Tool condition monitoring based on artificial neural networks in micromilling

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Abstract

Tool condition, used during micromilling operation has a significant influence on whole microcutting process. Before performing the micromilling operation it is necessary to accurately define tool parameters to avoid machining errors. This is a complex issue which concern many researchers [2]. This article describes an original tool condition monitoring system used in micromilling. The digital signal processing methods which were exploited to gain proper diagnostic signals are presented in details. The monitoring system is based on artificial neural networks trained using acceleration signals. For visualization purposes the user interface was implemented presenting outputs of the diagnostic system.

1. Micromilling

Milling can be considered as micromilling when tool diameter is less than 0.5 mm. Due to very small tool dimensions any process variation is hard to observe and to measure [10;12;14], e.g. cutting forces < 1 N. Performing faultless microcutting operation requires large experience and intuition from operator. The smallest tool damage can cause abnormal machine work and generally lead to workpiece damage.

1.1 Diagnostic signals

The most popular signals used in diagnostic of micromilling process are: cutting forces, acoustic emission, acoustic pressure and acceleration signals [3;13;16]. Suitable measuring system and DSP functions can gain information contained in those signals to define specified changes occurring in the micromilling process. Measurements analysis both in time and frequency domain, are basic, operations in diagnostic process [7;9]. In micromachining it is an important factor due to impossibility of observing milling variation with unaided eye [8;11].

2. Artificial neural Network

The artificial neural network is a computational structure inspired by biological neural human systems. Artificial neural network is formed of simple and highly interconnected processors called neurons. These neurons are connected to each other by weighted links denoted by synapses. These connections establish the relationship between input data and output data. The biases in the neurons of the hidden and output layers, respectively, are controlled during data processing [1;6]. Artificial neural networks are used in the diagnosis and classification of patterns [15]. Tool condition monitoring system was based on artificial neural networks due to their flexibility, fault tolerance as well as possibility of learning and identification of unknown earlier states.

3. Diagnostic system

Presented diagnostic system was performed on prototype three-axial micromilling machine SNTM-CM-ZUT-1 which was build in Mechatronics Centre of West Pomeranian University of Technology [4;5]. It is equipped with hardware and software solutions of National Instruments Company. Acceleration measurements were taken using three, one axis PCB Piezoelectronics sensors attached in three axis of the spindle base. NI cRIO 9022 PAC controller with NI 9234 analog modules (sampling frequency – 51200 S/s) was used for data acquisition. For measurements analysis, data storage and visualization PC computer was used.

Fig.1. Location of accelerometers on spindle basis.
3.1 Objective of diagnostic system

The main objective of developed diagnostic system is to identify tool condition mounted in the spindle, before attempting to micromilling operation. System has ability to recognize three different states:

- There is no tool in the spindle,
- Tool in the spindle is damaged,
- Tool in the spindle is not damaged.

During run of diagnostic process all measured data is stored at the hard drive of PC and then results are presented on specially for these purposes created visualization.

3.2 Signal conditioning

There is a necessity to perform adequate signal processing before passing it on inputs of artificial neural networks. In case of developed artificial neural networks, acquired with sampling frequency of 51200 S/s, spindle X-axis acceleration signal is transformed after every subsequent pack of 4096 samples into frequency domain using Fast Fourier Transform algorithm. Length of the sampling window was selected experimentally and guarantee satisfactory spectral resolution at minimal necessary acquisition time.

For every subsequent 4096 acceleration signal samples Fast Fourier transform is calculated.

$$X(\omega_k) = \sum_{n=0}^{N-1} x(t_n)e^{-j\omega_k t_n}, \quad k=0,1,2,...,N-1 \quad (1)$$

$$\sum_{n=0}^{N-1} f(n) = f(0) + f(1) + \cdots + f(N-1) \quad (2)$$

where:

- $x(t_n)$ – input signal amplitude at time $t_n$
- $t_n = nT$ – $n$th sampling instant, $n$ an integer $\geq 0$
- $X(\omega_k)$ – spectrum of $x$, at frequency $\omega_k$
- $\omega_k - k$-th frequency sample
- $N$ – number of time samples (number of frequency samples)

In every subsequent spectrum calculated from 4096 acceleration signal samples three frequencies related with excitation frequency of rotating tool are observed. For rotational speed of 24000 RPM first harmonic equals 400 Hz, second 800 Hz and the third 1200 Hz. To make the algorithm more resistant for spectral leakage some additionally frequency series lying near given harmonics, calculated in previous operations were given on the inputs of artificial neural networks.

3.3 Artificial neural Network training

Artificial neural networks were trained to recognize appropriate patterns based on acceleration signals acquired from sensors attached to three axis of spindle basis. Sampling frequency of analog modules acquiring signal was set to 51200 S/s and the acquisition was made for various spindle rotational speeds. Experiment showed that spindle rotational speed, ensuring the best measurements is equal to 24000 RPM, while the most proper diagnostic signal containing the finest information is X-axis acceleration signal. Quotient of adequate harmonics and frequency series lying near those harmonics, calculated in previous operations were given on the inputs of artificial neural networks.

Performed artificial neural network training and testing procedures indicated that the best effectiveness in identifying tools condition characterized feed-forward networks. Basing on performed research two types of artificial neural network were developed:

- Three separate artificial neural networks with two inputs and one output – each indicating one specified tool condition,
- One artificial neural network with two inputs and three outputs – simultaneously indicating all possible tool conditions.
Artificial neural networks errors were calculated as a difference between expected value of the network output and actual value of this output. For artificial neural network recognizing state – no tool in spindle, the error was equal to 0. Error for networks – tool damaged and tool not damaged were respectively 8% and 7.8%. For artificial neural network identifying simultaneously three tool conditions error value was 5.2%.

3.4 Functionality of diagnostic system

The main assumption of developed tool condition diagnostic system is to support operators decision in defining tool state before micromilling operation. Users interface was created as an algorithmic application presenting following steps in diagnostic procedure. Operators task is to activate the application and to follow given instructions. System automatically perform one second acquisition and signal processing for acquired measurements, then user is informed about analysis results on specially developed graphs. To improve reliability and for comparison purposes the results of all implemented artificial neural networks are presented simultaneously.

For every subsequent pack of 4096 samples obtained during 1 second of measurement, artificial neural networks outputs are presented on two types of graphs. On circular graph, outputs of three separate artificial neural networks and artificial neural network simultaneously indicating all three tool conditions are presented using different colors – smaller circles. There is also a function calculating mean value of every following network output – bigger circles on the graph, which diameter depends on variance of networks outputs. Simultaneously results of every artificial neural network is presented on linear graph. Operator can choose which type of graph to use deciding about condition of the installed tool.

4. Summary

Developed diagnostic system allows to monitor tool condition installed in spindle before performing micromilling operation. Application of the system improve operators work and helps to reduce workpiece damages during microcutting. Artificial neural networks provide flexibility, fault tolerance as well as possibility of learning and identification of unknown earlier states. However it is important to remember that diagnostic system is only advice instrument and every decision related with further micromilling process must be made by operator.

Bibliography:


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