Expert system for the definition of the cutting parameters and machining strategies

L.Zaquini[1], J.Charpy[1], J-P. Bendit[2], T.Voumard[3], P-E Mathez[3], L. Béguelin[3]

[1]HE-ARC-Ingénierie LMO (Laboratoire de Machines-Outils), University of Applied Science, Le Locle, Switzerland,

[2] Jurasoft SA, Porrentruy, Switzerland,

[3] Haute Ecole ARC – Software Engineering, University of Applied Science, St-Imier, Switzerland, Switzerland,

Abstract

The definition of the cutting parameters (Vc, fz, ae, ap), and the definition of the machining strategies or the strategies to engage the tool in the material and to start the cutting process, are usually requested by the CAM systems as input information. These data are usually strongly influenced by the consolidated experience of the operators, by the specific previous similar machining cases and by several other factors depending on the machining practices. In a project, financed by the Swiss national organization for the industrial research, the authors have developed an expert system (ES) in order to get this information through software processes.

The paper shows the structure of this expert system.

The ES has been realized through the definition of ontology of components and elements of the machining.

The ES includes a very large data base of cutting parameters, and is based on the establishment of rules for the competition between the machining strategies. The ES includes learning methods which are able to identify similar operations. The learning methods are based on the measure of the distance between the actual machining conditions and those already experimented. Therefore the system is able to learn from similar cases.

The system has been designed especially for an application in the field of the watch industry which requests a very large spectrum of machining operations and includes also the cases of the HSC.

The new expert system is today implemented in a CAM, SylvieXpert, commercially distributed by the company Jurasoft.

Keywords:

Machining, Cutting, Parameters, Expert system

1 INTRODUCTION

At the present state of the art, frequently the CAM systems ask a set of information to the users, but in frequent cases the users (the CAM operators) are not prepared to answer these questions.

For instance the system asks the CAM operator to define parameters like: «the rpm of the spindle », or the « cutting feed », or the strategies to engage the tool in the material, but in frequent cases the CAM operator does not have the technological skill for this kind of questions.

People in the shop are sometimes better prepared and better skilled in this technological field, but the shop has not the proper environment for calculations, computations (for instance for the prediction of the roughness) or for consulting catalogues. In any case the CAM workstations are placed in the offices and from the office the part program goes down to the shop. More over, the NC operators are used to react on the basis of the experience, the « intuition » and these elements are difficult to be transferred.

This difficulty is enhanced in case of adoption of HSC. In this case, the lacks of experience, the absence of « intuition » based on a previous practice, are generalized and interfere with the introduction of new cutting parameters and machining strategies. The same problem occurs in case of new and unknown materials, which is a frequent case in the field of the watch industry.

On the basis of these considerations, we developed a system giving answers more than asking questions.

It represents an enhancement of the degree of automation in the field of the machining of materials. The system had to include the « experience » and the « intuition » of the better skilled operators. Therefore we moved to the development of an « Expert System ».

We operate in a region with a long tradition in machining small mechanical pieces of high precision (which is the case of the Swiss watch industry). The realization of these pieces needs complex, multi spindle machines.

Une broche porte-outils | Peignes et tourelle | Ensemble de broche

Figure 1: Examples of machine tools.

More over the realization of the pieces needs the adoption of a very high number of types of machining (milling, turning, drilling, tapping etc.) carried out on the same machine. Therefore the development of the expert system had to take care of this complexity, offering proper values and machining strategies in a very large spectrum of working conditions. It is impossible to include in a single paper the description of the solutions adopted for such a large list of different cases. This paper will offer you an overview of the methodology, followed for the development.

2 STRUCTURE OF THE SYSTEM

The general overview of the system is sketched in the figure that shows: the inputs, divided in two groups:

Material, Type of Machining (milling, turning, drilling, tapping … etc. , Surface quality (i.e. Finishing, Roughing,

… etc.). A second set of input is represented by the inputs that in the future could even become outputs. Nevertheless, for the moment, they are seen as inputs by the system: Machine tool, Spindle, Tool and piece clamping systems, Coolant, Tool.

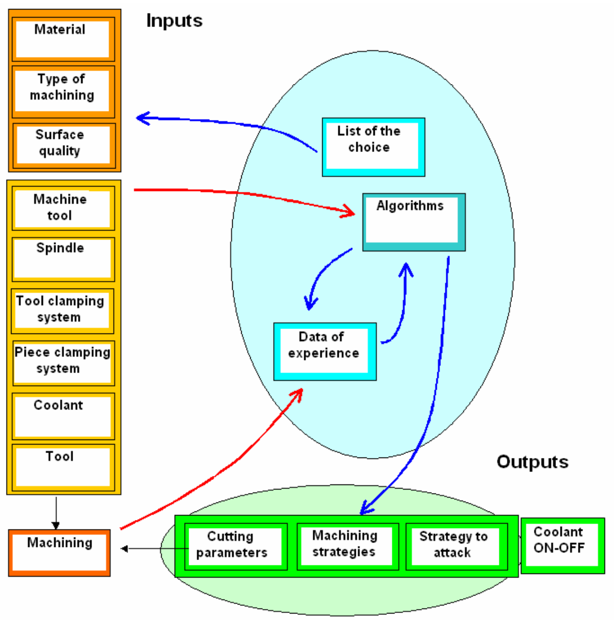

Figure 2: General structure of the system.

The Outputs are: The Cutting Parameters, The machining strategies, the strategies for entering and going out of the material, the choice to switch on or off the coolant.

The system includes a feed back, as evaluation of the machining process and this feed back activates the learning process.

3 DEFINITION OF THE ONTOLOGY

The definition of the ontology of the machining process was our first activity.

The structure also is a consequence of this definition. The definition of the ontology includes also other entities.

We adopted the UML (Unified Modeling Language) for the representation of the structure of the system and we succeeded to organize the full structure in just two levels.

Class (named also « Catégories »)

Properties (named « Propriétés », in French).

Figure 3: Prototypes of classes.

It is not possible here to describe the full ontology; nevertheless it is possible to give a better idea of it, just listing the classes of the system:

1- The inputs and the outputs (listed above).

The sets of numeric coefficients:

2-Coefficients for the computation of the stress on the tool («Table phi, & epsilon »)

3-Coefficients for the regulation of the cutting parameters (« Table cse & μ ») taking care of the particular conditions of the cutting environment (rigidity of the machine, of the spindle . . etc.).

4-Coefficients for the choice of strategies through the competition between the strategies

(i.e. drilling, turning, conditions of the tool engagement).

5-Coefficients for computation of the similarity of the machining cases.

In addition a special kind of class is:

6-the set of the Rules.

4 DEFINITION OF THE RULES

The full operating of the system, based on the system analysis, is presented in the following flow chart:

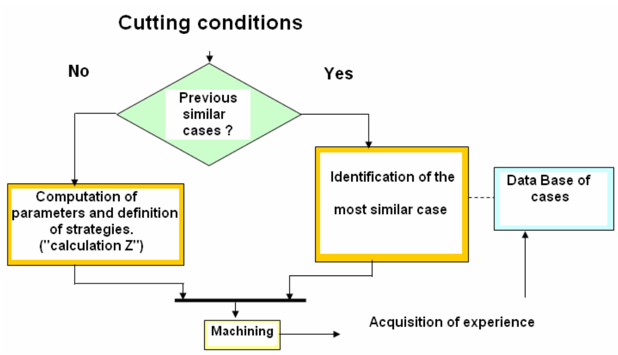

Figure 4: General flow chart of the system.

The part related to the "computation of the parameters" is better explained as follows. The vector of input values generates three separate computations:

1) For the definition of the cutting parameters (like Vc or fz).

2) For the definition of the parameters describing the engagement of the tool (like ae and ap).

3) For the choice of the strategies.

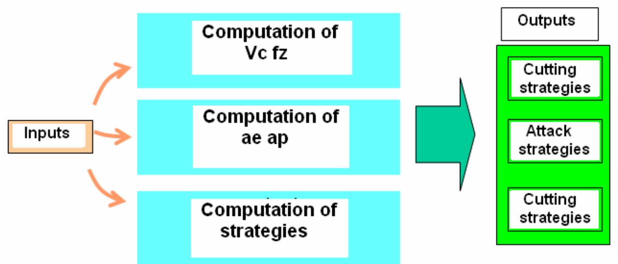

Figure 5: General structure of the computations.

1) The definition of the material, the type of machining (i.e. face milling, turning, grooving, tapping . . .etc.), the quality of the surface (i.e. rough, finish, . . . etc.), the definition of the material to be cut and the material of the tool (i.e.

HSS, HM, . . .etc), all these information produce a first set of parameters (Vc, fz).

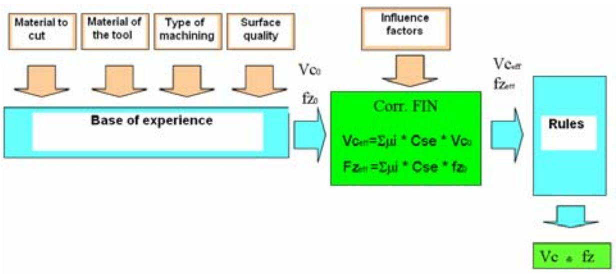

Figure 6: Definition of Vc and fz

Additional properties, related to the objects involved in the machining process, like the machine, the spindle, the tool etc. (i.e. an evaluation of the rigidity, some element of the geometry of the cutting tool, . . . etc.), produce a "correction" of the nominal value of the first set of cutting parameters.

2) The second set of parameters, ae ap, (defining the engagement of the tool into the metal) are defined on the basis of the kind of machining. Some of them already define some of these parameters, in some other cases the remaining degrees of freedom are computed on the basis of the compatibility of the tool with an estimation of the cutting forces.

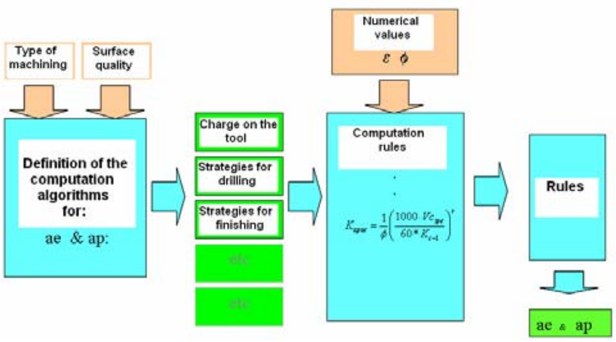

Figure 7: Definition of ae ap.

3) A final set of outputs is the one related to the strategies to be defined.

(For instance: drill with a standard or a peck drilling cycle? Entering the metal through a ramp, or directly?).

All these questions are solved by setting in competition the different possible choices, on the basis of definition of factors influencing the choice (F) and the weights (μ).

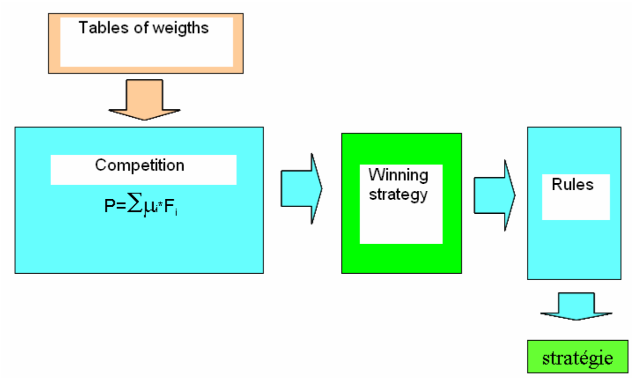

Figure 8: Definition of the strategies.

5 DEFINITION OF THE NUMERICAL VALUES

The system is based on several sets of numerical values. These numerical values are not deduced from analytical computations but from the experience of the experts, except special cases (like for instance the power requested by the cutting which is computed from the value of the specific force). Therefore we had to develop a method for this deduction.

First of all we had to better establish the set of numbers and the "form" of the set of numbers.

In fact, depending of the kind of numerical value, or its "form", we would have to store a huge amount of numbers of very different values or a more limited number of values more similar between them.

For example: it is obvious that, in milling, the feed per tooth (fz) is depending on the dimension of the tooth. Therefore it depends on the diameter of the tool (D). It is better to store the feed per tooth in form of: fz/D, and not just fz (as normally made in catalogues of tools).

For this kind of preparation, or definition of the structure of the numerical values, we studied several catalogues of several tool builders searching for "constant", in the meaning of searching how to represent the numerical values in a way that reduces its number or its dispersion.

A second step was to establish who the "experts" are.

Three persons of the machine-tool laboratory during their previous professional activity gathered an important experience in metal cutting. Their experiences have been the most important base of experience for our expert system. The literature was also used as basis of experience [1][2]. More over, for more special or difficult cases, or in case of disagreements, or also in case of special and rare material (like gold, platinum, palladium or other precious metals), we had selected an external list of contacts.

Material by material or case by case we asked the experts specific questions and to give us the "numerical values", without consulting each other.

The numerical values gathered in this way produced:

- An average value (Av).
- A standard deviation (σ).

Depending on the particular set of values (which need to be "as low as . . . ", "as big as . . . "or" as precise as") we adopted as border of our set:

Limit = Av - 2*σ (1)

Limit = Av + 2*σ

or

Limit = Av

This selection was made considering that the realization of our expert system followed the commitment: "to be sure and prudent".

(This procedure offers the possibility to establish also fuzzy sets. Nevertheless we did not adopt this technique).

In some cases the numerical values are the result of functions of one or more independent variables. In these cases the experts were requested to answer specific correlations of values in form of tables of values. The average values were interpolated on the basis of regressions.

In other cases the set of numerical values was necessary for the definition of strategies.

In this case the definition of the numerical set is more complex and the expert cannot be requested to do it directly.

In these cases we defined the "factors of influence" for each strategy, which means that we defined the factors that influence the decision to follow one strategy or another one.

The experts were requested to answer these questions:

1- How important did they consider each factor. (This importance influences the "weight" of the factor).
2- Which strategies would he choose, in a list of practical examples of cases.

Based on the answers to these questions, we verified if the "weight" of the factors produced the same choice, in algorithms of the forms:

$$P = \sum_{0}^{n} \mu_i * F_i \qquad (2)$$

In case of incoherence between the weight (μ) of each factor (F) and the results suggested as "correct" by the experts, we adapted the weights aiming to do them coherent to the results, supposed "correct".

6 LEARNING CAPABILITIES

The learning system is another part of the expert system. It doesn't share the rules described in the previous chapters, but its aim is to learn and adapt itself with the operator's habits and activities.

The learning system gathers information about the machining parameters entered by the user when the machining is correct. For each operation, the whole set of parameters (material, process, speed …) is stored. When a new piece is designed, every operation is compared to the knowledge base and the output parameters are predicted from the experience the user previously entered.

The Artificial Intelligence type used is based on the CBR system [3]. CBR stands for "Case Based Reasoning" and is especially designed for such developments [4]. The principals can be explained with the next schema:

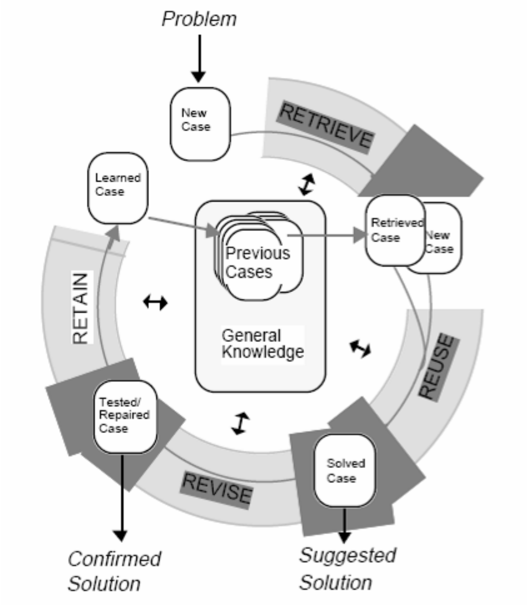

Figure 9: CBR system overview

The cycle is done in four steps.

The system takes the new operation and determines each part of its parameters. This new case is compared to every learned operation and the most similar one is retrieved from the knowledge base. This research of similarity is built on arithmetic that measure the distance between each case. The similarity is in percent compared to the new case.

The closest case, which is near 100%, is taken and adapted to the new situation (for example new material, different tool's diameter, etc …). Of course, the closer the found case is, the more the final result is good. Many strategies are developed to get the right case and to adapt it to the current situation.

The result is presented to the user which can correct it if needed. The final result is stored as a new case in the knowledge base and that new entry increases the precision of the learning system.

Usually, both the rules based system and the learning system work together and the best result is returned to the operator. The user has also the possibility to choose which results he wants by a graphical window that shows the different results ordered by similarity.

7 VALIDATIONS

The system has been finally implemented in C++, but before this final implementation we developed several prototypes using other languages (Access, Mathcad, also Excell) and testing, step by step, particular modules and specific functionalities, before the final implementation.

A final general prototype was available in Mathcad.

This final prototype was a precious instrument for the final testing and validation of the system in its final software package (C++). This validation has been carried out as with the following steps:

1. Definition of experimental pieces.
2. Extraction of values and strategies from the prototype and from the final package.
3. Reduction of the incoherencies between the prototype and the package.
4. Practical machining.
5. Computation of the errors.
6. Correction of the errors.

The number of errors or bugs per pieces has been computerized and the reliability of the system increased rapidly as shown in the plot describing the number of errors found in the final package (red line, "Err Impl") and in the prototype (black line, "Err Analyse"), compared with the practical results of the real machining of the specific piece.

The final feeling was that the system reacted as a "wise operator".

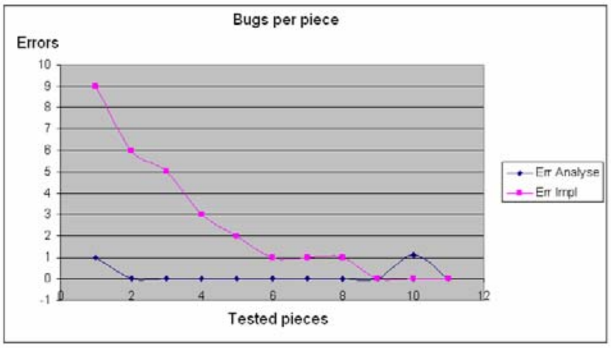

Figure 10: Results of the validation process, and removal of implementation bugs.

Before the first issue, we machined 14 pieces, testing 25 different types of machining operations, on 7 different materials, using 4 different machines.

		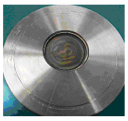	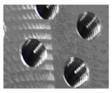	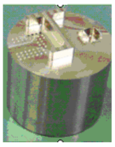
Titan grad 2	Stainless steel 904L	Electrolytic copper	Aluminum, Drilling & Tapping,	Stainless steel 904L

Figure 11: Some of the pieces realized for the validation.

The system is systematically used in our machine tool laboratory, helping us in our day-by-day working practice.

In frequent cases we compared the results of the ES with the data obtained from dedicated methods of analysis of the chip formation [5]. The comparisons have confirmed the good choices of the ES.

Moreover, today the system is included in "SylvieXpert" developed by the Swiss company Jurasoft (http://www.sylviexpert.com/).

Some customers are already using it, since a short time, for the automatic calculation of the cutting parameters with SylvieXpert CAM software. The customers use especially the system for unusual materials for their production. Indeed, when using a well known material in the company, the programmers, by experiment, know the specific parameters to their types of parts and their machine tools. On the other hand, they use the module of SylvieXpert to get values when machining materials on which they do not have the practice, which is happening more and more with the diversification of the fields of production. In this case, the first echoes are positive and the values suggested represent an invaluable help for the users of SylvieXpert CAM Software.

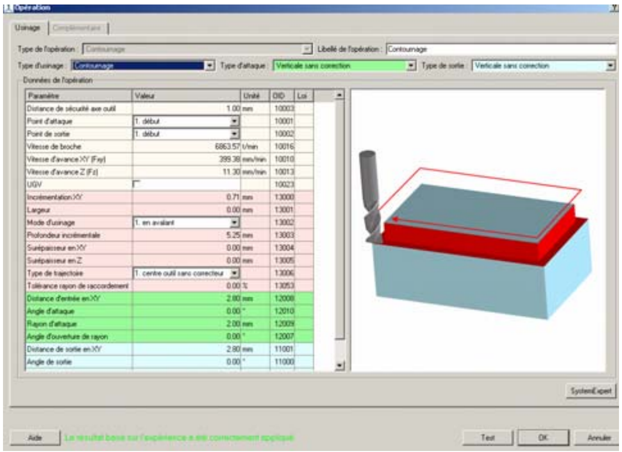

Figure 12: The main page of the ES, in its commercial version.

8 CONCLUSIONS

We have explained the structure and the validation of an expert system suitable for the definition of the cutting parameters and the machining strategies.

Our system can be evaluated in terms of number of rules and amount of numerical values, based on the experience.

In our case the amount of rules is : 3'975

(a rule is a logical element, the simplest being: IF . . . THEN).

The amount of numerical values is: 15'883.

The system is available on the market as a module of a commercial CAM system: SylvieXpert.

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