DEVELOPMENT OF AN INTELLIGENT TOOL SELECTION SYSTEM IN PROCESS PLANNING

A MASTER'S THESIS

in

Mechanical Engineering
University of Gaziantep

By
Mehmet Emin ÖZCAN
September, 2001

Approval of the Graduate School of Natural and Applied Sciences

Assoc. Prof. Dr. A. Rıza Tekin

Director

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

Assoc. Prof. Dr. Melda Çarpınlıoğlu

Chairman of the Department

I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Prof. Dr. İ. Hüseyin FİLİZ

Supervisor

Examining Committee in Charge:

Prof. Dr. İ. Hüseyin FİLİZ (Chairman)

Assoc. Prof. Dr. Cengiz DOĞAN

Assist. Prof. Dr. Türkay DERELİ

ABSTRACT

DEVELOPMENT OF AN INTELLIGENT TOOL SELECTION SYSTEM IN PROCESS PLANNING

ÖZCAN, M. Emin

Ms. In Mechanical Engineering

Supervisor: Prof. Dr. İ. Hüseyin FİLİZ

September, 2001, 94 pages

Despite the rapid development in process planning systems, there has been insufficient progress in the area of cutting tool selection by using expert system of artificial intelligence techniques. This study is an attempt to fill this gap.

Automatic selection of cutting tools for machining operations is a complex task which requires considerable experience and knowledge. In this study, cutting tool selection process is carried out by a computer program through extensive searching of difference between catalogues and manuals. The most suitable cutting tool is selected among various cutting tool types by using all related cutting tool selection criteria which are stored in the database. They are classified into subgroups considering their machining type, material property and application type. For the optimum cutting conditions, dept of cut, feed and cutting time are calculated and used for selection of cutting tools.

The computer program is written in DELPHI 5.1 programming language on personal computer. The use of program is illustrated with practical examples.

Key words: Process Planning, Expert System, Cutting Tool

ÖZET

İŞLEM PLANLAMASINDA ZEKİ KALEM SEÇİMİNİN GELİŞTİRİLMESİ

ÖZCAN, M. Emin
Yüksek Lisans Tezi, Makina Mühendisliği Bölümü
Tez Yöneticisi: Prof. Dr. İ. Hüseyin Filiz
Eylül, 2001, 94 sayfa

İşlem Planlamasındaki hızlı gelişmeye rağmen, yapay zeka tekniklerinden uzman sistem'i kullanarak kesici takım seçiminde yeterli ilerleme sağlanamamıştır. Mevcut çalışma, bu alandaki boşluğu doldurmak amacıyla yapılmıştır.

Talaş kaldırma işlemlerinde otomatik kesici takım seçimi karmaşık bir iş olup, tecrübe ve bilgi gerektirmektedir. Bu çalışmada kesici takım seçim işlemi, katalog ve yardımcı el kılavuzlarının bilgisayar programı tarafindan geniş bir şekilde araştırılmasıyla yapılmaktadır. Uygun kesici takım'ı seçebilmek için pek çok kesici takım ve ilgili seçme kriterleri veri tabanında saklanmaktadır. Bunlar, imalat çeşidi, malzeme özelliği ve işlem türüne göre altsınıflarda gruplandırılmıştır. En iyi kesici takım şartları için talaş derinliği, ilerleme ve kesme süresi hesaplanarak kesic takımın seçiminde kullanılmıştır.

Bu bilgisayar programı bir kişisel bilgisayarda DELPHI 5.1 programlama dili kullanılarak hazırlanmıştır. Programın kullanılışı örneklerle gösterilmiştir.

Anahtar Kelimeler: İşlem Planlama, Uzman Sistem, Kesici Takım.

ACKNOWLEDGEMENT

I would like to express my deepest gratitude to my supervisor, Prof. Dr. İ. Hüseyin Filiz, without whose valuable help and guidance, this thesis would never have been completed.

I also wish to thank to Assoc. Prof. Dr. İ. Halil Güzelbey for his continuous motivation and support.

I am thankful to Assoc. Prof. Dr. Cengiz Doğan for his valuable criticism.

I am very grateful to Turkay DERELI for his help in programming and Mr. N. Fazıl Yılmaz for his help in preparing the manuscript.

Many thanks are due to my dearest wife for her patience.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

There is no doubt that modern computing technologies have made a significant impact on manufacturing systems. These technologies have been used for developing many methods, techniques and tools to support the design and manufacturing functions. This includes such developments as Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), Computer Aided Process Planning (CAPP) and Computer Integrated Manufacturing (CIM).

The main objective of a CIM system is to integrate the CAD and CAM components. The total integration of these two components into a common environment CAD or CAM is still under development. Many of the major developments have been uncoordinated and there is a great deal of overlap in terms of their intended functions. For example, the present CAD or CAM systems have their strength in geometrical definition, i.e., CAD component and CAM is mostly limited to CNC programming.

Since many activities within design and process planning have been implemented as computer software in the form of computer-aided design (CAD) and computer-aided process planning (CAPP), it is now becoming feasible to automate process planning tasks as a design takes place and information about the component being designed becomes available. Computer Aided Process Planning (CAPP) consists of determining the processes required to produce the part and putting those processes in a suitable sequence. Many different process sequences may be obtained for a part, taking some criteria into account like machinability and safety. Although the ultimate goal in process planning is to decrease total production time, the primary objective is to provide a suitable way to produce the most functional parts with high quality in an optimum time [19].

In automated batch production, on-line process planning is desirable. The conflicting demands of increasing flexibility and efficiency on the shop floor require the rapid transfer of manufacturing information. Hence, there is a need for CAPP systems, which cover the whole process of decision-making, from the integration of the product model through to the generation of programs. These systems must be capable of taking routine decisions automatically to ensure that the user is not an essential bottleneck in the information flow and only required to act as supervisor dealing with exceptions. In this way, process planning can be carried out quickly and accurately to meet the demand of the automated machine shop

The main function of a Computer Aided Process Planning (CAPP) system is to provide process planning information to other manufacturing systems in an efficient and cost-effective way. CAPP interacts with systems such as Computer Aided Design (CAD) connected at its upper level and Computer Aided Manufacturing (CAM) connected at its lower level

The CAPP systems available in the market are incomplete and limited when compared to the number of CAD and CAM systems available. Process planning function involves a number of activities as follows:

- Analysis of part requirements.
- Selection of raw workpiece.
- Selection of manufacturing processes.
- Selection of machine tools.
- Selection of cutting tools.
- Selection of operations.
- Sequencing of operations.
- Determination of machining conditions.

Among the functions of modules of a process planning system given above, there has been little progress in the area of tool selection. The development of systems for the automatic selection of cutting tools for machining operations is complex, and owing to the complexity and variety of machining and availability of many cutting tools for the same operation type, it is a very complex process to automate the selection of cutting tools therefore the tool selection process is mostly carried out manually through extensive searching of catalogues and manuals. The optimum selection of cutting tools and conditions cannot be simply based upon the familiarity, experience and the memory of individuals.

Success in metal cutting depends upon the selection of the proper cutting tool (material and geometry) for a given work material. A wide range of cutting tool materials is available with a variety of properties, performance capabilities and cost. The tool materials are rated by their permissible cutting speed in machining steel materials. The cutting tool is the most critical part of the machining system. The cutting tool material, cutting parameters, and tool geometry selected directly influencing the decision are:

- Work material characteristics (chemical and metallurgical state).
- Part characteristics (geometry, accuracy, finish and surface-integrity requirements).
- Machine tool characteristics including the workholders (adequate rigidity with high horsepower and wide speed and feed ranges).
- Support systems (operator's ability, sensors, controls, methods of lubrication and chip removal).

Selection of cutting tools and holders are important steps in Computer Aided Process Planning (CAPP) systems because a part program must include tooling information. There is variety of cutting tools and holders available in the market from which the most suitable one is to be selected for each operation. Tools and holders databases are extracted from manufacturers catalogue are prepared and used for this purpose.

From 1980 or so expert systems began to be used in process planning. An expert system is a computer program, which simulates human experts to make decisions and solve problems. An expert system contains two major and related components, a knowledge base and an inference engine. The knowledge base provides specific facts about the subject, and the inference engine provides the reasoning ability that enables the expert system to form conclusions.

Expert systems are one of the most developed branches of Artificial Intelligence. An expert system is a software program that encodes the knowledge of experts and uses techniques other than conventional computer languages to represent that knowledge. Frequently, experts possess knowledge which is extremely valuable to a company, but which cannot be expressed easily in conventional computer programs. Their knowledge often relies on experience from past situations, which is reapplied when necessary to deal with a similar situation. This knowledge is often represented in the form of rules.

Like conventional programs, expert systems usually perform relatively well-defined tasks. Unlike conventional programs, expert systems also explain their actions, justify their conclusions and provide end users with details of the knowledge they contain. An expert system may be easier to debug and modify than a traditional program performing the same task, because the knowledge is separated from the algorithms and is readily accessible at run time.

The aim of this study is to prepare a computer-based intelligent system for the automatic selection of cutting tools. The main objective of the thesis is to develop a procedure for the selection of cutting tools, to develop a dynamic programming-based system and to determine the resulting cutting parameters. This will help the designers and manufacturing planners to select an optimal set of cutting tools and cutting conditions for different material properties and to give users alternatives on how to reduce processing time.

The most relevant works are reviewed in Chapter 2. General theory of artificial intelligence and structure of expert system are stated in Chapter 3 and Chapter 4 respectively. Chapter 5 and Chapter 6 present cutting tools for turning and milling operations. In these chapters all cutting parameters, types of cutting tools and cutting tool selection criteria are explained. In Chapter 7, cutting tool and material selection are expressed and execution of the program is presented with screen views. Finally, in Chapter 8 discussion and conclusions are given.

CHAPTER 2

LITERATURE SURVEY

2.1. INTRODUCTION

This chapter presents a brief survey of the most relevant literature related to the study reported in this thesis. The following section is devoted to the reviews on cutting tool selection systems.

2.2 CUTTING TOOL SELECTION SYSTEM

Over the last few decades, the range of engineering materials encountered in machine shops has increased greatly, as has the variety of cutting tools that are capable of machining these materials. In the early 1980s research work was undertaken in the area of Computer Aided Manufacturing (CAM) and Computer Aided Process Planning (CAPP). A number of systems have been developed to select a tool or a set of tools for a specific operation or a set of operations [1].

There are two approaches for tool selection. One is; "selection of tool by using type of operation only", and the other is "selection of tool by taking optimum cutting conditions into consideration".

Maropoulos and Hinduja [2,3] used the automatic tool selection system (ATS), which selects the optimum tools for rough turning and finishing operations. Operations performed on a CNC (Computer Numerically Controlled) turning center tool selection procedures are described. Tools are selected by using the cutting data for first and last passes in a multi pass situation. The tools considered herein consist of a holder and an indexable tungsten carbide insert. The finishing profiles may be stepped or even contain a recess or shoulder. For all tools that are plausible, the system calculates the machining cost based on approximate cutting data for the first and last passes in multi-pass situation.

Domazet [4] developed an automated tool selection system by the production rule matrix method. The system is designed by a production rule matrix method using a table formed rule base to replace IF-THEN rules. The system is very heavily dependent on information provided by the manufacturer.

Hinduja, S. and Barrow, G developed [5] a semi-intelligent tool selection system for turning components. The system is user friendly and highly interactive. It is capable of dealing with all the operations normally associated with the manufacturing of turning components.

Dereli et al. [6] developed an integrated system called OPTTOOL, which is capable of selecting the best tool among many alternatives that can work with optimum parameters, while minimizing the number of tool changes and/or tool traveling distance within a set-up, as well. Tool selection procedures are directly incorporated the optimization procedures in order to control fitness of optimized cutting parameters to the selected cutting tools simultaneously.

Veeramani and Gau [7] described a two-phase methodology for selecting an optimal set of cutting-tool sizes to machine a 2½D pocket. In the first phase, they employed a new concept called the Voronoi mountain in order to calculate the material volume that can be removed by a specific cutting-tool size, the material volume that will subsequently remain to be machined, and the cutter-paths (and corresponding processing times) for each cutting-tool. In the second phase, they applied a dynamic programming approach for optimal selection of cutting-tool sizes on the basis of the processing time.

Ribeiro and Coppini [8] presented a machining database system involving procedures to make comparative tests using different tools and optimize the attained results. The objective is to find suitable cutting conditions for application at industrial scale. The selection of the conditions and cutting tools was based on the maximum production conditions achieved in the industrial plants.

Wong et. al., [9] developed a first prototype of a rule based expert system containing a fuzzy logic described strategy. This paper further describes development of fuzzy models and their feasibility. Development of several models for different cutting tools is presented and discussed. The feasibility of a generalized fuzzy model for all the cutting tools is also presented.

Arezoo et al., [10] developed a knowledge-based system for selection of cutting tools and conditions of turning operations. The system developed can be used to select the toolholder, insert and cutting conditions (feed, speed and depth of cut). It is able to analyze and optimize cutting tools and condition selection. In addition, the user or tool supplier is able to modify and enhance the system to meet their individual requirements. This system is constructed and implemented using Prolog. It contains an inference engine, a user interface and explanation facility a complete shell, a knowledge base, and an optimization model for machining conditions. The input to the system developed is the part and tool files, which include the representation of the part features and cutting tools.

Baker and Maropoulos [11] defined architecture to enable the vertical integration of tooling considerations from early design to process planning and scheduling. The architecture is based on a "five-level" tool selection procedure.

Yuan-Hung and Landers [12] studied the implementation of multiple process controllers in which multiple process controllers and strategies in machining operations is coordinated by a supervisor

Maropoulos et. al., [13] describes the cutting data estimation functions of an aggregate tool selection system during the early stages of design. They concentrated on the data structures and methods required to implement tool selection within a feature-based design environment and also discusses the estimation of machining times necessary to assess the tools selected using machining performance related criteria.

Edalew, Abdalla and Nash, [14] developed a computer-based intelligent system for the automatic selection of cutting processes and tools within a concurrent engineering environment. The system comprised of several modules; the knowledge acquisition module, the knowledge base module, the inference engine, the user interface, and the database. The developed system, which was designed to cover different component shapes including cylindrical, prismatic, different types of machining techniques, conventional and less conventional, has the potential to deal with complex products that are made up of multiple components. The system is capable of selecting cutting tools. It calculates cutting conditions and estimates component cost, based on the properties of the work piece material and features attributes, which include surface finish and tolerances, as well as using a number of production criteria such as material removal rate, tool life, machining time, and cost.

Mookherjee and Bhattarcharyyaa [15] presented an expert system, which automatically selects the turning tool insert or milling insert, the material and the geometry, based on the requirements of users. Trade-off among the different cutting parameters of the operation is also performed by the developed system as and when necessary. Executing some practical problems highlights the application of this developed expert system.

Ahn et al., [16] investigated how current CAD/CAM tools and environments are evolving to facilitate distributed design and fabrication processes, design analysis services for distributed design and fabrication uses.

Kengskool and Resnick [17] developed an innovative method, which can be used to provide the necessary information directly to the workplace. This approach is the use of a computer-based knowledge system. This system would assist the ergonomist in selecting among the evaluation tools by providing detailed information about the tool's applicability to a particular manufacturing system. The developed program has several important characteristics, including a user-friendly interface, a comprehensive database of ergonomic evaluation tools, and a robust design for tool selection.

Iwata and Fukuda [18] developed KAPPS (Know-how and Knowledge Assisted Production Planning System). The machined surface and initial shape of the part can be recognized by the system. It also selects the reference surface, determines precedence relations, selects machine tools, determines cutting conditions and selects the required cutting tools and fixtures.

CHAPTER 3

THEORY OF ARTIFICIAL INTELLIGENCE

3.1. INTRODUCTION

In the past decade, there has been great explosion in the area of artificial intelligent (AI) techniques. The power of AI comes from its role in the production of items, plant organization, representing and utilizing knowledge by computers. In other words, the main goal of AI is to simulate human behavior on the computer. The knowledge and use of knowledge are the key characteristics. The art of bringing relevant principles and tools of AI together for solving difficult application problems is therefore sometimes referred to knowledge engineering [16].

AI has provided several techniques with applications in manufacturing, such as Expert System (ES), Fuzzy Logic (FL), Artificial Neural Network (ANN), and Genetic Algorithm (GA).

3.2. EXPERT SYSTEM

Although there are some different definitions, an expert system can be defined as a computer program that exhibits, within a specific domain, a degree of expertise in problem solving that is comparable to that of a human expert. As this definition is, in fact, quite typical of those provided in a fair number of texts on expert system. When properly interpreted this definition serves to capture, but only to a certain degree, the expert system concept.

Expert system serves to rather strongly imply that an expert system is, quite literally, nothing more than a computer program or, at best, some type of alternative to conventional computer programming. There are, in fact, a number of authors who use the term expert systems programming in their discussions of expert systems. This emphasis on computers and computer programming can, in turn, lead one to presume that the designation of knowledge engineer is just a fancy term for computer programmer. Those knowledge engineers are individuals who employ expert systems programming in place of more conventional programming languages, such as FORTRAN, BASIC, C, or COBOL [25].

Expert system methodology and its components are presented in the following chapter.

3.3 FUZZY LOGIC

In the simple form, fuzzy logic theory is an extension of traditional theory. In traditional theory, events are considered as true or false. But in fuzzy logic theory, it can be true, false and between them, means that a certain degree of truth or a certain degree of false. So fuzzy logic theory is dealing with vague concepts such as more or less. [31].

Generally, simple linear systems or naturally automated processes have not been improved by the implementation of fuzzy logic. On the other hand, fuzzy logic seems to be most successful in two kinds of situations:

1. Very complex models where understanding is strictly limited or, in fact quite judgemental.
2. Processes where human reasoning, human perception, or human decision making are inextricably involved.

The reason to use fuzzy logic is listed in general in the following [32,33].

1. Fuzzy logic is conceptually easy to understand.
   The mathematical concepts behind fuzzy reasoning are very simple. What makes fuzzy nice is the naturalness of its approach and its far-reaching complexity.

2. Fuzzy logic is flexible
   With any given system, it's easy to massage it or layer more functionality on top of it without starting again from scratch.

3. Fuzzy logic is tolerant of imprecise data.
   Everything is imprecise if you look closely enough, but more than that, most things are imprecise even on careful inspection. Fuzzy reasoning builds this understanding into the process rather than tacking it onto the end.

4. Fuzzy logic can model nonlinear functions of arbitrary complexity.
   You can create a fuzzy system to match any set of input-output data

5. Fuzzy logic can be built on top of the experience of experts.
   In direct contrast to neural networks, which take training data and generate opaque, impenetrable models, fuzzy logic lets you stand on the shoulders of people who already understand the system

6. Fuzzy logic can be blended with conventional control techniques.
   Fuzzy systems don't necessarily replace conventional control methods. In many cases fuzzy systems augment them and simplify their implementation.

7. Fuzzy logic based on natural language.
   The basis for fuzzy logic is the basis for human communication. This observation underpins many of the other statements about fuzzy logic.

The basis for fuzzy logic is the basis for human communication. This observation underpins many of the other statements about fuzzy logic.

3.4.GENETIC ALGORITHMS

Genetic Algorithms (GAs) are search algorithms based on the mechanics of neural selection and neural genetics. They combine survival of the fittest among string structures with a structured yet optimized information exchange to form a search algorithm.

Many papers and dissertations establish the validity of GA technique in function optimization. Having been established as a valid approach to problems requiring efficient and effective search, GAs are finding more widespread applications in CAD/CAM area recently. These algorithms are computationally simple and powerful in their search for improvement and are limited by restrictive assumptions about the search space [34].

GAs work with a coding of the parameter set and search from a rich population of strings. They use only objective function information, not derivatives or any other auxiliary knowledge. GAs use probabilistic transition rules, not deterministic rules. A simple genetic algorithm is composed of three genetic operators; reproduction, crossover and mutation. There are also other types of operators that yield good results like partially matched crossover, inversion [35].

3.5. ARTIFICIAL NEURAL NETWORKS

Artificial Neural Networks are intended for modeling the organizational principles of the central nervous system, with the hope that biologically inspired computing capabilities of the ANN will allow the cognitive and sensory tasks more easily and more satisfactorily than with conventional serial processors [36]. The study of neural networks is an attempt to understand the functionality of human brain. The technology mimics the brain's own problem solving process. Neural networks are systems composed of many simple processing elements operating in parallel whose functions are determined primarily by the pattern of connectivity. These systems are capable of high-level functions, such as adaptation or learning, and lower level functions such as data pre-processing for different kinds of inputs.

Adaptation or the ability to learn is the most important property of neural networks. A neural network can be trained to map a set of input patterns onto a corresponding set of output patterns simply by means of exposure to examples of the mapping. This training is performed by a gradient descent algorithm, which gradually adapts the internal weights of the network, so as to reduce differences between the actual network outputs and the desired network outputs. These types of ANNs can produce reasonable output vectors for input pattern outside of the set of training examples [37].

CHAPTER 4

STRUCTURE OF EXPERT SYSTEM

4.1. INTRODUCTION

This chapter is devoted to the explanation of structure of Expert System.

4.2. EXPERT SYSTEM (ES)

There are numerous expert systems being developed for almost any manufacturing activity [29]. Many major applications of expert systems can be found in the manufacturing area. Expert system is widely used in design, process planning, scheduling, material handling, quality control, machine diagnosis, machine layout and other operations [19].

In the early 1980s, people expected that expert systems would revolutionise computing and displace conventional computer systems. When this did not happen, the general comment was that expert systems had failed. In fact, exactly the opposite had happened. Expert Systems had become another tool that software engineers could use to solve problems. Instead of revolutionising computing, expert systems had become a step in the development of computing in general [20,21]

As a definition; Expert System is a computer program that uses knowledge and reasoning techniques to solve problems that are difficult enough requiring significant human expertise for their solution [22].

An expert system, also called knowledge based system, is an intelligent computer program that uses knowledge and reasoning techniques to solve problems that are difficult and require significant human expertise for their solution [23]. An expert system may emulate the external behaviour of an expert, or it may attempt to closely model the internal mental processes of the expert as well. Expert system has the ability to justify or explain the rationale behind a specific problem solution. Unlike conventional programs, expert systems can explain their actions, justify their conclusions and provide end users with details of the knowledge they contain. One of the main difference between the conventional program and expert systems is that the knowledge is separated from algorithms and is readily accessible at a run time in the expert systems, while data and algorithm are executed together in conventional programming.

4.3. EXPERT SYSTEM COMPONENTS

An expert system generally consists of the components as shown in Figure 4.1. They are; a user interface, a knowledge base, an inference engine, a working memory and a knowledge acquisition mechanism.

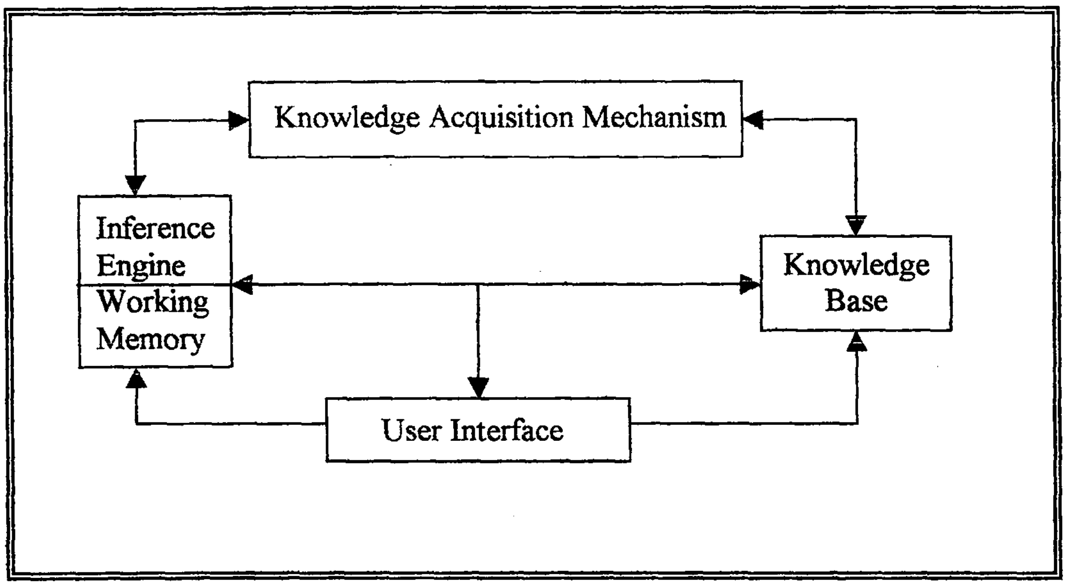


Figure 4.1. General Structure of an Expert System [24]

4.3.1. User Interface

The "user interface" is designed to provide a convenient means of two way communication between the user and the inference engine. It enables a tutor to set up and maintain the expert system, and prepare the knowledge to be entered into the knowledge database.

4.3.2. Knowledge Base

Knowledge base is to capture the problem solving expertise of an expert in a highly constrained problem area and represent this person's knowledge or expertise in a computer that can approximate the expert's ability to solve a particular class of problems [26]

The knowledge base is a file that contains the facts and heuristic that makes up an expert's knowledge. The knowledge base is expressed in computer codes, usually in the form of IF-THEN rules or frames, with series of question. The problems are solved by using these rules through inference engine. The knowledge required to solve a specific problem is called the *domain* of an expert system.

4.3.3. Inference Engine

The "inference engine" is the knowledge processor, which looks at the problem description and tries to find a solution. It can be considered as a program that applies *domain* knowledge to known facts to draw conclusions. Inference engines are domain independent such that they apply domain knowledge to case specific application. The explainer is used to find out how a solution was obtained from an expert system and which individual steps were taken. The user can communicate with the explainer to obtain a report about the operation of the expert system. If the user desires, he can obtain intermediate data and information on how the knowledge was used.

An important subset of the general area of expert systems concentrates on explicitly representing an expert's knowledge about a class of problems and providing a separate reasoning mechanism called "inference engine" that operates on this knowledge to produce a solution. The inference engine serves as the inference and control mechanism for the expert system and, as such, is an essential part of the expert system as well as a major factor in the determination of the effectiveness and efficiency of such systems. Inference, in turn, is the process of drawing a conclusion by means of a set of rules, for a specific set of facts, for a given situation. Inference is thus the knowledge processing element of an expert system [25].

The inference engine contains rules and facts. However, the rules and facts of the knowledge base pertain to the specific domain of expertise while the rules and facts of the inference engine pertain to the more general control and search strategy employed by the expert system in the development of a solution. These two sets of facts and rules are purposely kept separate in the typical expert system.

This separation results in several advantages. First, it permits one to make changes in the knowledge base with minimal impact on the inference engine. Second, it provides for the development and use of expert systems shell. Expert system shells contain all of the necessary components of an expert system with the exception of the knowledge base.

4.3.4. Working Memory

Working memory is a part of inference engine. It heavily depends on the Randomly Accessed Memory (RAM) of the used computer.

4.3.5. Knowledge Acquisition Mechanism

A knowledge acquisition mechanism is used to acquire human expertise and transform into the knowledge base. This module processes the data entered by the expert and transforms it into a data presentation understood by the system. A knowledge base can involve all of the methods that the expert uses to perform a task. When the explicitly represented knowledge is combined with the fact of a specific problem, the expert system is able to compute a solution to the problem.

In other words, knowledge acquisition is that of expert systems development dedicated to the identification of the rules and facts that comprise the knowledge base. In some cases, such acquisition may be accomplished through interviews with human experts. In others, human experts either do not exist or are unavailable. In this latter instance, one may either attempt to be one's own expert or utilise, if possible, historical data to construct a set of production rules. Yet another alternative is that we might consider training the domain expert to at least recognise the existence of problems that might be approached by expert systems [24].

4.4 REASONING METHODOLOGIES IN EXPERT SYSTEMS

There are mainly two types of reasoning methodology in expert system programming in order to find a solution to problem [28,39].

4.4.1. Forward Chaining

This method is used to infer all possible solutions from given information. In forward chaining, when one rule fires and asserts values and assertions that match the antecedents of other forward or bi-directional rules, the system can then fire these rules, asserting more values and creating more assertions, initiating further forward chaining. The system forward chains until there are no more forward or bi-directional rules whose antecedents match objects in the knowledge base.

4.4.2. Backward Chaining

This method enables you to direct your search toward a particular goal by using the reverse of the algorithm used in forward chaining. It is supposed that the application is large, and only particular partial amount of the problem will be considered. If forward chaining is used for the solution, resources will be used searching for solutions which might not be needed. Instead, it is more efficient to consider only that particular amount of the problem as a goal, and using backward chaining to solve for that one goal.

4.5. REASON TO USE EXPERT SYSTEM

Expert systems can help to solve problems that cannot be handled effectively by conventional systems. The types of problems that normally lend themselves to successful expert system solutions include diagnosis, configuration, planning, scheduling, selection, machining and routing [20].

Expert systems represent a revolutionary transition from the traditional data processing to knowledge processing. They offer an environment for incorporating data processing to knowledge processing. They offer an environment for incorporating the capabilities of humans and the power of computers. Some of the advantages of expert systems are summarised as follows:

- Expert systems can accommodate new expertise whenever new knowledge is identified
- Expert systems are able to explain their recommendations
- Expert systems can apply heuristics to reduce the complexity of search
- Expert systems reduce the company's reliance on human experts by capturing expert knowledge and store the knowledge in computers

4.6. DIFFERENCE BETWEEN EXPERT SYSTEMS AND CONVENTIONAL PROGRAMS

Main Difference between the conventional program and an expert system lies in the documentation of heuristic rule set (or, as it is known in expert systems, the knowledge base). This is known as the knowledge representation phase in expert systems, wherein a relatively formal procedure exists regardless of the ultimate choice of representation (e.g. frames and rules). No such formal scheme exists in conventional programming.

Another main difference lies in the separation of the knowledge base from the inference engine within an expert system. In a typical conventional program, heuristic rules and the inference procedures are all part of a single unit within the associated computer program. And this commingling tends to complicate changes to either the heuristic rules or the solution strategy, as well as to obscure the differences between the two elements of knowledge [25].

The differences can be outlined considering the following [27]:

1. Expert Systems are knowledge intensive programs.
2. Expert Systems are highly interactive
3. Expert Systems use heuristics, conventional systems use algorithms
4. Expert Systems have intelligent user interface
5. Expert Systems have to deal with "fuzzy" data, which is derived from a consensus of expert opinion
6. In Expert Systems expert knowledge is usually divided into many separate rules
7. Expert Systems justify the knowledge of the program. For example, if the program claims a hypothesis as true, the user could ask for an explanation
8. The program might justify this conclusion on the basis of a rule.

CHAPTER 5

CUTTING TOOLS FOR TURNING

5.1. INTRODUCTION

The purpose of this chapter is to give a brief review of fundamentals of cutting tools for turning processes.

5.2. TURNING PROCESSES

Turning is the process of machining external and internal cylindrical surfaces. Relatively simple work and tool movements are involved in turning a cylindrical surface. The workpiece is rotated into a longitudinally fed, single-point cutting tool. If the tool is fed at an angle to the axis of rotation, an external conical surface results. This is called "taper turning". If the tool is fed at 90° to the axis of rotation, using a tool that is wider than the width of the cut, the operation is called "facing", and a flat surface is produced.

Boring is a variation of turning. Essentially it is internal turning. Boring can use single-point cutting tools to produce internal cylindrical or conical surfaces. It does not create the hole but, rather, bores the hole to a specific size. Boring can be done on most machine tools that can do turning. Other operations, like threading and knurling, can be done on machines used for turning. In addition, drilling, reaming, and tapping can be done on the rotation axis of the work.

By using a tool having a specific form or shape and feeding it inward against the work, external cylindrical, conical, and irregular surfaces of limited length can also be turned. The shape of the resulting surface is determined by the shape and size of the cutting tool. Such machining is called form turning. If the tool is fed to the axis of the workpiece, it will be cut in two. This is called parting or cutoff and a simple, thin tool is used. A similar tool is used for necking or partial cutoff.

Turning operations can be basically classified in the following nine types of machining processes:

TURNING PROCESSES	
Facing	Turning
Profiling	Grooving
Drilling	Boring
Threading	Chamfering
Cutting off	

All nine processes are illustrated in Table 5.1 by their process type.

Table 5.1. Turning Machining Processes

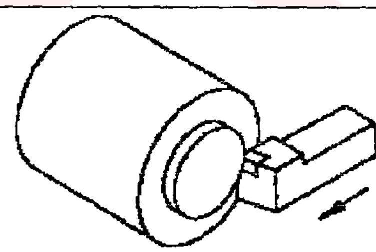
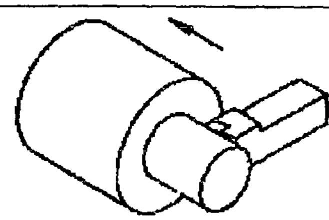
PROCESS TYPE	**TOOL**	**ILLUSTRATION**
1. Facing: Producing flat and face **a.** Facing to centre **b.** Facing to shoulder	Facing tool	
2. Turning: Producing line profiles. **a.** Straight turning	Turning Tool	

Table 5.1 Turning Machining Processes (Continued)

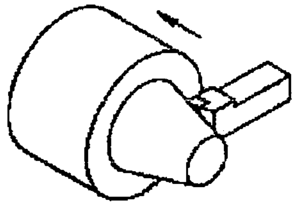
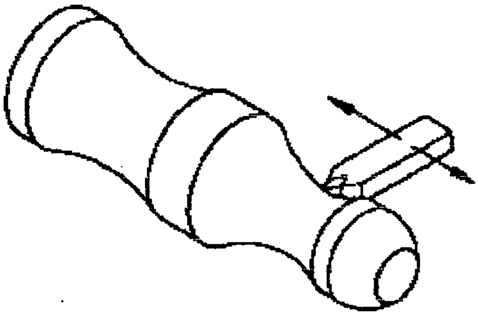
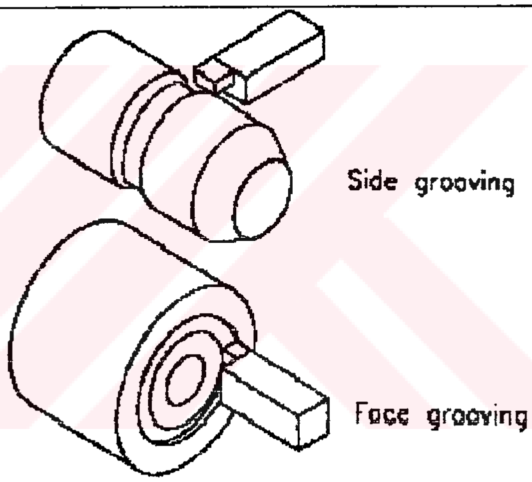
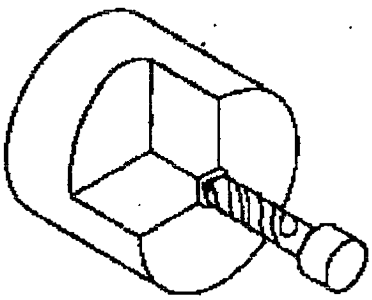
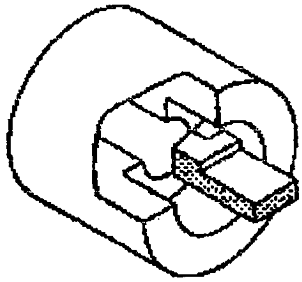
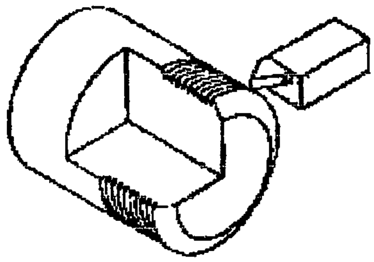
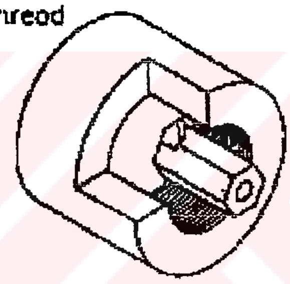
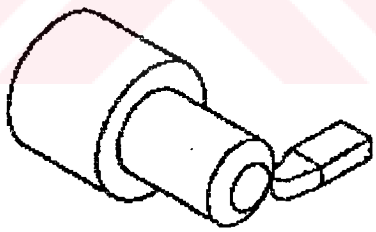
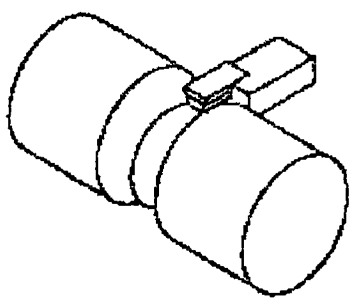
b. Taper turning	Turning Tool	
3. Profiling Producing external line and circular profiles	Profiling Tool	
4. Grooving: Cutting various forms of grooves **a.** Side grooving **b.** Face grooving	Grooving Tool	
5. Drilling Producing holes in the spindle axis	Drill	

Table 5.1 Turning Machining Processes (Continued)

6. Boring Producing internal line and circular profiles	Boring tool	
7. Threading: Cutting various thread forms **a.** External thread **b.** Internal thread	Threading tool	External thread  Internal thread 
8. Chamfering Generative chamfers at sharp corners	Chamfering tool	
9. Cutting off Separating the working from the stock	Cut-off tool	

5.3. FUNDAMENTALS OF TURNING

Turning constitutes the majority of lathe work. The cutting forces, resulting from feeding the tool, from right to left, should be directed toward the headstock to force the workpiece against the workholder and thus provide better work support.

If good finish and accurate size are desired, one or more roughing cuts usually are followed by one or more finishing cuts. Roughing cuts may be as heavy as proper chip thickness, tool life, lathe horsepower and the workpiece permit. Large depths of cut and smaller feeds are preferred to the reverse procedure, because fewer cuts are required and less time is lost in reversing the carriage and resetting the tool for the following cut.

On workpieces that have a hard surface, such as castings or hot-rolled materials containing mill scale, the initial roughing cut should be deep enough to penetrate the hard materials. Otherwise, the entire cutting edge operates in hard, abrasive material throughout the cut, and the tool will dull rapidly. If the surface is unusually hard, the cutting speed on the first roughing cut should be reduced accordingly.

Finishing cuts are light, usually being less than 0.38 mm. in depth, with the feed as fine as necessary to give the desired finish. Sometimes a special finishing tool is used, but often the same tool is used for both roughing and finishing cuts. In most cases one finishing cut is all that is required. However, when exceptional accuracy is required, two finishing cuts may be made. If the diameter is controlled manually, a short finishing cut (6.4 mm. long) is made and the diameter checked before the cut is completed. Because the previous micrometer measurements were made on a rougher surface, it may be necessary to reset the tool in order to have the final measurement, made on a smoother surface, check exactly. [42]

In turning, the primary cutting motion is rotational with the tool feeding parallel to the axis of rotation (Figure 5.1).

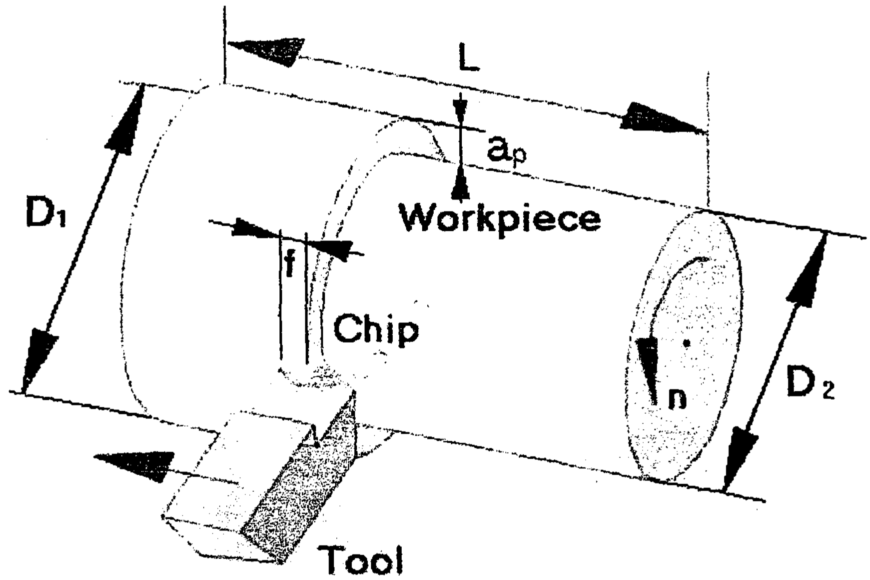


Figure 5.1. Basics of the Turning Process [39]

The rpm (*N*=*n*) of the rotating workpiece, establishes the cutting velocity, *V*, according to $V = \pi\ D\ n\ /\ 1000$ meter per minute. The feed, f, is given in mm per revolution. The depth of cut is ap where;

Depth of cut = ap = $(D_1 - D_2)/2$ in mm

The length of cut is the distance traveled parallel to the axis, L, plus some overrun, A, to allow the tool to enter and/or exit the cut. Once the cutting speed, feed, and depth of cut have been selected for a given material being cut with a tool of known cutting tool material, the rpm for the machine tool can be determined.

$n = \frac{1000.V}{\pi D_1}$ (Using the larger diameter).

The cutting time = $tc = \frac{(L+A)}{f.n}$ where A is overrun allowance

The Metal Removal Rate = $W = \frac{\text{volume removed}}{\text{time}} = \frac{(\pi D_1^2 - \pi D_2^2)L}{4(L/fN)}$ (omitting allowance term)

By rearranging for N, we obtain

$W = \frac{1000(D_1^2 - D_2^2)fV}{4D_1}$ also $W \cong 1000 \frac{V}{60} a_p f$

where

N =n = Rotational speed of workpiece (rpm)

tc = Cutting Time, (minute)

W = Metal Removal Rate, (m^3/sec)

V = Cutting Velocity, Cutting Speed, (m/min)

F = f = Feed per revolution (mm)

a_p = Depth of Cut (mm)

Last equation is an approximate equation, which assumes that the depth of cut, a_p, is small compared to the uncut from largest diameter D_1.

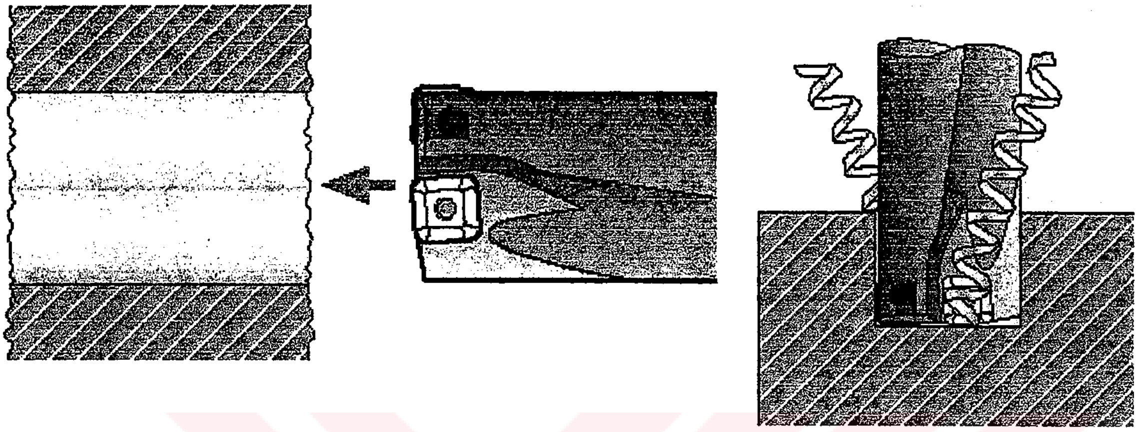
The profiling process is the similar formulation like basic of the turning process.

In the following sections some basic turning operations will be discussed.

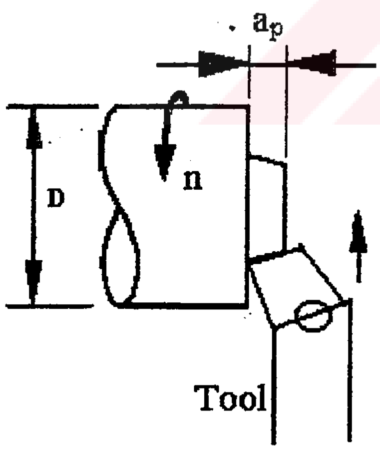
5.3.1. Boring

Boring always involves the enlarging of an existing hole, which may have been made by a drill or may be the result of a core in a casting. An equally important, and concurrent, purpose of boring may be to make the hole concentric with the axis of rotation of the workpiece and thus correct any eccentricity that may have resulted from the drill's having drifted off the centerline. Concentricity is an important attribute of bored holes.

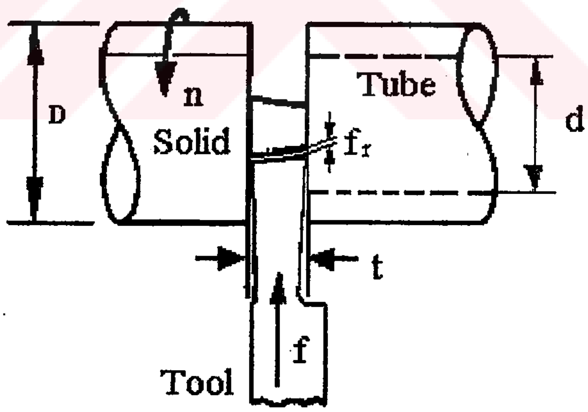
When boring is done in a lathe, the work usually is held in a chuck or on a face plate. Holes may be bored straight, tapered, or to irregular contours. Figure 5.2.a shows the relationship of the tool and the workpiece for boring. Boring is essentially internal turning while feeding the tool parallel to the rotation axis of the workpiece.



(a) Boring a drilled hole [44]



(b) Facing



(c) Cutoff or parting

Figure 5.2. Basic Movements of Boring, Facing and Cutoff Processes

Given V and f, for a cut of length L, the cutting time is; $tc = \frac{(L + A)}{f.N}$

Where; $n = \frac{1000.V}{\pi D_1}$ for D_1= Diameter of bore, where A is overrun allowance

$$\text{The } W = \frac{\text{volume removed}}{\text{time}} = \frac{(\pi D_1^2 L - \pi D_2^2 L)/4}{L/fN}$$

$$\cong \quad W \cong 500 \frac{V}{60} a_p f \qquad \text{(omitting allowance term)}$$

where; D_2 = original hole diameter

5.3.2. Facing

Facing is the producing of a flat surface as the result of a tool's being fed across the end of the rotating workpiece, as shown in Figure 5.2.b. Unless the work is held on a mandrel, if both ends of the work are to be faced, it must be turned end for end after the first end is completed and the facing operation repeated.

The cutting speed should be determined from the largest diameter of the surface to be faced. Facing may be done either from the outside inward or from the center outward. In either case, the point of the tool must be set exactly at the height of the center of rotation. Because the cutting force tends to push the tool away from the work, it is usually desirable to clamp the carriage to the lathe bed during each facing cut to prevent it from moving slightly and thus producing a surface that is not flat.

In the facing of castings or other materials that have a hard surface, the depth of the first cut should be sufficient to penetrate the hard material to avoid excessive tool wear. In facing, the tool feeds perpendicular to the axis of the rotating workpiece. Because the rpm is constant, the speed is continually decreasing as the axis is approached. The length, L, is D/2 or (D-D1)/2 for a tube.

The cutting time = $tc = \frac{(L + A)}{f.N}$

$$\text{The } W = \frac{Vol}{CT} = \frac{\pi D^2 a_p fN}{4L} = 500\frac{V}{60} f.a_p \text{ in } mm^3/min$$

for L=D/2

The Cutting off process is the similar formulation like facing process.

5.3.3. Parting

Parting is the operation by which one section of a workpiece is severed from the remainder by means of a cutoff tool as shown in Figure 5.2.c. Because parting tools are quite thin and must have considerable overhang, this process is less accurate and more difficult. The tool should be set exactly at the height of the axis of rotation, be kept sharp, have proper clearance angles, and be fed into the workpiece at a proper and uniform feed rate.

In parting or cutoff work, the tool is fed perpendicular to the rotational axis, as it was in facing. The length of cut for solid bars is D/2.

For tubes, $L = \frac{D - D_1}{2}$

The equations for CT and MRR are then basically the same as for facing. In boring, facing, and cutoff operations, the speeds and feeds selected are generally less than those recommended for turning because of the large overhang of the tool often needed to complete the cuts. Recalling the basic equation for deflection of a cantilever beam, modifying for machining. The reduction of the feed (or depth of cut) reduces the forces operating on the tools and the reduction of the speed usually reduces the probability of chatter and vibration.

The feed force, F_f, will deflect the tool to the side, resulting in loss of accuracy in cutoff lengths. At the outset, the forces will be balanced if there is no side rake on the tool. As the cutoff tool reaches the axis of the rotating part, the feed force will deflect the tool away from the spindle, resulting in a change in the length of the part.

5.3.4. Drilling

Most drilling on lathes is done with the drill held in the tailstock quill and fed against a workpiece that is rotated in a chuck (Figure 5.3). Drills with taper shanks are mounted directly in the quill hole. Feeding is by hand by means of the handwheel on the outer end of the tailstock assembly.

It also is possible to drill on a lathe with the drill bit mounted and rotated in the spindle while the work remains stationary, supported on the tailstock.

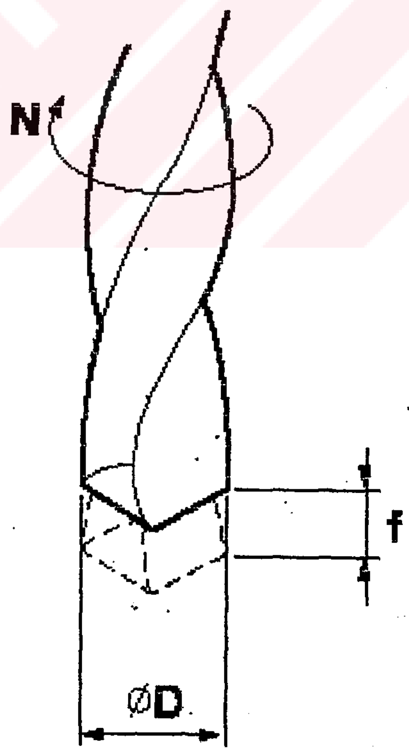


Figure 5.3.Types of Twist Drills and Shanks [44]

The process of drilling creates two chips. A conventional two-flute drill, with drill of diameter D, has two principle cutting edges rotating at an rpm of N and feeding axially. The rpm of drill is established by the selected cutting velocity, V, where;

$$N = \frac{1000V}{\pi D}$$

with V in feed per minute and D in mm.

Given a selected cutting speed and feed for drilling a hole in a certain metal with a drill of known tool material, the rpm of the spindle of the machine is determined from the equation, written above, the maximum velocity occurring at the extreme ends of the drill lips. The velocity is very small near the center of chisel end of the drill.

For drilling, cutting time is $tc = \frac{L+A}{f_r N} = \frac{L+A}{f_m}$

The metal removal rate is $W = \frac{\text{Volume}}{\text{cut}} = \frac{\pi D^2 L/4}{L/f_r N}$ (omitting allowances)

5.3.5. Reaming

Reaming on a lathe involves no special precautions. Reamers are held in the tailstock quill, taper-shank types being mounted directly and straight-shank types by means of a drill chuck. Rose-chucking reamers usually are used. Fluted-chucking reamers also may be used, but these should be held in some type of holder that will permit the reamer to float.

5.3.6. Threading

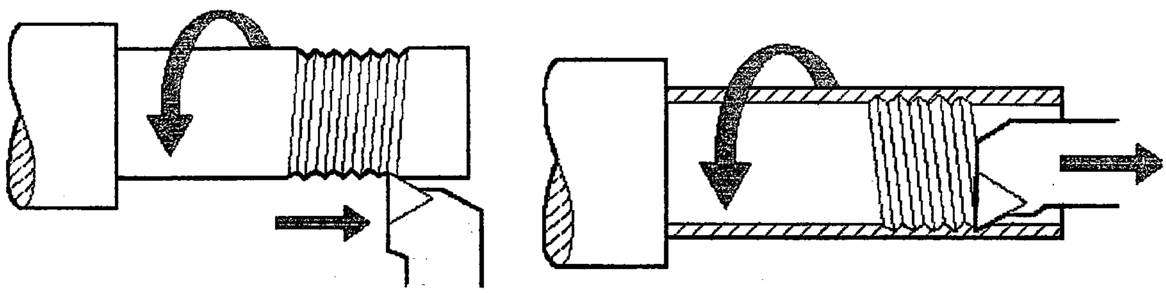
Threading is the one of machining type in turning. Lathes provide for cutting threads by machine. Although most threads are now produced by other methods, lathes still provide the most versatile and fundamentally simple method. Consequently, they often are used for cutting threads on special workpieces where the configuration or nonstandard size does not permit them to be made by less costly methods.

There are two basic requirements for thread cutting. An accurately shaped and properly mounted tool is needed because thread cutting is a form-cutting operation. The resulting thread profile is determined by the shape of the tool and its position relative to the workpiece. The second requirement is that the tool must move longitudinally in a specific relationship to the rotation of the workpiece, because this determines the lead of the thread.

Threads can be cut by the methods shown in Table 5.2. The cutting tool usually is checked for shape and alignment by means of a thread template, as indicated in Figure 5.4.

Table 5.2. Thread Cutting Methods

External	Internal
Threading (on an engine lathe)	Threading (on an engine lathe)
With a die held in a stock (manual)	With a tap and holder (manual, semiautomatic, or automatic)
With an automatic die (turret lathe or screw machine)	With a collapsible tap (turret lathe, screw machine, or special threading machine)
By milling	By milling
By grinding	

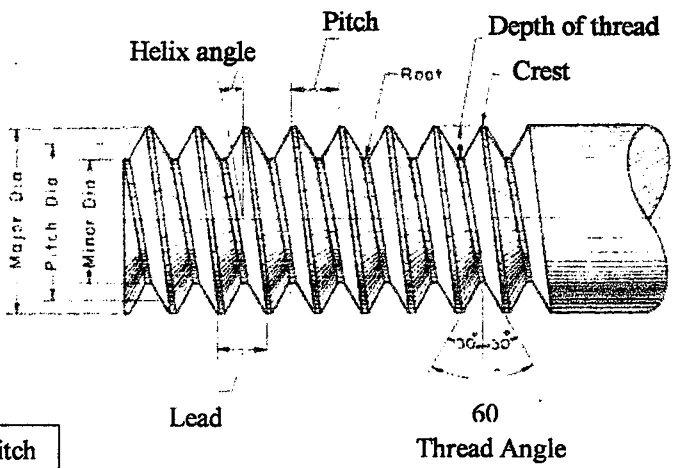


a. External Threading b.Internal Threading

Figure 5.4. Schematic Illustration of Threading Types [45]

External threads can be cut with the work mounted either between centers or held in a chuck. For internal threads, the work must be held in a chuck.

The standard nomenclature for screw thread components is illustrated in Figure 5.5. In both the Unified and ISO systems, the crest of external threads may be flat or rounded. The root usually is made rounded to minimize stress concentration at this critical area.



Single thread	= 1 x pitch
Double thread	= 2 x pitch
Triple thread	= 3 x pitch

Figure 5.5. Standard Screw-thread Nomenclature [44]

In the metric system, the pitch always is expressed in millimeters, whereas in the American (Unified) system, it is a fraction having as the numerator 1 and as the denominator the number of threads per inch, thus 1/16 pitch being 1/16 of an inch. Consequently, in the Unified system threads more commonly are described n terms of threads per inch rather than by the pitch. While all elements of the thread form are based on the pitch diameter, screw-thread sizes are expressed in terms of the outside, or major diameter and the pitch or number of threads per inch. In threaded elements, lead refers to the axial advance of the element during one revolution; therefore lead equals pitch on a single thread screw.

5.4. CUTTING TOOL MATERIALS

Three important properties of any cutting tool material are:

1. Wear resistance (resistance to the various wear mechanism)
2. Toughness (the ability to absorb energy and withstand plastic deformation without fracturing under compressive loading)
3. Hot hardness (the ability to resist stresses and maintain hardness and cutting efficiency at elevated temperatures)

The common cutting tool materials are high speed steel (HSS), tungsten carbides, cermets, ceramics, and polycrystalline. Table 5.3 summarizes the characteristics and applications of various cutting tool materials.

Table 5.3 Characteristics and Applications of Cutting Tool Materials

Material	Principal Characteristics	Typical Applications	Advantages
HSS	Tougher than carbides	Low speed machining, and interrupted cuts.	Lower cost than carbidc longcr tool lifc, better surface finish.
Uncoatcd carbide	Very tough, excellent edge wear resistance	Roughing to finishing virtually any material including iron, steel, stainless steel, high temperature alloy, non ferrous and non-metallic materials	Higher cutting speed than HSS and tougher than coated carbides.
PVD coated carbide	Very tough, good thermal shock resistance and crater resistance. High retained edge strength. Excellent resistance to buildup on the cutting edge.	Machining of steels, high temperature alloys, stainless steels, difficult to machine materials, aluminum, carbon and alloy steels.	Permit speeds to be increased up to 15% when compared to uncoated with no loss of tool life.
Cermet	Excellent resistance to wear, shock and heat.	Finishing operations on malleable cast irons, carbon steels, alloy stccls, stainlcss steels, and aluminum alloys.	Up to 20 times the tool life of conventional carbide grades.
Ceramics (alumina base)	High hardness, excellent chemical wear resistance.	For high speed rouging and finishing of cast irons and steels	Better finishes at higher machining rates.
Ceramics(silicon base)	High hardness plus high fracture toughness and thermal shock resistance.	Roughing and finishing operations on cast irons.	Machining speeds up to 5000 sfm and beyond.
Polycrystalline diamond (PCV)	Hardness of diamond plus toughness, excellent wear resistance.	Roughing to finishing operations on aluminum and other soft or abrasive non-ferrous or non-metallic materials.	Better than 30 times the tool life of carbide, even on high silicon aluminum.
Cubic born nitride (CBN)	Exceptional hardness, excellent wear resistance and mechanical shock resistance.	High speed machining on hardened ferrous materials in the 50 65 Rc (480 740 Bhn) range.	Provide many times the edge life of carbide, eliminate the need for costly alternative grinding operations.

CHAPTER 6

CUTTING TOOLS FOR MILLING

6.1. INTRODUCTION

This chapter covers cutting tools for milling processes. Fundementals of milling is briefly given which is followed by milling cutters.

6.2 MILLING PROCESSES

Milling is a basic machining process by which a surface is generated progressively by the removal of chips from a workpiece fed into a rotating cutter in a direction perpendicular to the axis of the cutter. Sometimes the workpiece remains stationary, and the cutter is fed to the work. In nearly all cases, a multiple-tooth cutter is used so that the material removal rate is high. Often the desired surface is obtained in a single pass of the cutter or work and, because very good surface finish can be obtained, milling is particularly well suited to and widely used for mass-production work. Several types of milling machines are used, ranging from relatively simple and versatile machines that are used for general-purpose machining in job shops and tool-and-die work to highly specialized machines for mass production. Unquestionably, more flat surfaces are produced by milling than by any other machining process.

Milling machines and machining centers are used to perform basically six types of machining processes (Table 6.1). These are: [42]

- Facing
- Profiling
- Pocketing
- Slot cutting
- Hole machining
- 3-D surface machining

Table 6.1. Milling Machining Processes [42]

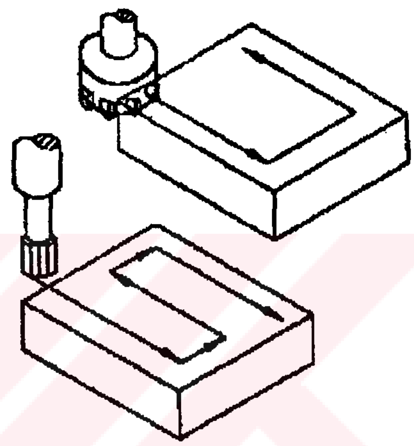
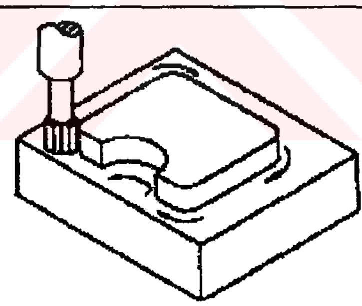
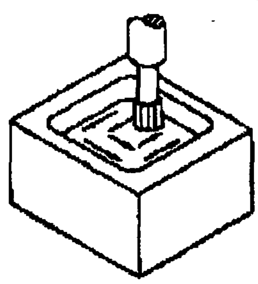
PROCESS TYPE	**TOOL**	**ILLUSTRATION**
1. Facing Producing flat surfaces	Face mill for larger surface End mill for small surfaces	
2. Profiling Producing part contours	End mill	
3. Pocketing Removing the material enclosed by a closed boundary	End mill	

Table 6.1. Milling Machining Processes (Continued) [42]

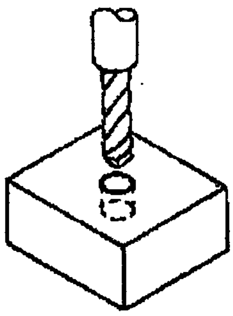
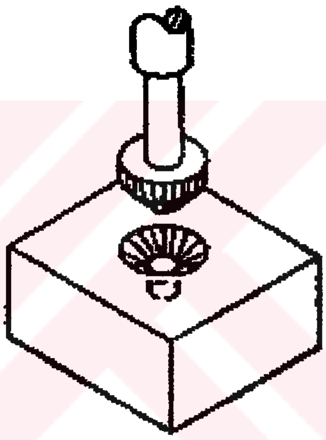
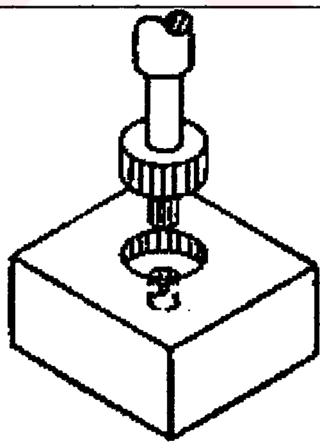
4. Hole machining **a.** Drilling	Drill	
b. Countersinking	Countersink tool	
c. Counterboring	Counterbor tool	

Table 6.1. Milling Machining Processes (Continued) [42]

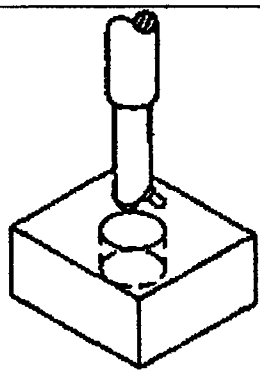
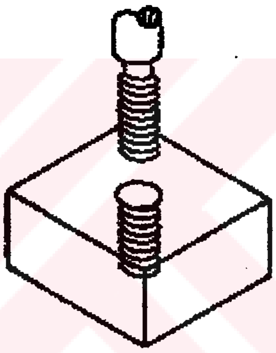
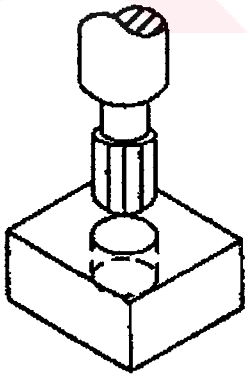
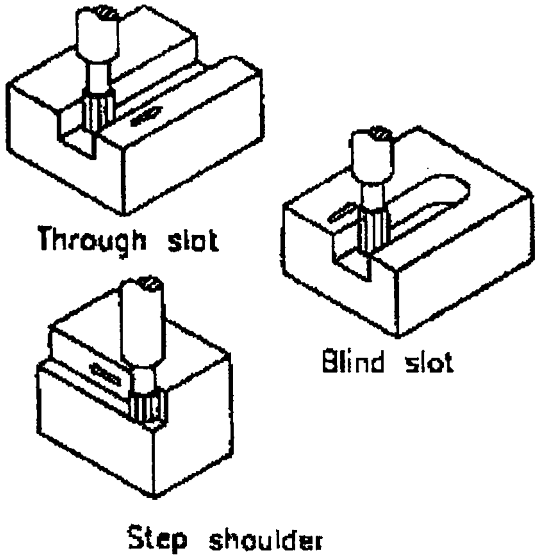
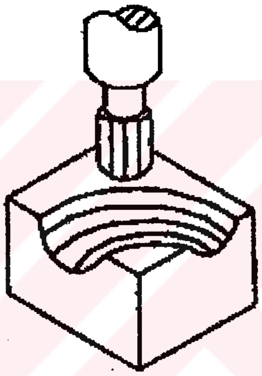
d. Boring	Boring tool	
e. Tapping	Tap	
f. Reaming Producing smooth And precise holes	Reamer	

Table 6.1. Milling Machining Processes (Continued) [42]

5. Slot Cutting Producing Various types of slots	End mill	
6. 3-D Surface machining Cutting various types of surfaces	Boll-end mill	

6.3. FUNDAMENTALS OF MILLING

The cutting tool used in milling is known as a milling cutter. Equally spaced peripheral teeth will intermittently engage and machine the workpiece. This is called interrupted cutting. Milling operations can be classified into two broad categories called peripheral milling and face milling. Each has many variations.

In peripheral milling the surface is generated by teeth located on the periphery of the cutter body. See Figure 6-1. The surface is parallel with the axis of rotation of the cutter. Both flat and formed surfaces can be produced by this method, the cross section of the resulting surface corresponding to the axial contour of the cutter. This process is often called slab milling and is usually performed on horizontal spindle machines. In slab milling, the tool rotates at some rpm (N) while the work feeds past the tool at a rate f_m.

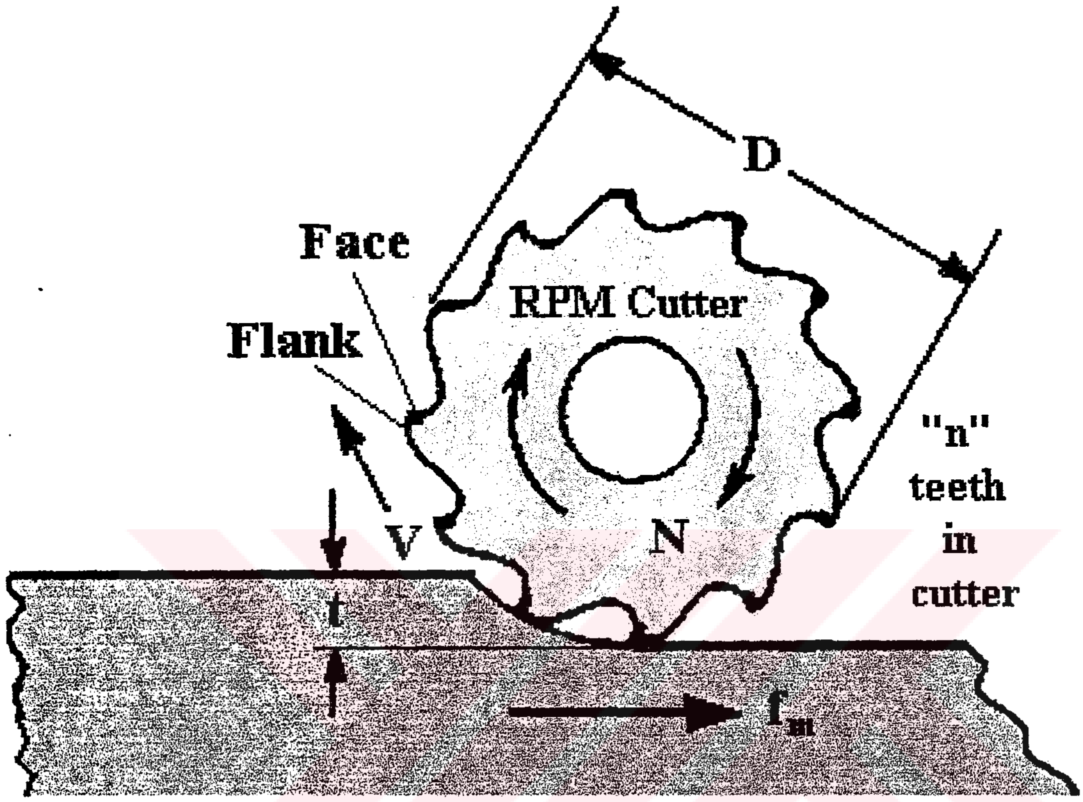


Figure 6.1. Basics of the Milling Process [42]

The surface cutting speed is established *by* the cutter of diameter (D) according to:

$$V = \pi DN/60$$

in feed per minute where D is in mm. The depth of cut is t in mm. The width of cut is the width of the cutter or the work in mm and is given the symbol W. The length of the cut, L, is the length of the work plus some allowance, L_A, for approach and overtravel. [42]

The feed of the table, f_m, in mm per minute is related to the amount of metal each tool removes during a revolution (this is called the feed per tooth), f_t, according to

$$f_m = f_t N n$$

where n is the number of teeth in the cutter (teeth/rev.). Given a selected cutting speed, V, and feed, f_t, for a given work material and tool material combination. The cutting velocity is that which occurs at the cutting edges of the milling cutter. [42]

The cutting time = tc = $(L + L_A)/f_m$ in minutes, where

$$\text{the length of approach} = L_A = \sqrt{\frac{D^2}{4} - \left(\frac{D}{2} - t\right)^2} = \sqrt{t(D-t)}$$

$$\text{The MRR} = \frac{Vol}{tc} = \frac{LWt}{tc} = Wtf_m \quad mm^3/min, \text{ ignoring } L_A$$

where

N = Rotational speed of tool (rpm)
tc = Cutting Time, (minute)
W = width of cut (mm)
V = surface cutting speed (mm / minute)
n = number of teeth in the cutter
t = Depth of Cut (mm)
D = Cutter diameter (mm)
f_m = feed of the table (mm / minute)
f_t = feed per tooth (mm)
L = length of the cut (mm)
L_A = length of the work (mm)
MRR = Metal Removal rate (mm^3/min)

In face milling and end milling, the generated surface is at right angles to the cutter axis. Most of the cutting is done by the peripheral portions of the teeth, with the face portions providing some finishing action. Face milling is done on both horizontal-spindle and vertical-spindle machines.

In face milling the tool rotates at some rpm (N) while the work feeds past the tool. See Figure 6.2. The surface cutting speed is related to the cutting diameter D. The depth of cut is *t* in mm.

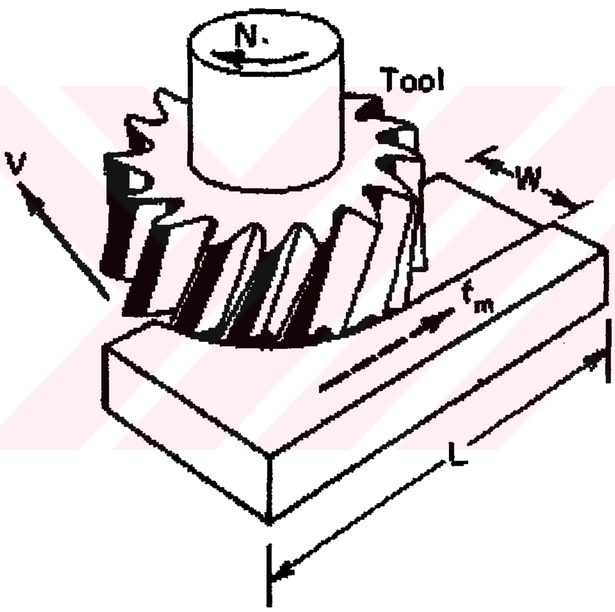


Figure 6.2. Basics of Face Milling [40]

The width of cut is W in mm and may be width of the workpiece or width of the cutter depending upon the setup. The length of cut is the length of the workpiece, L, plus an allowance for approach, L_A and overtravel, L_0 in mm. The feed of the table, f_m, in mm per minute is related to the amount of metal each tooth removes during a pass over the work and this is called the feed per tooth, f_t, where $f_m = f_t N n$. The number of teeth in the cutter is n.

The cutting time, tc=(L+L_A+L0)/f_m in minutes.

The MRR= Vol/tc=Lwt/tc= Wtf_m in mm^3/min (ignore L_0 and L_A)

The length of approach is usually equal to the length of overtravel, which usually equals *D/2* mm. For a setup in which the tool does not completely pass over the workpiece,

$$L_0 = L_A = \sqrt{W(d - W)} \quad \text{for} \quad W < \frac{D}{2}$$

In milling, surfaces can be generated by two distinctly different methods, illustrated in Figure 6.3. Up milling is the traditional way to mill and is called conventional milling. The cutter rotates against the direction of feed of the workpiece. In climb or down milling, the rotation is in the same direction as the feed. The method of chip formation is completely different in the two cases. In up milling the chip is very thin at the beginning, where the tooth first contacts the work, and increases in thickness, becoming a maximum where the tooth leaves the work. The cutter tends to push the work along and lift it upward from the table. This action tends to eliminate any effect of looseness in the feed screw and nut of the milling machine table and results in a smooth cut. However, the action also tends to loosen the work from the clamping device, therefore greater clamping forces must be employed. In addition, the smoothness of the generated surface depends greatly on the sharpness of the cutting edges. If milling conditions create a built-up edge on the cutting edge, the BUE will not affect the surface in climb milling.[40]

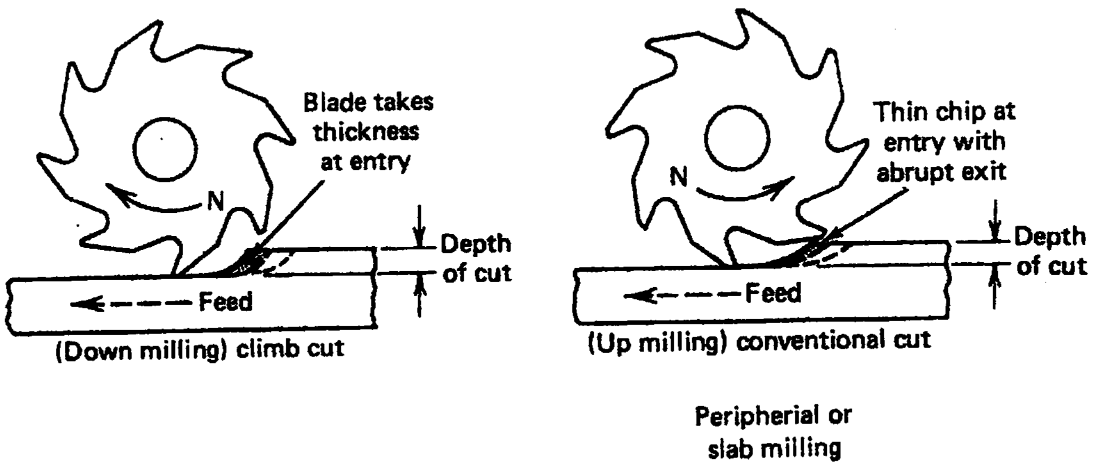


Figure 6.3. Up and Down Milling [40]

In down milling, maximum chip thickness occurs close to the point at which the tooth contacts the work. Because the relative motion tends to pull the work-piece into the cutter, any possibility of looseness in the table feed screw must be eliminated if down milling is to be used. It should never be attempted on machines that are not designed for this type of milling. Virtually all modern milling machines are capable of doing down milling. Because the material yields in approximately a tangential direction at the end of the tooth engagement, there is less tendency for the machined surface to show toothmarks and the cutting process is smoother with less chatter. Another advantage of down milling is that the cutting force tends to hold the work against the machine table, permitting lower clamping forces. However, the fact that the cutter teeth strike against the surface of the work at the beginning of each chip can be a disadvantage if the workpiece has a hard surface, as castings sometimes do. This may cause the teeth to dull rapidly. Metals that readily work-harden should be climb milled. [40]

Milling is an interrupted cutting process wherein entering and leaving the cut subjects the tool to impact loading, cyclic heating, and cyclic cutting forces. The interrupted-cut phenomenon explains in large part why milling cutter teeth are designed to have small positive or negative rakes, particularly when the tool material is carbide or ceramic. These brittle materials tend to be very strong in compression, and negative rake results in the cutting edges' being placed in compression by the cutting forces rather than tension. Cutters made from HSS are made with positive rakes, in the main, but must be run at lower speeds. Positive rake tends to lift the workpiece while negative rakes compress the workpiece and allow heavier cuts to be made. Table 6.2 summarizes some additional milling problems.

Table 6.2 Probable Causes of Milling Problems [42]

PROBLEM	PROBABLE CAUSE	CURES
Chatter (vibration)	1. Lack of rigidity in machine, fixtures, arbor, or workpiece 2. Cutting load too great 3. Dull cutter 4. Poor lubrication 5. Straight-tooth cutter 6. Radial relief too great 7. Rubbing, insufficient clearance	Use larger arbors Decrease feed/tooth or number of teeth in contact with work Sharpen or replace Flood coolant Use helical cutter Check tool angles
Loss of accuracy (cannot hold size)	1. High cutting load causing deflection 2. Chip packing 3. Chips not cleaned away before mounting new piece of work	Decrease number of teeth in contact with work Adjust cutting fluid to wash chips out of teeth
Cutter rapidly dulls	1. Cutting load too great 2. Insufficient coolant	Decrease feed/tooth or number of teeth in contact Add blending oil to coolant
Poor surface finish	1. Feed too high 2. Tool dull 3. Speed too low 4. Not enough cutter teeth	Check to see if all teeth are set at same height
Cutter digs in (hogs into work)	1. Radial relief too great 2. Rake angle too large 3. Improper speed	Check to see that workpiece is not deflecting and is securely clamped
Work burnishing	1. Cut is too light 2. Insufficient radial relief 3. Land too wide	Enlarge feed Sharpen cutter
Cutter burns	1. Not enough lubricant 2. Speed too high	Add sulfur-based oil Reduce cutting speed Flood coolant
Teeth breaking	1. Feed too high	Decrease feed/tooth Use cutter with more teeth Reduce table feed

6.4. MILLING CUTTERS

CNC Milling Cutters can be classified according to the way the cutter is mounted in the machine tool. Arbor cutters have a center hole so they can be mounted on an arbor. Shank cutters have either a tapered or straight integral shank. Those with tapered shanks can be mounted directly in the milling machine spindle, whereas straight-shank cutters are held in a chuck. Facing cutters usually are bolted to the end of a stub arbor. Common types of milling cutters, classified in this manner, are as follows:

ARBOR CUTTERS	SHANK CUTTERS
Plain	End mills
Side	Solids
Staggered-tooth	Inserted-tooth
Slitting saws	Shell
Angle	Hollow
Inserted-tooth	T-slot
Form	Woodruff key seat
Fly	Fly

Figure 6.4 shows types of arbor-type milling cutters.

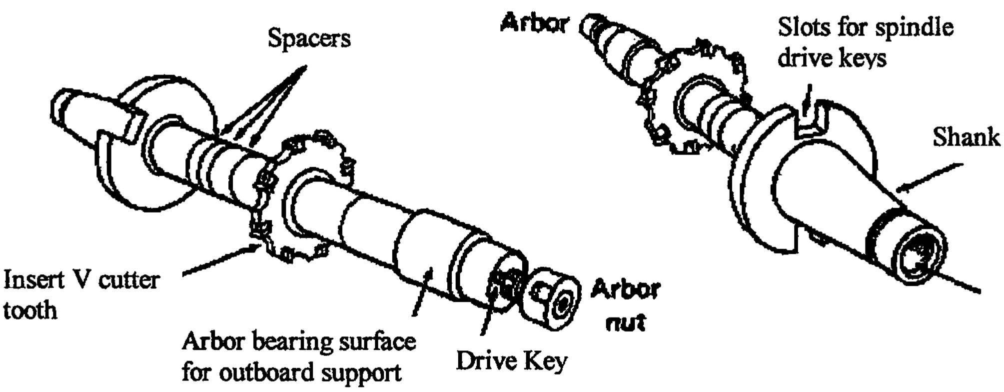


Figure 6.4. Arbor-Type Milling Cutters [40]

Another method of classification applies only to face and end-mill cutters, and relates to the direction of rotation. A right-hand cutter must rotate counterclockwise when viewed from the front end of the machine spindle. Similarly, a left-hand cutter must rotate clockwise. All other cutters can be reversed on the arbor to change them from one hand to the other. Positive rake angles are used on general-purpose HSS milling cutters. Negative rake angles are commonly used on carbide- and ceramic-tipped cutters employed in mass-production milling in order to obtain the greater strength and cooling capacity, which they provide. TiN coating of these tools is quite common, resulting in significant increases in tool life.

6.5. TYPES OF MILLING CUTTERS

Milling cutters are classified by their different properties. Milling cutters are usually made of high-speed steel and are available in a great variety of shapes and sizes for various purposes. The names of the most common classifications of cutters, their uses, and, in a general way, are stated below sections.

6.5.1. Plain Milling Cutters

These type of cutters are used for plain or slab milling have straight or helical teeth on the periphery and are used for milling flat surfaces. Helical mills (Figure 6.5) engage the work gradually, and usually more than one tooth cuts at a given time. This reduces shock and chattering tendencies and promotes a smoother surface. Consequently, this type of cutter usually is preferred over one with straight teeth.

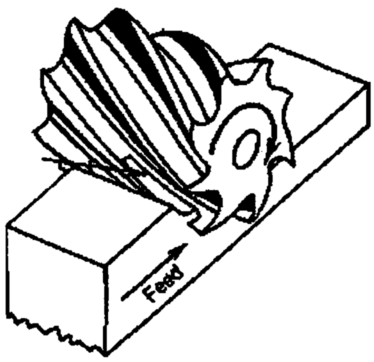


Figure 6.5. Helical–tooth Milling Cutter [40]

6.5.2. Side Milling Cutters

Side milling cutters are similar to plain milling cutters except that the teeth extend radially part way across one or both ends of the cylinder toward the center. The teeth may be either straight or helical. When teeth are added to one side only, the cutter is called a half-side milling cutter and is identified as being either a right-hand or left-hand cutter. Side milling cutters are generally used for slotting and straddle milling.

6.5.3. Interlocking Milling Cutters

Interlocking slotting cutters consist of two cutters similar to side mills but made to operate as a unit for milling slots. The two cutters are adjusted to the desired width by inserting shims between them. Interlocking tooth side milling cutters can be repeatedly sharpened without changing the width of the slot they will machine.

6.5.4. Staggered Milling Cutters

Interlocking tooth side milling cutters and staggered tooth side milling cutters are used for cutting relatively wide slots with accuracy. Staggered-tooth milling cutters are narrow cylindrical cutters having staggered teeth, and with alternate teeth having opposite helix angles. They are ground to cut only on the periphery, but each tooth also has chip clearance ground on the protruding side. These cutters have a free cutting action that makes them particularly effective in milling deep slots.

6.5.5. Slitting Saws

Slitting saw teeth are either straight or helical in the smaller sizes of plain milling cutters, metal slitting saw milling cutters, and end milling cutters. The cutting edge is usually given about 5 degrees primary clearance. Sometimes the teeth are provided with offset nicks, which break up chips and make coarser feeds possible. Slitting saws are thin, plain milling cutters, usually from 0.8 mm to 4.8 mm in thick, which have their sides slightly "dished" to provide clearance and prevent binding. They usually have more teeth per unit of diameter than ordinary plain milling cutters and are used for milling deep narrow slots and cutting-off operations.

6.5.6. Angle Milling Cutters

Angle milling cutters are made in two types: single-angle and double-angle. Angle cutters are used for milling slots of various angles or for milling the edges of workpieces to a desired angle. Single-angle cutters have teeth on the conical surface, usually at an angle of 45 to 60 degrees to the plane face. Double-angle cutters have V-shaped teeth, with both conical surfaces at an angle to the end faces, but not necessarily at the same angle. The angle of the cutter edge is usually 30°, 45°, or 60°, both right and left. Double-angle cutters have included angles of 45, 60, and 90 degrees.

Most larger-sized milling cutters are of the inserted-tooth type. The cutter body is made of steel, with the teeth made of high-speed steel, carbides, or TiN carbides, fastened to the body by various methods. This type of construction reduces the amount of costly material that is required and can be used for any type of cutter but most often is used with face mills.

6.5.7. Form Milling Cutters

Form milling cutters have the teeth ground to a special shape, usually an irregular contour, to produce a surface having a desired transverse contour. They must be sharpened by grinding only the tooth face, thereby retaining the original contour as long as the plane of the face remains unchanged with respect to the axis of rotation. Convex, concave, corner-rounding, and gear-tooth cutters are common examples.

6.5.8. End Milling Cutters

End mills are shank-type cutters having teeth on the circumferential surface and one end. They thus can be used for facing, profiling, and end milling. The teeth may be either straight or helical, but the latter is more common. Small end mills have straight shanks, whereas taper shanks are used on larger sizes.

6.5.9. Plain End Milling Cutters

Plain end mills have multiple teeth that extend only about halfway toward the center on the end. They are used in milling slots, profiling, and facing narrow surfaces. Two-lip mills have two straight or helical teeth that extend to the center. Thus they may be sunk into material, like a drill, and then fed lengthwise to form a groove.

6.5.10. Shell End Milling Cutters

Shell end mills are solid-type, multiple-tooth cutters, similar to plain end mills but without a shank. The center of the face is recessed to receive a screw head or nut for mounting the cutter on a separate shank or a stub arbor. One shank can hold any of several cutters and thus provides great economy for larger-sized end mills.

6.5.11. Hollow End Milling Cutters

Hollow end mills are tubular in cross section, with teeth only on the end but having internal clearance. They are used primarily on automatic screw machines for sizing cylindrical stock, producing a short cylindrical surface of accurate diameter.

6.5.12. T-Slot Cutters

T-slot cutters are integral-shank cutters with teeth on the periphery and both sides. They are used for milling the wide groove of a T-slot. In order to use them, the vertical groove must first be made with a slotting mill or an end mill to provide clearance for the shank. Because the T-slot cutter cuts on five surfaces simultaneously, it must be fed with care.

6.5.13. Woodruff Keyseat Cutters

Woodruffkey seat cutters are made for the single purpose of milling the semi-cylindrical seats required in shafts for Woodruff keys. They come in standard sizes corresponding to Woodruff key sizes. Those below 2 inches in diameter have integral shanks; the larger sizes may be arbor-mounted.

CHAPTER 7

INTELLIGENT CUTTING TOOL SELECTION SYSTEM

7.1 INTRODUCTION

In this chapter, the intelligent cutting tool selection system developed in this study is discussed. The features of prepared computer program and the method used in the programming are presented.

7.2. GENERAL APPROACH FOR CUTTING TOOL SELECTION

Knowledge base for Intelligent Cutting Tool Selection System (ICTSS) should include which is prepared by this thesis, includes the following functions..

1. Selection of workpiece material
2. Selection of manufacturing processes
3. Selection of machine tools
4. Selection of cutting tools
5. Determination of machining condition

The development of systems for the automatic selection of cutting tools for machining operations is in its infancy, and the tool selection process is still carried out manually through searching of catalogues and manuals.

The suitable selection of cutting tools and conditions cannot be simply based upon the familiarity, experience and the memory of individuals. A system is required to identify and specify various tools and to verify their suitability and availability.

In the current study, manual-based tool selection system is equipped with a suitable methodology. This system includes the following features:

- A cutting tool database,
- A method of defining component geometry,
- A method optimizing cutting conditions,
- An interface with the end user.

The prepared computer program is written in DELPHI 5.1 programming language on personal computer. The system is extended by the use of following:

- Borland Delphi, (which supported object-oriented programming)
- Paradox 7.0 Database
- Microsoft Access Database
- SQL, (enables the knowledge to be represented in a rule and frame format)
- HTML Codes,
- Autocad 2000
- Adobe Acrobat Photoshop 5.5

The system also has the facility to interface with any tool manufacture and enable them to place their tooling system in the package. In addition, the system should be flexible enough to enable the user to feed his own shop floor experience into the system and adapt it to specific requirements.

The Intelligent Cutting Tool Selection System (ICTSS), which can select cutting tools and cutting conditions for operations, is developed based upon several considerations. (Figure 7.1) illustrates the general configuration of the ICTSS.

In the design of ICTSS, the following considerations were considered;

1. System is developed in a modular basis to add different machining operations and tool manufacturers.
2. It permits the user to develop the knowledge base, about either material or cutting tool. Initial tool selection is made from the tools available in the current knowledge base
3. For a given set of input, the system can select the cutting tool from cutting tool manufacturer's catalogues, which is initially loaded into the system.
4. It selects optimized cutting parameters according to the criteria used in manufacturing industry

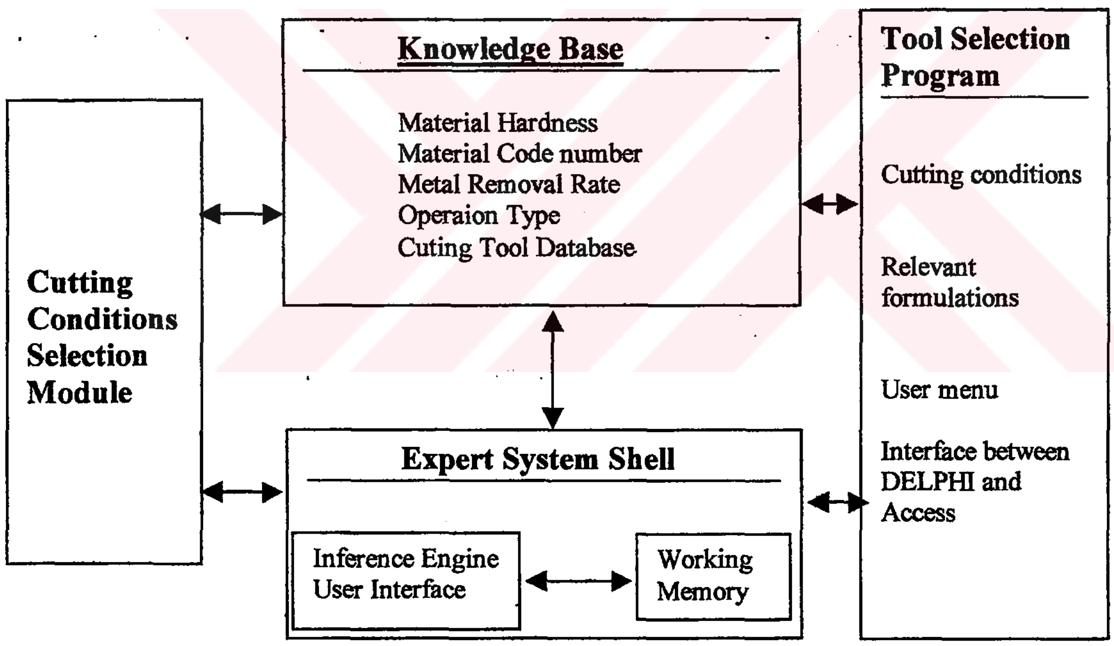


Fig. 7.1. ICTSS System Configuration

The system examines the workpiece material feature geometry and type of machining operation selected for the feature and determines the tool specifications by applying related rules in the knowledge base. It then generates the necessary cutting tool characteristics based on the workpiece material, the geometry of part features and operation type, etc. Once these characteristics have been determined the cutting tool file is searched to find a tool, which fulfills such characteristics. The rest of the tools are discarded in the cutting tool data file, which cannot be used to carry out the operations.

7.3. CUTTING TOOLS IN A DATA BASE

7.3.1 The Program Database

The developed software has a multilanguage option that can be used under various languages i.e. English, Turkish .etc. It can store data from various firms (Seko,Hertel..etc.) appropriate for cutting tools to be classified under hierarchy tree. A database structure was formed using Paradox 7.0, to transfer image and numeric data fast to the user and to respond fast to query of SQL and Delphi 5. One of the most difficult tasks in the addition of the data to the database was the hierarchy tree in the database. A part of the hierarchy tree is shown in Figure 7.2 .

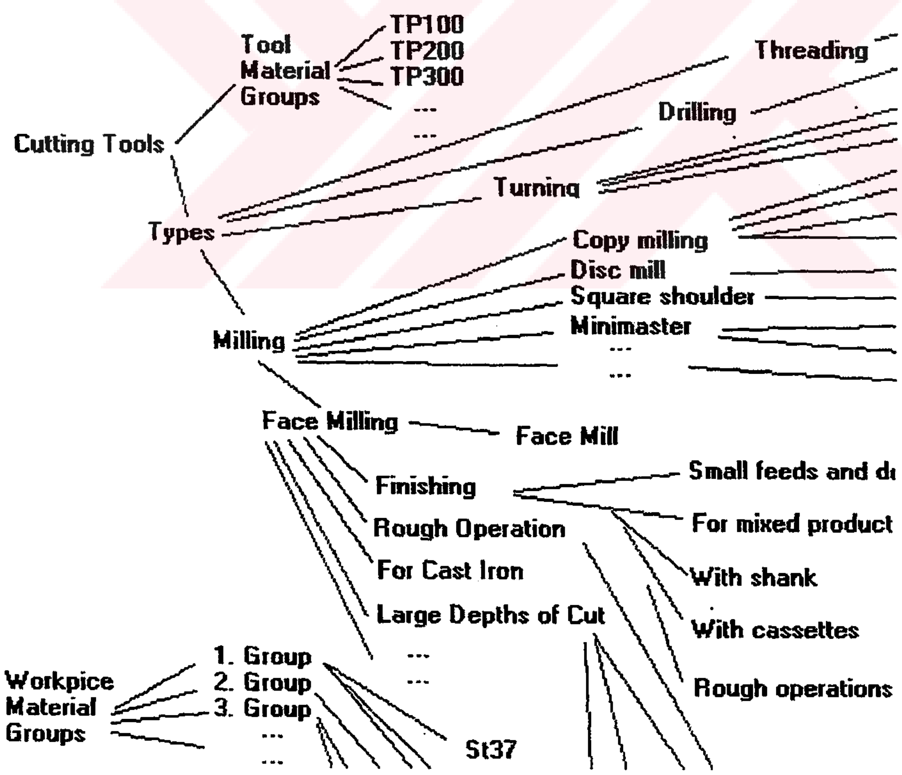


Fig. 7.2 Cutting Tools and Workpiece Material Groups Hierarchy Tree

To be able tp solve the tree structure in the database, 3 field are as namely, ID, Group uppergroup shown in figure 7.3 were added to the database structure. The binary tree structures of the fields were solved by means of paths shown by arrows shown below.

From Machining Types Database. Turning ID=2064400

Toolholder Groups Database	ID	GroupID	Name1	Name2	Active	UpperGroup	Enabled	Bresim	Kresim
	2064400	2064384	Tool holders for turning		TRUE	TRUE	TRUE	(Picture)	(Picture)
	2064516	2064400	Turning	External	TRUE	TRUE	TRUE	(Picture)	(Picture)
	2064550	2064516	External turning	ISO-C holders	TRUE	TRUE	TRUE	(Picture)	(Picture)
	2064883	2064550	External turning	CS..	TRUE	TRUE	TRUE	(Picture)	(Picture)
	2064960	2064883	External turning	CSDN..	TRUE	FALSE	TRUE	(Picture)	(Picture)

	ID	GroupID	Rem1	Tool Material	MatchC1	MatchM1	Teeth	CLength	Length	MainA	CRadius
Toolholder	2072597	2064960	CSDNN3225P12		65786	65691	1	12	0	45	0
Insert	2069794	2064479	SNUN120408	TP100		65786	0	12	12,7	0	0,8

Fig. 7.3 The Interrelationship Between Toolholder Groups and Toolholder Database.

Data fields of toolholder groups and toolholder databases and the arrows indicating the interrelations between them are shown above.

The solution of the Binary Tree Storage algorithm is given in Figure 7.4.

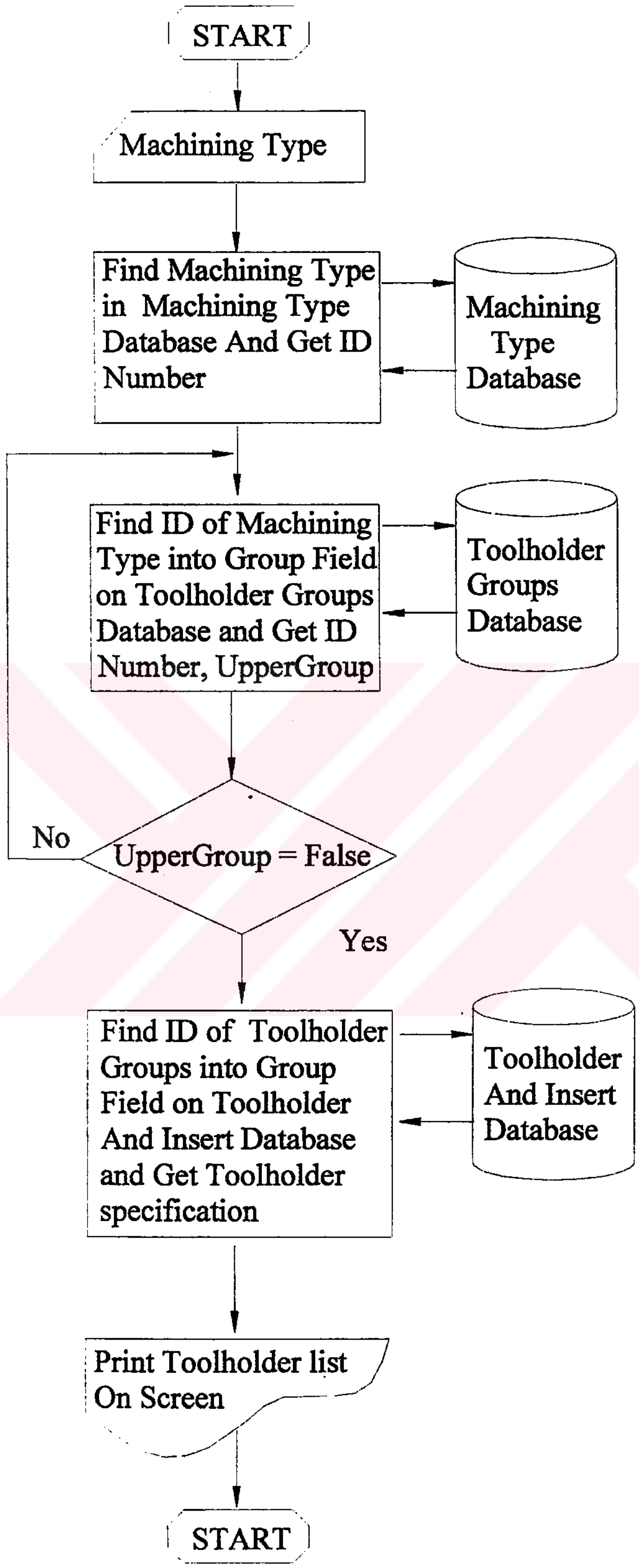


Fig. 7.4. The Algorithm of Binary Tree Storage Method.

Since available using Cutting Tool Catalogs data on computer program was insufficient, Cutting Tool Catalogs in Portable Document Format (PDF) were ordered from various firms. These Catalogs were mailed by these firms. As a result a huge document of 180 PDF files was obtained. This document was tried to be added to the software, but the PDF formatted documents were Acrobat Reader files which did not let them to construct an interface between various programs. These PDF files could only be used by calling them from Internet Explorer. By doing so the PDF files embedding themselves into the explorer were used by a different interface construction.

In order to construct an interface by embedding PDF files, Microsoft COM "Component Object Model" technology was due to use the advantages of object oriented programming. By obeying the rules of COM on OLE (Object Linking and Embedding) the program's own "Internet Explorer" was formed. Afterwards, web site calling these PDF files in HTML format was constructed. As soon as the site called PDF and Acrobat reader is embedded into the program. As a result, a user-friendly interface is constructed between Acrobat Reader.

The codes enabling the interface between Acrobat Reader by using OLE technology is given Figure 7.5.

```
procedure TFrmCatalog.FormPaint(Sender: TObject);
   var f:OleVariant;
begin
     // When Program are Painted, show own internet browser that copied
     // internet explorer object
  f:=0;
  WebBrowser1.Navigate(WideString('C:\Belgelerim\ictsse_cat.htm'),f,f,f,f)
end;


procedure TFrmCatalog.FormClose(Sender: TObject; var Action: TCloseAction);
begin       // When Program are closed, close Web Browser.
        Action := caFree;
end;
```

Fig.7.5. Computer Programs Code Share the Internet Explorer Objects with OLE Technology.

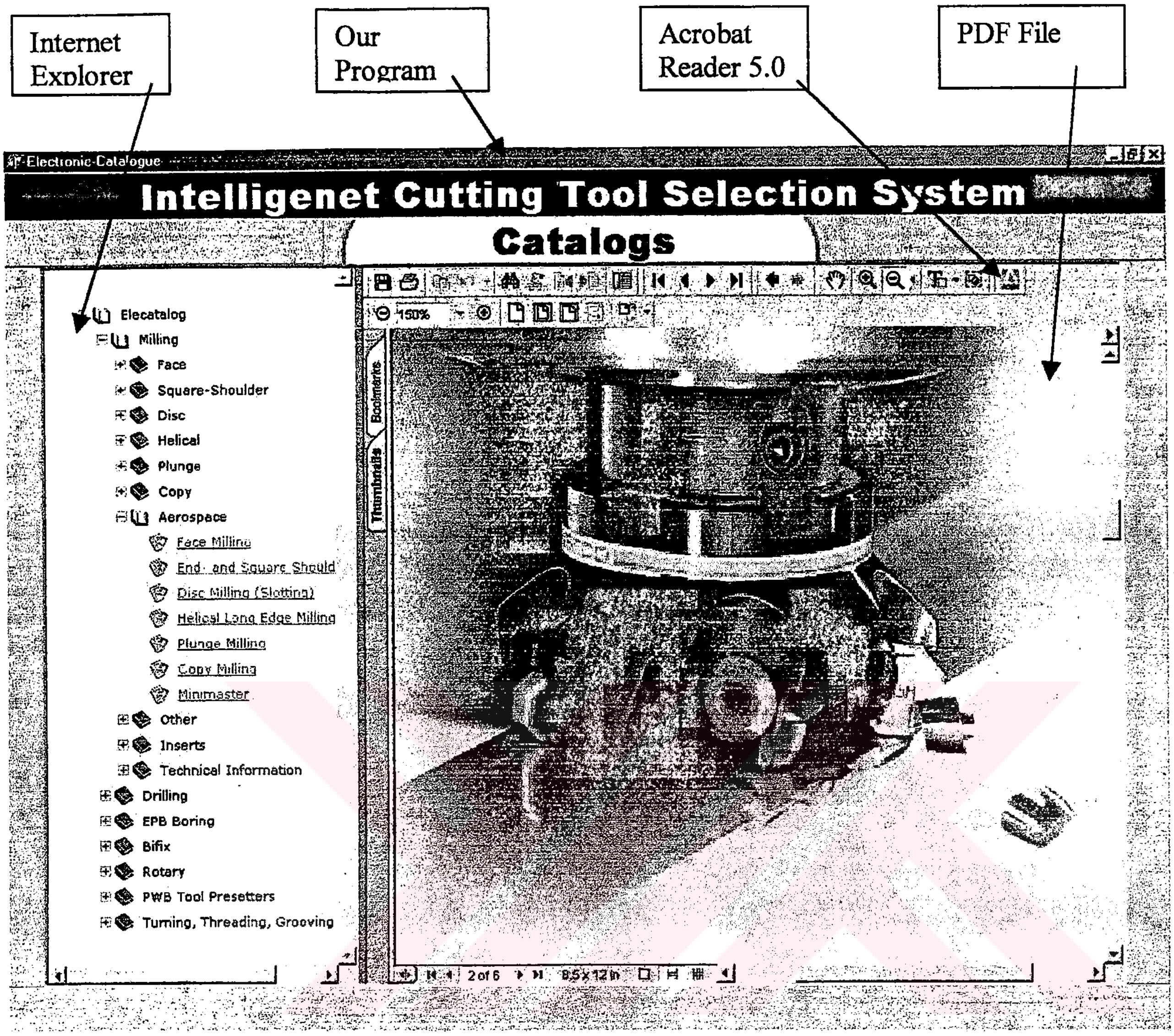


Fig.7.6 Acrobat Reader Embedded As An Interface In The Program.

On a working time the program has worked a bit slowly because there were many kinds of tools and the image data were of very large sizes. Paradox Database Program and Borland Database Engine (BDE) were not sufficient enough to use the big data (above 200MB) of database. Therefore Microsoft ODBC was used because it enabled us to use The Database of Microsoft access. The Database of Microsoft access stores images and enables the query significantly faster. As a result database engine for both ODBC and BDE were used in the program.

Microsoft Database Engine (ODBC) is given in Figure 7.7 and Borland Database Engine (BDE) is given Figure 7.8

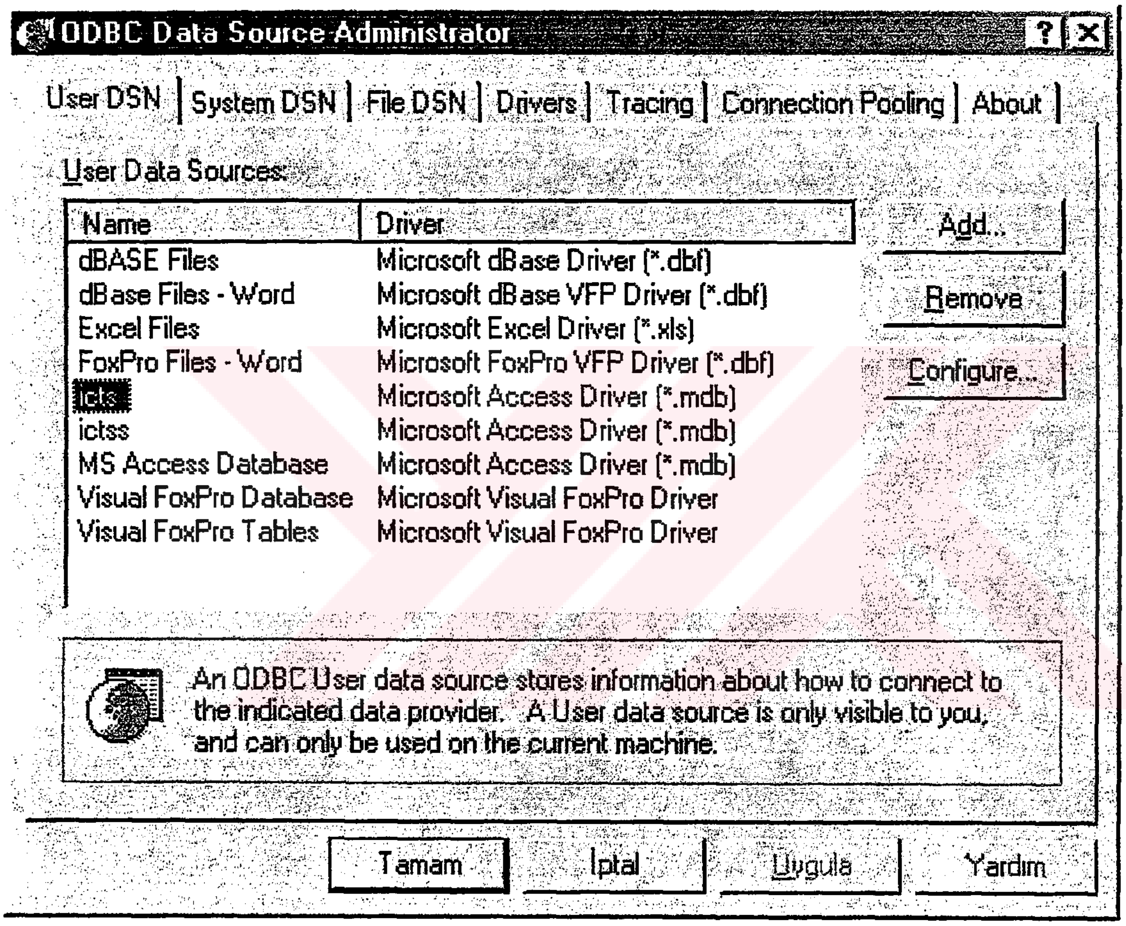


Fig. 7.7 ODBC (Microsoft Database Engine)

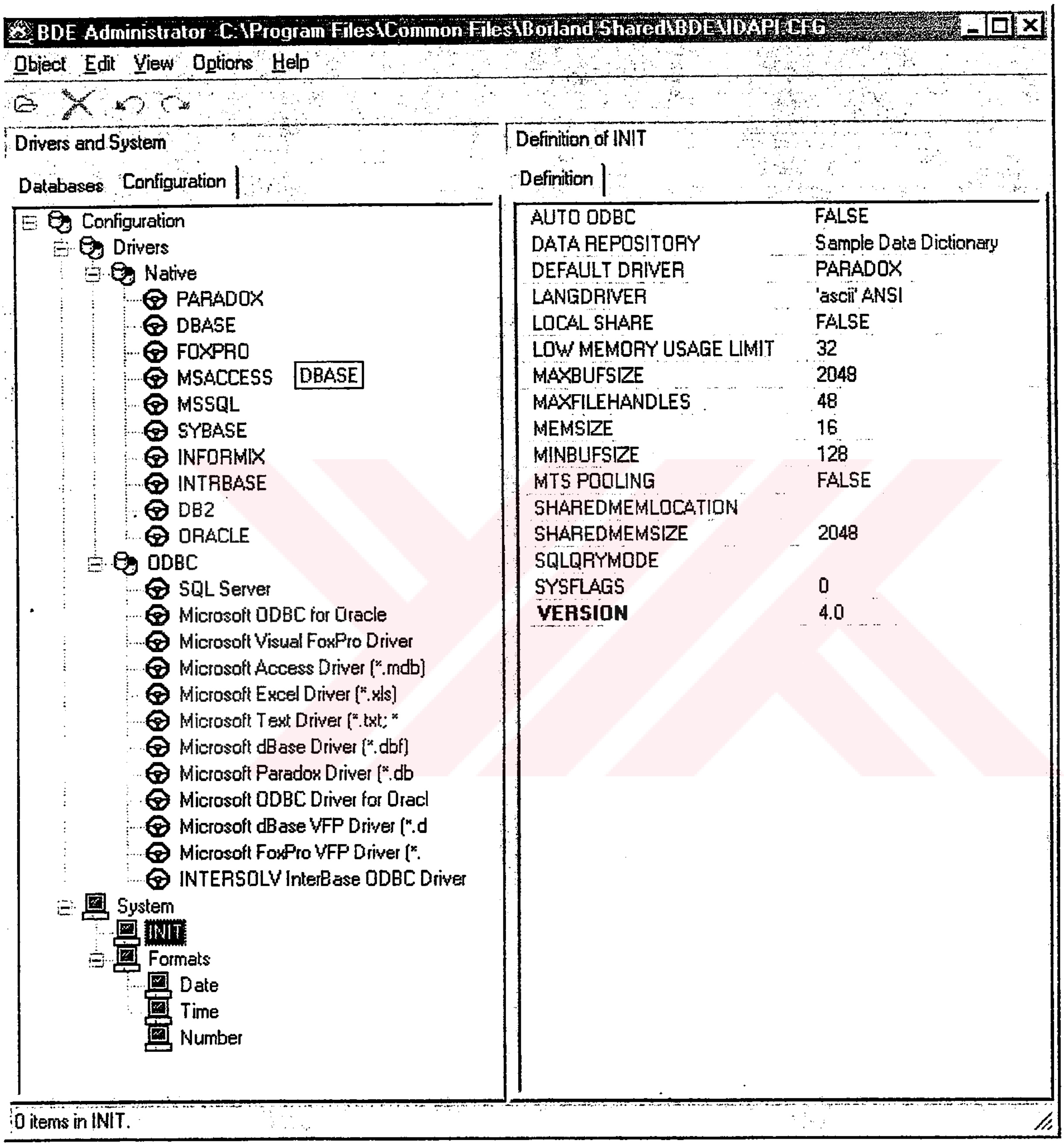


Fig 7.8 BDE (Borland Database Engine)

Transferring catalog data to the database takes a long time. Some of the data was entered manually. Scanning entered some of it and the rest of the data was entered from PDF format, which has been copied, and paste on Microsoft Excel Programs. This Microsoft Excel data was transferred by an interface formed by using Microsoft COM [38] Technology that is written in Figure 7.9. This interface program automatically transfers the data in the Excel files to the own database of the developed program.

```
// This Program Copy a matrix that is 1000 row and 2 columns from
// Microsoft Excel and store that matrix in Table1 Database.
-   ------
-   ------
type
-   ------
-   ------
  private
    MyExcel: Variant;
-   ------
-   ------
  public
  end;
var
  Form1: TForm1;
implementation

uses
  ComObj, XLConst;

{$R *.DFM}

procedure TForm1.FormDestroy(Sender: TObject);
begin
  if not VarIsEmpty(MyExcel) then begin
    MyExcel.DisplayAlerts := False;  // Discard unsaved files....
    MyExcel.Quit;
  end;
end;
```

Fig 7.9. Computer Programs Code, Which Do Interface With Microsoft Excel

```
procedure TForm1.Button1Click(Sender: TObject);
begin
  MyExcel:= CreateOleObject('Excel.Application');
  MyExcel.Visible := True;
  MyExcel.Workbooks.Add(xlWBatWorkSheet);
  MyExcel.Workbooks[1].WorkSheets[1].Name := 'MyEmin';
  InsertData;
  HandleRange;
  ChangeColumns;
end;

procedure TForm1.InsertData;
var
  i: Integer;
  Sheet: Variant;
begin
  Sheet := MyExcel.Workbooks[1].WorkSheets['MyEmin'];
  for i := 1 to 1000 do
    DM.Table1.insert;
    DM.Table1Name1:=Sheet.Cells[i, 1];
    DM.Table1Name1:=Sheet.Cells[i, 1];
    DM.Next;
end;
end.
```

Fig 7.9. Computer Programs Code, Which Do Interface With Microsoft Excel (Continued)

By using the above specifications of the program over 500 Toolholder groups and 9400 Toolholder and inserts were stored in the developed program database material 788 different types among 30 material groups were stored in the database. Also Maximum feed, maximum depth-of–cut, and cutting velocity of various workpiece for each cutting is stored in the database. The reason why such a large amount of data is entered is for preparation of further study.

A Database Module is given Figure 7.10, is formed to call the database files in the program. The advantage of this module is that it works fast without error. The database module serves as a buffer by reading the data from the harddisk and the storing it to the RAM of the computer. The database is taught the interrelation of the data between each other. It also enables other modules or interfaces of the developed program to transfer data directly without referring to the database.

7.3.2 Database and Expert Module

Cutting tools are stored in a database using Microsoft Access and Paradox of DELPHI. Cutting tool facts are structured in readable format. But in expert module, the program has a facility to add new cutting tools (Figure 7.10.).

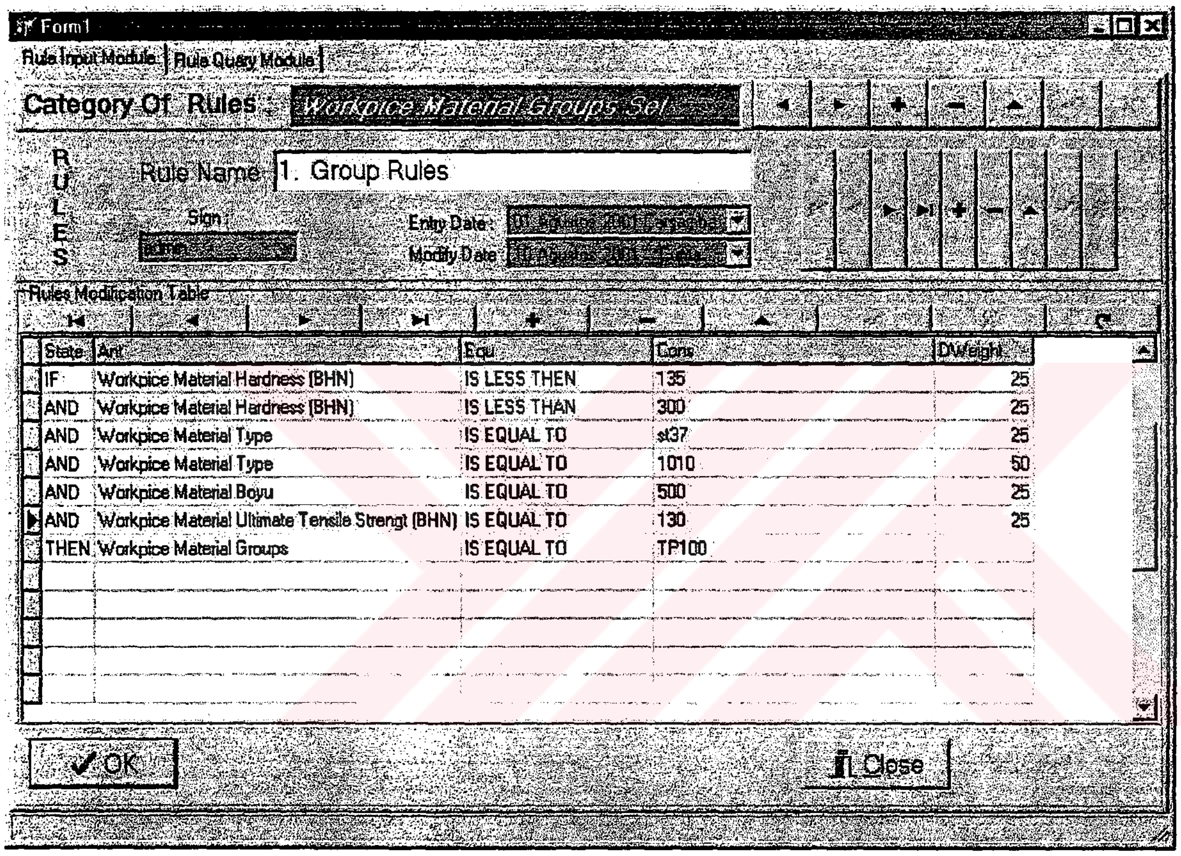


Figure 7.10. Cutting Tool Expert Module

The information of cutting tools has been taken from the machining data handbooks and *Tools Company Catalogues* [40,41,42,43,44,45,46]. In the following Table 7.11 a small section of cutting tool database are presented. In this table, *groupID* represents cutting tool number, which is used in programming logic. *Position* is the sequence of the cutter in the related list. The other two columns represent the holder name and holder type respectively. Although, more than these knowledge are in hand, but some them are not presented for the sake of brevity.

Table 7.11. Cutting Tool Data Base

GroupID	Position	Holder Name	Holder Type
2064508	1	R220.13-09	Small feeds and depths of cut
2064508	3	R220.13-09C/09CG/09CT	With cassettes
2064508	5	R220.13-12C(4)/12CG/12CT(4)	With cassettes
2064508	4	R220.13-12	For mixed production
2064508	6	R220.13-15	For mixed production
2064388	3	R220.29-10CH	Rough operations
2064982	2	R220.74-12	For machining hard materials
2064398	2	Square shoulder and slot	milling cutters
2064542	1	Copy mill - round inserts	R217.29 / R220.29
2064718	2	R220.69-09/09T Micro Turbo	for small depth of cut
2064510	3	R217.69/R220.69-15.XH	For large depths of cut
2064510	4	R220.69-15H	Difficult operations
2064766	1	R217.90/R220.90-26	Cutting depths up to 20 mm
2064724	1	Disc mill 335.18	Slotting width 14-18.5 mm
2064768	2	R220.99-09	for mixed production
2064512	6	R235.15A	Finishing
2064725	1	Disc mill 335.19	Slotting width 4-12 mm
2064724	2	Disc mill R335.18	Slotting width 14-30,5 mm
2064725	2	Disc mill R335.19	Slotting width 4-12 mm
2064744	5	R217.79-16	medium rough and rough op.
2064744	3	R220.79-12	Rough operations
2064508	2	R217.13-09	With shank
2064506	1	R220.43-05	Small depths of cut
2064396	4	Groove milling cutter R335.15	Slotting width 1.10-2.65 mm
2064398	6	Thread milling cutters	R396.18
2064387	1	Turning, threading, MDT and	parting off inserts
2064387	3	Drilling inserts and Reamer	blades
2064539	1	Disc mill R335.10	mounted on holder
2064723	3	Disc mill R335.10	with weldon holder
2064398	7	Minimaster	Shanks and inserts
2064435	2	Minimaster insert	Centre drilling
2064778	1	SD52-R7	ISO 9766 Shank
2064780	1	SD55-R7	ISO 9766 shank
2064435	3	Minimaster insert	Copy mill
2064435	4	Minimaster insert	Slotting/square should milling
2064444	1	Milling inserts	Shape A..
2064444	3	Milling inserts	Shape O..
2064444	4	Milling inserts	Shape R..
2064471	3	Milling inserts	Shape SE..
2064444	2	Milling inserts	Shape C..

7.4. CUTTING TOOL MATERIAL SELECTION MODULE

Tool material selection involves two stages:

Stage one involves the component material selection. There are two options for selecting component material. The first option allows the user to select the component material from the material database, which is linked to the system. The second option allows users to rely on their own knowledge and thus enter the component material themselves.

In stage two, the user has to describe this selected material by inputting its mechanical properties such as hardness, Young's Modulus, tensile strength, thermal properties and the cutting temperature. The user has to select and input the hardness value. After inputting the hardness value, the user then enters the values of tensile strength, Young's Modulus, thermal conductivity and cutting temperature (Figure 7.11). On the other hand, mechanical and thermal properties of the component material can also be entered to the system. The system provides a set of rules, which are used to select tool material type that would be suitable for machining this type of component material.

In the following an example for workpiece selection is given in word format and then in programming logic respectively.

> **IF**
>
> Workpiece hardness is less than 250 BHN and Young's modulus is less than 220 GPa, tensile strength is less than 500 MPa, thermal conductivity greater than 10 W/M.K, and less than 60 W/M.K, and cutting temperature is less than 200°C,
>
> **THEN**
>
> Suitable cutting tool material for machining this material is coated cemented tungsten carbide.

IF

Workpiece_hardness > 0 BHN And

Workpiece_hardness < 250 BHN

Workpiece_youngs_modulus > 0 GPa and

Workpiece_youngs_modulus < 220 Gpa

Workpiece_tensile_strength > 0 MPA And

Workpiece_tensile_strength < 500 Mpa

Workpiece_thermal_conductivity > 10W/M.K And

Workpiece_thermal_conductivity < 60 W/M.K

Workpiece_cutting_temperature > 0^0 C And

Workpiece_cutting temperature < 200^0 C

THEN
{Set_value_for_tool_material} is "Tool material is Coated Cemented Tungsten Carbide"

7.5. EXECUTION OF THE PROGRAM

This computer program is written in DELPHI computer programming language. Main structure of the program is formed by databases of Delphi, Paradox, Microsoft Access and Excel.

When the program is executed, the main opening screen, shown in Figure 7.3, presents three choices for cutting tool selection. These are:

- Manual
- Automatic
- Catalogue

When "Manual" choice is picked, all of the cutting tools, which are classified by their machining type, are presented on the screen and user selects one of them. When "Automatic" choice is picked, cutting tool is selected by entering machining type, operation type and material properties. "Catalogue" choice is used for wide range of cutting listing. Also technical information is available in this section.

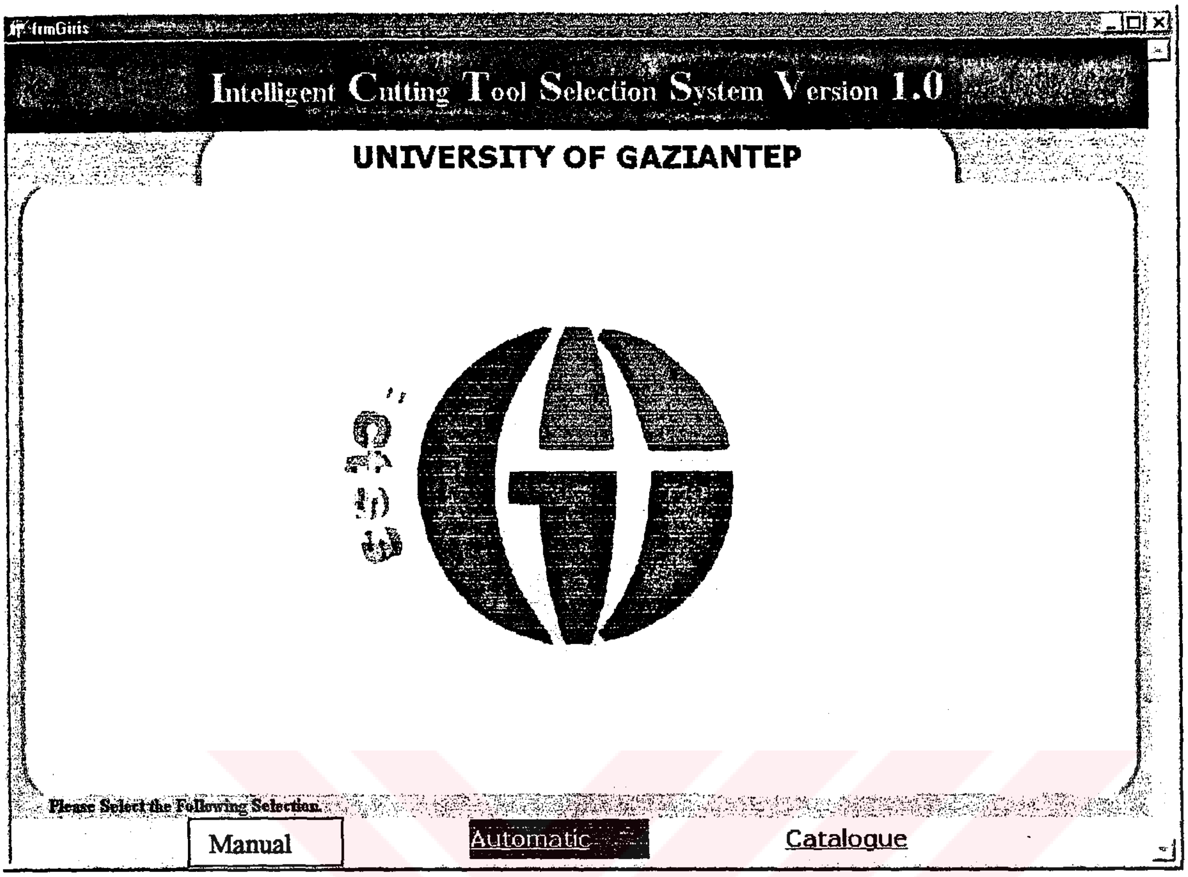


Figure 7.12. Main Opening Screen of the Program

7.5.1. Manual Choice

When "Manual" button is klicked, four types of machining are seen on the left hand side of the screen. These four machining types are:

1. Turning
2. Milling
3. Drilling
4. Threading

Each type has also subgroups. Once one of them is selected, the subgroup of this machining type is screened immediately at the same place. User can select one of the choices. The cutting tool for selected machining type is appeared on the right hand side of the screen with an extensive data. Cutting tool material is also available in the data.

Figures 7.13 to 7.16 are the picture of turning, milling, drilling and threading from the program screen, respectively.

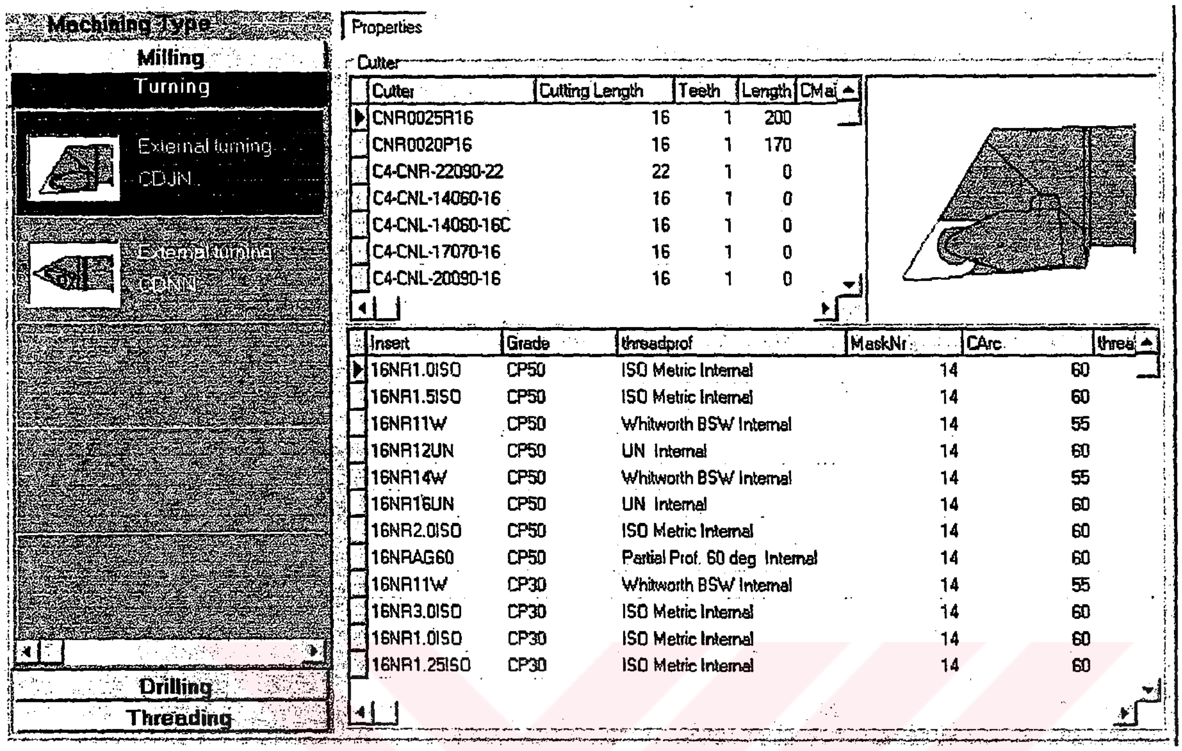


Figure 7.13 Turning Screen from Manual Button

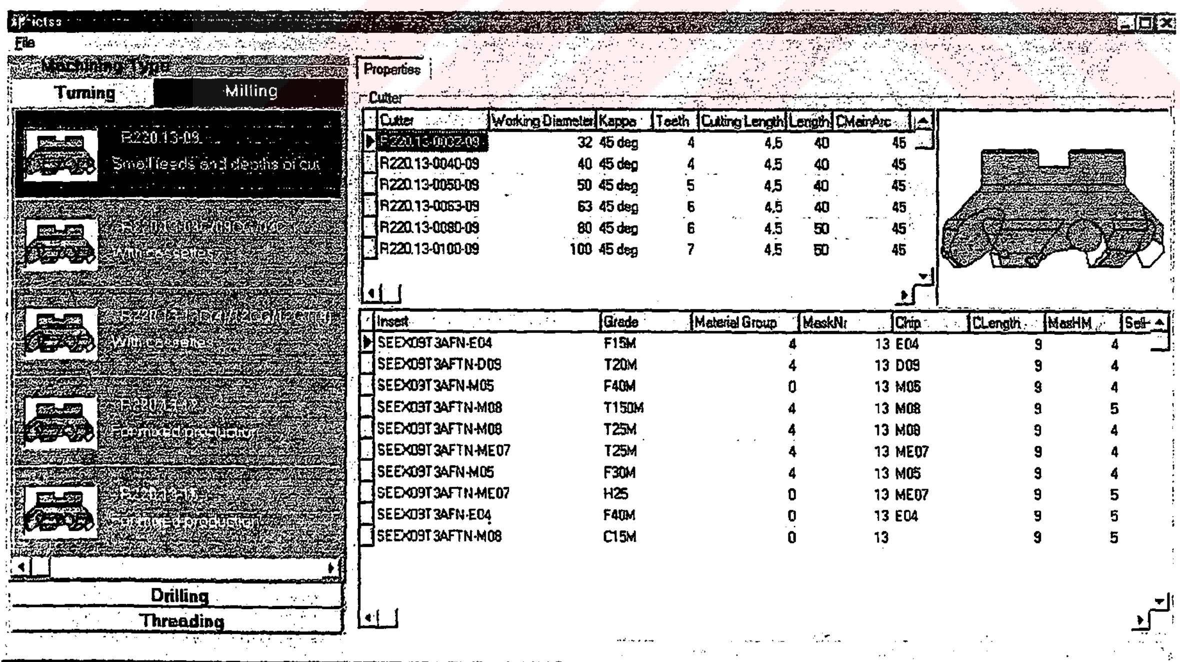


Figure 7.14 Milling Screen from Manual Button

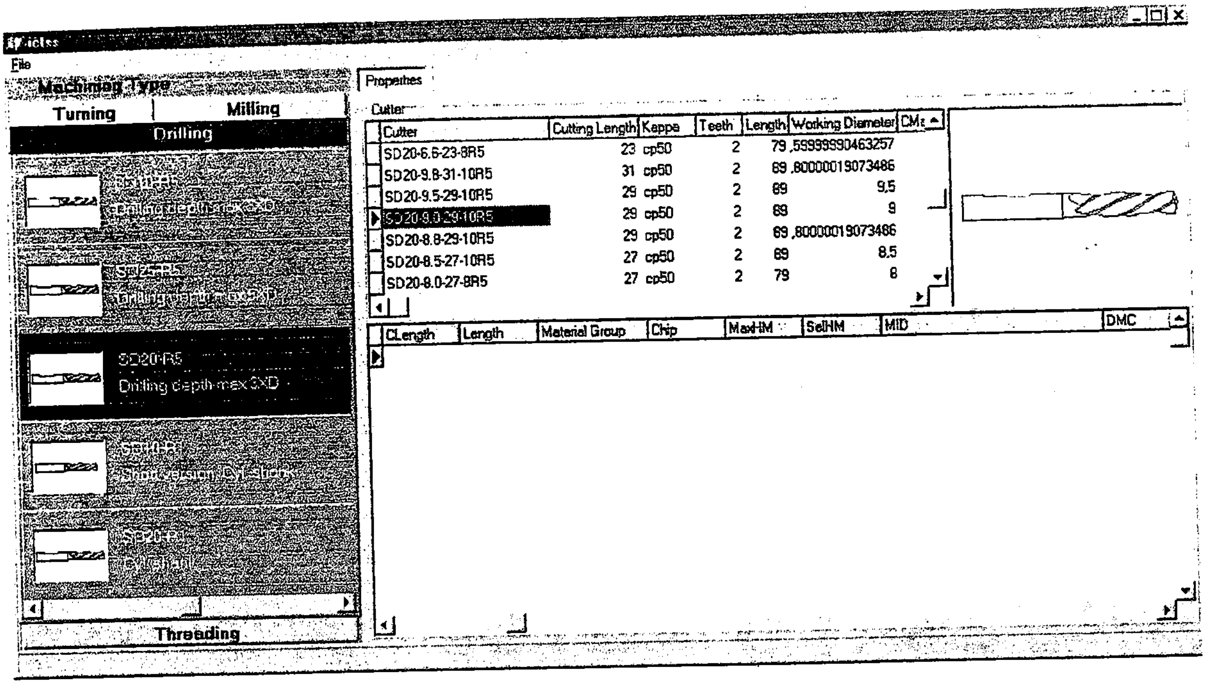


Figure 7.15 Drilling Screen from Manual Button

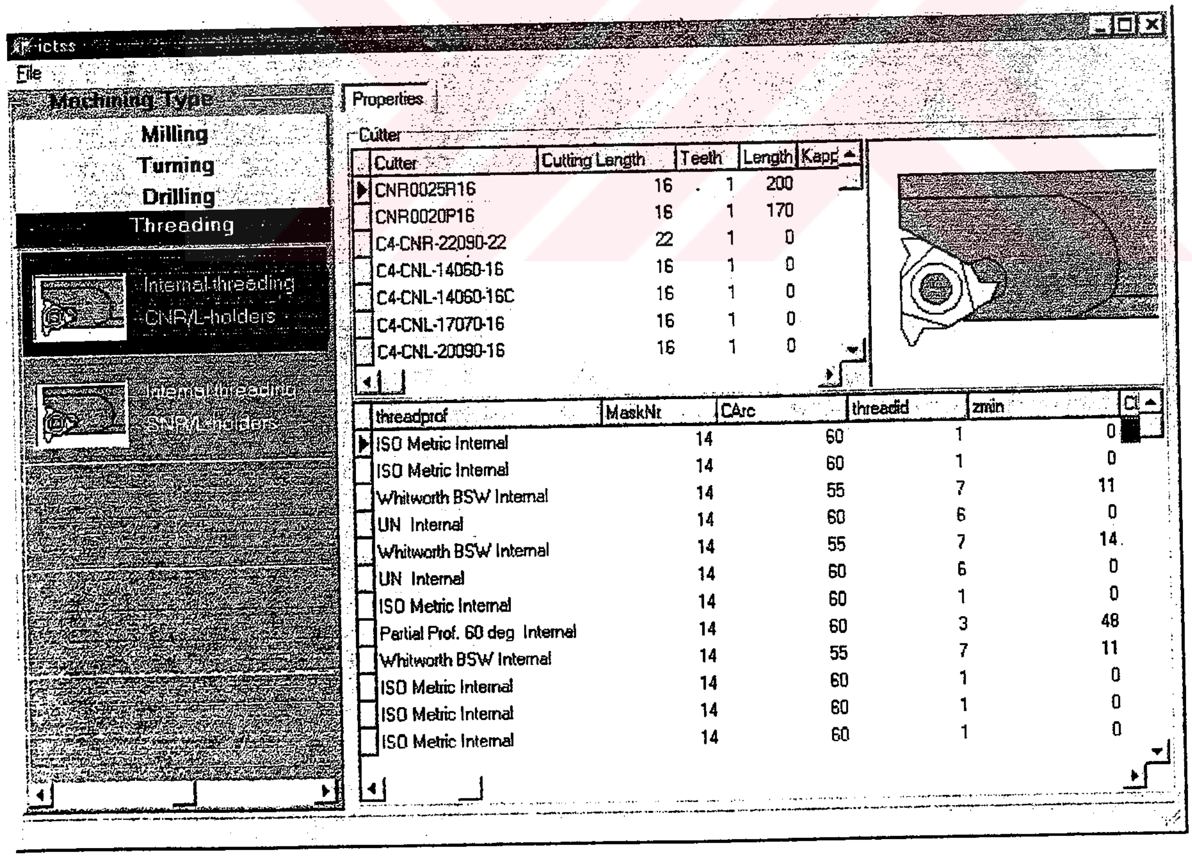


Figure 7.16 Threading Screen from Manual Button

7.5.2. Automatic Sub - Module

The following Figure 7.17 shows the main screen for automatic button. Left hand side is used for inputting data and right hand side is used for outputting data. The necessary data is provided by the user in INPUT DATA section and then program gives output data in OUTPUT DATA section.

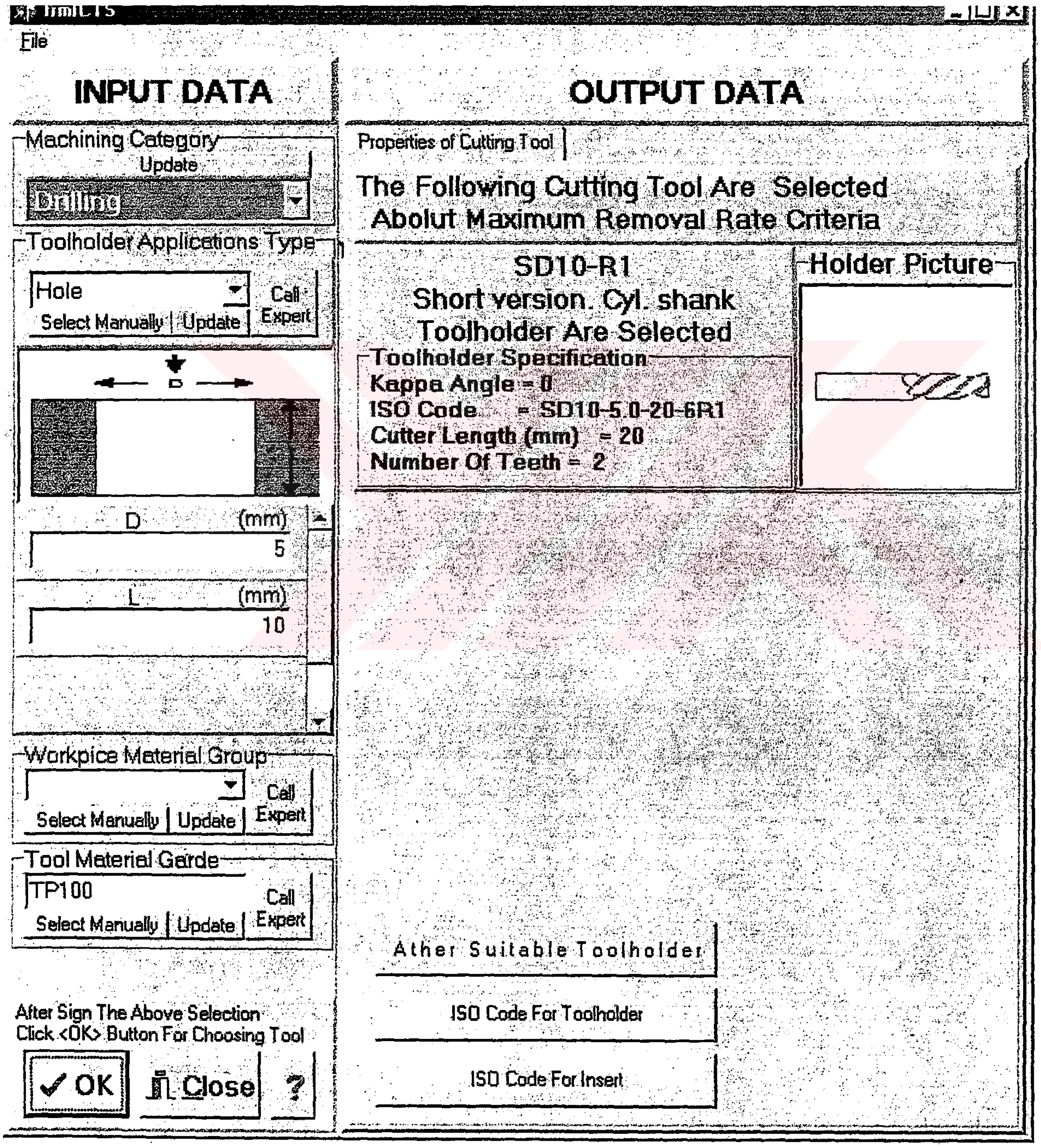


Fig. 7.17. Main Screen for Automatic Button

In the machining category there are three machining type, such as turning, milling, and drilling as in the case of Manuel selection. At this section "Update" button can only be used by experts. A new machining type can be added by an expert by using this button. Due to expert system methodology, adding a new machining or operation type does not affect the structure of the program. For each machining type, there is also a set of application type. For example;

Machining Type: Turning

Available Operation Types: Straight turning, facing, taper turning, profiling, side grooving, face grooving, drilling, boring, chamfering and cut-off.

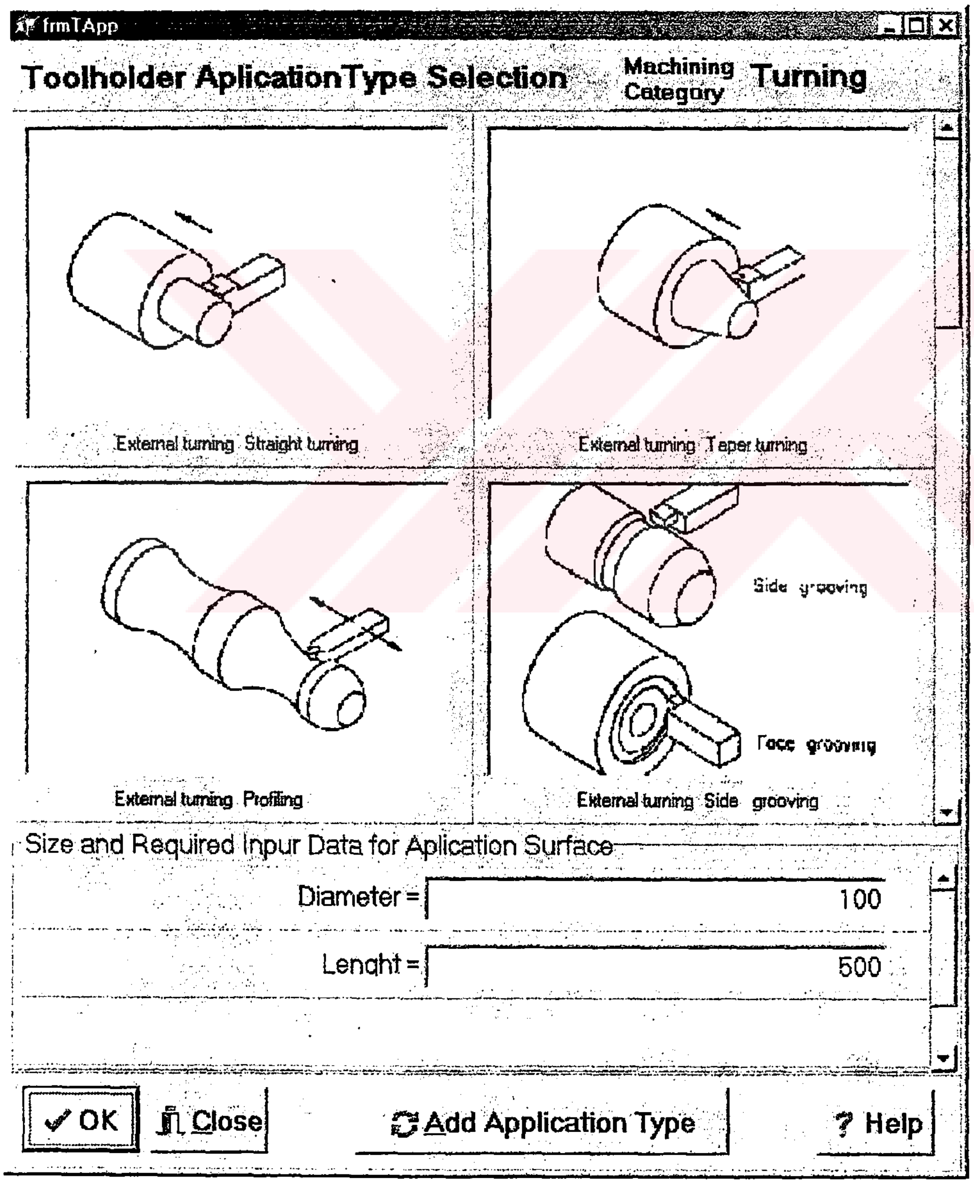


Fig. 7.18. Tool Holder Application Type Selection Screen

In this section it is also available to add a new application type by an expert by only picking the "Update" button. "Select manually" option used for selecting one of the operation types given in Figure 7.18. At this stage, if "Add Application Type" button is clicked, then the following Figure 7.19 appears to provide the expert user to enter a new application type with some questions.

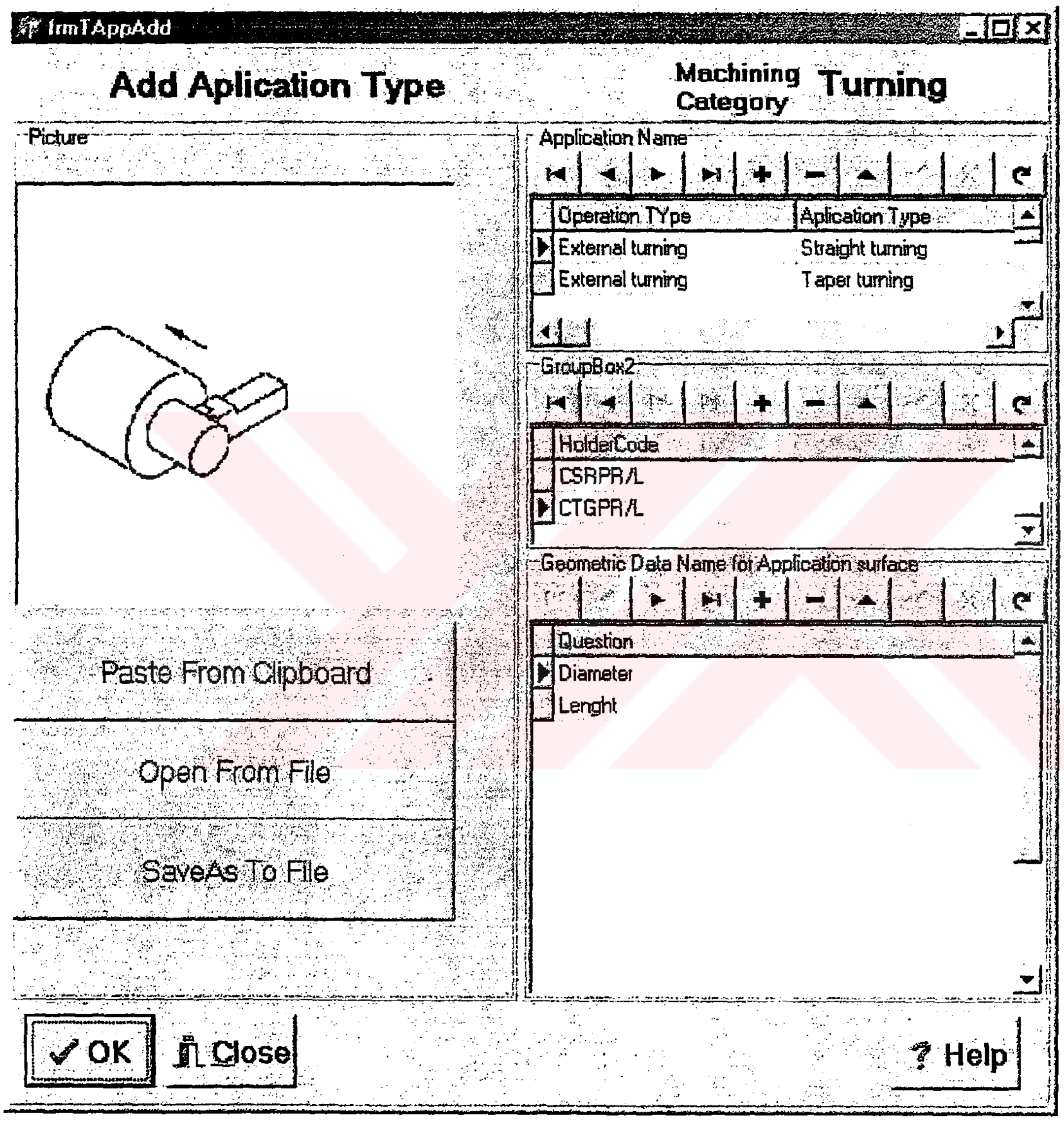


Fig. 7.19 Add Application Type Screen

After selection of machining and operation type, some relevant questions appear such as diameter, length, hole diameter, pitch and etc. The answers of these questions are important for cutting tool selection criteria.

"Workpiece Material Group" button provides the selection of wide range of material (Figure 7.20). In this material database lots of material and their properties are stored. User can select one of material group, which is titled by "Mat. Grp". The bottom of the screen presents the properties of selected material group.

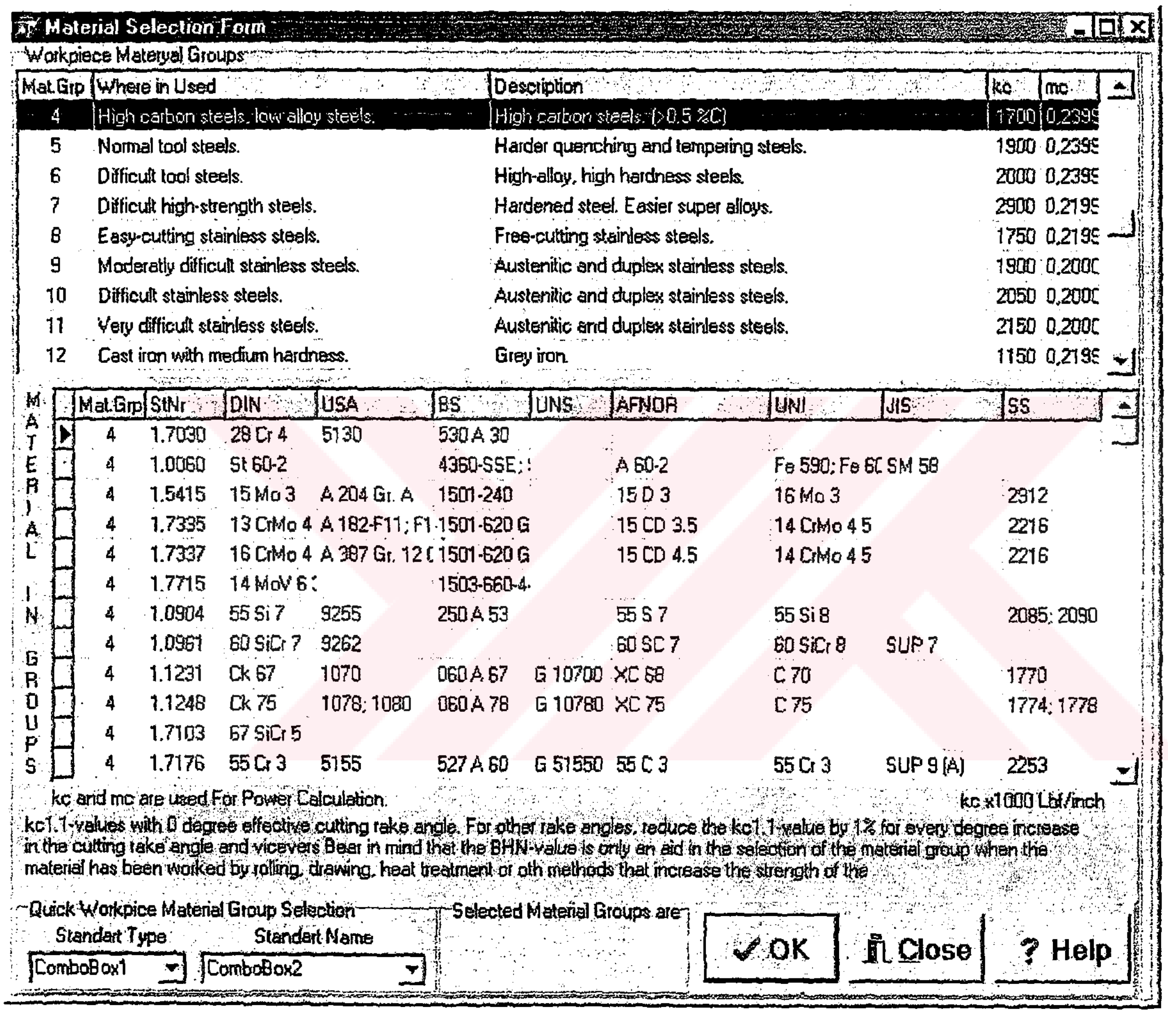


Fig. 7.20. Workpiece Material Group Screen

As a final stage for INPUT DATA, "Tool Material Group" button enables the user to enter tool material (Figure 7.21). Tool material grade, microstructure and material properties are presented in this screen.

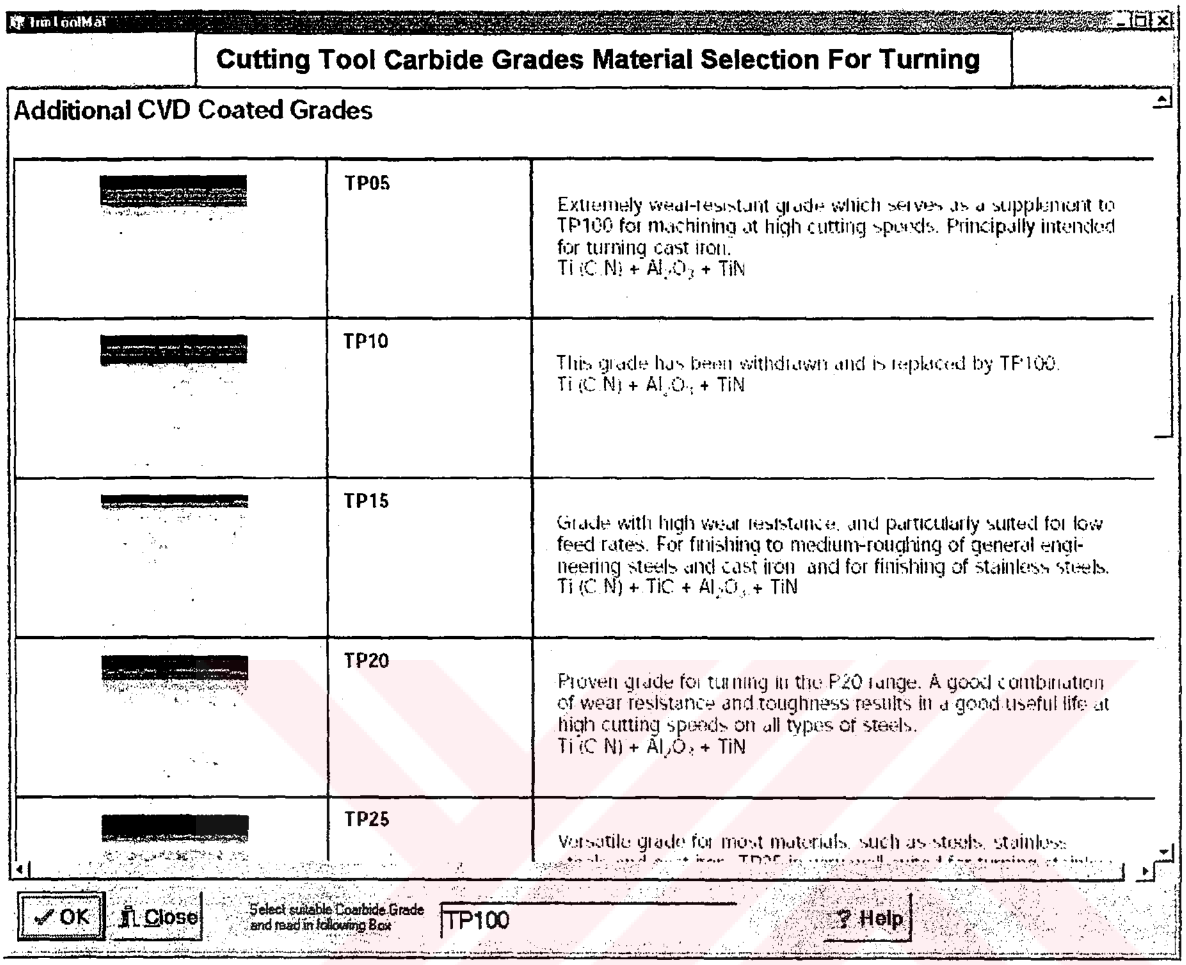


Fig. 7.21 Tool Material Group Screen

7.5.3. Catalogue Button

The following Figure 7.22 shows the main screen for catalogue button. As it is seen from the figure left hand side is used for listing all data. In this section it is intended to present in Microsoft Help manner. Right hand side is used for presenting the cutting tool shape, tool holder knowledge, dimensions and etc.

"Technical Information" section handles lots of technical information and formulae. Tool material, workpiece material, insert code and shapes, cutting data formulae, power calculation, feed and surface finish quality are the examples, which are given in the technical information section.

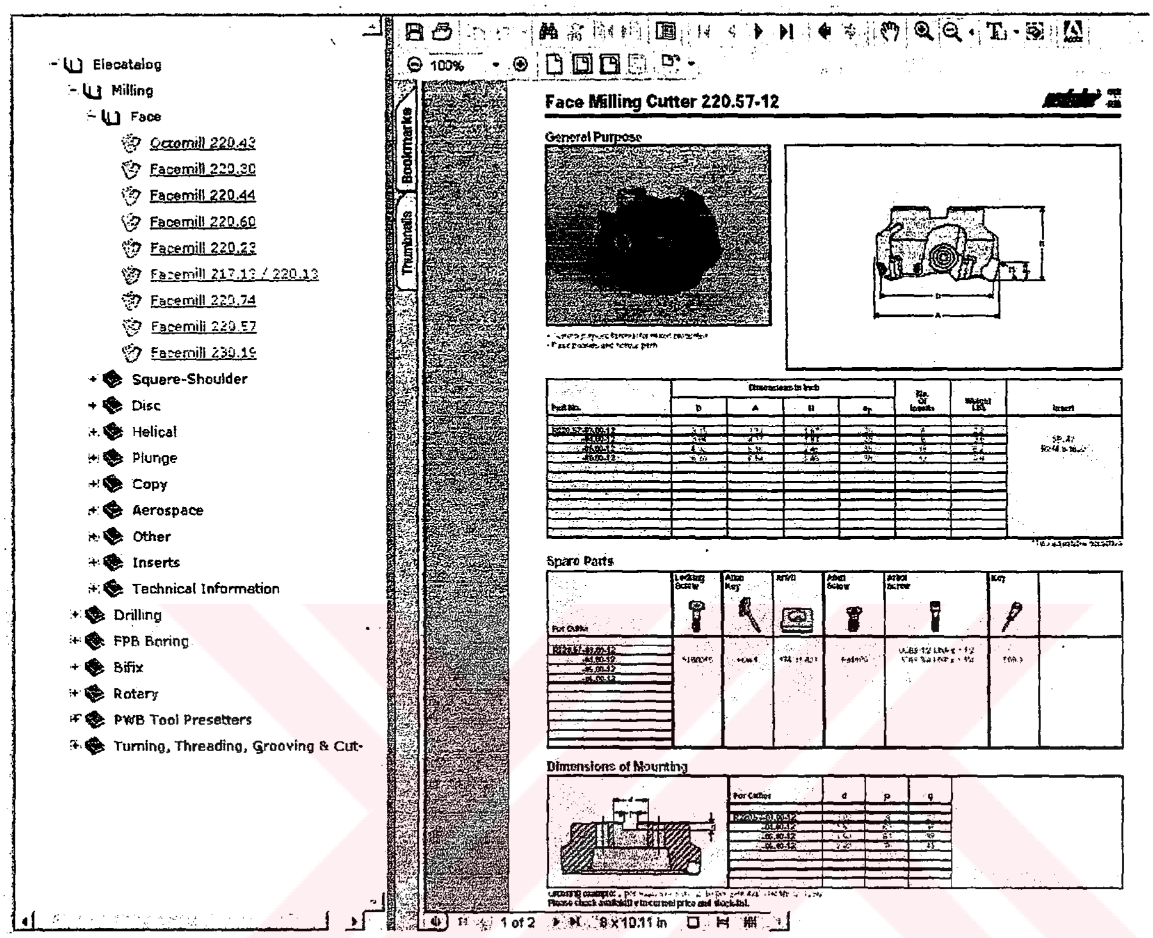


Fig. 7.22 Main Screen for Catalogue Button

7.5.4 Execution of Automatic Cutting Tool Selection Module

This part has 2 features: One feature links relation with the database module and the other communicates with the user. The program asks various specific questions about cutting tool parameters and directly transfers the answers to the database module. The database module selects possible suitable cutting tools due to the users answers. It then sequences the possible cutting tools with respect to the Metal Removal Rate of the cutting tools beginning from the largest to the smallest. The database sends this possible cutting tool list to the program and the program finally selects the cutting tool, which is the largest Metal Removal Rate.

The automatic module of the program enables the user to update data.

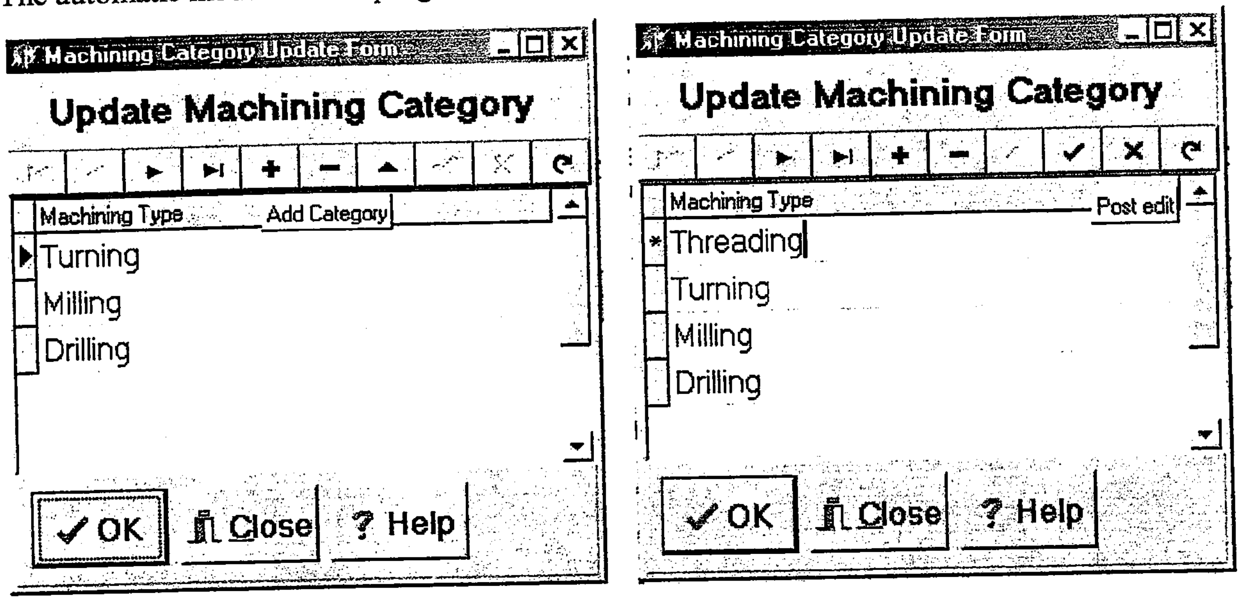


Figure 7.23. Addition of Database Machining Category

User-friendly buttons were added to the ICTSS program, which enables the user to catch data from CACHE memory of the computer and transfers directly the program database. As a result of this, data entrance to the program has been quite easy. For example, data from AUTOCAD like software in dwg format can be directly saved as image format without converting the dwg format. (Figure 7.24, Figure 7.45)

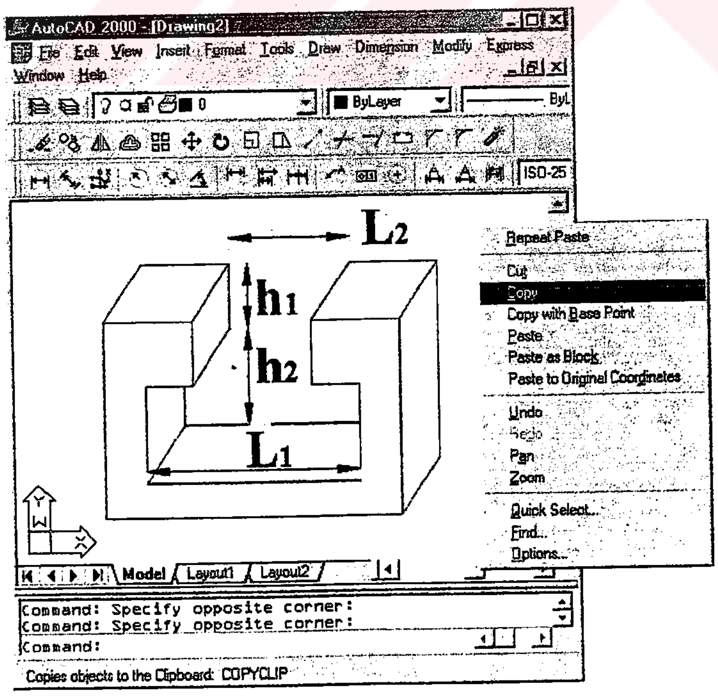


Fig. 7.24 . Directly Saving Dwg Format as Image Format Without Converting the Dwg Format.

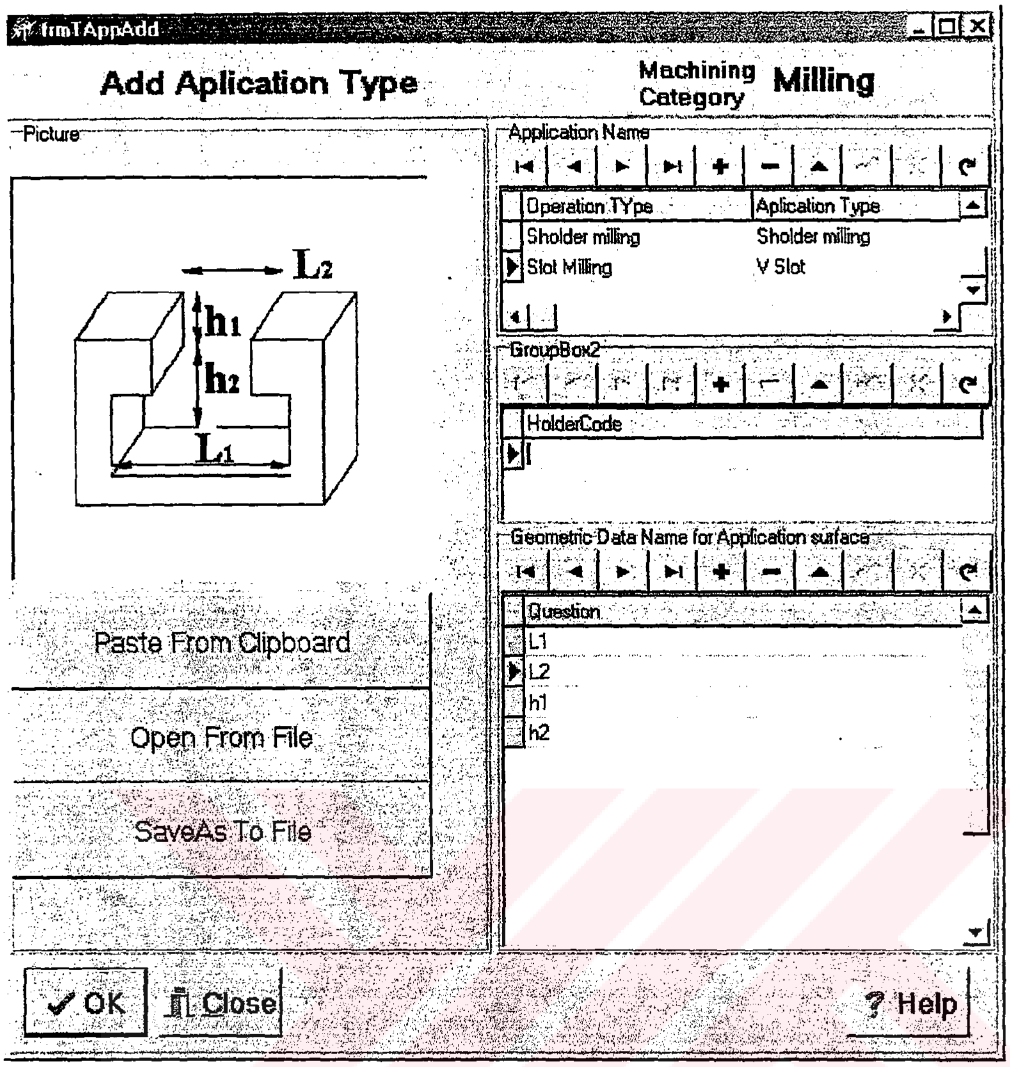


Fig 7.25. Paste From Clipboard Button

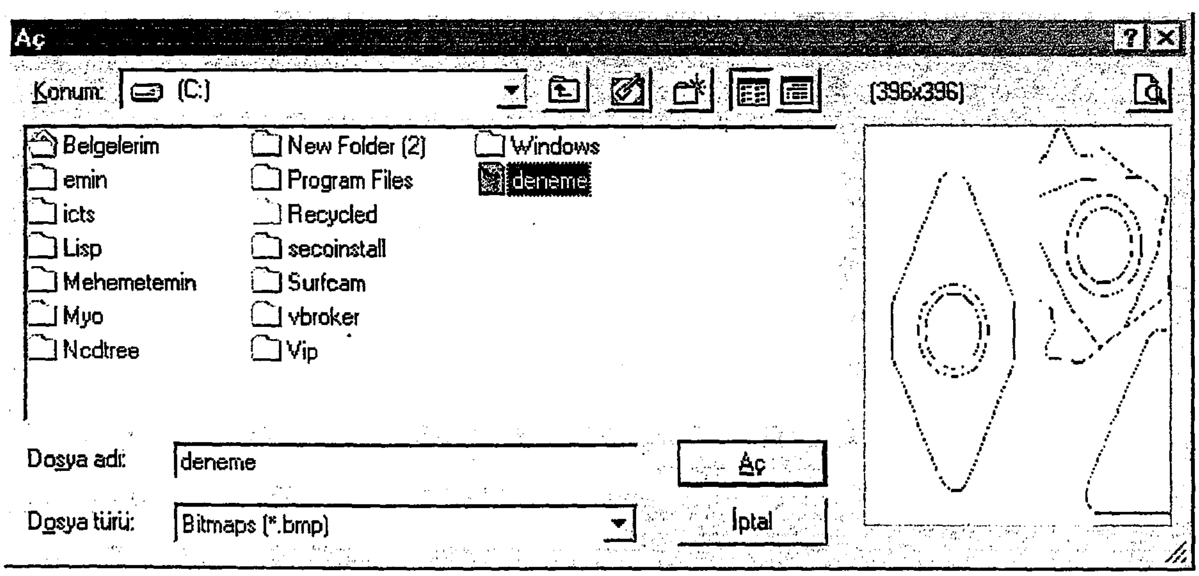
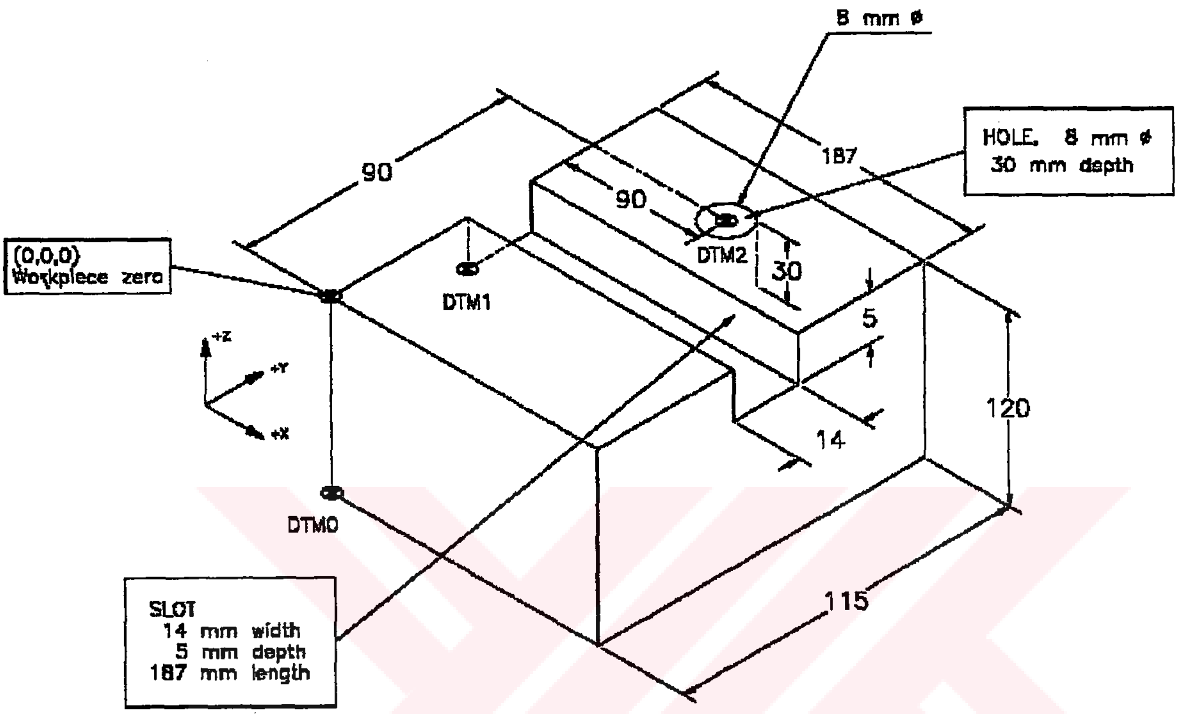


Figure 7.26 Open From File Buttons Form

7.6 Case Study 1

As a case study to the problem below taken from Dereli [19] is solved by using the developed program. The solution is given below.



F. No	Feature ID	Distance to main datum			Feature Attributes			Approach Directions						SR/FR (?m) / (mm)
		d-x	d-y	d-z	d	w	l	1	2	3	4	5	6	
1	T-SLT	0	47	115	5	14	187	1	0	0	0	0	0	-
2	B-HOL	90	90	120	-	8	30	1	0	0	0	0	0	-

Op. No	Operation Type	Workpiece Zero Shift			Associated Feature	Tooling			
		wsx	wsy	wsz	No	TN	ID	HOLDER	INDEX
1	Slot Milling	0	0	120	1	1	EM14	W14	1
2	Twist Drilling	Workpiece: ST-52			2	2	TD8	KMA1	2

Pass	Operation	Depth of cut	Feed (mm/min)	Speed (rpm)
1	1	5	400	1200
-	2	-	60	600

Tool	Diameter	Shank Diameter	Cutting Length	# of teeth	Material	Firm	Code
EM14	14	12	26	4	HSS	MT	-
TD8	8	8	10	-	HSS	MT	-

Fig. 7.27 Data and Component Figure Of Case Study-1 [19]

Machining Category = Milling

Toolholder Application Type = Slot Milling

Width = 14mm

Depth = 5mm

Length = 187mm

Workpice Material = ST-52

Tool Material = HSS

7.6.2 Workpiece Material Group Selection:

The workpiece material group selection is selected by entering St-52. After entering St-52 The program selects Material Group 3 as shown below (Figure 7.28).

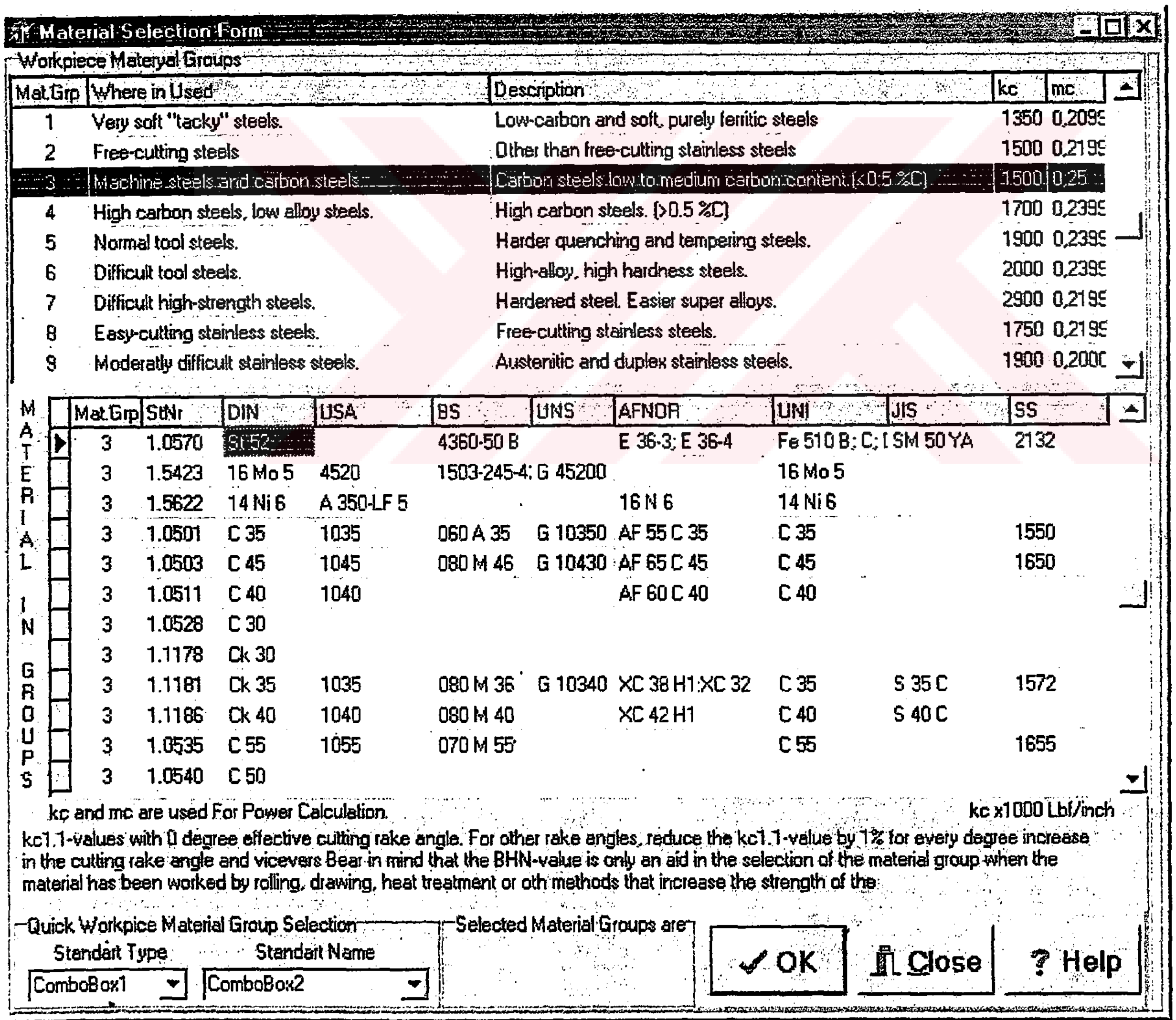


Fig. 7.28 The Workpiece Material Group Selection

7.6.3. Tool Material Grade (Carbide Grade) Selection:

ICTSS program serves for CNC machines , HSS tool materials are not used. Since the workpiece material is steel so T25M carbide grade type is selected given below Figure 7.29.

	T25M	First choice for medium machining to roughing in steel and stainless steel with or without coolant. TiC/Ti(C,N) + TiN

Figure 7.29 T25M Carbide Grade Type [45]

7.6.4 Output of Automatic Selection Module:

Cutting speed is dependent on the cutting tool and workpiece material specification so it will be found from result. The Metal removal rates is automatically calculated from ICTSS programs.

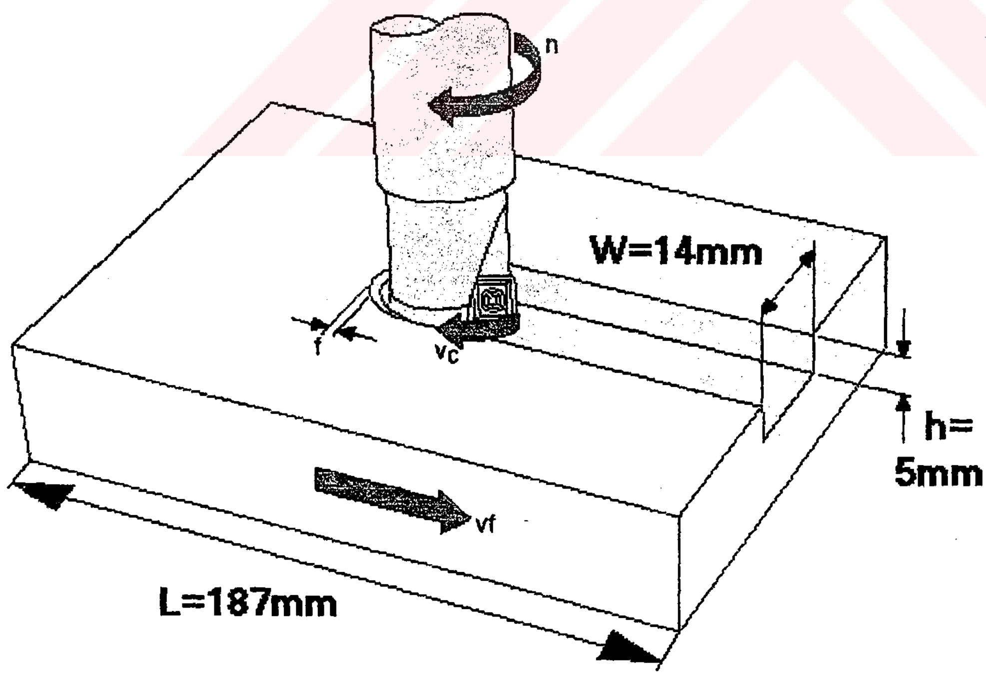


Fig. 7.30 Illustration of Component and Size

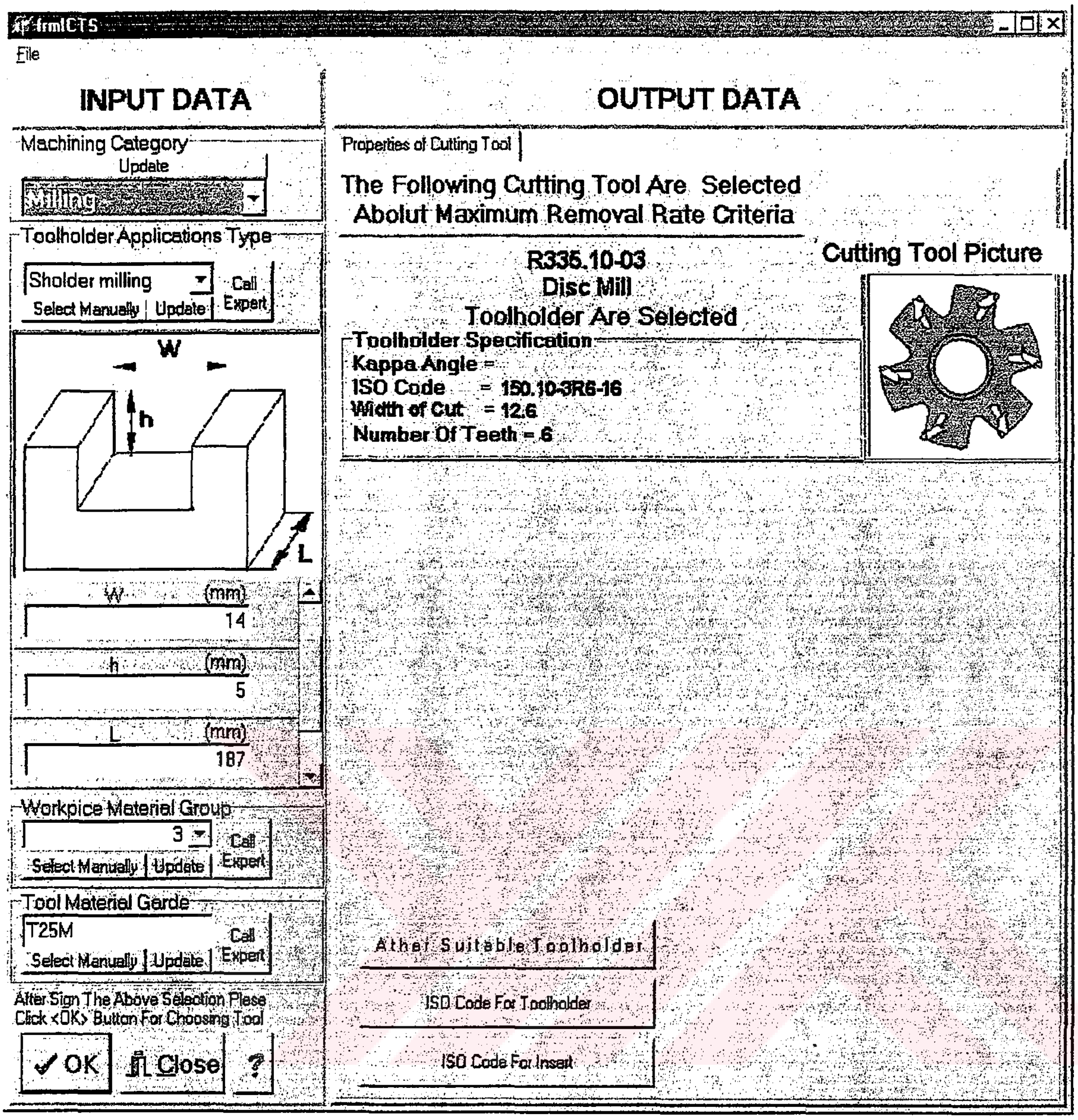


Figure 7.31 Automatic module and output result.

CHAPTER 8

DISCUSSION AND CONCLUSION

8.1. DISCUSSION

In this study a computer program, which requires considerable experience and knowledge, has been developed through extensive searching of catalogues and manuals for the automatic selection of cutting tools of machining operations.

The program, considered in the development of the study, involve three main stages:

1. Cutting tool selection by MANUALLY
2. Cutting tool selection by AUTOMATICALLY
3. Cutting tool selection from CATALOGUE

Manuel cutting tool selection is based on machining type, such as turning, milling, drilling and threading. Each of them has also subgroups. Facing, straight turning, taper turning and etc. can be given as example for turning operations.

The second approach for cutting tool selection is titled "Automatically" by the program. To perform cutting tools and condition selection for a component, the input to the program comprises, information relate to the description of the machining type, operation type and material group.

The method developed for knowledge representation is easy to use and understand and little knowledge of computers is required. The machining application type and workpiece representation method forms the skeleton of the system. The system allows for an easy identification and direct relationship between cutting tool and the workpiece. All tool holders, inserts, cutting tool types and material types supplied by any tool manufacturer can be represented in this manner.

The knowledge base is structured by knowledge intensive and in some cases rule-based. The knowledge base is designed to be adapted to different working environments. The logic of the tool selection criteria is based upon a series of rules, which can be changed by users to meet specific needs. The metal removal rate is taken into account within the constraints imposed by the properties of the workpiece materials, tools and tool materials.

The third approach for cutting tool selection can be carried out from catalogue. “Catalogue” button is used for this purpose. Wide range of cutting tool, insert and material groups are listed according to their machining type. Also technical information is available in this section.

8.3. CONCLUSION

Most of the studies in cutting tool selection system up to now have been generally based on ready-package expert system software codes written on PROLOG, KES, LISP and etc. However, in this thesis it is preferred to use his own expert system software called *GEXPERT* by using conventional programming language, DELPHI.

The main reasons of having developed own expert system are as follows:

1. The ICTSS program otherwise could not be used without Ready-package expert system software.

2. The prepared expert system software (*GEXPERT*) is a module of the overall system (ICTSS) it works more efficiently and user-friendly
3. The expert system (*GEXPERT)* can also be used as a module with various software also.

In this thesis, an intelligent system for automatic cutting tool selection, for different work material properties, has been developed .The developed system was enabled for users and manufacturing planners to select suitable cutting tools, that could machine the workpiece material.

The system determines all the feasible tool sets, which can completely machine the component and then selects the most appropriate tool using the preference rules within the knowledge base. The tool preference rules were based upon the recommendations of cutting tool manufacturers. The expert users to suit their own machining environment can change the rules.

The prototype system dealt with different classes of tool materials currently in use for machining operation; high-speed steel, cemented carbides and cermets. The system worked in a fully interactive mode and was operated by guiding users through several stages: tool material selection in order to select a suitable tool material that can machine the desired work piece material; feature specification including cylindrical and prismatic feature and design attributes; and machining technique selection in order to select a suitable machining process that can achieve the desired feature at low cost. For cutting tool selection and optimum cutting conditions, the system selected the best cutting tool and determined the optimum cutting conditions, based on high material removal rate, long tool life and less machining time.

One case study was performed by using the ICTSS program.

8.4. RECOMMENDATIONS FOR FUTURE WORK

Future works that can be considered as the modification of the system can be extended in the following areas.

1. Whole application types can be developed and integrated into the package
2. Operation sequence and by the way cutting tool sequence can be added to the system
3. Development of the system into a complete process planning system can be achieved.
4. Geometry of the product can be introduced with the system and therefore future recognition module can be integrated.
5. Dimensional and geometrical tolerances can be added to the system.
6. The prepared program is about 170 Megabyte with its databases (and 30 Megabyte catalogues databases). Therefore, some works can be carried out to get smaller program.

9. Wong, S. V., Hamouda, A.M.S., El Baradie, M.A., 1999, "Generalized Fuzzy Model for Metal Cutting Data Selection", Journal of Materials Processing Technology, Vol. 89-90, pp 310-317.

10. Arezoo, K., Ridgway, A.M.A., Al-Ahmari, 2000, "Selection of Cutting Tools and Conditions of Machining Operations Using an Expert System", Computers in Industry, Vol. 42, pp 43-58.

11. Baker, R.P., Maropoulos, P.G., 2000, "An Architecture for the Vertical Integration of Tooling Considerations from Design to Process Planning", Robotics and Computer Integrated Manufacturing, Vol. 16, pp 121-131.

12. Yuan-Hung, M., Landers, R.G., 2000, "Supervision of Machining Process Controllers: A Turning Simulation Example", Japan-USA Symposium on Flexible Automation, Michigan, Vol. 23-26, pp 1-9.

13. Maropoulos, P.G., Baker R.P., Paramor, K.Y.G., 2000, " Integration of Tool Selection with Design Part 2: Aggregate Machining Time Estimation", Journal of Materials Processing Technology, Vol. 107, pp 135-142.

14. Edalew, K.O., Abdalla, H.S., Nash, R.J., 2001, "A Computer-Based Intelligent System for Automatic Tool Selection", Materials and Design, Vol. 22, pp 337-351.

15. Mookherjee R., Bhattacharyya, H., 2001, "Development of an Expert System for Turning and Rotating Tool Selection in a Dynamic Environment", Journal of Materials Processing Technology, Vol. 113, pp 306-311.

16. Sung, A., Sequin, C., and Wright P., 1999, "Internet-Based Design and Manufacturing", Computer Science and Mechanical Engineering Departments, University of California, Berkeley, California, 94720 Final Report 1998-99 for MICRO Project 98-136

17. Kengskool, K., and Resnick, M., "Knowledge-Based Decision Support System for Job Analysis-Tool Selection for Manufacturing Industry", Industrial and Systems Engineering Department College of Engineering and Design Florida, International University Park, Miami, Florida.

18. Iwata, K., and Fukuda, Y., 1987, "KAPPS: Know-how and Knowledge Assisted Production Planning System in the Machining Shop", 19th CIRP International Seminar on Manufacturing Systems, USA.

19. Dereli T., 1998, "Development of a Process Planning System for Prismatic Parts", Ph.D Thesis, University of Gaziantep.

20. Kaewert, J., W., and Frost, J. M., 1990, "Developing Expert Systems for Manufacturing (A Case Study Approach)", McGraw Hill.

21. Bozdana, T., 1999, "Development of an Expert System for the Determination of Injection Moulding Parameters of Thermoplastics", M. Sc. Thesis, University of Gaziantep. , Gaziantep, Turkey.

22. ---------, 1990, Knowledge Base Author's Manual, Knowledge-Based Expert System (KES PS), Software Architecture& Engineering Inc.

23. Figenbaum, E. A., 1977, "The Art of Artificial Intelligence: Themes and Case Studies of Knowledge Engineering", Proceedings of 5th International Joint Conference on Artificial Intelligence, pp. 1014-1029.

24. Huang, S. H. And Zhang H. C., 1995, "Neural-Expert Hybrid Approach for Intelligent Manufacturing: A Survey", Computers in Industry, V.26, 107-126., Gaziantep, Turkey

25. Ignizio, J. P., 1991, "Introduction to Expert Systems", McGraw Hill.

26. Partridge, D., and Hussain, K. M., 1994, "Knowledge-Based Information Systems", McGraw Hill.

27. Adeli, H., 1988, "Artificial Intelligence and Expert Systems", Expert Systems in Construction and Structural Engineering, Chapman and Hall, London.

28. -----------, 1989, "User Guide", Goldworks II, Gold Hill Computers Inc

29. Badiru, A.B., 1992 "Expert Systems Applications in Engineering and Manufacturing", Prentice-Hall, NJ, USA.

30. -----------, 1989, "Reference Manual", Goldworks II, Gold Hill Computers Inc.

31. Ross, T.J., 1995, "Fuzzy Logic with Engineering Applications", McGraw-Hill, USA.

32. Roger and Guley, 1997, "Fuzzy Logic Toolbox, User's guide", The MathWorks Inc., USA.

33. Yılmaz, O., 1999, "Computer Aided Selection of Cutting Parameters by Using Fuzzy Logic", M.Sc. Thesis, University of Gaziantep.

34. Goldberg, E. D., 1989, "Genetic Algorithms in Search, Optimisation and Machine Learning", Addison-Wesley, Reading, MA.

35. Dereli, T., Baykasoglu, A., 2000, "Artificial Intelligence in Design and Manufacturing", Journal of Polytechnic, Vol.3, No2.

36. Bose, N. K. and Liang, P., 1996, "Neural Network Fundamentals with Graphs, Algorithms and Applications", McGraw-Hill, Singapore.

37. Chryssolouris, G., et al., 1990, "Use of Neural Networks for the Design of Manufacturing Systems", Manufacturing Review, Vol. 3, No. 3.

38. Charlie Carvert,1999, "Delphi 4 Unleashed", Sistem Yayıncılık ve Mat. San. Tic.A.Ş., İstanbul, Turkey.

39. Sava M., Pusztai J, 1990, "Computer numerical Control Programming.", Prentice-Hall, Inc., London, UK.

40. ----------, 1998 ,"MasterCam", Scholar's International Publishing Corp.

41. HERTEL, "Cutting Tool Catalogue", Hertel Cutting Technologies, inc, Tennessee, USA

42. Walker J. R., 2001, "Machining Fundamentals", Domato Inc,

43. SECO, 1995, "Cutting Tool Catalogue" , Carboloy inc, Sweden.

44. Degarmo P., Black J.T, Kohser A,R, 1990, "Materials and Processes in Manufacturing", Macmillan Publishing Company, New York, USA

45. SECO Toll Selection Programs , 2000, "SECOCAD "

46. KOMET, "Rotating Tools Catalogue ", KOMET of AMERICA, Inc. USA.