main

This option returns back to the menu defined for the option Part.

### A 1.2.2 File

Sub menu for this option is

Open New Save Save as Print

Again in this case, Open option is used to open an already existing file. New file can be created and saved or saved as using New, Save and Save as options. Finally Print option is used to print an already existing data file defining a workpiece.

### A 1.2.3 Help

Small help about the program can be obtained using this option.

A 1.2.4 Quit

This option exit from the program and return to the main menu.

A 1.3 Tool Selector

Menu bar for this program is

- File
- Option
- Analyze
- Display

A 1.3.1 File

The following three sub menu appear under the option File

- Load F3
- Save data F2
- Exit Alt-X

Part drawing drawn with the help of Drawing Editor can be retrieved using the first option Load. Second option 'Save data' is used to save the ISO codes of the tools selected for the given workpiece. Final option exit from the program and returns to the main menu. Corresponding values against each sub menu represent their hot keys.

A 1.3.2 Option

Sub menu appearing under the heading Option is

- Settings
- View
- Shank height
- Shank Width
- Insert nose radius (rough)
- Insert nose radius (finish)

A 1.3.2.1 Setting

Setting option provides three sub options

Minimum in-copy angle : 50

Minimum change angle : 50

Taper approximation : Y

Default setting for in-copy angle on a workpiece profile is 50°. However, the program facilitates the user to change this angle considering the availability of new tools in the market with different in-copy angles. Similar changes can also be made for change angles of the part profile handling the second option. Third option is directly related to change angle where changing the taper approximation to N make change angle as zero.

A 1.3.2.2 View

During part geometry analysis a given workpiece can be viewed with the following options.

- Show original workpiece [X]
- Cutting from right to left [X]
- Cutting from left to right [X]
- Show all possible tools [X]
- Display inserts [ ]

Default values for this sub menu can be changed by bringing the selection bar to appropriate choice, pressing space bar and finally pressing enter key. The last two options i.e. Show all possible tools and Display inserts allows the user to view the ISO codes of tool holders and inserts during the selection procedure.

A 1.3.2.3 Shank height and Shank Width

The values which are available for shank height and shank width in two different options are given below.

| | | |
|---|---|---|
| 1 | 12 | ( ) |
| 2 | 16 | ( ) |
| 3 | 20 | ( ) |
| 4 | 25 | ( * ) |
| 5 | 32 | ( ) |
| 6 | 40 | ( ) |

Default values for shank height and shank width are 25 mm. However, these values can be changed by bringing the selection bar to appropriate choice, pressing space bar and finally pressing enter key.

A 1.3.2.4 Insert nose radius for rough and finish machining

These values are also given in two different options. Insert nose radius for rough and finish machining has the following choices.

1 0.0 ( )

2 0.2 ( )

3 0.4 ( )

4 0.8 ( )

5 1.2 ( )

6 1.6 ( )

7 2.4 ( )

8 3.2 ( )

Default value for rough machining is 1.2 mm whereas for finish machining it is 0.4 mm. These values can also be changed by applying the same procedure discussed in the previous section.

A 1.3.3 Analyze

This option provides the following sub menu

- Reset
- Analyze profile

- Select tools  F5
- Arrange for rough turning
- Arrange for finish turning

Profile analyzed using the second option can be restored to its original form using the first option reset. Third option selects tools whereas the last two options allow the user to display selected tools arranged for rough or finish machining. Tool selection can also be made using the hot key F5.

A 1.3.4 Display

Tools selected during the analysis of a given workpiece can only be displayed if the Display option is selected. Sub menu for this option is as follows.

- Selected tools
- Recommended Tools  F9
- Roughing tools
- Finishing tools
- Threading tools
- Grooving tools
- Inserts

Options provided here are self explanatory and are used to display the ISO codes along with the shape of the tools recommended for a given workpiece. Hot key to display recommended tools to the user is F9.

A 1.4 Production Routing Sheet

This program allow the user to create a database for production routing sheets. Menu bar for production routing sheet contains

- File
- Edit

A 1.4.1 File

This option also provides a sub menu for

- Load F3
- New
- Save F2
- Save as
- Print
- Exit Alt-X

The functions performed by these commands are self explanatory and are similar to the ones that have already been explained in the tool database. However, the print option in this case also provides a sub menu as.

[ ] Double Width

[ ] Emphasized

[ ] Double Strike

[ ] Condensed

( * ) Pica (10 cpi)

(   ) Elite (12 cpi)

Default value for print option is Pica and without special emphasis on line quality of print out. However, the user can improve the output by bringing the menu bar to required option and pressing space bar. Pressing enter key completes the selection.

A 1.4.2 Edit

Edit option has the following sub menu

- Header Editing F4
- Operation Editing F5
- Clear all operations
- Erase only header

Editing part of a Production Routing Sheet is mainly divided into two parts: Header editing and Operation editing. The first option, Header Editing is used to edit entries used in header part. Arrow keys can be used to switch between the entries. Editing of an entry in header part can be made by bringing the menu bar to the entry to be edited and pressing enter key. Similarly, Operation Editing can be activated using the second option. In this case, tab key can be used to switch between the entries. Similar to header editing, editing of an entry in operation part can also be made by bringing the menu bar to the entry to be edited and pressing enter key. Pressing enter key complete editing operation. Therefore, the first two options provide a facility to the user to switch between two options.

Hot keys for these sub menus are F4 and F5 respectively. The program also provides a facility to the user to erase entries from either operation part or from header part of a production routing sheet. This can be done by using the last two options.

A 1.5 Exit

The last option Exit terminates the program and returns back to DOS.