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ONLINE VIBRATION MONITORING PROCEDURE FOR MACHINE TOOLS

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Abstract: *The monitoring techniques in machine tools: condition and process, has developed considerably lately, moving from classic models to complex models. The purpose of the research is to determine an optimal method of online monitoring using both the signals supplied by the MT and those from the external sensors. The actual procedure considers a coupling between monitoring of machine parameters with parameters measured by additional sensors/transducers. The research focuses on the online monitoring system, being tested directly on the machine: current, vibration, temperature, noise, etc. as well as in case of a spindle failure situation. Spindle was monitored and diagnosed being identified the defect, while also obtaining the condition of operation until the repair.*

Key words: *monitoring, vibration, machine-tool, spindle.*

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1. INTRODUCTION

In the current context of industrial development with the new requirements imposed by the Industry 4.0 design, it required the implementation of integrated solutions for real-time monitoring and continuous optimization of operating conditions. The growing demands to increase the accuracy of processing processes in today's industry imply an increase in the process accuracy and in the quality of machine tools respectively.

In the last decade there has been numerous researches regarding the monitoring of different parameters: kinematic, thermal, dynamic, wear, vibration, etc. A number of methods of analysis and determination have also been used and even implemented in machine tool-specific monitoring models [1, 2, 3]. The monitoring techniques in Machine Tools (MT): condition and process, has developed considerably lately, moving from classic models to complex models based on artificial intelligence, as well as their total integration into production [4, 5]. Knowing the process parameters, machine parameters, environment and being able to monitor and analyze them in real time is the key to digital integration of production. According to statistical analysis, over 75% of equipment defects in the cutting process are caused by wear or excessive tool damage [6]. In this situation, the influence of this wear on the other components is interesting. Propagation of various negative effects generated by the process, towards the tool, respectively tool wear and in time the appearance of spindle wear. According to Zhang et al. [5], previous TCM research can be divided into two main parts: direct methods and indirect methods. Direct methods require a lot of equipment and sensors to measure the condition of the tools, which is costly and time consuming. Due to high costs and inflexibility, the methods are not applied in industry. On the other hand, indirect methods are a solution for monitoring the condition of cutting tools to which certain sensors are added in order to improve the quality of analysis and data efficiency [7].

For an optimal monitoring process, it is important to determine the communication method for obtaining the acquisition data from the MT. Currently, the main methods of collecting data from the MT are either through the PLC interface, through the additional acquisition using the external sensors, respectively through the CNC interface.

One of the most commonly used options is to combine signals from external sensors with internal signals generated by the machine tool PLC interface.

The research is focused on the main shaft and spindle motor as part of the MT regarding the continuous real-time monitoring. The spindle unit has an important role in the functionality and performance of a machine tool, being characterized by energy, dynamic, kinematic and thermal parameters. The Abele et al., 2010 [8], present the spindle as the heart of MT, give accurate rotational motion to the tool or workpiece and at the same time ensures the transmission of the necessary energy to the cutting zone for material removal. During machining, the spindle is subjected to load variations, generating dynamic and thermal effects that lead in time to the occurrence of various problems in the spindle unit. Problems in spindles are one of the main sources of machine tools downtime in manufacturing industry. Problems are represented by different parameters of load, vibration, temperature, shocks, crash, which are transmitted through the tool, to the tool/holder, shaft and bearings. The location and identification of defects represent the obligatory premises for understanding and determining the operating state, especially in the context of digitization and integration in Industry 4.0.

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The purpose of the research is to determine an optimal method of online monitoring using both signals supplied by the MT and those from the external sensors.

2. RESEARCH SCOPE

Given the current industrial conditions regarding the transition to Industry 4.0 and the complete digitization of production flows and systems, the need to integrate permanent online monitoring solutions is mandatory. In this case, an analysis of the optimal parameters necessary for real-time monitoring at the spindle is considered. The research aims to provide a solution that answering performance and innovative real-time on monitoring requirements and provide qualitative information to anticipate, identify and locate the defect of the spindle and cutting tool. The monitoring and diagnostics involves both spindle and tool during machining. The system is useful in monitoring the status of spindle and cutting process regarding the predictive maintenance task and optimization of cutting parameters.

Given the growing need for autonomy and digitization of parameters, a real-time monitoring model is proposed. The main purpose is the operating condition of the machine tool components, even if in this paper we are focused on monitoring the condition of the spindle.

Lately, many research and development canters, both scientific and industrial, are concerned with obtaining an integrated product that best represents the need in the market. The machine tool is a system of great complexity and which generates many parameters, direct and indirect, resulting from the machine itself or from the action of various parameters of cutting process. The application of artificial intelligence algorithms is the key to achieving integrated and global results. However, the complexity of the parameters and the lack of dynamic behavior patterns specific to system couplings, in the case of ball screws and guides, make the implementation not fully efficient. The trend is predictable that the use of these solutions represents the future in terms of digital production systems, respectively of CN machine tools. In the case of conventional machine tools, there is also a major interest in introducing them into online monitoring platforms, being subject to a specific monitoring protocol. The current procedure involves taking data from the drive systems of the machine tools coupled with the signals collected from additional sensors and transducers. In a first stage, it will be applied for the case of spindle, to provide the parameters needed to obtain an intelligent monitoring model.

3. PROCEDURE PRESENTATION

The actual research considers a coupling between monitoring of machine parameters (MMP) with parameters measured by additional sensors/transducers (AST) and based on speed and time synchronization. In this regard in Fig. 1 one presents the procedure view, the situation with the two configurations MPM and AST, coupled to a control monitoring system (CMS), Fig. 2.

This information is also essential for the operation and management of the machine tool, and is indispensable when automated operations are required. Basic operating conditions such as cycle start, errors, limit reached, speed parameters, position, acceleration; speed may be desired directly from one of the operational data. On the other hand, the identification of changes over a period of time requires complex intelligent conditions or application of artificial models to provide an image of the condition of machine tools, the existence of wear, or defect. At the same time, the monitoring of the operating condition can generate higher level information, such as energy consumption or the condition impact on the quality of cutting process.

Based on the data collection protocol from the machine, in spindle case, the following parameters are targeted: electrical current, electrical power, electrical frequency, electrical torque, encoder position and speed, etc. On the other hand, the parameters provided by the additional sensors / transducers are: acceleration of vibration, vibration velocity, noise, acceleration envelope, etc.

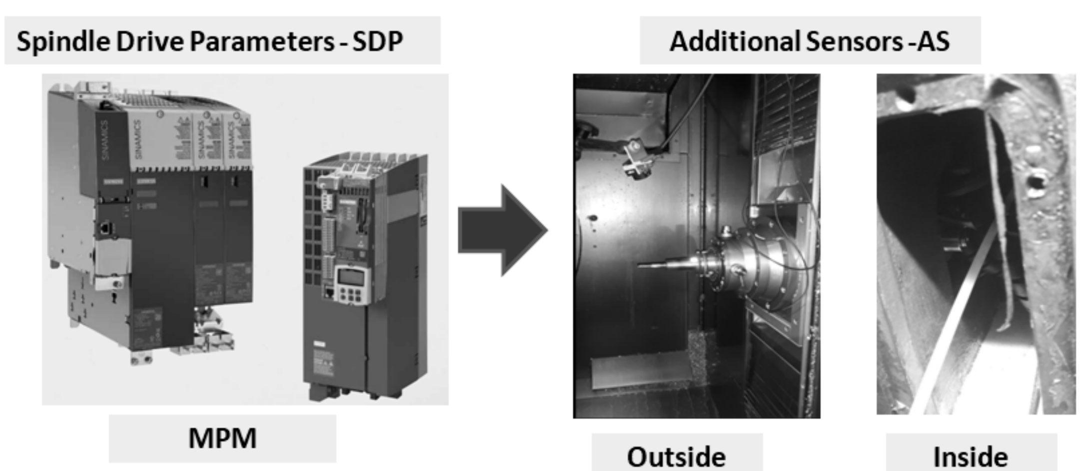

Fig. 1. Concept of online monitoring procedure.

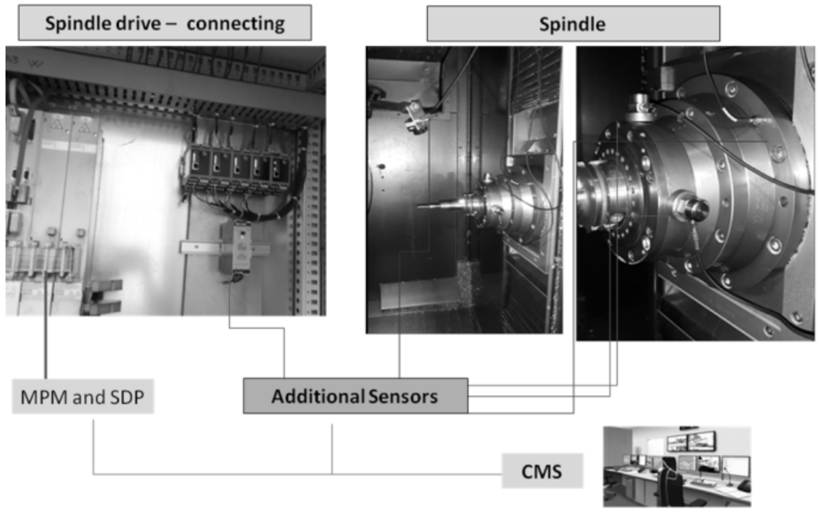

Fig. 2. The setup view for online monitoring.

4. MONITORING PARAMETERS AND SETUP

To increase flexibility and quality of data an experimental protocol is implemented. For this purpose, in addition to a series of parameters collected directly from the machine, a series of additional sensors are used. To collect the signals from protocol data of a machine tool, a validation collected data (VCD) is required (Fig. 3). The VCD is an algorithm that functions read the date and confirm the status accordingly with sensors information, Fig. 3. For this purpose a list of monitored parameters is presented in Table 1.

The measurement protocol was designed to couple the two types of parameters, spindle drive parameters and dynamic parameters (Fig. 4). For a good evaluation, the two configurations of using the machine tool were considered: in process and out of process.

Given that some machine tools have a very old control drive without optimal connection possibilities, the solution of using additional current sensors can also be used. The use of current sensors is very common and easy to do, and can be permanently implemented on the machine (Fig. 5). It is very important to set the signal so that it can synchronize with the same time base; it involves the use of flexible acquisition board.

To assess the capability of the developed system, a study case has been applied to use the accelerometers transducers and speed laser to monitor the spindle condition. Simultaneously with the vibration measurements, an industrial microphone connected to one of the inputs channel of the acquisition equipment was used for the analysis of the noise that appears at high speeds of the main kinematic chain motor (Fig. 4). The microphone was placed near of the drive motor of spindle. The analysis of the vibrations and noises of the spindle and drive motor is performed within 3 families of harmonics, corresponding to the following synchronization signals: intermediate speed, main speed and electric current absorbed by the drive motor (Figs. 6 and 7).

Table 1

Parameter list

Parameter	Drive motor	Spindle
Vibration velocity [mm/s] (rms)	■	■
Acceleration [g] (pk)	■	■
Noise [dB] (rms)		■
Acceleration envelope [gE] (rms)	■	■
Current [V] (rms)	■	
Speed [min^{-1}] (max)	■	
Torque [Nm] (max)	■	
Power [kW] (max)	■	

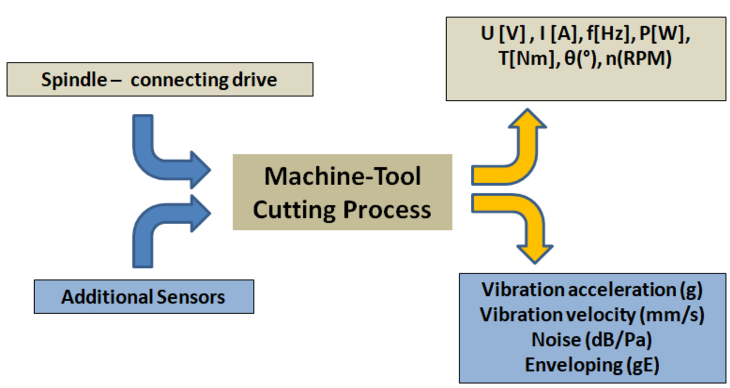

Fig. 3. The structure of parameters.

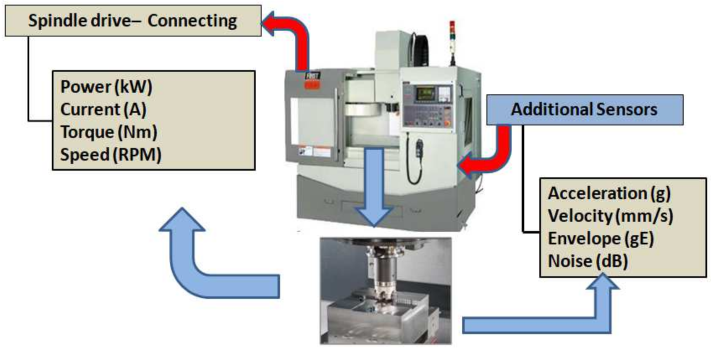

Fig. 4. Experimental setup.

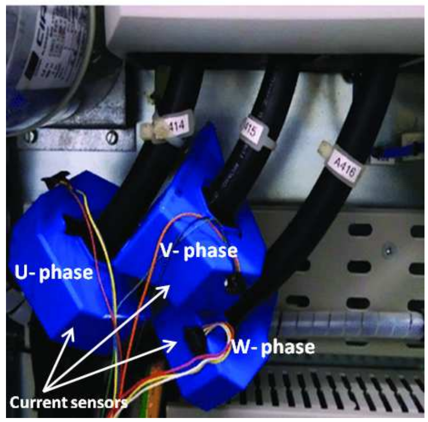

Fig. 5. Current sensor for monitoring the current consumed.

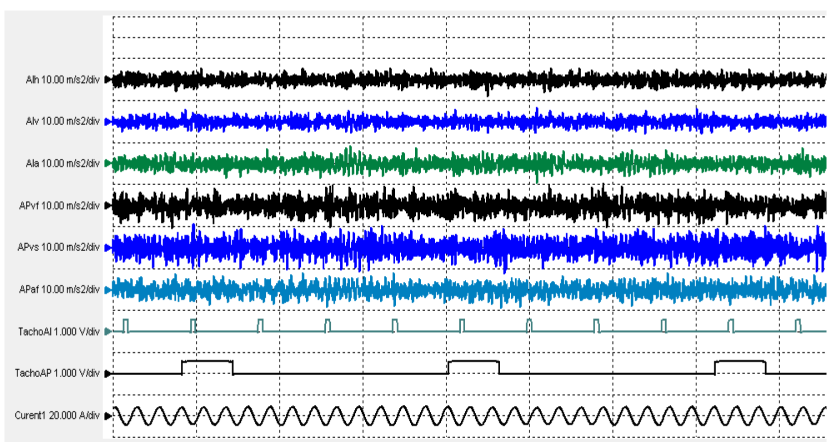

Fig. 6. Waveform for spindle monitoring parameters.

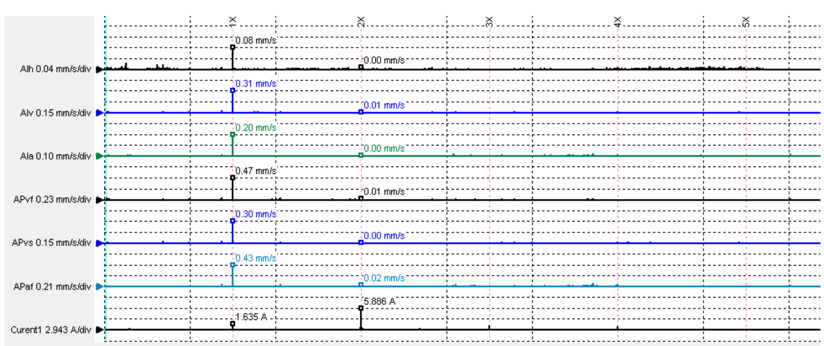

Fig. 7. Spectrum for spindle monitoring parameters.

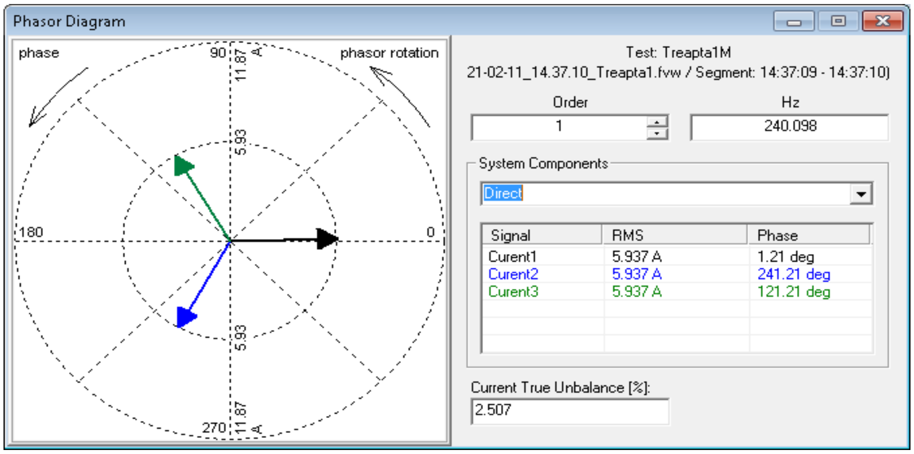

Fig. 8. Phase diagram for electrical current.

Because the drive motor of the spindle is an asynchronous type, there is a difference between the frequencies of the harmonic families of mechanical and electrical type (Fig. 7). This frequency difference is due to the slip between the frequency of the electric current and the rotor speed and has low values. For the exact identification of mechanical and electrical vibration sources, in addition to frequency analysis, vibration phase analysis was used. It is mentioned that it was not possible to directly monitor the rotor speed because there is no access to the motor shaft to fix the reflective part.

The synchronization of the motor vibration analysis will be performed based on the current absorbed by the motor (Fig. 8). The proposed monitoring method considers the coupling of the data collected from the machine tool with those from the external sensors. There are situations when the connection to the MT is impossible due to the existence of special conditions or the old CNC system. Under these conditions, the use of external sensors is the only option. It is very important in this situation to determine the number and type of sensors. Knowing the growing industrial need for monitoring the condition of the machine tool and its component units, a case study was conducted.

5. INDUSTRIAL MONITORING CASE

For the online monitoring of the operating condition and the detection of defects in a spindle, a case study was performed on Doosan CNC milling center, with 24000 rpm and HS-A/E50-B tool holder.

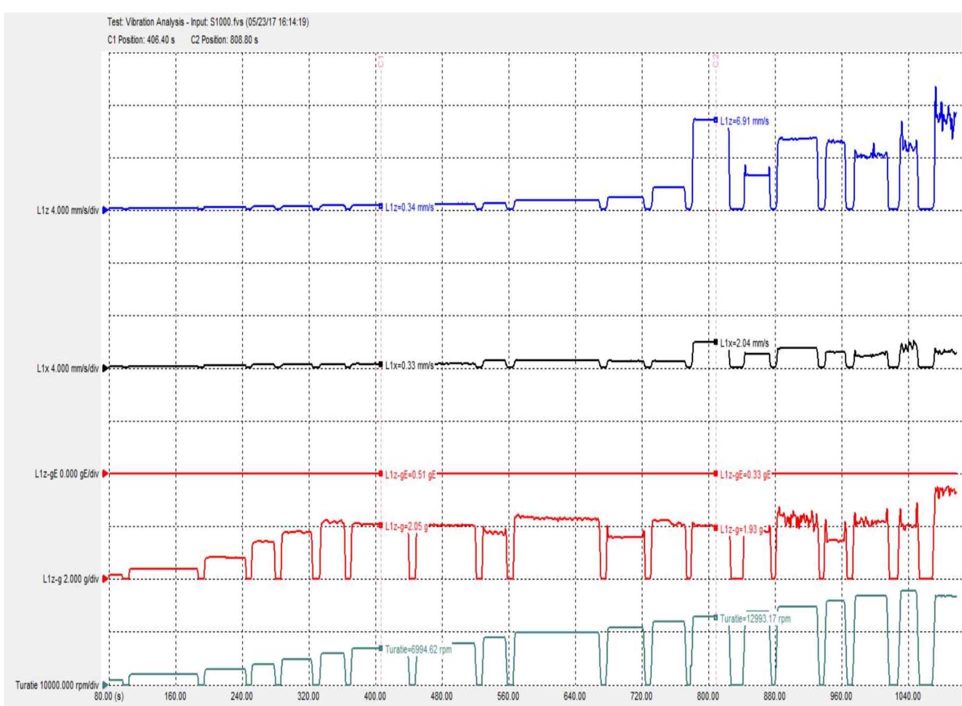

Fig. 9. Trend of vibration parameter during the speed increase.

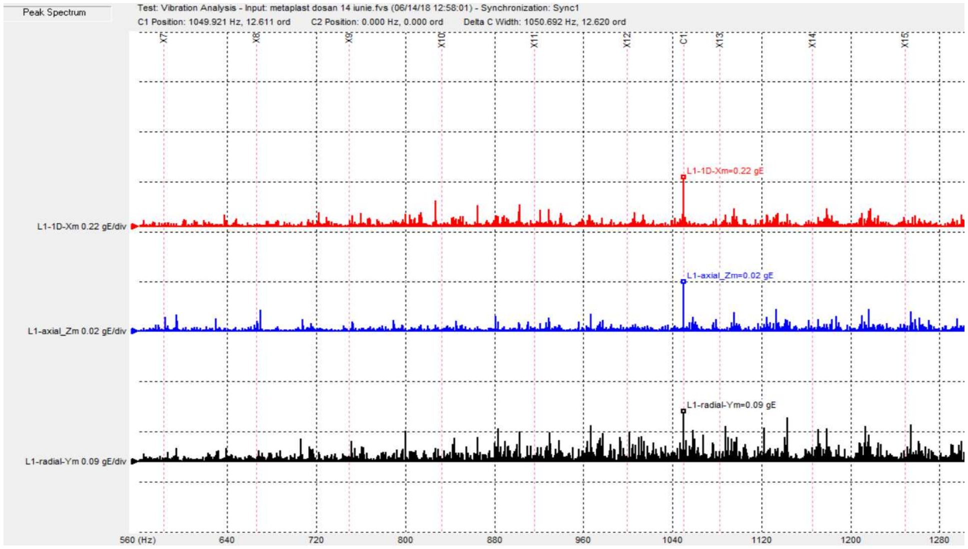

Fig. 10. Acceleration spectrum with bearing defect highlighting.

After a crash of the spindle, an increase on the vibration levels was registered and implicitly the risks of damage of the spindle by the accentuated bearing wear. The spindle was instrumented with vibration sensors and online monitoring equipment that allowed the acquisition of monitored signals. By vibration measurements and analysis was obtained the optimisation of the cutting parameters, respectively optimal speeds, recommended for a normal vibration level. In this condition the cutting velocity, feed and cutting depth was modified to avoid critical zones of vibration, respectively high-level of acceleration (Fig. 9). Figure 10 shows the bearing defect, analyzed by the spectrum of the enveloped acceleration. Due to the knowledge of the operating state of the spindle, respectively of the bearings, it was possible to determine the evolution until shutdown. Based on the parameter optimizations, it was possible to increase the operation period and the preparation of stopping and repairs in controlled production conditions.

6. CONCLUSIONS

The need for control and detailed knowledge of the manufacturing process is growing especially in the current market conditions. Monitoring during processing provides information continuously. It allows a real-time reaction and limiting damage of the machine. With online monitoring system integration, downtime can be reducing. Through online monitoring the productivity can be increased by using optimal production parameters. Implementation of protection systems leads to the elimination of financial losses due to defects.

For an optimal solution in industrial application the combination of the signals collected from the machine tool protocol and those from the external sensors is mandatory.

The system was tested directly on the machine tool both in terms of monitoring the parameters on the machine: current, vibration, temperature, noise, etc. as well as in case of a spindle failure situation.

Using the online monitoring method in manufacturing industry it is necessary not only for predictive maintenance but at the same time is very useful for cutting parameters optimization.

Future research includes data analysis algorithms using all parameters collected into the intelligent artificial system.

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