Force-measurement based tool-workpiece contact detection in micromilling

Bogdan Broel-Plater*, Marcin Matuszak, Paweł Waszczuk***

*Faculty of Electrical Engineering, West Pomeranian University of Technology

**Faculty of Mechanical Engineering and Mechatronics, West Pomeranian University of Technology

Abstract: Due to a very small tool dimensions in micromilling process finding contact of tool and workpiece is difficult. Observation of tool and its position in a relation to workpiece is only possible with a microscope. Cutting forces signals exploitation is proposed for tool-workpiece contact detection. Cutting forces were not used before for detecting contact of tool and workpiece. This paper presents results of cutting forces measurement occurring during toll-workpiece contact. Method of cutting forces signal processing that gives possibility of automatic tool-workpiece contact detection is shown. Current analysis was made off-line and obtained results will be used for further on-line tool-workpiece contact detection. Conclusions and further research plans arising from performed experiments are presented.

Keywords: micromilling, tool-workpiece contact detection, cutting forces, signal processing

1. Introduction

1.1. Micromilling process

Micromilling process differs from milling in macro scale in several aspects. Milling can be considered as micromilling when tool diameter is smaller than 0.5 mm. Small tool diameter implies high rotational speed of spindle which can be greater than 100 000 RPM [1, 2]. Cutting forces are also different than in classical milling [3]. Moreover, amplitude of cutting forces can be very low (less than 1 N) [1, 3].

1.2. Tool-workpiece contact detection

Information about tool location according to workpiece is crucial for performing correct micromachining process. Workpiece prepared for micromilling process can have different dimensions after previous machining operations. There is a need of finding "zero" point of workpiece surface in tool axial direction (Z). Zero point is usually specified as point of toll and workpiece contact.

There are different methods of detecting tool-workpiece contact in micromilling process. The easiest but most time consuming and most demanding for machine operator is finding contact by observation of the rotating tool which is slowly moved toward the workpiece. Due to very small tool dimensions this method requires usage of microscope for tool observation.

There are some known methods for automatic detection of tool-workpiece contact. In [4] there is a proposition of technique based on on-line tool-workpiece voltage monitoring. Main disadvantage of the method based on voltage monitoring is need of burr removal from tool before application of this method. Burrs attached to milling tool can cause current flow before real tool-workpiece contact.

Another method is based on vibration signals [5]. Vibrations can be measured by accelerometers attached to machine spindle or workpiece. Monitoring of changes in power spectral characteristics of the vibration signal allows to detect tool-workpiece contact. Method based on vibration signal is sensitive on tool condition. Better results can be achieved with worn tool than with new tool.

Acoustic emission (AE) signals usage for tool-workpiece contact detection is presented in [6, 7]. AE gives best and most repetitive results. Main disadvantage of this method is cost of acoustic emission sensor and need of attaching sensor to the workpiece.

Every of listed methods requires attaching additional sensors to machine or workpiece (accelerations, voltage measurement, acoustic emission) or is relatively expensive (acoustic emission).

2. Experiment setup

Experiment was performed on prototype three-axial micromilling machine SNTM-CM-ZUT-1 (fig. 1) which was build in Mechatronics Centre of West Pomeranian University of Technology.

Block diagram of tool-workpiece contact detection system is shown in fig. 2.

Micromilling machine is equipped with three-axial Kistler 9256C1 dynamometer that was used for cutting forces measurement. Dynamometer was connected to Kistler 5070 charge amplifier. National Instruments CompactRIO with

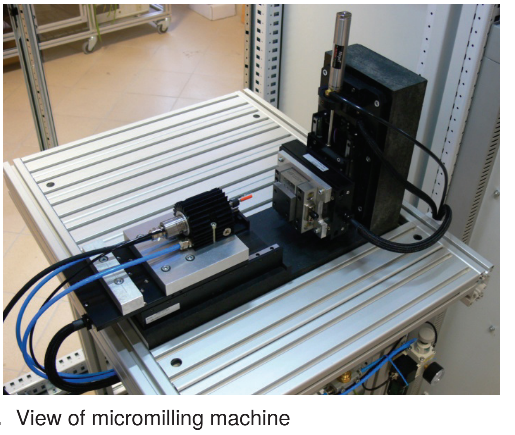

Fig. 1. View of micromilling machine
Rys. 1. Mikroobrabiarka SNTM-CM-ZUT-1

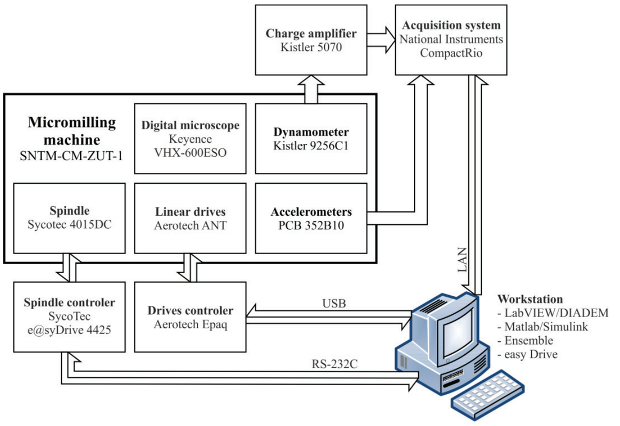

Fig. 2. Block diagram of tool-workpiece contact detection system

Rys. 2. Schemat blokowy systemu wykrywania kontaktu narzędzia z przedmiorem obrabianym

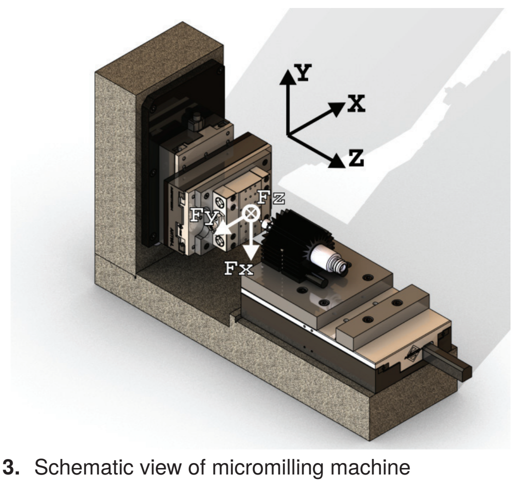

Fig. 3. Schematic view of micromilling machine

Rys. 3. Schemat mikroobrabiarki

NI 9234 modules was used for cutting force signal acquisition. Sampling frequency during signal acquisition was set to 51 200 Hz. Off-line signal processing was performed by National Instruments LabVIEW software. Tool was optically observed during experiment with Keyence VHX-600ESO microscope.

Experiment was performed for two different tools: Kyocera 2FESM005-010-04 (diameter 0.5 mm) and Microcut 82005 (diameter 0.127 mm). To verify versatility of method of tool-workpiece contact detection experiment was performed for two different rotational speed (15 000 RPM and 21 000 RPM).

Schematic view of micromilling machine is shown in fig. 3. Dynamometer is attached vertically to the micromilling machine. On the dynamometer was mounted workpiece made of 18G2 carbon steel. Before tool-workpiece contact detection procedure workpiece was milled with 2 mm diameter tool to ensure low surface roughness.

View of dynamometer with workpiece, cutting tool and microscope lens is shown in fig. 4.

Tool was moved towards the workpiece in 0.5 µm steps at speed of 1 mm/s. When tool-workpiece contact was observed on microscope tool movement was stopped.

3. Data processing

The most adequate signal for analysis is axial force (F_z). Due to high noises in cutting force signal, data processing based on signal amplitude (e.g. RMS value) is not proper for tool-workpiece contact detection.

Specified tool rotational speed correspond excitation frequency that depends on number of cutting blades and tool rotational speed. Excitation frequency is calculated from the following formula:

$$f_{ex} = \frac{n}{60} z \tag{1}$$

where: n – rotational speed [RPM], z – number of cutting blades.

For rotational speed of 15 000 RPM and 21 000 RPM excitation frequencies are respectively 500 Hz and 700 Hz. Finding excitation frequency in cutting force signal gives possibility of tool-workpiece contact detection.

$$f_a = \frac{m f_s}{N} \tag{2}$$

where: f_a – analyzed frequency, f_s – sampling rate, m – bin number, N – number of time samples (number of frequency samples).

For every subsequent 1024 cutting force signal samples Fast Fourier transform is calculated.

$$X(\omega_k) = \sum_{n=0}^{N-1} x(t_n) e^{-j\omega_k t_n} \quad k = 0, 1, 2, ..., N-1 \tag{3}$$

$$\sum_{n=0}^{N-1} f(n) = f(0) + f(1) + \ldots + f(N-1) \tag{4}$$

where: (t_n) – input signal amplitude at time t_n, $t_n = n\mathrm{T}$ – n-th sampling instant, n an integer ≥ 0, $X(\omega_k)$ – spectrum of X, at frequency ω_k, ω_k – k-th frequency sample, N – number of time samples (number of frequency samples).

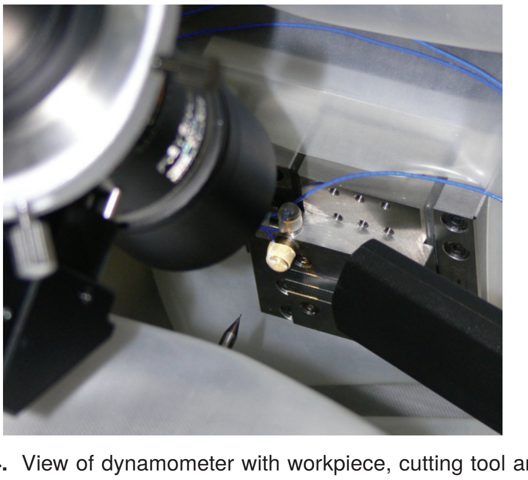

Fig. 4. View of dynamometer with workpiece, cutting tool and microscope

Rys. 4. Umiejscowienie siłomierza, przedmiotu obrabianego, narzędzia oraz mikroskopu

Tool-workpiece contact detection method bases on comparing currently obtained excitation frequency amplitude with averaged excitation frequency amplitude before milling.

In the first step a reference value is created by obtaining and averaging some amount of samples packages (1024) recorded at the beginning of milling, when there is certainty, that cutting tool is outside the workpiece.

In the next step there is performed a comparison of every subsequent pack of acquired signal with the reference value. Basing on analysis there were made an special indicator showing the ratio of cutting forces signals for every next pack of 1024 samples. Large indicator's value means the better recognition of tool-workpiece contact. In addition to prevent spectral leakage there were used a simple averaging of two corresponding excitation frequencies.

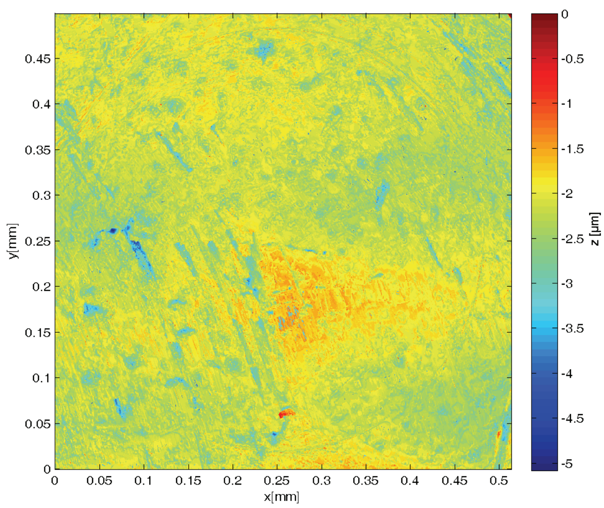

Fig. 5. Surface topography after tool-workpiece contact for speed of 15 000 RPM and 0.5 mm tool diameter

Rys. 5. Zdjęcie powierzchni przedmiotu obrabianego po kontakcie z narzędziem o średnicy 0,5 mm przy 15 000 obr./min

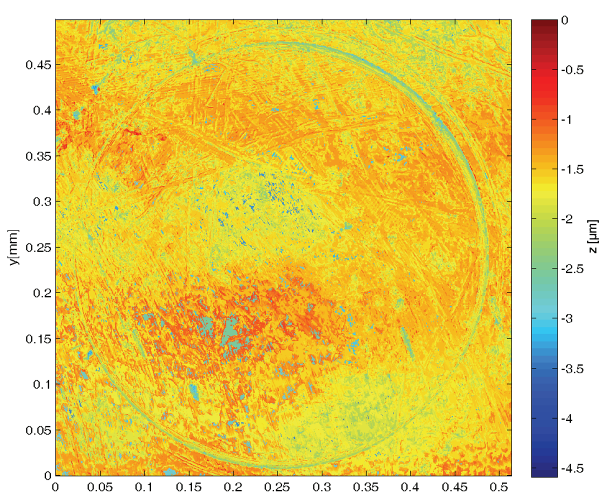

Fig. 6. Surface topography after tool-workpiece contact for speed of 21 000 RPM and 0.5 mm tool diameter

Rys. 6. Zdjęcie powierzchni przedmiotu obrabianego po kontakcie z narzędziem o średnicy 0,5 mm przy 21 000 obr./min

3. Experiment results

Surface topography after tool workpiece contact was measured with Polytec MSA-500 Micro System Analyzer. Surface topography after tool-workpiece contact for 0.5 mm tool diameter and rotational speed of 15 000 RPM is shown in fig. 5. Due to large surface roughness trace left by tool is barely visible.

Surface topography after tool-workpiece contact for 0.5 mm tool diameter and rotational speed of 21 000 RPM is shown in fig. 6. Surface roughness is lower than in fig. 5. and trace left by tool is visible.

Cutting force signal in axial direction (Z) for 0.5 mm tool diameter and rotational speed of 15 000 RPM is shown in fig. 7. Excitation frequency amplitude in time domain is shown in fig. 8.

As can be observed in fig. 7 cutting force signal without signal processing does not give information about tool-workpiece contact. Proposed signal processing method

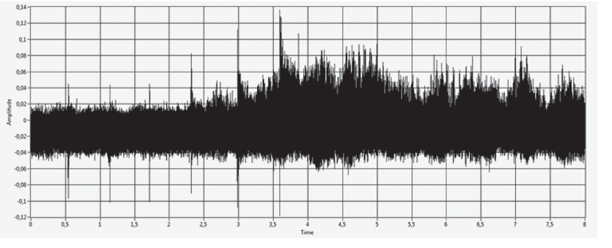

Fig. 7. Cutting force signal for speed of 15 000 RPM and 0.5 mm tool diameter

Rys. 7. Zarejestrowane siły skrawania dla narzędzia o średnicy 0,5 mm przy 15 000 obr./min

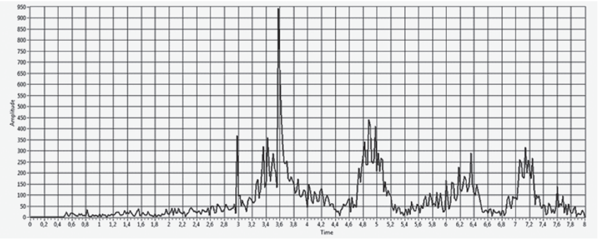

Fig. 8. Excitation frequency amplitude for speed of 15 000 RPM and 0.5 mm tool diameter

Rys. 8. Przebieg stworzonego wskaźnika dla narzędzia o średnicy 0,5 mm przy 15 000 obr./min

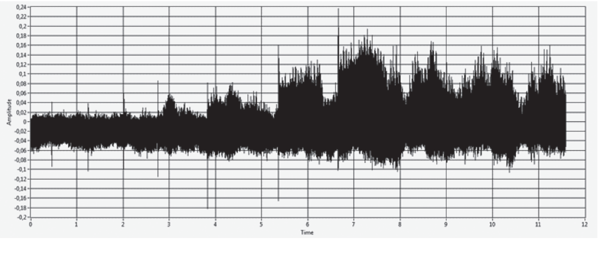

Fig. 9. Cutting force signal for speed of 21 000 RPM and 0.5 mm tool diameter

Rys. 9. Zarejestrowane siły skrawania dla narzędzia o średnicy 0,5 mm przy 21 000 obr./min

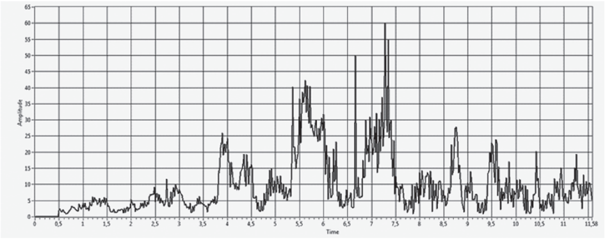

Fig. 10. Excitation frequency amplitude for speed of 21 000 RPM and 0.5 mm tool diameter

Rys. 10. Przebieg stworzonego wskaźnika dla narzędzia o średnicy 0,5 mm przy 21 000 obr./min

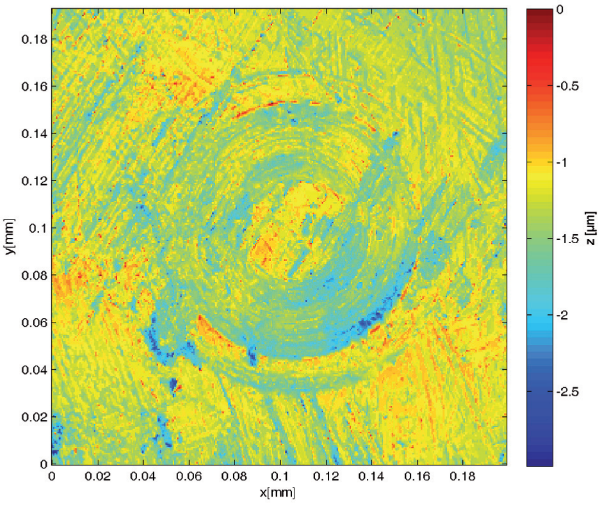

Fig. 11. Surface topography after tool-workpiece contact for speed of 15 000 RPM and 0.127 mm tool diameter

Rys. 11. Zdjęcie powierzchni przedmiotu obrabianego po kontakcie z narzędziem o średnicy 0,127 mm przy 15 000 obr./min

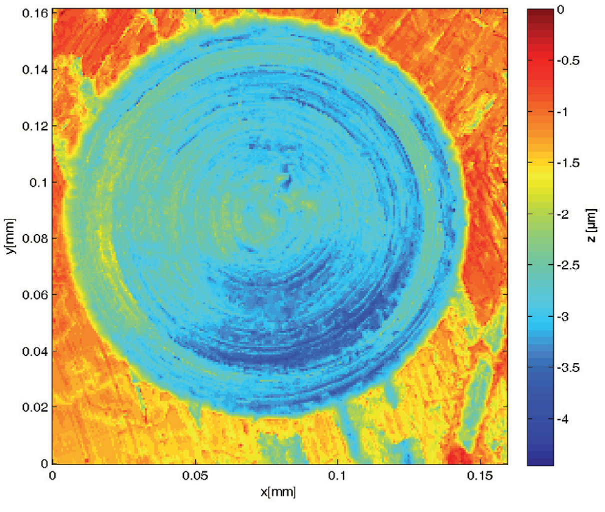

Fig. 12. Surface topography after tool-workpiece contact for speed of 21 000 RPM and 0.127 mm tool diameter

Rys. 12. Zdjęcie powierzchni przedmiotu obrabianego po kontakcie z narzędziem o średnicy 0,127 mm przy 21 000 obr./min

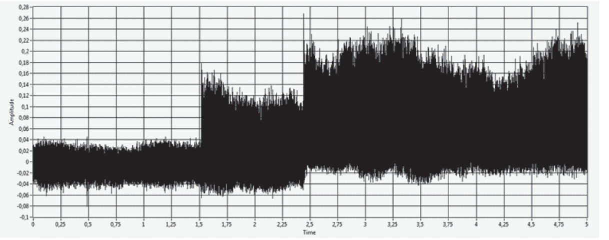

Fig. 13. Cutting force signal for speed of 15 000 RPM and 0.127 mm tool diameter

Rys. 13. Zarejestrowane siły skrawania dla narzędzia o średnicy 0,127 mm przy 15 000 obr./min

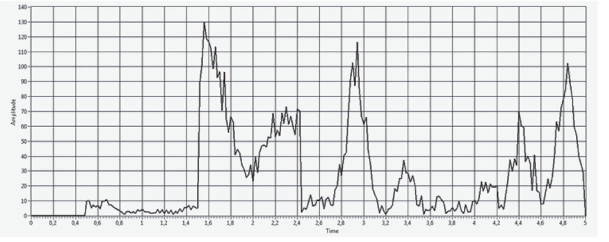

Fig. 14. Excitation frequency amplitude for speed of 15 000 RPM and 0.127 mm tool diameter

Rys. 14. Przebieg stworzonego wskaźnika dla narzędzia o średnicy 0,127 mm przy 15 000 obr./min

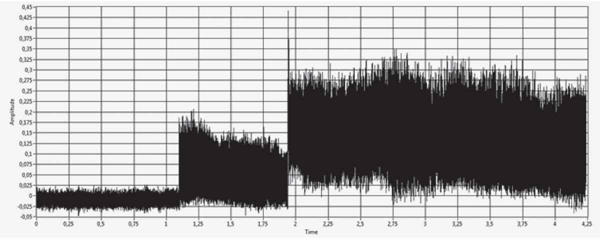

Fig. 15. Cutting force signal for speed of 21 000 RPM and 0.127 mm tool diameter

Rys. 15. Zarejestrowane siły skrawania dla narzędzia o średnicy 0,127 mm przy 21 000 obr./min

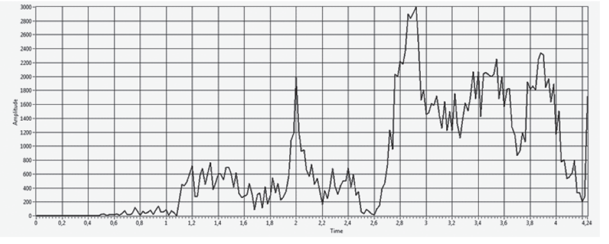

Fig. 16. Excitation frequency amplitude for speed of 21 000 RPM and 0.127 mm tool diameter

Rys. 16. Przebieg stworzonego wskaźnika dla narzędzia o średnicy 0,127 mm przy 21 000 obr./min

(fig. 8) gives reliable information about moment of tool-workpiece contact.

Cutting force signal in axial direction (Z) for 0.5 mm tool diameter and rotational speed of 21 000 RPM is shown in fig. 9. Excitation frequency amplitude in time domain is shown in fig. 10.

Fig. 11–16 shows the same measurements and signals as fig. 5–10 for tool of 0.127 mm diameter, respectively.

4. Summary

Tool rotational speed do not have significant impact for obtained cutting force signal and for tool-workpiece contact detection.

Quality of surface with which contact is detected can be considered as important factor that could have influence on obtained results. Surface topology measurements (fig. 5, 6, 11) shown that surface roughness is comparable to tool-workpiece contact overshoot.

Results obtained by proposed method of tool-workpiece contact detection based on FFT and amplitude of excitation frequency can give possibility of on-line tool workpiece contact detection. Crucial factor in usage of proposed technique is setting up appropriate threshold level that will ensure right method reliability. Main advantage of the method is noise resistance, as reference signal amplitude value is used noised force signal recorded before machining.

In further work proposed technique will be used for on line tool-workpiece contact detection. There is also possibility of acceleration signal usage for tool-workpiece contact detection.

Acknowledgements

The work is financed by development grant
N R03 0050 06/2009.

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Wykrywanie kontaktu narzędzia z przedmiotem obrabianym w mikrofrezowaniu z wykorzystaniem sił skrawania

Streszczenie: Z uwagi na małe wymiary narzędzia wykorzystywanego podczas procesu mikroobróbki znajdowanie kontaktu frezu z materiałem obrabianym jest relatywnie trudnym zadaniem. Obserwacja narzędzia i jego pozycji w stosunku do obrabianego przedmiotu jest możliwa jedynie z wykorzystaniem mikroskopu. W artykule zaproponowano wykorzystanie, nigdy wcześniej nie stosowanych dla tych celów, sił skrawania do określenia kontaktu narzędzia z przedmiotem. Dodatkowo opisano wyniki pomiarów oraz zaimplementowane sposoby przetwarzania sygnału, dające możliwość automatycznego wykrycia kontaktu. Przeprowadzone analizy zostały wykonane off-line, ich wyniki posłużą do przyszłej implementacji algorytmu w trybie on-line. W artykule zaprezentowano również wnioski płynące z badań oraz plany przyszłych eksperymentów.

Słowa kluczowe: mikroobróbka, kontakt narzędzia z materiałem obrabianym, siły skrawania, przetwarzanie sygnału

Bogdan Broel-Plater, PhD

Department of Industrial Automation and Robotics, Faculty of Electrical Engineering, West Pomeranian University of Technology Szczecin. The main fields of his interest are: controlling algorithms used in PLCs, fuzzy logic, controlling algorithms in digital servodrives and automation of plastic processing.

e-mail: bbp@zut.edu.pl

Paweł Waszczuk, MSc Eng.

Department of Industrial Automation and Robotics, Faculty of Electrical Engineering, West Pomeranian University of Technology Szczecin. PhD student, the main fields of his interest are: digital signal processing, diagnostics in milling and micromilling process and digital servodrives.

e-mail: pawel.waszczuk@zut.edu.pl

Marcin Matuszak, MSc Eng.

Faculty of Mechanical Engineering and Mechatronics, West Pomeranian University of Technology Szczecin. PhD student, the main fields of his interest are: cutting forces and dynamics of micromilling process.

e-mail: marcin.matuszak@zut.edu.pl