429. Research of ultrasonic assisted turning tool

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Abstract. In turning process surface quality can be improved by using an ultrasonic assisted tool. Therewith surface roughness of work piece is better in comparison to traditional turning. Moreover, application of ultrasonic turning results in lower rate of wear of cutting tool insert. In the present study custom-made cutting tool was used, while the vibrations were generated by piezoelectric transducer. A numerical model was developed for thorough analysis of ultrasonically assisted turning tool. Performed simulations revealed the type of vibrations that are the most influential for improvement of the turning process. This information is valuable for selection of optimal parameters for achieving the best effect.

Keywords: turning process, surface quality, ultrasonic

Introduction

Ultrasonic cutting (cutting by using ultrasonic vibrations) is obtained when applying ultrasonic frequency vibrations to the cutting tool edge [1]. The absolute value of cutting forces during turning process with ultrasonic vibrations is decreasing, which also reduce an average cutting temperature generated in a contact zone (it becomes equal to room temperature). Metal chips after turning process with ultrasonic vibrations are without white spots, which appear during traditional cutting as a result of high temperature. The temperature does not influence significantly the accuracy of manufactured surface during ultrasonic cutting but is crucial for the wear of cutting tool [2].

Turning process was subjected to extensive research. To this end a special tool with piezoelectric actuator was designed and fabricated for the excitation of vibrations. Earlier experiments demonstrated that ultrasonic vibration in turning process results in better surface quality of work piece (Fig. 1) [2]. In this paper the research is focused on the determination of type of vibrations, which allow achieving the best surface roughness.

Experimental study

The influence of ultrasonic frequency vibrations was studied during turning process. Experiments were carried out by using CNC turning machine and work pieces made from aluminium. A special turning tool was developed that incorporates piezoceramic elements for generating ultrasonic vibrations on cutting edge of insert [3]. The tool form is designed in such a way that it can act as a horn. Ultrasonic vibrations are generated through piezoceramic rings connected to high voltage generator through power amplifier (Fig. 1) [3].

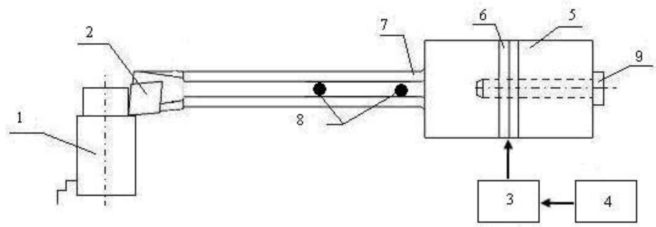


Fig. 1. Experimental setup for the turning process with ultrasonic vibrations: 1 – work piece, 2 – insert, 3 – high-voltage power amplifier, 4 – signal generator, 5 – backing, 6 – piezoceramic rings, 7 – cutting tool – horn, 8 – fixing areas of tool, 9 – connecting bolt

The Langevin type transducer [5] consists of piezoelectric ceramic elements, the backing (metal cylinder) and the front matching metal horn - cutting tool. The tool is fixed in two places. The backing 5, piezoceramic rings 6 and cutting tool (horn) 7 are connected with bolt 9. Standard insert 2 is fixed in cutting tool.

Cutting tool and backing were made from steel C45 (Young's modulus - 210 GPa, density - 7850 kg/m^3, Poisson's ratio - 0,33). Piezoelectric elements consist of two piezoceramic PZT5 rings (Young's modulus - 66 GPa, density - 7,5 kg/m^3, Poisson's ratio - 0,371) [6]. Standard insert CCGT09T304-AlKS05F (Tungaloy) was used (Young's modulus - 360 GPa, density - 3900 kg/m^3, Poisson's ratio - 0,22).

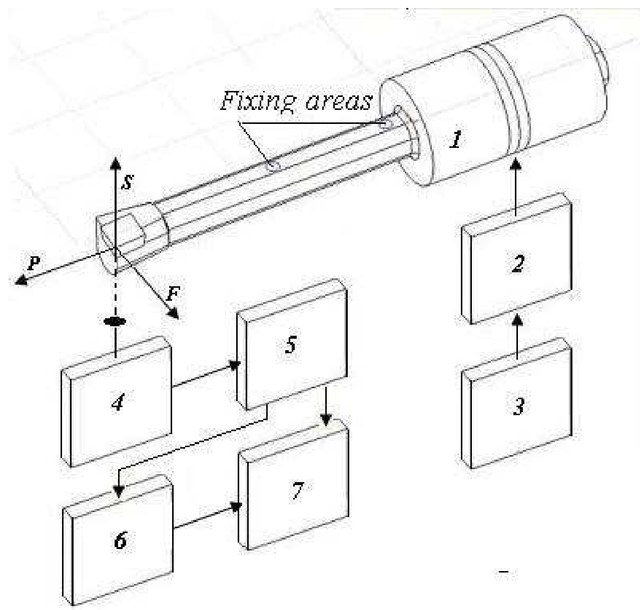


Fig. 2. Experimental setup for measurement of frequency response characteristics: 1 – vibrator - cutting tool; 2 – power amplifier EPA-104; 3 – signal generator ESCORT EGC-3235A; 4 – laser vibrometer Polytec OFV-512; 5 - vibrometer controller Polytec OFV–5000, 6 – analog-to-digital converter PicoScope-3424, 7 – computer

The first step in our experimental work was measurement of resonant frequencies (Fig. 3). Experimental setup for measurement of amplitude - frequency characteristics is illustrated in Fig. 2. The tool is fixed in two points and the vibrations are generated with signal generator 3 trough power amplifier 2. With laser vibrometer 4 amplitudes on edge of insert were measured in three directions: x – cutting direction, y – radial direction to work piece surface and z – vibrations in feed direction. In the vibrometer controller 5 trough analog-to- digital converter 6 the measurement signals were converted and transmitted to the computer 7. PicoScope software was used for visualization of the measured signal.

The EPA-104 is a high voltage (±200 Vp), high current (±200 mA) and high frequency (DC to 250 KHz) amplifier designed to drive higher capacitive (low impedance) loads, such as low-voltage stacks at moderate frequencies or lower capacitive loads, such as ultrasonic devices, at high frequencies.

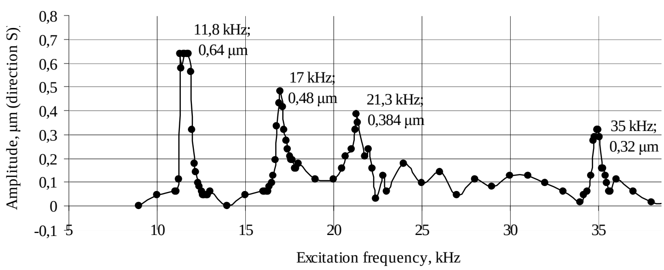
Output frequency of the signal generator ESCORT EGC-3235A is from 0.01 Hz to 5 MHz, in 8 ranges. Amplitude offset is +/- 10V.

Polytec OFV-5000 controller is designed to accept a choice of signal processing modules, each optimized for different frequency acceleration, velocity or displacement performance.

Vibrations were measured with a laser vibrometer - Polytec fiber interferometer OFV 512.

The analog-to-digital converter provides a solution for measuring and recording voltage signals onto PC.

PicoScope is a program, which enables us to use the Pico Technology range of analog-to-digital converters to provide the function of a storage oscilloscope, a spectrum analyzer and a digital meter. In combination with the PicoScope software, the PicoScope-3424 as PC ascilloscope constitutes a fast, 4-channel memory oscilloscope, a multimeter and a FFT spectrum analyzer.



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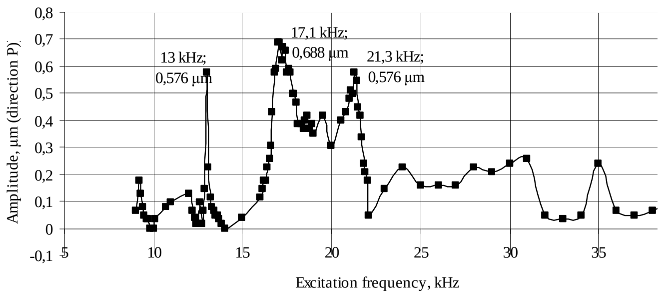

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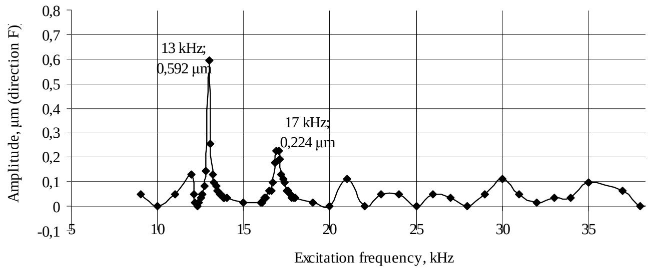

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Fig. 3. Experimentally estimated frequency response characteristics of cutting edge of tool in three directions: a – vibrations in cutting direction; b – vibrations in radial direction to work piece surface; c – vibrations in feed direction

The resonant frequencies were determined from measurement results of frequency response. From frequency response results we can observe resonant frequencies of cutting tool. Also measurement results contain information about frequency direction.

During turning experiments excitation amplitude was maintained constant by means of constant voltage from high-voltage power amplifier. The following excitation frequencies were used in the course of experimental testing: 11.8, 17, 21.3 and 35 kHz (Fig. 1). At these excitation frequencies the following values of surface roughness (Ra) of work pieces were obtained: 1.44, 1.32, 1.26 and 1.48 µm respectively. Thus we can conclude that at excitation frequency of 21.3 kHz the roughness of work piece is better in comparison to results obtained at other frequencies.

Theoretical investigation of ultrasonic assisted turning tool

Numerical model of experimental cutting tool was developed by means of finite element software ANSYS (Fig. 4). Material properties were taken for steel C45 (horn, connecting bolt and backing), piezoceramic PZT5 (piezoceramic rings) and hard steel C85W1 (insert).

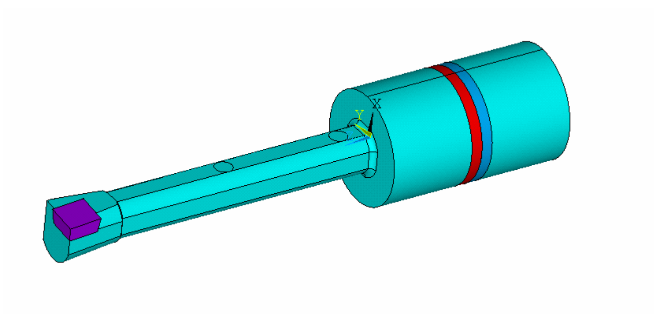


Fig. 4. Numerical model of experimental turning tool

Equation of motion in matrix form:

$$\begin{bmatrix} M_{uu} & 0 \\ 0 & 0 \end{bmatrix} \begin{Bmatrix} \ddot{u} \\ \ddot{\varphi} \end{Bmatrix} + \begin{bmatrix} K_{uu} & K_{u\varphi} \\ K^T & K_{\varphi\varphi} \end{bmatrix} \begin{Bmatrix} u \\ \varphi \end{Bmatrix} = \begin{Bmatrix} 0 \\ A\sin wt \end{Bmatrix} \quad (1)$$

where $\left[M_{uu}\right]$ – Mass matrix;

$\left[K_{uu}\right]$ – Mechanical stiffness matrix;

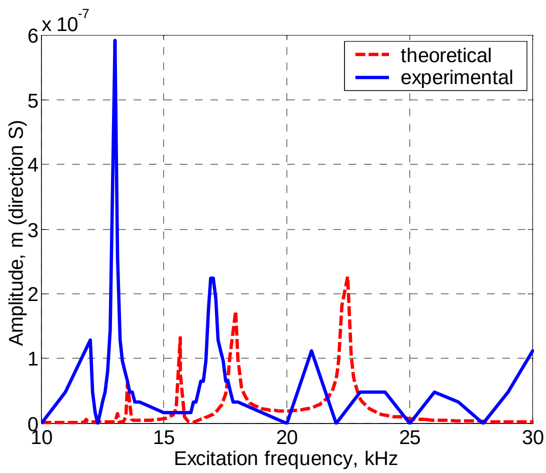
$\left[K_{u\varphi}\right]$ – Piezoelectric coupling matrix;

$\left[K_{\varphi\varphi}\right]$ – Dielectric stiffness matrix;

$\left[F_S\right]$ – Mechanical surface forces;

$\left[Q_S\right]$ – Electrical surface forces.

Experimental and numerical frequency response characteristics are presented in Fig. 5.



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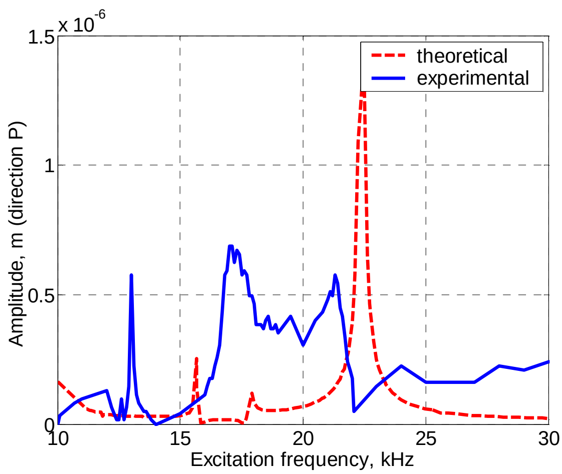

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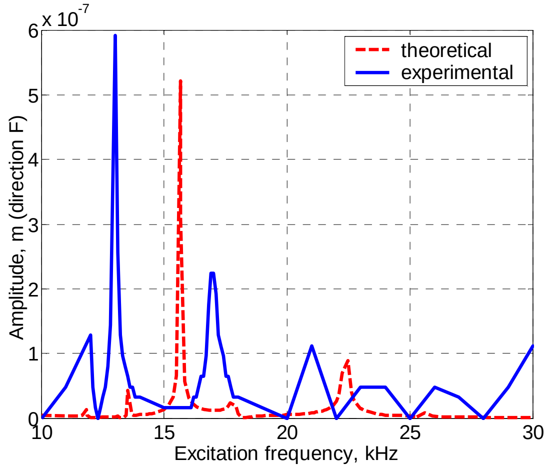

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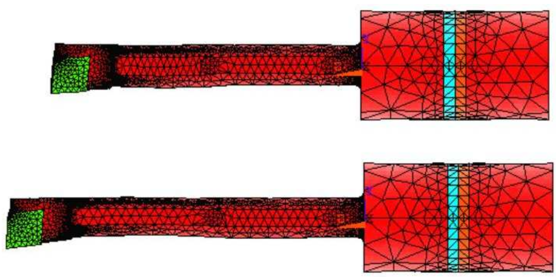
Fig. 5. Comparison of measured and simulated frequency response characteristics of cutting edge of tool in three directions: a – vibrations in cutting direction; b – vibrations in radial direction to work piece surface; c – vibrations in feed direction

Results

During modal analysis tool vibrations were studied at excitation frequency of ≅ 22 kHz. It was estimated that at frequency of 22,383 kHz dominant vibrations were excited in two directions: cutting (S) and passive force (P) direction (see Fig. 6).



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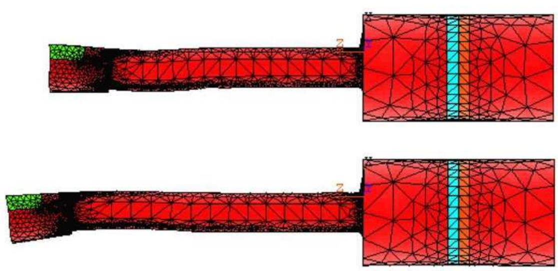

b)

Fig. 6. displacement at 22,3 kHz excitation frequency: a – view from top side, b – view from front side

Conclusions

The investigation of the ultrasonically assisted experimental turning tool has led to the conclusions that:

1. The best surface roughness – 1.26 μm – is achieved by using ≅ 22 kHz excitation frequency.

2. Numerical simulation with the developed finite element model revealed that at excitation frequency of ≅ 22 kHz dominant vibrations are generated in cutting direction S and radial direction to work piece (passive force direction) P. Obtained experimental results confirm that at this excitation frequency vibrations are dominant in directions S and P.

3. Obtained research results are very valuable for the future studies of cutting tool. For optimization task the aim would be to excite the vibrations in two directions simultaneously: in cutting and passive force directions.

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