AN EXPERT SYSTEM FOR SELECTION OF CARBIDE CUTTING TOOLS FOR TURNING OPERATIONS

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Abstract

Majority of the components machined in industries have cylindrical shapes with large variety in shape, size and accuracy. An engineer has to select the tools based on his experience or by referring tooling catalogues which is time consuming. In the present research work, an expert system is developed for the optimal selection of carbide cutting tools for turning operation. Technical knowledge acquired from various sources of knowledge acquisition is refined and framed in form of production rules of ‘IF-Then’ variety. ISO specifications along with trade names of various leading cutting tool manufacturers are included in the knowledge base of proposed system. This system determines several parameters such as tool holder (clamping system, approach angle, and size), insert (shape, size, and nose radius) and cutting condition (speed, feed, and depth of cut). The most important feature of the system is the cross reference list of inserts. Use of this system will avoid cumbersome work of referring tooling catalogues of various tool manufactures. The system has been tested successfully in a manufacturing industry.

Keywords: Expert system, Turning, Cutting tool selection, Carbide tools

1 Introduction

In modern manufacturing sector computers are used formost of the activities like process planning, design, scheduling etc. The advancement in computer technology, such as artificial intelligence, computer-aided design and computer numerical control has reduced human efforts in manufacturing and hence improved quality and productivity (Chee et al., 2012). Nowadays, information technology has been integrated with the manufacturing practice in order to shorten the time from product conceptual to product marketing. Computer is an important tool for manufacturing engineer to launch good quality products in markets in a short time. Expert system (Arezoo et al., 2000) and neural network (Kadi et al., 2010; Deiab et al., 2010; Guedri, 2007) techniques are being used in manufacturing to improve quality of products and productivity. An expert system contains a knowledge base, a dialog structure and an inference engine, which consists of an interpreter and a scheduler. The knowledge base is the collection of the domain knowledge. The dialog structure provides communications and interaction with the user during the processing of the expert system. The inference engine contains the general problem solving knowledge. The interpreter makes decisions on how to apply the rules for inferring new knowledge and the scheduler prioritizes the rules in appropriate order. The expert system is an interactive support system for experts (Chin et al., 1996; Sapuan et al., 2000).

The present paper describes research work involved in the development of an expert system for selection of carbide cutting tools for turning operations. By selecting correct cutting tool and its associated cutting parameters, significant reduction in cost can be achieved. The proposed system selects best tool holder and insert from available cutting tools. The factors which influence the tool selection decision are work piece material (chemical and mechanical properties), part characteristics (geometry, accuracy and finish required) and machine tool including tool magazine and tool holder size (Oral et al., 2004).

2 Literature review

Er and Dias (2000) developed a rule-based expert system to select casting process for manufacturing of engineering components. Arezoo et al. (2000) and proposed an expert system to select general turning tools considering only type of operation that is facing and plain turning. An expert system, namely EXTOOL, has been developed by Moookherjee et al. (2001). This system is based on the customer requisite material and geometry, to select inserts for turning and milling processes automatically. Sapuan et al. (2002) developed the expert tool material selection system for machining of automobile components. Mustafa et al. (2003) developed a knowledge-based decision support system (KBDSS) for short-term scheduling in FMS strongly influenced by the tool management concept. Chourou (2005) introduced ESMRS (Expert System for Manufacturing Resource Selection) which was used in a simulation based
approach in order to structure the solution search mechanism and to overcome trial and error aspect. Wanget al. (2007) carried out development and integration of hybrid models for single and multi-pass turning operations using nonlinear programming techniques for single-pass operations, and genetic algorithm approach was used for multi-pass operations. While selecting cutting tools and speed-feed they considered cutting force, tool wear/tool life, chipform/chip breakability, and surface roughness. Cutting Data Module (2008) developed by Sandvik is helpful as calculator to find the power required for cutting, based on suggested speed-feed data and depth of for selected insert. Chee et al. (2012) developed an expert system for selection of carbide cutting tools for computer numerical control (CNC) lathe machine.

From the literature review, it is found that various systems have been developed for tool selection. But these systems do not suggest complete specification of indexable turning tools in detail. These systems need in depth knowledge and experience of all metal cutting operations on the part of user. In the present work, an expert system is developed for the optimal selection of carbide cutting tools for turning operation.

3 Proposed expert system

For development of proposed system, technical knowledge is acquired from various sources including tooling catalogues of Mitsubishi Carbide (2012), Sumitomo Electric (2010), SandvikCoromant(2008), Kennametal(2013), Seco(2008), Iscar(2013), Kyocera(2010) and discussion with domain experts. Cutting parameters such as cutting speed-feed, material hardness (HRC) are obtained from Machinery’s Handbook(2004). Knowledge acquired from these sources is refined and framed in form of production rules of ‘IF-Then’ variety and then coded using Visual Basic 6 language. ISO specifications along with trade names of various leading cutting tool manufacturers are included in the knowledge base of proposed system. User can select any trade name and can find its equivalent cutting tool along with ISO specification of other cutting tool manufacturers for comparison. This system determines parameters such as tool holder (clamping system, approach angle, and size) insert (shape, size, and nose radius) and cutting condition (speed, feed, and depth of cut). The system has been tested successfully in a manufacturing industry. Execution of the proposed system is depicted in the Figure 1.
While developing the system following points are mainly considered.
- ISO specification of tool holder with indexable inserts
- Minimizing the tool holder variety for the same job or similar type of cutting condition
- Insert material selection based on work-piece material hardness and production quantity
- Maximum depth of cut that cutting edge or insert length will permit
- Strongest shape of insert to achieve productivity
- Tool holder cross section to suit the selected machine tool

Steps and considerations of system in detail are discussed in the following section

3.1 Work-piece geometry, material and cutting data

This section describes rationale and implementation of the speed-feed assessment. Main input required for the tool selection system is geometry of the work-piece. Though the system is designed for the operations like turning, milling and hole making, here lathe operations are covered in detail.

![Figure 2 Work-piece detail entered to the system](image)

In case of round shaped components input required are name of work-piece (description), drawing number, maximum length of work-piece, maximum diameter of work-piece, and material type as shown in Figure 2. This part features entered in system helps in determining initial cutting conditions. A wide range of work-piece materials and tool material are included in the database of the proposed system. Data driven and highly flexible method enables system effective functioning with precise output. User has to select the work piece material from the database. Facility of addition of new material through the material master is also provided.

Generally ferrous metals are specified by various standards like En, I.S., AISI, JIS, and DIN. In the proposed system user has given choice to select the material with AISI and En standard as it is most widely used in industries. Material hardness has to be entered by the user which helps in deciding the speed-feed data. Main material library contains more than 800 engineering materials which are divided into 11 main classes of material. These groups are subdivided into 150 machinability groups. Each of this is related to a set of typical cutting data for roughing, semi-finishing and finishing. Cutting tool material selection is also related to the work piece material grades.

Initial cutting data has been collected from various handbooks and tool manufacturers’ catalogs. Then the rules are framed based on the data collected. A sample of the rules is shown in Table 1. System calculates speed-feed based on information provided by the user related to material and type of operation.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Condition</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>If work material = plain Carbon steels &amp; Hardness &lt;=160 BHN &amp; Depth of cut &lt;=1 mm;</td>
<td>Then Feed = 0.3 mm/rev &amp; Speed = 290 m/min</td>
</tr>
<tr>
<td>2</td>
<td>If work material = plain Carbon steels &amp; Hardness &lt;=160 BHN &amp; 1 mm &lt; Depth of cut &lt;=6 mm;</td>
<td>Then Feed = 0.4 mm/rev &amp; Speed = 350 m/min</td>
</tr>
<tr>
<td>3</td>
<td>If work material = plain Carbon steels &amp; Hardness &lt;=160 BHN &amp; 6 mm &lt; Depth of cut &lt;=9 mm;</td>
<td>Then Feed = 0.6 mm/rev &amp; Speed = 350 m/min</td>
</tr>
<tr>
<td>4</td>
<td>If work material = plain Carbon steels &amp; 160 BHN &lt; Hardness &lt;= 280 BHN &amp; Depth of cut &lt;=1 mm;</td>
<td>Then Feed = 0.3 mm/rev &amp; Speed = 280 m/min</td>
</tr>
</tbody>
</table>

3.2 Operation Selection

Unlike traditional CAPP system, this operation definition does not require too much information from user. Icon based operation selection allows user to select correct operation from predefined operation list. Lathe operations are mainly categorized as facing, axial boring, external turning, chamfering, grooving, taper turning, axial drilling, axial reaming, and axial tapping (Figure 3). Another input required is type of cutting which is divided in to finish (light cut), semi-finish (Medium), and rough (Heavy). This operation definition allows fast evaluation of speed-feed data.
3.3 Tool Holder Selection

While selecting the tool, two main points have given the most importance, first is the tool holder type and another is the insert with ISO grade and trade name. ISO specification of turning tool holder consist minimum nine parameters as shown in Figure 4. Meaning of alphabets and the numbers as per sequence are: P- Insert holding method, C- Insert shape, L- Approach angle N- Clearance angle, R- Hand of cutting, 16 & 16- Shank cross section (mm), H- Tool length, 12- Insert size (mm).

Compatible tool holders as per operation are displayed to the user. Mostly more than one type of holder becomes eligible. In such case, images provided in the system for every approach angle and possible operation helps the user to select required tool holder based on work piece geometry and tool combination (Figure 5). As an example of external turning with tool holder of an approach angle 95° with suitable inserts are given in Table 2. And the same information is used while preparing the knowledge base for this operation. The system has rich knowledge base for different operations with variety of tool holders and inserts. System suggests most suitable cross section (i.e. width and height) of cutting tool based on selected machine tool.

The knowledge base includes tools required for all possible operations on lathe like facing, axial boring, external turning, chamfering, grooving, taper turning, axial drilling, axial reaming, axial tapping etc.

3.4 Inserts material, grade and size

A system provides option for selection of all the latest tool material and inserts’ grades available in the market. Selection of tool material and grade is suggested to the user, based on various combinations of work piece material, type of cutting (i.e. light, medium or heavy). Insert size suitable to selected tool holder is also suggested by the system and user can select any one of them.

3.4.1 Material

Following are various tool materials provided in knowledge base and information given below is used while defining the rules for selection.

Carbide - Tungsten carbide based material with a cobalt binder is offered in two industry-class grades. Both grades are for general-purpose machining of aluminum, cast iron and nonferrous metals as well as high temperature alloys and plastics.

Coated carbide – For materials that are very difficult to machineplane carbide is now being replaced by the
coatings, ceramics and super hard materials. TiN coated (Titanium Nitride) recommended for light-roughing and finishing grade of alloys and stainless steels as well as ductile irons. Tricoated (TiN-AlOx-TiN) is recommended for heavy-duty turning of cast steel, stainless steel and alloys with interruptions and rough surface conditions. TiC coated (Titanium Carbide) abrasive, flank and nose wear resistance used in machining cast iron, steel and alloyed steel.

Cermet - Cermet is a carbide blend, solid (100% titanium) carbide with a nickel binder. Cermet grades are based on TiCN with superior hardness and excellent high temperature compared to conventional carbides. Specific grades for machining carbon and alloy steels, stainless steels and cast iron where tool life and improved workpiece finish are desired.

Ceramic - Ceramic inserts should be considered when machining cast iron and highhardness materials above Rc 35. Used for cast iron and can be machined at higher speeds than conventional carbides. Ceramic inserts have superior edge strength.

3.4.2 Insert grade

Insert selection is carried out on a nine squares matrix symbolizing different work piece materials and different machining conditions (Figure 6). The actual work piece material (Steel, Stainless steel or Cast Iron) and the actual application (finishing, semi-finishing or roughing) will lead to recommendation of a grade. While categorizing into type of cut, following values of depth of cut are considered: Finish = 0.2-0.8 mm, Semi-finish = 0.8 – 3 mm and Rough = 3-7 mm

3.4.3 Insert size

For selection of size of insert, two parameters, insert length (cutting edge length) and nose radius are considered. The nose radius, \( r_e \), on the insert is a key factor in turning operations. Selection of nose radius depends on depth of cut, feed, and influences the: surface finish, chip breaking, and insert’s strength. In case of finish cut, system asks for finish required on the work piece. User has to input surface roughness value in Ra (in micron). Information given in Table 3 is used to set remaining values like nose radius and feed. Otherwise if the user selects both the values of surface roughness and nose radius, system suggest the feed required to achieve inputted surface roughness. The formula used to calculate mean \( R_a \) value is:

\[
R_a = \frac{f^2 \times 50}{r_e} \tag{1}
\]

Where,

- \( f \) = feed rate (mm / rev)
- \( r_e \) = nose radius (mm)

<table>
<thead>
<tr>
<th>Surface Finish (Ra value)</th>
<th>Nose radius ( r_e ) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed f (mm/rev.)</td>
<td>0.2 0.4 0.8 1.2 1.6 2.4</td>
</tr>
<tr>
<td>0.6</td>
<td>0.05 0.07 0.1 0.12 0.14 0.17</td>
</tr>
<tr>
<td>1.6</td>
<td>0.08 0.12 0.16 0.2 0.23 0.29</td>
</tr>
<tr>
<td>3.2</td>
<td>0.12 0.16 0.23 0.29 0.33 0.4</td>
</tr>
<tr>
<td>6.3</td>
<td>0.23 0.33 0.4 0.47 0.57</td>
</tr>
<tr>
<td>8</td>
<td>0.4 0.49 0.57 0.69</td>
</tr>
</tbody>
</table>

4 Conclusions

In the present research work, an expert system is proposed which is capable of suggesting the correct carbide cutting tools for various turning operations. This can be useful to process planners and tool manufacturers as well. Tool manufacturer cannot provide all the information required to their customers. Technical knowledge acquired from various sources of knowledge acquisition is refined and framed in form of production rules of ‘IF-Then’ variety. ISO specifications along with trade names of various leading cutting tool manufacturers are included in the knowledge base of the system. The most important feature of the system is the cross reference list of inserts. Use of this system will avoid cumbersome work of referring tooling catalogues of various tool manufacturers. Person having less experience can find out the required cutting tool and compare the cost of various tools. The system has been tested successfully in a manufacturing industry. System is capable of producing tool report with process sequence as shown in Figure 7.
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Figure 7 Selected cutting tool details with process sequence

<table>
<thead>
<tr>
<th>Op.No</th>
<th>Description</th>
<th>Tool</th>
<th>Insert Material</th>
<th>Insert Shape</th>
<th>Insert Size</th>
<th>Cost</th>
<th>Insert Info</th>
<th>Approach Angle</th>
<th>Grade</th>
<th>Trade Name</th>
<th>Equivalent Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>External Turning 0.30/00 X 5.00</td>
<td>PCBN</td>
<td>CN820F</td>
<td>6.0</td>
<td>C</td>
<td>Coated Carbide</td>
<td>450/00</td>
<td>Negative insert series with</td>
<td>15°</td>
<td>P 10</td>
<td>Sandvik</td>
</tr>
<tr>
<td>20</td>
<td>External Turning 0.40/00 X 6.00</td>
<td>PCBN</td>
<td>CN820C</td>
<td>9.0</td>
<td>C</td>
<td>Coated Carbide</td>
<td>465/00</td>
<td>Negative insert series with</td>
<td>15°</td>
<td>P 10</td>
<td>Sandvik</td>
</tr>
<tr>
<td>30</td>
<td>Facing 0.30/00 X 15.00</td>
<td>CN220S</td>
<td>SN2M0</td>
<td>9.0</td>
<td>S</td>
<td>Coated Carbide</td>
<td>390/00</td>
<td>Positive insert series and clamp-on type</td>
<td>15°</td>
<td>P 10</td>
<td>Sandvik</td>
</tr>
<tr>
<td>40</td>
<td>External Turning 0.30/00 X 5.00</td>
<td>PCBN</td>
<td>CN820F</td>
<td>12.0</td>
<td>C</td>
<td>Coated Carbide</td>
<td>450/00</td>
<td>Negative insert series with</td>
<td>15°</td>
<td>P 10</td>
<td>Sandvik</td>
</tr>
</tbody>
</table>

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