Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Materials and Design 27 (2006) 1027–1034
Materials & Design
www.elsevier.com/locate/matdes

Development of a knowledge-based expert system for solving metal cutting problems

M. Cemal Cakir *, Kadir Cavdar [1]

Uludag University, Mechanical Engineering Department, Gorukle 16059, Bursa, Turkey

Received 8 September 2004; accepted 31 January 2005
Available online 21 March 2005

Abstract

In metal cutting, the problems need to be well analyzed in order to take precautions before any unexpected results are encountered. This process plays a significant role in achieving consistent quality and in controlling the overall cost of manufacturing. However, it is a difficult task that needs an expert who has a great deal of information and experience in metal cutting. In the present paper, a knowledge-based expert system (COROSolve) that investigates problems that are encountered in three main metal cutting areas: turning, milling and drilling is developed. A great deal of metal cutting operations such as external/internal turning with negative/positive inserts, aluminum turning, parting bars/tubes, grooving, profiling, recessing and threading operations in turning; face milling, square shoulder milling, end milling, multi-purpose milling and side and face milling operations in milling; and drilling operations that use solid drills or drills with indexable inserts in drilling are taken into consideration. COROSolve gives recommendations for the cutting data (i.e., cutting speed, depth of cut, and feed) and updates the problem, cause and remedy database, thus the number of problems that the system can handle is increased.

Keywords: Metal cutting problems; Expert systems; KBS; Tool wear

1. Introduction

The objective of modern manufacturing is to have efficient control over the organizational facilities in order to produce high quality products at lower prices within a shorter time period. To achieve better quality at a lesser price, every attention has to be paid in the manufacturing division by employing better cutting tools, inserts and high precision machines, etc. [1]. However, this is not sufficient for productivity in most of the cases. Choosing the right tool for the right job is important, but tool wear should also be considered for more efficient manufacturing. In the literature, many publications do exist on the tool wear in manufacturing of various materials [2].

Metal cutting is a chip forming process. Although the process is directed at cutting metal to shape and size, this has to be done by creating defined chips. The chip-forming process means that a fresh metal interface is continually produced and forced at very high pressure and temperature along the tool material [3]. The zones produced make it an attractive environment for diffusion and chemical reactions of metal. All cutting tools are worn during machining and continue to do so until they come to the end of their tool-life. Tool wear is inevitable and as such not a negative process if the answers of when, how much and what type is known. There are certain types of wear mechanisms on different types of metal cutting processes and similar/different types of problems are encountered as a result of these mechanisms. If these

* Corresponding author. Tel.: +90 224 4428176; fax: +90 224 4428021.
E-mail addresses: cemal@uludag.edu.tr (M.C. Cakir), cavdar@uludag.edu.tr (K. Cavdar).
[1] Tel.: +90 224 4428176; fax: +90 224 4428021.

0261-3069/$ - see front matter
doi:10.1016/j.matdes.2005.01.022

problems are well analyzed, it could be possible to find the right solutions to each of them.

To analyze a problem in metal cutting, the problem should be defined precisely and its possible causes should be well determined. This is a difficult task that needs an expert who has a great deal of information and experience in metal cutting. Today in metal cutting, the expertise facilities about the problems in chip forming are mainly provided by the cutting tool producing companies. Since the number of people working in this area is limited, it is not always possible to find an expert when he/she is really needed. Since expert systems have been particularly welcome in fields where existing experts are expensive and in short supply, an expert system that solves metal cutting problems will be very useful.

2. Expert systems for aiding manufacturing processes

Knowledge-based systems, or expert systems, are computer programs embodying knowledge about a narrow domain for solving problems related to that domain. An expert system usually comprises two main elements, a knowledge base and an inference mechanism (Fig. 1). The knowledge base contains domain knowledge which may be expressed as any combination of 'IF-THEN' rules, factual statements, frames, objects, procedures and cases. The inference mechanism is that part of an expert system that manipulates the stored knowledge to produce solutions to problems [4].

A human expert uses knowledge and reasoning to arrive at conclusions, so does an expert system. The reasoning carried out in an expert system attempts to mimic human experts in combining pieces of knowledge. Thus, the structure or architecture of an expert system partially resembles how a human expert performs. Thus, there is an analogy between an expert and an expert system.

A more obvious problem is that of gathering the rules. Human experts are expensive and are not extremely likely to want to sit down and write out a large number of rules as to how they come to their conclusions. More to the point, they may not be able to. Although they will usually follow a logical path to their conclusions, putting these into a set of IF ... THEN rules may actually be very difficult and maybe impossible.

It is quite possible that many human experts, though starting off in their professions with a set of rules, learn to do their job through experiential knowledge and 'just know' what the correct solution is. Again they may have followed a logical path, but mentally they may have 'skipped some steps' along the way to get there. An Expert System cannot do this and needs to know the rules very clearly.

A very strong benefit of expert systems is being able to widely distribute the knowledge of a single expert, or being able to accumulate the knowledge of several widely separated experts in one place. Expert systems are especially helpful when a task is performed only occasionally and the expert has to relearn the procedure each time it is performed.

Expert systems are used to standardize operations. If you have three machine operators (or engineers) that perform the same task but each does it differently, an expert system will do it the same way everytime. These systems can be used to train employees, advise them, or can actually perform a task such as a calculation. Another use for expert systems is as job aids for your experts. They will allow them to perform more accurately, more consistently, and faster, freeing up time for the expert to be more creative performing the task. This is especially helpful when dealing with tedious, repetitious tasks.

Consequently, once the domain knowledge to be incorporated in an expert system has been extracted, the process of building the system is relatively simple.

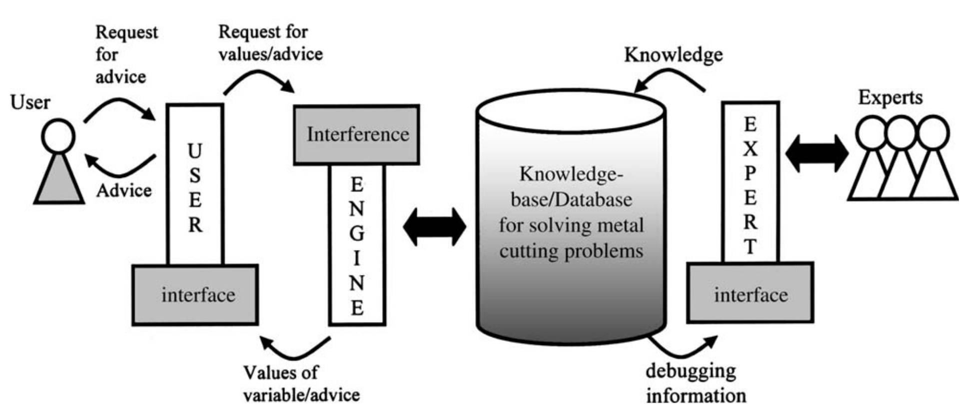

Fig. 1. Knowledge based expert system.

The ease with which expert systems can be developed has led to a large number of applications of the tool. In engineering, applications can be found for a variety of tasks including selection of materials, machine elements, tools, equipment and processes, signal interpreting, condition monitoring, fault diagnosis, machine and process control, machine design, process planning, production scheduling and system configuring. Some recent examples of specific tasks undertaken by expert systems are:

- identifying and planning inspection schedules for critical components of an offshore structure [5];
- training technical personnel in the design and evaluation of energy cogeneration plants [6];
- configuring paper feeding mechanisms [7];
- carrying out automatic re-meshing during a finite-elements analysis of forging deformation [8];
- storing, retrieving and adapting planar linkage designs [9];
- designing additive formulae for engine oil products [10];
- selecting cutting tools or cutting data [11–13].

Several potential research areas were identified with respect to expert systems in manufacturing [14,15]. Kojiyama et al. [16] have discussed in their articles that a framework for machining operation planning systems, in which machining know-how extracted and organized from electronic tool catalogs and machining instance databases available in the Internet environment plays a principal role. On the use of reference machining data can be constitute, which is derived from the investigation of tool catalogs, related international standards, reference textbooks, and handbooks.

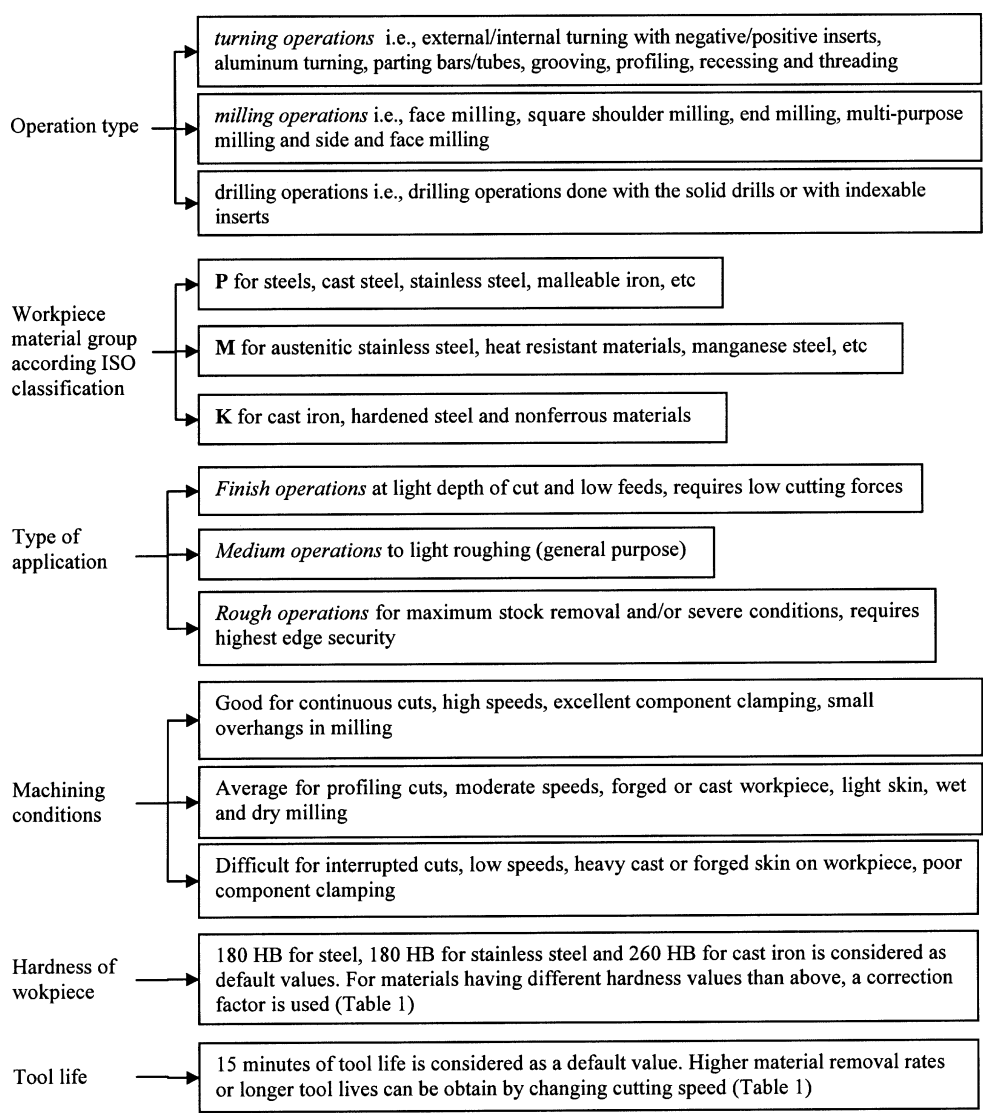

Fig. 2. Inputs of the software.

The application of Mookherjee and Bhattacharyya [11] on expert system in the general turning and milling operation is very useful for solving some of the challenging problems presently faced by manufacturing engineers during the integration of CAD and various CNC machining centers. Jiang et al. [17] have developed an expert system to optimize the milling operations for prismatic components. They have described a new GT based coding scheme that represents the surfaces to be machined of prismatic components.

Limsombutanan [18] has presented an algorithm to select the cutter size and tool orientation in 5-axis surface machining that can act as a holon. Milling the surface is divided in to three phases, namely, roughing, semi-roughing and finishing. This algorithm selects the best tool and plans the tool path autonomously for a bicubic (convex–concave) surface based on analysis of the curvature.

The main objective of the present paper is to build such system that covers most of the major metal cutting problems and helps the people who are involved in metal cutting to improve the quality.

3. A knowledge-based expert system for metal cutting problems

3.1. Factors considered in solving metal cutting problems

Most of the problems in metal cutting are the result of wear mechanisms. All cutting tools wear during machining and continue to do so until they come to the end of their tool-life. Tool wear is inevitable and

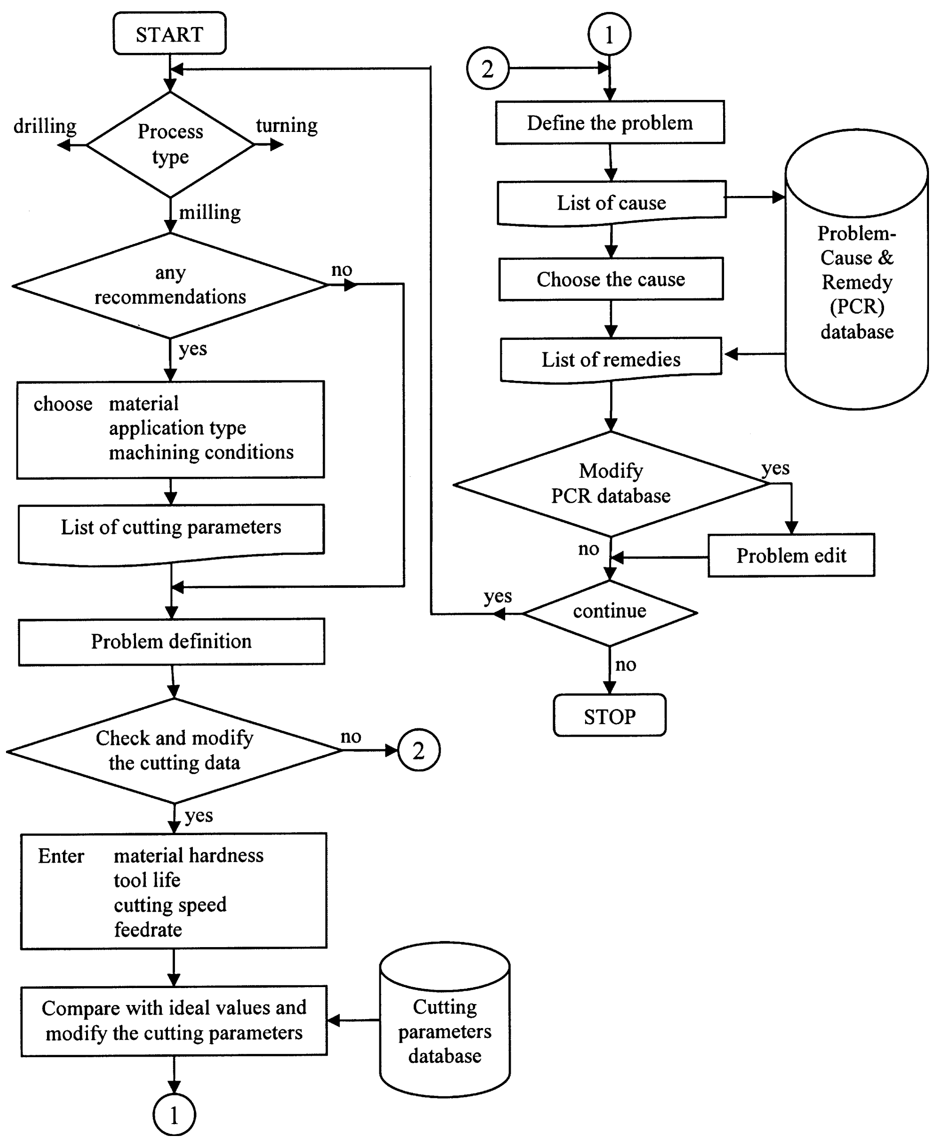

Fig. 3. Flowchart of COROSolve.

as such not a negative process if the answers of when, how much and what type is known. Thus, if the problems resulted from tool wear as well as the other harmful factors effecting the machining operations are well analyzed, it could be possible to find the right solutions to each of them. This would reduce the unproductive fault searching time, therefore reduce machining time, unproductive stoppage times of machine tools, machining cost and therefore increase the efficiency of the process. Architecture of the expert system used in solving metal cutting problems is given in Fig. 1. Inputs that are taken into consideration by the software are given in Fig. 2.

3.2. Features of COROSolve

The software has been developed using DELPHI Visual programming language. A major difficulty in building a consultation system was in capturing and examining the knowledge elements used in the solution of the problem. Based upon the design for solving problems in metal cutting study, once the operation type is selected, four major stages have been identified for each type of operation:

– Cutting data recommendations.
– Problem definition.
– Cutting data evaluation.
– Problem editor.

The flowchart of the software is given in Fig. 3.

3.2.1. Cutting data recommendations

The selection of the right cutting tool is critical for achieving maximum productivity during machining. But although the tooling is right, if the machining conditions are not up to standard, especially as regards cutting data and general stability, problems arise and optimum tool-life will not be reached. Incorrect cutting data, vibrations and lack of rigidity in tool holders and clamping are the main reasons of the metal cutting problems.

Apart from being a problem solver, the software provides cutting data recommendations for each type of *operation* (types of operations were mentioned previously), for each type of *material group* (ISO P, M or K), for each type of *application* (rough, medium or finish), for each type of *machining condition* (good, average, difficult) and displays the list of inserts available (Fig. 4). Here, it is not intended to find the most suitable insert for the application, but to monitor the starting values and the working ranges of cutting data (i.e., the cutting speed, feed rate and the depth of cut) for the insert used in metal cutting. At this stage, it is possible to see the suitable grade that was determined due to the selected operation, material group, application, etc. Besides, the list of materials that each material group consist of can also be observed.

Recommended cutting data values were acquired from Sandvik Coromant [20], the cutting data from the other cutting tool vendors can be used as the recommended values as well. Cutting data values displayed are for a certain material hardness and for a certain tool-life. For any workpiece material having different hardness values than the specified values, and the tool-life different than 15 min, the cutting data provided should be multiplied by the correction factors (see Table 1).

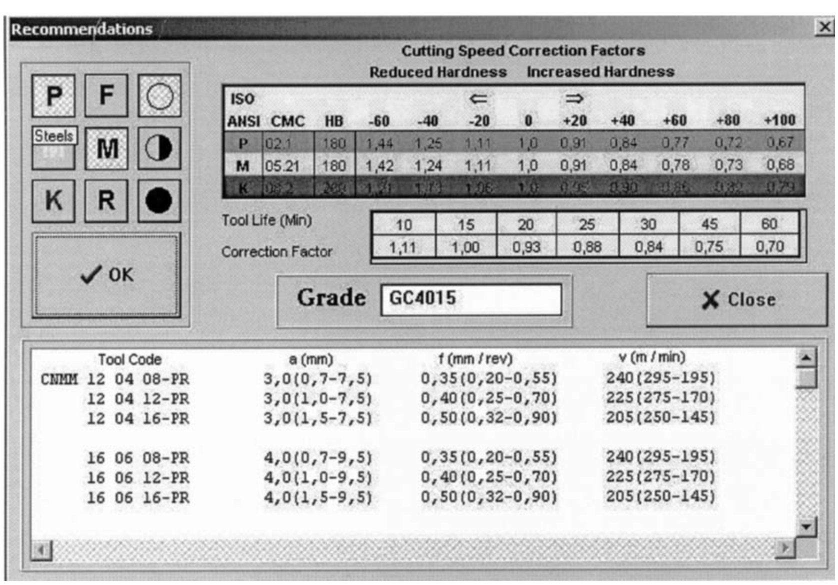

Fig. 4. Cutting data recommendations.

Table 1
Material hardness and tool life considerations [19]

ISO/ANSI	HB	Reduced hardness				Increased hardness				
		−60	−40	−20	0	+20	+40	+60	+80	+100
P	180	1.44	1.25	1.11	1	0.91	0.84	0.77	0.72	0.67
M	180	1.42	1.24	1.11	1	0.91	0.84	0.78	0.73	0.68
K	260	1.21	1.13	1.06	1	0.95	0.9	0.86	0.82	0.79

Tool life (min)	10	15	20	25	30	45	60
Correction factor	1.11	1.0	0.93	0.88	0.84	0.75	0.70

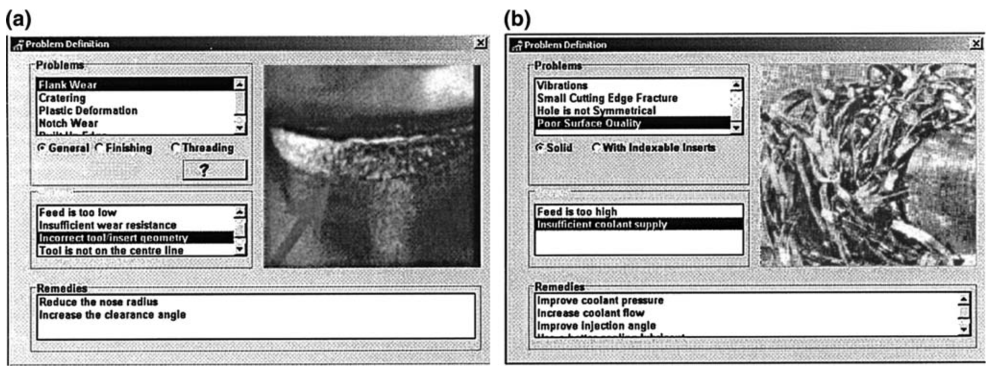

Fig. 5. Problems, causes and remedies.

3.2.2. Analysing the metal cutting problems

There are various different/similar types of problems in metal cutting processes. In appearance some of these problems are identical and very hard to be distinguished from each other. The classification of problem types has been developed to form an important basis for assessing the machining operation and to optimize productivity by getting the tool grade and machining conditions right for the type of cut and material. The right tool, good starting values for cutting data, expert support, own experience, good quality of workpiece materials and machine conditions are important ingredients for success in machining. Aggregation of problem lists from various tool manufacturers is classified to form KBS used by the software.

The user analyses the metal cutting problems either in one or two stages: by straightforwardly picking out *Problem Definition* option from the menu or by checking out the cutting data used in the metal cutting process first and accessing to the problem definition section afterwards. Problem Definition section displays the list of problems, their possible causes and the remedies with respect to the causes. Once a problem is selected (i.e., flank wear in turning or chip jamming in drill flutes in drilling), a picture that provides a clear definition to the problem and the list of possible causes are displayed. Consequently once a possible cause is selected, the remedies are determined. More information about the problem is obtained by clicking on "?" (Fig. 5).

3.2.3. Cutting data evaluation

In metal cutting, most of the problems are the result of unsuitable cutting data for the application. Thus, before straightforward listing of the problems, the user is advised to check the cutting data for the operation, for the application and for the machining conditions to find out whether the cutting speed, feed rate and the cutting depth are correct for the length, thickness and nose radius of the insert used. The Cutting Data option checks if the cutting data in the operation are right for the insert in use and this task is basically the

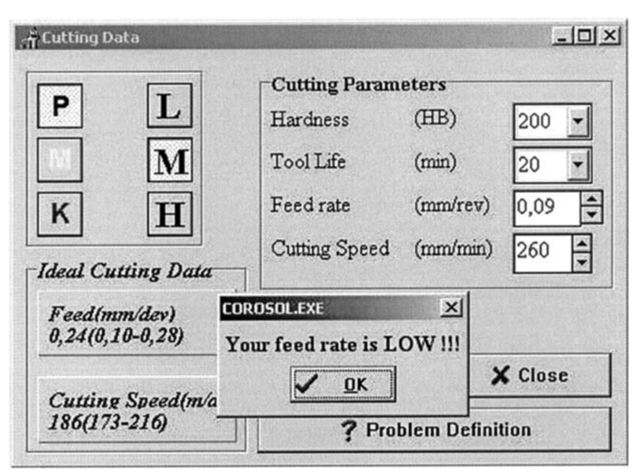

Fig. 6. Checking the cutting data.

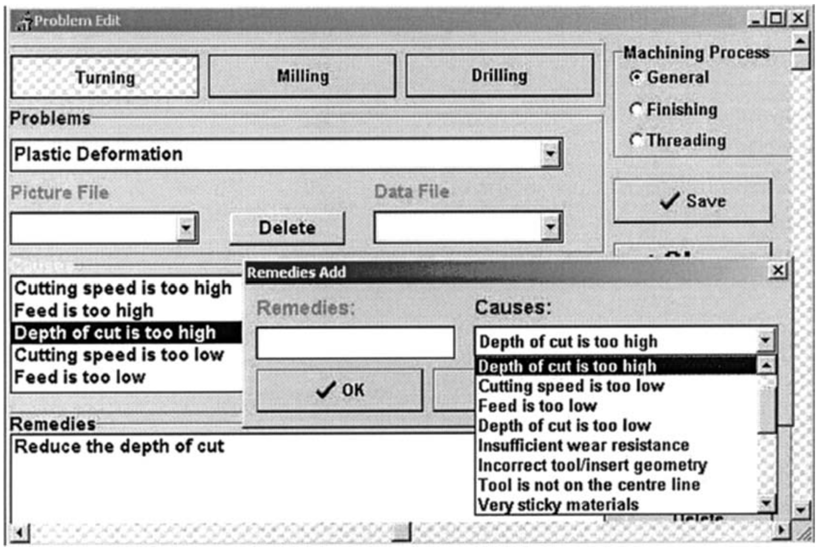

Fig. 7. Adding a new remedy.

comparison of the cutting data with the ideal values calculated from the multiplication of the catalogue values and the correction factors. If there is no match (this means the values of cutting data are not in the range) the user is advised to correct the cutting data. In milling and drilling only cutting speed and feed rate values are considered, in drilling this consideration takes the drill diameter and the grade of the centre/periphery insert into account (Fig. 6). In the figure, cutting data for face milling of steel for medium feed rates (L for light, M for medium, H for heavy milling operations) are evaluated and since the feed value is lower than the ideal values calculated for given hardness and tool life, a warning is displayed.

Once the cutting data are reviewed (and corrected), accessing to the problem definition section is the next step. Since the cutting data are corrected, the list of causes and the remedies will now be different and no such causes as "*Cutting speed is too high*" or "*Feed rate is too low*" will not be amongst the causes of the related problem.

The software is capable of analysing more than 100 types of problems in various types of operations and providing remedies to the nearly 200 causes (340 remedies). The knowledge contained in the system has been compiled from two main sources: from human experts working in the field of metal cutting and from the technical documents, catalogues or handbooks of various cutting tool producing companies [21–25].

3.2.4. Problem editor

The knowledge contained in the system has been compiled from two main sources: from human experts working in the field of manufacturing and from the technical documents, catalogues or handbooks of various cutting tool producing companies. The success of an expert system is hidden in its expandable structure like a human expert who adds every new solution he comes across to his knowledge and uses this knowledge in his future analyses. Thus, COROSolve has an expandable database structure that grows to handle more and more problems everyday.

Since the system has a separate and modular knowledge base, it is very easy indeed to update the system by simply getting into the database and editing the knowledge files. The more information the system contains, the more problems it can handle in metal cutting. Knowledge base is the heart of the system, therefore it is the task of a few people who are responsible from the production to add, delete or modify it. Thus, the user needs to know the password to access to the knowledge base.

Problem edit allows the new problems, picture and information files related to the problems, causes and the remedies of the problems to be added to the knowledge base. Besides, it is possible to add new causes to the problems, or new remedies to the causes that are already exist in the knowledge base (Fig. 7).

The system is multi-linguistic, therefore it is capable of handling the metal cutting problems both in Turkish and English. Once the language is determined, all the program menus and problem, cause and remedy lists are displayed in the language chosen.

4. Conclusions

This paper introduces an expert system approach for the task of solving metal cutting problems in various machining operations. Since there are not many work exist in the literature about this subject and since this type of system can mostly fulfil the requirements in metal cutting industry, the work described here can be considered as a useful piece of work. In manufacturing industry, especially in small or medium-volume machine shops, incorrect cutting data are the main reason of the problems. Tools were generally run at lower cutting data to make them last longer for less frequent changes. This then obviously meant poor utilization of the metal cutting time. Since one of facilities that the system provide is the evaluation of the cutting data, it will help the user to choose the right speed, feed or the depth of cut for the application. If the cutting data are correct and the metal cutting problems are solved, the stoppages due to the breakdowns will be shorten, good utilization of power capacity will be achieved and the metal cutting time will therefore be reduced. This means a great deal of reduction in production cost.

The system developed intends to educate the people in metal cutting industry as well. The pictures and the information about the problems help the users to recognize and learn more about them. These pictures and the information were congregated from various handbooks and catalogues used in the industry.

References

[1] Modern metal cutting. Sandvik Coromant. 1994.

[2] Ciftci I, Turker M, Seker U. Evaluation of tool wear when machining SiCp-reinforced Al-2014 alloy matrix composites. Mater Design 2004;25:251–5.

[3] Wang HP, Wysk RA. A knowledge-based approach for automated process planning. Int J Prod Res 1988;26(6).

[4] Cakir MC, Irfan O, Cavdar K. An expert system approach for die and mold making operations. Robot Comput Int Manuf 2005;21(2):175–83.

[5] Peers SMC, Tang MX, Dharmavasan S. A knowledge-based scheduling system for offshore structure inspection. In: Rzevski G, Adey RA, Russell DW, editors. Artificial intelligence in engineering IX (AIEng 9), Computational Mechanics, Southampton, 1994. p. 181–8.

[6] Rosano FL, Valverde NK, De La Paz Alva C, Zavala JA. Tutorial expert system for the design of energy cogeneration plants. In: Proceedings of the third world congress on expert systems, Seoul, Korea. February 1996. p. 300–5.

[7] Koo DY, Han SH. Application of the configuration design methods to a design expert system for paper feeding mechanism. In: Proceedings of the third world congress on expert systems, Seoul, Korea. February 1996. p. 49–56.

[8] Yano H, Akashi T, Matsuoka T, Nakanishi K, Takata O, Horinouchi N. An expert systems to assist automatic remeshing in rigid plastic analysis. Toyota Tech Rev 1997;46:87–92.

[9] Bose A, Gini M, Riley D. A case-based approach to planar linkage design. Artif Intell Eng 1997;11:107–19.

[10] Shi ZZ, Zhou H, Wang J. Applying case-based reasoning to engine oil design. Artif Intell Eng 1997;11:167–72.

[11] Mookherjee R, Bhattacharyya B. Development of an expert system for turning and rotating tool selection in a dynamic environment. J Mater Process Technol 2001;13:306–11.

[12] Wong SV, Hamouda AMS. Development of generic algorithm-based fuzzy rules design for metal cutting data selection. Robot Comput Int Manuf 2002;18:1–12.

[13] Wong SV, Hamouda AMS, El Baradie MA. Generalized fuzzy models for metal cutting data selection. J Mat Proc Tech 1999;89–90:310–7.

[14] Pande SS, Prabhu BS. An expert system for automatic extraction of machining features and tooling selection for automats. Computer Aided Engineering Journal 1990;99.

[15] Parsaye K, Chignell M. Expert systems for experts. Wiley; 1988.

[16] Kojiyama T et al.. An expert system of machining operation planning in Internet environment. J Mater Process Technol 2000;107:160–6.

[17] Jiang B, Baines K, Zockel M. A nex coding schema for the optimisation of milling operations for utilisation by a generative expert C.A.P.P. system. J Mater Process Technol 1997;63:163–8.

[18] Limsombutanan B. Curvature analysis based holon for 5-axis milling cutter selection and tool path planning. Electronic Journal of the School of Advanced Technologies, Asian Institute of Technology 1999;1(2).

[19] Sandvik Coromant, COROKEY tool selection guide, C-2903: 6-ENG, 2000.

[20] Sandvik coromant turning tools, C-l000: 7-ENG, 2002.

[21] Kennametal cutting tools, 2001.

[22] Side and face milling, Sandvik Coromant, C-l 129: 022-ENG, 1996.

[23] Valentine indexable cutting tool INSERTS, 1993.

[24] HERTEL boring and countersinking guidelines, Technical handbook, 103 GB, 1994.

[25] Carboloy turning GT5-265 M-59-03, 1995.