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TOOL MONITORING IN DRILLING PROCESS

Summary. The paper presents the concept and implementation of tool monitoring system for drilling process. Some results of research work are presented as well.

1. Introduction

Twist drill made of HSS is a tool used very often.
Monitoring of the wear process in drilling operation is to be of big practical significance, especially regarding the process character which makes the direct supervision impossible.
Taking this into consideration, in the Computer Automation and Electronics Dpt.of IOS there have been designed a tool monitoring system (TMS) for drilling operations. The presented version of TMS is intended for CNC NUCON 400 controller. Experiments have been carried out on machining center HP4 in IOS.

2. The general concept of the TMS

On the basis of total value measurement of supervised parameters α_c, which can be the power consumption of the main drive or current intake, and the measurement of parameter value at the idle run α_0, the TMS microcomputer determines the value of α_{cut} parameter netto, which represents the cutting process [1]

$$\alpha_{cut} = \alpha_c - \alpha_o$$

At the next step the calculated value of parameter is compared to the level values, reaching of which results in

setting outputs into a certain state which signalises reaching the wear criterion or tool breakage.
The way of alarm level values determining and their interpretation depend on the process character. For the slow changing and static process the alarm level mode is applied. In the process characterized by strong change of the supervised parameter - the pattern recognition mode is used.The kind of mode is chosen by part program, using appropriate command sequences for TMS.

2.1. Alarm level mode

In this mode of work alarm level values are defined by TMS microcomputer according to formula:

$$\alpha_p = a \cdot \alpha_{cut} = a \cdot (\alpha_c - \alpha_o)$$

where
α_p - alarm level value of supervised parameter
α_{cut} - parameter value corresponding to stable cutting process with sharp cutting edge
a - coefficient

The parameter value corresponding to the cutting process is determined with the given delay which is counted by the number of total machining cycles (SKIP).Delay is used because of tool wear behaviour which is characterized by an intensive wear at the initial stage of cutting process with sharp cutting edge. So alarm level values have to be determined in the area of stable wear. They are computed on the basis of mean value from several machining cycles. The list of passes is made by the programmer on the basis of known or predicted material machinability variation. The number of measurement passes can be identical for the whole program or can be modified locally in part program. The locally given number of passes has a higher priority to that for the whole program, given before calling the TMS function i.e. before appearing of the first TMS command.
The number "a" is a coefficient determined for each type of tool according to its wear characteristics. The set of coefficients "a" define alarm level values for a given value of α_{cut} in the alarm mode. These coefficients can be valid for the whole program or can be changed locally. The tool change is accompanied by the change of level coefficient sets. This permits dynamic adaptation of alarm level values for different types of tools and their characteristic dimensions.
The reactions of the machine tool for the level of wear or the tool breakage are determined by subprogram called from CNC program.
In this way the reactions of the machine tool in alarm states are defined by the programmer.
The reaction for reaching determined alarm level value can take place with the determined in the part program delay. In the discussed solution the following assignment of such level has been taken (fig.1.):

ALARM LEVEL 1 - is a level with a possibly low value determined experimentally for a given tool. Reaching the alarm level 1 means that the tool gained contact with the workpiece.
Reaching alarm level should be accompanied by calling previously defined subprogram, in which there can be for instance switching rapid travel GO to G1 with the right value of tool offset or approach of the tool to the material with programmed value F, feed stop at the moment of tool - material contact.
Further in the subprogram there can occur determined measurement cycles. This gives conditions for creation of automatic workpiece setting on the machine tool,measurements automation, self-correction and automatic restart.
So an effect similar to probe application is achieved with the possibility to utilise standard measurement cycles.
ALARM LEVEL 2 - this is also limitation of very low value determined experimentally. Reaching it permits to turn coolant on, provided that it was programmed in part program, only after the tool goes into contact with the workpiece.
ALARM LEVEL 3 - reaching it means fulfilling the tool wear criterion. Reaching this alarm level causes sending a message to the CRT monitor (printer) about the disturbance and generating impulse on TMS output. This impulse calls subprogram or sequence of subprograms defining reaction of the machine tool. In such case,depending on the kind of the tool it can be:

- calling tool change cycle M06
- change of spindle rotation direction
- tool retraction from the hole to remove chips
- feed stop for a defined period, and so on.

In alarm level mode both tool wear and breakage of the cutting edge are checked simultaneously. Tool wear process is checked between two "z" coordinates which correspond to positions 1 and 2 (Fig 1). In this case results of supervised parameter measurements (power/current) are stored in the TMS memory and in the next step the mean value of the results is calculated.
The mean value of the supervised parameter is compared with calculated alarm level value just after reaching the specified in TMS command (position 2) depth of drilling process, and as a result a signal is generated for the CNC controller.Supervision of breakage behaviour of cutting edge is carried out constantly in the alarm level mode between positions 0 and 2, optionally 3.
It includes also the two most dangerous situations i.e. entering the drill into the workpiece and withdrawing the drill out of the workpiece.More intelligent reactions of CNC controller would be possible in the case of macroprogram (subprogram) number modification with the use of parametric technique, due to which every following reaching of the alarm level could cause a different reaction of the CNC controller by calling another macroprogram (subprogram).

ALARM LEVEL 4,5 - reaching this alarm level situated closely to alarm level 3 allows creation of a more intelligent system by calling different procedures, defining the machine tool reaction in the machining process at the end of tool life. Alarm levels 4 and 5 permit creation of a complex system of informing about the emergency state or its probable approaching.
ALARM LEVEL 6 - means tool breakage. Reaching the level releases the emergency stop of the machine tool and sets output of alarm level 6 coupled with the CNC controller in order to generate proper reaction of the machine tool.
Reaching of a given alarm level 1-6 may cause immediate reaction of the system or with a delay, where delay value can be different for different alarm levels.
ALARM LEVEL 7 - is a spare alarm level. It can be used to protect overloading of the tool. It is set for a value lower than maximum value of the supervised parameter. Reaching it causes generating of pulse on the TMS output.
ALARM LEVEL 8 - is the maximum value of the supervised parameter.
It serves to protect the machine tool. Blocking the TMS does not comprise alarm level 8, which works continuously. Reaching alarm level 8 results in emergency stop calling.

2.2. Pattern recognition mode of the supervised parameter (power/current)

This mode of work is used in the case of strongly changeable parameters which represent the cutting process as for instance in the case of step holes machining, strong machinability changes which may occur for instance in machining cast iron.
In pattern recognition mode the supervised parameter measurements are carried out in selected points which are listed in PAT command (Fig.2.). The points are selected between position "1" and position "j" in such a way to get as much information as possible about changes of the supervised parameter along the depth of machining (Fig.2).
Supervising of breakage behaviour takes place between position "0" and position "j+1" in the same way as in the level mode described above.
Taking into consideration "i" measuring passes, i.e.fixed cycles of drilling operation (measuring holes) and "j" measuring points along the "z" coordinate for each machining hole one can get the following table of results.

$$\begin{bmatrix} \alpha_{11}, & \alpha_{21}, \ldots, & \alpha_{j1} \\ \alpha_{21}, & \alpha_{22}, \ldots, & \alpha_{j2} \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \alpha_{1i}, & \alpha_{2i}, \ldots, & \alpha_{ji} \end{bmatrix}$$

hence

$$\bar{\alpha}_1,\ \bar{\alpha}_2, \dots,\ \bar{\alpha}_j$$

where $\bar{\alpha}_j$ - mean value of the supervised parameter in j measurement point (z coordinate)

In the next step TMS computes the upper and lower values of the supervised parameter for each measurement point along depth of machining according to the formula:

$$\alpha_{jmin} = \left(1-a_T\right)\ \bar{\alpha}_j$$

$$\alpha_{jmax} = \left(1+a_T\right)\ \bar{\alpha}_j$$

The instant value of the supervised parameter should be kept within the range [αjmin, αjmax].
Exceeding of these limits generates the signal which can call macroprogram (subprogram) via PLC of the CNC controller.
In this way correction of cutting parameters (S,F) becomes available and as a result, the intensity of wear process can be controlled.

3. Implementation of CNC NUCON 400 version of TMS

3.1. The TMS

Implementation of the concept of tool monitoring system for drilling operations is intended for unmaned production on machining centers [2],[3].
The basic component of the TMS is a IBM PC/XT computer with A/D converter card. The integrated main drive current/power sensor is coupled via A/D card to the TMS computer. The TMS computer works under real-time operating system which rules the TMS software modules.
Function software modules of the TMS create the function of TMS according to the concept of system monitoring described earlier (p.2).
In order to couple the TMS to CNC NUCON 400, modifications of control program and interface program of CNC NUCON 400 have been done. A serial link RS 232C is used to couple the TMS to the CNC NUCON 400 controller.

3.2. Sensor

To measure main drive current/power ratio a special sensor has been designed. The sensor is a microprocessor measuring device based on Z80 microprocessor.
Tests showed that the sensor has good static and dynamic performances.

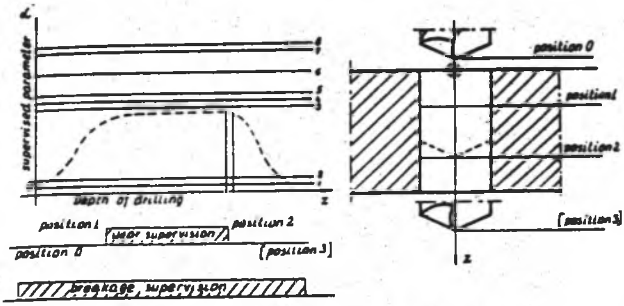
3.3. The TMS programming

The TMS is a programmable device. Thanks to modification of NUCON 400 control program, the TMS programs can be

segments of part program. Programming process does not concern description of machining process only but also monitoring of the process in selected points of machining.
The TMS commands are placed directly in program block (N) or macroprogram block. The TMS command is placed between two characters: character of the start "(" and character ofthe end command ")". The CNC controller interprets a string of TMS command characters as a comment and does not signalise the error during reading in the part program into the CNC controller memory. The program block which contains TMS commands is interpreted as an empty block by the CNC NUCON 400 controller.
The TMS command can be placed only in separate program or macroprogram block.

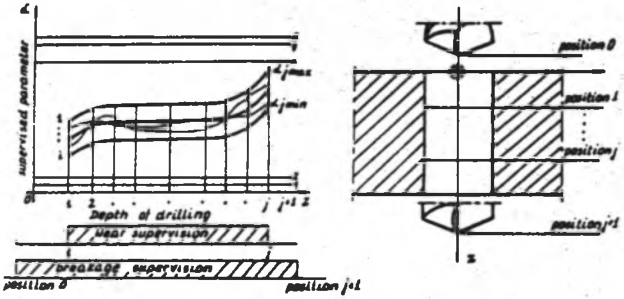
4. Supervision of drilling process under the TMS

A cast iron test workpiece has been used in drilling experiments. First two holes of each row of holes have been treated as measuring holes. Current/power ratio measurement has been carried out at the very begining of each row of holes.
The measuring channel consists of a current/power sensor, measuring amplifier and IBM PC/XT computer. Current/power signals have been amplified in measuring amplifier. The amplifier output has been coupled to A/D converter card placed in IBM PC/XT slot.
The results of current/power measurements have been stored in the computer memory and presented in BCD code in a table form.
Drill wear (VB) has been measured on a special setup by means of microscope (MWD type) and calculated as the mean value of four results (A,B,C,D) in a way presented in fig 3. In the investigations twist drills NWKc dia.10 mm and dia.15 mm made of HSS - SW7M have been used. Drill wear morphology is shown in Fig.3.
Experiments have been carried out on machining center HP4 in the automatic cycle (AUTO) of CNC NUCON 400. The measurement results have been presented in Fig.4. One can see sharp increrase of drill wear (VB) in the first stage of machining, which is well known from cutting theory. Next wear process becomes less intensive.
Changes of current/power ratio correspond to changes of drill wear process, particularly in the first and the last phase of the process.
It means that making a choice of alarm level value is possible in the tested cutting conditions. In that case TMS works properly, i.e in the described earlier manner. But experiments also show that machining of cast iron - ZL250 does not show so rapid increase of current/power ratio in spite of strong wear of the chisel edge (Fig.3).
It means that in such a case one-sensor TMS will not work properly. Multisensor tool monitoring systems should be developped in order to make the monitoring process more reliable. The wear criterion should be verified as well.



Command
LEV position 0,
position 1,
position |3|

FIG.1. Alarm level mode illustration



Command
PAT position 0,
position 1, ...,
position j,
position j+1

FIG.2. Pattern recognition mode illustration

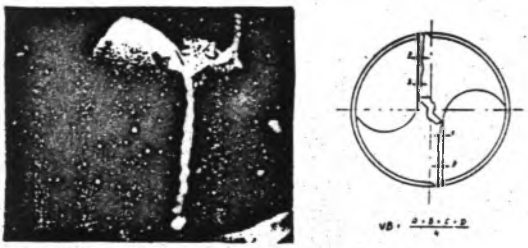


FIG.3. Drill wear morphology and the way of wear calculation

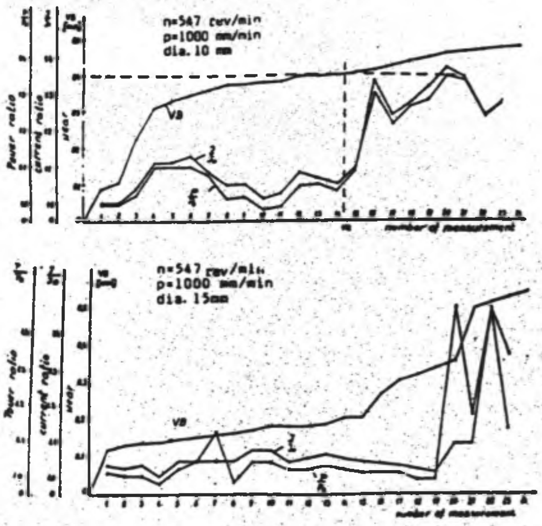


FIG.4. Measurement results of spindle drive current/power ratio and drill wear during drilling proces of cast iron Zl 350

Not only wear of clearance surface, but also wear of chisel edge, should be taken into consideration in the new criterion of wear.

Conclusions

In order to determine precisly the right range of TMS application, further investigations should be carried out. The drill diameter and kind of machining material should be variable in these investigations. The recomendations for the application range of TMS should be the main task of such planned investigations in the future.
Also the pattern recognition mode has to be tested for determining anticipated range of application.
As it is clear that one-sensor monitoring system has its faults and limitations, so a new method of monitoring should be developped. AI approach is one of the new methods which can give better, but more sofisticated and expensive solution. It means that in the future in practical applications there will be place both for one-and multisonsor systems for different applications.

REFERENCES

[1] Z.Adamczyk: Opracowanie monitora stanu narzędzia. Opracowanie założeń monitora. PIOS Sprawozdania,Kraków 1986.

[2] Z.Adamczyk, H.Małek: Opracowanie środków automatyzacji dla bezzałogowych metod wytwarzania. Opracowanie i uruchomienie oprogramowania systemów monitora oraz adaptacji programu sterującego i interfejsowego systemu CNC. PIOS Sprawozdania, Kraków 1989.

[3] Z.Adamczyk, H.Małek: Opracowanie środków automatyzacji dla bezzałogowych metod wytwarzania. Opracowanie dokumentacji konstrukcyjnej prototypu monitora, wykonanie prototypu oraz badania dla doboru wartości progowych dla wybranych wierteł i materiałów konstrukcyjnych. PIOS Sprawozdania, Kraków 1990.

MONITORING DES WERKZEUGZUSTANDES BEIM BOHRUNGSPROZESS

Zusammenfassung

In der Arbeit wurde ein algemeiner Konzept der Wirksamkeit eines Monitor prasentiert, Implentation eines Monitor, Zustand des Werkzeng fur einen CNC NUCON 400 Steuerer besprochen und enige Untersuchungsergeknise vorgestellt.

MONITOROWANIE STANU NARZEDZIA W PROCESIE WIERCENIA

Streszczenie

W pracy zaprezentowano ogólną koncepcję działania monitora, omówiono implementację monitora stanu narzędzia dla sterownika CNC NUCON 400 oraz przedstawiono niektóre wyniki badań.

Wpłynęło do redakcji w styczniu 1992 r. Recenzent: Jan Kosmol