Concept of tool condition diagnostic system for micromachining

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Abstract: The paper shortly describes newly designed and realized machine for micromilling, under research/development grant N R03 0050 06 / 2009. First assumptions due to diagnostic system for that machine, as well as preliminary results of recorded signals, which have been the basis for diagnostic system conclusion, are presented. The final remarks about quality of diagnostic system are concluded in last part of the article.

Keywords: micromachining, diagnostics, FFT

1. Introduction

Problems occurring under operation of milling machines are quite well recognized and solutions for most of them are also rather known, still issues connected with machines for micromilling operations are under investigation process in many research centres. The differences between machining and micromachining are especially related to rotational speed of tool, linear velocity and distances of drives moving the tool in 3-D space and of course expected precision of machining [1–3]. Small feed per tool tooth which is comparable to cutting edge radius leads to differences in chip formation [2–4]. Such differences involve the differences in observed values of forces and accelerations on the machined object and on the machine spindle and base [1, 5]. Moreover the tools used during micromilling processes are much more susceptible for damage, especially in resting state and in case of leading cutting process with adjusted not proper parameters [6].

Taking into consideration lack of knowledge in micromilling topics, expectations of high machining precision and cost of operation diagnostic system for such micromilling machine seems to be even much more necessary then in the case of the common milling machine. For the micromilling machine first assumptions about diagnostically important signals were made on the basis of the knowledge in the subject of the classical milling machines. In aim of leading diagnostic tests the acceleration were measured in three axes: on the workpiece, on the machine spindle as well as forces on the object and sounds. Multicomponent dynamometer Kistler 9256C1 with measuring range up to 250 N is used for force measure. PCB Piezotronics model 352B10 sensors with sensitivity equal 1.02 mV/(m/s^2) ±10 %, measure range ±4905 m/s^2 pk are used for acceleration measure. Sound is measured via G.R.A.S. Sound & Vibration model 46AE microphones.

The paper presents first steps of designing diagnostic issue. The first paragraph provides brief information about the machine. Deliberation on parameters of measured signals and their transformation for usage in diagnostic procedure is presented in the second paragraph. In the next subparagraphs graphs illustrating the chosen measured signals and their Fast Fourier Transformation will be presented. Based on this figures, especially presenting FFT graphs drown conclusions for diagnostic system will be stated in the following paragraphs. Finally assumptions and observations will be compered, and remarks given.

2. The machine for micromilling

Machine named SNTM-CM-ZUT-1, on which the researches are conducted, were built, as it was mentioned, under works of development grant. During the international fair *Innovations Technology Machines* which held in Poznan in June 2011 describing machine was awarded a gold medal. Photography of the machine is showed at fig. 1.

The machine consists of the base made of granite, shaped due to individual project. The spindle is driven by Sycotec 4015 DC servomotor, that enable for achieve the rotary velocity up to 100 000 rpm, and max torque value 0.04 Nm. The object is oriented perpendicular with

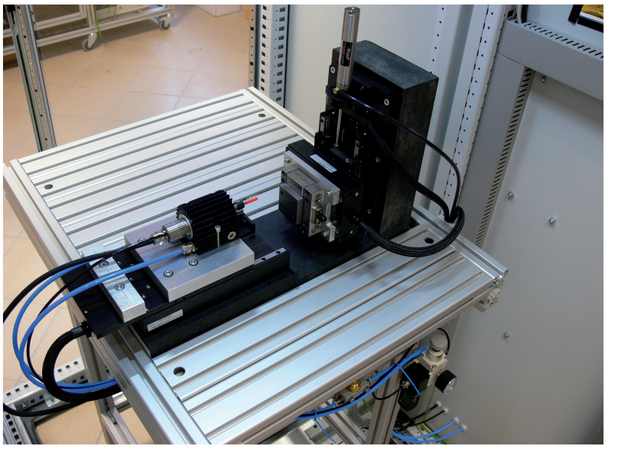

Fig. 1. The SNTM-CM-ZUT-1 micromilling machine
Rys. 1. Mikrofrezarka SNTM-CM-ZUT-1

reference to the base and the operations are conducted in vertical and horizontal orientation. The depth of operation is obtained in line with the base.

The linear movements of the spindle in the 3-D space allow more three linear Aerotech brushless servomotors: ANT95-50-L-Z (axis Y), ANT95-50-L (axis X) and ANT130-110-L (axis Z). The linear motion drives enable for minimal distance with the resolution of 1 nm, with accuracy ±4 µm, and linear velocity of motion in the range up to 350 mm/s. Machine described above allows conducting micromilling process with precision on the level up to 1 nm, with accuracy ±3.0 µm.

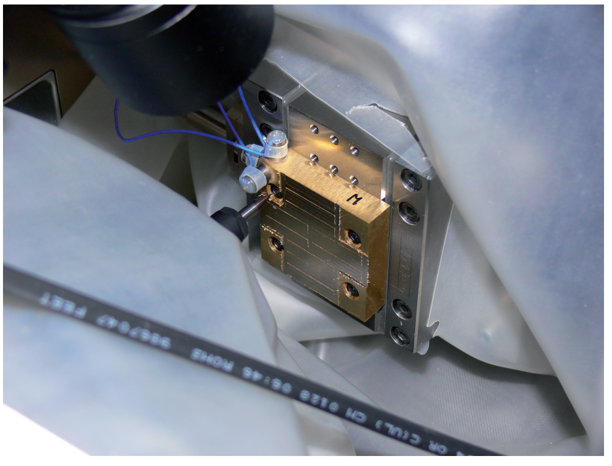

Fig. 2. The microtooling machine under operation
Rys. 2. Mikrofrezarka podczas pracy

Whole control system is combined with three dependent each other units: Aerotech, Sycotec controllers for drives and National Instruments CompactRIO control system for collecting measured signals, implementing diagnostic procedures and leading all overriding control algorithms. As it was mentioned CompactRIO system via 4, 4 channels, analogue input modules 9234 allow to measure signals in 3 axes of acceleration on spindle and workpiece, cutting forces on the workpiece and, what is more, sound via 2 microphones.

Schematic view of micromilling machine with sensors directions and their locations is presented at fig. 3.

Due to grant assumptions for such realized machine with pointed measure points the diagnostic procedures were analysed.

3. Signal analysis

The first step of signal analysis determined the useful parameters of that signals. Initially only acceleration signals were taken under account, and in the paper description is only focused on that signals.

3.1. Additional windowing before FFT

As it is well known, from literature [1, 3], analysis of periodically alternating signals, as are observed in that case, in time domain is useless, however at fig. 4 the example of such plot was presented.

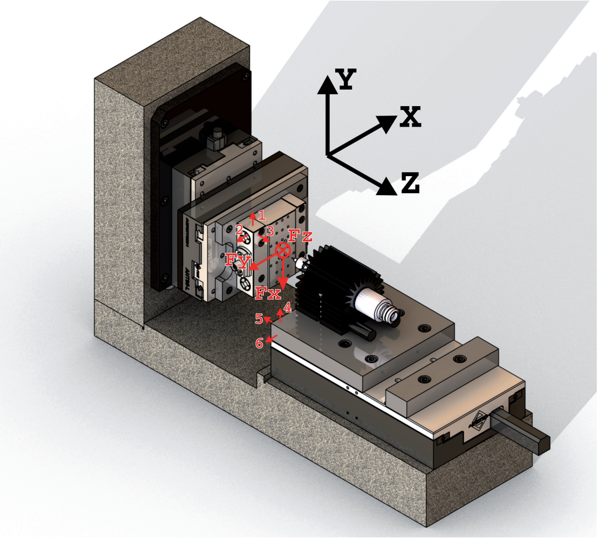

Fig. 3. Schematic view of micromilling machine
Rys. 3. Schematyczny widok mikrofrezarki

For that reason Fast Furier Transformation was chosen as the useful source of information. Of course the quality of obtained spectrum depends very hard on the spread of the window (quantity of samples) taken under calculation. Moreover, using additional operation on that window may provide better results. For that reason many windows were tested. The next two figures (fig. 5 & 6) present FFT operation preceded by using different MATLAB windows. The graphs reflect recorded signal with parameters: spindle rotary velocity 38 400 rpm, moved in all axis X, Y and Z; 51 200 samples per minute. The graphs present resultant acceleration calculated as a 3-D vector. Moreover the bound of presented frequency is limited to show only first 3 component of the signal. The FFT was calculated with 8192 samples. As it is well seen at that figures applying additional window operation inserts changes in FFT waveforms.

As it was assumed by authors the most important information is in bands spectrum connected with basic 1st, 2nd and 3rd harmonic, eventually in bands near the firstly mentioned bands. The bands zones near 1st harmonic (640 Hz) for each window operation are presented at fig. 7 and fig. 8.

Taking that assumption into consideration and analysis of window operation in in the next analysis steps additional Taylor window would be used. Such window, as one of the

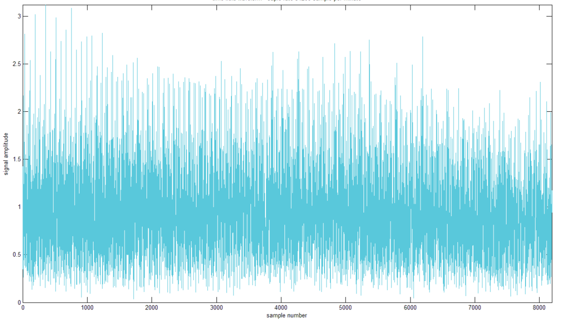

Fig. 4. Raw acceleration signal
Rys. 4. Przebieg zarejestrowanego sygnału przyspieszenia

few, does not decrease the height of the basic harmonic band and has acceptable form of leafs. From this point of view also Kaiser and rectangular windows could be used.

3.2. FFT window spread

As it is also well known, the quality of waveforms depends on FFT window spread [7–9], hence in the next step influence of that parameter on quantity of delivered information in the graphs were investigated. The graphs for the range between 16 and 8 of the power the number 2 were drown for the same rest parameters of the signal, described in previous subsection. FFT graphs for different window spread are presented at fig. 9.

Taking into consideration further compromise, which will have to be obtain in diagnostic system three windows spreads are still deliberated. The most probable solution is the case with 4096 samples used to make FFT. It is the consequence of still good/satisfactory quality of

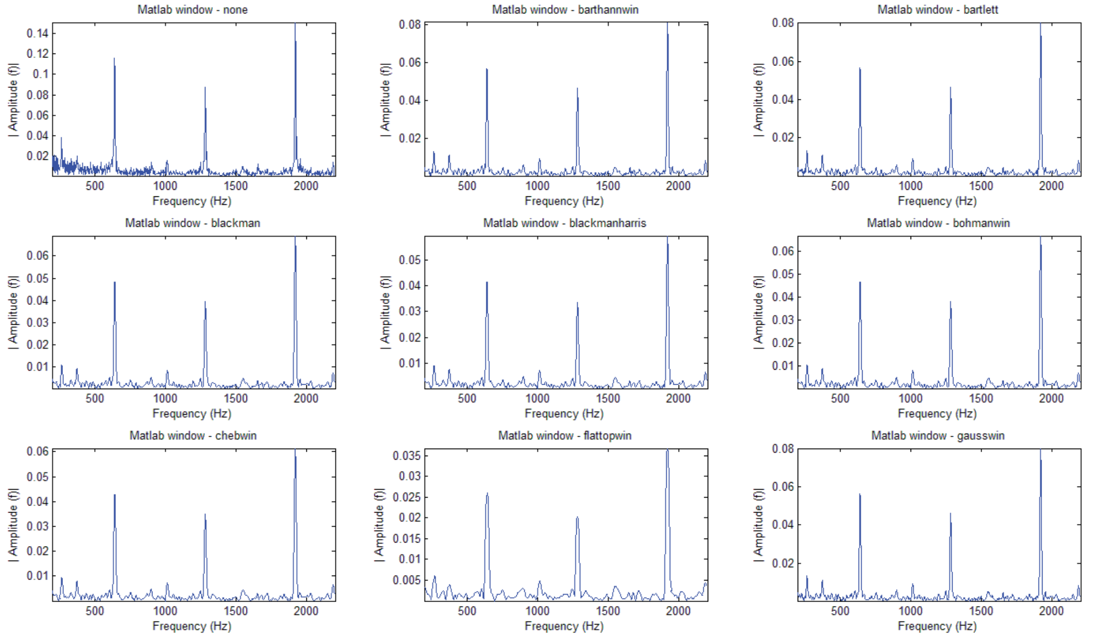

Fig. 5. Graphs presenting usage of different FFT windows (part I)
Rys. 5. Wykresy przedstawiające zastosowanie różnych okien FFT (część I)

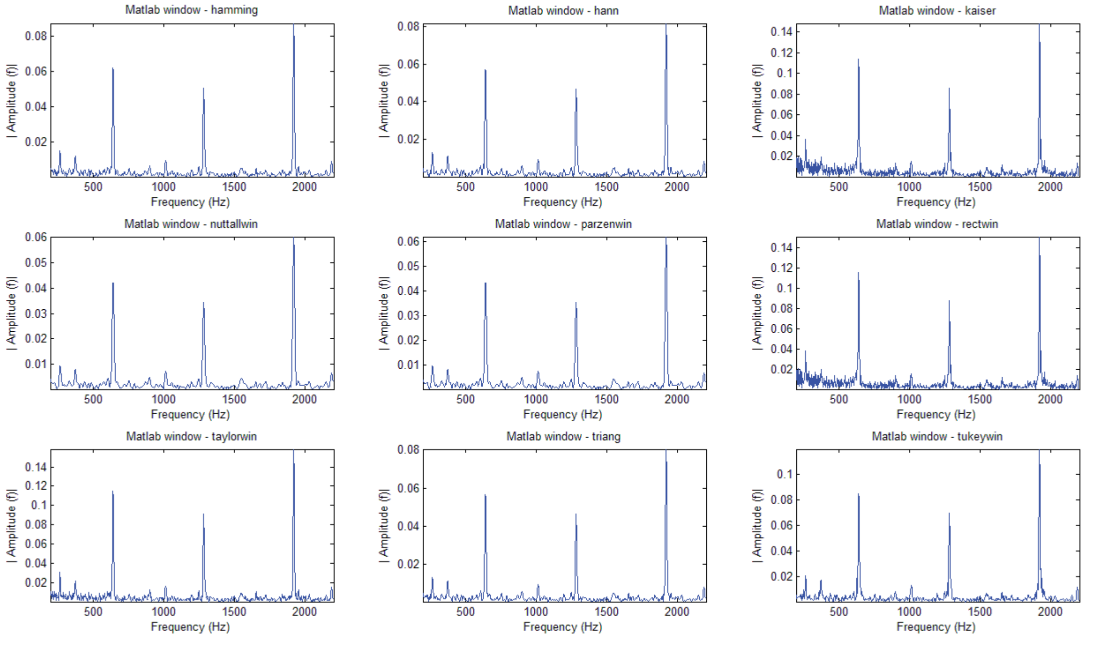

Fig. 6. Graphs presenting usage of different FFT windows (part II)
Rys. 6. Wykresy przedstawiające zastosowanie różnych okien FFT (część II)

bands FFT resolution and enough short period of time for calculate FFT in real time using FPGA in mentioned previously CompactRIO diagnostic system.

3.3. FFT graphs against spindle rotational speed

Till now presented graphs were plotted for only one rotational speed of the spindle. However, the same observations were seen for the others. Of course, due to dependency of the main frequency and the next their components, observed at the graphs, from the rotational speed of the spindle, different ranges of frequency are taken into consideration for different spindle speed. Based on many observations it was established that first three components of harmonic are the most important and will delivered the diagnostic information.

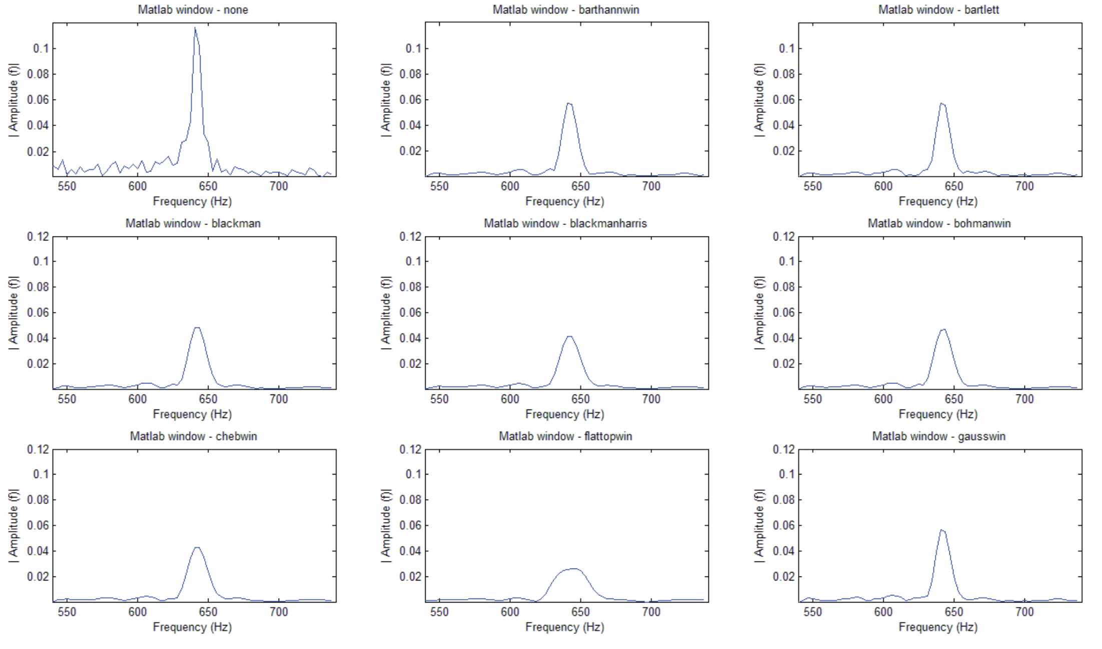

Fig. 7. Graphs presenting usage of different FFT windows (part I)
Rys. 7. Wykresy przedstawiające zastosowanie różnych okien FFT (część I)

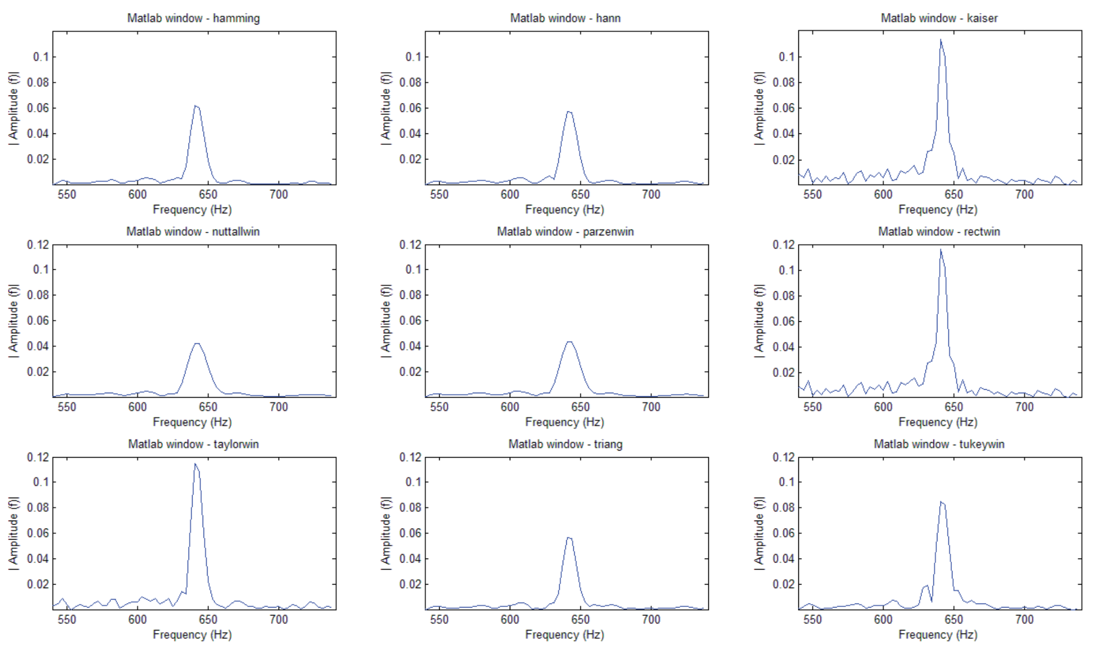

Fig. 8. Graphs presenting usage of different FFT windows (part II)
Rys. 8. Wykresy przedstawiające zastosowanie różnych okien FFT (część II)

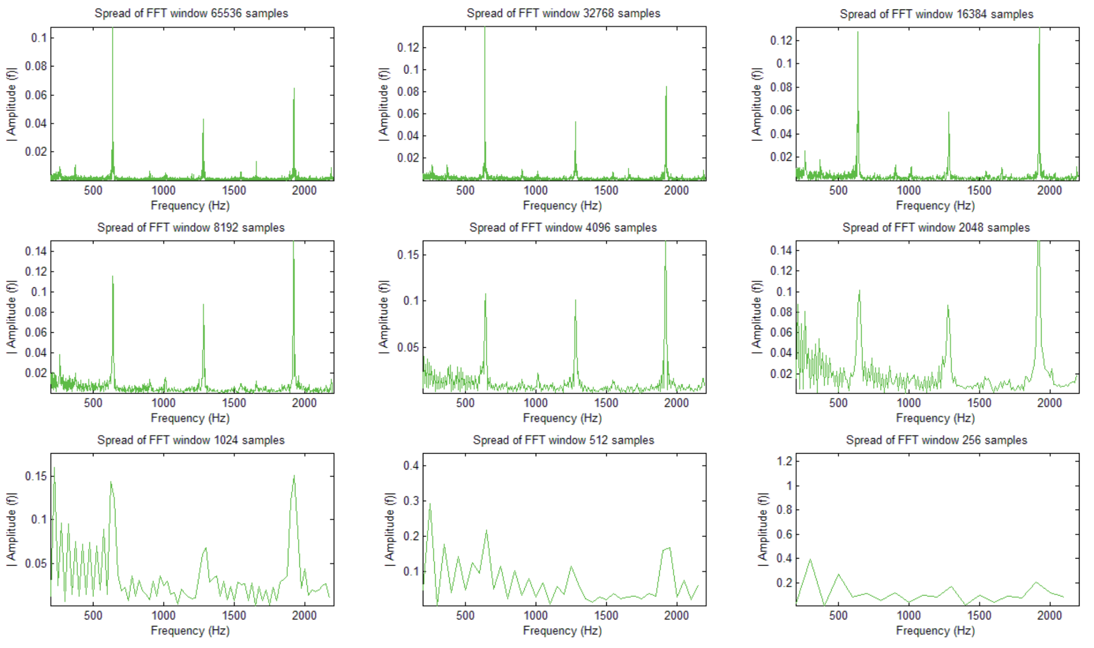

Fig. 9. FFT graphs for different number of samples
Rys. 9. Wykresy FFT dla różnej liczby próbek sygnału

4. One of the diagnostic test assumptions

Based on above conducted signal analyse parameters of signals which deliver diagnostic information were finally chosen. At fig. 6 FFT plots for efficient and damaged tool are presented. Further deliberation connected with diagnostic tests was conducted due to comparison FFT graphs: efficient and damaged tool.

As it is well seen at the mentioned figure in case of tool damage the value of amplitude for each components of spectrum waveform is changing. Of course these changes depend on particular kind of damage. Nevertheless, constant difference seems to be the change between first and second and third waveform components ratio. That observation allows achieving that one of the diagnostic tests could be based on checking the ratio of waveform components. Such test could briefly and initially diagnose the state of the tool. For avoiding errors in diagnostic conclusion process using integration of properly set range of frequency instead of maximum values main waveform components is proposed.

5. Summary

In the paper concept and realization of microtooling machine were presented. Signals measured in machine system were described, and on the basis on acceleration signal analysis of their usefulness were deliberated. The concept of one of the diagnostic test for damage tool detection was presented. The further concepts were presented as well.

General conception of diagnostic system assumed that whole procedures will be conducted in multi stages. First step before machining process is FFT inspection of tool which will confirm if tool is mounted properly. Then for a mounted properly efficient tool, during machining process other procedures will lead to detect and localise any damage. During periods in which tool leaves the material FFT inspection tests will be executed. Diagnostic tests “in the air”, outside the material, based on FFT analysis will be performed for two spindle speeds: 100 000 RPM and nominal speed for operation. Test conducted under operation will be based on signals recorded during drive motions with parameters depending of process.

Acknowledgments

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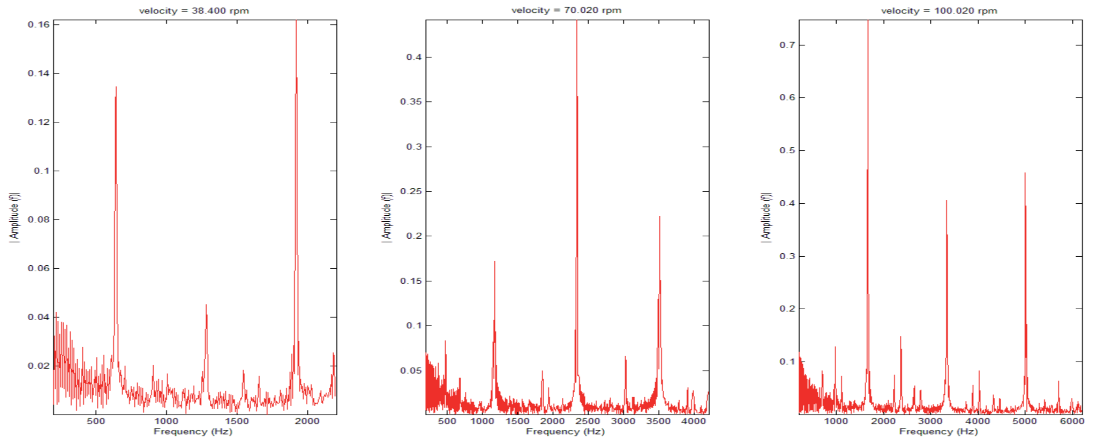

Fig. 11. Spectrum graphs for different velocity of the spindle – tool no 3
Rys. 11. Wykresy widma dla różnych prędkości obrotowych narzędzia nr 3

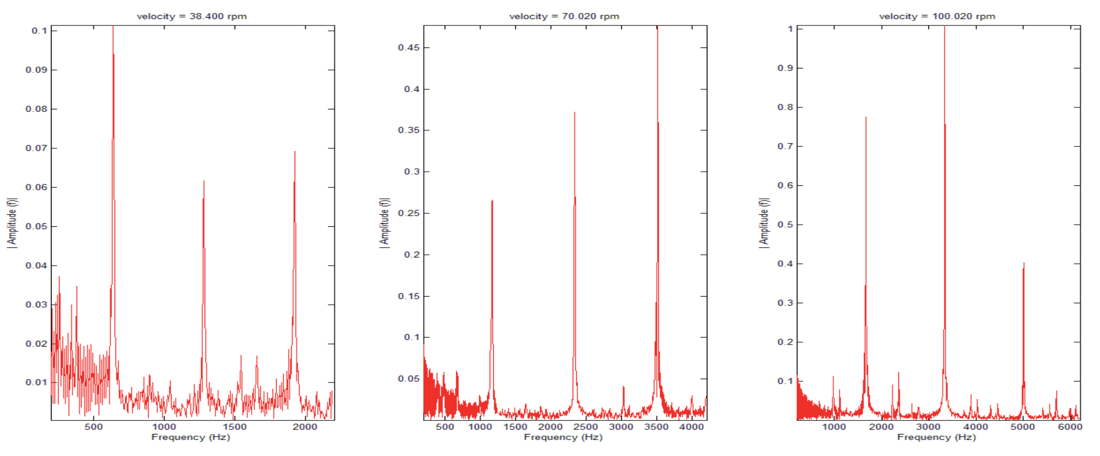

Fig. 12. Spectrum graphs for different velocity of the spindle – tool no 5
Rys. 12. Wykresy widma dla różnych prędkości obrotowych narzędzia nr 5

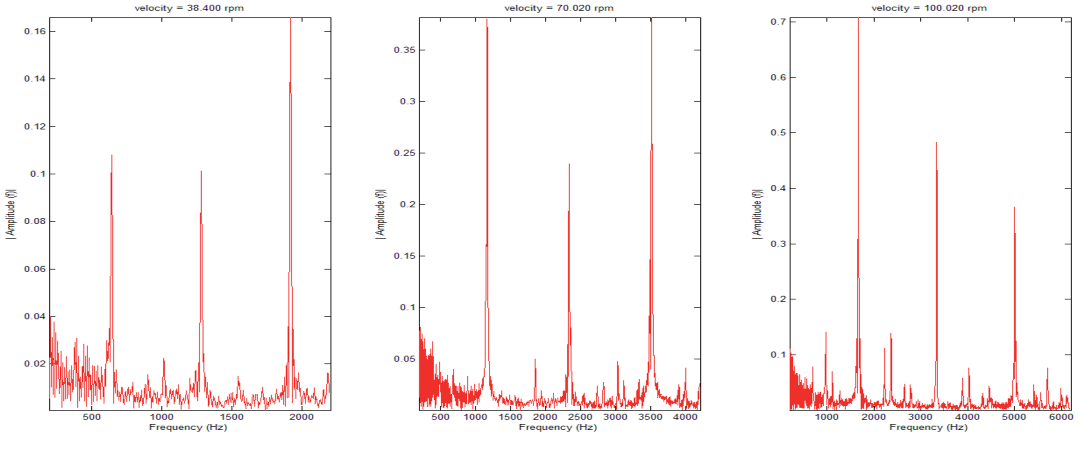

Fig. 10. Spectrum graphs for different velocity of the spindle – tool no 4
Rys. 10. Wykresy widma dla różnych prędkości obrotowych narzędzia nr 4

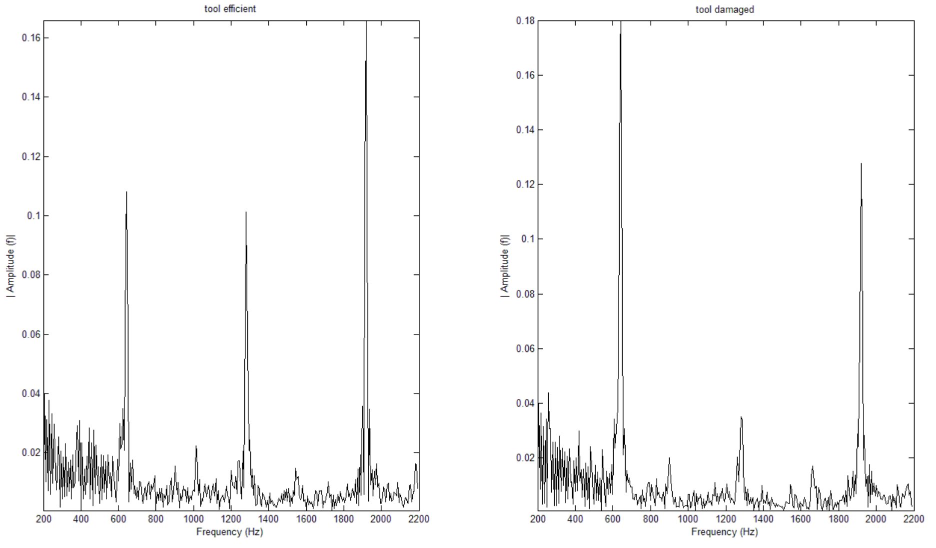

Fig. 13. Comparison of efficient and damaged tool no 4

Fig. 13. Porównanie niezużytego i uszkodzonego narzędzia nr 4

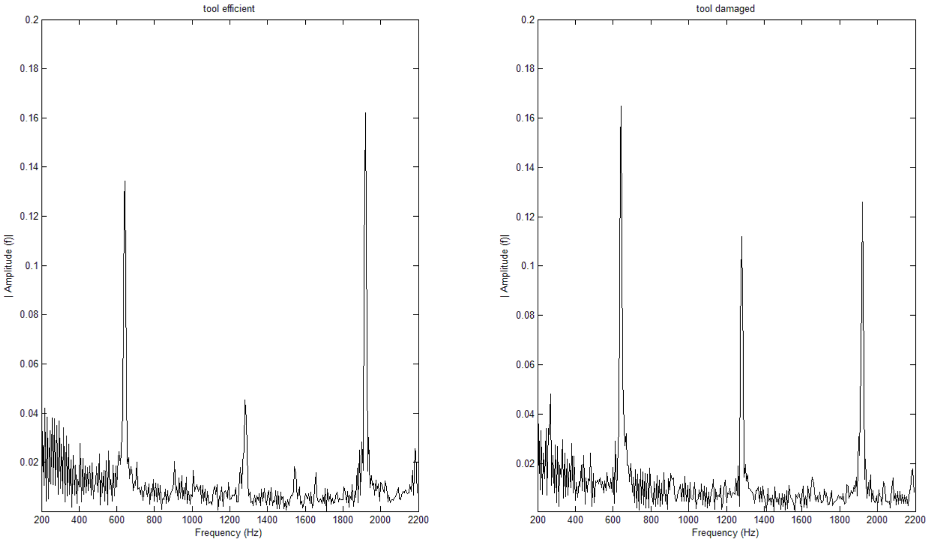

Fig. 14. Comparison of efficient and damaged tool no 3

Fig. 14. Porównanie niezużytego i uszkodzonego narzędzia nr 3

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Założenia systemu diagnostyki stanu narzędzia w mikrofrezowaniu

Streszczenie: W artykule została opisana nowo zaprojektowana i wykonana mikrofrezarka zbudowana w ramach projektu ba-

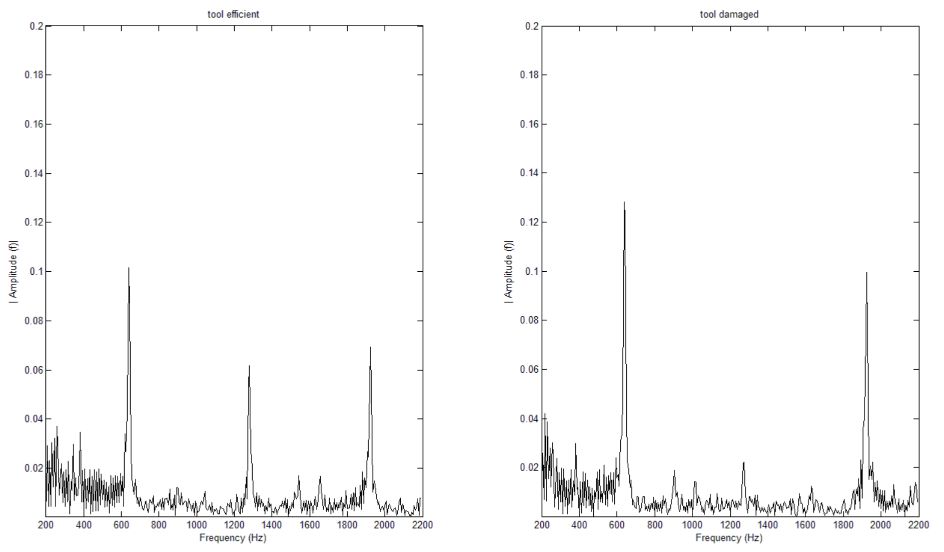

Fig. 15. Comparison of efficient and damaged tool no 5
Fig. 15. Porównanie niezużytego i uszkodzonego narzędzia nr 5

dawczego rozwojowego N R03 0050 06 / 2009. Przedstawiono wyniki wstępnych rejestracji sygnałów, które wykorzystano jako podstawę do diagnostyki procesu mikrofrezowania. Zaprezentowano wnioski donośnie jakości zbudowanego systemu diagnostycznego.

Słowa kluczowe: mikroobróbka, diagnostyka, FFT

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