Application of Eddy Current Sensor System and LDV Device for Ultrasonic Vibrations Measurements

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Abstract. The article presents eddy current sensor system in respect to the measurements of vibrations for ultrasonic assisted machining processes. The comparison of eddy current sensor system with laser doppler vibrometer (LDV device) is also presented. The paper concerns the analysis of the influence of the distance between the tool and the sensor on amplitude value, filtering of raw voltage signals in MATLAB and amplitude values presentation for different tools after MATLAB and LDV software analysis. Functionality of two applied devices can be discussed after investigations. Differences in recorded amplitude's values are also discussed. The examples of measurements and test stand configuration are presented. For better understanding of hybrid machining process, it is important to indicate the possible methods of amplitude measurements and to analyze the results of measurements.

Keywords: laser doppler vibrometer, eddy current sensor system, ultrasonic assisted machining, ultrasonic assisted grinding, vibrations.

1 Introduction

Machining of hard to machine materials (e.g. advanced ceramics, nickel based alloys, hardened steel) may be assisted by applying hybrid machining processes.

One of the most effective methods to achieve high performance indexes for machine parts and tools shaping process consists in combining various physical and chemical processes, acting on workpiece material, into one machining process, which is often defined as "hybrid machining process" [3]. The use of hybrid manufacturing technologies can be a solution if new options for manufacture of a new product are needed [7]. Ultrasonic assisted machining processes are the part of these technologies.

Elastomechanical ultrasonic vibration is generated by the transformation of electric energy in piezoceramic or magnetostrictive sonic converters. A voltage generator serves to convert a low-frequency mains voltage into high-frequency electric alternating-current voltage. The generated longitudinal vibrations are periodical elastic deformations of the mechanical vibration system in the micrometer range at supersonic

J. Awrejcewicz et al. (eds.), *Mechatronics: Ideas for Industrial Applications*,
Advances in Intelligent Systems and Computing 317, DOI: 10.1007/978-3-319-10990-9_38

frequencies, that is, higher than 16 kHz [10]. These vibrations may be related to a workpiece or a tool.

Research institutes which investigate ultrasonic assisted processes, concentrate on their effectiveness. The examples of investigations are presented in [1, 4, 5, 8–13]. Process forces, cutting performance, surface quality measurements are, inter alia, published. The influence of oscillations' parameters on process course is also discussed. The main parameters are amplitude and frequency of oscillations. Ultrasonic oscillations parameters values are usually presented as constant values in these papers. The integer values of amplitude or sometimes [13] values accurate to one decimal place are presented.

Previous investigations in Rzeszow University of Technology have shown that presentation of amplitude values is a very complex issue. It depends on measuring technique, methods of data analysis and physical phenomena connected with excitation system. Thermal phenomena of excitation system caused by ultrasonic vibrations may be defined as important factor for amplitude variability during machining process realization. Amplitude values changes are observed, mainly, at resonance frequency, when the highest amplitude values are reported. Amplitude values also depend on measuring direction and selected place on the tool. These conclusions are presented after measurements of ultrasonic vibrations using laser doppler vibrometer (LDV device) on Ultrasonic 20 linear machine tool. It has been concluded that LDV measurements of ultrasonic vibrations should be compared with other measuring methods. Microscopic investigations have been carried out [14], new knowledge has been obtained and compared with other investigations [2], but inaccuracy in reading amplitudes and frequency on microscopic images are the reason for the new future investigations in this area and also searching different methods. Ultrasonic vibrations are clearly visible on oscilloscope's display if the appropriate eddy current sensor system is chosen. Thus, eddy current sensors have been chosen, as possible measuring method of ultrasonic vibrations. The usability of eddy current sensors for measurements of vibrations during process is significant, because the measurements may be carried out if cooling lubricant is applied for process realization. LDV measurements do not provide this, because laser beam cannot be reflected if liquid is applied to the machining zone. Researchers showed the usage of these sensors to measure amplitude of vibrations for ultrasonic assisted machining processes [13, 15], but the knowledge about their functionality, data acquisition, accuracy and their analysis is still insufficient and comparisons with the other devices is needed. The clear visibility of ultrasonic vibrations on oscilloscopes and visible changes in values of voltage signal during frequency changes are the base for usability predictions of eddy current sensor systems for amplitude and frequency measurements.

2 Test Stand Configuration

EddyNCDT3300 measuring system from MICRO-EPSILON with the 0.4 mm measuring range sensor ES04, together with digital oscilloscope, were the base for carrying out the eddy current measurements. Scanning laser doppler vibrometer Polytec

PSV-400 has been also applied for comparison. The eddy current sensor has been located under the grinding wheels with metal bonding or metal wheels' models (called tools in this paper). Three tools were applied for the presented results of measurements: 8 mm grinding pin with metal bond (T8), 6 mm steel model of a tool (T6), and 30 mm steel model of the 1A1 grinding wheel (T30). The ultrasonic action of a tool is possible, because the machine tool is equipped with the ultrasonic excitation system of a tool. Thus, ultrasonic vibrations are connected with a tool clamped to the special tool holder which contains piezo transducer. The complete test stand for investigations is presented in Fig. 1.

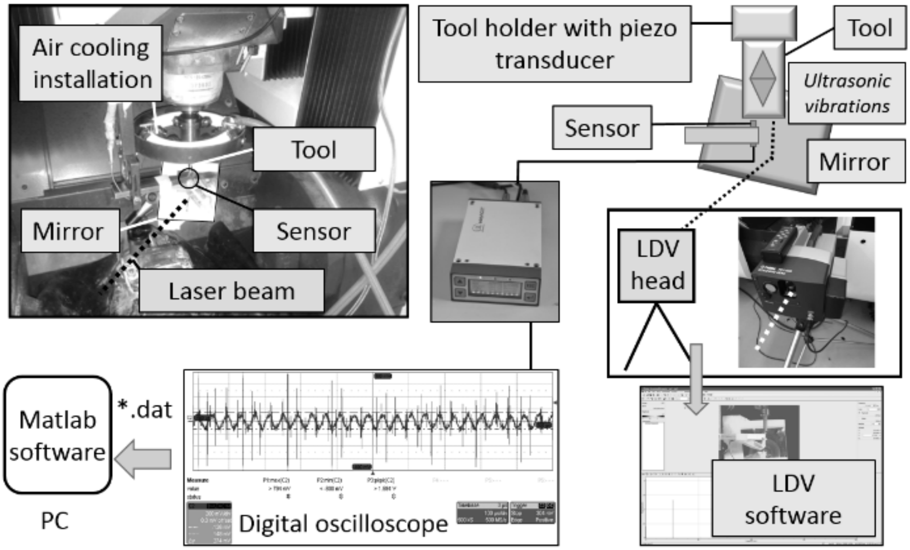

Fig. 1. Test stand for ultrasonic parameters investigations

The data presented in this paper concern influence of the distance (gap) between the tool and the sensor on amplitude value, filtering of raw voltage signals in MATLAB and amplitude values presentation for different tools after MATLAB and LDV software analysis. The measurements were carried out (for each tool) at one operational frequency, which was chosen on machine tool from the range of operational frequencies: 20,000 Hz to 30,499 Hz. Switching on the ultrasonic generator, if the sensor distance to the measuring object complies with its measuring range, causes that sinusoidal changes of analog output voltage signal, which are clearly visible for tested tools on the oscilloscope's display at resonance frequency. Fast measurements of amplitude and frequency are possible directly on the oscilloscope's display, but only for clear sine graphs. The amplitude is presented in volts then. Transformation into microns may be done if the right ratio is defined. Series of tests showed that 1 mV change in voltage should be multiplied by 0.02. Voltage signals can also be saved as *.dat format MATLAB files in oscilloscope's software and filtered in MATLAB software. Fig. 2 presents the visibility of the voltage changes for T8 and

T30 tools. These voltage signals are transferred to displacement units from the spectrum. Displacement is presented in this pictures as peak-to-peak amplitude of raw signal (A_1) and filtered signal (A_2).

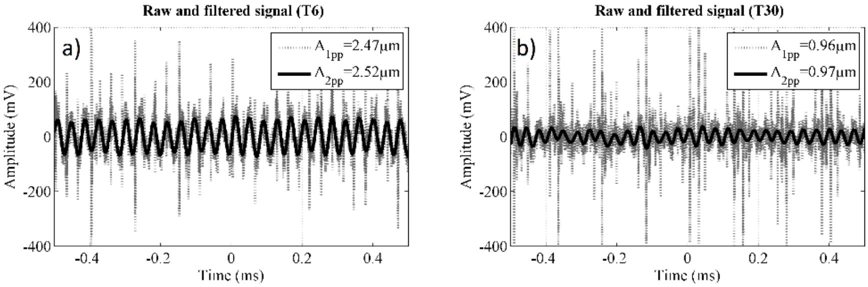

Fig. 2. Ultrasonic action visibility on the graphs created in MATLAB: a) T6 mm tool at frequency 25,800 Hz, b) T30 mm tool at frequency 28,100 Hz

The visibility of voltage changes for T8 and T6 was very good near resonance frequency and sinusoidal signal is easily observed. For T30 visibility of voltage changes was good but sinusoidal graph is distorted by signal noise. At the end of measuring range, vibrations was not clearly visible at selected frequency for T30. It was assumed that for analysis of the signal in MATLAB software, the changes of signal on oscilloscope's display must be visible. Then, signal changes between the state, when generator is switched on and the state, when it is switched off can be analyzed.

Laser Doppler vibrometer measurements can be done after concentrating the laser beam on the mirror. After reflection, the beam goes on the tool's surface. Mirror lets measure vibrations in the tool axis direction, but some inaccuracy in LDV device location must be considered. The result may be analyzed in LDV software in "Fourier Transformation mode" (FFT), "Fast scan mode" or "Time mode". For purposes of this paper FFT mode has been chosen, because values of amplitude can be read directly in vibrometer's software. Depending on the area available on the tool's face, the specific number of points (grid) was located. It was mentioned that the values of amplitude for different points of the tool's surface may not be the same. Scanning of the whole tool's surface was performed and after this procedure the eddy current sensor may have been located for comparison with LDV measurements results. It must be stated that amplitude values of smaller area on tool can be analyzed with LDV device than with eddy current sensor system, because of sensor's diameter.

3 Measurements in Eddy Current Sensor Measuring Range

The experiment consisted of single measurements in the whole (0.4 mm) measuring range of the sensor. The distance of the tool to the sensor was changed with the step of 10 μm. Distance was changed from the end of measuring range (400 μm) to 0 and back to 400 μm for T8 and T30 tools. For T6 distance was changed from the end of measuring range (400 μm) to 0 value. The 0 value means "the start of measuring range", which is 0.04 mm distance between the tool and the sensor. EddyNCDT3300 calibration procedure in three points had also been carried out before measurements. The results showing the amplitude values for three tools are presented in Fig. 3 to 5.

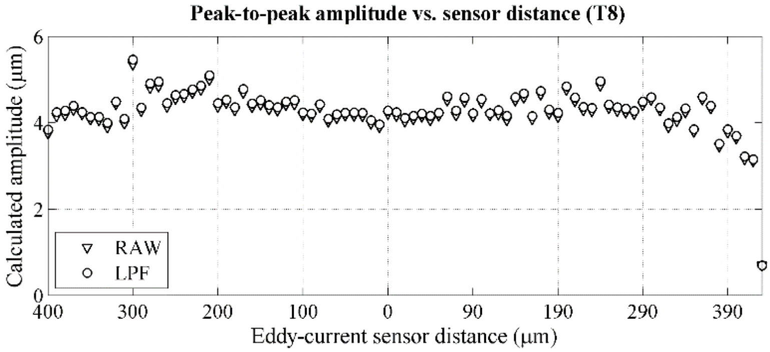

Fig. 3. Amplitude values for T8 for specific distance, frequency 23,400 Hz

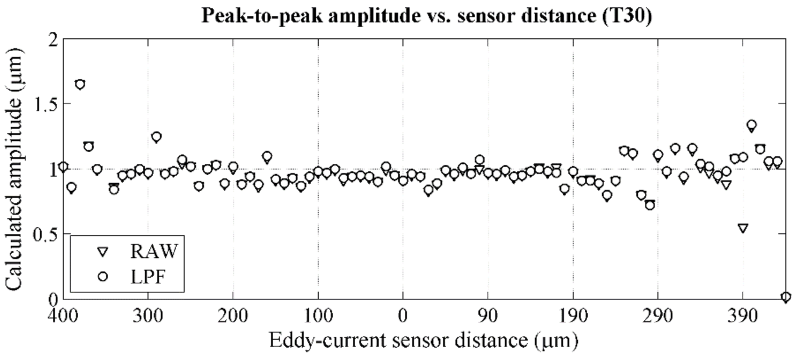

Fig. 4. Amplitude values for T30 tool for specific distance, frequency 28,100 Hz

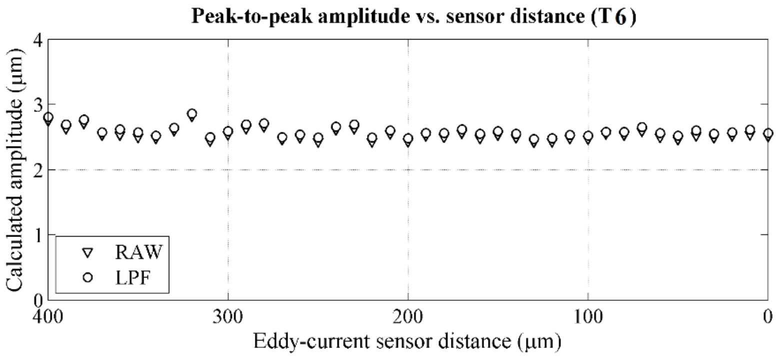

Fig. 5. Amplitude values for T6 tool for specific distance, frequency 25,800 Hz

The previous pictures present some amplitude values differences in measuring range of the sensor – mainly for T8 and T6 tool. Next tests were applied, mainly for better check of this results. For one tool T6, in one operational frequency 25,800 Hz, 100 measurements were carried out on digital oscilloscope. The results are presented in Fig. 6 and Fig. 7 after MATLAB analysis. Raw and filtered (LPF) signals are visible in these pictures and standard deviation value 0.04 μm is also computed for them.

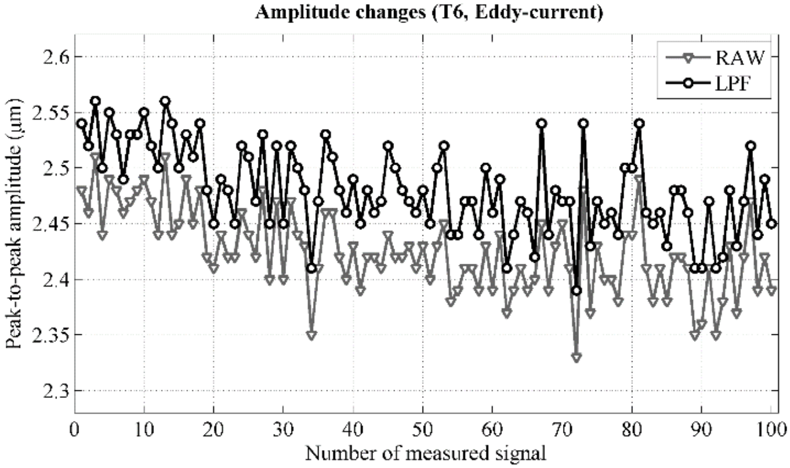

Fig. 6. Amplitude values for one selected distance after 100 subsequent measurements

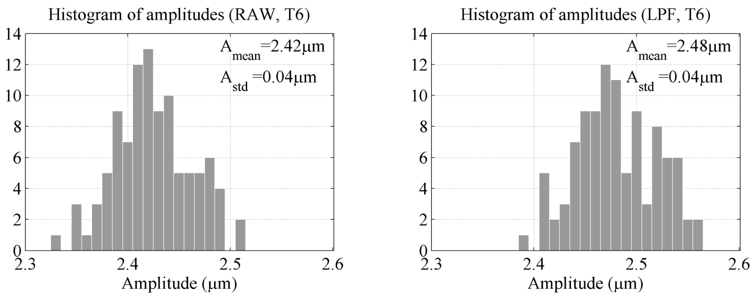

Fig. 7. Histograms of amplitudes for raw and filtered signals for T6 tool

4 Comparison of Eddy Current Sensor and LDV Device

Amplitude values (for eddy current sensor system) obtained from MATLAB was compared to the LDV measurements in FFT mode. The signal quality and magnitude depend on the scan point selection. This selection results also in a frequency spectrum form and amplitude values. On the basis of previously acquired knowledge and experience [6], vibrometer measurements were performed. This was to determine whether values after LDV measurements and eddy current sensor measurement are comparable. All the parameters were not changed for specific tool. Because of the influence of mounting torque of the tool to the holder, tools were not remounted. Fig. 8 presents the results. Three measurements for each tool were carried out with eddy current sensor. Data was acquired on digital oscilloscope and analyzed in MATLAB environment. Raw signal amplitude values and filtered values are presented for these measurements. The highest amplitude value is reported for T8 tool and the smallest for T30 tool. The same result was obtained during LDV measurements.

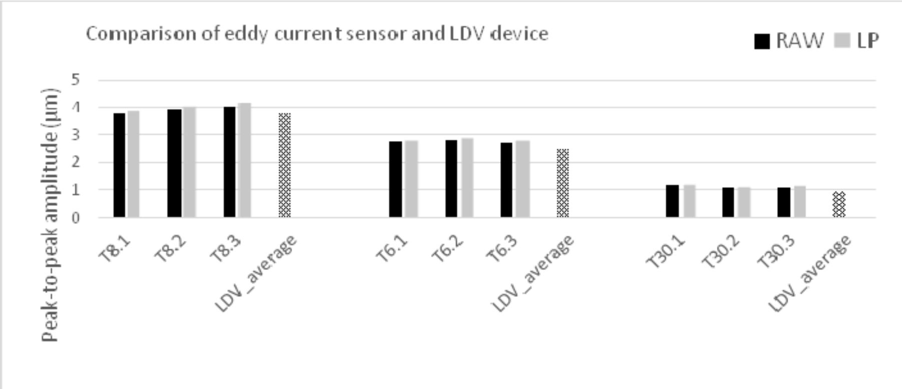

Fig. 8. Comparison of peak-to-peak amplitude values for T8, T6 and T30 tools

The results of LDV measurements mainly depend on laser beam direction, signal quality, software selections, possibilities in location of grid points. The parameters of excitation system on machine tool like temperature of tool holder also influence results of measurements. The average value for all LDV measurements for one tool is presented in Fig. 8 (48 amplitude values for T8, 20 values for T6 and 39 values for T30 were taken into account for averaging). The LDV measurements were carried out together with eddy current sensor measurements and were repeated in the next days in comparable conditions. It should be stated after all this test, that the highest amplitude values were observed for T8 tool and the smallest for T30. The same result was achieved for eddy current sensor measurements.

5 Summary

Experiments are the basis for conclusions, which indicates that many factors influence the results of measurements. Both, LDV device and eddyNCDT3300 let measure ultrasonic oscillations parameters. The analysis of the measuring gap (distance between the sensor and vibrating tool) influence on amplitude values showed that values which has been read are not the same in full measuring range of the sensor. Next tests were performed to define the reason for this fact. The most important results are presented in Figures 6 and 7 and show that even for the one distance between sensor and the tool values in subsequent 100 measurements are not the same. Analog voltage signal noise, temperature phenomena are pointed to explain this fact. The differences are comparable with those after measurements with the distance (gap) change. The bonding material of the tool may also be important for the results of eddy current measurements. The signal on oscilloscopes' screen changed visibly for one tool at the end of measuring range. The tool holder was cooled down with pressured air but thermal phenomena may have influenced these values. The analysis for one tool and constant distance between the tool and the sensor also showed differences, so it can be stated, after all these tests, that presentation of amplitude value as constant value for this hybrid process investigations is not the best solution, because of the measuring devices characteristics and physical phenomena influencing the vibrations in resonance frequency. The values of amplitude can be defined (e.g. as average values) if dispersion of values is strongly considered. The change of the tool results in the change of measured amplitude values – the calibration was mentioned for new tool. It means that the average values for each tool are different. Comparison with LDV amplitude measurements shows that average amplitude values measured with these two apparatus are similar, but this similarity must now be defined only as clear – the biggest value for 8 mm tool and clear – the smallest value for 30 mm tool. Therefore, industrial application of eddy current sensor for ultrasonic vibrations measurements must be taken into account but thermal phenomena, measuring gap, noise in the voltage output signal, filtering method, area of the sensor to area of measuring object ratio must be strongly taken into consideration during data analysis. Beyond any doubt is the good usability of eddy current sensor for resonance frequency detection, frequency of oscillations control and amplitude level defining. For Ultrasonic 20 linear machine tool eddy current sensor ES04 may be used for resonance frequency detection and analysis of amplitude level for operational frequencies where vibrations are detected on oscilloscope.

Acknowledgments. The investigations were funded by The National Centre for Research and Development within the Applied Research Programme and the project "Technology of high performance machining of geometrically complex ceramic parts with ultrasonic assistance" (PBS2/B6/17/2013).

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