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DECISION SUPPORT SYSTEM FOR CUTTING PARAMETERS SELECTION IN MACHINING PROCESSES USING FUZZY KNOWLEDGE

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Abstract - This paper presents the decision support system using fuzzy knowledge to adapt the cutting conditions chosen by a conventional expert system to a particular machine tool, workpiece and clamping system. These preliminary results demonstrate the capability of fuzzy logic to adjust cutting parameters taking into account parameters difficult to quantify.

1. INTRODUCTION

The proper choice of the cutting parameters is very important in modern manufacturing, because it constitutes the ultimate goal of the planning and numerical control processes. A unified adequate method for such a choice has not yet been developed, although, since Taylor's approach, many scientists and researchers have tried to find optimal parameters of exploitation of cutting tools. The obtained formulas are more or less similar, because of the existence of many uncontrollable factors the coefficients used in these formulas deliver significant imprecision in the value of the resulting parameters. This is mainly due to:

- various machinability of identical materials,
- differences in tool geometry, tool materials, surface roughness, tool clamping,
- different machine tool wear,
- various rigidity and power of machine tools,
- various rigidity of machined parts,
- others.

Several computer-aided decision making systems for the selection of cutting parameters based on both theoretical and experimental methodologies have already been developed. These systems rarely consider variables such as part configuration, condition of the machine tools, type of fixturing, etc. Because, the effects of these variables on tool life are not precisely known, it becomes difficult to easily define the optimum machining conditions. However, it is possible to express the necessary knowledge for the adjustment of the operating conditions using fuzzy linguistic rules.

2. DECISION SUPPORT SYSTEM

The diagram of the Decision Support System for the selection of the cutting parameters in turning and their modification unit using imprecise but valuable information is shown in Fig.1.

The whole system was created using the expert system shell GURU (Expert Systems for Information Management). The means provided by that software made it possible to easily gather knowledge expressed in the form of "If-Then" statements with relational data bases and conventional procedures. The system incorporates 10 rule bases (that include a total of 70 rules), 47 procedure routines written in GURU specialized language and 12 relational data bases [1].

It is very important to notice the use of modification unit included in the system using imprecise (fuzzy) knowledge (rules) to modify the preliminary parameters. It should be pointed out that this knowledge is usually underestimated in the world of conventional computer systems developed for the selection of cutting parameters.

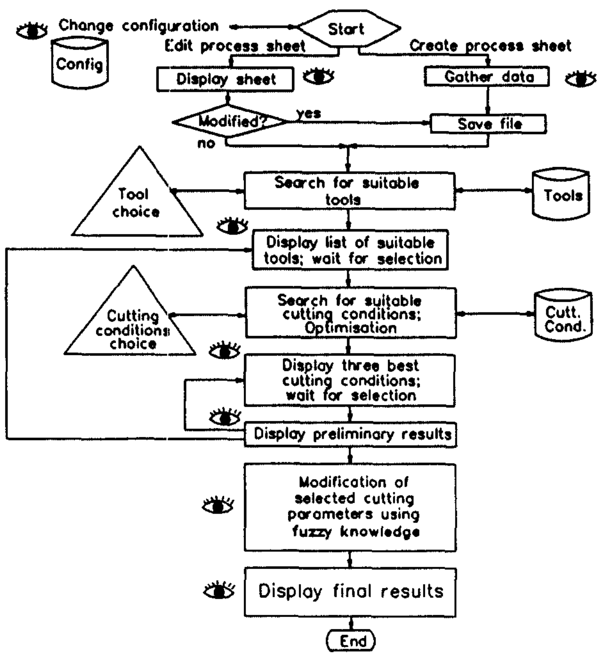

Fig. 1 Decision support system for cutting parameters selection

3. MODIFICATION UNIT

3.1 Mathematical formulation

The imprecise knowledge delivered by a human expert is usually expressed by fuzzy rules in the following form:

R_r: If A is $A_i^{(r)}$ and B is $B_j^{(r)}$ and ...and C is $C_p^{(r)}$
then U is $U_k^{(r)}$ and V is $V_l^{(r)}$ and ... and W is $W_q^{(r)}$ (1)

where $A_i^{(r)}$, $B_j^{(r)}$,..., $C_p^{(r)}$ denote linguistic values of the condition variables defined in the following universes of discourse: **X**, **Y**,..., **Z** and $U_k^{(r)}$, $V_l^{(r)}$,..., $W_q^{(r)}$ stand for linguistic values of the conclusion variables defined in universes of discourse **U**,**V**,...,**W** respectively. Such a rule corresponds to a relation which may be represented by a respective fuzzy implication [2].

The approximate reasoning is performed by means of compositional rule of inference which may be written in the form:

$$(U', V', \ldots, W') = (A', B', \ldots, C') \circ R \quad (2)$$

R represents the global relation aggregating all rules and may be expressed as

$$R = \text{also}_r\,(R_r) \quad (3)$$

where the sentence connective "also" may denote any t- or s-norms (e.g. usual min or max operators).

The symbol $\circ$ stands for the compositional rule of inference operation (e.g. sup-min, sup - bounded_product etc.). (A', B',..., C') denotes input information and (U',V',...,W') stands for output decisions.

Taking into account the fact that usually the fuzzy rules are formulated for each chosen cutting parameters separately, we may consider the simplified rules (one conclusion only). For this case the compositional rule of inference may be taken in the form:

$$U' = (A', B', \ldots, C') \circ R \quad (4)$$

Such a fuzzy output information is defuzzified, for example, using center of gravity method. Information of this kind may denote, for instance, a percentage of change for the previously obtained parameter.

3.2 Description of the fuzzy modification unit

The fuzzy shell unit called FUZZY-FLOU was developed at École Polytechnique de Montréal in collaboration with Mr. E. Czogala from the Technical University of Silesia and constitutes the essential components of the fuzzy modification unit.

This module running on IBM-PC or compatible systems can calculate inference relations of four different types (SUP MIN, SUP PROD, SUM MIN, SUM PROD). An other very important amelioration over the previous systems is that the user can enter crisp and fuzzy evaluation of a concept in the system. The inference engine can run 300 fuzzy relations of inference in linguistic rules with up to 5 input linguistics concepts and up 2 output linguistics concepts. Each concept is related to 11 linguistic realities.

With the program, it is also possible to visualise linguistic realities in a graphical form, concept by concept.

An interface in C code is possible for development of simulation, of control, and of different rule bases chaining applications.

The program can also process a data file to help define and correct a control surface. The user can get a rule in a linguistic form for easier development of rule bases.

4. FUZZY MODIFICATION UNIT FOR CUTTING PARAMETERS

4.1 General overview

The system developed on GURU already takes into account some parameters used to select the cutting parameters such as:

- the hardness of the workpiece material,
- the type of workpiece material,
- the desired surface roughness,
- the type of tools,
- the tool life,
- the type of pass (roughing, finishing).

With these parameters GURU can estimate the cutting parameters for the average operating conditions.

The modification unit takes these results and defines a correcting factor for the speed and the feedrate. The fuzzy adjusting concepts that are considered in this paper are:

- the machine quality,
- the rigidity of the machine-tool-workpiece system,
- the desired part tolerances.

With these concepts, several rules can be defined to establish correcting factors of the cutting speed and of the feedrate.

Rules are expressed in the linguistic form like:

RULE 10
IF Machine Quality is poor
AND System Rigidity is flexible
AND Part Precision (mm) is class 9
THEN Speed Factor is large decrease (large dec.)
AND Feedrate Factor is decrease (dec.)
RULE 11
IF Machine Quality is medium
AND System Rigidity is flexible
AND Part Precision (mm) is class 9
THEN Speed Factor is large decrease (large dec.)
AND Feedrate Factor is decrease (dec.)

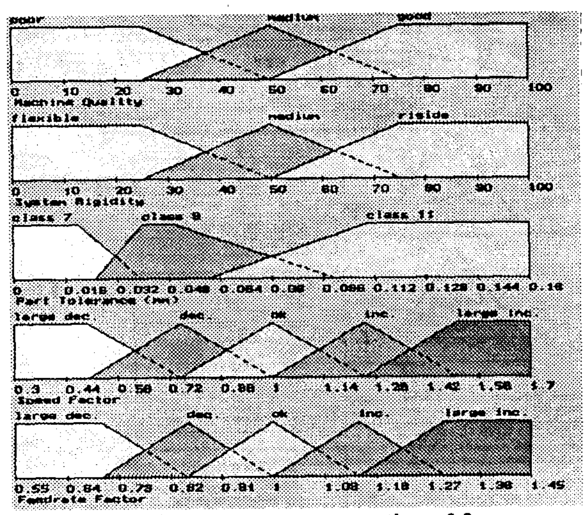

Fig. 2 Graphical screen representation of fuzzy concepts

The machine quality and the system rigidity are defined with an evaluation scale from 0 to 100. The machine quality concept is divided in the following linguistic realities: poor, medium and good. The system rigidity is defined by the following linguistic realities: flexible, medium and rigid. The concept of part precision is defined, using a numerical scale in millimeters, by the classes of quality: class 7, class 9 and class 11. Finally, the concepts of the cutting speed factor and of the feedrate factor are defined as multiplicative factors of the results obtained previously with the GURU system.

The system user only has to enter the fuzzy evaluation of a case. Then the system calculates using a set of rules, the adjustments of the speed and feedrate factors. The result shows up in a fuzzy form, so it needs to be defuzzified. The defuzzification is accomplished by using the center of gravity method.

4.2 Example of execution

This section will show an example of the modification unit using the previously mentioned knowledge base.

The used trapezoidal membership function form is defined as (m1, m2, am, bm, hm) where:

- m1: the beginning of the maximum belief zone,
- m2: the end of the maximum belief zone,
- am, bm: the left and right distances between the none belief to the maximum belief zone, respectively.

- hm: the maximum degree of belief.

The machine quality concept with the evaluation m1=68, m2=71, am=10, bm=10 and hm=1 is represented on screen as shown in figure 3.

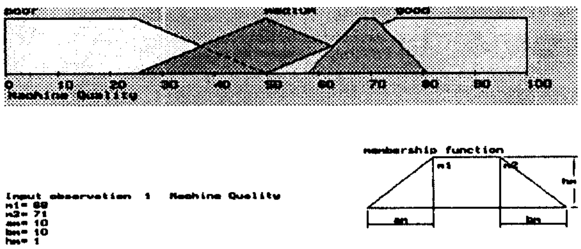

Fig. 3 Representation of the machine quality concept with fuzzy evaluation

The figure 4 represents a complete case, with the following fuzzy evaluations:

- Machine quality (68, 71, 10, 10, 1), **(1)**
- System Rigidity (65, 70, 15, 5, 1), **(2)**
- Part Precision (0.06, 0.07, 0.01, 0.01, 1). **(3)**

The last two graphs, (4) and (5), represent the fuzzy results of calculations for the speed and feedrate factors.

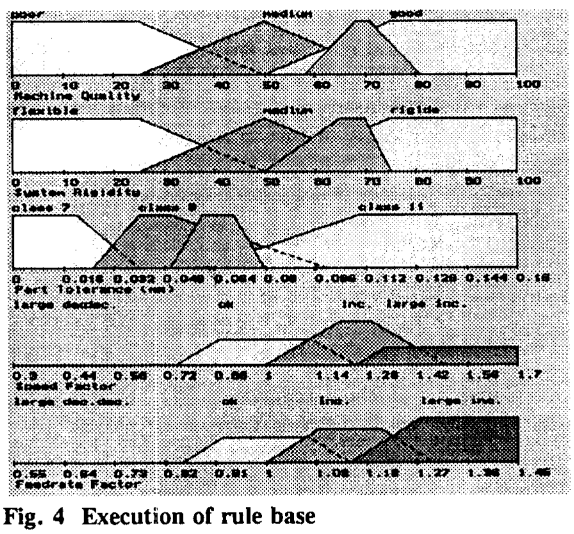

Fig. 4 Execution of rule base

In this example after defuzzification, the modification unit output is the cutting speed and the feedrate corrective factors, respectively 1.228 and 1.193. These results are applied to the cutting parameters obtained previously with the GURU knowledge base system.

5.0 CONCLUSION

The results of tests performed using a fuzzy modification unit show that fuzzy logic is appropriate for solving cutting parameters choice problems considering variables difficult to define such as the machine quality and the fixtures rigidity. These variables affect the performance of the machining process and their considerations allow to select cutting parameters nearer optimum than conventional expert system.

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