UNIVERSITY OF JORDAN

FACULTY OF GRADUATE STUDIES

# COMPUTER AIDED PROCESS PLANNING
# CASE STUDY : CIM Lab , University of Jordan

عميد كلية الدراسات العليا

By

**Mohammad Dheif Alla AL- Tahat**

Under the Supervision of

**Dr. Zain El-Abdeen Tahboub**

**Dr. Sabah Al - Bermani**

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*AND APPROVED BY*

**Dr. Zain El-Abdeen Tahboub** Z. Tahboub CHAIRMAN

**Dr. Sabah Al - Bermani** ٩٣/٤/٢٨ COMMITTEE MEMBER

**Dr. Khaled Toukan** COMMITTEE MEMBER

**Dr. Yousef El - Assaf** COMMITTEE MEMBER

**Dr. Khaldoun Tahboub** COMMITTEE MEMBER

# DEDICATION

*TO my parents*
*sisters , brothers*
*and relatives.*

# ACKNOWLEDGMENT

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# ABSTRACT

The aim of this thesis is to study the computer aided process planning topic in general, and to develop a computer aided process planning system for the products that can be produced in the Computer Integrated Manufacturing Laboratory (CIM-Lab) in the Department of Industrial Engineering at the University of Jordan .

To achieve our goal a study of the topics related to process planning was carried out such as studying of the manufacturing environment (CIM-Lab) and studying of group technology (G.T.) and coding techniques.

This thesis consists of seven chapters , the first chapter briefly discusses what process planning is , the need for automation in process planning, and the approaches to CAPP systems. A literature survey has been done in the second chapter . In the third chapter the followed research methodology is introduced .

In the fourth chapter a study of the (CIM-Lab) is done which includes , an introduction to CIM system , description of CIM-Lab components , and the selection of cutting speeds and feeds for the (CIM-Lab) manufacturing facility.

A study of the group technology techniques and some of the different existing coding and classification systems is given in the fifth chapter in order to develop a coding and classification system for the products that can be produced in the CIM-Lab .

Finally , we discuss in detail the developed CAPP system which is based on G.T. in chapter six . Examples , conclusions and recommendations are introduced in the last chapter .

# CHAPTER ONE

# INTRODUCTION

Process planning is the subsystem responsible for the conversion of design data to work instructions in the manufacturing system. It is a systematic determination of the methods by which a product is to be manufactured economically and competitively . It is an intermediate stage between designing and manufacturing the product .

After a product is designed the manufacturing process to be used to produce it must be determined , this involves determining the sequence of operations required , the machine tools or work stations to be used , and the machining parameters to be set (such as cutting speed , feed rate , etc......) .

Many of these decisions were left to the skilled machinist on the factory floor , which must be made in advance Powers [1].

Process planning procedures may vary somewhat with each individual for the same product , but in general it include the following :-

1- Analysis of part drawing , specifications and tolerancing .

2- Listing of basic operations .

3- Selection of processes .

4- Determination of sequence of operations .

5- Selection of proper machinery with applied tooling .

6- Selection of cutting tools and cutting conditions .

7- Specifying the gauging .

8- Estimating the operation time .

9- Documenting the process plan .

## 1.2 The Objective

The obective of this research is to study the computer aided process planning system and it's integration with the manufacturing environment . Based on that , create a CAPP software to obtain a feasible sequence of operations given the following :-

1- Available manufacturing resources .

2- Quality of the product .

3- Cost of the product .

4- Time needed to produce one unit

## 1.3 The Need For Automation In Process Planning

The recent world-wide drive towards a computer aided design and flexible manufacturing systems (CAD & FMS) has drawn considerable attention to the development of computerized process planning techniques , as a basis for rational and logical approach for manufacturing of parts in the most economical manner .

Errors in process planning obtained from skilled machinist can lead to inefficiencies or parts damage if the cutting speeds and feed rates are not suitable . The use of computers will diminish this problem . In computer aided process planning (CAPP) the skills and experience of machinists are built into the computer program [1] .

Using CAPP can be very helpful in decreasing the development time of process sequecne for new products . Hence, in our manufacturing environment in Jordan CAPP will encourage and decrease cost of developed new products , which we "in Jordan" badly need .

### 1.4 Computer Aided Process Planning (CAPP) :

Computer aided process palnning systems link design and manufacturig in CAD/CAM systems together . The manufacturing processing sequence is documented on a route sheet which typically lists the necessary information .

CAPP is basically an effort to convert the know-how of manufacturing planning from an experience-based technology to a science based technology .

Because of the problems that occur through process planning , in recent years many attempts have been made to capture logic , judgment , knowledge , and experience required for this important function and translate them into computer commands, based on the specification of a given part . The program automatically generates the manufacturing operations sequence .

### 1.5 Approaches To CAPP System

In computer aided process planning there are three main different approaches , these are , variant (retrieval), generative and automatic approach T.C. Chang[2].

The variant approach uses computer terminology to retrieve process plans for similar components using table look-up procedures .The process planner then edits the plan to create a variant to suit the specific requirements of the component to be produced . Creation and modification of standard process plans are the process planners responsibility .

The generative approach is based on generating a process plan for each component without refering to existing process plans .

Generative -based systems are systems that perform many of the functions in a generative manner .

Automated systems on the other hand , completely eliminate humans from the planning process , the computer is used in all aspects, from interpreting the design data to generating the final cutting path .

### 1.5.1 Variant Approach To CAPP

In order to implement variant process planning which is based on the concept that similar parts will have similar process plans , (G.T.) based on part coding and classification is used as a foundation . Parts are coded based upon several characteristics and attributes . Part families are created of parts having sufficiently common attributes to group them into a family by analyzing the codes of the part spectrum .

A standardized plan is created and stored for each part family , the computer will retrieve the best process plan when the planner enters the (G.T.) code of a part , if none exists the computer will search for routings and operations sequence for similar parts, recall , identify and retrieve the existing plan for that similar part and make the necessary modifications for the new part .

A number of retrieval-type computer aided process planning systems have been developed (such as a real computer aided process planning system which was developed by Link in 1976 and MIPLAN system which was developed by Houtzeal in (1980) .

The variant approach is highly advantageous by increasing the information management capabilities , it deals with the complicated activities and decisions required with less time and labour .

The variant process planning system has two stages : the preparatory stage , and the production stage .

### Preparatory Stage

Existing components are coded, classified and grouped into families, see Figure 1.1. The part family formation can be performed in several ways .

Families can be obtained based on geometric shapes or process similarities , several ways can be used to form these groups .

The effectiveness and performance of the variant process planning system depends to a very large extent on the effort put at this time consuming stage .

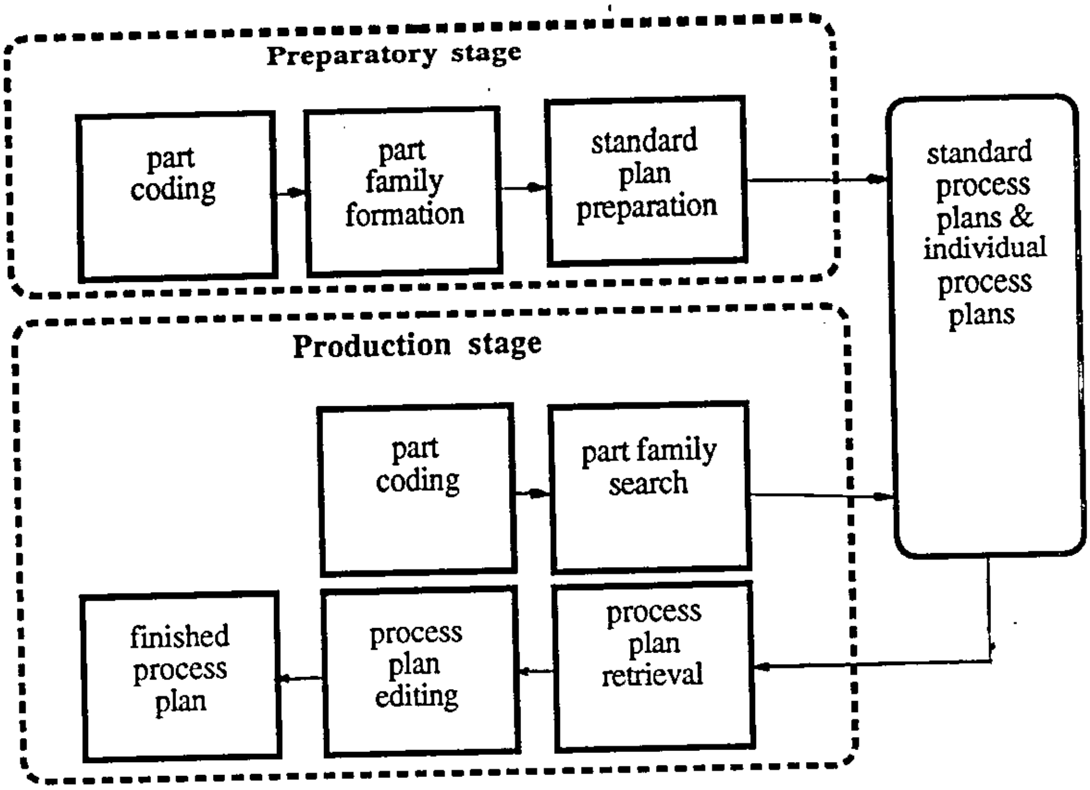


Figure 1.1 Variant Process Planning Approach

**Production Stage**

Production stage occurs when the system is ready for production , new parts can be planned in this stage . An incoming part is first coded, by sending its code to a part family to which it belongs , the standard plan is indexed and can be easily retrieved from the data base .

The biggest disadvantage is that the quality of the process plan depends on the experience of the process planner . The variant based planning is still popular because of :

1- Less investment and shorter development time , especially for the medium sized companies which want to establish their own research groups .

2- Lower development and hardware costs especially for small size companies where the products do not vary extensively  Alting. Leo and Zhang[3].

A variant system can improve the planning efficiency dramatically, in most batch manufacturing industries where similar components are produced repetitively. Some other advantages of variant process planning are the following :-

1- Once the standard plan has been prepared  a variety of components can be planned .

2- Comparatively simple programming and installation is required to implement  a planning system.

3- The system is understandable , and the planner has control of the final plan .

4- It is easy to learn and easy to use .

### 1.5.2 Generative Approach to CAPP

This is the system which automatically synthesizes a process plan for a new part from information available in manufacturing data base . When receiving the design model , the system is able to generate the required plan for the part.

It operates like an expert system in order to generate a new process plan . Generative-based CAPP systems use rules and experience to make decisions based on the analysis of the geometry and  materials  involved.

The rules of manufacturing and the equipment and machines capabilities are stored in a computer system , a specific process plan for a specific part can be generated without any involvement of a process planner when the system is used .

When designing a generative CAPP system the following ingredients must be included Groover[4].

First the technical knowledge of manufacturing and the logic that is used by successful process planners must be captured and coded into a computer program (manufacturing databases) .

The second ingredient in generative process planning is a computer compatible description of the part to be produced , two possible ways of providing this description are (part description) :

1- The geometric model of the part is developed on a CAD system during product design .

2- A group technology code number of the part that defines the part features in significant details .

The third ingredient is the capability to apply the process knowledge and planning logic contained in the knowledge phase to a given part description .

The biggest advantage of the generative-based CAPP system is that the process plan is consistent and fully automated . This kind of systems is mostly oriented towards large companies and research organizations, since they can afford the investment in a long term project. Especially, for companies which have a large number of products in small lot sizes, the generative approach is attractive .

The generative process planning have the following advantages, :

1- It generates consistent process plans rapidly .

2- New component can be planned as easily as existing components .

3- It has potential for integrating with an automated manufacturing facility to provide detailed control informantion .

### 1.5.3 Automatic Process Planning

Automatic process planning denotes process planning systems that can generate a complete process plan directly from an engineering design model (CAD, data) . It possesses two special features: Automated CAD interface and complete and intelligent process planning.

There are three kinds of (CAD) data approaches that can be used as input , one approach is to take a general CAD model and develop an interface to recognize the manufacturing features from this model .

The second approach uses a specially designed CAD model incorporating shapes that are immediately recognizable by the manufacturing plan.

These familiar shapes, or features , are designed around manufacturing operations .

Such a feature-based design environment limits the designer to the available manufacturing features , which are by definition feasible for manufacturing [2] .

By using a feature model , one can ensure that the component designed can be produced .

The third approach is a hybrid approach ; dual models are used. Pointers are used to link between the two models .

A design can be done by using a feature based modeler . The feature model is then evaluated into boundary model. It reduces constraints a designer has to obey during the design stage .

### 1.6 Benefits Of CAPP

The benefits of computer aided process planning can be summarized as follows Groover and Zimmers [5] :

1- Process rationalization and standardization .

2- Increased productivity of process planners .

3- Reduced turn around time .

4- Improved legibility .

5- Incorporation of other application programs .

6- Suitable in computer integrated manufacturing CIM environment .

Finally CAPP can decrease the unit cost through manufacturing parts in an optimal way .

### 1.7 Implementation Techniques

#### 1.7.1 Group Technology (G.T.)

G.T. can be defined as the philosophy in which similar parts are grouped together to take advantage of their similarities in manufacturing and design by studying a large population of different items .

### 1.7.2 Artificial Intelligence and Expert Systems

The term Artificial Intellegence (A.I.) was created at the end of 1950's , the first successful utilization of (A.I.) was in the medical diagnostic and consulting areas in the mid 1970's .

"The CAPP system in which (A.I.) techniques have been applied are called Expert System (E.S) or Knowledge Based Systems (K.B.S), or Knowledge Based Expert Systems (K.B.E.S)" [3] .

KBES generally are classified into the two following categories [3].

1- The rule based systems or the rule-driven approach [IF THEN] rule which consists of two major components (1) a knowledge base which contains the rules and (2) an inference engine which controls the invocation of these rules . Example of such an IF THEN rule is :

IF : it is an external diameter .

THEN : a turning operation is suggested .

2- The frame-based system or the pattern-directed approach which consists of (1) knowledge sketch and (2) knowledge details. The knowledge sketch is characterized by entities, attributes , and relationships .

Sometimes we can construct a Knwoldege Based Expert System using a combination of both types of reasoning such as , XPLAN-R an expert process planning system for rotational parts which was developed by Zhang and Alting

1988 [3].

Finally a KBES generally conists of the following four components :-

1- A knowledge base .

2- A knowledge acquisition mechanism .

3- A recognition /interference scheme.

4- User interface shceme.

Expert systems have been applied to a variety of situations such as , production planning , [Intelligent Scheduling Assistant (I.S.A.)] , repair and fault-diagonsis , robotics and computer vision , process control etc. Masued,S.M[6].

The development of Knowledge Based Systems have reached such a stage that they are now ready to be taken into the real world.

Abu S.M in 1987 concluded that expert systems are not yet developed enough to displace the human link completely and it is not expected that they will replace these experts [6].

### 1.8 Problem Definition

The question in this research is to find a method suitable for expressing the knowledge pertaining to process planning in computer software to enable us of generating process plans for parts with the aid of the computers .

This work will be limited to parts that can be produced on the CIM-lab at the industrial engineering department .

The production process needs a predetermined procedure to complete it , these predetermined procedures include the preparation of the operations sequence needed to produce a certain part .

Because there is a large number of parts that can be produced , the planning process for finding the process plan for each part is tedious and needs large effort. The role of CAPP is to solve this problem by creating plans for all parts producible in the manufacturing environment . To make this effort managable , classification of parts into families is then in order.

# CHAPTER TWO

## LITERATURE REVIEW

With the rapid development of computer aided techniques both the direction and implementation of CAPP has changed greatly . "Since its begining,twenty years ago more than two hundred papers have been published in the area in the last two decades most of the papers introduce specific CAPP systems[3]" .

In this chapter we will briefly review the important developments in CAPP and the important historical events that led to CAPP development.

### 2.1 Historical Background Of CAPP Development

Since CAPP is a bridge between the design and manufacturing processes it is appropriate to discuss the significant development in both areas .

The development in CAD and CAM is shown in Figure 2.1 . The development of CAM can be traced back to the late 1949's when the concept of numerical control was first proposed .

The development of an NC machine tool marks the begining of the CAM hardware development .

After the first NC machine was built , it was found that NC part program preparation was extremely tedious if done by hand .

In the later part of 1950's NC machine tools became commercially available . By 1960's several thousand NC machine tools have been installed in industry.

| **Software** | 1945 | **Hardware** |
|---|---|---|
| | | James T. Parsons proposed NC concept |
| | 1950 | MIT servo mechanism lab<br>USAF NC milling m/c proj |
| Part programs prepared manually | | |
| | 1955 | Automatic tool changer - IBM |
| MIT started APT developmet | | |
| | | 1st production skill -miller - G&L |
| LISP language<br>APT language | | Machining center - K&T |
| | 1960 | |
| SKETCHPAD Interactive computer graphics | | 1st industrial robot<br>CRT display<br>Adaptive control |
| UINISURF Bezier sparch . sculptured surfaces<br>CAD Drafing . | | |
| | 1965 | 7,700 NCs installed |
| | | CNC-DNC concept & Mini-computers PLC |
| Solid Modelling development started<br>Build-1 solid modeller. | 1970 | 1st DNC system |
| 3- D CAD systems. | | CAM-CAD/CAM |
| | | Micro- computers<br>FMS |
| PADL-1-0 solid modeller<br>IGES graphics exchange standards<br>Super -computers . | 1975 | |
| | | Super-minicomputers |
| Solid modeller became commercialized<br>PC based CAD | 1980 | PC<br>Micro - based workstations |
| MAP, Top LAN standards . | | |
| PDES<br>Expert CAD systems (future) | 1985 | Automated factory |

**Figure 2.1 History of CAD and CAM.**

NC control was put on nearly every kind of machine tool, those machines replaced hand skill with programming skill.

The industrial robot was also invented during this period, it could replace some simple material handling tasks which used to be handled by human operators . Since early industrial robots were not computer controlled , the intergration of robots with machine tools was not possible .

The major development on the CAM side , before the late 1960's was the development of manufactuting hardware automation , the development was slow due to the lack of powerful computers and software tools .

On the software side of the advancment , Artificial Intillegence (A.I.) research started in the mid-1950's . A LISP language was proposed during that time .

In the early 1960's the invention of interactive computer graphics and sculptured surface model resulted in the development of CAD drafting and surface modelling system .

By the late 1960's , mini-computer become available , although they were slower than the main-frames but were cheap enough that small engineering department could afford them .

By 1970's other significant development in CAM, was the invention of Programmable Logic Controller (PLC) . PLC was initially designed as a replacement of relay panels for industrial control .PLC is a computer based device which became the most important control device on the shop floor .

The concept of CAPP was proposed during this period. The 1970's were also a time for micro-computer development which employs many of the industrial controllers , application such as CNC control were gradually replaced by micro computers .

By 1980's the micro computer became increasingly popular, and by the mid-1980's there were millions of personal computers installed in offices , homes and shop floors. Many CAD and CAM applications that need super-minicomputer, can now run on desktop engineering workstation . Another significant advancment was Local Area Network (LAN) which allows many computers to be networked together to share resources such as disks and printers , the CAD and CAM software can now run on personal computers at a reasonable speed .

Ethernet LAN and UNIX operating systems also became the standard, the computational speed is no longer a concern for many CAD and CAM applications .

In the early 1980's, several highly successful expert systems E.S. applications, such as the VAX computer configuration system and XCON of digital equipment corporation , resurrected A.I. , subsequently many manufacturing applications have been developed including many E.S. based process planning system prototypes .

## 2.2 Historical Development Of CAPP

Alting et. al. [3] stated that in 1965 Neibel first presented the idea of using the speed and consistency of the computer to assist in the determination of process plans , and it stated that Schenk (1966) discussed the feasibility of automated process planning in his Ph.D dissertation at Purdue University .

Computer aided process planning has not been broadly addressed until the begining of 1970's. This is probably due to the fact that the computer capabilities of both hardware and software were limited and manufacturing engineering was more less isolated from the computer aided techniques at that time .

The year 1976 was probably the first harvest year in the computer aided process planning area. Early attempts to create automated process planning systems consisted of building computer-assisted systems for report generation , storage, and retrieval. When used effectively these systems can save up to 40% of a process planners time . A typical example is Lock Heeds CAP system. Such a system can by no means eliminate the process planning tasks , rather it helps to reduce the clerical work of the process planning [2].

Most CAPP systems development in the 1970 used G.T. retrieval as the major approach while in the 1980's more generative and knowledge based approaches were used in CAPP development .

Some of the major advancments in CAPP can be seen in Figure 2.2 the figure shows the time versus the intelligence of the CAPP system which is used as a measure of the capablity of the system .

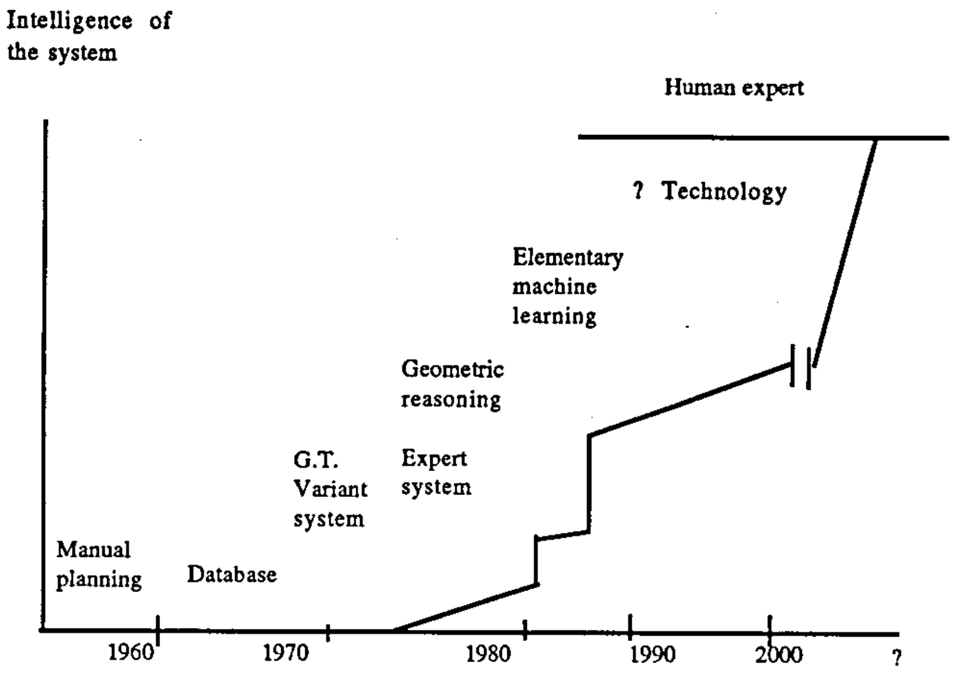


Figure 2.2 The Develpement of CAPP Systems [2] .

The higher the intelligence measure , the more sophisticated the system is and the better it can generate plans .

From the figure we can see that manual process planning was used before the 1960's, in the 1960 database was introduced to store and to help format process plans on a computer system. Since those systems do not help in making decisions the decision is made by the user of the system .

The first variant CAPP system was developed under the direction and sponsorship of Computer Aided Manufacturing - International CAM-I and presented in 1976 at the NC conference .

Alting [3] also stated that in the same year (1976) another CAPP system was developed by the Organization of Industrial Research (OIR) and presented by Houtzeel . The system titled was MIPLAN.

Since 1977 CAPP has begun to be widely addressed , in the mean time the number of skilled process planners has declined in many industrial countries, in order to replenish this shortage of skilled process planners, companies tried to adopt flexible automation . So the skilled process planners competitiveness will increase . CAPP has not kept pace with the development of CAD and CAM.

Because CAPP is a main element in the integration of design and production , this situation has made process planning a bottleneck in the manufacturing process . Thus more and more effort has been applied in the CAPP area and numerous CAPP systems have been reported .

In 1987 and 1980 as stated in [3] several Delphi forecasts were commissioned and reported by the Society of Manufacturing Engineers (SME).

At the begining of the 1980's CAPP has not yet shown many successes in spite of all the effort put and development, since process planning in the manufacturing environment is an area requiring a considerable amount of human expertise .

"Generative process planning systems today are still some what elusive on the whole and can be considered as being in their early stages of development and use[3]" . Five altrernative approaches to generative process planning were discussed by Allen as stated in [3] these are: decison tables ;

decsion trees /decision tables ' axiomatic ; rule based decison tree and constraint-based.

In 1989 Husseini [7] intoduced a retrieval CAPP approach to the flat rolling of copper alloys industry . He concluded that a retrieval CAPP approach fails to take account of the dynamic nature of the parameters involved in the planning . He developed a generative approach to select the optimal routes for single orders and then for batch orders.

I. Lopez et. al. [8] developed a knowledge based system to automatically generate process plans for Printed Circuit Boards (PCB) for small batch flexible line production . The system is called SAPIENT system for alternative planning in electronic assembly using net work technique.

T.C. chang [9] stated that Kang J. developed a methodology for determining automated manufacturing process planning system by means of knowloedge-based approach for machining parts which can generate sufficient information regarding process planning .

Y.S.Liu [10] in the same year 1989 presented a symbolic-oriented frame-based process planning system which describes, a component shape by using descriptive vector premitives in the design stage which can be extended to the stage of manufacture.

The system designed to combine the merits of both the generative and variant techniques.

Figure 2.3 shows the major differences among some of the approaches that are currently used and their capabilities . The differences among them are the CAD input format and the degree of automation in the planner when the input is a 2-D drafting , the automatic drawing interpretation is almost

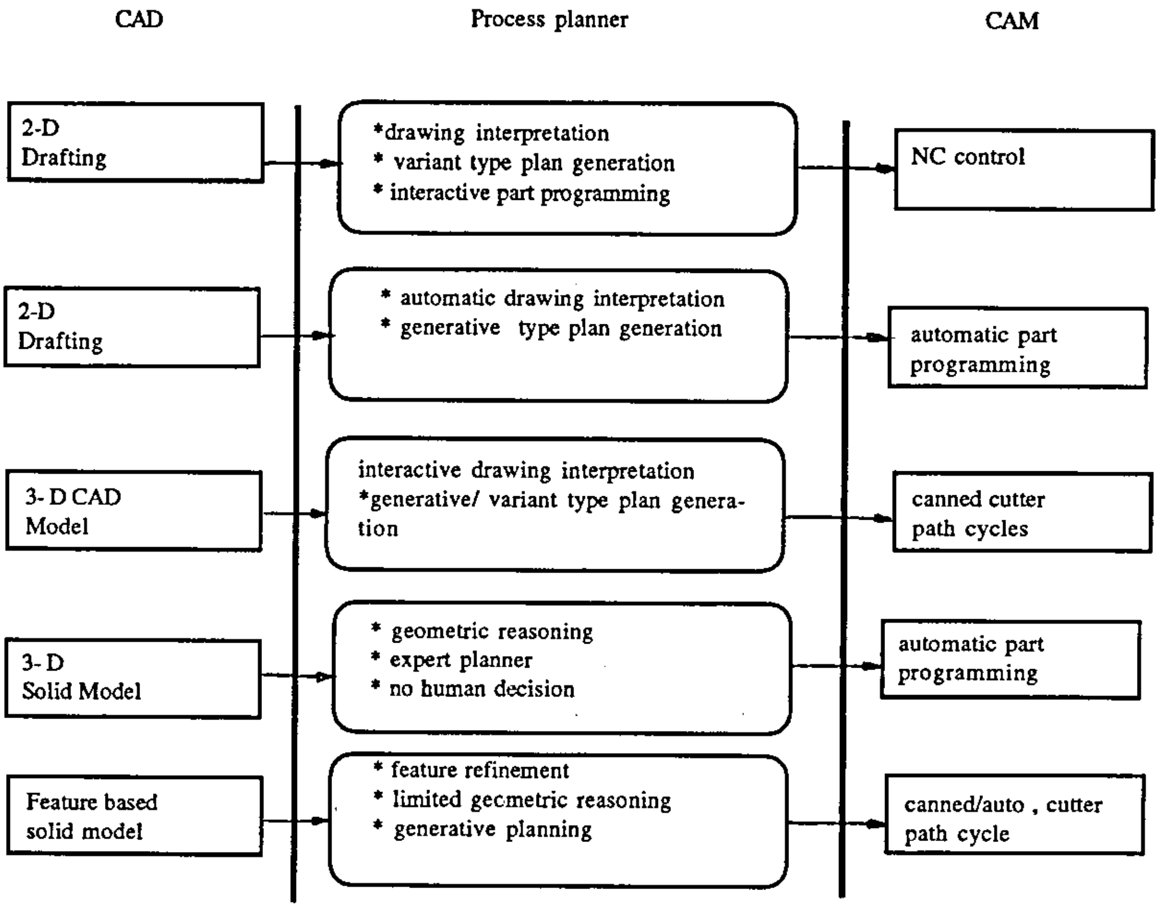


Figure 2.3 Some Process Planning Approaches

impossible in a general sense , the majority of systems which take 2-D drafting as impossible input use a human drawing interpretation and a variant process planning approach .

For generative process planning a 3-D CAD model that provides more information is more likely to be used . A feature-based model is a special kind of solid model , the difference is that it carries addititional semantic information .

The geometric reasoning is made easier because of the semantic information embedded in the feature models .

### 2.3 Group Technology and CAPP

In 1970's computer aided technologies and flexible manufacturing systems (FMS) were introduced into the manufacturing industry. The concept of G.T. was first discussed about 40 years ago by Sokolowski at Leningrand in the Soviet Union [3].

In 1970's G.T. became recognized and was widely utilized in CAPP systems . The idea of G.T. has pushed the American industry in the mid 70's .

### 2.4 Historical Development Of G.T.

The use of group technology in production organization has the two following main origins , firstly, these methods were developed by engineers who were mainly interested in finding methods , secondly, organization in groups was developed by behavioral scientists who were looking for ways to increase worker motivation and job satisfaction .

### 2.4.1 The engineers development of G.T.

The development of G.T. sprang initially from the work of Mitrofanov of Leningrad University E. A . Arn[11] . He found that considerable reduction in set-up time and therefore increase in capacity, could be achieved with lathes if similar parts were loaded on the machines one after the other.

The early development on G.T. was devoted to exploiting these findings. In order to reduce setting time and achieve an increase in capacity many attempts were made to plan the sequencing of work on machines .

The next advancement was to place supporting machines such as milling machines and drilling machines next to the lathes to form groups composed of a mixture of different types of machines , it was believed at this stage that groups would only be suitable for a limited range of parts , because these groups were usually formed by selecting parts by eye from the floor of the shop. This stage in the development of G.T. is some times called the PILOT group stage.

Most of the early methods were based on classification and coding methods . But these have largely been replaced by production flow analysis (PFA).

So it was necessary to change the departmental organization in many companies and also to change many of the supporting systems. This has led to the total system approach to group technology.

### 2.4.2 The Behavioral Scientists Approach to Groups

"The behavioral scientists were looking for new methods of work organization in order to increase worker motivation and job satisfaction, unlike the engineers who were mainly interested in machine shop. Most of the work by behavioral scientists has been done in assembly in process industries[11]".

The groups created by engineers and behavioral scientist have very similar features . Both hit the definition of G.T. concept , and both have succeeded in most of their applications of groups in achieving the benefits for which they were looking .

### 2.4.3 Classification and Coding

The objective of classification and coding systems is to classify components by their design features and to code these features so that parts having similar code numbers possess similar features.

There are three basic features of a component which can be classified[11].

1- Shape

2- Function

3- Manufacturing operations and tooling .

Different classification systems use different features or combinations of these features . But always similarity in features is used to group components into families. Figure 2.4 lists 46 clssification and coding systems . There are undoubtedly many more , the difference with most of these systems when

| Name of coding system | Country of origin |
|---|---|
| 1. OPITZ | W.Germany |
| 2. BRISCH | UK |
| 3. PERA | UK |
| 4. VUOSO | Czechoslovakia |
| 5. MIRTOFANOV | Russia |
| 6. WILLIAMSON | UK |
| 7. VUSTE | Czechoslovakia |
| 8. KC-1 | Japan |
| 9. TOYODA | Japan |
| 10. PGM | Sweden |
| 11. NITIMASH | Russia |
| 12. PITILER | W. Germany |
| 13. GILDEIMEISTER | W. Germany |
| 14. STUTTGART | W. Germany |
| 15. ZAFO | W. Germany |
| 16. COPIC-BRISCH | W. Germany |
| 17. IAMA | Yogoslavia |
| 18. DDR STANDARD | E. Germany |
| 19. HANIMAN GREEN | UK |
| 20. VPTI | Russia |
| 21. KOLAC | Czechoslovakia |
| 22. STOCKMAN | W. Germany |
| 23. CVM-TNO | Holland |
| 24. WERNER and PFLEIDER | Germany |
| 25.PERA SPECIALIST TOOL CODE | UK |
|  | Russia |
| 26. LITMO | W. Germany |
| 27. LANGE ROSSBERT | Russia |
| 28. FOUNDRY CODE | Russia |
| 29. IVANOV | W. Germany |
| 30. BRUKHANOV and REBELSKI | Russia |
|  | Russia |
| 31.KULEV | W. Germany |
| 32. ANDREEVA | W. Germany |
| 33. CZIKEL and ZEBISCH | Russia |
| 34. PACYNA | E. Germany |
| 35. GUREVICH | E. Germany |
| 36. VALTER | W. Germany |
| 37. AUERSWALD | Czechoslovakia |
| 38. PUSCH MAN | Uk |
| 39. NAKEK | Russia |
| 40. SALFORD | Russia |
| 41. ROMANOUSKII | Russia |
| 42. KOBLOV | Russia |
| 43. LABUTIN | Russia |
| 44. VOSTRODOUSKII | Russia |

**Figure 2.4 Classification and Coding Systems J.L. Burbidge[12] .**

using them to form group families , is that they only combine some of the components into easily recognizable families and that they do not divide the parts into groups of machines .

Another difficulty is that they tend to bring together into the same families, components which are similar in shape, but which due to differences in requirement , quantities or tolerances should be made on different types of machines and should therefore be made in different groups .

Conversely, these systems do not bring together into the same families, parts which are dissimilar in shape or function.

### 2.5 Expert Systems and Artificial Intelligence

Knowledge Based Expert Systems (KBES) are considered to have the largest potential for development of CAPP systems .

"The success of RI (XCON) (an expert system for computer configuration) and ISIS (an expert system for job shop scheduling) have enhanced the confidence of KBES in the area of CAPP [3]".

Since when several knowledge-based systems or expert systems have been developed for process planning such as "TOM (Matsushima *et. al.* , 1982), GARI (Descotte and Latombe 1981), EXCAP (Davius and Darbushire 1984), SIPP (Nau and Chang 1985) etc. [3]" .

### 2.6 Existing CAPP Systems

Appendix (A) includes about 156 CAPP systems with the necessary information such as computer programming languages; input and output styles, interface possibilities; data base methodologies; commerical availability and developers of each system [3] .

# CHAPTER THREE

# RESEARCH METHODOLOGY

Any CAPP system consists mainly of three major parts as shown in Figure 3.1 below ; these parts are declaritive or descriptive knowledge about the problem , procedural knowledge about the problem solving method , and the control system or the inference engine.

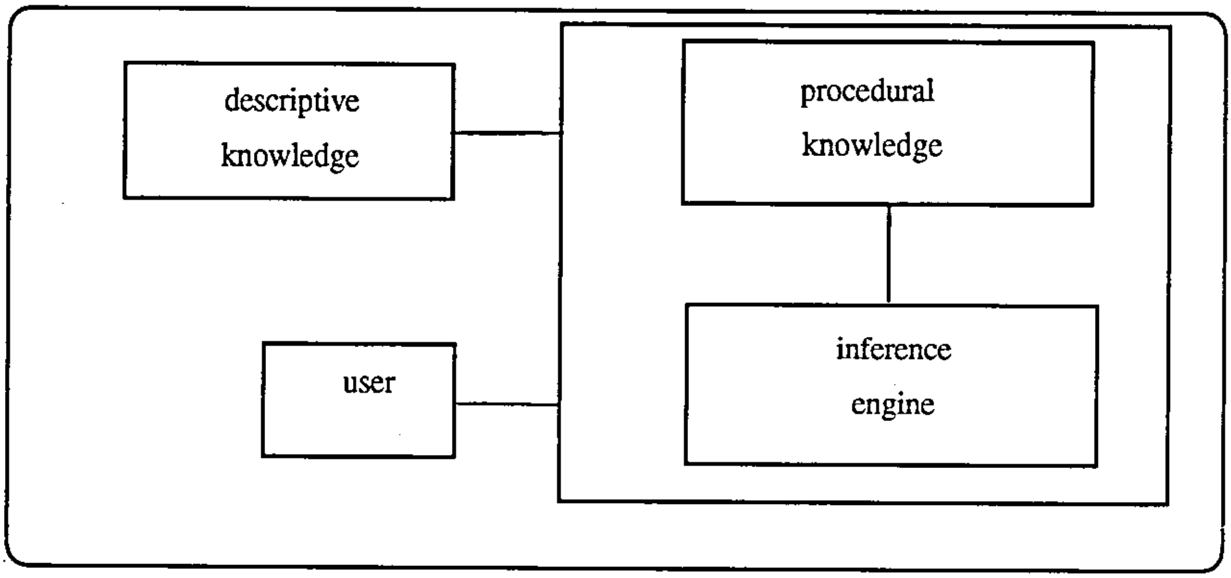


**Figure 3.1 CAPP System Structure .**

After designing each individual part we can create our complete CAPP system by combining them together . The following represents the steps that were followed to design each of the developed CAPP system components .

### 3.1 Declarative Knowledge Phase

It is the description of the parts which needs to be complete and unambiguous to make the CAPP system efficient.

At this phase the conversion of external representations of the parts into internal representations occurs. External representation is the original part design , either on a CAD system or on an engineering drawing , while the translated external representation into a data format is the internal representation .

The conversion process in this research has been done by the use of (G.T.) technique . The following procedures were taken to design the declarative knowledge phase .

1. Studying the manufacturing environment (CIM- Lab in our case) to identify the features of the products which can be produced with this facility from both design and manufacturing point of view , based on the specifications and limitations of the machines available .

2.A study of G.T. techniques and their coding and classification systems in order to create a coding and classification system to represent the parts found from step (1) above .

3. Using the created classification and coding system to group parts into families based on the composite part concept principle .

4 . Translating the information obtained from (1), (2) and (3) above into a computer program to build up the declarative part of the CAPP system .

### 3.2 Pocedural Knowledge Phase

Procedural knowledge or planning knowledge is that part of the CAPP system that does the following.

1. Selects the process .
2. Sequences the operations.
3. Selects the cutting tools.
4. Selects the machining parameters .
5. Selects the machines.

In order to do so , the system must possess knowledge about the manufacturing processes, which includes both the geometric and technological capabilities . To achieve this the following procedures were followed .

1. Studying the manufacturing environment (CIM-Lab) to know , the levels of process knowledge and process constraints .

2. Assigning a standard process plan based on (1) above for each family group obtained from declerative knowledge phase .

3. Translating (1) and (2) above into a computer data base as a process knowkedge representation .

### 3.3 Inference Engine

It is the part of the CAPP system that is responsible for feature recognition and linking the declarative part to the procedural part .

For a certain part code the inference engine will search for the family group that includes this part code , search for the standard process plan for this family group, recognize the part features based on the value for each digit on the code number, and make the necessary modification in the standard process plan to get the final plan for the part .

The linking process and the feature recognition process had been represented by a computer program that links process knowledge representation with the design representation .After the linking process our created CAPP system is obtained .

Finally we can summarize the methodolgy followed in this research by the following steps .

1- Studying the features of the products which can be produced in the (CIM-Lab) from both design and manufaturing points of view based on the specifications and limitations of the machines available .

2- Grouping these products into a number of group families according to their similarities in both design and manufacturing processes by using the suitable coding and classification system .

3- Creating a standard process plan for each group family based on the features of the products included in that group .

4- Translating the information obtained from (1), (2) and (3) above into a computer program by using a suitable language to build the (CAPP) system.

5- Using the system developed in step (4) to create the process plan for other products and compare these plans with the manual process plans .

# CHAPTER FOUR

# COMPUTER INTEGRATED MANUFACTURING LABORATORY

P.G. Ranky [13] gives the following definition of CIM: "CIM is concerned with providing computer assistance , control and high level integrated automation at all levels of manufacturing (and other) industries, by linking islands of automation into a distributed processing systems" .

CIM addresses the total information needs and management of a company from the development of a business plan to the shipment of a product and the follow - up support .

CIM systems have emerged as a result of the development in manufacturing and computer technology . The computer plays an important role in integrating the following functional areas of a CIM system A.Kusiak[14].

- * Part and product design .
- * Tool and fixture design .
- * Process planning .
- * Programming of numerically controlled (NC) machines and material handling system (M.H.S).
- * Production planning .
- * Machining .
- * Assembly .

## 4.1 Overview Of CIM-Lab

The CIM- Lab at the university of Jordan is a laboratory equiped with advanced equipment in the field of computer integrated manufacturing . The integrated flexible manufacturing system (FMS) consists of four robots , two CNC machines and a complete conveyor belt system. It simulates a real modern automated industrial plant with product development traced from the initial phase to finish . The laboratory includes all the neccessary automation islands to make a fully automated manufacturing system . The next sections give a brief description of the subsystems .

## 4.2 Description Of The CIM-Lab System

The CIM-Lab includes the following automated subsystems:

1. Automated storage/retrieval system .
2. Automated material handling system consisting of :
    - Belt conveyor .
    - CENTARI robot system .
    - MERCURY robot system .
    - Bar code reader .
3. CNC milling machine
4. CNC lathe machine .
5. Assembly system (JUPITER robot system).
6. Quality control (Vision system).

The following are brief descriptions of each subsystem in the laboratory.

### 4.2.1 Automated Storage/ Retrieval System (AS/RS)

It is a small storage with a nominal height 95 cm , nominal length of 133 cm and a nominal depth of 22 cm . This store is divided into 25 bays with dimensions of 19 cm high , 26.5 cm length and 22 cm width each see Figure 4.1 .

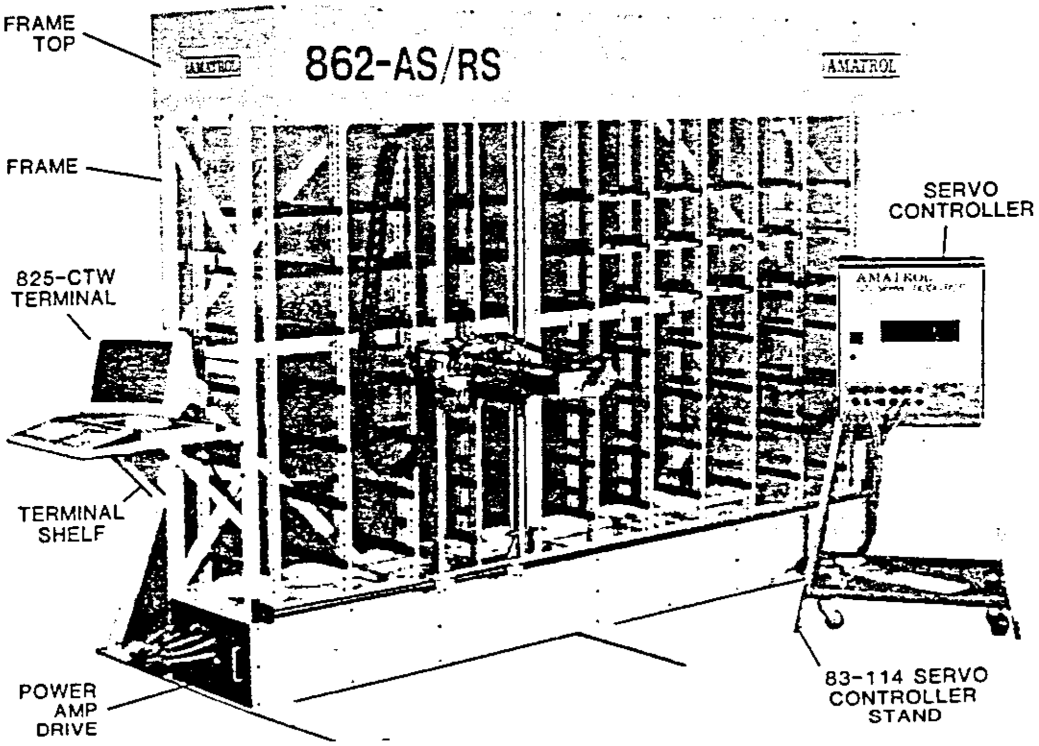


**Figure 4.1 Automatic Storage and Retrieval System**

These bays are used to retain pallets before and after machining processes. This store is served by a cartesian robot . The robot transfers the parts from the store to the belt conveyor and vice versa .

The system operates as an inventory station . Parts stored are identified by numbers and a control system is aware of the part locations and their number. The central computer directs the operation of this inventory unit and issues operating commands .

### 4.2.2 The Conveyor

It is a closed loop irreversible constant speed automated conveyor belt used to transfer parts between the different automated stations, see Figure 4.2. The conveyor is controlled by PLC, Whose job is to control motion of the pallets.

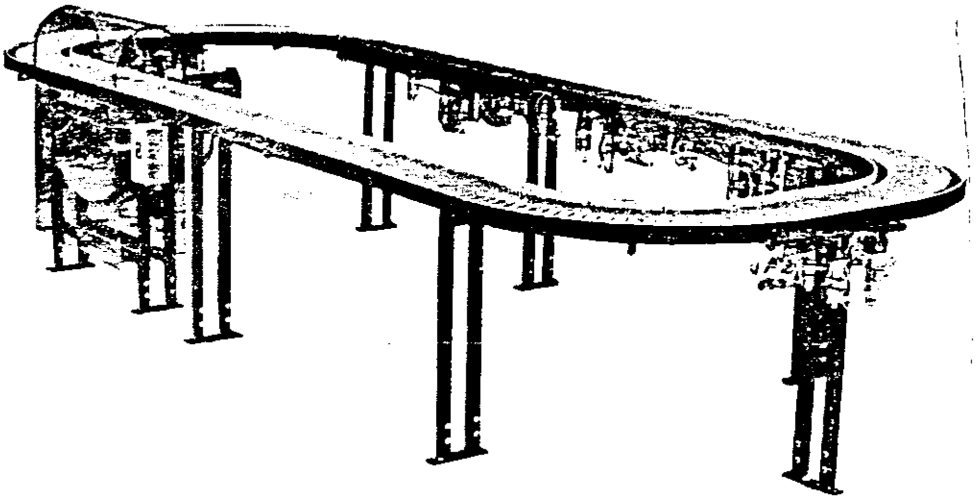


**Figure 4.2 The Conveyor System**

### 4.2.3 CENTARI Robot System

It is an hydraulic articulated servo robot system with a pneumatic gripper. It handles the parts between the CNC milling machine and the belt conveyor system as shown in Figure 4.3 .

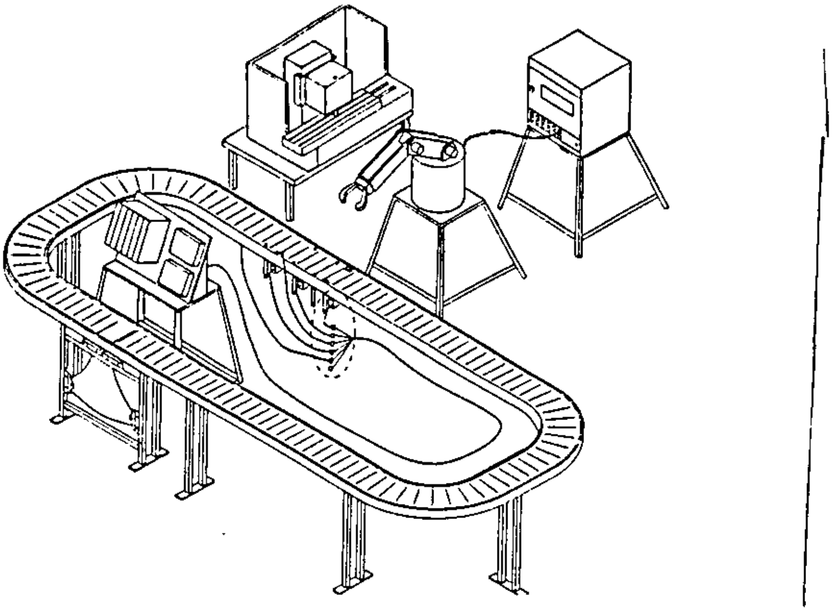


Figure 4.3 The CNC Milling Machine Cell

### 4.2.4 CNC Milling Machine

It is a computerized numerically controlled machine tool provided with its own control unit and all necessary tools and fixtures , it can do a number of jobs such as , NC spot drilling ,taping , drilling , champhering , circular pocket milling cycle, with a range of spindle speeds between 10-4000 RPM and an accuracy of 0.001mm.

### 4.2.5 MERCURY Robot System

It is a pneumatic non servo robot system controlled by the (PLC) . It handles the parts between the CNC lathe machine and the conveyor system . The robot can rotate 180 degrees and has a vertical stroke = 4.5 cm and a horizontal stroke = 11 cm (Figure 4.4) .

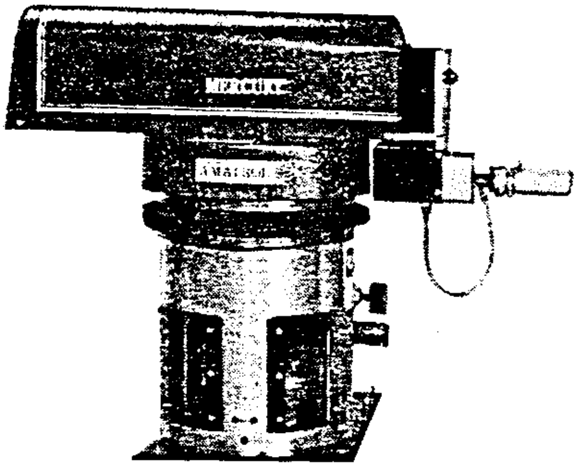


Figure 4.4 MERCURY Robot System

### 4.2.6 CNC Lathe Machine

It is an automated turning machine which is capable of a number of turning operations (drillig ,turning, facing, parting, knurling etc.). The computer control continuosly reads axis positions, using resolvers and commands the appropriate axis motion through simple electronic drives .

The controller is a specially built IBM-PC compatible computer which is the heart of the lathe control .

Since the CNC is computer-controlled, it has programming language and capabilities to interface with the robot controller , to acomplish a CNC machining cell as shown in Figure 4.5 .

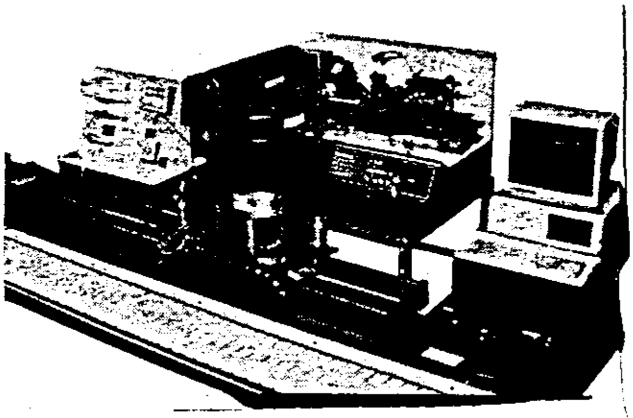


Figure 4.5 CNC Lathe Machine Cell.

### 4.2.7 Assembly and Quality Control Station

This station is served by the JUPITER robot system and quality inspection . The robot system is a servo robot system driven by electrical motors. This station is provided with assembly requirements such as screws and glue.

## 4.3 CIM-Lab Capabilities

The capabilities of any manufacturing system can be measured by the different types of manufacturing processes that the system can do .

Process knowledge is the knowledge about the capabilities of manufacutring processes, all process capabilites information comes either in the form of experience or in handbook lists and guides .

The division of process knowledge into levels helps us to distinguish the difference between general and specific process knowledge . The following is a brief description for the different levels of process knowledge [2].

1. Universal level of process knowledge: It is the knowledge of a process without regard to the individual shop or machines which perform the process. This knowledge is normally presented in handbooks and textbooks, see Table4.1.

2. Shop level of process knowledge: Where additional processing details are considered , the knowledge may not be applicable by other companies or perhaps certain equipment is old and not so well maintained.It represents the best machine in the shop for the job. To obtain this knowledge one has to collect data on all machines in the CIM-Lab .

3. Machine level of process knowledge: It is only applicable to a specific machine which does not necessarily follow the shop level . A machine level knowledge information is important for selecting the specific machine to perform a specific process .

### 4.4 Tolerance

Tolerances are classified into two different types; conventional tolerancing and geometric tolerancing .

### 4.4.1 Conventional Tolerancing

Conventional tolerancing is used to show the acceptable variation in a dimension. There are two types of conventional tolerancing: bilateral, , and unilateral tolerancing . Bilateral tolerance such as $1.00 \mp 0.05 = (0.95\text{-}1.05)$.

On the other hand a unilateral tolerance expresses an increase (or decrease) in one direction such as $1.00 \substack{-\ 0.05 \\ +\ 0.00} = (0.95\ \text{-}1.00)$. Universal

## Table 4.1 Universal Level of Process Knowledge [2]

| Process | Sub-Process | Cutters | Tolerances, surface finish, etc., capabilities |
|---|---|---|---|
| Milling | Face milling | Plain<br>Inserted-tooth | roughting finishing<br>tol 0.002 0.001<br>flatness 0.001 0.001<br>angularity 0.001 0.001<br>parallelism 0.001 0.001<br>surface finish 50 30 |
| | Peripheral milling | Plain<br>Slitting Saw<br>Form<br>Inserted-tooth<br>Staggered-tooth<br>Angle<br>T-slot cutter<br>Woodruff keyseat cutter<br>Form milling cutter | roughting finishing<br>tol 0.002 0.001<br>flatness 0.001 0.001<br>surface finish 50 30 |
| | End milling | Plain<br>Shell end<br>Hollow end<br>Ball end | roughting finishing<br>tol 0.004 0.004<br>parallelism 0.0015 0.0015<br>surface finish 60 50 |
| Drilling | | Twist drill<br>Spade drill<br>Trepanning cutter<br>Center drill<br>Combination drill<br>Countersink<br>Counterbore | length/dia = 3 usual = 8 maximum<br>mtl < Rc 30 usual mtl < Rc 50 maximum<br>Dia Tolerance<br>0 - 1/8 +0.003 −0.001<br>1/8-1/4 +0.004 −0.001<br>1/4-1/2 +0.006 −0.001<br>1/2-1 +0.008 −0.002<br>1-2 +0.010 −0.003<br>2-4 +0.012 −0.004<br>usual best<br>True position 0.008 0.0004<br>roundness 0.004<br>surface finish 100 |
| | | Deep-hole drill<br>Gun drill | Dia Tolerance<br><5/8 0.0015<br>>5/8 0.002<br>surface finish > 100<br>straightness 0.005 in 6 Inch |
| Reaming | | Shell reamer<br>Expansion reamer<br>Adjustable reamer<br>Taper reamer | Dia Tolerance<br>0-1/2 0.0005 to 0.001<br>1/2-1 0.001<br>1-2 0.002<br>2-4 0.003<br>roughting finishing<br>roundness 0.0005 0.0005<br>true position 0.01 0.01<br>surface finish 125 50 |
| Boring | | Adjustable boring bar<br>Simple boring bar | length/dia 5 to 8<br>Dia Tolerance<br>roughing finishing<br>0-3/4 0.001 0.0002<br>3/4-1 0.0015 0.0002<br>1 - 2 0.002 0.0004<br>2 - 4 0.003 0.0008<br>4 - 6 0.004 0.001<br>6 -12 0.005 0.002<br>straightness 0.0002<br>roundness 0.0003<br>true position 0.0001<br>surface finish 8 |
| Turning | Turning<br>Facing<br>Parting<br>Knurling<br>Boring<br>Drilling<br>Reaming | Plain<br>Inserted<br>Knurling tool<br>Boring bars<br>Drills<br>Reamers | diameter tolerance<br>to 1.0 0.001<br>1 - 2 0.002<br>2 - 4 0.003<br>surface finish 250 to 16 |
| Broaching | | Form tool | tolerance 0.001<br>surface finish 125 to 32 |
| Sawing | | Hacksaw<br>Bandsaw<br>Circular saw | length tol / squareness / surface finish / cutting rate / material<br>0.01 / 0.2 / 200-300 / 3-6 sq in/min / to Rc45<br>0.01 / 0.2 / 200-300 / 4-30 sq in/min / to Rc45<br>0.008 / 0.2 / 125 / 7-36 sq in/min / to Rc45 |

### Table 4.1 Universal Level of Process Knowledge ( cont'd) [2]

<table>
<tr><th>Process</th><th>Sub-Process</th><th>Cutters</th><th>Tolerances, surface finish, etc., capabilities</th></tr>
<tr><td>Shaping</td><td></td><td>Form tool</td><td rowspan="2"><table><tr><th></th><th>roughing</th><th>finishing</th><th></th></tr><tr><td>location tol</td><td>0.005</td><td>0.001</td><td></td></tr><tr><td>flatness</td><td>0.001</td><td>0.0005</td><td></td></tr><tr><td>surface finish</td><td>60</td><td>32</td><td>(cast iron)</td></tr><tr><td>surface finish</td><td>125</td><td>32</td><td>(steel)</td></tr></table></td></tr>
<tr><td>Planing</td><td></td><td>Inserted tool</td></tr>
<tr><td rowspan="3">Grinding</td><td rowspan="3">Internal grinding<br>Cylindrical grinding<br>Centerless grinding<br>External grinding<br>Surface grinding</td><td>Internal</td><td><table><tr><th>Dia</th><th colspan="2">Tolerance</th></tr><tr><th></th><th>roughing</th><th>finishing</th></tr><tr><td>0 - 1</td><td>0.00015</td><td>0.00005</td></tr><tr><td>1 - 2</td><td>0.0002</td><td>0.00005</td></tr><tr><td>2 - 4</td><td>0.0003</td><td>0.0001</td></tr><tr><td>4 - 8</td><td>0.0005</td><td>0.00013</td></tr><tr><td>8 - 16</td><td>0.0008</td><td>0.0002</td></tr></table></td></tr>
<tr><td>center ground and centerless</td><td><table><tr><th></th><th>roughing</th><th>finishing</th></tr><tr><td>tolerance</td><td>0.0005</td><td>0.0001</td></tr><tr><td>parallelism</td><td>0.0005</td><td>0.0002</td></tr><tr><td>roundness</td><td>0.0005</td><td>0.0001</td></tr><tr><td>surface fin</td><td>8</td><td>2</td></tr></table></td></tr>
<tr><td>flat</td><td><table><tr><th></th><th>roughing</th><th>finishing</th></tr><tr><td>tolerance</td><td>0.001</td><td>0.0001</td></tr><tr><td>parallelism</td><td>0.001</td><td>0.0001</td></tr><tr><td>surface fin</td><td>32</td><td>2</td></tr></table></td></tr>
<tr><td>Honing</td><td></td><td>Honing stone</td><td><table><tr><th>Dia</th><th colspan="2">Tolerance</th><th></th><th></th></tr><tr><th></th><th>roughing</th><th>finishing</th><th></th><th></th></tr><tr><td>1</td><td>+0.0005-0.0</td><td>+0.0001-0.0</td><td>surface finish</td><td>4</td></tr><tr><td>2</td><td>+0.0008-0.0</td><td>+0.0005-0.0</td><td>roundness</td><td>0.0005</td></tr><tr><td>4</td><td>+0.0010-0.0</td><td>+0.0008-0.0</td><td></td><td></td></tr></table></td></tr>
<tr><td>Lapping</td><td></td><td>Lap</td><td><table><tr><th></th><th>roughing</th><th>finishing</th></tr><tr><td>tolerance</td><td>0.000025</td><td>0.000015</td></tr><tr><td>flatness</td><td>0.000025</td><td>0.000012</td></tr><tr><td>surface fin</td><td>4-6</td><td>1-4</td></tr></table></td></tr>
<tr><td>Tapping</td><td></td><td>Tap</td><td><table><tr><td>tolerance</td><td>0.003</td></tr><tr><td>roundness</td><td>0.003</td></tr><tr><td>surface fin</td><td>75</td></tr></table></td></tr>
</table>

tolerances for different processes are shown in Table 4.1.

### 4.4.2 Geometric tolerancing

Geometric tolerancing is the method to specify the tolerance of geometric characteristics. Basic geometric characteristics include (straightness , flatness, roundness , symmetry etc.) .

Symbols that represent these features are shown in Table 4.2 and the use of form geometry symbols and their meaning are illustrated in Appendix(B) T.C. Chang and R.A. Wysk[15].

## 4.5 Surface Finish

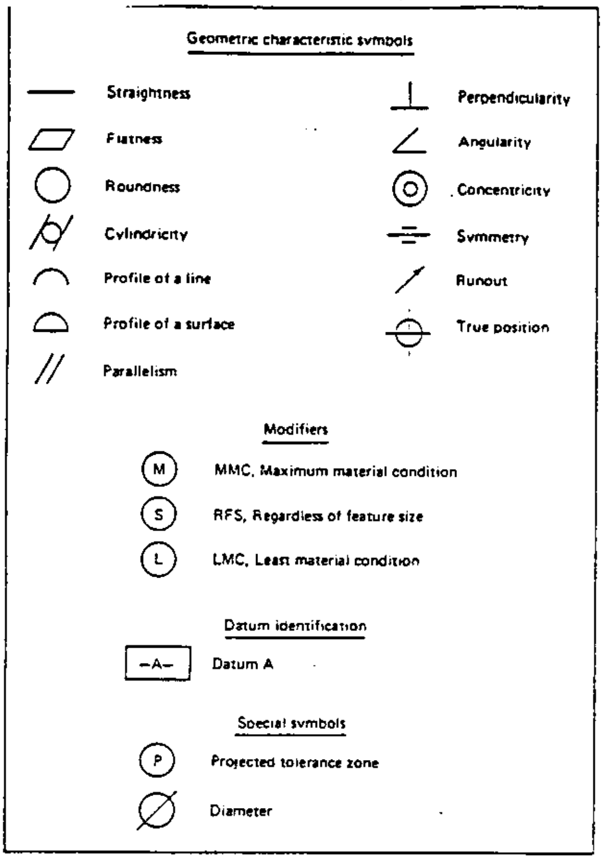
Different machining operations generate surfaces of different characteristics . Surfaces generated by turning, milling, shaping , etc , show marked variations when compared with each other.

Surface finish is , normally , denoted by roughness value which is a function of roughness height. It is the average amount of irregularity above or below an assumed center line . It is expressed in microinches or in the metric system , in micrometers . Recommended universal roughness values are given in Table 4.3 .

## 4.6 Feed, Speeds and Depth of Cut

There are many conditions which determine the suitable depth of cut and feed rate , that it is impossible to give one rule for either the shape of the tool, the way in which it is held , the kind of material being cut , the kind of steel from which it is made, the shape of the piece to be cut . All these factors must

## Table 4.2 Geometric Tolerancing Symbols [15]



Geometric characteristic symbols

Straightness

Flatness

Roundness

Cylindricity

Profile of a line

Profile of a surface

Parallelism

Perpendicularity

Angularity

Concentricity

Symmetry

Runout

True position

Modifiers

MMC, Maximum material condition

RFS, Regardless of feature size

LMC, Least material condition

Datum identification

Datum A

Special symbols

Projected tolerance zone

Diameter

## Table 4.3 Recommended Roughness Values [15]

| Roughness value (μin) | type of surface | purpose |
|---|---|---|
| 1000 | Extremely rough | Used for clearance surfaces only where good appearance is not required |
| 500 | Rough | Used where vibration , fatigue or stress concentration are not critical and close tolerances are not required . |
| 250 | Medium | Most popular for general use where stress requirements and appearance are essintial . |
| 125 | Average smooth | Suitable for mating surfaces of parts held together by bolts and riverts with no motion between them . |
| 63 | Better -than - average finish | For close fits or stressed parts except rotating shafts , axies , and parts subject to extreme vibration . |
| 32 | Fine finish | Used where stress concentration is high and for such applications as bearings . |
| 16 | Very fine finish | Used where smoothness is of primary importance , such as high -speed shaft bearings and extreme tension members |
| 8 | Extremely fine finish produced by cylindrical honing , lapping grinding | Used for such parts as surfaces of cylinder . |
| 4 | Superfine finish produced by honing lapping or polishing . | Used on areas where packing and rings must slide across the surface where lubrication is not dependable. |

be taken into consideration when obtaining an efficient depth of cut or amount of feed, H. Burghardt [16].

The higher the sterngth of the material the lower the cutting speed .The higher the stength of the material the lower the feed rate and depth of cut .

### 4.6.1 Speeds , Feeds and Depth of Cut for Milling Operations

After determining the work piece material and tool material, by using Table 4.4 .We can determine the cutting speed (S) for either rough operation or finishing operation. By the following equation we can compute the spindle speed (N) in rpm .

$$N = \frac{S}{(D/12)\,(\pi)}$$

where,

S : Cutting speed (fpm).

D : Outer diameter of cutter (inch) .

N : Cutter rpm .

**Table 4.4 Table of Cutting Speeds (S) (Surface Feet per Minute)[6].**

| work material | High-speed steel tools | | Carbide-tipped tools | |
|---|---|---|---|---|
| | Rough mill | Finish mill | Rough mill | Finish mill |
| Cast iron | 50-60 | 80-110 | 180-200 | 350-400 |
| Semisteel | 40 -50 | 65-90 | 140-160 | 250-300 |
| Malleable iron | 80-100 | 110-130 | 250-300 | 400-500 |
| Cast steel | 45-60 | 70-90 | 150-180 | 200-250 |
| Copper | 100-150 | 150-200 | 600 | 1,000 |
| Brass | 200-300 | 200-300 | 600-1,000 | 600-1,000 |
| Bronze | 100-150 | 150-180 | 600 | 1,000 |
| Aluminum | 400 | 700 | 800 | 1,000 |
| Magnesium | 600-800 | 1,000-1,500 | 1,000-1500 | 1,000-5,000 |

Table 4.5 and Table 4.6 give suggested feed rates per tooth (Ft) for high speed steel milling cutter and sentered carbide tipped cutter.

By determining the milling subprocess we can find from the above tables the suggested feed rates per tooth ,(Ft), .The feed rate (F) at which the work piece advances past the cutter, measured in inches per minute (ipm), is as follows :

$$F = n\,N\,Ft$$

where

Ft :feed per tooth (Inch per revolution per tooth (inch/rev/ tooth))
N : Spindle speed (rpm).
n : number of cutter teeth .

For roughing operations the depth of cut may range from 1/8 inch to .03 inch . While for finishing operations the depth of cut may vary from a few thousands of an inch to 1/14 inch .The width of cut in milling operations is equal to the tool diameter . The horse power (hp) required can be computed as follows :

$$hp = \frac{FWH}{K}$$

Where :

F : Feed rate inches per minute (ipm)
W : Width of cut in inch
H : Depth of cut in inch
K : A machinability factor which is given in Table 4.7.

Table 4.5 **Suggested Feed Per Tooth (Ft) for High Speed Steel Milling Tools (inch/ rev/tooth) D.B Dallas [17].**

| Material | Face mills | Helical mills | Sloting and side mills | End mills |
|---|---|---|---|---|
| Plastics | 0.013 | .010 | .008 | .007 |
| Magnesium and alloys | 0.022 | .018 | .013 | .011 |
| Aluminum and alloys | 0.022 | .018 | .013 | .011 |
| Free cutting brasses and bronze | 0.022 | .018 | .013 | .011 |
| Medium brasses and bronzes | 0.14 | .011 | .008 | .007 |
| Hard brasses and bronzes | 0.009 | .007 | .006 | .005 |
| Copper | 0.012 | .01 | .007 | .006 |
| Soft cast Iron | 0.016 | .013 | .009 | .008 |
| Medium cast iron | 0.013 | .01 | .007 | .007 |
| Hard cast iron | 0.011 | .008 | .006 | .006 |
| Malleable iron | 0.012 | .010 | .007 | .006 |
| Cast steel | 0.012 | .010 | .007 | .006 |
| Low carbon steel (free machining) | 0.012 | .010 | .007 | .006 |
| Low carbon steel | 0.010 | .008 | .006 | .005 |

Table 4.6 Suggested Feed Per Tooth (Ft) for Carbide Milling Tools (inch/rev/ tooth) [17].

| Material | Face mills | Helical mills | Sloting and side mills | End mills |
|---|---|---|---|---|
| Plastics | .010 | .012 | .0008 | .005 |
| Magnesium and alloys | .018 | .016 | .012 | .005 |
| Aluminum and alloys | .018 | .016 | .014 | .006 |
| Free cutting brasses and bronze | .018 | .016 | .010 | .005 |
| Medium brasses and bronzes | .012 | .010 | .008 | .003 |
| Hard brasses and bronzes | .010 | .008 | .006 | .004 |
| Copper | .012 | .009 | .008 | .004 |
| Soft cast Iron | .016 | .016 | .012 | .004 |
| Medium cast iron | .012 | .013 | .008 | .003 |
| Hard cast iron | .012 | .010 | .008 | .003 |
| Malleable iron | .012 | .011 | .010 | .003 |
| Cast steel | .012 | .011 | .008 | .004 |
| Low carbon steel (free machining) | .014 | .013 | .009 | .004 |
| Low carbon steel | .014 | .011 | .008 | .004 |

### 4.6.2 Speeds and Feeds for Turning Operations

After determining the hardness of the work piece , measured in brinell, select a low feed rate for finishing operation and high value for roughing operation then use Table 4.8 to derermine the cutting speed (S) in fpm then compute the spindle speed N in rpm where N= [S /((D/12) x ( $\pi$ )] .

### 4.7 Limitations and Constraints on CIM-Lab

Manufacturing processes must satisfy the constraints and limitations of the manufacturing system before they can be applied. Basically there are two types of constraints, geometric constraints , and technological constraints

**Table 4.7 K Factor for Various Materials**

| Material | K= ($in^3$/min)/hp |
|---|---|
| Aluminum and magnesium | 2.5-4 |
| Bronze and brass, soft | 1.7-2.5 |
| Bronze and brass, medium | 1-1.4 |
| Bronze and brass, hard | .60-1 |
| Cast iron, soft | 1.5 |
| Cast iron, medium | .8-1 |
| Cast iron, hard | .6-.8 |
| Malleable iron | .9 |
| Copper | .84 |
| Steel | .505 |
| Nickel | .525 |
| Titanium | .75 |

### 4.7.1 Geometric Constraints

Geometric constraints are those constraints which can be identified by the geometric relations of features . There are several causes of these geometric constraints:

Table 4.8 Cutting Speeds on Carbon and Alloy Steel for Different Feeds and Hardnesses , SPFM [17] .

| Hardness | finishing | | | | | Feed, in | roughing | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Brinell | Under 0.005 | 0.005 | 0.010 | 0.015 | 0.020 | 0.025 | 0.030 | 0.040 | 0.050 | 1/16 | 3/32 | 1/8 |
| 150 | 2,000-1,500 | 1,500-1,100 | 900-675 | 700-525 | 575-425 | 500-375 | 450-325 | 350-275 | 300-225 | 250-175 | 200-150 | 175-125 |
| 175 | 1,600-1,300 | 1,200-900 | 750-550 | 575-425 | 475-350 | 400-300 | 375-275 | 300-225 | 250-200 | 225-175 | 175-125 | 150-100 |
| 200 | 1,400-1,100 | 1,000-800 | 625-475 | 500-350 | 400-300 | 350-250 | 300-225 | 250-200 | 225-175 | 200-150 | 150-100 | 140-90 |
| 225 | 1,200-900 | 900-700 | 550-425 | 425-300 | 350-250 | 300-225 | 250-200 | 225-175 | 200-150 | 175-125 | 140-90 | 125-75 |
| 250 | 1,000-800 | 800-600 | 475-375 | 375-275 | 300-225 | 250-200 | 225-175 | 200-150 | 175-125 | 150-100 | 125-75 | |
| 275. | 900-700 | 700-525 | 425-325 | 325-250 | 275-200 | 225-175 | 200-150 | 175-150 | 150-100 | 125-90 | | |
| 300. | 850-650 | 600-475 | 375-275 | 300-225 | 250-175 | 200-150 | 175-125 | 150-125 | 125-100 | | | |
| 350 | 700-550 | 500-375 | 300-225 | 250-175 | 200-150 | 175-125 | 150-125 | 125 | | | | |
| 400 | 600-450 | 425-325 | 250-200 | 200-150 | 175 | | | | | | | |
| 450 | 500-375 | 375-275 | 225-175 | 175 | | | | | | | | |

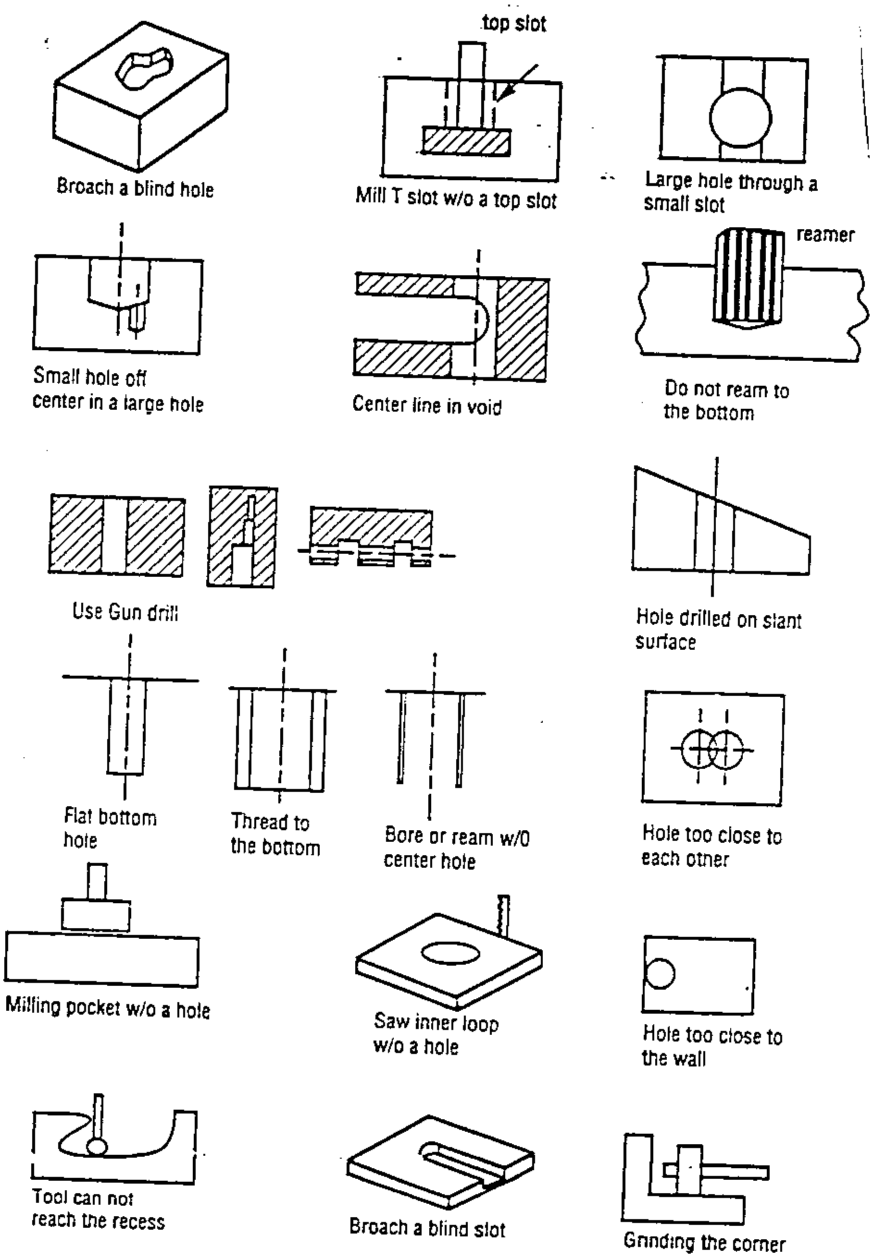


Figure 4.6 Geometric Constraints [2].

A- Interference between the non-cuting part of the tool with the workpiece.

B -Technological reason:

Some universally geometric constraints for machining processes are listed below and are also shown in Figure 4.6 .

1. We can not drill on a slant surface due to the drill bit slippage problem. Several options can be done to take care of the problem . If the slant surface is also machined, one can drill the hole before milling the slant surface . If the slant surface already exists , a milled counter bore may be machined .

2. We can not drill a flat bottom hole with a twist drill due to the drill bit's conical shape constraint . The cutting edge of a drill is arranged at an angle. The bottom of the hole produced must also carry the same angle . When a flat bottom is desired , an end mill can be used to flatten the bottom .

3. We can not tap to the bottom of a flat bottom hole (must leave some clearance) due to tap structure . The tip of a tap is not effective to reach the flat bottom .

4. We can not bore nor ream before a hole is already in existence due to tool structure . The bottom of the boring bar and reamer is the noncutting part of the tool . Tool cannot plunge into the material without a center hole .

5. We can not drill two holes too close to each other due to uneven cutting force , slippage and potential wall damage .

6. We can not mill a pocket before a hole is plunged due to the tool

structure . A hole is drilled first , or a hole is slowly milled(with an end mill) . Milling cutters need side clearance to remove chips .When breaking a pocket , there is no opening for chip removal .

7. We can not drill when the location of the hole is too close to the wall. The thin wall between the hole and the side of the workpiece may break during drilling .

8. We can not use certain tools for recess because they cannot reach certain areas .

9. We can not broach a blind hole nor a blind slot due to tool structure limitation . A broach is pulled from both sides . The cutting edge on a broach is on part of one face of the tool . It can machine either an open surface or enlarge an existing hole (usually, but not necessarily, not round hole) .

#### 4.7.1.1 Constraints on AS/RS System

From the shape and dimension of each store cell in the store we can summarize the following constriants .

1. The store cannot carry more than 25 parts at a time

2. The pallet height which is used for each part is estimated to be 4 cm.

3. The part width and length should be less than 22 cm and 26.5 cm, respectively, to move the part easily from the cell .

4. The height of the part must be less than the difference between the cell height and the pallet height minus the tolerance needed to move the part easily which is estimated to be 2 cm .

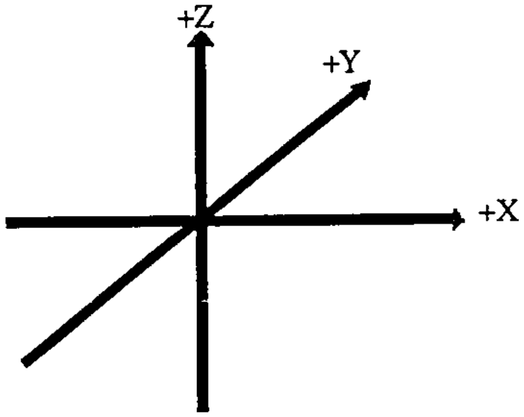
#### 4.7.1.2 Constraints on the CENTARI System

1. The maximum part load that the robot can carry is 2.5 (lb).
2. The part thickness (height) must be equal to 1 cm if its not , the gripper must be replaced .
3. The part length must be less than 18 cm and more than 9 cm .

#### 4.7.1.3 Constraints on CNC Milling Machine

1. The dimension of the workpeice must be less than or equal to 18 cm for the length in X dimension and less than or equal to 9cm for the width in Y direction and less than or equal to 6 cm for the height in Z dimension .

2. The table stroke in X,Y,Z direction is 185 ,95 , 20 cm, respectivly, according to the axis shown bellow .



#### 4.7.1.4 Constraints on MERCURY System

1. The maximum part load that could be carried by the robot is 200 gm.
2. It cannot carry parts with diameters less than 1 cm or more than 3cm .

#### 4.7.1.5 Constraints on The CNC Lathe Machine

1. It turns shafts which have 1.9 cm diameter easily but if diameter is

different the chucking operation must be done mannually.The allowable diameter range is $1cm \leqslant D \leqslant 5cm$ .

2. The maximum part length has to be less than 18 cm .

### 4.7.2 Technological Constraints

Constraints such as power consumption, cutting force (Fc) , and constraints related to the deflection of the workpiece and the strength of materials , are called technological constraints, which determine the fixturing method and the machine tool needed for carrying out the process. Many variables contribute to the cutting force for a given tool , the feed (F) , speed (S) depth of cut (af or ap), width of cut (bw) , cutting fluid, work piece material and the sharpness of the tool . For each operation to compute the power and then select the suitable machine tool , a rough estimation can be done using the formulas shown below A. Kusiak [18]. .

| (process) | computed power (hp) |
|---|---|
| 1. Milling | $\frac{Fc\ Sc}{33,000\ \eta_m}$ |
| 2. Drilling | $\frac{Ts\ rpm}{63.03\ \eta_m}$ |
| 3. Turning<br>Boring<br>Drilling | $\frac{FcSc}{33,000\ \eta_m}$ |

where

Fc : cutting force Ib
S : cutting speed (fpm)
Ts : torque (lb.ft)
$\eta m$ : machine efficiency

The above formula must take into account the machine h.p and ranges of feeds and speeds.

For the CNC milling machine the following data is given:

Tightening force = 1100 N.

Maximum torque = 8.4 N.M .

Feed force = 1800 N .

Feed range = 1-200 mm/min .

Spindle speed range = 10 -4000 RPM .

# CHAPTER FIVE

# GROUP TECHNOLOGY (G.T.)

"Manufacturing is a means to realize the design which is a process that expresses a design requirement by a physical entity which must satisfy the design requirement. At the design stage the result of the design process is a concept expressed in a communicable media .Often we call the concept expressed in a communicable media , the design.

In order not to get confused with other uses of the term design, we will use design representation . To denote a design in a communicable media there are many ways a product can be represented , not every representation is apprciated for process planning purposes , however , for automated process planning purposes one needs to select the representation that is complete in the modeling domain and is also easy to use for planning methods . The following are a list of the basic part representation methods [2]" :

1. Natural language description .
2. Free hand sketch .
3. Engineering drafting .
4. Physical models-clay model , template .
5. Surface model .
6. G.T. model .
7. Solid models .

- Constructive Solid Geometry models .
- Boundary representation method .

8. Symbolic representation .

G.T. is a method of utilizing the similarities of parts to simplify the problem[2].

G.T. codes are commonly used in variant process planning systems for standard process plan retrieval. On the other hand , in generative planning G.T. codes are not needed.

## 5.1 The Meaning Of Group Technology

The definition extended by several persons and schools of thought explains the concept of G.T.. While examining the meaning of the word group technology one finds that a group is a number of things classed together and technology is the science of industrial arts, so G.T. is the science of the industrial arts to a number of things calssed together P.C.Pandey et.al.[19].

Basically the idea of G.T. is to decompose a manufacturing system into subsystems based on the parts similarities, which are of two types: design attributes and manufacturing attributes, to take advantage of their similarities in both design and manufacturing .

G.T. is the realization of the concept that many problems are similar , and that by grouping similar problems , a single solution can be found to a set of problems, thus saving time and effort [15].

In process planning , to create the process plan for each part in the system is a great problem , thus creating a standard process plan for a certain group familiy can save a lot of time while at the same time solving the problem.

Part classification and coding is concerned with identifying the similarities among parts and relating these similarities to a coding system .

In changing over to G.T. from traditional production shop the biggest single obstacle is the problem of grouping parts into families .

To solve these problems there are three common methods, these are :-

1. Classification and Coding .
2. Cluster Analysis .
3. Production Flow Analysis (PFA).

### 5.2 G.T. And Production Process

G.T. has been considered as a method for rationalizing medium and small batch production for some time , one of the first considerations to be made on G.T. was put forward by Mitrofonov [11].

With the increasing possibilities of being able to analyze and evaluate the resultant data with the aid of electronic data processing equipment, this method is becoming a practical solution .

The effort of G.T. on the various factors of the corporation are shown in Figure 5.1 [11].

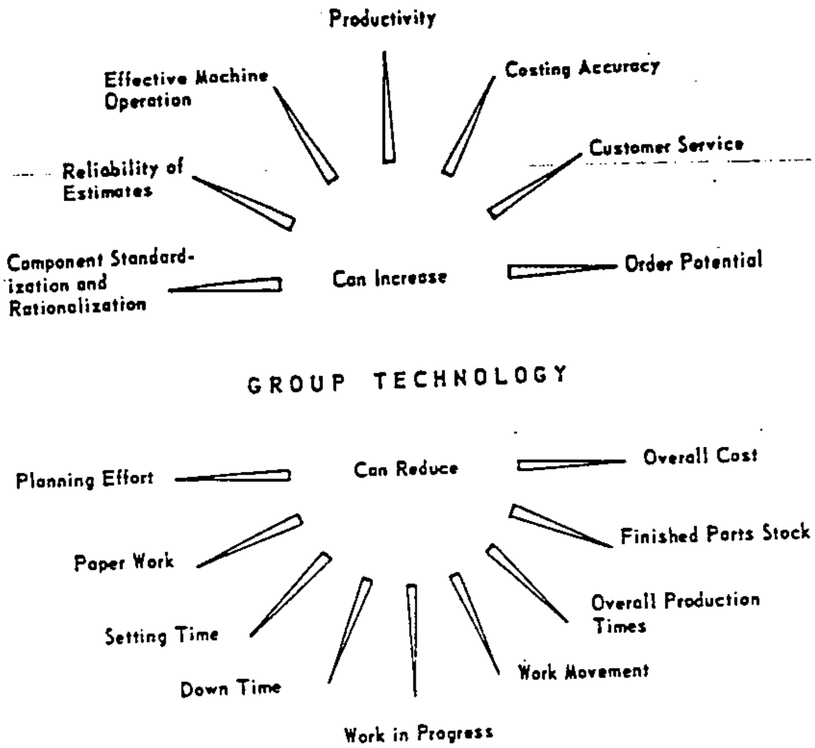


**Figure 5.1 General Achievements of Group Technology [11]**

The preliminary measures that have to be adopted to attain these achievements are complex and require a comprehensive concept which permits a gradual but integrated implementation. The overall steps and interactions among different aspects in implementing G.T. are shown in Figure 5.2.

The external influential factors concerning G.T. systems engineering and the new scientific knowledge in the field of production engineering constitue the foundation for the work .

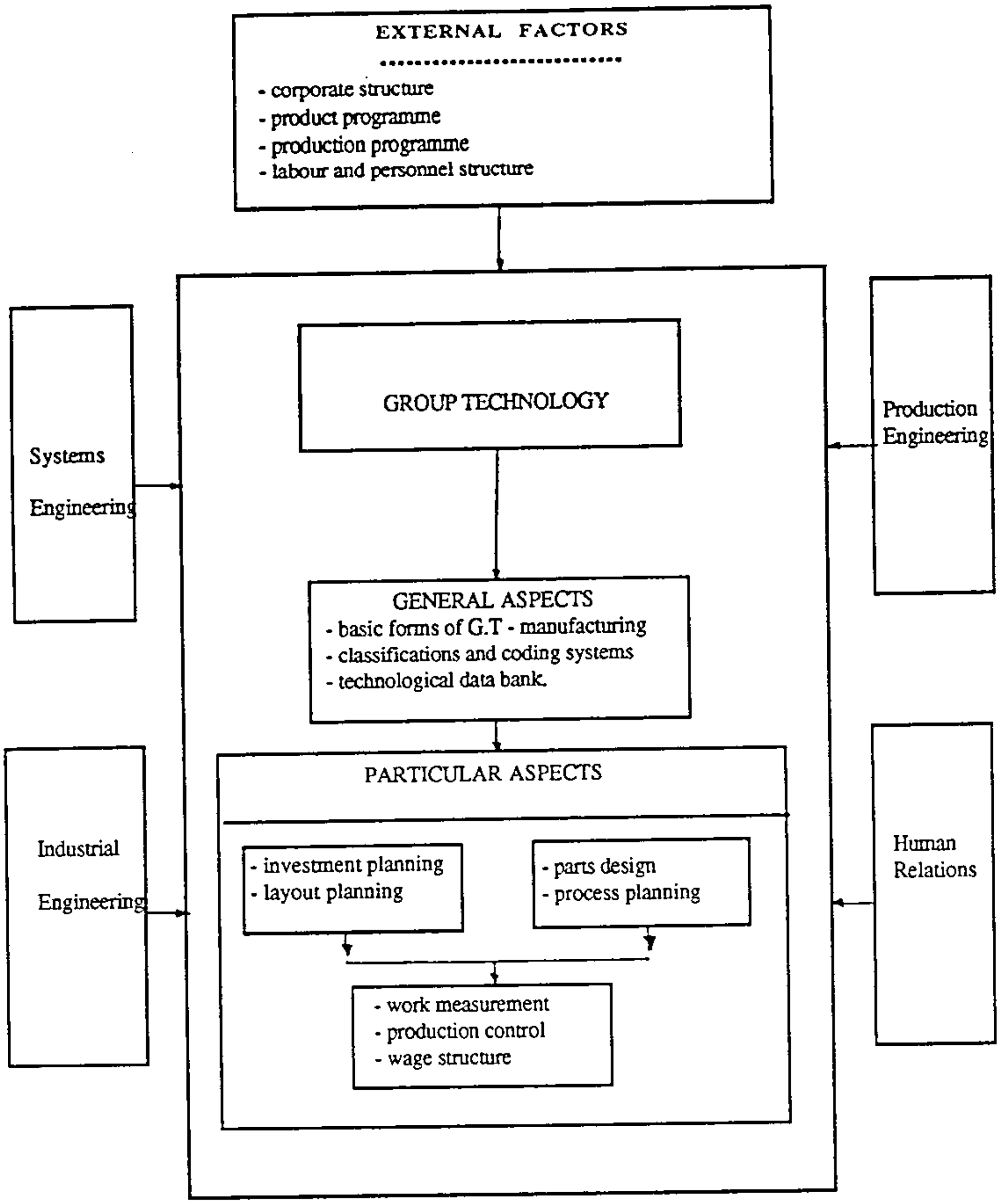


**Figure 5.2 G.T. Implementation FrameWork [11].**

A comprehensive classification and coding system for workpieces, operations and equipment is used to create a general planning basis for the development of the various aspects of G.T. .

## 5.3 The Basic Forms Of G.T. Manufacturing Systems

The basic forms of G.T. manufacturing system derived from grouping workpieces into families (Figure 5.3), shows a process-type layout for batch production in a machine shop .

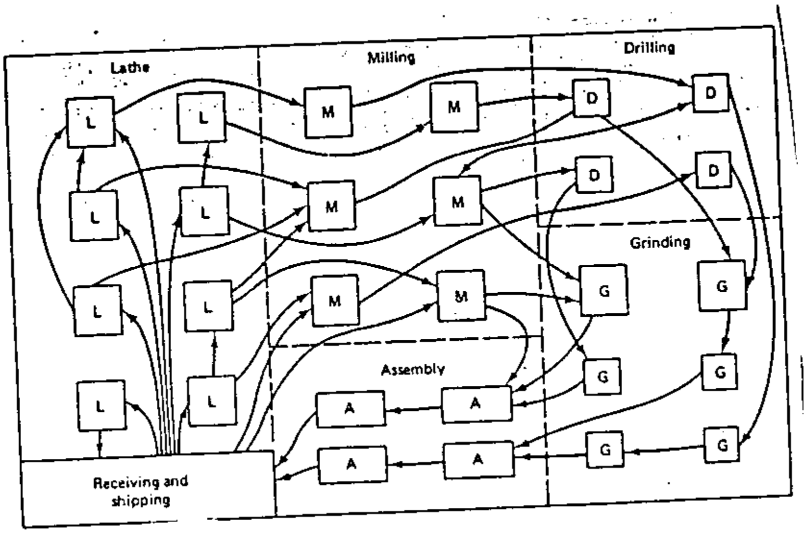


**Figure 5.3 Process Type Layout [5]**

The different machine tools are arranged by function. During the machining of a given workpiece, the workpiece must be moved between sections with perhaps the same sections being visited several times . The result is a significant amount of material handling, a large in process inventory, usually, more setups than necessary , long manufacturing lead times and high cost .

Figure 5.4 shows a production shop of, supposedly, equivalent capacity, but with the machines arranged into cells . Each cell is organized to specialize in the manufacture of particular part family, advantages are gained in the form of reduced workpiece handling, less floor space, shorter lead times , lower setup times and less in-process inventory .

Some of the manufacturing cells can be designed to form production flow lines with conveyors used to transport workpieces between machines in the cell[5] .

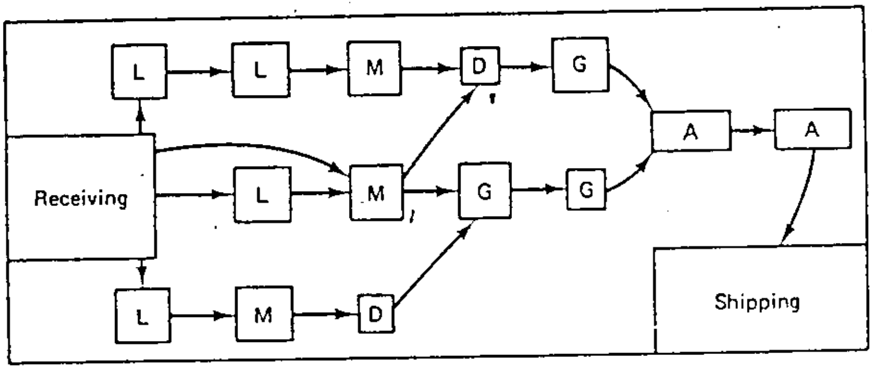


**Figure 5.4 Group Technology Layout [5]**

## 5.4 Systems Engineering And Production Process :-

The term systems engineering is understood to be a methodology which enables known and new scientific method and techniques to be represented in a schematic form so that they can be employed in gaining knowledge of complex facts , and in developing and realizing new systems .

Systems engineering enables complex problems to be broken down into individual partial problems in a logical manner and to investigate some without losing the interrelationship to the overall problem.

When applied to G.T. , it is advantageous to subdivide the complete process within a production company into problem oriented system areas which represent a limited area of activity. The formulated area of systems shown in Figure 5.5 represent the first assignment stage .

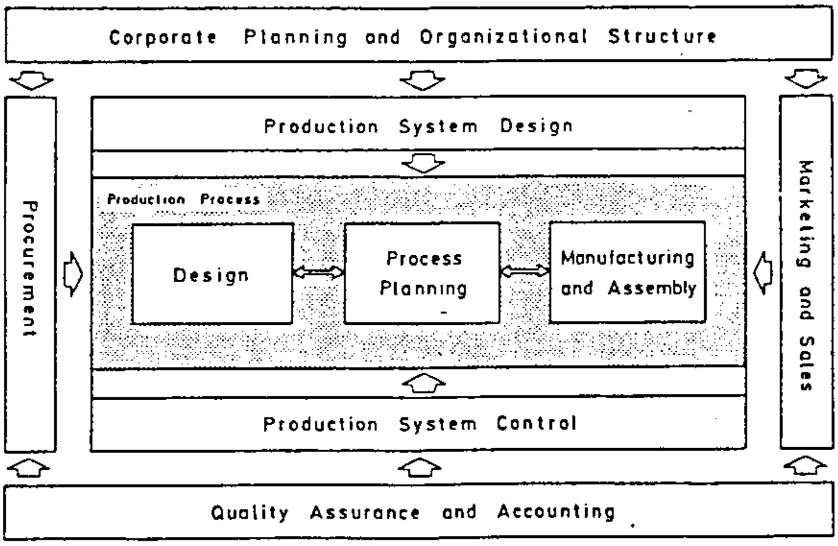


Figure 5.5 Systems Area at Corporate Level [11]

The specific tasks and activities of the production process are

- Design
- Process planning
- Manufacturing

## 5.5 Classification And Coding Method

The classification method is based on the design features of the parts to be grouped into part families . There are two variations of the classification method [14] .

-Visual method .

- Coding method .

### 5.5.1 Visual method

By looking at either the physical parts or their photographs and arranging them into similar grouping .This method is least sophisticated , least expensive and least accurate at the same time [4] .

### 5.5.2 Coding method

In this method parts can be classified on the basis of the following features [14].

- Geometric shape and complexity.
- Dimensions .
- Type of material .
- Shape of raw material .
- Required accuracy of the finished part .

## 5.6 Coding Systems Structure

A part coding scheme consists of a sequence of symblos that indentify the parts design and/ or manufacturing attributes .

The symbols in the code can all be numeric, all alphabetic, or a combination of both types [5]. There are three basic code structures used in group technology:

1. Monocode (hierarchical or tree structure) .
2. Polycode (chain-type structure) .
3. Hybrid structure.

### 5.6.1 Monocode structure

The interpretation of each succeeding symbol depends on the value of the preceding symbols and it provides a relatively compact structure which conveys much information about the part in a limited number of digits. Monocode structure is shown in Figure 5.6.

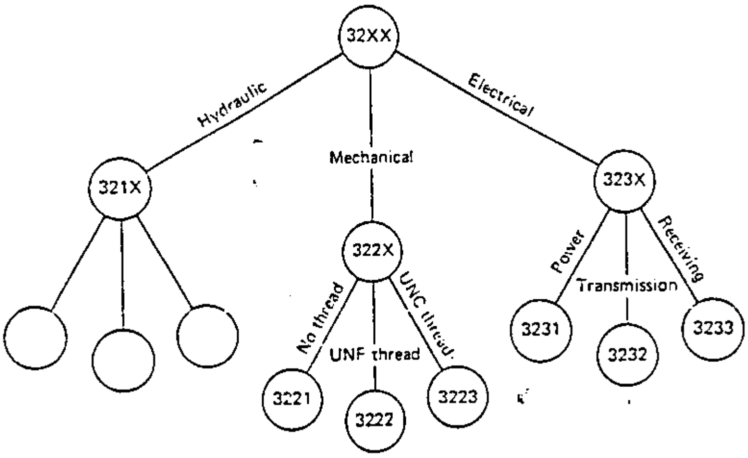


Figure 5.6 Hierarchical Structure [14] .

### 5.6.2 Polycode structure

The interpretation of each symbol in the sequence is fixed and does not depend on the value of preceeding digit, hence it tends to be relatively long , and the use of polycode allows for convenient identification of specific part attributes. This can be heplful in recognizing parts with similar processing requirements. Figure 5.7 shows the polycode structure .

### 5.6.3 Hybrid structure

The hybrid structure is an attempt to achieve the best features of monocodes and polycodes. Hybrid codes are typically constructed as a series of short polycodes , whithin each of these shorter chains the digits are independent but one or more symbols in the complete code number are used to classify the part population into groups as in the hierarchical structure Figure 5.8. shows the hybrid code structure .

| Digit position<br>class of feature<br>possible value | 1<br>External shape | 2<br>Internal shape | 3<br>Holes |
|---|---|---|---|
| 1 | shape 1 | shape 1 | Axial |
| 2 | shape2 | shape2 | Cross |
| 3 | shape 3 | shape 3 | Axial and cross |
| 4 | | | |

Figure 5.7 Chain Structure[15].

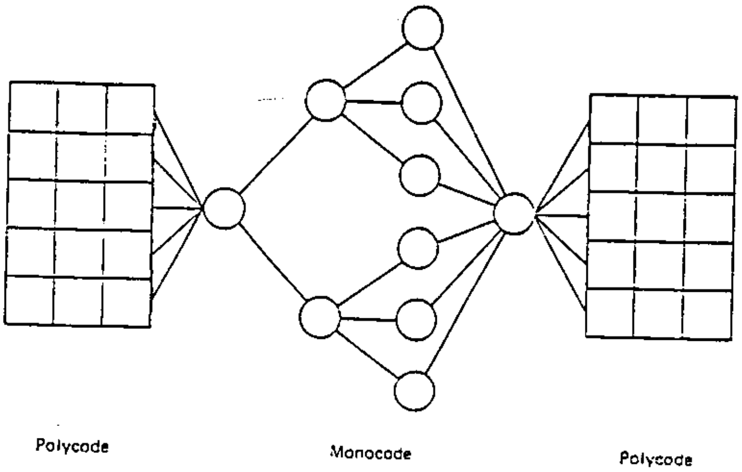


**Figure 5.8 Hybrid Structure [20].**

When selecting a parts coding and calssification system the following factors are considered [5]:

1. The objective for the system , will it be used for design retrieval or part family manufacturing .

2. Cost and time needs and saving from the code and classification system used .

3. Adaptability to other systems like process planning , NC programming, production scheduling and other fields .

4. Management problems .

Some of the most commonly used coding schemes are the following [15] .

1 . OPITZ system .

2. MICLASS system (metal institute class system) .

3. CODE system .

4. GTTC system . ( a generic "G.T. characterization code") .

5. KK-3 system .

6. DCLASS system .

7. COFORM system .

Once the parts have been coded, then classification which simply means grouping of parts with similar characteristics can be done.

### 5.7 The OPITZ Coding And Classification System

This part classification and coding system was developed by H. OPITZ of the University of Achen in West Germany and is shown in Figure 5.9. The OPITZ coding system uses the following digit sequence .

12345 6789 ABCD

The basic code consists of (nine) digits which can be extended by adding four more digits . The first five digits are called the "form code" and describe the primary design attributes of the part. The next four digits (6789) constitue the attributes that would be of use for manufacturing .

The last four digits (ABCD) are referred to as the "Secondary code" which can be designed by the firm to serve its own particular needs [4] .

An example of coding a component in Figure [5.10]

| | |
|---|---|
| -L/D ratio = 1.5 | first digit =1 |
| - Stepped on both ends with screw thread on one end | 2nd digit =5 |
| - Through hole | 3 rd digit =1 |
| - No surface machining is required and no auxiliary holes on. | 4 th digit =0 |
| -Gear teeth on the part | 5 th digit =0 |

The complete form code in OPITZ is **15100**.

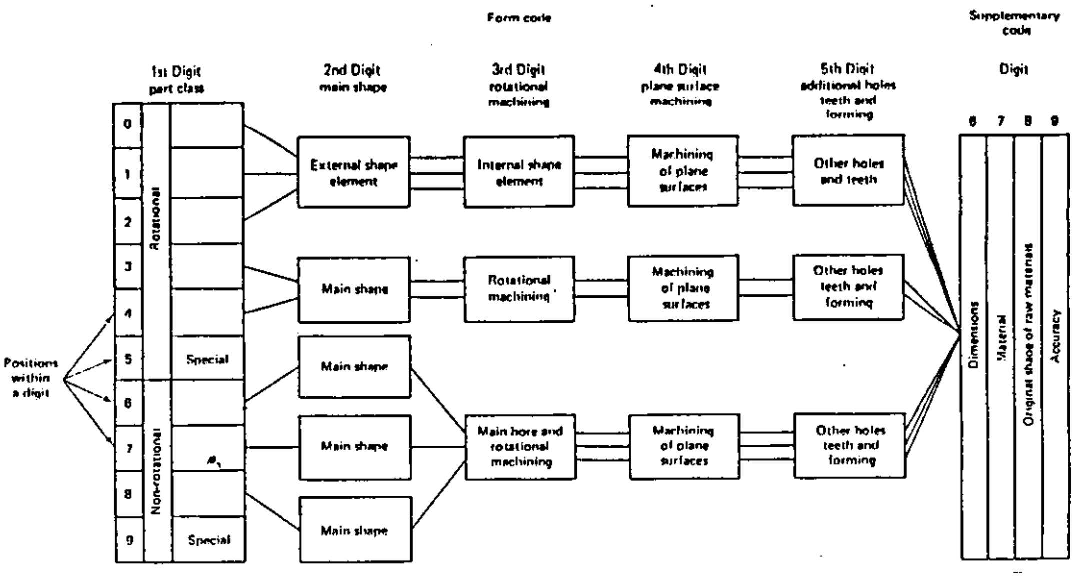


Figure 5.9 OPITZ Coding and Classification System[15].

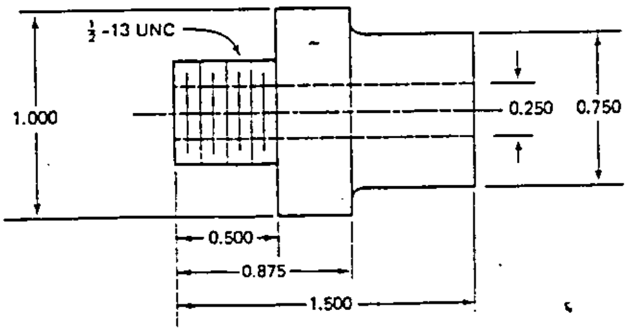


Figure 5.10 Workpart Example [5].

## 5.8 The CODE System

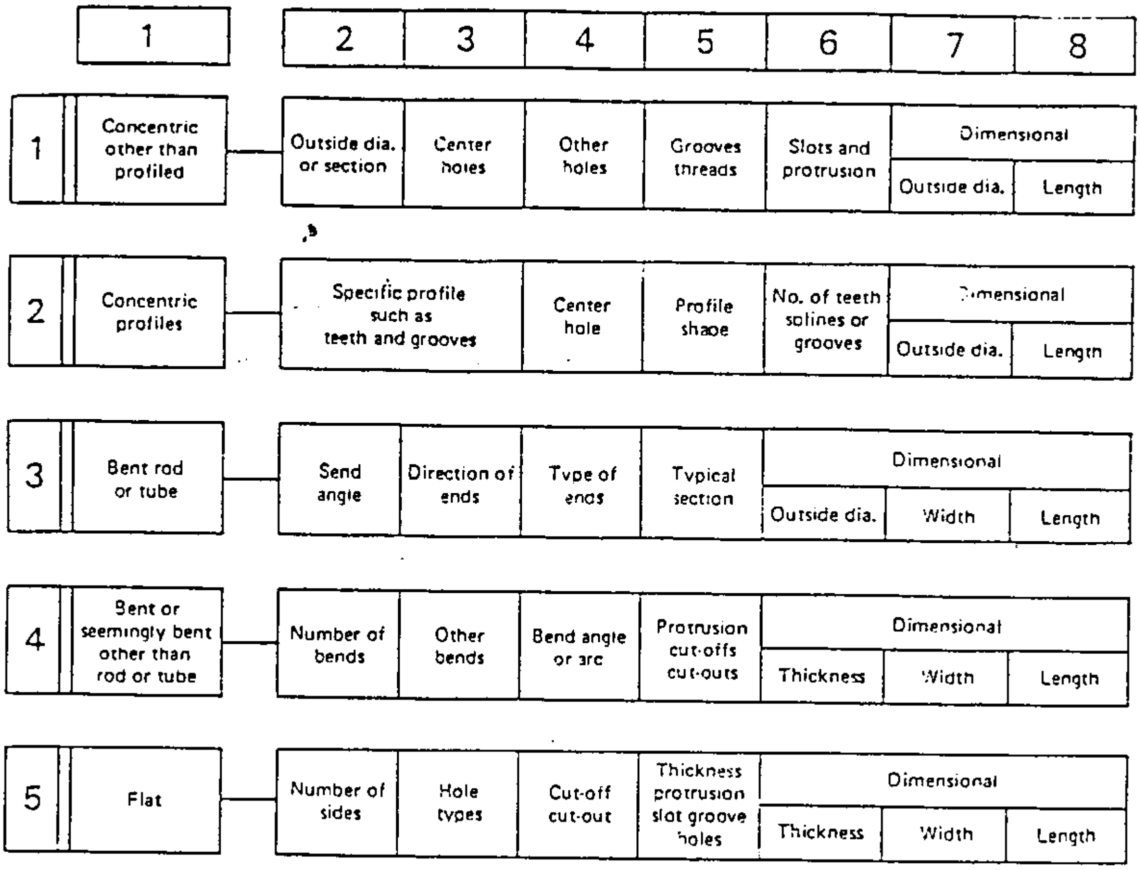
CODE is a coding and classification system developed by manufacturing data systems . The code is an eight-digit mixed code structure.

Each digit of CODE is represented by a hexidecimal value which allows more information to be represented with the same number of digits the structure of the code is shown in Figure 5.11.

CODE contains form and dimensional information , but does not include material or accuracy information .

## 5.9 The KK-3 System

It is a general purpose classification and coding system for machining



Figuer 5.11 Summary of CODE Major Divisions [31]

parts , it was developed by Japan Society for the Promotion of Machine Industry (JSPMI) . It was first presented in 1976 , and uses a 21-digit decimal system .

The code structure for rotational components is shown in Figure 5.12. Parts to be classified are, primarily, metal cutting and grinding compoments.

With two digits KK-3 can classify 100 functions for rotational and non rotational components .An example of coding a component using KK-3 is illustrated in Figure 5.13.

### 5.10 Benefits Of Group Technology

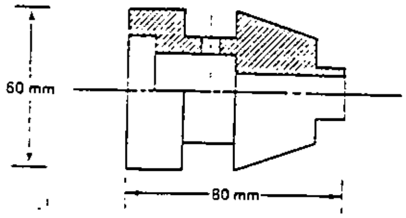
Changing to G.T. brings with it many major benefits. It can result in operation benefits, due to the greater simplicity of the material flow system , the organizational system and the communication system[12]. The following are some of the benefits.

1. Simplification of material flow system : the first of these benefits is a major simplification of the material flow system, which gives a number of major advantages to production management , it greatly simplifies production control, and material handling, material throughput times can be greatly reduced which results in reducing the level of work in progress in the factory, and reduces data processing .

2. To change to group technology also makes it possible to allocate responsibility to individuals at shop floor level for component production achievement .

| Digit | Items | (Rotational components) | |
|---|---|---|---|
| 1 | Parts name | General classification | |
| 2 | | Detail classification | |
| 3 | Materials | General classification | |
| 4 | | Detail classification | |
| 5 | Chief dimensions | Length | |
| 6 | | Diameter | |
| 7 | Primary shapes and ratio of major dimensions | | |
| 8 | Shape details and kinds of processes | External surface | External surface and outer primary shape |
| 9 | | | Concentric screw threaded parts |
| 10 | | | Functional cut-off parts |
| 11 | | | Extraordinary shaped parts |
| 12 | | | Forming |
| 13 | | | Cylindrical surface |
| 14 | | Internal surface | Internal primary shape |
| 15 | | | Internal curved surface |
| 16 | | | Internal flat surface and cylindrical surface |
| 17 | | End surface | |
| 18 | | Nonconcentric holes | Regularly located holes |
| 19 | | | Special holes |
| 20 | | Noncutting process | |
| 21 | Accuracy | | |

Figure 5.12 Structure of the KK-3 (Rotational Components) [15]



| Code digit | Item | Component condition | Code |
|---|---|---|---|
| 1 | Name | Control valve (others) | 0 |
| 2 | | | 9 |
| 3 | Material | Copper bar | 7 |
| 4 | | | |
| 5 | Dimension length | 30 mm | 2 |
| 6 | Dimension diameter | 60 mm | 2 |
| 7 | Primary shape and ratio of chief dimension | L/D 1 3 | 2 |
| 8 | External surface | With functional tapered surface | 3 |
| 9 | Concentric screw | None | 0 |
| 10 | Functional cutoff | None | 0 |
| 11 | Extraordinary shaped | None | 0 |
| 12 | Forming | None | 0 |
| 13 | Cylindrical surface ≥ 3 | None | 0 |
| 14 | Internal primary | Piercing hole with dia. variation, NO cutoff | 2 |
| 15 | Internal curved surface | None | 0 |
| 16 | Internal flat surface | None | 0 |
| 17 | End surface | Flat | 0 |
| 18 | Regularly located hole | Holes located on circumferential line | 3 |
| 19 | Special hole | None | 0 |
| 20 | Noncutting process | None | 0 |
| 21 | Accuracy | Grinding process on external surface | 4 |

Figure 5.13 Example of a KK-3 Coding System [15].

3. The foreman of a group usually receives a batch of orders at the begining of each period , he can then plan the sequence of loading the parts on the loaded machines in order to bring together parts with similar setup, consequently, obtain major reductions in setting time and increased capacity.

4. Due to the dearease in setup time the system becomes more flexible and hence smaller batches can be produced, consequently , greater market responce is acheived .

5. With group technology it is simpler to introduce new products , or modify existing ones.

6. The change to G.T. also simpifies the introduction of new methods and new machines into production .

7. Group technology leads to standardization of several areas like tooling and setups .

8. The time and cost of the process planning function can be reduced through standardization associated with group technology .

Finally proper parts classification and code lead to automated process planning system . Even without automated process planning system, reduction in the time and cost of process planning can still be accomplished.

## 5.11 Summary

In this chapter group technology was reviewed. The different coding systems were analysed . A hybrid newly developed code will be introduced as part of the next chapter.

# CHAPTER SIX

# DEVELOPED RETRIEVAL CAPP SYSTEM

In the previous chapters we have discussed group technology as a design representation method for process planning , and the process knowledge data - base pertaining to (CIM-Lab). In this chapter a developed retrieval computer aided process planning system will be discussed .

The environment in which this system is developed is for one kind of prismatic parts and one kind of rotational parts , that can be produced in the CIM-Lab facility at the Industrial Engineering Department at the University of Jordan .

The system which is intended for the production of two types of parts is using part family concepts for process planning . It is supposed to find new plans based on the knowledge of machinning processes .

The requirement of the system can be summarized as :

1. One type of prismatic part machining .
2. One type of rotational part machining .
3. Utilizes the available resources of CIM- Lab to produce the parts quickly .
4. Integrated design/ process knowledge systems .

## 6 .1 The System Architecture

The developed CAPP system consists , as mentioned previously , of three major components .

Design representation part, knowledge representation and the inference engine part as shown in Figure 6.1. A more detailed architecture is shown in Figure 6.2 .

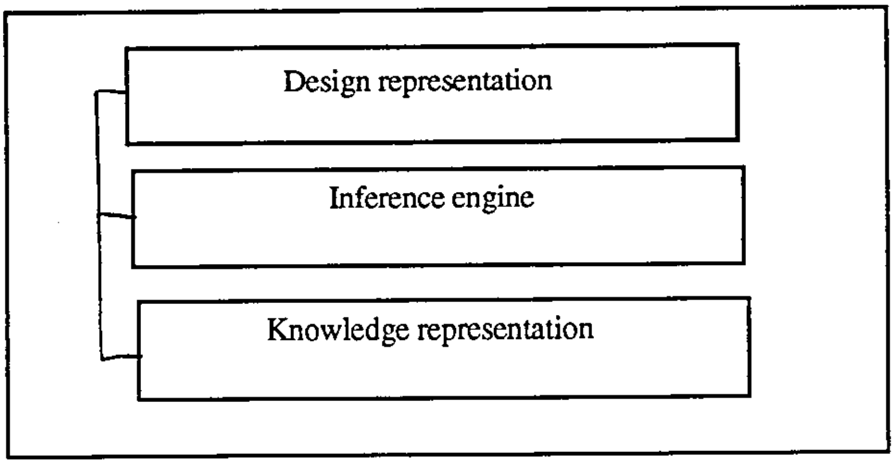


**Figure 6.1 Overall Structure of CAPP System**

Data files are used as interface between functional parts of the system.This arrangement helps in developing each functional part separately.

### 6.2 The Design Stage Of The CAPP System

The structure of the design stage is shown in Figure 6.3. The design environment is feature-based where each feature is loosely related to machining operations, such as a hole or a slot . These features are not stringent manufacturing features , for example , a hole can carry different meanings . It can be blind , througoing , or even degenerate into a pocket .

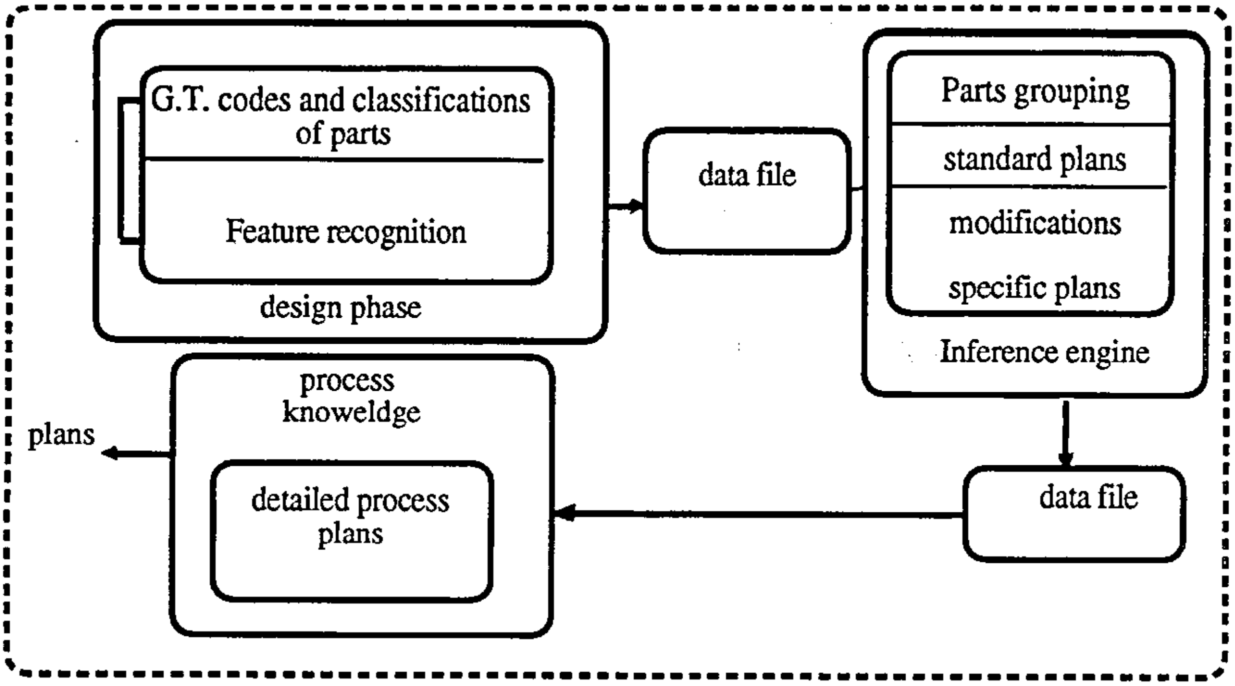


**Figure 6.2 Detailed System Architecture**

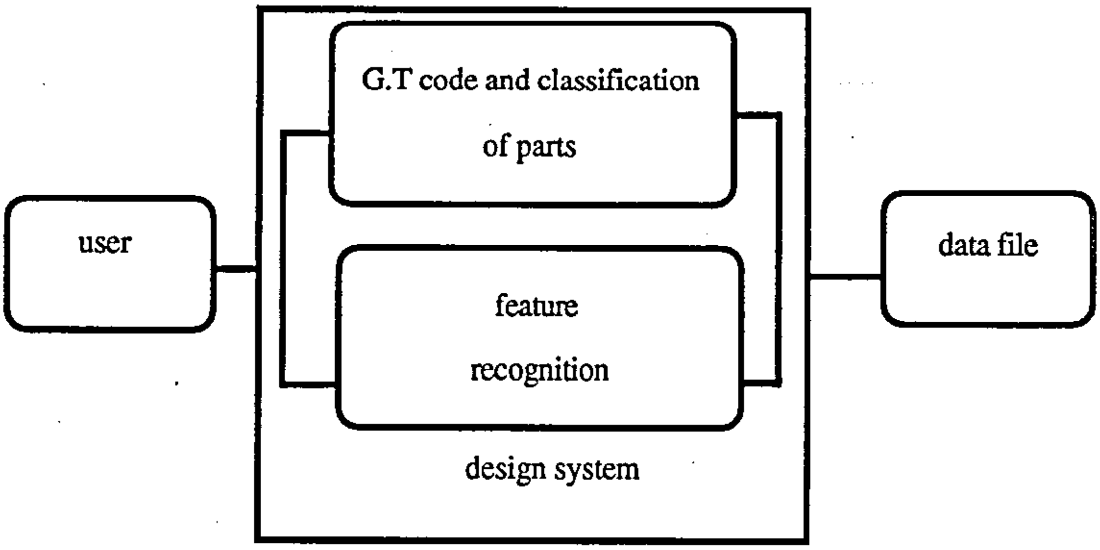
The feature recognition phase analyzes the part design and further classifies design features into manufacturing features . Loosely speaking , each feature corresponds to a machining process .

For the recognition of features with the three dimensional geometry a group technology coding and classification system has been developed for the studied manufacturing environment (CIM-Lab) .

### 6.2.1 Developed Code and Classification System

The developed coding and classification system is a hybrid structure which consists of 10 digits . For prismatic parts the ten digits are used while in the case of rotational parts only seven of these digits are used .

As shown in Figure 6.4 the first digit of the system gives a code value



**Figuer 6.3 The Design System**

for the shape of the raw workpiece , while the other digits give a code values for the part design characteristics (features) and the part design dimensions for each digit a value from (0) to (9) can be assigned.

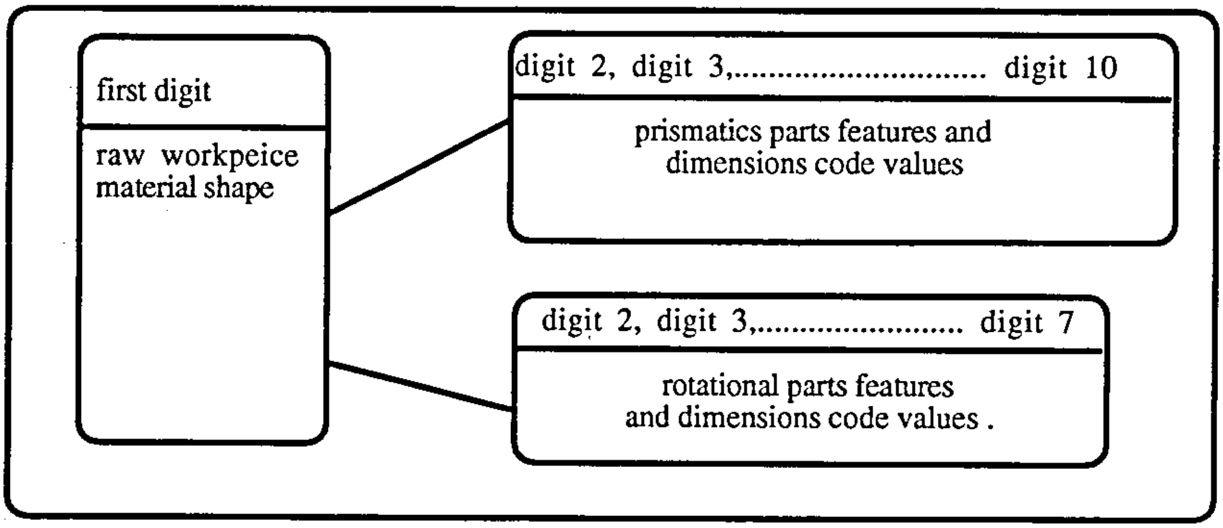


**Figure 6.4 The Overall Structure of The Developed Coding and Classification System**

For the first digit a code value of (0) is assigned if the raw workpiece shape is rectangular , while a code value of (6) is assigned if the raw workpiece shape is round bar shaped as shown in Figure 6.5 .

| | First digit |
|---|---|
| Code | raw material shape |
| 0 | rectangular |
| 1 | rectangular bar |
| 2 | plate |
| 3 | sheet |
| 4 | square bar |
| 5 | hexagonal bar |
| 6 | round bar |
| 7 | tube bar |
| 8 | disk shape |
| 9 | other |

**Figure 6.5 First Digit Assignment**

### 6.2.1.1 Codes of prismatic parts

Digits assigned for prismatic parts are digit 2 through digit (10) . These digits represent the overall part design shape, part design features such as holes , slots, grooves , and part design dimensions (length , width , height) .

The overall design shape is coded by the second digit , for example if the part shape is multiconcave along all the part length the second digit will take a value of (2) , but if the part shape is multiconcave along part of the length the second digit will take a value of (6) , as shown in Figure 6.6 A .

The part design features are coded by the third, fourth , fifth , sixth and seventh digit .If there is a pocket in the side view of the part design , the third digit will take a value of (1) Figure 6.6 B. But if the pocket is in the top view then the fourth digit will take a value of (1) Figure 6.6 C. The fifth digit is assigned code values for holes, if there is a blind hole in the part the fifth digit will take a value of (1) but if the hole is threaded and througoing the fifth digit will take a value of (8) Figure 6.7 A.

| **(A) Second digit** | | **(B) Third digit** | | **(C)Fourth digit** | |
|---|---|---|---|---|---|
| Code | overall shape | Code | features on side view | Code | feature on top view |
| 0 | | 0 | | 0 | |
| 1 | | 1 | pocket | 1 | pocket |
| 2 | multiconcave | 2 | | 2 | |
| 3 | | 3 | | 3 | |
| 4 | | 4 | | 4 | |
| 5 | | 5 | | 5 | |
| 6 | multiconcave | 6 | | 6 | |
| 7 | | 7 | | 7 | |
| 8 | | 8 | | 8 | |
| 9 | | 9 | | 9 | |

**Figure 6.6 The Sturcture of The Second , Third and The Fourth Digit for Prismatic Parts**

The sixth digit assigned code values for features such as , grooves. If there is a straight groove on the top surface of the part , digit six will be assigned a code value of (1). While if the groove is radial the value will be (3) Figure 6.7 B .

The seventh digit assigns code value for features like , T-Slot , V-Slot. If there is a T-Slot on the part the seventh digit will take a value of (1) , while if there is a V-Slot the value of this digit will be (2); Figure 6.7 C.

| (A) Fifth digit | | (B)Sixth digit | | (C) Seventh digit | |
|---|---|---|---|---|---|
| Code | holes | Code | grooves | Code | slots |
| 0 | | 0 | | 0 | |
| 1 | blind hole | 1 | straight grooves | 1 | T-Slot |
| 2 | | 2 | | 2 | V-Slot |
| 3 | | 3 | Radial grooves | 3 | |
| 4 | | 4 | | 4 | |
| 5 | | 5 | | 5 | |
| 6 | | 6 | | 6 | |
| 7 | | 7 | | 7 | |
| 8 | througoing and threaded hole | 8 | | 8 | |
| 9 | | 9 | | 9 | |

**Figure 6.7 The Structure of The Fifth ,Sixth, and Seventh Digit For Prismatic Parts .**

Digits (8) (9) and (10) give a code for the part length , width and height respectively . If the part length , width and height is (10)cm , (2)cm , and (1)cm respectively , the eighth , nineth and tenth digits will take code values of (5) , (1) and (1) repectively as shown in Figure 6.8 .

| (A)Eight digit | | (B)Nineth digit | | (C)Tenth digit | |
|---|---|---|---|---|---|
| Code | Length (L) cm | Code | Width (W) cm | Code | Height (H) cm |
| 0 | | 0 | | 0 | $o < H \leqslant 0.5$ |
| 1 | | 1 | $0<W\leqslant 2$ | 1 | $0.5<H\leqslant 1$ cm |
| 2 | | 2 | | 2 | |
| 3 | | 3 | | 3 | |
| 4 | | 4 | | 4 | |
| 5 | $9 <L\leqslant 10$ cm | 5 | | 5 | |
| 6 | | 6 | | 6 | |
| 7 | $11<L\leqslant 12$ | 7 | | 7 | |
| 8 | $12<L\leqslant 18$ | 8 | $8 <W\leqslant 9$ | 8 | $4 < H \leqslant 4.5$ |
| 9 | | 9 | | 9 | |

**Figure 6.8 The Structure of Eighth , Nineth and Tenth Digit for Prismatic Parts .**

### 6.2.1.2 Codes for Rotational Parts

Digits assigned for rotational parts are , digit 2 , digit 3, digit 4, digit 5, digit 6 and digit 7 . These digits represent also , part overall shape , part features and part dimensions .

The second digit gives a value code for the overall shape of parts. If the part design , for example , is a multiconvex shape the digit will assign a code value of (2) ,while if the part shape is a cone the value will be (8) as shown in Figure 6.9 A .

The third and the fourth digit give code values for features such as holes and grooves, if there is a multidiameter blind hole feature and external threaded feature in a certain part, the code values assigned to these features by the third and fourth digit are (6) and (5) respectively as shown in Figure 6.9 B and C .

| **(A) Second digit** | | **(B)Third digit** | | **(C)Fourth digit** | |
|---|---|---|---|---|---|
| Code | overall shape | Code | holes | Code | grooves and threaded |
| 0 | | 0 | | 0 | |
| 1 | | 1 | | 1 | |
| 2 | multiconvex | 2 | | 2 | |
| 3 | | 3 | | 3 | |
| 4 | | 4 | | 4 | |
| 5 | | 5 | | 5 | outer threaded |
| 6 | | 6 | multidiameter blind hole | 6 | |
| 7 | | 7 | | 7 | |
| 8 | cone shape | 8 | | 8 | |
| 9 | | 9 | | 9 | |

**Figure 6.9 The Structure of the Second , Third , and Fourth Digit for Rotational Parts.**

The fifth, sixth and seventh digits are coded miscellaneous features such as uncenterd holes and pockets and dimension of the part such as length and diameter .

If a radial round hole is included in a rotational part which has a length of

10cm and a diameter of 4cm the fifth, sixth and seventh digits will be assigned code values of (1) , (4) and (5) ,respectively, as shown in Figure 6.10 .

| (A) Fifth digit | | (B)Sixth digit | | (C)Seventh digit | |
|---|---|---|---|---|---|
| Code | Miscellaneous features | Code | Lenght (L)cm | Code | Diameter (D) cm |
| 0 | | 0 | 0<L≤3 | 0 | 0<D≤1.5 |
| 1 | Radial round hole | 1 | | 1 | |
| 2 | | 2 | | 2 | |
| 3 | | 3 | | 3 | |
| 4 | | 4 | 9<L≤11 | 4 | |
| 5 | | 5 | | 5 | 3.5<D≤4 |
| 6 | | 6 | | 6 | |
| 7 | | 7 | | 7 | 4.5<D≤5 |
| 8 | | 8 | 17<L≤19 | 8 | |
| 9 | | 9 | | 9 | |

**Figure 6.10 Structure of the Fifth, Sixth, and Seventh Digits for Rotational Parts.**

By combining the machining and geometric constraints obtained from the study of the manufacturing environment (CIM-Lab) in the previous chapters with the devoloped G.T. coding and classification system, the system can determine whether a certain part can be produced in the (CIM-Lab) or not . If the part can be produced the system will create its code number to send this code to the next phase of the system which is the inference engine .

## 6.3 Inference Engine

Inference engine links the design representation phase with the process knowledge data-base . It links the part code number with the corresponding operations, by the use of data files as shown in Figure 6.2, shown previously. The parts codes are stored in these data files then they are passed through to the inferene engine .The inference engine recognizes these codes numbers then classifies parts into family groups based on the code values which represent the parts features and dimensions .

After creating the different family groups the inference engine starts searching for the operations which correspond to each code number to create the standard process plans for each family group .

Not only does the inference engine create group families and standard sequence of machining operations for each group as shown in Figure 6.11 , but also it makes the necessary modifications on the standard process plan to create the specific sequence of operation that fits a specific part .

After determining the rough process plans by this stage the process plan is stored in a data file before passing it through to the last stage of the CAPP system which is the process knowledge data base .

## 6.4 Knowledge Representation Phase

After determining the sequence needed to produce a certain part which is stored in a data file , the plan will be expanded in order to determine the machining parameters for each operation in the sequence to obtain the detailed process plans .

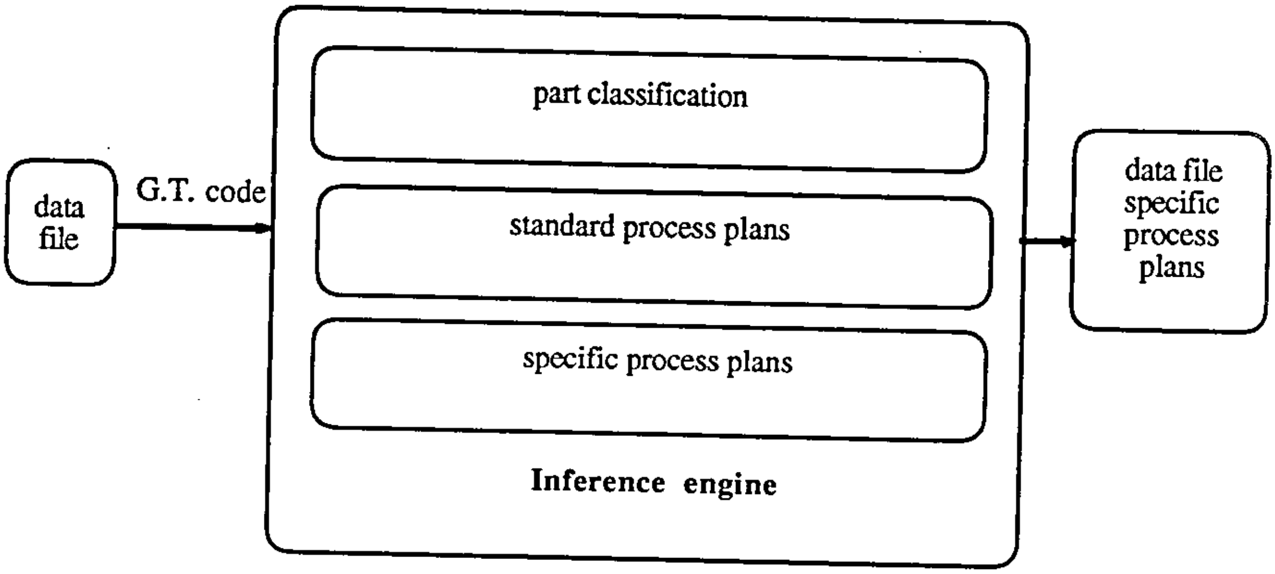


Figure 6.11 The Structure of The Inference Engine .

The detailed process plans obtained by this phase include the necessary information needed for each operation such as feed rate, cutting speeds , spindle revolution per minute and the time in minutes needed to accomplish each operation.

The selections of the machining parameters determined are based on the work piece material , workpiece brinell hardness and the machining conditions whether the operation is rough or finish .

## 6.5 Discussion

In this section we are going to discuss briefly the developed computer program which represents our proposed CAPP system. The program has been written in Quick Basic language because it can be used for drawing and programing at the same time .

The computer program as mentioned in the previous chapter consists of three major parts, the first part of the program is responsible for the representation of parts or the G.T. code and classification system, the flow of information is represented by the flow chart shown in Figure 6.11.

This part of the program divides parts into three types , prismatic , rotational and others, the first two parts only can be produced in the CIM-Lab while the other parts can not because of shape and dimension constraint .The system can create a code number of seven digits for rotational parts while it can create a code number of 10 digits for prismatic parts . After the code number has been created for a certain part it is sent to the inference engine to classify this part into a certain group . Figure 6.12 represents the program flow chart for the case of prismatic parts , while Figure 6.13 represents the program flow chart for the case of rotational parts . After determining the family group that includes the part code number the system will make the necessary modification on the standard process plan to obtain the specific process plan for the code number .

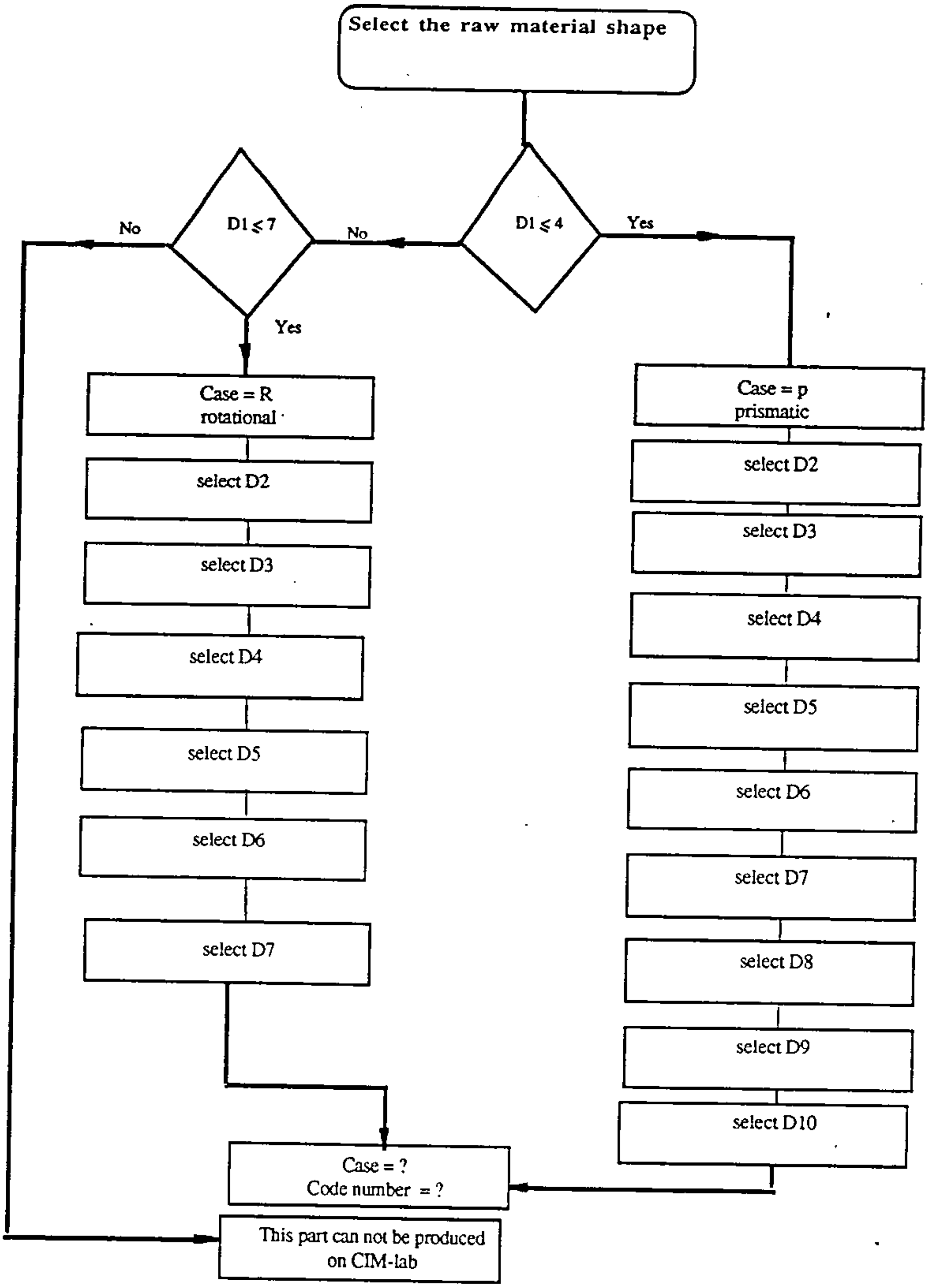
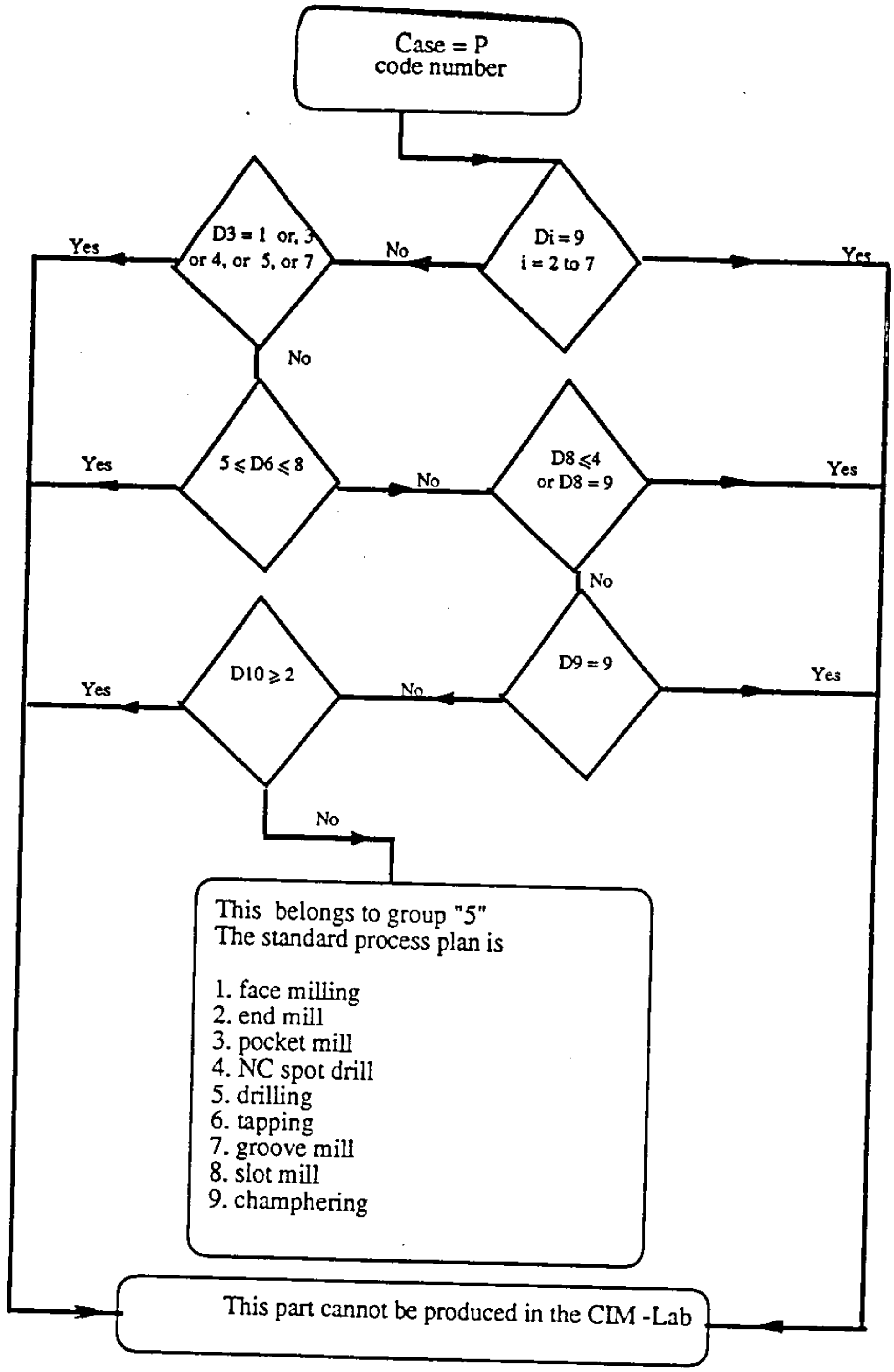


Figure 6.11 Flow Chart of Design Representation

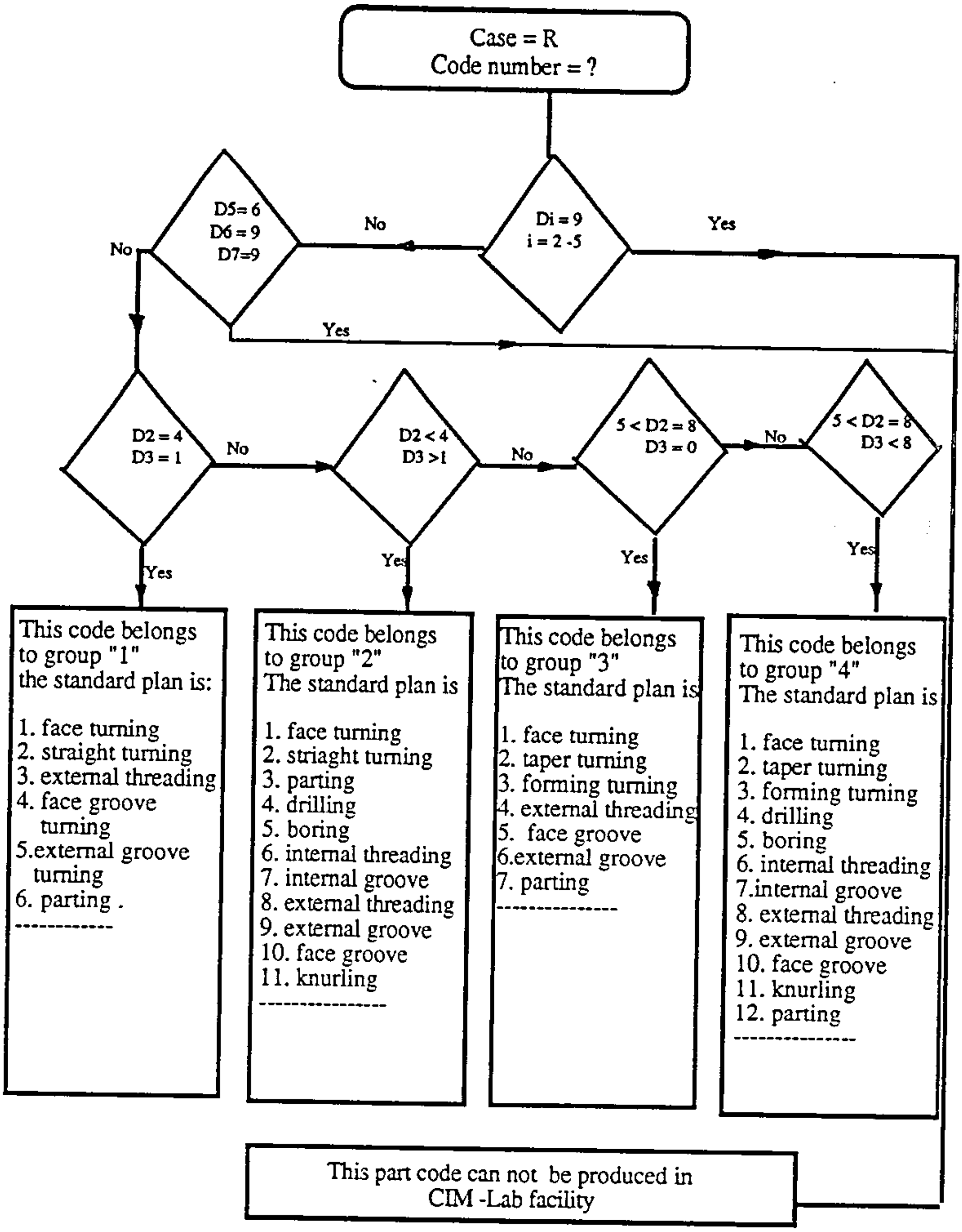


This belongs to group "5"
The standard process plan is

1. face milling
2. end mill
3. pocket mill
4. NC spot drill
5. drilling
6. tapping
7. groove mill
8. slot mill
9. champhering

This part cannot be produced in the CIM -Lab

**Figure 6.12 Inference Engine Flow Chart for Prismatic Parts**



This code belongs
to group "1"
the standard plan is:

1. face turning
2. straight turning
3. external threading
4. face groove turning
5. external groove turning
6. parting .

------------

This code belongs
to group "2"
The standard plan is

1. face turning
2. striaght turning
3. parting
4. drilling
5. boring
6. internal threading
7. internal groove
8. external threading
9. external groove
10. face groove
11. knurling

----------------

This code belongs
to group "3"
The standard plan is

1. face turning
2. taper turning
3. forming turning
4. external threading
5. face groove
6. external groove
7. parting

---------------

This code belongs
to group "4"
The standard plan is

1. face turning
2. taper turning
3. forming turning
4. drilling
5. boring
6. internal threading
7. internal groove
8. external threading
9. external groove
10. face groove
11. knurling
12. parting

---------------

This part code can not be produced in
CIM -Lab facility

**Figure 6.13 Inference Engine Flow Chart for Rotational Parts**

Figure 6.14 shows how the modifications are carried out for group number"1" .

The process of modifications is based on the code value . For example, if digit 4 in the case of rotational part equals 4 then a knurling process is required while if its equal 5 a threading process is required and there is no need for groove turning .

After creating a specific process plan the system starts to calculate the machining parameters (feeds , speeds and depth of cut), the time, and the horse power needed to accomplish the operation .

These calculations are accomplished based on the material of the work piece (brinell hardness) , the diameter of the workpiece , the length of the surface to be cut, the operation and operation condition (rough or finished operation), and the material of the tool (high speed steel , carbide , etc. , ) .

## 6.6 Examples

The following examples illustrate the operation of the developed CAPP system . Firstly , a raw material of the desired shape is selected from the raw material menu then features are added . A boundary model display can provide a much better picture for the design as shown in the pages

The current feature being positioned is the one which is highlighted in the menu choices .

After the complete process planning task is finished , the system generates a process plan documentation .

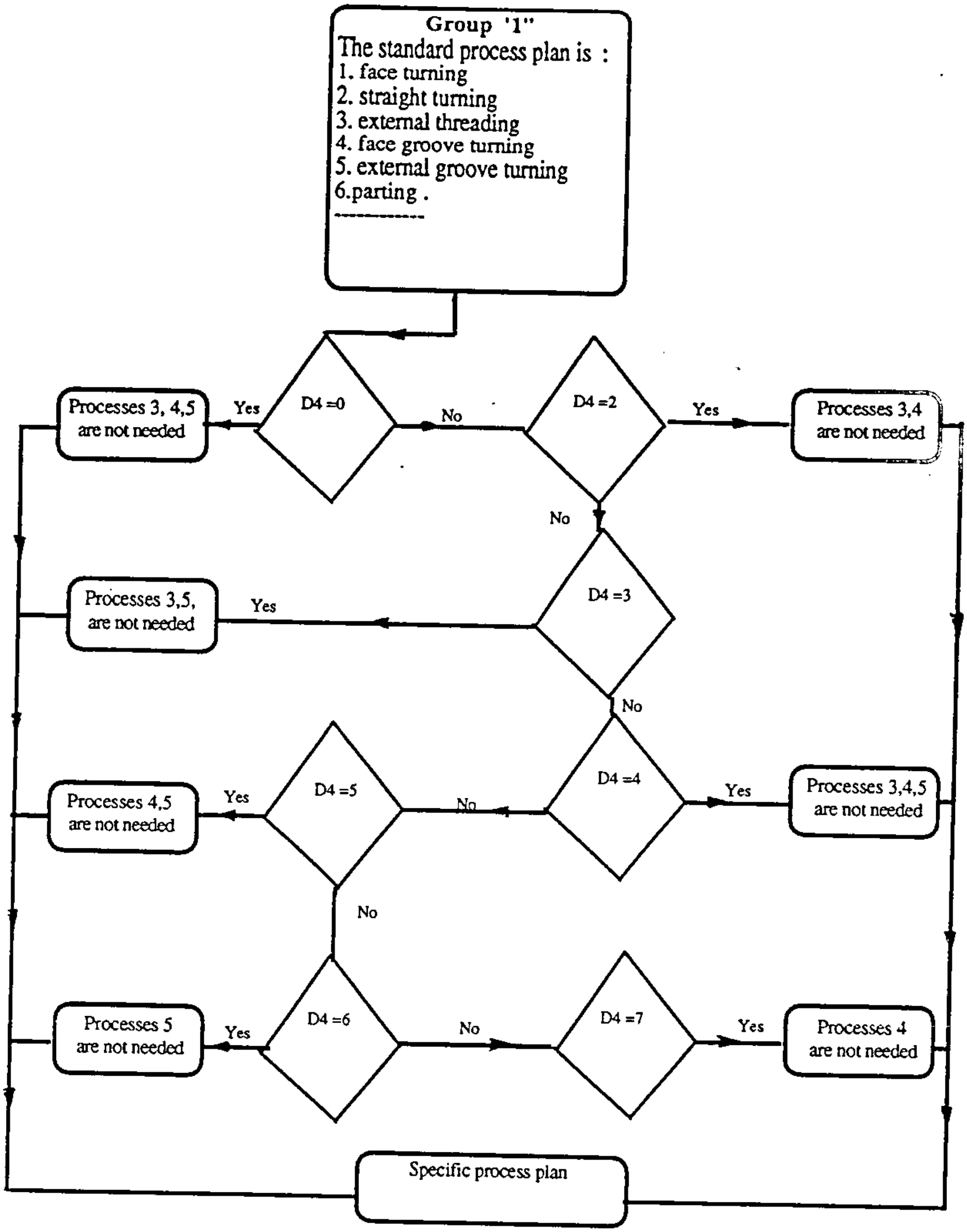


Figure 6.14 Modifications on Group Number "1"

The fowlloing rotational part design shown in Figure 6.15 is presented on page 95 to page 101, this part belongs to the family group number 2 , the standard process plan for this group is shown on page 102, the route sheet needed to produce this part is shown on page 103 .

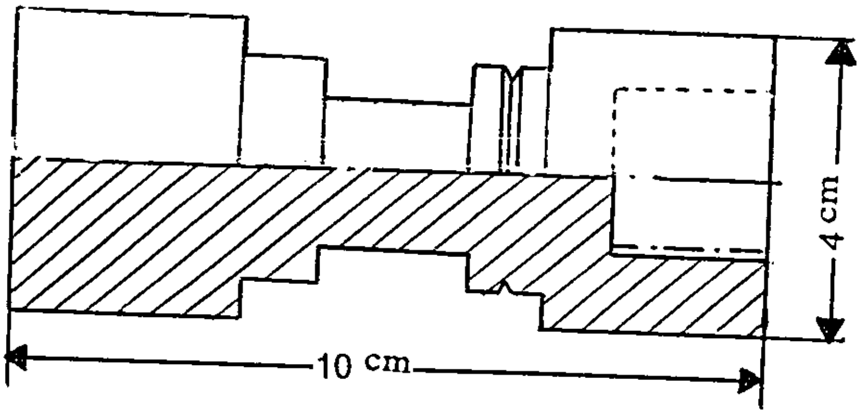


Figure 6.15 Rotational Part Design Example

while the fowlloing prismatic part design shown in Figure 6.16 is presented on page 104 to page 113 this part belongs to the family group number 5 , the standard process plan for this group is shown on pages 114 , and 115 , the route sheet needed to produce this part is shown on page 115 .

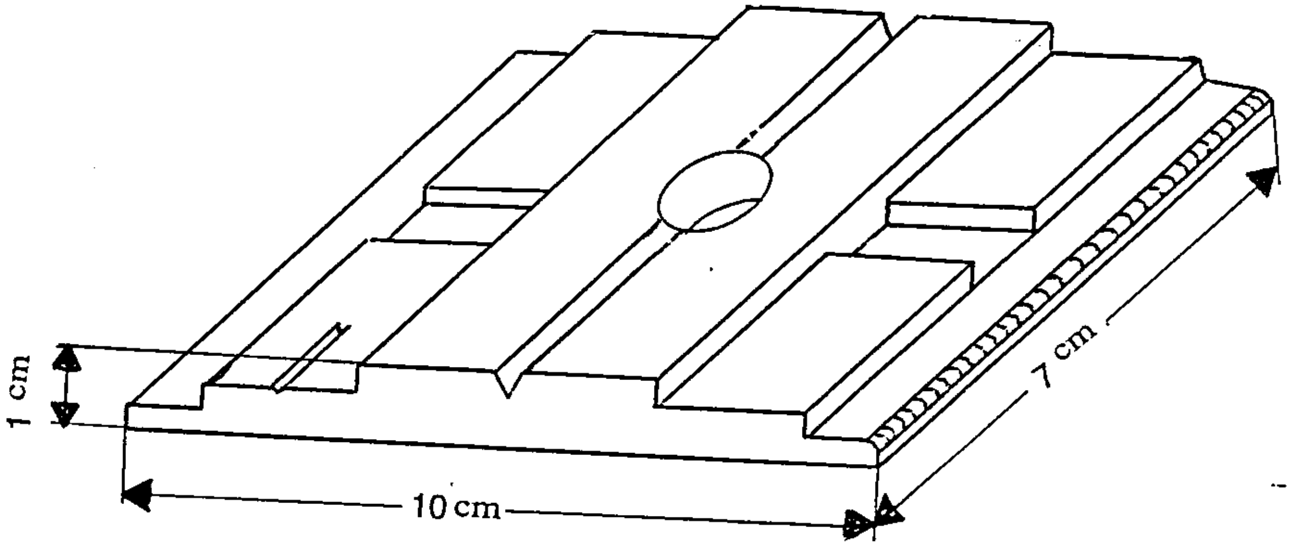


Figure 6.16 Prismatic Part Design Example

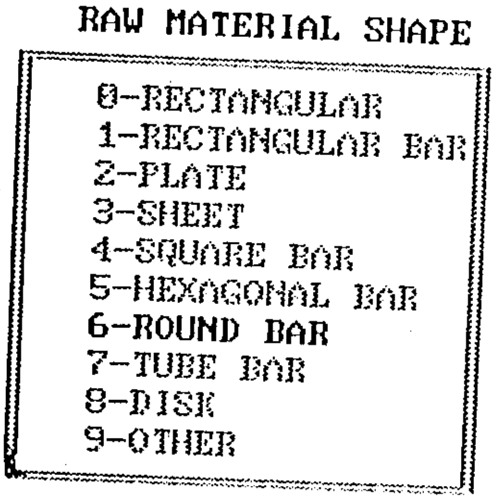
### 6.7 Personnel In Building The System

Building a usable CAPP system requires many people . It is worthwhile to discuss briefly the personnel needed for such an undertaking . We may classify the people around a CAPP system into three categories : user , developer, and information provider .

The developer is the system analyst and the programer , the developer job is to acquire knowledge from the information provider and build the software using this knowledge .

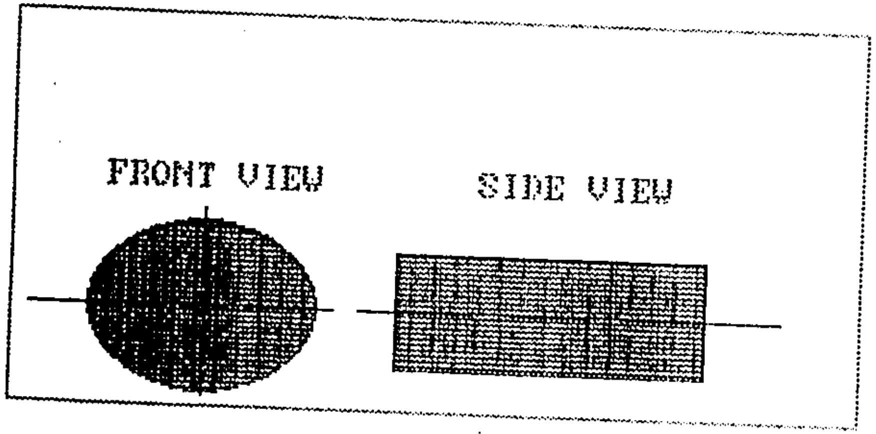
The information providers are experienced process planners, manufacturing engineers, methods engineers , and machinists . They can provide first hand knowledge about the practices of the shop and information from other sources , such as handbooks and manuals .

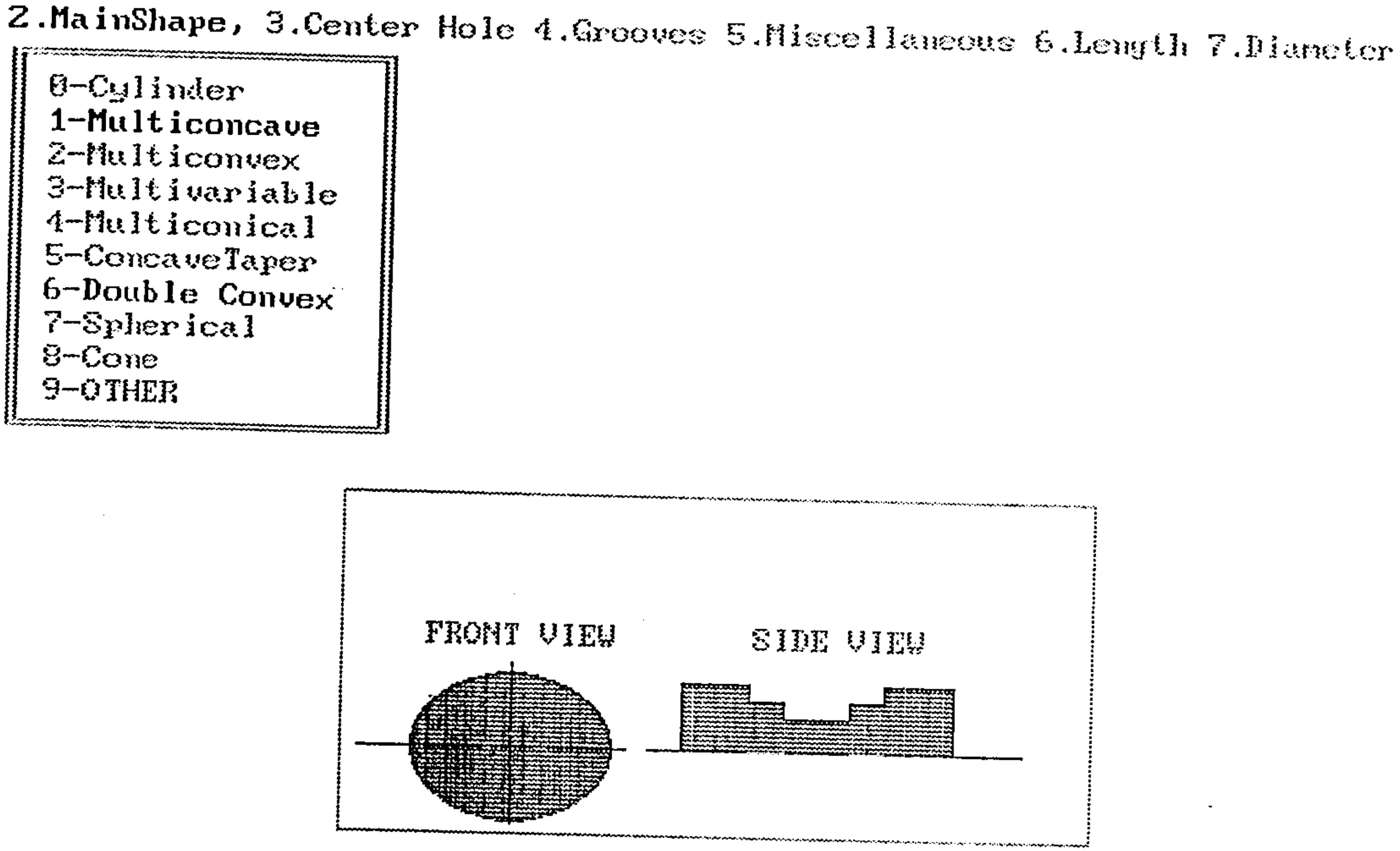
**EXAMPLE "1"** **Rotational part Design**



RAW MATERIAL SHAPE

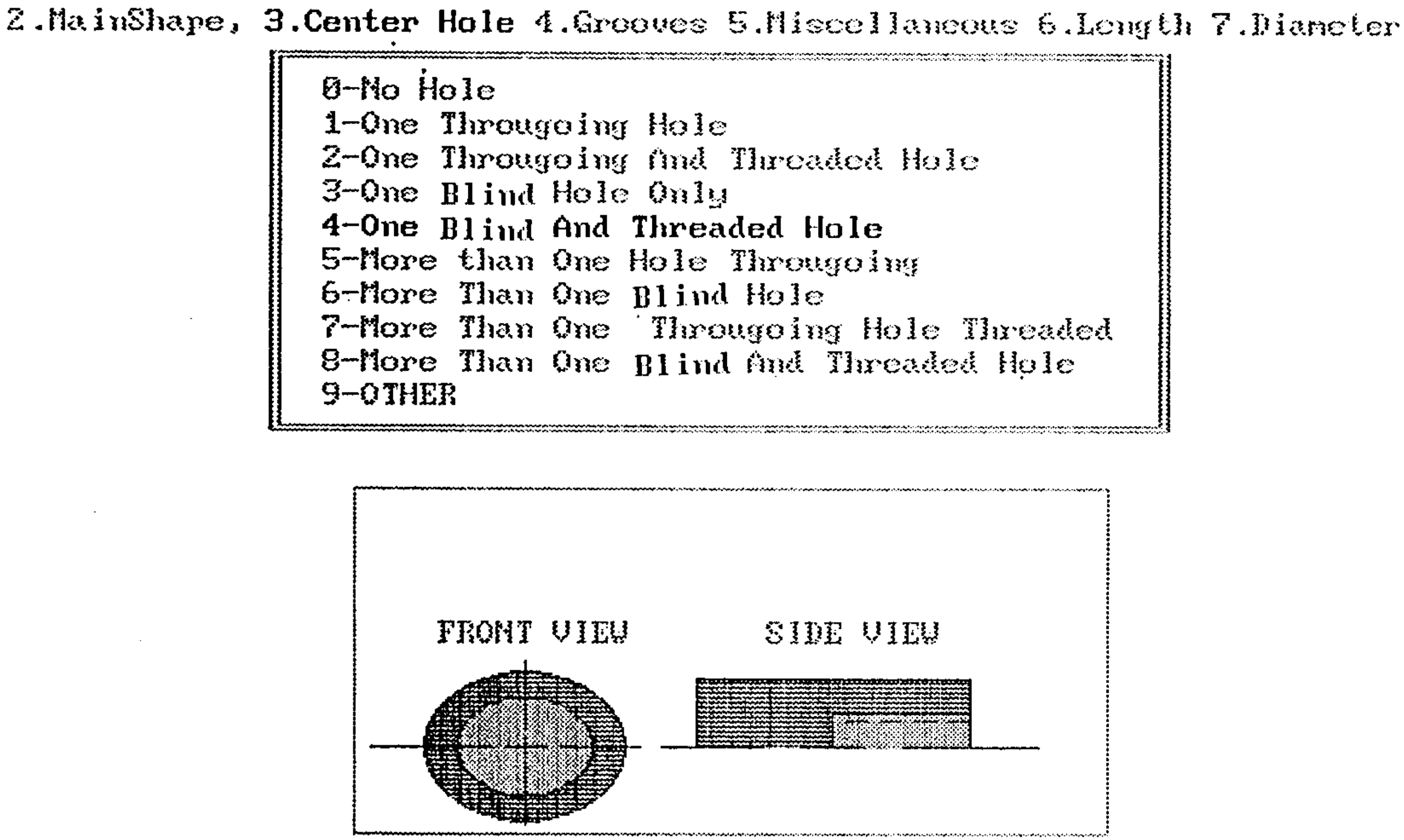
0-RECTANGULAR
1-RECTANGULAR BAR
2-PLATE
3-SHEET
4-SQUARE BAR
5-HEXAGONAL BAR
6-ROUND BAR
7-TUBE BAR
8-DISK
9-OTHER





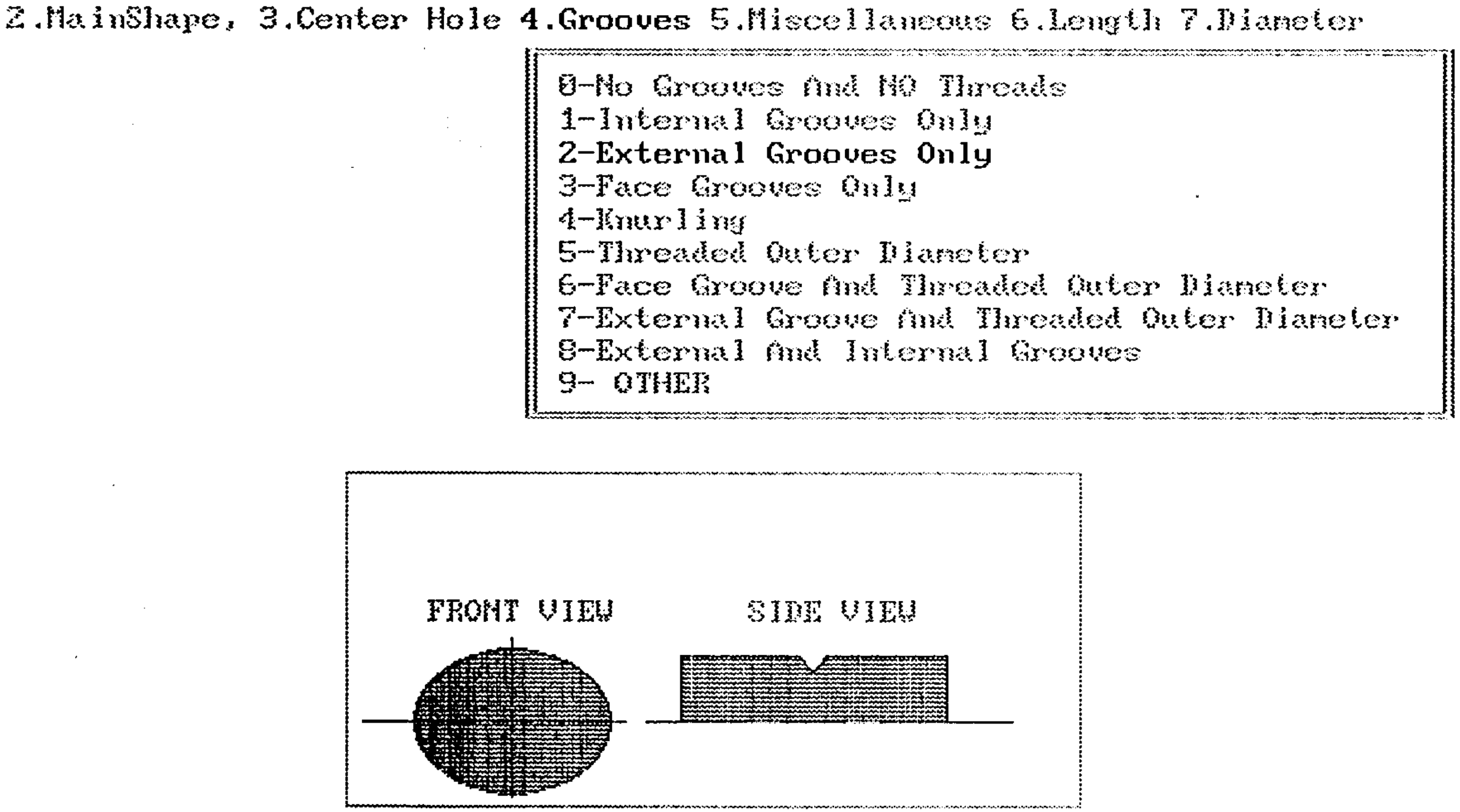
2.MainShape, 3.Center Hole 4.Grooves 5.Miscellaneous 6.Length 7.Diameter

0-Cylinder
**1-Multiconcave**
2-Multiconvex
3-Multivariable
4-Multiconical
5-ConcaveTaper
6-Double Convex
7-Spherical
8-Cone
9-OTHER



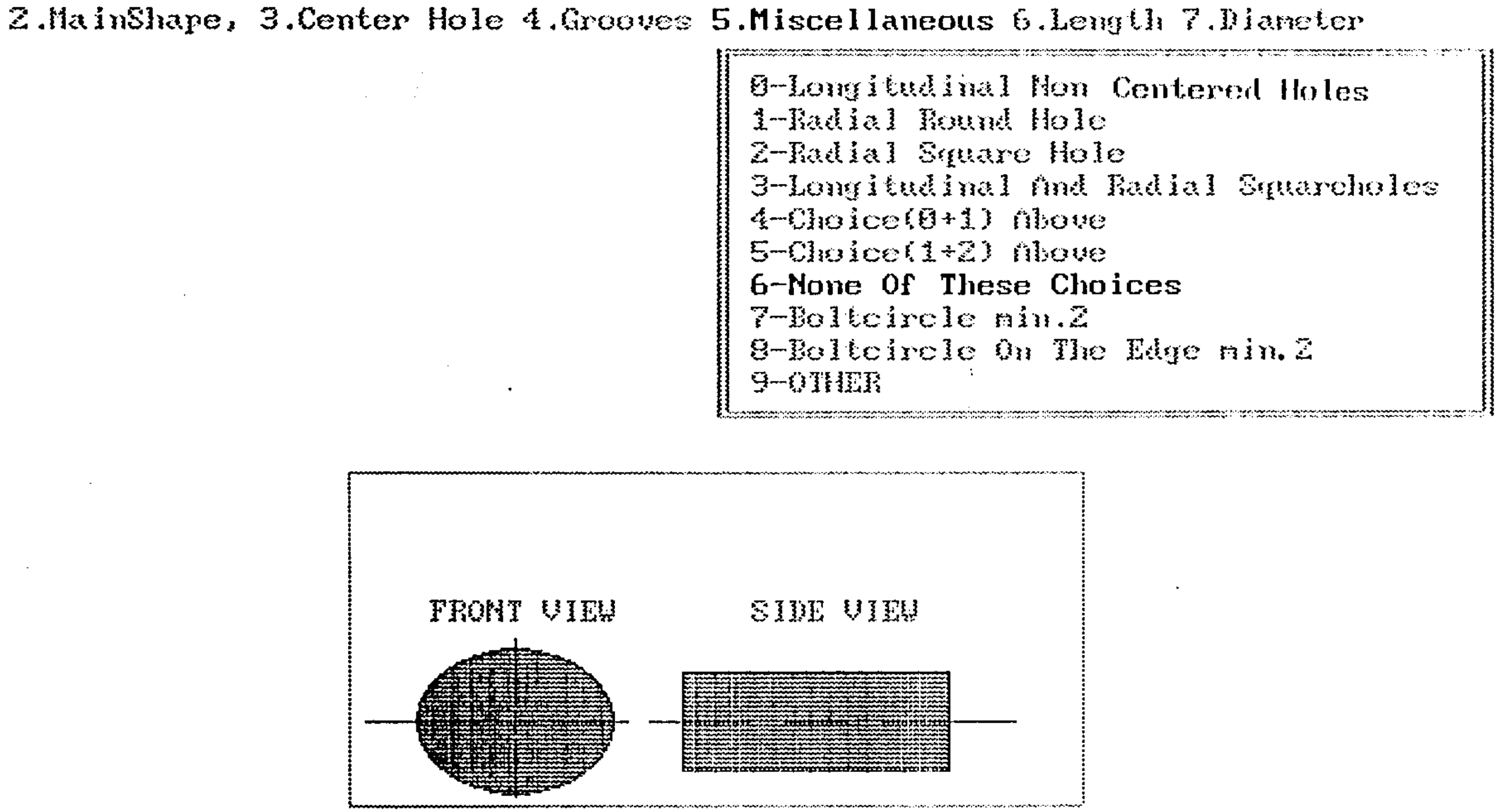
```
2.MainShape, 3.Center Hole 4.Grooves 5.Miscellaneous 6.Length 7.Diameter

    0-No Hole
    1-One Througoing Hole
    2-One Througoing And Threaded Hole
    3-One Blind Hole Only
    4-One Blind And Threaded Hole
    5-More than One Hole Througoing
    6-More Than One Blind Hole
    7-More Than One  Througoing Hole Threaded
    8-More Than One Blind And Threaded Hole
    9-OTHER
```



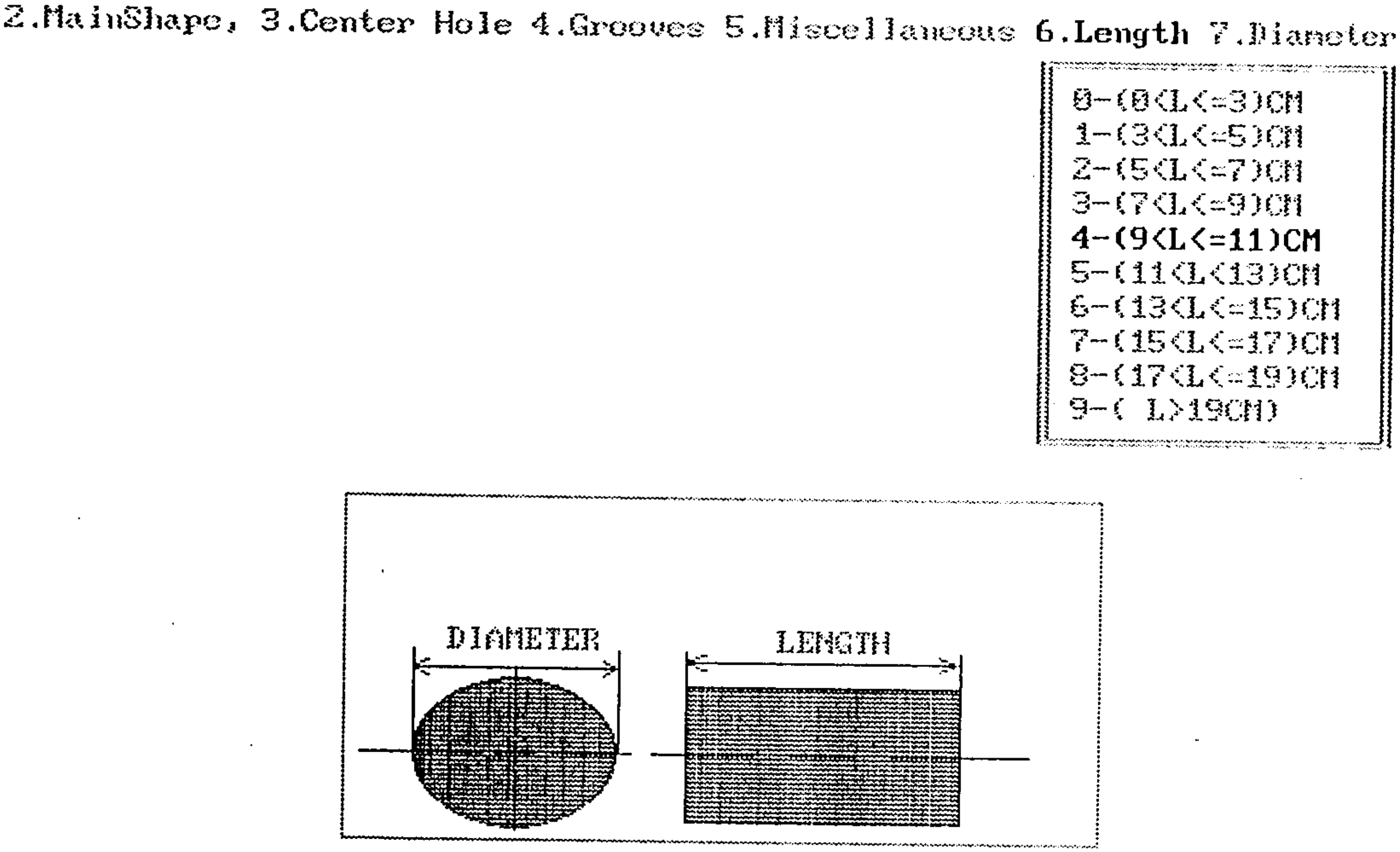
2.MainShape, 3.Center Hole **4.Grooves** 5.Miscellaneous 6.Length 7.Diameter

0-No Grooves And NO Threads
1-Internal Grooves Only
**2-External Grooves Only**
3-Face Grooves Only
4-Knurling
5-Threaded Outer Diameter
6-Face Groove And Threaded Outer Diameter
7-External Groove And Threaded Outer Diameter
8-External And Internal Grooves
9- OTHER



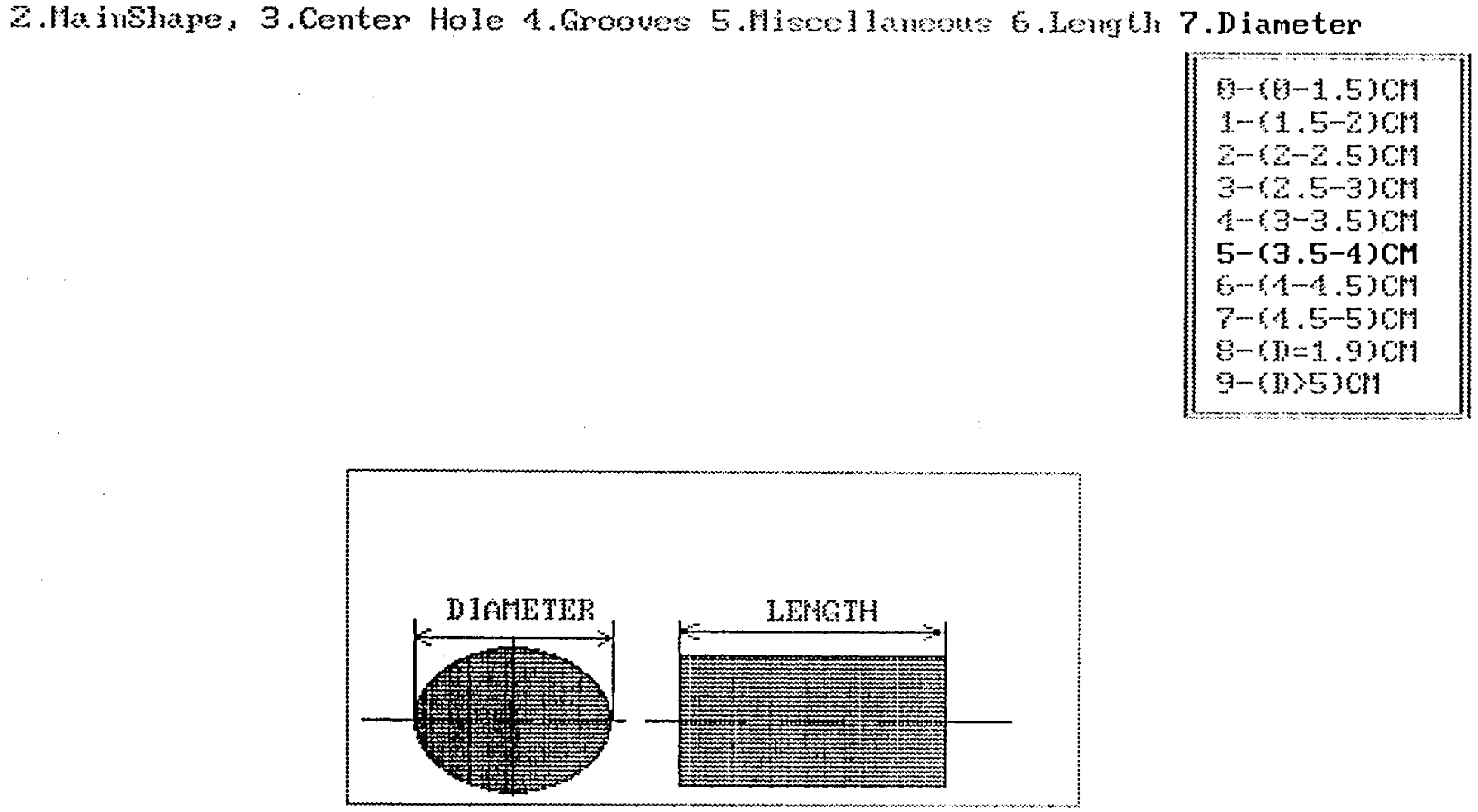
2.MainShape, 3.Center Hole 4.Grooves 5.Miscellaneous 6.Length 7.Diameter

0-Longitudinal Non Centered Holes
1-Radial Round Hole
2-Radial Square Hole
3-Longitudinal And Radial Squareholes
4-Choice(0+1) Above
5-Choice(1+2) Above
**6-None Of These Choices**
7-Boltcircle min.2
8-Boltcircle On The Edge min.2
9-OTHER



2.MainShape, 3.Center Hole 4.Grooves 5.Miscellaneous **6.Length** 7.Diameter

0-(0<L<=3)CM
1-(3<L<=5)CM
2-(5<L<=7)CM
3-(7<L<=9)CM
**4-(9<L<=11)CM**
5-(11<L<13)CM
6-(13<L<=15)CM
7-(15<L<=17)CM
8-(17<L<=19)CM
9-( L>19CM)



2.MainShape, 3.Center Hole 4.Grooves 5.Miscellaneous 6.Length **7.Diameter**

0-(0-1.5)CM
1-(1.5-2)CM
2-(2-2.5)CM
3-(2.5-3)CM
4-(3-3.5)CM
**5-(3.5-4)CM**
6-(4-4.5)CM
7-(4.5-5)CM
8-(D=1.9)CM
9-(D>5)CM

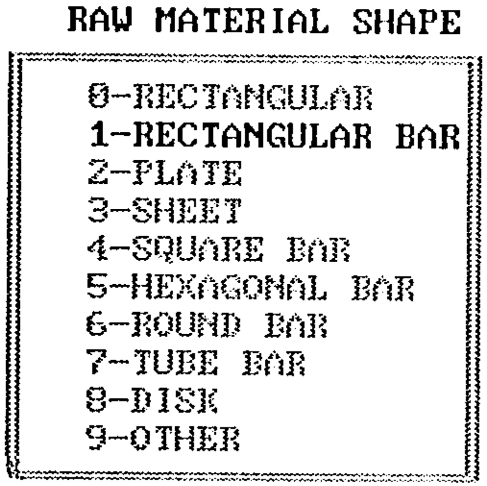
```
PART CODE IS 6  1  4  2  6  4  5  FAMILY NO, 2
THE STANDARD PROCESS PLAN FOR FAMILY NO: 2
 1 -FACE TURNING
 2 -STRAIGHT TURNING
 3 -PARTING
 4 -DRILLING
 5 -BORING
 6 -INTERNAL THREADING
 7 -INTERNAL GROOVE TURNING
 8 -EXTERNAL THREADING
 9 -EXTERNAL GROOVE TURNING
 10 -FACE GROOVE TURNING
 11 -KNURLING TURNING
PART CODE IS 6  1  4  2  6  4  5  FAMILY NO,2
THE SPECIFIC PROCESS PLAN FOR THIS PART CODE IS
 1 -FACE TURNING
 2 -STRAIGHT TURNING
 3 -PARTING
 4 -DRILLING
 5 -BORING
 6 -INTERNAL THREADING
 7 -EXTERNAL GROOVE TURNING
THE MATERIAL OF THE WORKPIECE AS ABOVE=W.P$? SOFT BRASS
THE SELECTED BRINELL HARDNES(150,175,200,225,250,275,300,350,400,450)IS BRL=? 15
0
 1 -FACE TURNING
THE  DIAMETER IN INCH TO BE CUT =DW(S)? 2
THE LENGHT OF SURFACE TO BE CUT. IN INCH=LW(S)? .1
CUTTING CASE$(S) (ROUGH OR FINISH)=? FINISH
THE SELECTED FEED RATE IN(IPR) FROM (<.005,.005,.01,.015,.02,.025)=F(S)? .02
  2 -STRAIGHT TURNING
THE  DIAMETER IN INCH TO BE CUT =DW(S)? 2
THE LENGHT OF SURFACE TO BE CUT  IN INCH=LW(S)? 3
CUTTING CASE$(S) (ROUGH OR FINISH)=? ROUGH
THE SELECTED FEED RATE IN(IPR) FROM (.030,.040,.05,.0625,.094,.125)IS F(S)=? .05

  3 -PARTING
THE  DIAMETER IN INCH TO BE CUT =DW(S)? 2
THE LENGHT OF SURFACE TO BE CUT  IN INCH=LW(S)? .01
CUTTING CASE$(S) (ROUGH OR FINISH)=? FINISH
THE SELECTED FEED RATE IN(IPR) FROM (<.005,.005,.01,.015,.02,.025)=F(S)? .02
  4 -DRILLING
  5 -BORING
THE  DIAMETER IN INCH TO BE CUT =DW(S)? .5
THE LENGHT OF SURFACE TO BE CUT  IN INCH=LW(S)? 1
CUTTING CASE$(S) (ROUGH OR FINISH)=? ROUGH
THE SELECTED FEED RATE IN(IPR) FROM (.030,.040,.05,.0625,.094,.125)IS F(S)=? .04

  6 -INTERNAL THREADING
  7 -EXTERNAL GROOVE TURNING
THE  DIAMETER IN INCH TO BE CUT =DW(S)? 2
THE LENGHT OF SURFACE TO BE CUT  IN INCH=LW(S)? .05
CUTTING CASE$(S) (ROUGH OR FINISH)=? FINISH
THE SELECTED FEED RATE IN(IPR) FROM (<.005,.005,.01,.015,.02,.025)=F(S)? .01
```

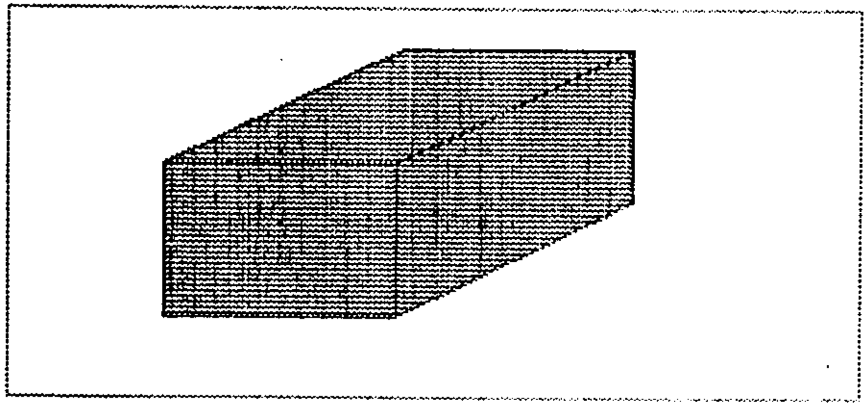
```
                              PROCESS PLANNING ROUTE SHEET
 PART CODE : 6  1  4  2  6  4  5              PREPARED BY:MOH'D AL-TAHAT
 FAMILY GROUP: 2                              DATE  :
 PART MATERIAL :SOFT BRASS                    I.E.DEP.CIM-LAB
 BRINELL HARDNESS : 150                       UNI.OF JORDAN
SEQ|    PROCESS            |SPEED(FPM)|SPINDLE RPM |FEED(IPM)|TIME(SECOND)
 1 |FACE TURNING           | 500      | 955.414    | .02     | 3.14
 2 |STRAIGHT TURNING       | 262.5    | 501.5923   | .05     | 7.177143
 3 |PARTING                | 500      | 955.414    | .02     | .0314
 4 |DRILLING               | 0        | 0          | 0       | 0
 5 |BORING                 | 312.5    | 2388.535   | .04     | .628
 6 |INTERNAL THREADING     | 0        | 0          | 0       | 0
 7 |EXTERNAL GROOVE TURNING| 787.5    | 1504.777   | .01     | .1993651
```

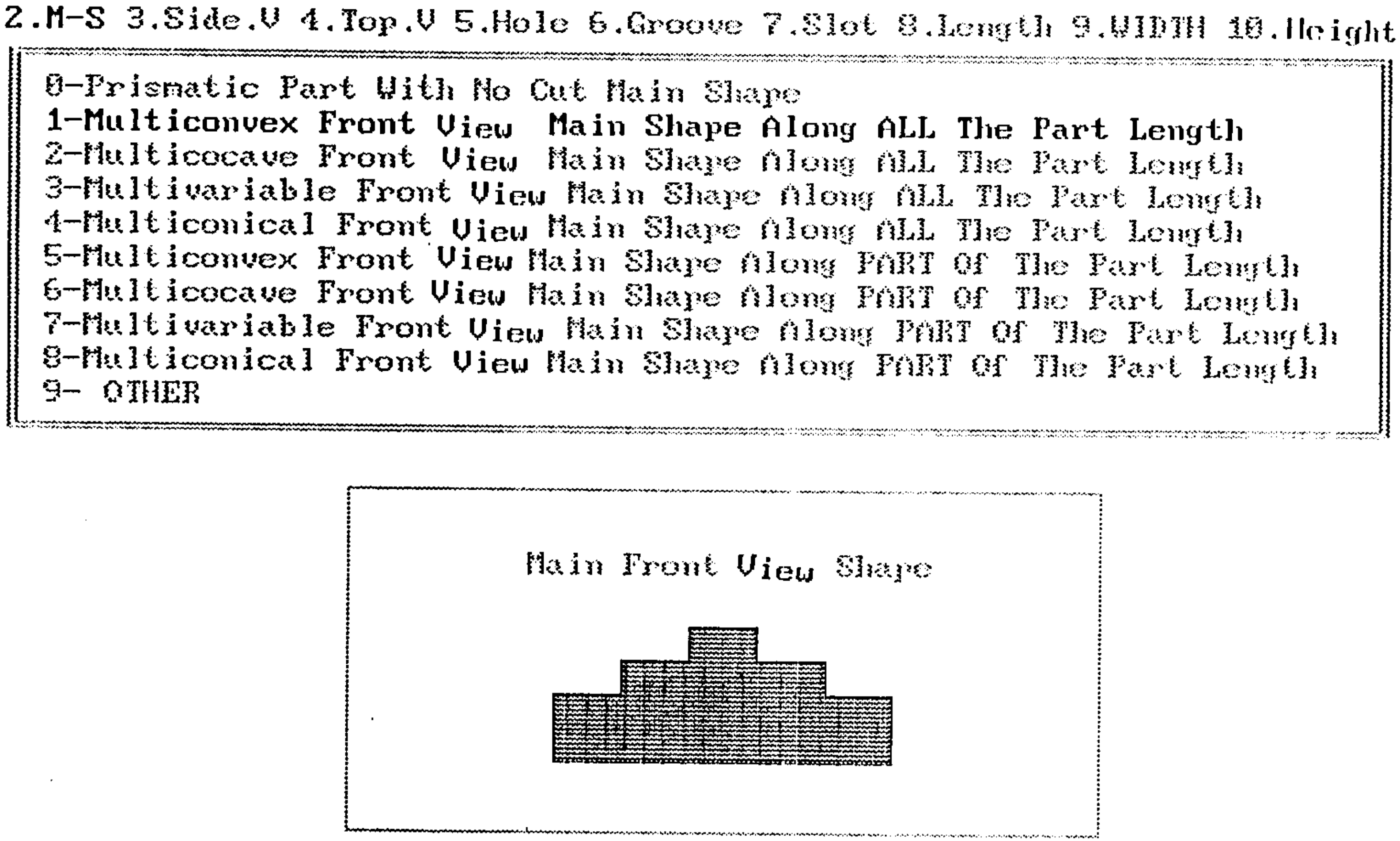
EXAMPLE "2" Prismatic Part Design



RAW MATERIAL SHAPE

0-RECTANGULAR
1-RECTANGULAR BAR
2-PLATE
3-SHEET
4-SQUARE BAR
5-HEXAGONAL BAR
6-ROUND BAR
7-TUBE BAR
8-DISK
9-OTHER

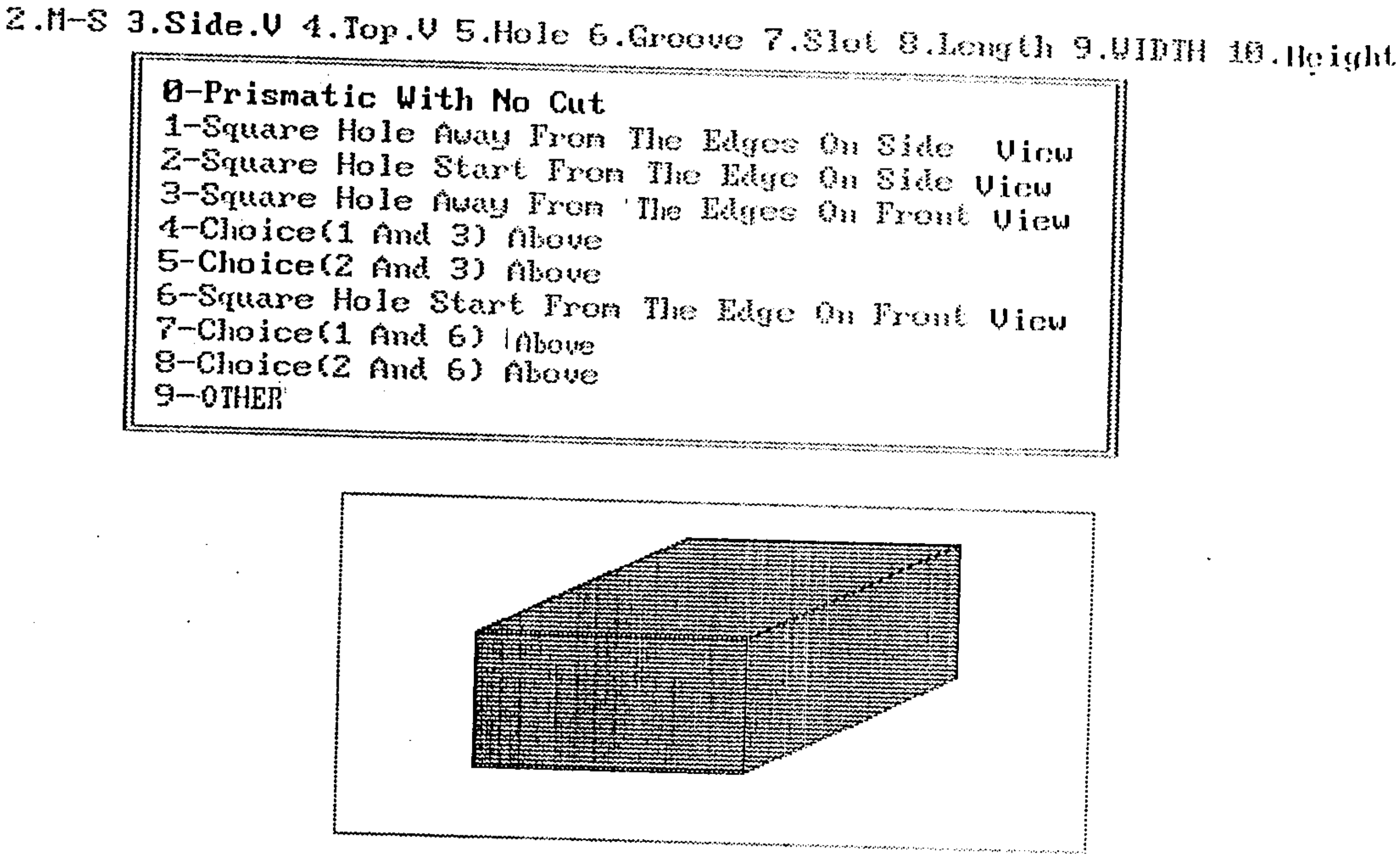




2.M-S 3.Side.V 4.Top.V 5.Hole 6.Groove 7.Slot 8.Length 9.WIDTH 10.Height

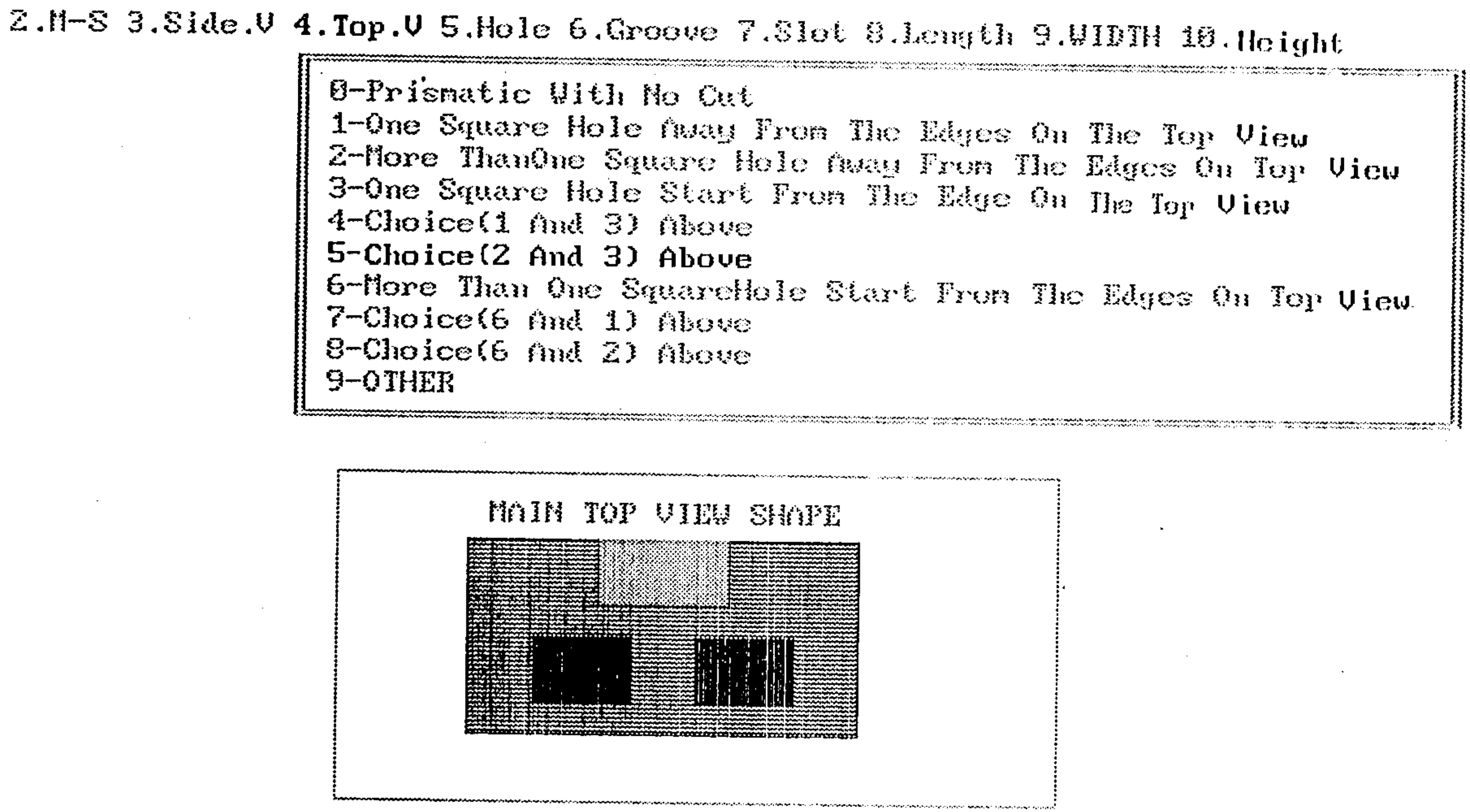
0-Prismatic Part With No Cut Main Shape
**1-Multiconvex Front View Main Shape Along ALL The Part Length**
2-Multicocave Front View Main Shape Along ALL The Part Length
3-Multivariable Front View Main Shape Along ALL The Part Length
4-Multiconical Front View Main Shape Along ALL The Part Length
5-Multiconvex Front View Main Shape Along PART Of The Part Length
6-Multicocave Front View Main Shape Along PART Of The Part Length
7-Multivariable Front View Main Shape Along PART Of The Part Length
8-Multiconical Front View Main Shape Along PART Of The Part Length
9- OTHER

Main Front View Shape



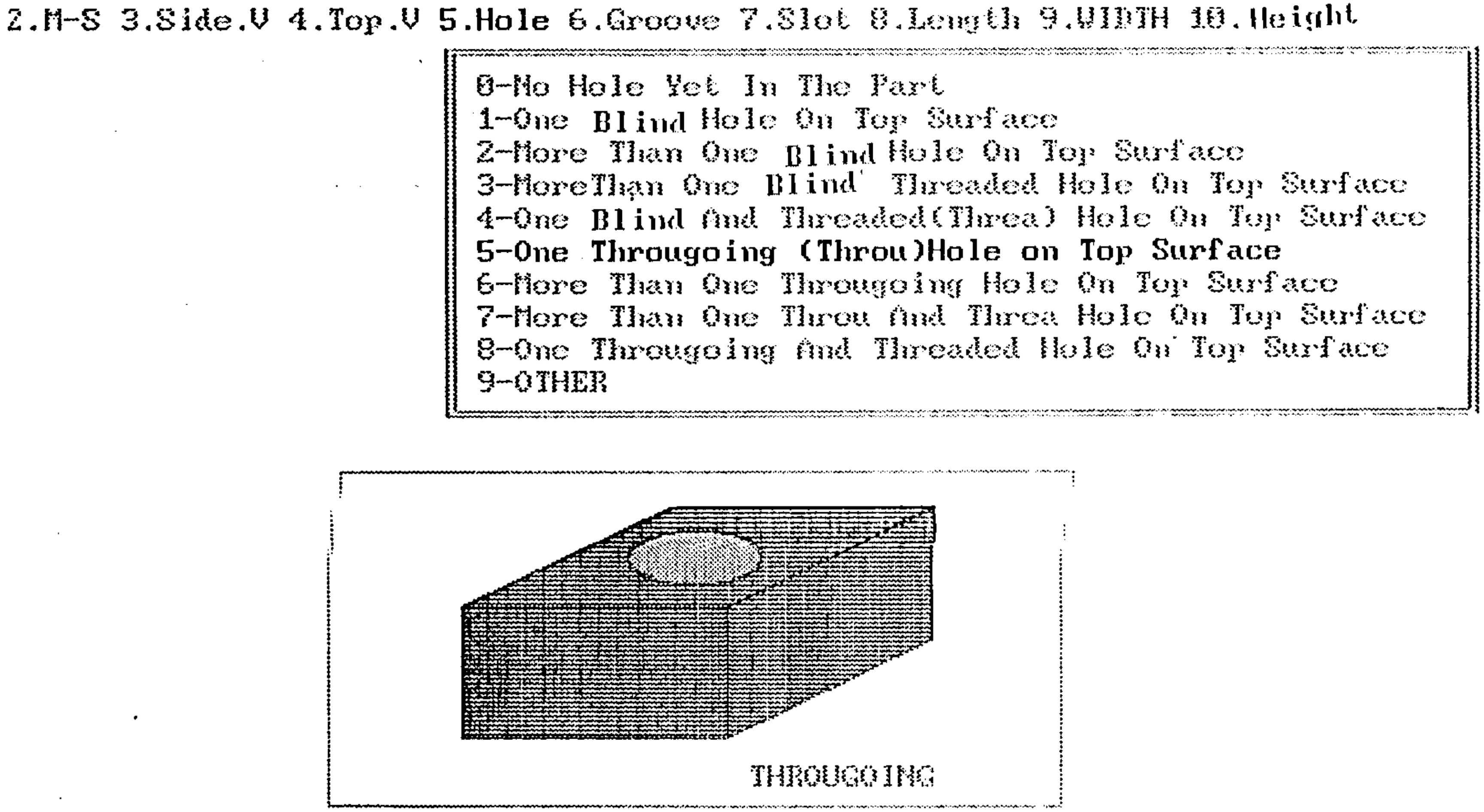
2.M-S 3.Side.V 4.Top.V 5.Hole 6.Groove 7.Slot 8.Length 9.WIDTH 10.Height

**0-Prismatic With No Cut**
1-Square Hole Away From The Edges On Side View
2-Square Hole Start From The Edge On Side View
3-Square Hole Away From The Edges On Front View
4-Choice(1 And 3) Above
5-Choice(2 And 3) Above
6-Square Hole Start From The Edge On Front View
7-Choice(1 And 6) Above
8-Choice(2 And 6) Above
9-OTHER



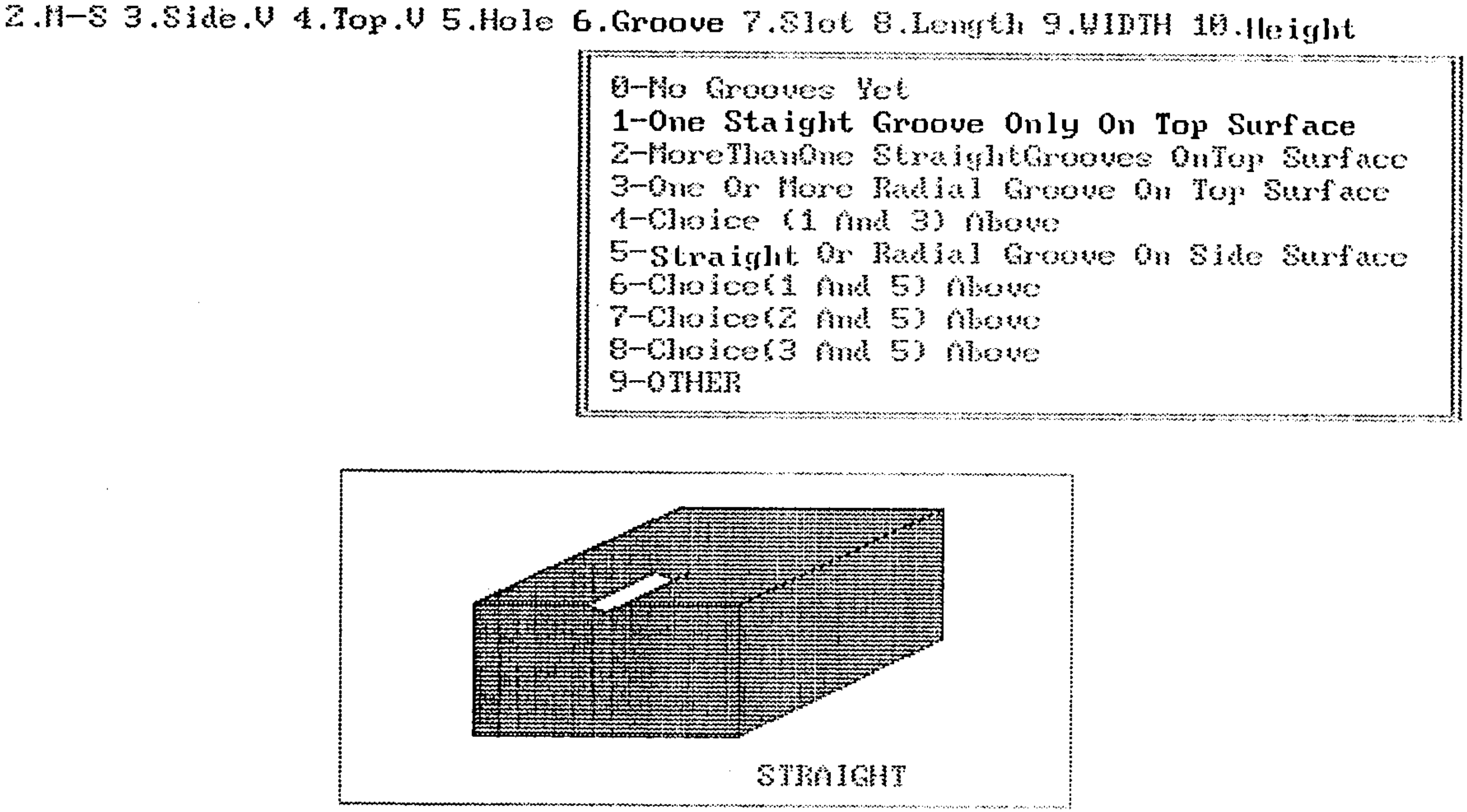
```
2.M-S 3.Side.V 4.Top.V 5.Hole 6.Groove 7.Slot 8.Length 9.WIDTH 10.Height

0-Prismatic With No Cut
1-One Square Hole Away From The Edges On The Top View
2-More ThanOne Square Hole Away From The Edges On Top View
3-One Square Hole Start From The Edge On The Top View
4-Choice(1 And 3) Above
5-Choice(2 And 3) Above
6-More Than One SquareHole Start From The Edges On Top View
7-Choice(6 And 1) Above
8-Choice(6 And 2) Above
9-OTHER
```



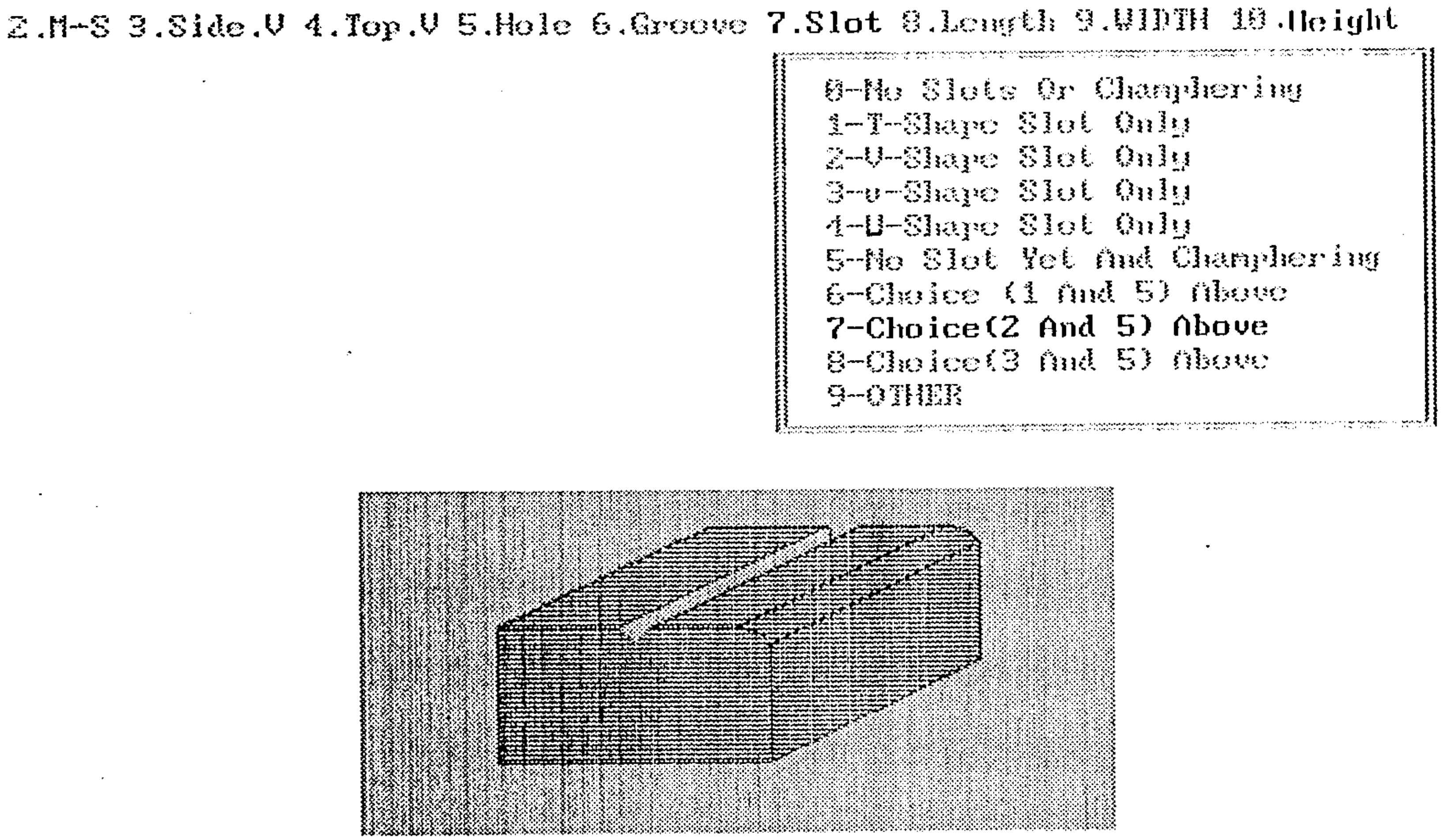
2.M-S 3.Side.V 4.Top.V **5.Hole** 6.Groove 7.Slot 8.Length 9.WIDTH 10.Height

0-No Hole Yet In The Part
1-One Blind Hole On Top Surface
2-More Than One Blind Hole On Top Surface
3-MoreThan One Blind Threaded Hole On Top Surface
4-One Blind And Threaded(Threa) Hole On Top Surface
**5-One Througoing (Throu)Hole on Top Surface**
6-More Than One Througoing Hole On Top Surface
7-More Than One Throu And Threa Hole On Top Surface
8-One Througoing And Threaded Hole On Top Surface
9-OTHER



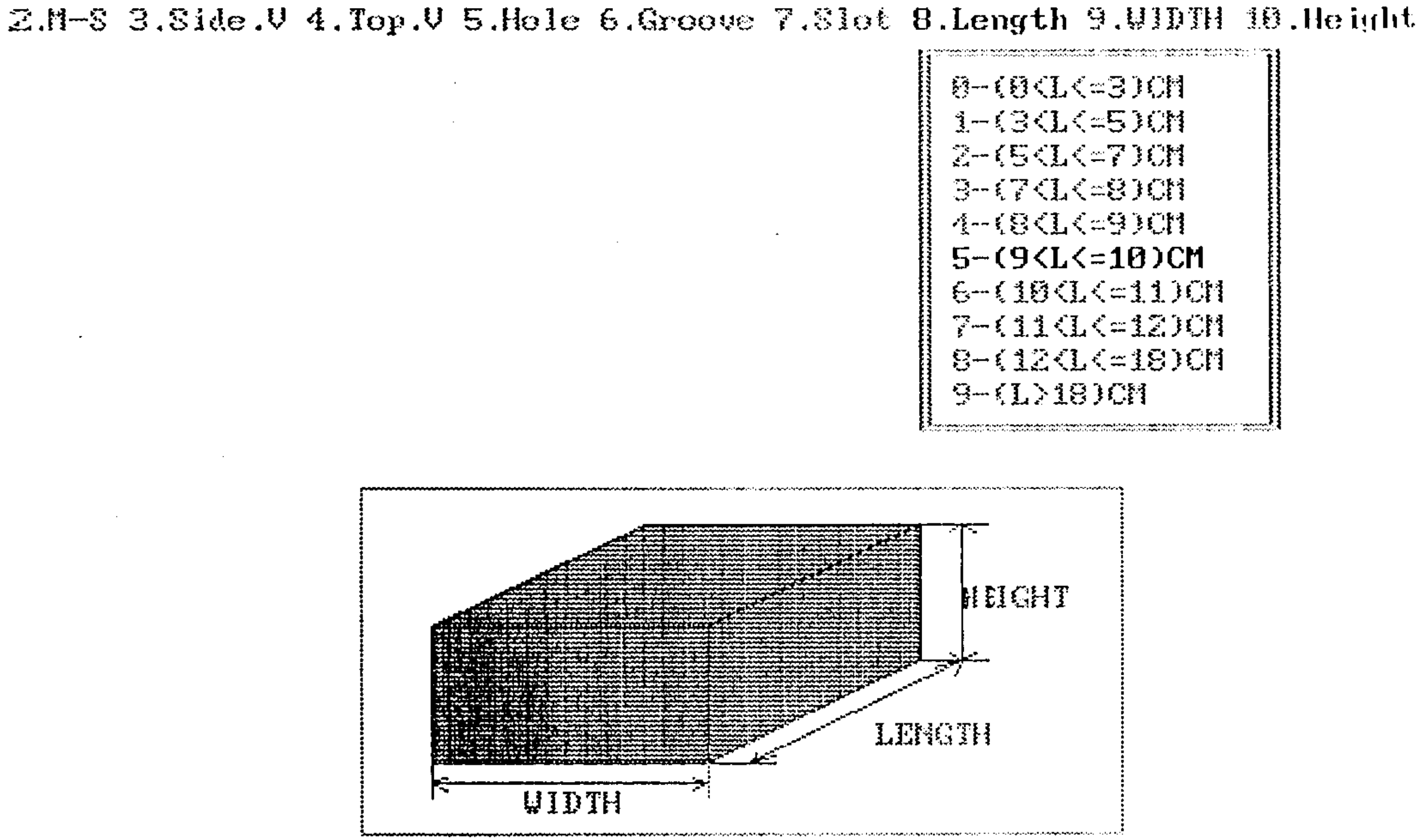
```
2.M-S 3.Side.V 4.Top.V 5.Hole 6.Groove 7.Slot 8.Length 9.WIDTH 10.Height
```

```
0-No Grooves Yet
1-One Staight Groove Only On Top Surface
2-MoreThanOne StraightGrooves OnTop Surface
3-One Or More Radial Groove On Top Surface
4-Choice (1 And 3) Above
5-Straight Or Radial Groove On Side Surface
6-Choice(1 And 5) Above
7-Choice(2 And 5) Above
8-Choice(3 And 5) Above
9-OTHER
```



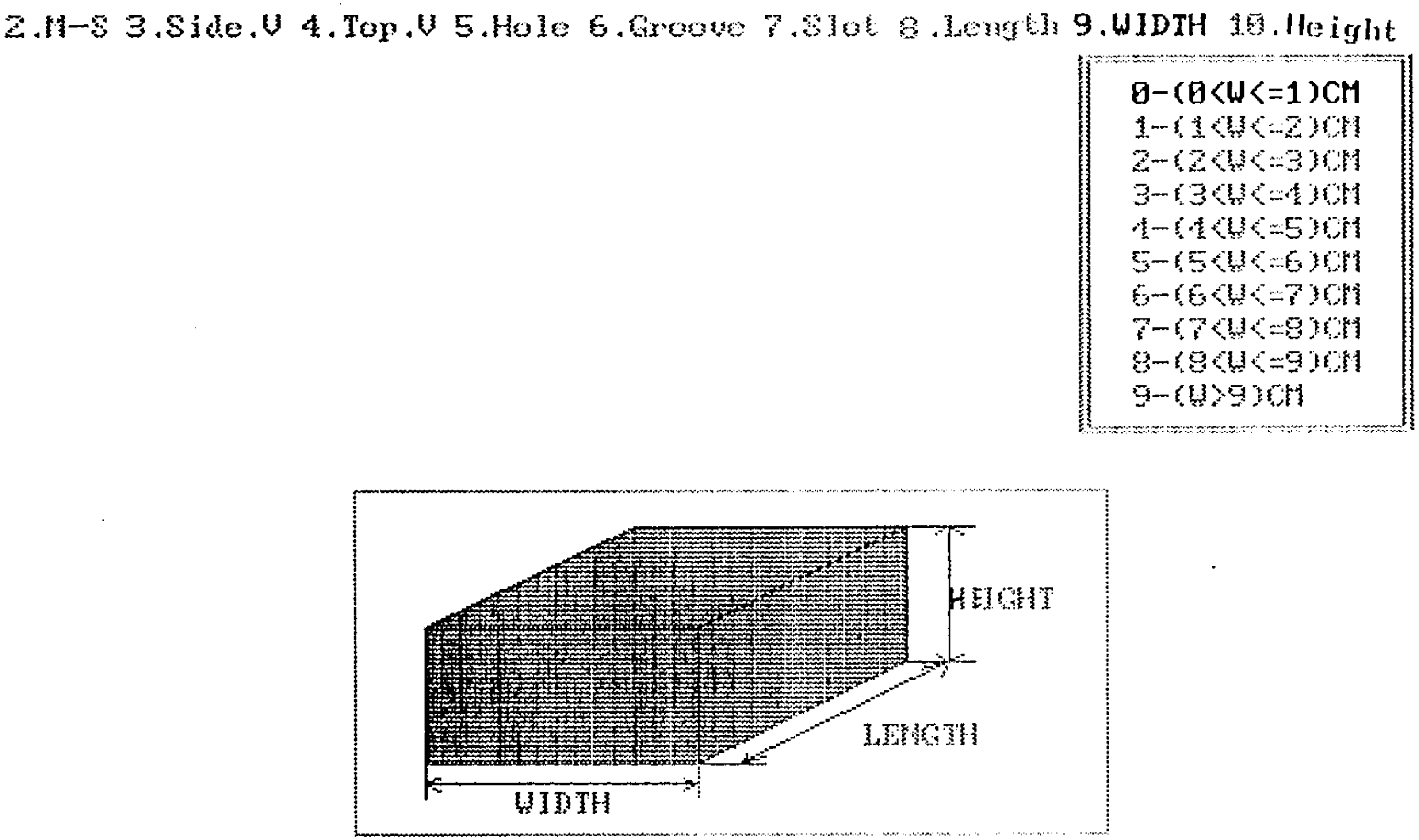
2.M-S 3.Side.V 4.Top.V 5.Hole 6.Groove **7.Slot** 8.Length 9.WIDTH 10.Height

0-No Slots Or Champhering
1-T-Shape Slot Only
2-V-Shape Slot Only
3-v-Shape Slot Only
4-U-Shape Slot Only
5-No Slot Yet And Champhering
6-Choice (1 And 5) Above
**7-Choice(2 And 5) Above**
8-Choice(3 And 5) Above
9-OTHER



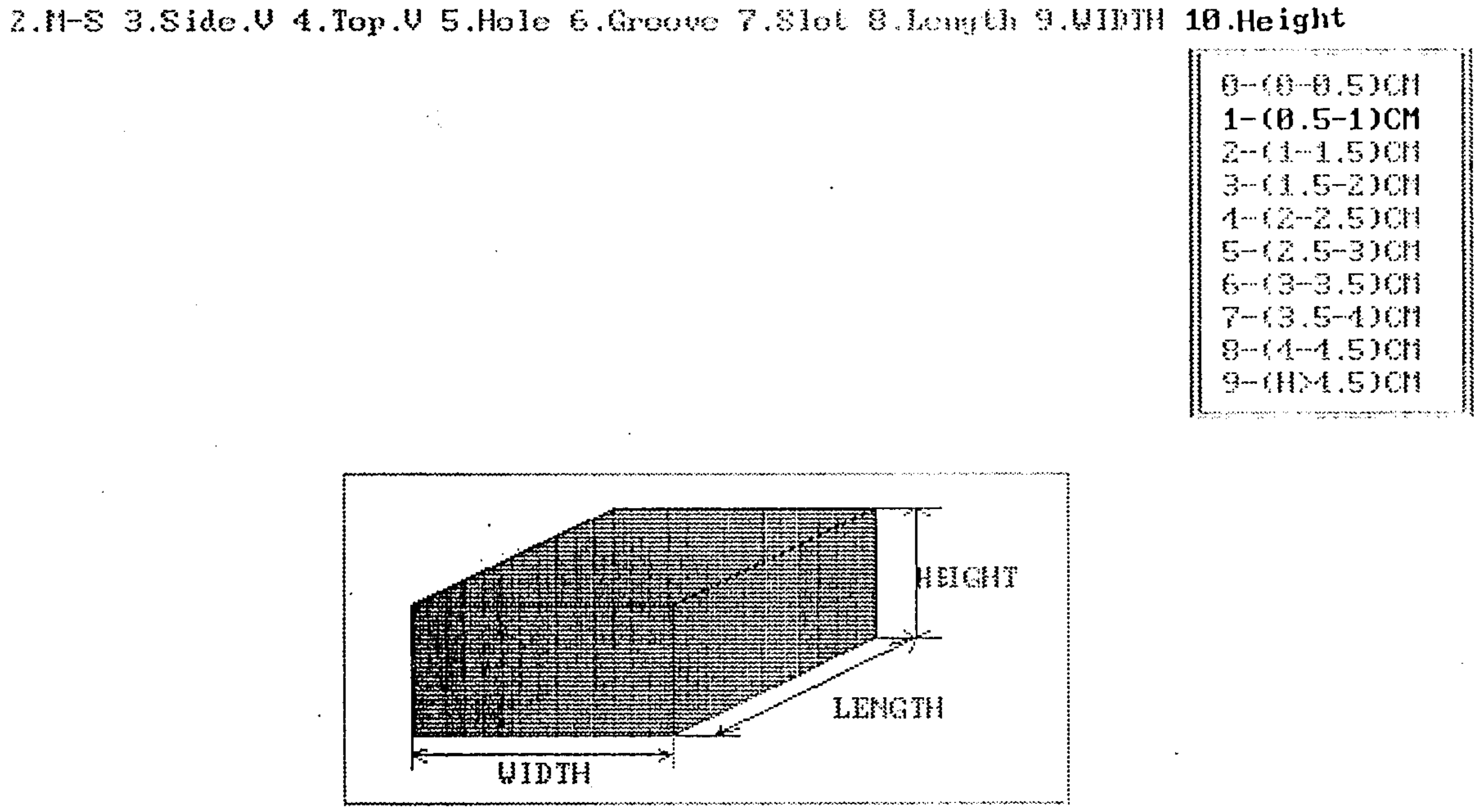
```
2.M-S 3.Side.V 4.Top.V 5.Hole 6.Groove 7.Slot 8.Length 9.WIDTH 10.Height

0-(0<L<=3)CM
1-(3<L<=5)CM
2-(5<L<=7)CM
3-(7<L<=8)CM
4-(8<L<=9)CM
5-(9<L<=10)CM
6-(10<L<=11)CM
7-(11<L<=12)CM
8-(12<L<=18)CM
9-(L>18)CM
```



2.M-S 3.Side.V 4.Top.V 5.Hole 6.Groove 7.Slot 8.Length 9.WIDTH 10.Height

**0-(0<W<=1)CM**
1-(1<W<=2)CM
2-(2<W<=3)CM
3-(3<W<=4)CM
4-(4<W<=5)CM
5-(5<W<=6)CM
6-(6<W<=7)CM
7-(7<W<=8)CM
8-(8<W<=9)CM
9-(W>9)CM


2.M-S 3.Side.V 4.Top.V 5.Hole 6.Groove 7.Slot 8.Length 9.WIDTH 10.Height
0-(0-0.5)CM
1-(0.5-1)CM
2-(1-1.5)CM
3-(1.5-2)CM
4-(2-2.5)CM
5-(2.5-3)CM
6-(3-3.5)CM
7-(3.5-4)CM
8-(4-4.5)CM
9-(H>4.5)CM
HEIGHT
LENGTH
WIDTH

```
PART CODEIS: 2  1  0  5  5  1  7  5  6  1 FAMILY NO: 5
THE STANDARD PROCESS PLAN FOR FAMILY NO,5 IS
 1 -FACE MILLING
 2 -END MILL
 3 -POCKET MILL
 4 -NC,SPOT DRILL
 5 -DRILLING
 6 -TAPPING
 7 -GROOVE MILL
 8 -SLOT MILL
 9 -CHAMPHERING
THE PART CODE IS: 2  1  0  5  5  1  7  5  6  1 FAMILY NO:5
 THE SPECIFIC PROCESS PLAN FOR THIS PART CODE IS
 1 -FACE MILLING
 2 -END MILL
 3 -POCKET MILL
 4 -DRILLING
 5 -GROOVE MILL
 6 -SLOT MILL
 7 -CHAMPHERING
 8 -
 9 -
 10 -
THE MATERIAL OF THE WORK PIECE AS ABOVE (S)=W.P$? CAST STEEL
 SELECT BRINELL HARDNES(150,175,200,225,250,275,300,350,400,450)IS BRL=? 200
 1 -FACE MILLING
THE LENGHT OF SURFACE TO BE CUT  ININCH=LW(S)? 3
THE WIDTH TO BE CUT  IS W=? 2
THE TOOL MATERIAL (H.S.S OR CARBIDE )=? CARBIDE
THE TOOL DIAMETER IN INCH     =? 1
THE TOOL TEETH NUMBER IS TN=? 4
THE RECOMENDED DEPTH OF CUT H IS =? .02
CUTTING CASE$(S) (ROUGH(R) OR FINISH(F))=? F
SELECT A FEED RATE IN(IPR) FROM (<.005,.005,.01,.015,.02,.025)=F(S)? .01
 2 -END MILL
THE LENGHT OF SURFACE TO BE CUT IN INCH=LW(S)? 3
THE WIDTH TO BE CUT  IS W=? .5
THE TOOL MATERIAL (H.S.S OR CARBIDE )=? CARBIDE
THE TOOL DIAMETER IN INCH     =? .5
THE TOOL TEETH NUMBER IS TN=? 4
THE RECOMENDED DEPTH OF CUT H IS =? .3
CUTTING CASE$(S) (ROUGH(R) OR FINISH(F))=? R
 SELECT A FEED RATE IN(IPR) FROM (.030,.040,.05,.0625,.094,.125)IS F(S)=? .04
```

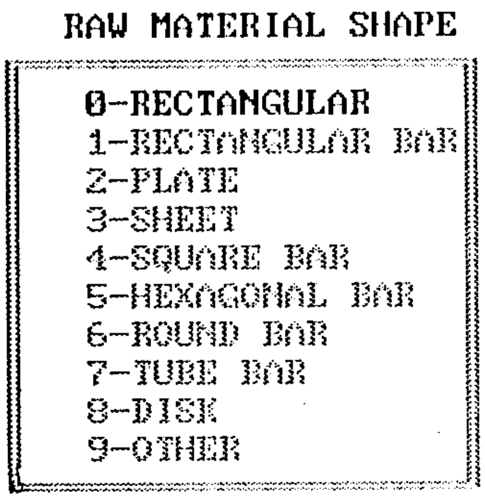
```
 3 -POCKET MILL
THE LENGHT OF SURFACE TO BE CUT IN INCH=LW(S)? .5
THE WIDTH TO BE CUT  IS W=? .2
THE TOOL MATERIAL (H.S.S OR CARBIDE )=? CARBIDE
THE TOOL DIAMETER IN INCH      =? .18
THE TOOL TEETH NUMBER IS TN=? 2
THE RECOMENDED DEPTH OF CUT H IS =? 1
CUTTING CASE$(S) (ROUGH(R) OR FINISH(F))=? R
 SELECT A FEED RATE IN(IPR) FROM (.030,.040,.05,.0625,.094,.125)IS F(S)=? .03
 4 -DRILLING
 5 -GROOVE MILL
THE LENGHT OF SURFACE TO BE CUT  IN INCH=LW(S)? 3
THE WIDTH TO BE CUT  IS W=? .01
THE TOOL MATERIAL (H.S.S OR CARBIDE )=? CARBIDE
THE TOOL DIAMETER IN INCH      =? .01
THE TOOL TEETH NUMBER IS TN=? 1
THE RECOMENDED DEPTH OF CUT H IS =? .02
CUTTING CASE$(S) (ROUGH(R) OR FINISH(F))=? F
SELECT A FEED RATE IN(IPR) FROM (<.005,.005,.01,.015,.02,.025)=F(S)? .01
 6 -SLOT MILL
THE LENGHT OF SURFACE TO BE CUT IN INCH=LW(S)? .3
THE WIDTH TO BE CUT  IS W=? .1
THE TOOL MATERIAL (H.S.S OR CARBIDE )=? CARBIDE
THE TOOL DIAMETER IN INCH      =? .2
THE TOOL TEETH NUMBER IS TN=? 2
THE RECOMENDED DEPTH OF CUT H IS =? .2
CUTTING CASE$(S) (ROUGH(R) OR FINISH(F))=? R
 SELECT A FEED RATE IN(IPR) FROM (.030,.040,.05,.0625,.094,.125)IS F(S)=? .094
 7 -CHAMPHERING
THE LENGHT OF SURFACE TO BE CUT IN INCH=LW(S)? 3
THE WIDTH TO BE CUT  IS W=? .3
THE TOOL MATERIAL (H.S.S OR CARBIDE )=? CARBIDE
THE TOOL DIAMETER IN INCH      =? 1
THE TOOL TEETH NUMBER IS TN=? 2
THE RECOMENDED DEPTH OF CUT H IS =? .2
CUTTING CASE$(S) (ROUGH(R) OR FINISH(F))=? R
 SELECT A FEED RATE IN(IPR) FROM (.030,.040,.05,.0625,.094,.125)IS F(S)=? .05
```

PROCESS PLANNING ROUTESHEET

PART CODE       : 2  1  0  5  5  1  7  5  6  1    PREPARED BY:MOH'D AL-TAHAT
FAMILY GROUP   : 5    DATE        :
PART MATERIAL :CAST STEEL    I.E . CIM-LAB
BRINELL HARDNESS : 200    UNI.OF.JORDAN

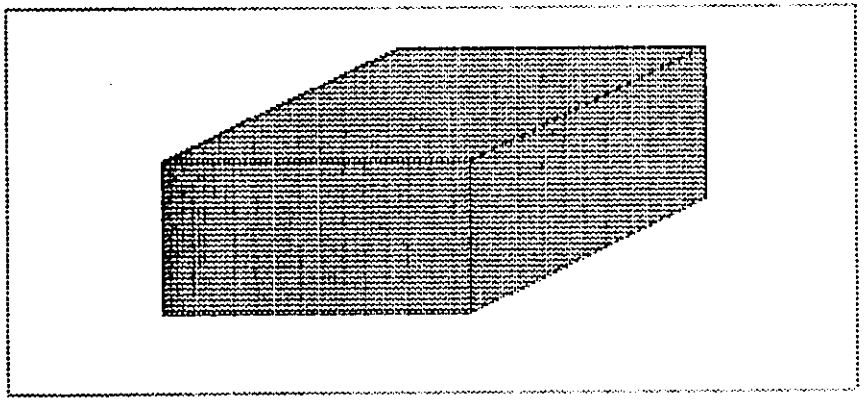
| SEQ | PROCESS | SPEED (FPM) | SPINDLE (RPM) | FEED (IPM) | H.POWER ( hp ) | DEPTH INCH | REMARK (R/F) |
|---|---|---|---|---|---|---|---|
| 1 | FACE MILLING | 225 | 859.8726 | 41.27388 | 3.301911 | .02 | FINISH |
| 2 | END MILL | 165 | 1261.146 | 20.17834 | 6.053504 | .3 | ROUGH |
| 3 | POCKET MILL | 165 | 3503.185 | 28.02548 | 11.21019 | 1 | ROUGH |
| 4 | DRILLING | 0 | 0 | 0 | 0 | 0 | ROUGH |
| 5 | GROOVE MILL | 225 | 85987.26 | 687.8981 | .2751592 | .02 | FINISH |
| 6 | SLOT MILL | 165 | 3152.866 | 50.44586 | 2.017834 | .2 | ROUGH |
| 7 | CHAMPHERING | 165 | 630.5732 | 10.08917 | 1.210701 | .2 | ROUGH |

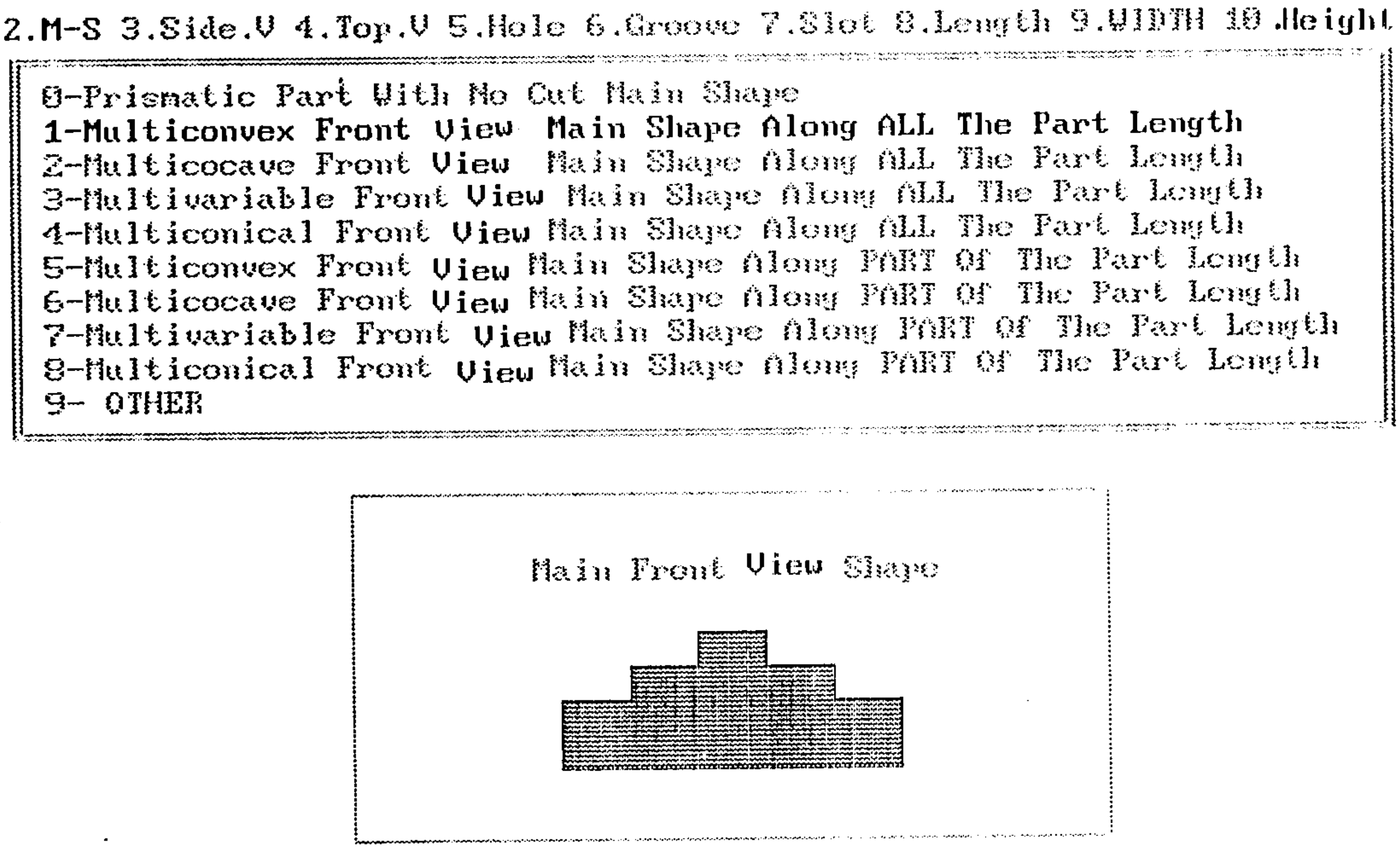
EXAMPLE "3" Product That Cannot Be Produced .



RAW MATERIAL SHAPE

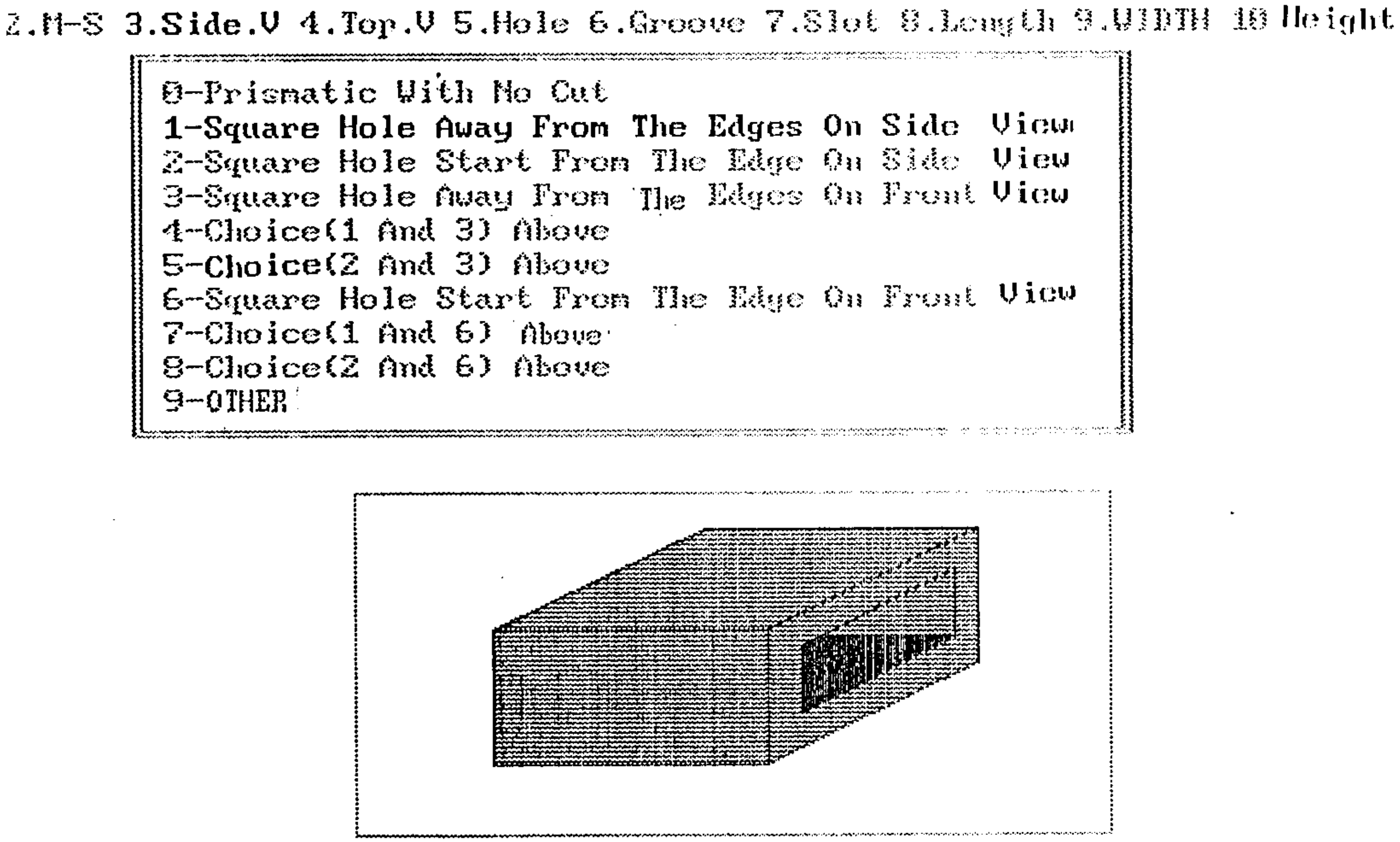
0-RECTANGULAR
1-RECTANGULAR BAR
2-PLATE
3-SHEET
4-SQUARE BAR
5-HEXAGONAL BAR
6-ROUND BAR
7-TUBE BAR
8-DISK
9-OTHER



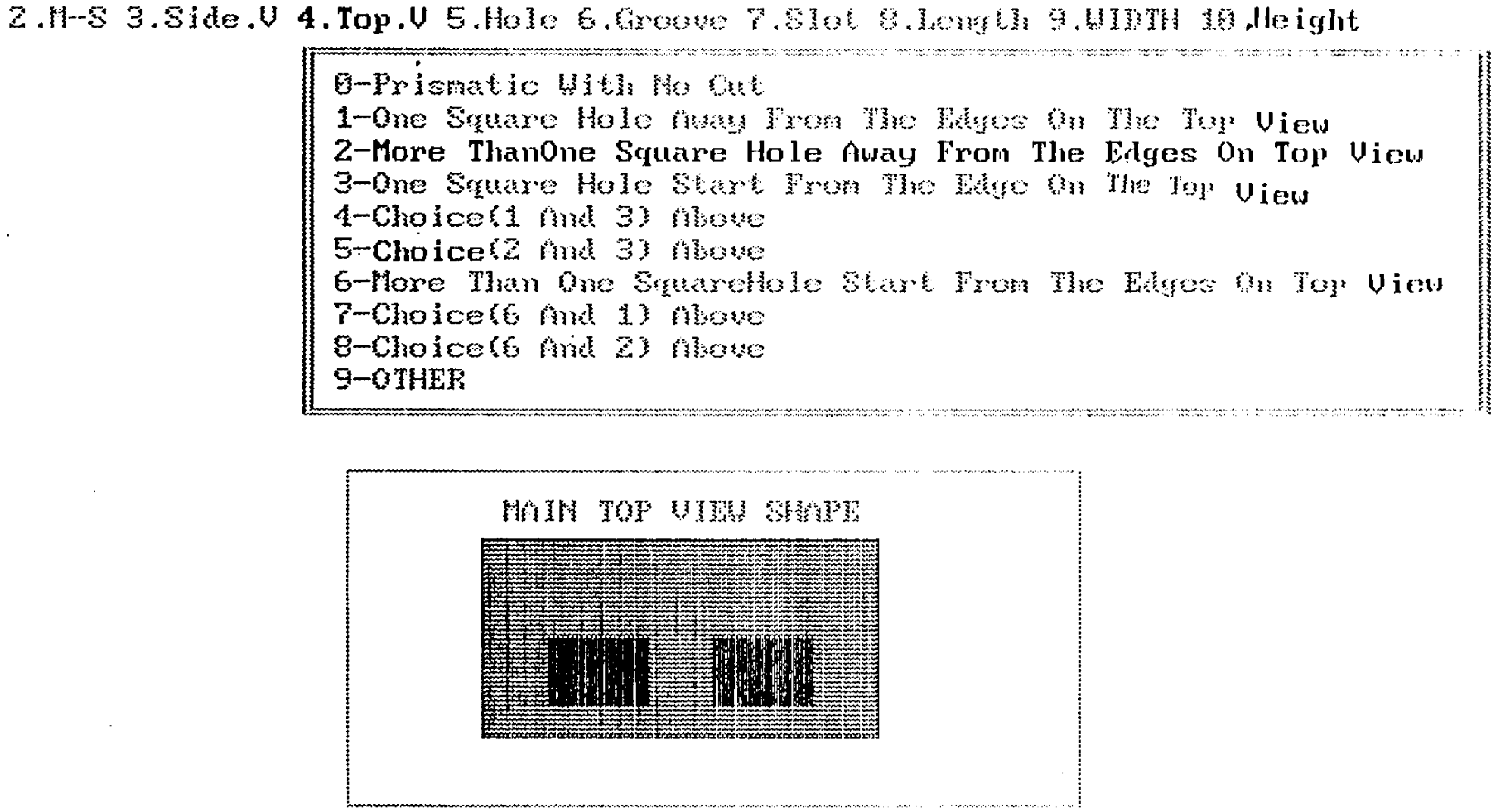


```
2.M-S 3.Side.V 4.Top.V 5.Hole 6.Groove 7.Slot 8.Length 9.WIDTH 10 Height
0-Prismatic Part With No Cut Main Shape
1-Multiconvex Front View  Main Shape Along ALL The Part Length
2-Multicocave Front View  Main Shape Along ALL The Part Length
3-Multivariable Front View Main Shape Along ALL The Part Length
4-Multiconical Front View Main Shape Along ALL The Part Length
5-Multiconvex Front View Main Shape Along PART Of The Part Length
6-Multicocave Front View Main Shape Along PART Of The Part Length
7-Multivariable Front View Main Shape Along PART Of The Part Length
8-Multiconical Front View Main Shape Along PART Of The Part Length
9- OTHER
```

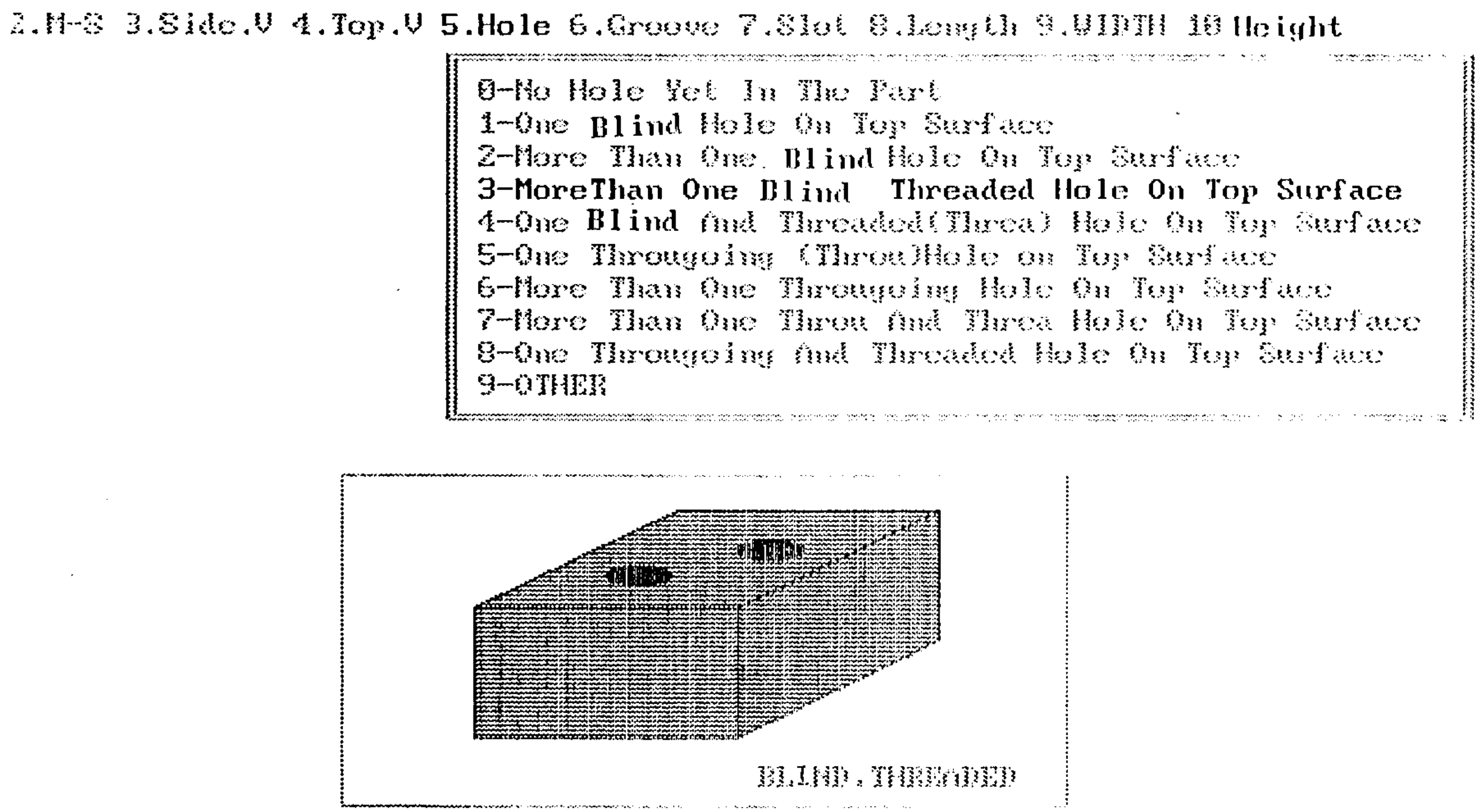
Main Front View Shape



```
2.M-S 3.Side.V 4.Top.V 5.Hole 6.Groove 7.Slot 8.Length 9.WIDTH 10 Height
0-Prismatic With No Cut
1-Square Hole Away From The Edges On Side  View
2-Square Hole Start From The Edge On Side  View
3-Square Hole Away From The Edges On Front View
4-Choice(1 And 3) Above
5-Choice(2 And 3) Above
6-Square Hole Start From The Edge On Front View
7-Choice(1 And 6) Above
8-Choice(2 And 6) Above
9-OTHER
```

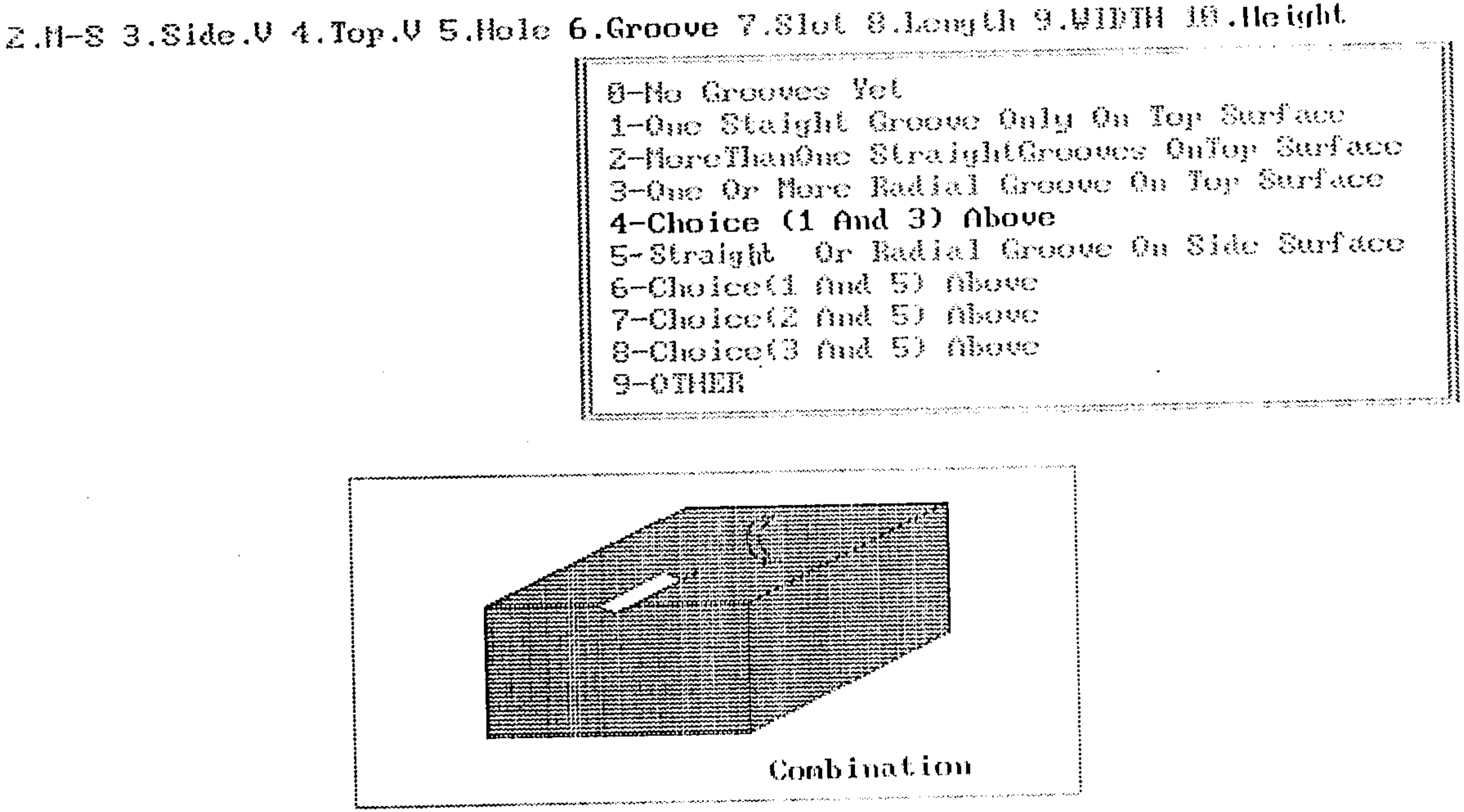


```
2.M-S 3.Side.V 4.Top.V 5.Hole 6.Groove 7.Slot 8.Length 9.WIDTH 10.Height
0-Prismatic With No Cut
1-One Square Hole Away From The Edges On The Top View
2-More ThanOne Square Hole Away From The Edges On Top View
3-One Square Hole Start From The Edge On The Top View
4-Choice(1 And 3) Above
5-Choice(2 And 3) Above
6-More Than One SquareHole Start From The Edges On Top View
7-Choice(6 And 1) Above
8-Choice(6 And 2) Above
9-OTHER
```



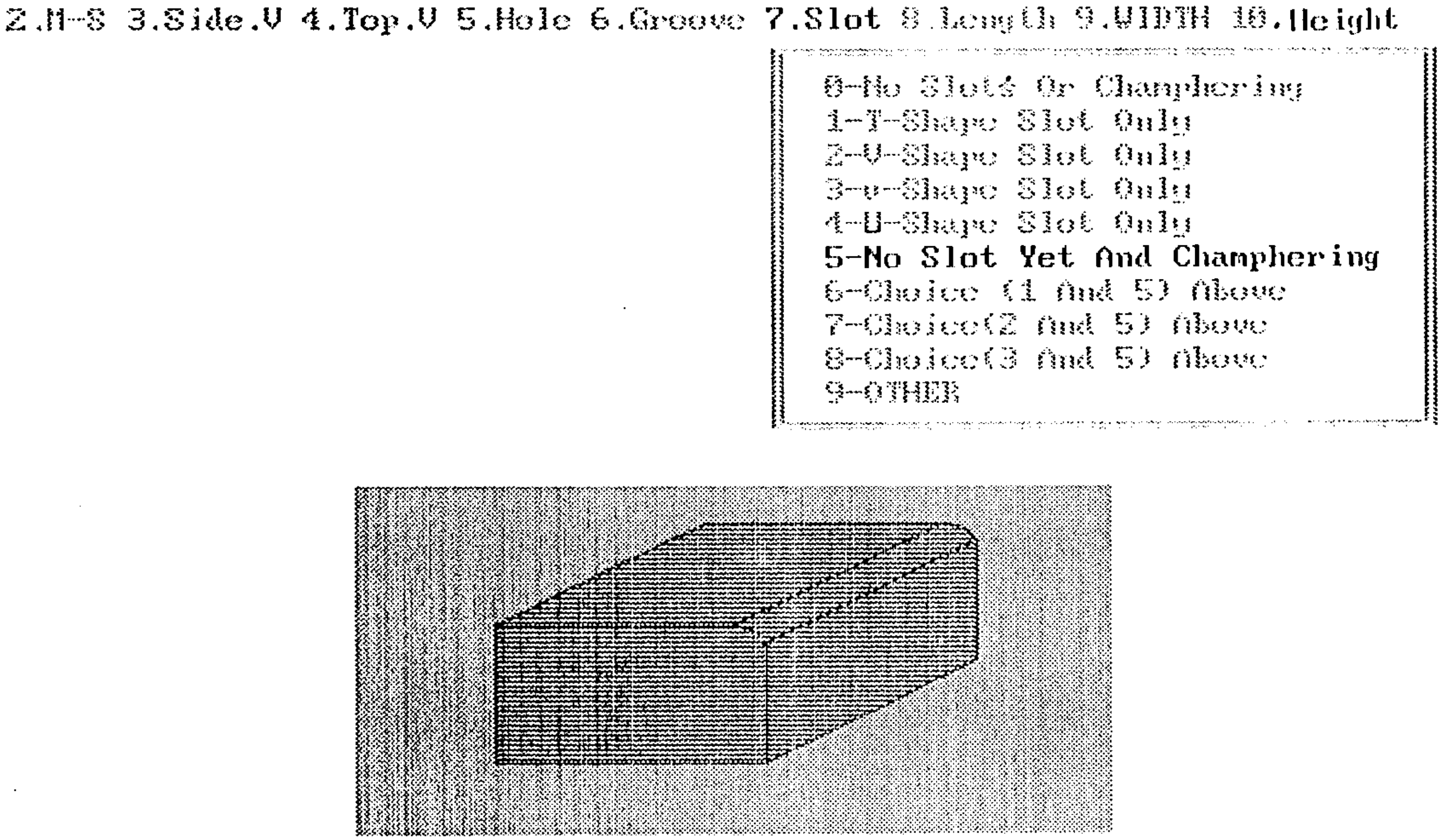
2.M-S 3.Side.V 4.Top.V 5.Hole 6.Groove 7.Slot 8.Length 9.WIDTH 10 Height

0-No Hole Yet In The Part
1-One Blind Hole On Top Surface
2-More Than One Blind Hole On Top Surface
**3-MoreThan One Blind  Threaded Hole On Top Surface**
4-One Blind And Threaded(Threa) Hole On Top Surface
5-One Throughing (Throu)Hole on Top Surface
6-More Than One Throughing Hole On Top Surface
7-More Than One Throu And Threa Hole On Top Surface
8-One Throughing And Threaded Hole On Top Surface
9-OTHER



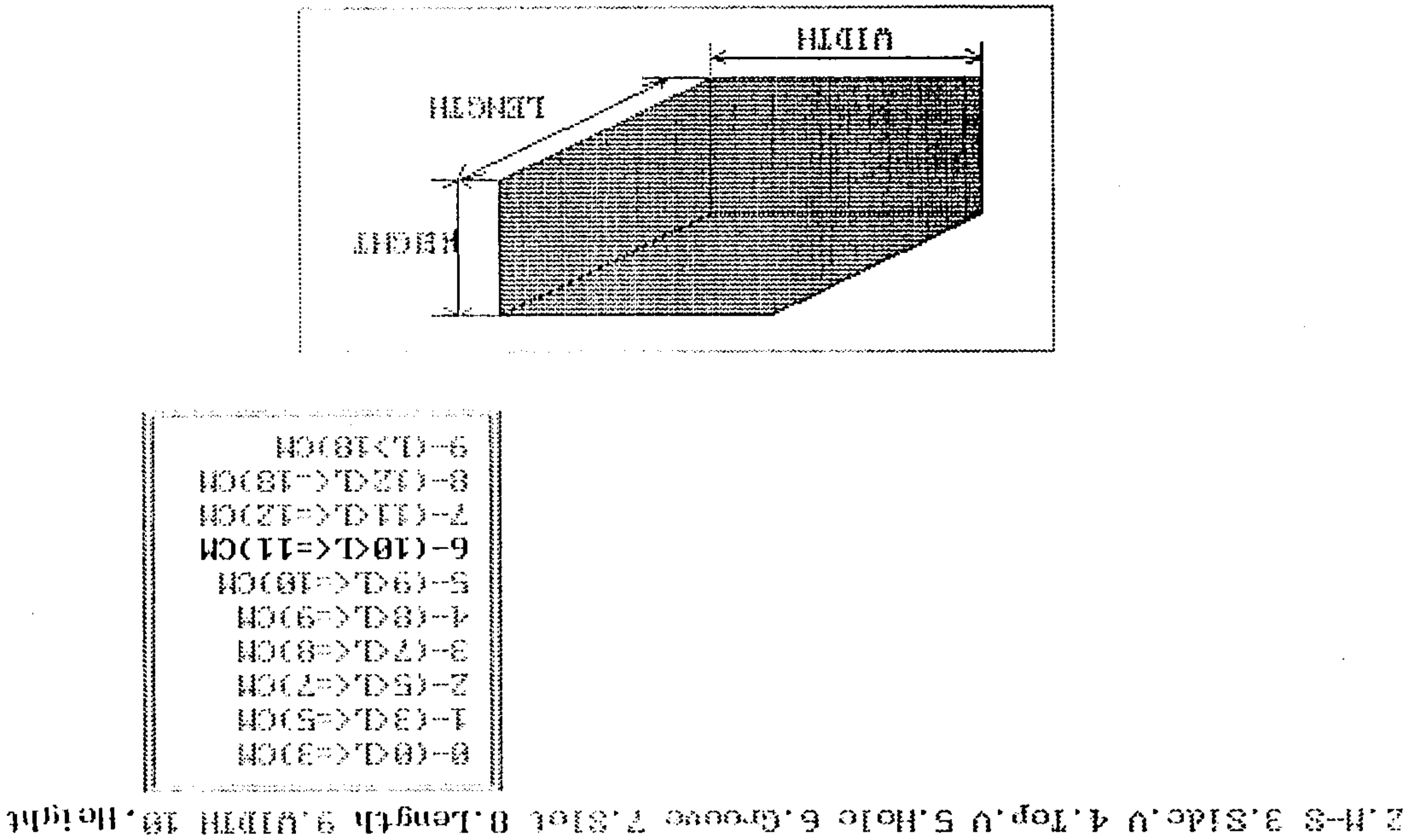
2.H-S 3.Side.V 4.Top.V 5.Hole 6.Groove 7.Slot 8.Length 9.WIDTH 10.Height

0-No Grooves Yet
1-One Staight Groove Only On Top Surface
2-MoreThanOne StraightGrooves OnTop Surface
3-One Or More Radial Groove On Top Surface
**4-Choice (1 And 3) Above**
5-Straight  Or Radial Groove On Side Surface
6-Choice(1 And 5) Above
7-Choice(2 And 5) Above
8-Choice(3 And 5) Above
9-OTHER



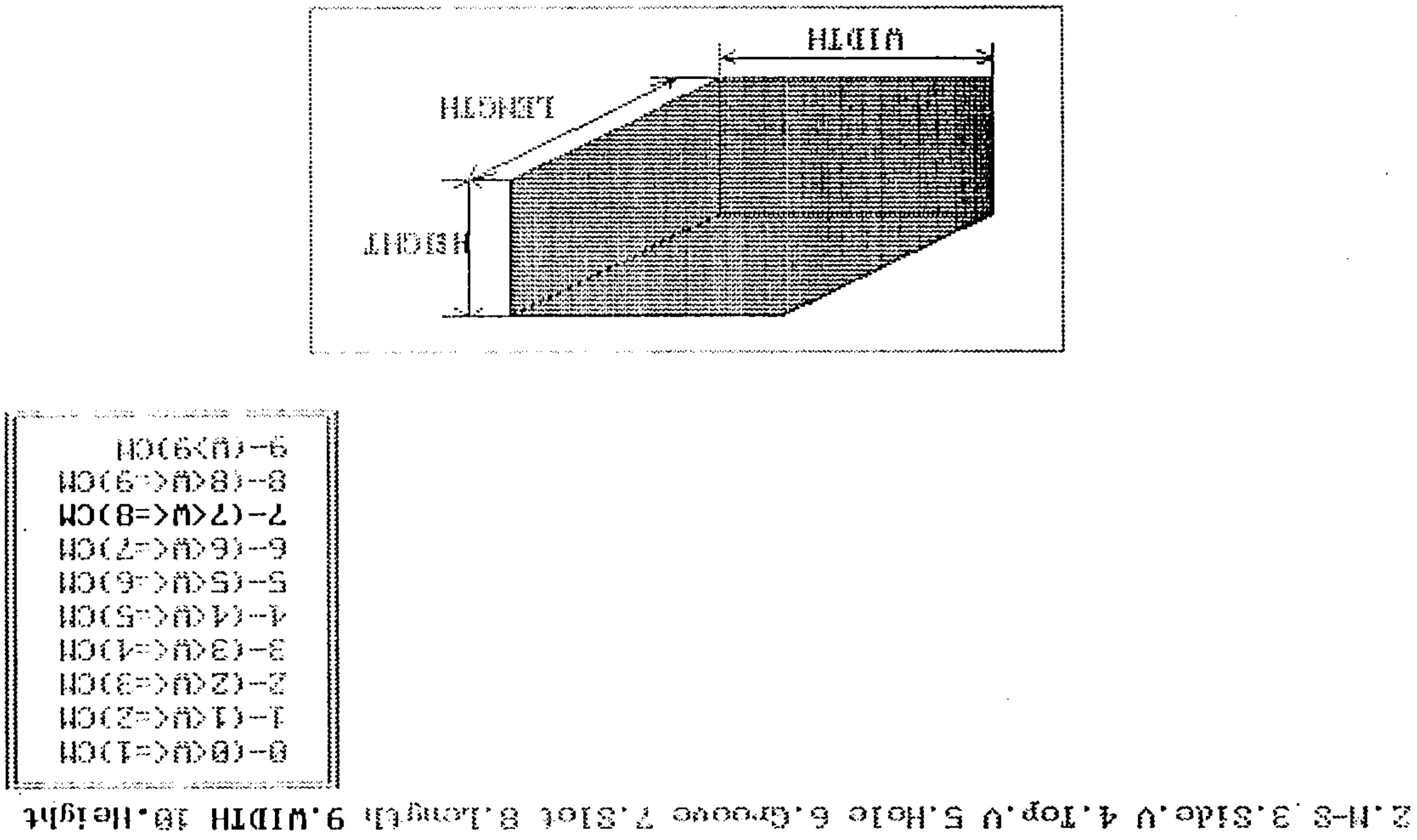
2.M-S 3.Side.V 4.Top.V 5.Hole 6.Groove **7.Slot** 8.Length 9.WIDTH 10.Height

0-No Slots Or Champhering
1-T-Shape Slot Only
2-V-Shape Slot Only
3-v-Shape Slot Only
4-U-Shape Slot Only
**5-No Slot Yet And Champhering**
6-Choice (1 And 5) Above
7-Choice(2 And 5) Above
8-Choice(3 And 5) Above
9-OTHER



0-(0<L<=3)CM
1-(3<L<=5)CM
2-(5<L<=7)CM
3-(7<L<=8)CM
4-(8<L<=9)CM
5-(9<L<=10)CM
**6-(10<L<=11)CM**
7-(11<L<=12)CM
8-(12<L<=18)CM
9-(L>18)CM

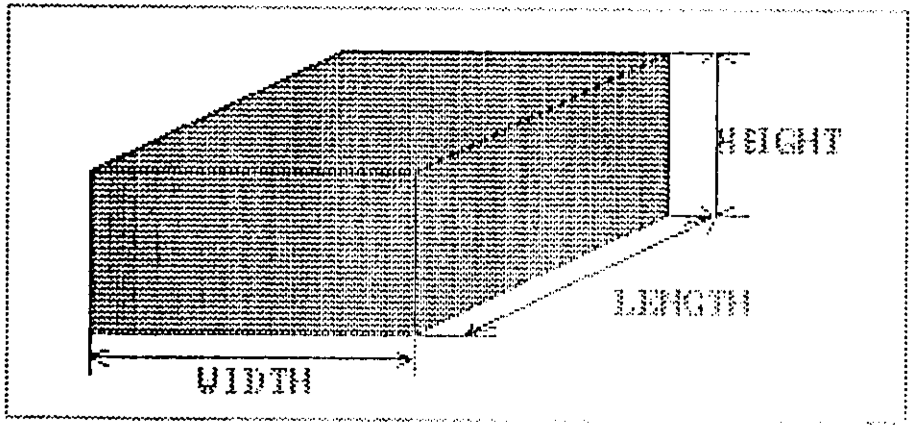
2.H-S 3.Side.V 4.Top.V 5.Hole 6.Groove 7.Slot 8.Length 9.WIDTH 10.Height



0-(0<W<=1)CM
1-(1<W<=2)CM
2-(2<W<=3)CM
3-(3<W<=4)CM
4-(4<W<=5)CM
5-(5<W<=6)CM
6-(6<W<=7)CM
**7-(7<W<=8)CM**
8-(8<W<=9)CM
9-(W>9)CM

2.M-8 3.Side.V 4.Top.V 5.Hole 6.Groove 7.Slot 8.Length **9.WIDTH** 10.Height

```
2.H-S 3.Side.V 4.Top.V 5.Hole 6.Groove 7.Slot 8.Length 9.WIDTH 10.Height
0-(0-0.5)CM
1-(0.5-1)CM
2-(1-1.5)CM
3-(1.5-2)CM
4-(2-2.5)CM
5-(2.5-3)CM
6-(3-3.5)CM
7-(3.5-4)CM
8-(4-4.5)CM
9-(H>4.5)CM
```



```
INPUT YOUR FILE NAME? xz.dat
CIM LAB CAN NOT PRODUCE THIS PART BECAUSE OF FEATURE SHAPE CONSTRAINT
```

# CHAPTER SEVEN

# CONCLUSION

## 7.1 Conclusions

1. The developed CAPP system has been designed with the goal of being used in the (CIM-Lab) environment . It has successfully indicated that the concept is realizable .The system is able to create a sound detailed process plan. It has the ability to create a process sequence automatically and correctly.

2. Feature recognition is difficult not only because there is no general theory of geometric reasoning , but also because the deifinitions of features are imprecise although a few features , such as a hole , straight slot , curved slot etc., are generally understood , the defintion of features normally are vague.

## 7.2 Recommendations

1. Based on the language (Quick Basic) used in building the CAPP program which is numerical based language , and since building CAPP systems needs symbol manipulation it is recommended to use a symbol manipulation language like LISP or PROLOG language , etc .

2- This CAPP system is recommended to be used by undergraduate students to familiriaze them with CIM environment. To achieve this the system should be connected with the(CIM-Lab) .

3-Similar CAPP system is recommeded to be used by shops who have CNC machines in their own factories .

### 7.3 Further Research

1. New development can be integrated with the CAPP software package that has been developed throughout this study , such as; increasing the number of tools that can be used other than those available in the CIM-Lab, applications to other types of work pieces materials and more manufacturing processes .

2. The use of other design representation methods such as ; Constructive Solid Geometry (CSG) or CAD modeling , to develop CAPP system .

3. Expanding the present CAPP system to Generate CNC programs for all the parts that can be produced in the CIM-Lab .

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# APPENDICES

APPENDEX (A) : Existing CAPP System .

APPENDEX (B) : Illustration Of The Form Geometry Symbols.

# APPENDEX (A) : Existing CAPP System.

## APPENDEX (A) : Existing CAPP system .

Rot=rotational pris-prismatic *

| systems | part shapes | approaches | characteristics & commercial situation | Programming Languages | Reference & time | Developers |
|---|---|---|---|---|---|---|
| (1)ABTOTPZK | Rot | Variant | | | Eversheim &<br>Shulz(1985) | CIOMB(Bulgaria) |
| (2) ACAPS | Rot | Semi - Generative | Part family coding | FORTRAN IV | 1982<br>Emerson & Ham<br>1982 | Westinghouse Elec. Co(USA) |
| (3) ACPLAN | ALL | Variant &Genrative | $ | | Appllo Computer catalogue (1986) | American channels (USA) |
| (4) ACPSAP | | Generative | KK3 .coding scheme | | Wang & Wysk (1986) | Penn StateU.(USA) |
| (5)ACUDATA/ UNIVATION | Rot & Pris | Variant | Part number need | | 1978<br>Chang & Wysk<br>1985 | Allis Chalmers(U.S.A) |
| (6) AGFPO | Forming process | Generative | Knowledge- based | PROLOG | 1985<br>Chryssolouris & Wright(1986) | Eshel et al (USA) |
| (7) AIMSI | Rot | Generative | Intergrated with CAD CAM | | Wang & Wysk (1988) | State U.of New York (USA) |
| (8) AMPS | Sheet. | Generative | Expert system<br>Intergrated with CAD modelling | Common-LISP<br>C & LISP | 1988<br>Inui et al (1987)<br>1988 | U.of Tokyo (Jopan)<br>Purdue U.(USA) |
| (9) AMPS | Pris | Generative | Expert system<br>Developed for an integrated system QTC | | Change et al (1988)<br>Eversheim & Schulz(1985) | Gebr.honsberg (W.Germany) |
| (10) APLAN | Rot & Pris | Generative | | | Haas & Chang (1987) | Ge & LA(USA) |
| (11)APP | All | Generative | $ interfaced with CAD | FORTRAN IV | 1977<br>Wysk(1977) | Purdue U.(USA) |
| (12) APPAS | Milling & drilling | Generative | Surface Modelling Language (COFORM) used | | | |

| systems | part shapes | approaches | characteristics & commercial situation | Programming Languages | Reference & time | Developers |
|---|---|---|---|---|---|---|
| (13) APS | | Variant & Generative | | | Moseng(1984) | VTL.WZL<br>(W.Germany) |
| (14) AUSPLAN | Rct | Semi - Generative | based on the DCLASS system | FORTRAN 77 | 1987<br>Lin & Bedworth (1988) | Arizona State U (USA) |
| (15) AUTAP | Rot & Sheet | Generative | $ interfaced with CAD | | 1975<br>Eversheim et al (1980) | WZL(Germany) |
| (16)AUTAP-NC | Rot & Sheet | Generative | $part program interfaced with CAD | | 1978<br>Eversheim et al (1980).Eversheim & Holz(1982) | WZL(W.Germany)<br>RWTH |
| (17) AUTAP Prism | Pris | Generative | | | Eversheim & Schulz(1985) | WZL(W.Germany) |
| (18) AUTOCAP | Rot | Variant | | BASIC | 1977<br>Wright et al(1987) | UMIST(UK) |
| (19) AUTODAK | Rot | Generative | for single &multiple spindle automatic lashes | | 1976<br>Weill et al (1982) | IPK(W.Germany) |
| (20) AUTODYN Arbeitspl | ROT | | $ | | Evershem & Schulz(1985) | Hoff.& Pariner (W.Germany) |
| (21) AUTGAM | | | | | Weill et al(1982) | CETIM(France) |
| (22) AUTOPLAN | Rot | Variant& Generative | $Special language used for input | FORTRAN IV | 1980<br>Wolfe(1985) | MRA(USA) |
| (23) AUTOPRO GRAMMER | All | Variant | $ | | Evershem & Schulz(1985) | Oerlikon-Boeh (W.Germany) |
| (24) AUTOPROS | | Variant | $ | | 1966<br>oseng(1984) | NAKK(Norway) |

| systems | part shaprs | approaches | characteristics & commercial situation | Programming Languages | Reference & time | Developers |
|---|---|---|---|---|---|---|
| (25) BGCAP | ALL | Variant | Shaped surface input | BASIC | Jiang & Xu(1987) | BIME(China) |
| (26) BHCAP | Rot | Variant | Shape surface input | BASIC | Jiang & Xu(198 ) | BIAA(china) |
| (27) BITCAPP | Rot | Semi-Generative | Primitive approach input | FORTRAN | Jiang & Xu(1987) | BIT(China) |
| (28)BPT Atbeitspl | Sheet | | | | Fversheim & Schul/(1985) | VEB Indus.KMS (W.Germany) |
| (29) CACAPSS | Rot | Variant | GTcode & shped surface input | BASIC | Jiang & Xu(1987) | Sheryong No3 Machine Tool Works (China) |
| (30) CADCAM | Hole making | Generative | Extension of APPAS | FORTRAN | 1980<br>Chang & Wysk (1985) | VIP & Su(USA) |
| (31) CAOS | Rot | Generative | for single-spindle automatic lathe | FORTRAN | Huang et al (1986) | North Westren Polytechnical U (China) |
| (32) CAP | Sheet | Variant | Part number needed | | 1963<br>Chang & Wysk (1985) | Lockheed-Georgia (USA) |
| (33) CAPF | All | Variant | Interfaced with CAD | | Haas & Chang (1987) | Carrett Turbine(USA) |
| (34) CAPES | Pris | Generative | Expert system CAD | C & Franz LISB | 1988<br>Fujita et al (1988) | Mitsubishi El Co. (Japan) |
| (35) CAPES | ALL | Variant | $ | | Eversheim & Schulz(1985) | Methods Workshop (UK) |
| (36) CAPEX | ALL | Variant | | | Eversheim & Schulz(1985) | EXAPT (W .Germany) |

| systems | part shapes | approaches | characteristics & commercial situation | Programming Languages | Reference & time | Developers |
|---|---|---|---|---|---|---|
| (49) C-PLAN | All | Variant | $ |  | CAD Centre Ltd (1987) | CAD Centre(UK) |
| (50) CPPP | Rot | Generative | $COPPI language<br>used for interactive |  | 1978<br>Nau & Chang 1983 | UTRC(USA) |
| (51) CRUNCH | All Assemb | Variant & Generative |  |  | Haas & Chang (1987) | Sperry Co(USA) |
| (52) CSD & AMI |  |  | $ |  | Special report(1987) | Rath & Serang Co. Lexington(USA) |
| (53) CUTDATA | Rot & Pris | Variant |  |  | special report(1987) | MRAT(USA) |
| (54)CUTPLAN | Rot & Pris | Variant | $ Only process determination |  | Tulkoff(1987) | MRAT(USA) |
| (55) CUTTECH | Rot | Gernerative | $ Knwoledge based for operation planning |  | 1984<br>Darkocy & Zdeblick(1984) | MRAT(USA) |
| (56) CWOS-GPP | Rot & Pris | Generative |  |  | Hass & Chang (1987) | Texas Instrument (USA) |
| (57) DAPP | Rot & Pris | Variant & Generative | Interfaced with CAD |  | Haas & Chang (1987) | NBS(USA) |
| (58) DATASAAB | All | Variant |  |  | Eversheim & Schulz(1985) | Saab Scania (Sweden) |
| (59) DCLASS | All | Variant & Gernerative | $ Tree structure system | FORTRAN 77 | Allen & Smith (1980)Allen(1987)<br>DCLASS manual (1985) | B.Y.U(USA) |
| (60) DISAP | All | Generative | $Extension AUTAP |  | 1981<br>Weill(1982) | WZI(W.Germany) |

| systems | part shapes | approaches | characteristics & commercial situation | Programming Language | Reference 7 time | Developers |
|---|---|---|---|---|---|---|
| (61) DOPS | Drilling only | Generative | Interface with 3D-COPMAC | FORTRAN<br>LISP | Major & Grottke (1987) | IPK(W.Germany) |
| (62) DREKAL | Rot | Generative | | | 1981<br>Weill(1982) | IFSW.U.of Hannover(W. Germany). |
| (63) EASE | | Variant | $ | | Special report(1987) | Ease(Co.Calif(USA) |
| (64) EMAPS | All | Generative | $Expert system | | Tipnis(1987) | Tipnis Co (USA) |
| (65) EXAPT | Rot & Pris | Variant | $ NC program | | 1964<br>Budde(1973) | EXAPT-Verein (USA) |
| (66) EXCAP | Rot | Generative | Expert System Derived from AUTOCAP | PROLOG | 1981<br>Wrigth et al(1987)<br>Davies & Datbyshire(1984) | UMIST(UK) |
| (67) EXCAPP | Rot | Generative | Expert System | PROLOG | 1988<br>Du & Lia(1988) | BIAA(China) |
| (68) FAUN | | Variant | Nc programming complex surface | | Eversheim & Schulz(1985) | TU Budapest (Hungary) |
| (69) FFS | | Variant | Nc programming Sculpured surcface | | Eversheim & Schulz(1985) | Computer & Auto inst.(Hungary) |
| (70) HARI | Holes only | Generative | Expert sysstem Rule-based | MACLISP | 1981·<br>Descotte & Latcombe(1981) | Grenoble U.(France) |
| (71) GFCAPP PLUS | All | Variant | $ | | Wolfe(1985) | GE Co(USA) |
| (72) GEMOS | | Generative | Knowledge-based based on CUTTFCH | | 1986<br>Schaffer(1986) | Mrat &GE Co(USA)<br>USA |

| systems | part shapes | approaches | characteristics & commercial situation | Programming Language | Reference 7 time | Developers |
|---|---|---|---|---|---|---|
| (73) GFNLAN | All | Variant & Generative | $ Part family code used | | Talkoff (1987 a.b) | Lockheed-Georgia (USA) |
| (74) GENTECH | Rot | Variant | | | Eversheim & Schulz(1985) | CIOM(Bulgaria) |
| (75) GETURE | All | Variant | $ | | 1975<br>Chang & Wysk (1985) | GE(USA) |
| (76) GIPPS | Pris | Generative | Shell.interface with CAD | | Kborami et al (1988) | U.of Strathclyde (UK) |
| (77) GLEDA FT.SZ | All | Variant | | | Eversheim & Schulz(1985) | Inst.of Tech. (Hungary) |
| (78) GLIM | Rot | Variant | | | Halevi & Weill (1980)Weill(1982) | ITT(Israell) |
| (79) Gt.CAPP | All | Variant | Part family numbers used | | Strochmeier | Rockwell Inc(USA) |
| (80) GTIPROG-E | Rot | Variant | | | Eversheim & Schulz(1985) | Inst.of Tech. (Hungary) |
| (81)GTIPROG.U & FM | Pris & Sheet | Variant | | | Eversheim& Schulz(1985) | Inst of Tech (Hungary) |
| (82) HAL.TI FT.AZ | Rot | | | | Everheim & Schulz(1985) | Hal-Roh ltd Israel |
| (83) HICLASS | Pris | Generative | $ Expert system interfaced with CAD | C | 1982<br>LAU (1985) | Huges Aircraft Cal (USA) |
| (84) HIMAPP | Rot | Generative | Artificial Intelligence | INTER-LISP | Berenn(1986) | USC (USA) |

| systems | part shapes | approaches | characteristics & commercial situation | Programming Languages | Reference & time | Developers |
|---|---|---|---|---|---|---|
| (85) HNDXCAPP | Pris | Variant | Shaped surface input | BASIC | Jiang & Xu(1987) | Human U.(China) |
| (86) ICAPP | Pris | Generative | Interfaced with CAD | FORTRAN | 1981<br>Wright et al(1987) | UMIST(UK) |
| (87) INTELLE CAPP | All | Generative | $ Combines expert system shell.GT.& related database | | Eskiecioglu & Davies(1983)<br>Tulkoff(1987)al | Cimtelligence Corporation (USA) |
| (88) IPROS | Rot | Variant | COMPAC is used for input | | 1984<br>Moseng(1984)<br>Rasch(1987) | APS(Ger-Nor) |
| (89) 12CAPP | All | Variant | GT code & primitive aproach input | BASIC | Jiang & Xu(1987) | Jinan No.2 Machine Tool Works (China) |
| (90) KAPPS | Rot& Pris | Generative | Know-how based expert system | Common LISP | 1986<br>Iwata& Fukuda (1986.1987) | Kob-U.(Japan) |
| (91) LOCAM | | Generative | $ | | Logan(1981)<br>Tulkoff(1987a) | Logan Asso(USA) |
| (92)MASTER PARTS LIST | All | Variant | | | Hass & Chang (1987) | General Dynamics Co(USA) |
| (93)MAYCAPP | | Variant | $Based on DCLASS | FORTRAN 77 | (1982)<br>Zandin(1982) | Maynard H.B (USA) |
| (94) MIAPP | Rot & Pris | Variant | $Based on DCLASS | | Wolfe(1985)<br>1979<br>Schalffer(1980) | OIR(USA) |
| (95) MICAPP | Rot | Variant | | M-BASIC | Sundaram & Cheng(1986) | Tennessee TU(USA) |
| (96) MICON | Rot & Pris | Variant | | | Eversheim & Schulz(1985) | TU Budapest (Hungary) |

| systems | part shapes | approaches | characteristics & commercial situation | Programming Languages | Reference & time | Developers |
|---|---|---|---|---|---|---|
| (97) MICRO CAPP | Rot | Variant | KK-3 coding scheme used | | Wang & Wysk<br>1986 | Penn State U.(USA) |
| (98) MICRO GEPPS | Rot | Semi Generative | | | Wang & Wysk<br>(1986) | Penn State U.(USA) |
| (99) MICRO- PLANN | Rot | Generative | Knowledge- based interfaced with CAD | | Philips et al.(1987) | UOD Ill. at chicago (USA) |
| (100) MIPLAN | Rot & Pris | Variant | $ Based on MICLASS | | 1976<br>Houtzeel (1976)<br>Lesko(1983) | OIR & GE Co (USA) |
| (101)MITURN | Rot | Variant | $ | | 1971<br>Koloe (1971)<br>Bockholts et al<br>1973 | TNO & OIR<br>(Netheri(USA) |
| (102)MOPS | Pris | Variant | Machining centre operation planning | FORTRAN | Pinte(1987) | WTCM CRIT<br>(Belgium) |
| (103)MSA | Rot | Variant | $ | | HAAS & Chang<br>1987 | MSA(USA) |
| (104)MULTI- CAPPH | All · | Variant | $Based on MICLASS | | 1986<br>OIR Procuct News-<br>Advance (1987) OIR<br>Group Technology<br>(1986) | OIR(USA) |
| (105) NITZLCP | Gears | Variant | GT code & shaped surface input | BASIC | Jiang & Xu(1987) | NIT(China) |
| (106) OLPS | | Variant | | | 1975<br>Tulkoff(1981) | Boeing Co(USA) |
| (107) OMS | All | Variant | Interfaced with CAD | | Haas & Chang<br>1987 | Cummins Engine (USA) |
| (108) OPPX | Rot | Generative | Expert system | PROLOG | 1986<br>Gams et al (1986) | FME Ljubljana (Yugoslavia) |

| systems | part shapes | approaches | characteristics & commercial situation | Programming Languages | Reference & time | Developers |
|---|---|---|---|---|---|---|
| (109) PCCAPP | All | Variant | GT code input | BASIC | Jiag & Xu(1987) | JIT(China) |
| (110)PICAP | Rot | Generative | Interfaced with COAST | PROLOG | 1986<br>Santochi & Giusti 1986 | Pisa U.(Italy) |
| (111) PI-CAPP | All | Variant | $ |  | 1980<br>Chang & Wysk (1985) | Planning Inst .(USA) |
| (112)POPS | Sheet | Variant | Punching operation planning | FORTRAN 77 | Pinte91987) | WTCM/CRIF (Belgium) |
| (113)POPS | Mech Assemb | Variant |  |  | Haas & Chang (1987) | Hughes Aircraft (USA) |
| (114)POPULAR | Rot | Variant & Generative | Interfaced with CAD |  | Sakamoto et al (1987) | KOMATSU Ltd (Japan) |
| (115) PRIKAL | Pris | Generative |  |  | Eversheim& Schulz (1985) | IFSW U.of Hannover (W.Germany) |
| (116)PROPLAN | Rot & Sheet |  |  |  | Marshall(1985) | PERA(UK) |
| (117) PROTEMPS |  |  |  |  | Weill(1982) | ADEPA(France) |
| (118) P.S system | All | Generative | $ |  | Eversheim & schulz(1985) | PS-Technik (W.Germany) |
| (119) PWA Planner | Printed Wiring board | Generative | Expert System | PROLOG | Kumara et al(1986) | Purdue U.(USA) |
| (120) (P&WA) | Pris | Variant | $ |  | 1977<br>Nilson(1977) | Pratt & Whitney Aircraft Co (USA) |

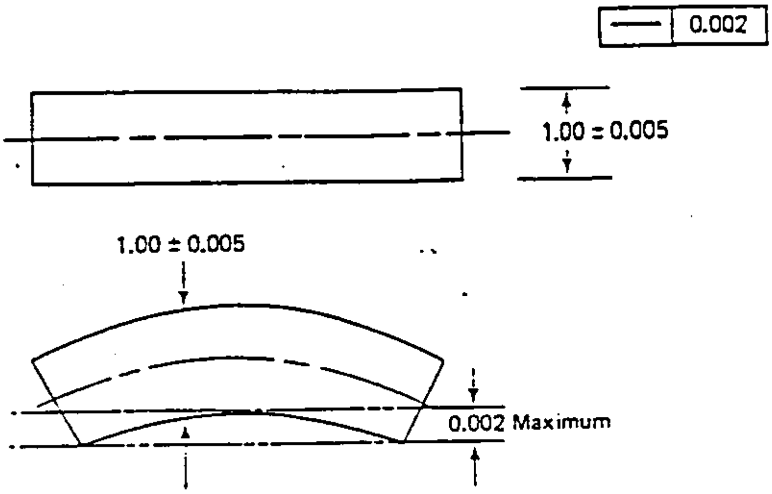
| systems | part shapes | approaches | characteristics & commercial situation | Programming Languages | Reference &time | Developers |
|---|---|---|---|---|---|---|
| (121) RATIBERT | All | Variant | | | Evershiem & Schulz (1985) | TH Otto V. Magdeburg(W. Germany) |
| (122) ROUND | Rot | Generative | | FORTRAN | 1986<br>Houten(1986) | Twente U.of Tech. (Netherland) |
| (123)RPO CAM | Rot | Variant | $Based on Autoplan | FORTRAN | 1980<br>Volgel & Dawson (1980) | MART & GE CO (USA) |
| (124) SAGT | | Variant | | | Chang & Wysk (1983) | Purdue U(USA) |
| (125) SAPT | Rot & Pris | Generative | Based on hybrid concept of GT | PROLOG-86 | 1986<br>Milacic et al(1987) | Beograd U (Yugoslavia) |
| (126) SIB | Sheet | Generative | | | 1982<br>Weill et al(1982) | Siemens AG (W.Germany) |
| (127) SIPP | | Generative | Expert system Semi intellegent frame base- | PROLOG | Nau & Chag (1985) | U.of Maryland (USA) |
| (128) SIPPS | All | Generative | Knowledge based | FORTRAN 77 | Liu & Allen (1986) | Southampton U (UK) |
| (129) SIPS | | Generative | Successor to SIPP semi- intelligent | LISP | Nau & Gray (1986) | U of Maryland (USA) |
| (130) SISPA | Rot | Generative | $ Based on SIB | | Luce(1987)<br>Weill et al(1982) | Siemens AG (W.Germany) |
| (131) STAR | All | Variant | | | Haas & Chang (1987) | Grumman Co(USA) |
| (132) SOPS | All | Variant | Squence of operation planning | FORTRAN 77 | Pinte(1987) | WTCM/CR17 (Belgium) |

| systems | part shapes | approaches | characteristics & commercial situation | Programming Languages | Reference & time | Developers |
|---|---|---|---|---|---|---|
| **(133)** system AV | All | Variant | | | Eversheim & Schulz(1985) | Microdata (W.Germany) |
| **(134)** system RW | All | Variant | | | Evershiem& Schulz(1985) | Weber Daten (W,Germay) |
| **(135)** TIPPS | Miling & Driling | Generative | Knowledege based developed from APPAS & CADCAM interfaced with CAD | | Chang & Wysk (1983.1985) | VPI & SU(USA) |
| **(136)** TOHCAP | All | Variant | $ GT code & shaped surface input | Basic | 1982 Zhang et al(1984) | Tongii U(China) |
| **(137)** TOM | Rot | Generative | Expert system interfaced with COMPAC & EXAPT | PASCAL | 1982 Matsushima et al (1982) | U.of Tokyo (Japan) |
| **(138)**TOPS | Rot | Vraiant | Based on DCLASS | FORTRAN77 | Pinte(1987) | WTCM/CRIF |
| **(139)**TRAUPROG-T | Rot. | Variant | | | Eversheim & Schulz(1985) | Inst of Tech (Hungary) |
| **(140)**TTR-S | Rot | Variant | | FORTRAN | 1982 Hoffmann & Garzo(1982) | Lang Eng Works (Hungary) |
| **(141)** TURBO-CAPP | Rot | Generative | Kowledge based interfaced with CAD | PROLOG | 1987 Wang & Wysk (1987 a.b) | Penn U.(USA) |
| **(142)** TURN2 | Rot & Pris | Variant | $ | | Special report (1987) | MICAPP Inc(USA) |
| **(143)**VARAGEN | All | Variant | | | Eversheim & Schulz(1985) | CRIF.K U.(Belgium) |
| **(144)** VERDI | Rot & Pris | Generative | $ | | Eversheim & Schulz(1985) | IPA-TU Stuttgart (W.Germany) |

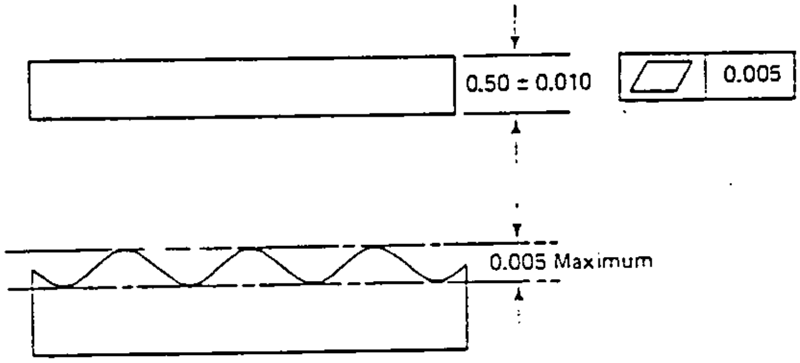
| systems | part shapes | approaches | characteristics & commercial situation | Programming Languages | Reference & time | Developers |
|---|---|---|---|---|---|---|
| (145)WICAPP | All | Variant | $ Based on DCLASS | FORTRAN 77 | 1982<br>Schwartz & Shreve 1982 | Westinghouse (USA) |
| (146) XMAPP | Pris | Generative | Expert system interfaced with CAD Modelling | Common LISP | 1988<br>Inui et al(1988) | U.of Tokyo(Japan) |
| (147) XPLAN | All | Generative | Expert system based on DCLASS | FORTRAN 77 | 1984<br>Lenau & Alting (1986)Alting et al (1988) | Tech U.of DK (Denmark) |
| (148) XPLANE | Pris | Generative | Knowledge-based | FORTRAN 77 | (1986)<br>Erve & Kals (1986) | Twente U.of Tech. (Netherlands) |
| (149) XPLAN -R | Rot | Generative | Expert system based on DCLASS | FORTRAN 77 | (1987)<br>Zhang(1987) | Tech U.ofDK (Denmark) |
| (150) XPS-I | All | Variant & Generative | $COPPL Used | FORTRAN 77 | 1982<br>Sack jr.(1983) Gropelti & Semeraro(1986) | UTRC & CAM-I (USA) |
| (151)XPS-F |  | Generative | Expert System based on GRAI |  | Chryssolouris & Wright(1986) | UTRC(USA) |
| (152)ZCAPPS | All | Variant & Generative | Interfaced with CAD |  | Haas & Chang (1987) | Zeus data Systems (USA) |
| (153) | Pris | Generative | Interfaced with CAD modelling |  | 1988<br>Kishinami et al | Hokkaido U (Japan) |
| (154) | Pris | Generative | Knowledge-based | C-PROLOG | 1988<br>Mill & Spraggett (1984.1985) | Coventry Polytechnic (UK) |
| (155) | Pris | Generative | Expert system interfaced with CAD | Common LISP | 1988<br>Joshi et al(1988) | Purdue U.(USA) |
| (156) | Rot | Generative | Employed in FMS |  | 1988<br>Kyttner et al(1988) | Tallinn T U(USSR) |

# APPENDEX (B) : Illustration of The Form Geometry Symbols .

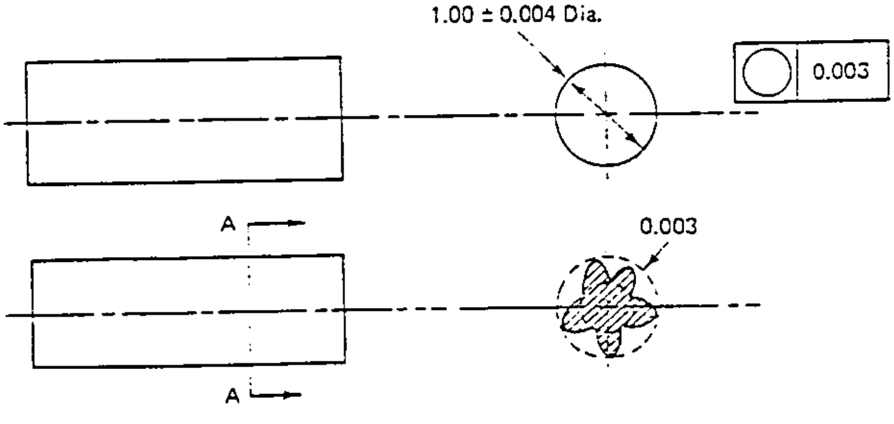
## APPENDEX (B) Illustration of The Form Geometry Symbols .



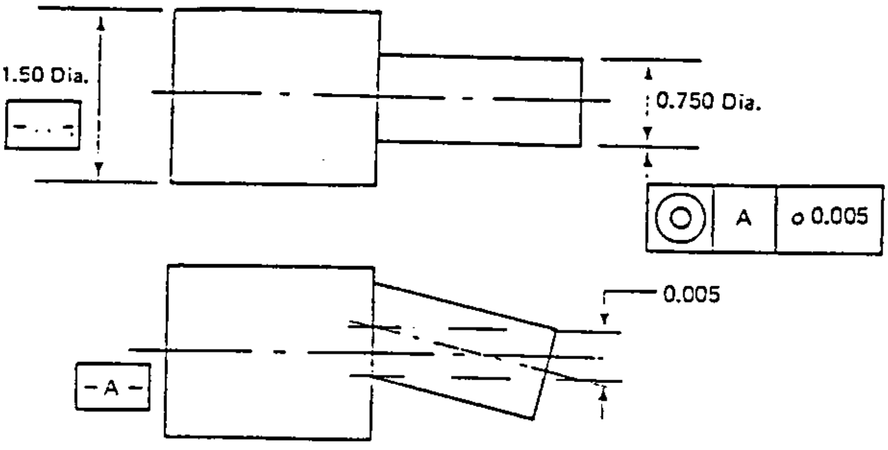
(a) Straightness



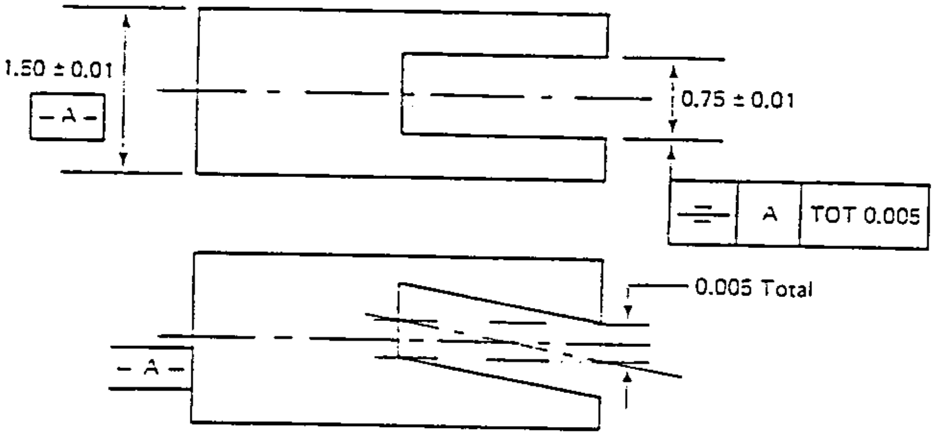
(b) Flatness



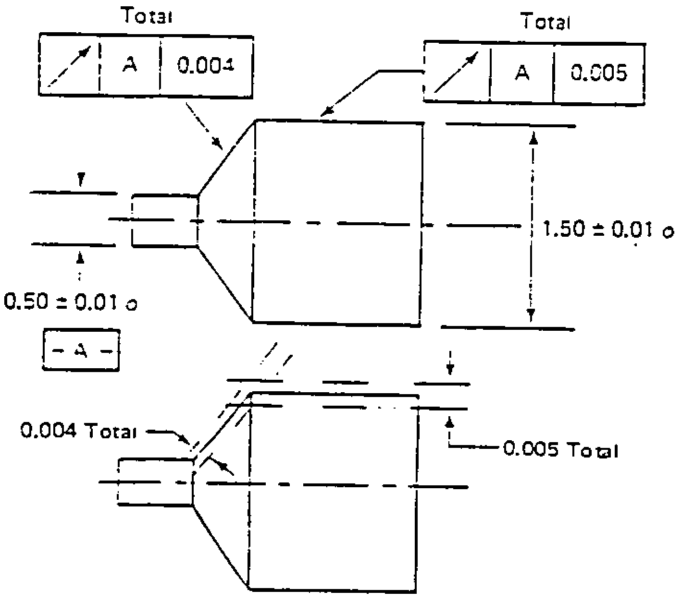
(c) Roundness



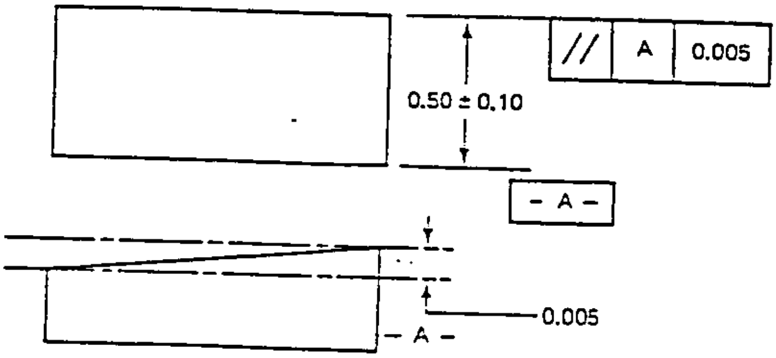
(j) Concentricity



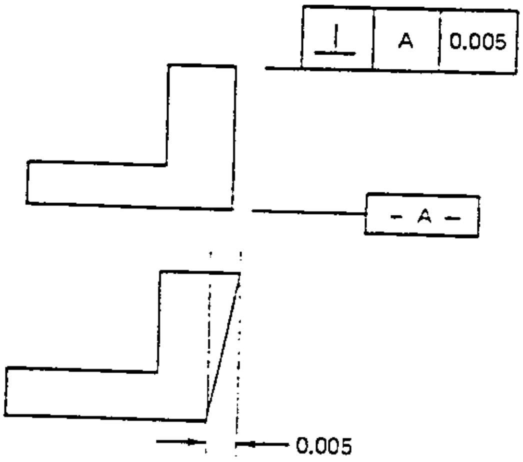
(k) Symmetry



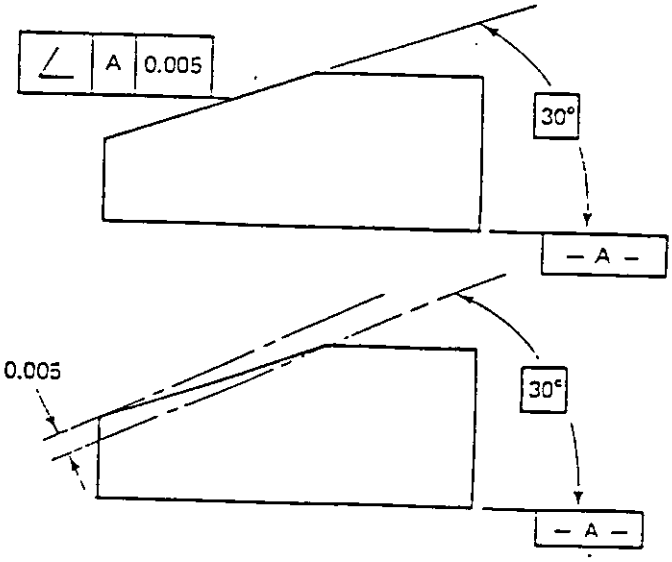
(l) Runout



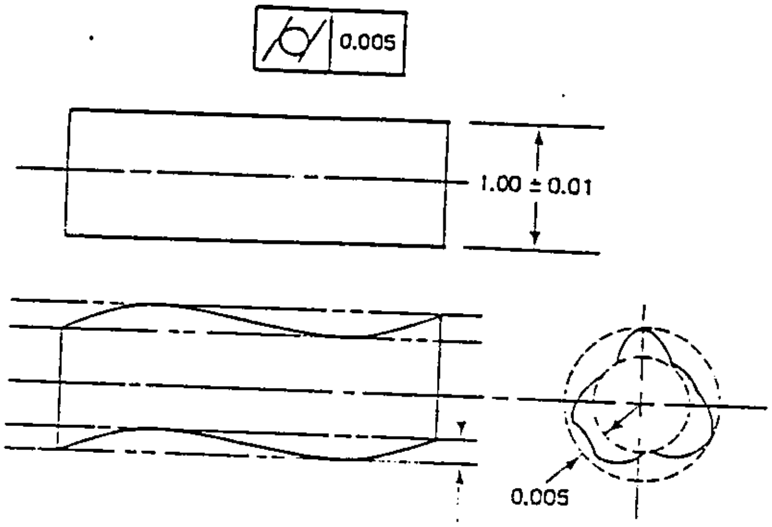
(g) Parallelism



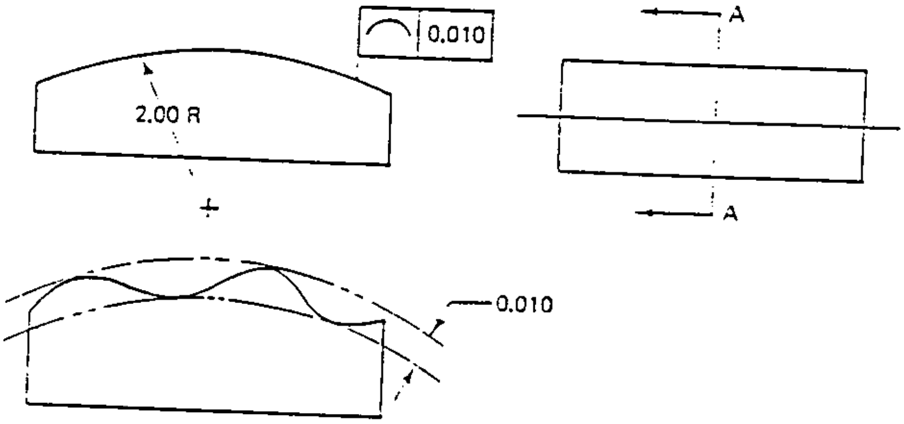
(h) Perpendicularity



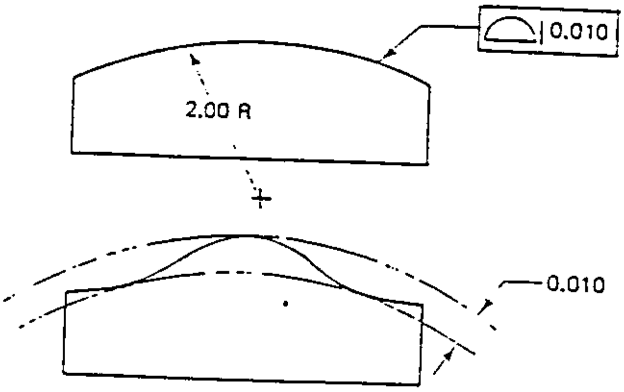
(i) Angularity



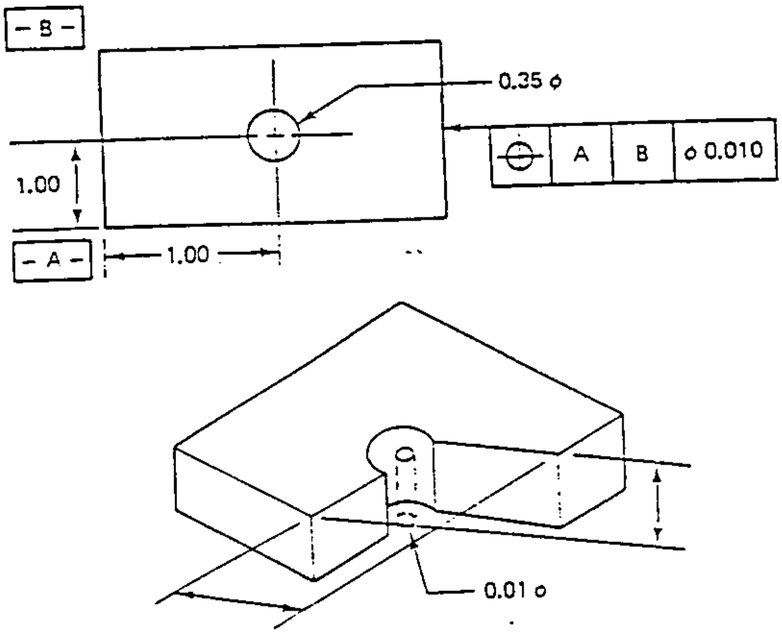
(d) Cylindricity



(e) Profile of a line



(f) Profile of a surface



(m) True position

# ملخص

تهدف هذه الرسالة الى دراسة موضوع استخدام الحاسوب لتحديد المسلك التكنولوجي للمنتجات بشكل عام ، وإلى تطوير نظام لتحديد المسلك التكنولوجي للمنتجات التي يمكن تصنيعها في مختبر التصنيع بتكامل الحاسوب، الموجود في قسم الهندسة الصناعية بالجامعة الاردنية بشكل خاص باستخدام اسلوب تقنيات المجاميع . لغرض تحقيق هذا الهدف ، تمت دراسة المواضيع المتعلقة بتحديد المسلك التكنولوجي كدراسة محيط التصنيع (مختبر التصنيع بتكامل الحاسوب)، ودراسة موضوع تقنيات المجاميع .

تتكون هذه الرسالة من سبعة فصول في الفصل الاول منها تم تعريف الموضوع والتقنيات المتعلقة به ، كما تم عرض لمحة تاريخية عن الموضوع في الفصل الثاني، اما الفصل الثالث فيعرض المنهجية العلمية التي اتبعت لاتمام هذا البحث .

في الفصل الرابع تمت دراسة مختبر التصنيع بتكامل الحاسوب واحتوت على تعريف بهذا النظام ، ووصف للاجهزة والماكينات الموجودة فيه . كما تمت دراسة عملية اختيار سرعة القطع والتغذية للعمليات التصنيعية المختلفة ضمن مجال المختبر .

شمل الفصل الخامس دراسة موضوع تقنيات المجاميع وعلاقتها بالعملية التصنيعية كما تمت دراسة الانظمة المختلفة المستخدمة لتصنيف المنتجات وتقسيمها الى مجاميع مختلفة ، وبناء على ذلك تم خلق نظام لتصنيف المنتجات التي يمكن تصنيعها في المختبر وتقسيمها الى مجاميع لغرض الاستفادة من خاصية التشابه في التصنيع والتصميم .

يعرض الفصل قبل الاخير بشكل تفصيلي نظام تحديد المسلك التكنولوجي بمساعدة الكمبيوتر الذي تم تطويره ، وفي الفصل الاخير تظهر نتائج تجريب هذا النظام بأمثلة مختلفة ومناقشة هذا النظام للوصول الى النتائج والتوصيات المتعلقة بهذا الموضوع .