Systems of automatic vibration monitoring in machine tools

Systemy automatycznego monitorowania drgań w obrabiarkach

PIOTR SZULEWSKI
DOMINIKA ŚNIEGULSKA-GRĄDZKA *

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The paper illuminates and discusses some examples of process status monitoring systems in machining. The special techniques based on advanced signals analysis from force sensors, accelerometers, or acoustic emissions are used to detect of chatter vibrations. Monitoring systems could also co-operate with CNC controllers for effective vibration elimination by changing process parameters.

KEYWORDS: vibrations, CNC machine-tools monitoring and supervision, EMO 2015

By observing the use of technological machines and cutting machines with numerical control in industry, it can be seen that their popularity has grown significantly over recent years. The increasingly widespread use of computerized control systems (CNC) is the answer to market requirements. Customers focus on high product quality, workmanship precision, low manufacturing cost, production speed and variety of offerings [1]. Accuracy of work, efficiency, minimal impact on the environment and reliability are features that describe the quality of today's machine tools. They are largely dependent on the dynamic susceptibility of a mass-elastic-damping system, which is essentially a machine tool. In most cases, modern machining centers carry out a number of different operations, which reduces the working time, and thus reduces production costs. The multiplicity and variety of technological operations, along with fine finishing (with small overheads) and the complex geometry of the workpieces often determine the use of slim tools, which in turn can contribute to vibration in the workpiece contact.

Vibrations

The machine as a complex mass-elastic-damping (MST) system is stimulated to vibrations, among others, free, forced and self-excited, under dynamic loads. Free vibrations occur when the system throws off balance by the sudden onset of a transient (startup) or breaking process. Forced vibrations are induced by external

variable force, e.g. in the case of cyclically varying cutting forces or unbalance of rotating parts of machines. The third type of vibration - self-excited vibrations - is associated with feedback between the MST and the force acting on it, and does not stop despite extinction [2]. Self-excited vibrations of the chatter type (fig. 1) have particularly negative impact on the course of the process, the condition of the workpiece (waveform, roughness), tool life and condition of the tool, as well as machining efficiency. In addition, they accelerate the wear of the spindle bearing and the wear of the cutting edge of a tool (not only faster but even catastrophic). They impede the required surface quality and cause excessive noise, which adversely affects the basic characteristic of each machine - accuracy - understood as the precision of reproducing the desired shape and dimension of the workpiece [3, 4]. The occurrence of such periodic vibrations is closely related to the cutting process. In order to avoid their negative impact, it is necessary to use very sophisticated process and machine condition diagnosis systems.

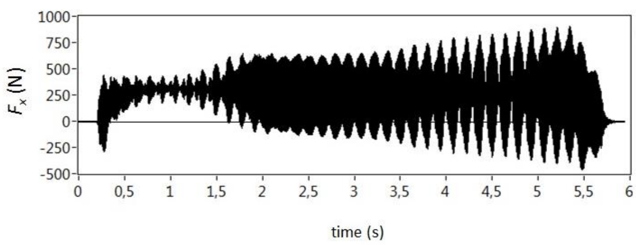

Fig. 1. Example of self-excited vibrations of a turning knife; F_x - force component when turning in X direction

Czas – Time

Measuring systems

Measurement systems can be an integral part of the CNC controller of a technological machine, either as an optional software component or as an external, hardware measurement module. Technically, these systems are most often based on the analysis of signals recorded by sensors, both in the time domain and frequency domain.

Various sensors are used for the construction of vibration detection systems, including rotary dynamometers mounted in milling spindles, accelerometers, force sensors (including plates) and acoustic emissions, microphones, laser interferometers and induction sensors. Examples of the use of various sensors for detecting machine vibrations or self-excited vibrations [5, 6] can be found in the research. Another simpler, and more inexpensive way to detect self-excited online vibrations is described in literature [7], which involves the use of a simple microphone connected to a

* Dr inż. Piotr Szulewski (maxer@cim.pw.edu.pl), dr inż. Dominika Śniegulska-Grądzka (d.gradzka@yahoo.pl) – Instytut Technik Wytwarzania Politechniki Warszawskiej

PC sound card and analysis of signal changes in time windows. It should be noted that manufacturers of modern machine tools increasingly standardize them in various types of sensors, and the signals derived therefrom can be made available also to external measuring systems [8].

Eliminating the vibrations

One of the most commonly used methods of avoiding self- excited vibrations is to work in a stable area, determined on the basis of the calculated stability limit, to determine the machining parameters, for which there is no self-excited vibrations [9]. For this purpose, the following methods can be used to prevent the development of self- excited vibrations [10-12]:

- choice of cut layer thickness,
- change of rotational speed,
- pulsation of rotational speed,
- selection of tool geometry,
- in milling machining - the use of variable pitch cutters,
- use of passive and active silencers.

Due to the changing machining conditions and the non-linear machining model, a control over the spindle speed seems to be a better way to ensure the stability of the machine. It can be implemented:

- offline (where the order of operations is as follows: vibration detection, feed stop, rotation speed change, and resumption of the cutting process)
- online (current speed correction, no feed stop, vibration occurring at all times, a command to change the speed is sent to the control system) [13].

In the monitoring/surveillance systems available on the market, striving to ensure a stable workpiece and optimize the cutting process is noticeable. It follows the necessity of two basic actions [14]:

- vibration detection and diagnostics,
- eliminate vibration or optimize the process.

In the latter case, it is necessary to provide effective communication between the measuring system and the machine control. Information from the monitoring system is sent to the NC controller that takes steps to minimize or eliminate adverse events [15].

Surveillance systems

Solutions available on the market are the proposals of both CNC driver manufacturers, machine tool manufacturers and independent suppliers. Systems and research concepts are presented with an emphasis on determining the current direction of work in the field of cutting process monitoring.

Machining Navi – by Okuma

This is a set of functions (software and hardware) that optimize the cutting conditions on the NC machine during machining (fig. 2). It consists of two independent modules. The M-g (guidance) module conducts continuous analysis of recorded vibrations. In the event of a disadvantage - the appearance of self-excited vibrations – it informs the operator and proposes specific changes in the speed value of the spindle. The M-i (intelligence) module operates independently, without supervision from the operator. The measurement uses acoustic emissions. The microphone sensor is installed on the machine housing (!) and the measurement signal is input directly to the CNC controller via the USB interface in the operator panel. The frequency range is from 0 to 10 kHz. The analysis of the acquired signal is carried out on an ongoing basis, its amplitude and frequency are monitored. It detects sudden increases in sound power (bands) and their number within the monitored band. The operator specifies the number of cutting edges of the tool used, but not the type of machining, tool type, or cutting edge geometry. The results of the measurements are presented on the display of the controller monitor (HMI) in the form of a graph. According to the manufacturer, the resulting spindle speed changes are not large - the tuning step is within 0.5 ÷ 2% of nominal speed. Best effects are observed for finishing.

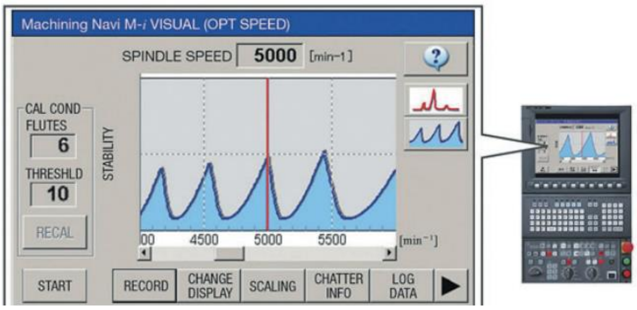

Fig. 2. Example of spindle vibration measurements performed by Machining Navi module by Okuma (www.okuma.com)

VCM System (Vibration Control Monitor) – by Omative

The system is based on measuring the vibration transmitted by the machine tool components. The measurement path consists of sensors, acquisition and operator panels for system configuration and presentation of calculation results (Figure 3). As the information panel, the HMI display is used in the machine tool. Sensors (ICPs) equipped with piezoelectric integrated circuit with load amplifier and current source (*integral electronic piezoelectric*) working as accelerometers, are the source of the measurement signals.

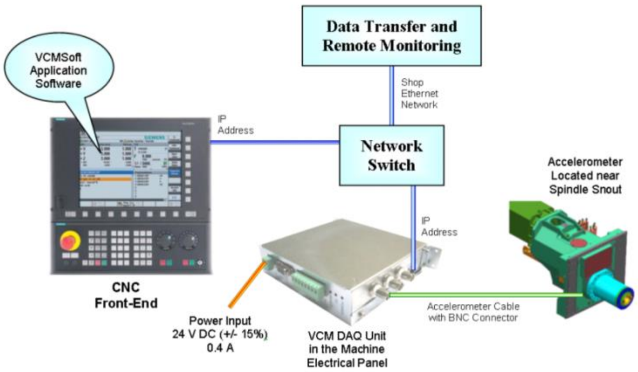

Fig. 3. Structure of VCM Surveillance System by Omative (www.omative.com)

Up to three monitors can be viewed simultaneously. Each of the inputs is equipped with an anti-aliasing low pass filter (<10 kHz) with very steep characteristics (at least 80 dB). The sampling rate is constant and is 20 480 samples per second. To increase the sensitivity of the measurement, the inputs have individual preamplifiers with adjustable gain factor (1 ÷ 16).

The controller is equipped with four programmable digital outputs, which are solid state relays for connecting PLC inputs to the machine controller. Response time for collision detection is less than 1 ms.

Base software consists of three modules. The basic module is a software program that handles the data processing and storage of Flash data stored inside the controller. In the HMI environment of the NC controller, dedicated software is provided as an operator interface (fig. 4). The PLC environment is equipped with interface software that manages the exchange of control signals between the acquisition and PLC systems. The software is compatible with the selected CNC machine control system. Diagnostic messages, warnings or, in extreme cases, processing is displayed. It is possible to record the measured signals to create a "machine condition image" - according to DIN ISO 10816-3 - Evaluate machine vibrations based on measurements on non-rotating parts.

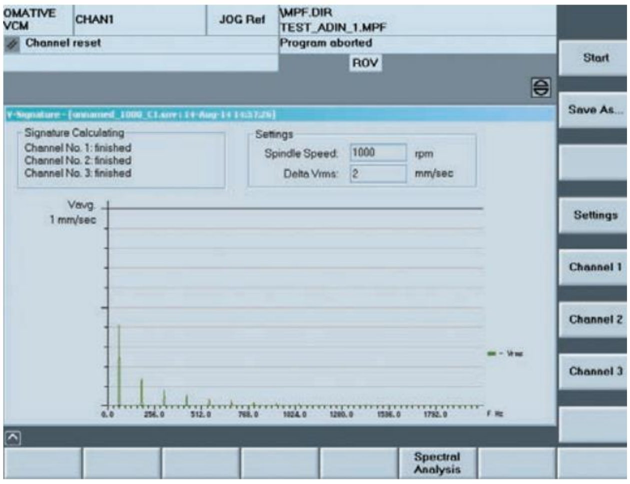

Fig. 4. Screen appearance of NC controller with VCM spectra measurement results for spindle vibrations (www.omative.com)

Promos 2 – by Prometec

The system enables collision detection, overloading due to change in cutting conditions, catastrophic blunting of the blade, tool breakage, tool start (tool contact) and end machining, as well as monitoring of the cutting process (including during roughing), cutting force detection and visualization, spindle monitoring (wear, the existence of unbalanced masses), rolling bearings, guides and other machine tool components. Piezoelectric force sensors are used, electrical power sensors supplied to the machine (intensity, voltage, power factor - *cos φ*), acoustic emission sensors (mounted on the machine body and measured by coolant), vibration and distance measurement sensors. The central module, equipped with a DSP signal processor (fig. 5), processes the real-time measurement signals, controls fixed limits and dynamic limits, analyzes trends, and performs discrete wavelet transformations. It is possible to process up to four independent signals simultaneously. In the emergency state, a stop signal for all machine tool drives is sent. The Input Processing Output (IPO) response time is 10 to 15 ms. The manufacturer declares that the sensitivity of the system is so great that it is able to monitor the drilling process of a diameter of min. 0,05 mm in aluminum. An adaptive control (ACfeed) option is also available to allow for active intervention in fixed feed rates to maximize machining efficiency while minimizing cycle time and maintaining or extending tool life. The system can work with NC Siemens controllers, Indramat (Bosch Rexroth) and Fanuc.

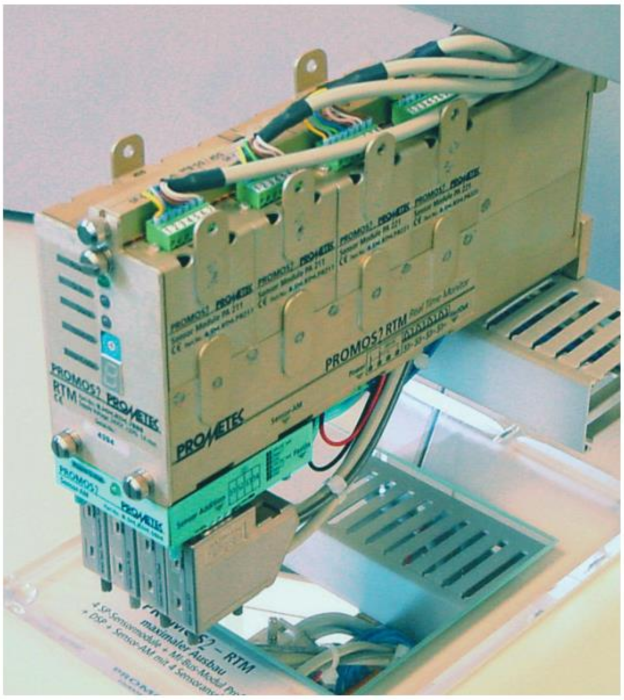

Fig. 5. Controller and acquisition system in Promos 2 by Prometec (www.prometec.com)

Toolinspect II – by MCU

This is an automated monitoring system with self-learning option and intelligent tool control strategies (fig. 6). It features an unlimited number of monitored tools, tool damage detection or catastrophic blunting, tool wear monitoring, support for adaptive control strategies for feed, optional MDA (Machine Data Acquisition) and data storage on secure external media (e.g. CF memory cards). It is equipped with four independent measuring channels allowing for the simultaneous analysis of three torque values or forces on each channel and the ability to observe and analyze the track (*s*). The achievable scanning loop speed of measured variables does not exceed 5 ms (200 Hz). The option is also to monitor analog signals in popular industry standards (0 ÷ 10 V, 0 ÷ 20 m, digital signals 24VDC). The force measurement on the tool fixing parts is performed by a piezoelectric sensor.

Fig. 6. Toolinspect II vibration monitoring system by MCU (www.mcu-gmbh.de)

Toolinspect II is especially recommended for machine tools with turret heads, pallet loading systems and robots. The electrical power supplied to the axle and spindle drives is controlled by the use of active, inductive measuring units equipped with filtering and reinforcing systems. The vibration transmitted by the machine tool components is measured by vibration sensors. The analyzer module communicates with the NC controller via Profibus DP (up to 12 Mbit/s) or FanucBus. Directly from the NC controller, it retrieves the current value of the spindle, drive position, feedrate and torque values, and the declared function G. The digital signals coming from, for example, the PLC of the machine, can also be entered. The maximum number of digital signals is 32. Thirty-two digital outputs can be used for rapid response. Information for the operator is directly transmitted to the control panel using serial bus in RS 232C and TCP/IP network. Currently, the monitoring system can work with Fanuc, Heidenhain, Bosch, Indramat and Siemens controllers.

Qass IM Optimizer 4D – by Toses

The use of a new HFIM (*high frequency-impulse-measurement*) method enables detection of structural changes in the material during machining. The frequency range is 100 ÷ 1500 kHz. The measurement is carried out in real time, by comparing the current emission with the registered standard within the tolerance range (fig. 7). If characteristic impulses are identified, their cause is determined. High frequency sampling, spectrum analysis and graphical interpretation allow to identify all phenomena occurring during machining. This is called an acoustic fingerprint. This device is useful for turning, milling and grinding.

Figure 7. Vibration monitoring system Qass IM Optimizer 4D by Toses (www.quass.net)

MZ84 – by Mozys

Dedicated data acquisition system (Figure 8) dedicated to vibration measurement is equipped with four main measurement paths (100 kHz maximum sampling frequency) and eight additional (10 kHz). High processing resolution (24 bits) and individual anti-aliasing filters allow for precise tracking of all phenomena. It is possible to integrate IEPE piezoelectric sensors (integrated electronics piezoelectric). The internal, user-accessible memory of the device allows to manually enter any data processing strategy according to the developed algorithm. No external computer is needed. The system is ready to use and can be fully automated.

Fig. 8. Vibration monitoring system MZ84 by Mozys (https://mozys.de)

Conclusions

It seems that the most important criterion for assessing monitoring/surveillance systems is the effectiveness of detecting unfavorable phenomena occurring during machining. The source of this is the interaction between the tool and the workpiece, so particular attention should be paid to the location of the sensor installation, assuming that the closer to the sensor, the more likely the diagnostic signal becomes.

Modern diagnostic systems generally process signals based on frequency spectrum analysis, coherence of vibration signals in two different axes, detection of changes in force over time, comparison of fluctuations in vibration amplitude or advanced wave analysis. In order for the information thus obtained to deliver real benefits in terms of improving the quality of the treatment, they should actively influence the cutting parameters in the process. This means that it is very important to ensure that the diagnostic system is properly communicated with the NC controller. Only such interaction will guarantee positive monitoring effects.

At present, research activities are focused on finding more complex strategies and adequate signaling measures. From the perspective of the use of surveillance systems it is important that such a system:

- the signal analysis included the dynamic model of the machine, effectively detecting self-excited vibrations, and effectively adjusting the cutting parameters,
- was resistant to disturbances in the machining environment,
- did not reduce the rigidity and the machine's attenuation capacity,
- did not limit the permissible cutting parameters, tool geometry, and workpiece dimensions.

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