International Journal of Modern Manufacturing Technologies
ISSN 2067–3604, Vol. VII, No. 1 / 2015

DECISION SUPPORT SYSTEM OF MACHINING PROCESS BASED ON THE ELEMENTS OF FUZZY LOGIC

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Abstract: The basis of efficient technical system suitable information system in the form monitoring and forecasting system. In order to increase operations efficiency, those systems are used for decision support systems.
The article presents the problems of diagnosis and monitoring of cutting tool wear. The authors briefly describe the terms of the diagnosis and monitoring systems concerning cutting tools used in production engineering. The significant advantages of these systems in the monitoring of cutting process and the prospects of their development were pointed out.
An attempt was taken to implement elements of fuzzy logic in decision support for the monitoring and diagnostic systems. Fuzzy logic is used in cases where the analytical determination of the reliability function is impossible. A decision-making process based on fuzzy logic is presented, in the area of the fitness of cutting tools for machining on an example of a ball nose end mill.
Key words: exploitation, monitoring, forecasting, wear, cutting tool, fuzzy logic.

1. INTRODUCTION

Machining is the most commonly used technique of mechanical manufacture and accounts for about 60 to 70% of all known and used methods. In reference to the paper [1] it was proven that half of the energy consumed in the manufacturing process of the product, attributes to machining processes. It is expected that many more years it will be the dominant method and its influence will be increasing, especially in the production of mold parts and matrices for the automotive and aviation industry. It is therefore relevant to make the machining process run smoothly and with the greatest possible efficiency. To meet these requirements, the monitoring and diagnostic systems of machining process were begun to be used.
After it had been used for a few years, it turned out that the majority of the installed basic systems stopped to be used before a year. The reason for the renouncement of the systems usage was their low efficiency (a rapid development of the form milling tooling on 3D surfaces) as well as the correct interpretation of the manufacturing process "capability" criteria identified by the operator which was a major diagnostic problem. The analysis presented in the paper [2] revealed that only 29% of machine tools' manufacturers and 38% of users were satisfied with these systems.
Currently, growing customer requirements, as well as economic factors associated with a reduction in production costs, caused a new interest regarding the monitoring and diagnostic systems. An additional incentive of these systems development is the increasing complexity of production processes, increasing requirements concerning the elements accuracy, commonness of usage of flexible manufacturing systems, automation and robotization of manufacturing processes.
Early detection and diagnosis of changes of the dynamic condition of the previously mentioned elements of manufacturing process is therefore important not only for reasons of operational safety, but also considering the economic success achieved by the company. Despite the involvement of many research centers in the construction of monitoring and diagnostic systems, it should be acknowledged that the problems of diagnostic and monitoring tools and machining process, especially the process of trimming, has not been sufficiently addressed and are therefore still valid.

2. MONITORING AND DIAGNOSTICS OF CUTTING TOOL WEAR PROCESS

Currently at the market there are varied blade cutting tool condition monitoring systems and they are of a different effectiveness. Monitoring techniques used there may be divided into two groups, e.g. [3, 4]:
-direct methods,
-indirect methods,
which proved to be more or less effective.
Intensive development of methods for the direct identification of the blade took place in the 70's and

early 80's. These methods are based on an assessment of indicators related to the change of geometric features of the tool tip, or a change in the dimensions of the workpiece. Methods commonly encountered include: optical [5], tactile or inductive methods. Direct methods are, however, difficult to use due to: the unavailability of the cutting area during processing, their ineffectiveness, time consuming and being burdened with a large measurement error. Due to those reasons, they are used only sporadically.

Indirect methods gained larger applications in industry. These methods are based on monitoring variables via a signal, where basing on the analysis, the degree of tool wear may be determined (predicted). In the indirect methods the signal is obtained when the tool is running. The indirect methods are so based on the measurements of the wear effects not just the wear. They are characterized by a technically simpler estimation of the wear characteristics than in the case of direct methods, but the results are subjected to uncertainty resulting from insufficiently recognized phenomena in the contact zone between the workpiece and the cutting tool. To assess the blade wear in the indirect method, the most commonly used measurement is that of such physical quantities as: cutting forces (static and dynamic) [6], acoustic emission (50 - 400 kHz) [7], the cutting temperature [8] or vibration (1 – 10 kHz) [9, 10].

Indirect methods require a two-stage action: measurement of a certain physical quantity and elaborating of an appropriate dependency which would allow drawing out conclusions regarding the state of the tool basing on the performed measurement. The most commonly used estimation algorithm of wear characteristics in the indirect method, which is used in almost all modern monitoring systems, is basing on the multi-sensor strategy. This strategy has several advantages, e.g.: measurement of a wide range of different physical quantities, but also disadvantages, of which the most important is a complicated structure, high cost, estimation of the signal from several sensors and uncertainty of a proper work. Therefore, such a strategy is suitable for laboratory tests and not for industrial activities. In industrial applications the monitoring systems are expected to be simple, must be characterized by the ease of implementation on the machine, the ease of use, and above all, high efficiency.

3. ORIGINAL MONITORING AND DIAGNOSTIC SYSTEM OF BALL NOSE END MILL BLADE WEAR

A monitoring and diagnostic system that meets the users' requirements for the industrial systems is a system basing on a single sensor, especially relying on the vibration sensor. The authors of the paper have elaborated such a system; the wear characteristics estimation system based on a strategy of a single-sensor with a special use of a vibration sensor for the 3D surface tooling processing with ball nose end mills. The basis for the elaboration of the system was a research stand, which concept and the structural diagram is shown in [11] and [12].

The elaborated system has been tested in laboratory conditions. As a result of these studies, a series of vibration signal waveforms in a function of time was obtained, which have been analyzed in accordance to the wear characteristics estimation algorithm shown in Figure 1.

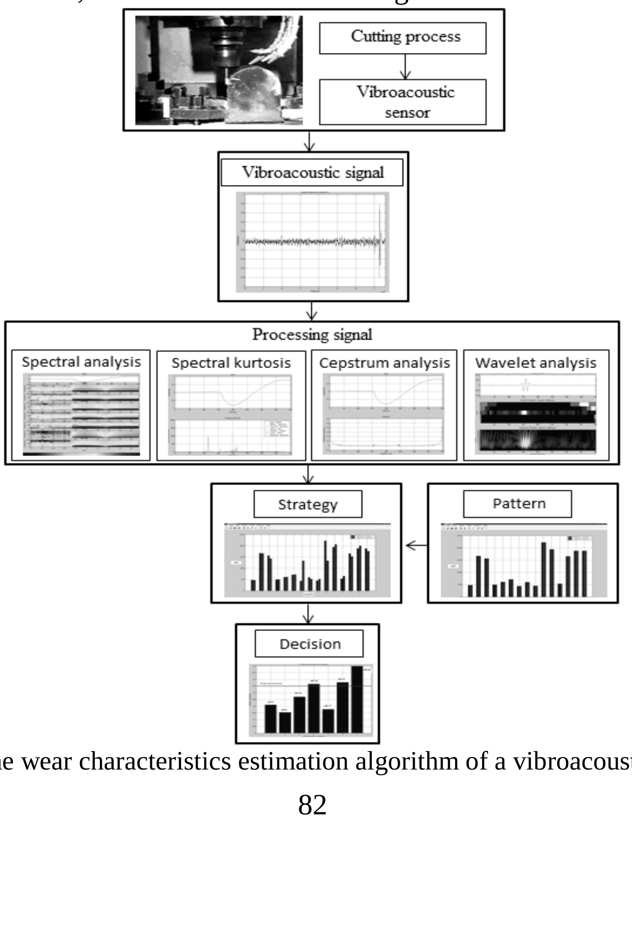


Fig. 1. The wear characteristics estimation algorithm of a vibroacoustic signal

The result of such a carried out extraction is a number of feature vectors, which represent a measurement signal, sensitive to changes of the parameters of the tested process. On the basis of the obtained feature vectors and an appropriate strategy, a decision on the status of the monitored tool is generated. In the era of an intensive development of information technologies the signal analysis with several different methods does not cause too many problems.

In order to obtain an algorithm for efficient analysis and measurement of data compression of a single wear signal, a connection has been made between various digital signal processing techniques. The combination of statistical methods with clustering techniques, has allowed not only for reliable detection of defects, but also on a more accurate classification. A high reliability of the classification was ensured by signal processing techniques, it means: specgram, spectral kurtosis and continuous wavelet transform.

In the elaborated system the decision to terminate or to continue the tooling is undertaken on the basis of an ongoing strategy to determine the threshold, where some of the characteristics of the measured signal were constantly compared with a pre-set threshold of wear (as the level of wear or breakage of the tool). A constant threshold was determined for a set of cutting conditions. It required development and storage of a set of components of threshold values for many parameters of each process conditions and each type of tool. In addition, the wear had to be established initially, experimentally designated level, in order to effectively prevent a breakage or the wear of the tool in the real process properly.

A system, used in the scheme, which identifies the wear cause (fixed threshold), only allows assigning one of two states: 'able' or 'unable' to be used in the further manufacturing process. Assignment to one of the two conditions is carried out basing on the fulfilment or not of the compliance criteria regarding selected parameters with their model range specified by the manufacturer or technologist.

Laboratory tests which were carried out revealed that assignment to one of the conditions is a method, which from the point of view of the machining economy is little effective and also little efficient in the case of diagnostic of exploitation wear process of the blade (natural). Therefore considerations on the use of fuzzy logic were taken up in order to allow the assignment of ambiguous features of the tool (in an approximate way).

4. THE USE OF FUZZY LOGIC IN THE ELABORATION OF KNOWLEDGE REPRESENTATION FOR THE SYSTEM SUPPORTING TOOLING PROCESSES

The basis for the elaboration of knowledge representation in fuzzy logic is inference rules that apply to predict the condition of the tool tip. Developing a diagnostic system using a fuzzy model, at the initial stage of qualifications, information contained in the linguistic form is used, and then it is specified throughout experimental data obtained from the object measuring devices.

Analysis of the rules premises, allowed assuming the following division of inference rules used in the system:

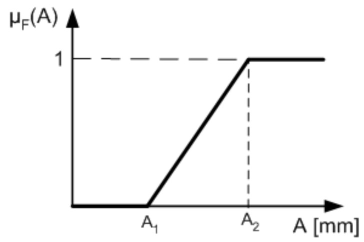
- accurate rules ("able" or "unable") - built for signal size section which can be accurately determine the status of the blade, which leads up to make a unanimous decision,
- approximate rule (intermediate states, "partially able") - built for the areas of ambiguous selections, it means these which cannot be unanimously concluded, what is the condition of the blade cutting tool. In this case, there are more options to select from.

Rules of decision making, was based on diagnostic reasoning, which takes into account the production's economy criteria and minimizes the risk of disruptions in production.

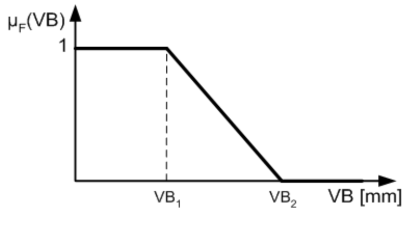
To interpret the condition of the cutting tool blade and to elaborate the fuzzy set a vibroacoustic signal was used, which was received during the milling process of the 3D shaped surfaces, [11].

Selected parameter having a decisive effect on the condition of the blade was a vibroacoustic signal amplitude. A fuzzy set has been elaborated with the use of the membership function μF(A), which represents the value of the signal amplitude corresponding with a particular condition of the cutting tool blade (Fig. 2a.).

In order to increase the decisions accuracy, fuzzy sets for the process of cutting tool nose wear have also been elaborated, using the relationship between the quality of the material surface after tooling (roughness parameter Ra), and the value of the VB tool flank detritions. The fuzzy set F is defined by the membership function μF (VB), which waveform is shown in Figure 2b.



a.



b.

Fig.2. Chart membership function for the fuzzy set describing:
a) the condition of the tool tip, b) the quality of the surface

For the performed tests, the exact and approximate rules have been formulated:

a) for the condition of the cutting blade:

R1: IF signal amplitude is less than or equal to 0.1 [mm] THEN the blade is correct and the cutting process may be continued;

R2: IF signal amplitude is equal to or greater than 0.75 [mm] THEN the blade is damaged and the cutting process must be stopped;

R3: IF signal amplitude is greater than 0.1 [mm] and smaller than 0.75 [mm], and the signal waveform is almost similar to the reference signal THEN the blade is correct and the cutting process can be continued;

R4: IF signal amplitude is greater than 0.1 [mm] and less than 0.75 [mm] and the signal waveform is not quite similar to the reference signal THEN the blade is damaged and the cutting process must be stopped.

b) for the condition of the machined surface:

R1: IF the value of the tool flank attrition VB is less than or equal to 0.05 [mm] THEN machined surface roughness is correct and the cutting process can be continued;

R2: IF the value of the tool flank attrition VB is equal to or greater than 0.95 [mm] THEN machined surface roughness is not correct and the cutting process should be stopped;

R3: IF the value of the tool flank attrition VB is greater than 0.05 [mm] and less than 0.95 [mm] THEN machined surface roughness is correct and the cutting process can be continued;

R4: IF the value of the tool flank attrition VB is greater than 0.05 [mm] and less than 0.95 [mm] THEN machined surface roughness is faulty and the cutting process should be stopped.

On the basis of certain rules of inference as an attempt of implementation was taken in the environment of Matlab in the package of Fuzzy Logic Toolbox (Fig. 3).

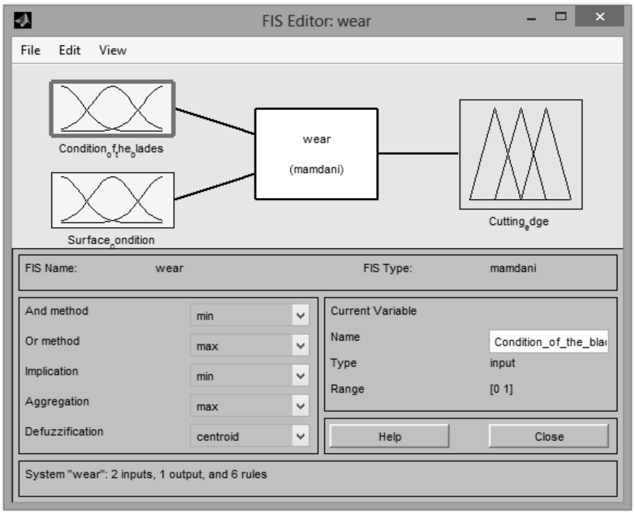


Fig. 3. Fuzzy logic system, for example the wear.fis

The result for each of the inference rules and the final course of sharpening is shown in Figure 4. Figure 5 shows a three-dimensional graph of the influence of individual inputs (condition of: the blade and the cutting tool surface) on the result of inference

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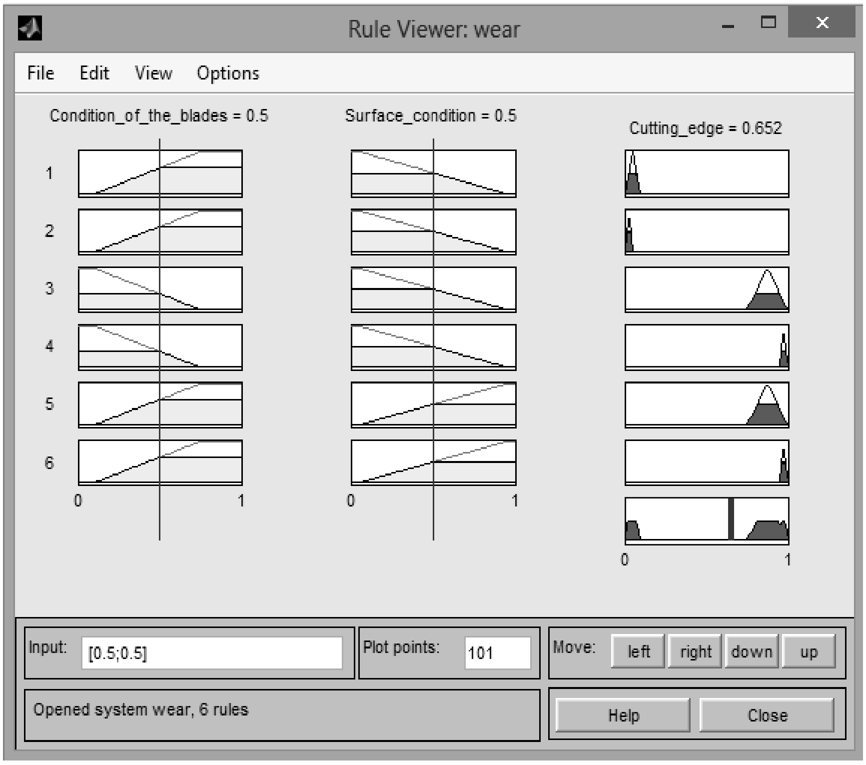

Fig. 4. Rules of inference

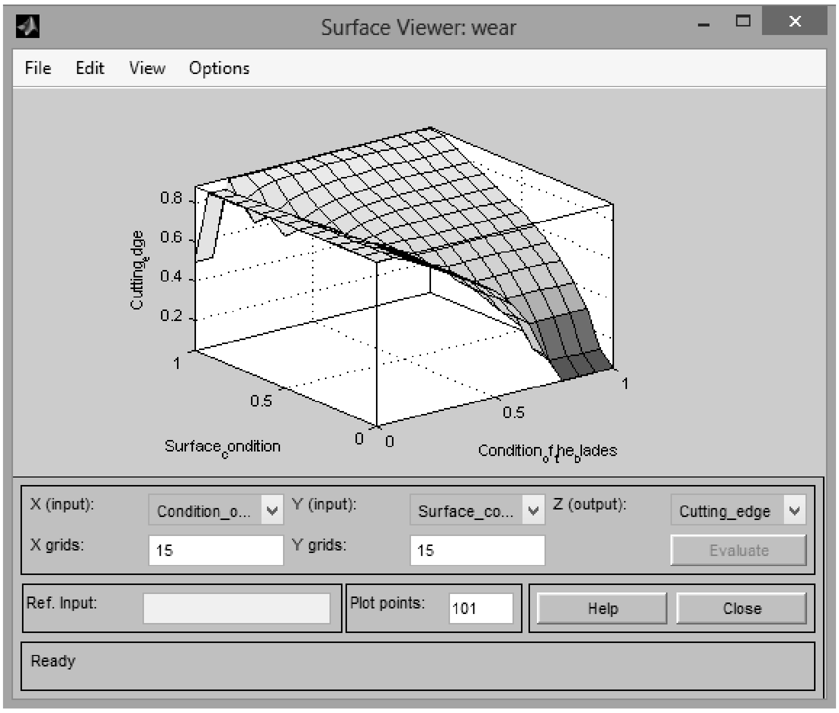

Fig. 5. Graphic representation of inference

5. CONCLUSIONS

The paper presents one sensor monitoring and diagnostic system along with an example of the implementation of fuzzy logic for decision supporting technology regarding the condition of the cutting tool. Its application is illustrated in the case study. The analysis results permit to conclude that the rules of inference are a representation of the knowledge considering the wear condition of the cutting tool blade and may be successfully used in the elaboration of knowledge representation for a system supporting machining processes. Fuzzy logic elements contributed significantly to an increase of the accuracy of the decision if to stop or continue processing.

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Received: February 27, 2015 / Accepted: June 15, 2015 / Paper available online: June 20, 2015 © International Journal of Modern Manufacturing Technologies.