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75TH ANNIVERSARY OF MGTU STANKIN

The Moscow State Technological University Stankin, one of the leading higher institutes of learning, recently recorded its 75th anniversary. At the faculties of MGTU Stankin for many years there has been considerable research work in metrological provisions for machine building and the preparation of highly qualified personnel for branches of metrology.

In this issue of the journal, the editors continue to publish an anniversary selection of articles by workers at the university.

We draw your attention to articles devoted to various questions of metrology and measurement techniques: measurement of tool vibrations during turning, a study of coherence using digital speckle-interferometry, diagnostics and monitoring of production processes by means of measuring vibration-acoustic signals, computerized contact interferometers in white light based on optical processing of images, etc.

For the start of the selection see Izmeritel'naya Tekhnika, No. 6, 2006.

MEASUREMENT OF CUTTING TOOL VIBRATIONS DURING TURNING

V. V. Yurkevich

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Results are provided for an experimental study of cutting tool vibrations during turning and their effect on the surface roughness of an article being machined.

Key words: *cutting tool vibrations, surface roughness.*

The height of unevenness for the surface roughness profile during cutting generally depends on the following actors:

$$R_z = h_1 + h_2 + h_3 + h_4,$$

where h_1–h_4 are components caused by the geometry of the operating part of the tool and the kinematics of its operating movement, tool vibrations with respect to the surface being machined, elastic and plastic strains for the material of the article being machined in the contact zone with the tool, and the roughness of the tool surface, respectively, [1–3].

Component h_1 depends on cutter angles in plan φ and φ_1, radius r at the tool tip, and feed S; h_3 depends on the same parameters and on the material of the article being machined. As a rule parameters φ, φ_1, and S remain constant during machining. Radius r at the tool tip during machining undergoes a change in the direction of an increase, although its effect on roughness is insignificant. Thus it is possible to state that according to [1–3] components h_1 and h_3 change within small limits during machining operation.

Component h_4 only depends on tool preparation technology and consequently it will also change within small limits.

In contrast to h_1, h_3, and h_4, component h_2, caused by tool vibrations during machining, may change within quite broad limits, and therefore more attention should be devoted to it. Results are provided in [4] for a study of vibrations under high-speed cutting conditions in lathes carried out by Sokolovskii.

Moscow State Technological University Stankin; e-mail: vitel@stankin.ru. Translated from Izmeritel'naya Tekhnika, No. 7, pp. 22–24, July, 2006. Original article submitted March 22, 2006.

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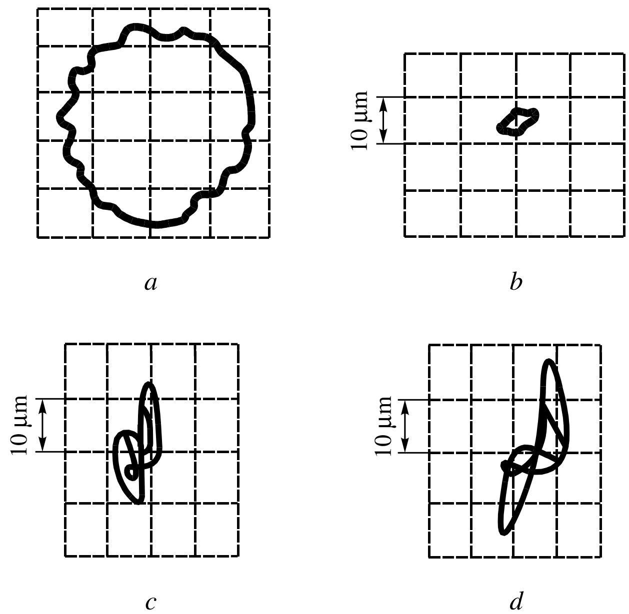

Fig. 1. Examples of a record of the trajectory for the axis of the article being machined and the tip of the tool.

Experimental studies are described below for determining tool vibrations using modern equipment.

Studies were performed in a lathe. A precise rule was fastened to the frame of a machine model MK-3002 made by the Krasnyi Proletarii machine tool plant so that deviations from parallelism of its horizontal and vertical working surfaces with respect to the direction of machine support displacement did not exceed 50 μm for a length of 200 mm (deviation from rectilinearity of the working surfaces of the rule did not exceed 5 μm for a length of 200 mm). Apart from the tool, attached to the tool holder there was a bracket with two contactless displacement transducers installed so that one transducer measured displacement of the tool holder in the vertical plane with respect to the working surface of the precision rule, and the second transducer measured in the horizontal plane; the measurement surface of each transducer was at a distance of 0.3 mm from the corresponding working surface of the rule.

Eddy current transducers were used as the displacement transducers that consisted of an eddy current probe, a driver and a supply unit. The probe was connected to the driver by means of a extension cable. The driver was an electronic unit that processed the probe excitation signal and separated the information parameter. The output signal of the driver is an electronic signal proportional to the distance from the end of the eddy current probe to the surface being measured.

The signal from the driver is fed to the board of the input, the output and processing of analog and digital information that is installed in an IBM personal computer. Software made it possible to process signals and to construct their curves on a monitor screen. In addition, there was the possibility of observing these signals on the screen of a digital electronic oscillograph.

Tests were carried out in a real cutting regime for blanks of steel 35. Tools were used with a plate made from hard alloy T15K6 with tool angles $\varphi = \varphi_1 = 45°$; $\alpha = 8°$; $\gamma = 0°$. The spindle rotation frequency was $n = 800$ min^{-1}, the feed was $S = 0.05$ mm/rev, and the cutting depth during tests was prescribed differently. During tests, a record was also made of the trajectory of the axis of the article being machined in one of its cross sections [5].

Given in Fig. 1 are examples of the record of the trajectory for the axis of the article being machined (Fig. 1*a*), and also the trajectory of the tip of the tool running free (Fig. 1*b*) with a cutting depth $t = 0.03$ mm (Fig. 1*c*) and $t = 0.20$ mm (Fig. 1*d*).

The trajectory of the axis of the article being machined has a shape close to a circle, distorted by vibrations, having a stochastic nature. This trajectory is the result of the kinematic interaction of the balls and races of the inner and outer rings

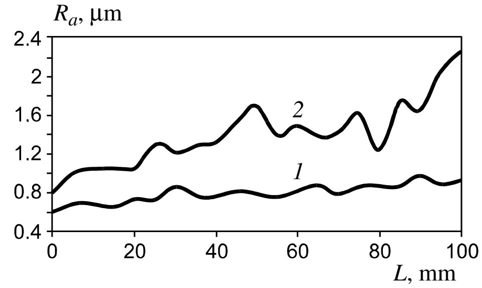

Fig. 2. Change in surface roughness over the length of an article surface: *1*) with machining in a 16K20 lathe; *2*) with machining in a MK-3002 lathe.

of the leading support of the spindle. In machining articles, if no significant vibrations are observed for the lathe–attachment–tool–article system the shape and maximum deviation of the trajectory are changed, but not to a considerable extent. In the case when article machining proceeded with clearly defined vibrations, then the shape of the trajectory changed markedly.

The trajectory of the tool tip in free running (see Fig. 1*b*) had small maximum deviation and it is a consequence of the fact that with spindle rotation the whole lathe vibrates, including the support and the tool holder with the tool.

From comparison of tool tip trajectories obtained for the same production regimes, it can be seen that the shape of the trajectory is not constant. In some cases, there is close similarity of vibrations, although this is more often an exception. It should be noted that the duration of trajectory recording is about one eleventh of the period of spindle rotation. If recording is continued for the whole period of spindle rotation, then a white spot is observed on the screen due to superimposition of many trajectories upon each other. The variability of tool tip trajectories is explained by many reasons. Primarily, it is nonuniformity of billet material, formation and breaking of build-up at the cutting edge, tool wear and a change in temperature in the cutting region.

Tool vibration frequency during billet machining with a cutting depth $t = 0.20$ mm was 288–295 Hz. With a reduction in cutting depth to $t = 0.03$ mm, it decreased to 245–253 Hz. A change in tool vibration frequency and amplitude led to a change in the waviness of the surface being machined. Calculations made it possible to determine that for a cutting depth $t = 0.20$ mm the article surface waviness parameters are: average waviness pitch $S_W = 7.09–7.19$ mm; average waviness height $W_z = 0.0139–0.0147$ mm.

In order to study the effect of vibrations during machining on machined surface roughness, articles were machined with a diameter of 50 mm and length of 100 mm in lathes 16K20 and MK-3002.

Machining was carried out with cantilever fastening of the article in a chuck with a spindle rotation frequency $n = 800$ min^{-1}; cutting depth $t = 0.4$ mm and feed $S = 0.05$ mm/rev. In order to measure machined surface roughness, a polygraph-profilometer model 252 from the Kalibr factory was used. The change in surface roughness is shown in Fig. 2. (The distance in millimeters from the end of the article, fastened in the chuck during turning, is shown on the ordinate axis).

It can be seen from Fig. 2 that roughness changes over article length L and increases as the fastened end is approached. For articles machined in a 16K20 lathe, this increase in roughness is small (curve *1*) since the 16K20 lathe exhibits significantly greater stiffness the MK-3002 lathe. For the latter, machined surface roughness around its unfastened end is almost three times greater than around the end fastened in the chuck. This is explained by the fact that with cantilever fastening of an article due to the low stiffness of the MK-3002 assemblies considerable vibrations arise that lead to the occurrence of increased roughness.

Experimental studies of the dependence of roughness on machining regimes were carried out in a 16K20 lathe. A billet of steel 12Kh18N10T was machined with a cutter made from hard alloy T15K6 with tool angles $\varphi = 45°$, $\alpha = 8°$, $\gamma = 12°$ and radius at the tip $r = 0.5$ mm. The cutting depth was kept constant and it was 0.4 mm. The cutting rates were 15, 36, and 56 m/min, and the feed was varied from 0.05 to 0.4 mm/rev. Experimental dependences are presented in Fig. 3. It can be seen

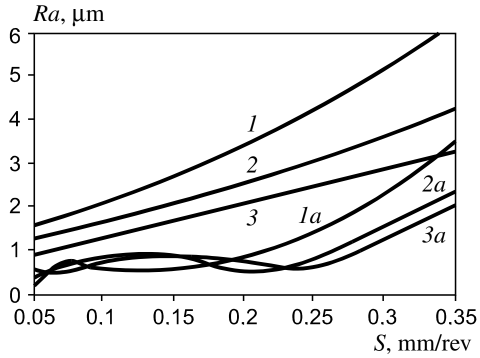

Fig. 3. Dependence of roughness parameter R_a on feed S and cutting rate V: *1–3*) theoretical curves; *1a–3a*) experimental curves; *1*, *1a*) with $V = 15$ m/min; *2*, *2a*) with $V = 36$ m/min; *3*, *3a*) with $V = 56$ m/min.

from the curves that a reduction in feed to less than 0.2 mm/rev has almost no effect on the change in roughness parameter R_a. The effect of cutting rate on roughness appears to a greater extent with high feed rates.

An empirical equation is given in [1] for determining the roughness parameter R_a in micrometers for finishing conditions:

$$R_a = k_0 \frac{s^{k_1}(90+\gamma)^{k_4}}{r^{k_2} V^{k_3}},$$

where S is feed (0.05–0.43 mm/rev); r is tool tip radius (0.5–2 mm); V is cutting rate (0.47–1.2 m/sec); and γ is tool leading angle (4–40°).

Values of coefficients $k_0 - k_4$ for different grades of machined material are taken from reference tables.

Theoretical dependences calculated by this procedure are also presented in Fig. 3. Comparison of them with experimental dependences makes it possible to conclude that there is sufficient similarity both in the nature of the curves and also in the values of the parameters in question. The main difference is the fact that theoretical curves with feeds less than 0.2 mm/rev continue to decrease uniformly, whereas experimental curves indicate that parameter R_a with these feeds remains almost constant.

Thus in order to reduce roughness parameter R_a turning should be carried out with higher cutting rates.

Vibration during turning of articles may cause scatter in machined surface roughness parameters over the length of an article by more than a factor of two.

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