УДК 621.9.015

P.P. Melnichuk, D.Sc. in Engineering, professor
O.O. Vynohradov, D.Sc. in Engineering, professor
V.E. Loiev, PhD in Engineering, professor
V.V. Otamanskyi, PhD student
Zhytomyr State Technological University

RESEARCH WAS UNDERTAKEN TO STUDY THE INFLUENCE OF NONUNIFORMITY MOTION DURING SUPPLY TO THE SURFACE ROUGHNESS ON DETAILS, PROCESSED WITH AN EDGE TOOL

The article provides a deep analysis concerning the formation of surface roughness on details, processed with an edge tool, the existing customaries about determined and probabilistic component in the calculations of its height. While final polishing with supply not more than 0,05 mm of the roughness value does not coincide with the calculation by more than 30...50 % upwards. Analyzing the reason for such an unconformity, the attention was drawn to the operative parts nonuniformity motion, especially finishing processing regimens. The «stick-slip» phenomenon, known as the slip-stick phenomenon or simply stick-slip, is the spontaneous jerking motion that can occur while two objects are sliding over each other. Assessment methods for motion smoothness in operative machine parts were considered. The results of preliminary studies related to the influence of saddle (toolhead) feed nonuniformity to the surface roughness. It was found that jerking motion with light (fine) feed of the operative parts in cutting machines provides a significant influence on the formation of roughness on the processed surface, increasing it by more than 50 percent.

Key words: *nonuniformity supply motion; surface roughness; processing with an edge tool; turning machine; milling machine.*

Challenge problem. Surface engineering in processing involves giving it some certain properties, connected with operation performance of products, in which the processed detail will be installed. Meanwhile the process of its engineering can be analyzed and above all corrected (improved) in accordance with its processed surface.

Ensuring the accuracy of the details surface relative positions, the parameters of their condition cannot be ignored, namely: waviness, roughness, hardness, residual strain and surface layer structure, exerting a significant impact on operating performance of products.

First of all it concerns the roughness. The standards DSTU 2413-94 and GOST 2789-73, existing in Ukraine, include the following parameters:

- arithmetic average roughness height R_a;
- peak-to-valley value in 10 points R_Z;
- maximum peak height of the profile $R_{\max}$;
- average peach of roughness S_m;
- mean spacing of local peaks of the profile S;
- profile bearing length ratio t_p.

Problems occurrence roughness of the treated surfaces of edge tool first concern when it comes to finishing. Presence in the process these transactions or conversions (grinding, surface plastic deformation, etc.) able to significantly reduce roughness, although in such cases, the performance and quality of the final surface finish greatly depends on the state of the previous edge cutting processing, as evidenced in studies of heredity P.I. Yashcheritsyn and other scientists.

That is, edge cutting processing a prerequisite of effective work of products.

The analysis of the literature. The vast majority of research regarding to the parts wearing process in friction pairs [1–4] clearly confirm the applicability of both values R_a and S, t_p, as well as type of micro roughness directions for specific conjugation and operation conditions.

Taking into consideration the fact that the roughness is measured only in several basic length (a limited area), the necessary condition to provide the required connection operative properties, except geometrical deviations (required dimensions, surface form deviation: for cylindrical – taper, barrel-shaped, saddle-shaped, axis bent, roundness, cut; for flat surfaces – concave, convex) is the measurement of a wavy surface.

Conventional division of errors on the surface roughness, waviness and macro geometric is obvious. The ratio between roughness width and their height within specified limits (roughness <40, waviness >40 up to 1000, macro geometric error >1000) prove this convention.

Even more conventional is the existing provision concerning designation of waviness parameters, using the similar roughness parameters: $W_{\max}$; W_a; W_Z; W_p; S_w (PC3951-73).

A certain convention exists in theoretical micro roughness height calculations, determinig R_Z .

The following papers [2, 5] present the following formula to calculate the height roughness:

$$R_Z = R_{Zp} = \Delta H, \quad (1)$$

where R_{Zp} – is a calculating height roughness; ΔH – is a deviation of the actual height roughness against the calculated one (a random component).

$$\Delta H = \Delta H_{elastic} + \Delta H_{plastic} + \Delta H_{rubbing} \, . \quad (2)$$

In the paper [5] S.A. Klimenko offers to take into consideration even three more components:

$$\Delta H = \Delta H_{elastic} + \Delta H_{plastic} + \Delta H_c + \Delta H_{rubbing} + \Delta H_{blade\ wear} + \Delta H_{vibra} \, , \quad (3)$$

where $\Delta H_{elastic}$ – is an elastic recovery of the material after cutting a metal layer or its deformation; $\Delta H_{plastic}$ – is a component, which shows changes in height roughness as a result of the plastic deformation in chip formation area; ΔH_c – is a micro roughness formation by chip convergence; $\Delta H_{rubbing}$ – is a deviation of the roughness, connected with rubbing the rear surface of the blade with the processed surface; $\Delta H_{blade\ wear}$ – is deviations from the change in the primary circuit in the edge of the blade as a result of its wear; ΔH_{vibra} – is deviations, connected with blade vibrations and processed work material.

Each of the components of the actual height roughness deviations, given above, has a probabilistic nature and is able both to worsen the surface roughness and improve it. In the papers [5, 6] attempts to define some certain components by calculating under milling were made:

$$\Delta H_{plastic} = 2,8 \cdot \left(F_p + S \cdot \xi \cdot \frac{\cos(\varphi + \varphi_1 + v)}{2 \cdot \sin\varphi} \right) \cdot \frac{e^{0,003\frac{\sigma_в}{\delta}}}{\left(0,1 - \frac{\sigma_в}{\delta}\right)^0} {,}45 \, , \quad (4)$$

where F_p – is a cross-section area of the calculated roughness; S – is a feed per tooth; ξ – is a chip shrinking; φ, φ_1 – is a lead and minor cutting edge angles in the instrument at the point, relevant to the peak of the calculated roughness; σ_B, δ – is a rupture strength and percent elongation of the work material.

$$\Delta H_{vibra} = \frac{\Delta P_y \cdot \omega}{\sqrt{\left(1 - \frac{\lambda^2}{f_p^2}\right)^2 + T_n^2 \cdot \lambda^2}} \, , \quad (5)$$

where ω – is a system suppleness; ΔP_y – is a relative difference between the maximum and minimal thrust force (classified as a force, that is corresponding the average processing conditions); λ – is an applied excitation force frequency; T_n – is a decrement response time; f_p – is a natural oscillation frequency of the instrument.

In the paper [2] I.A. Isaiev represents the formula to calculate the component by means of the material elastic recovery:

$$\Delta H_{elastic} = \frac{\sqrt{4 \cdot R^2 - S^2} - \sqrt{4 \cdot R \cdot (R - 2 \cdot \Delta H_e) - S^2}}{2} \, , \quad (6)$$

where ΔH_e – is a cavity elastic recovery; R – is a cutter corner radius; S – is a supply.

By calculating and the actual measurements it was found that [2], the value $\Delta H_{elastic}$ is equal to 1–8 % out of the value $\Delta H_{plastic} + \Delta H_{rubbing}$. As it is obvious, the pert of the elastic strain is very small comparing to other two components and does not matter practically.

The component $\Delta H_{rubbing}$, connected with the rear surface friction of the blade with the processed surface, with the rear turning angle cutter >5°, as well as with the work out of the build-up area, does not influence practically the roughness value [2]. It should be noted that in some cases the rear surface friction can produce positive influence on surface roughness reduction.

The value ΔH_c is also conditional. In most cases the chips come on the front face of the blade and have a high temperature, that reduces their hardness, comparing to the hardness of the processed surface.

Research, conducted by I.A. Isaiev [2], showed, when being worn on the back side up to 1 mm, ΔH_c increases by 20–30 %. It can be explained with the deterioration of the front face its geometrical form and its own micro geometry on the contact surface with a deformable material change.

To represent fully how the roughness is being formed, we think, it would be reasonable to add two more components: $\Delta H_{cutouts}$ – is a deviation, connected with cutouts of the material, removed from the processed surface; ΔH_S – is a deviation, connected with saddle (toolhead) feed nonuniformity supply and spindle speed.

The paper is dedicated exactly to the last component.

Statement of the basic material. Obtaining the necessary surface roughness on the details, processed with turning and milling machines, is possible only while maintaining the stability for the technological processes of their processing under conditions, maximum similar to calculations.

The cutting and supply speeds, set within the technological process, or automatically selected ones from the database of the TNC, are calculated and dependent from the processed work material, material and instrument geometry as well as from equipment technological and hardness characteristics.

If the operation if finishing, then the speed and supply are obviously connected with the requirements, submitted towards the processed surfaces in operative drawings of a detail.

It is considered that the designed component is a decisive one in the calculation of the roughness for all types of processing by a blade tool. Indeed, when applying for a turnover in the case of turning processing and when feed per tooth while milling processing is more than 0,2...0,3 mm and minor radius with instrument peak of (0,1...0,15 mm), as well as angles $\varphi > 15^{\circ}$ and $\varphi_1 > 10^{\circ}$ and cutting depth >0,5 mm this statement is justified.

While final polishing with supply not more than 0.05 mm under the same conditions of the roughness value does not coincide with the calculation by more than 30...50 % upwards.

Analyzing the reason for such an unconformity, the attention was drawn to the operative parts nonuniformity motion, especially finishing processing regimens.

There are not many papers, dedicated to the smooth motion of machinery operative parts, especially those ones, connected its influence on the blade-processing [7, 8, 9].

Machine operative parts nonuniformity motion distorts the concept of feed per spindle turnover, and even more while feed per tooth during milling. To a far lesser degree the spindle irregularity in speed rotation, which destabilizes the discharge rate, influences the processing.

Subject to the paper [10] the assessment of smoothness is produced by comparing the calculated value F/C for the construction with a marginal one for these conditions of friction.

To ensure the uniform motion it is essential that [10]:

$$\frac{F}{C} \le \frac{1}{n_s} \cdot \left[\frac{F}{C}\right], \tag{7}$$

where *F* – is a joint friction force; *C* – is a feed actuator stiffness; $n_s \approx 1{,}5$ – is an assurance coefficient; [*F*/C] – is a marginal ration for particular machine components.

For friction pair “cast iron-cast iron” in the paper [10] the analytical expression of the marginal ration, depending on the speed of motion:

$$\left[\frac{F}{C}\right] = 25 + 7.5 \cdot \ln(1 + 2 \cdot v). \tag{8}$$

With regard to the different layout design for friction joints, for the three fundamentally different [*F*/C] was less different than by ±30 %.

M.L. Orlikov, considering the movement of a slide (support, toolhead), connected with a spring with a leading unit, having a constant speed (drive), in the paper [11], identified the slide jump magnitude at low speeds of the master unit:

$$\xi = 2 \cdot \frac{\Delta F}{C}, \tag{9}$$

where *C* – is a spring rate.

$\Delta F = F_n - F_d$ – is a difference between force of static friction and friction force of motion. Also the laws of the slide movement were introduced:

$$x = \vartheta t - \frac{\vartheta}{\omega_{н}} \sin \omega_{н} t + \frac{\Delta F}{C}(1 - \cos \omega_{н} t). \tag{10}$$

Ones concerning changes in its speed:

$$\dot{x} = \vartheta - \vartheta \cos \omega_{н} t + \frac{\Delta F}{C} \omega_{н} \sin \omega_{н} t, \tag{11}$$

where ϑ – is a speed of the drive mechanism;

$$\omega_{н} = \sqrt{\frac{C}{m}},$$

m – is the mass of the slide; *t* – is the duration of the jump.

Also the dependence, with which one can roughly calculate the critical speed, below which slide jumps will always happen, was provided:

$$\vartheta_{К} = \frac{\Delta F}{\sqrt{\psi c m}}, \tag{12}$$

where $\psi = 4\pi\xi$ – is a relative energy dissipation during oscillations (quasi-harmonic and relaxation).

In the paper [12] approximate values ψ in guiding ones: sliding – $\psi = 0.8 - 1.0$; rolling – $\psi = 0.4 - 0.6$; hydrostatic – $\psi = 1.5 - 2.0$.

In the laboratories of Zhytomyr State Technological Universities and Technological College the investigations were undertaken concerning operative parts nonuniformity motion of the machines with models: 16К20, 6Р12 and 6Р81Г idling, using piezoelectric vibration detector ДН-3, which is designed to convert mechanical vibrations into electrical signals proportional to the vibrational acceleration of the vibrating objects, which can be converted into signals, proportional to the vibration velocity and displacement. To read and process the data, the analog and digital converter was used (ADC) E20-10 by the company L-CARD. The photo booth for the experiments is provided in the Figure 1 as an example with a turning machine.

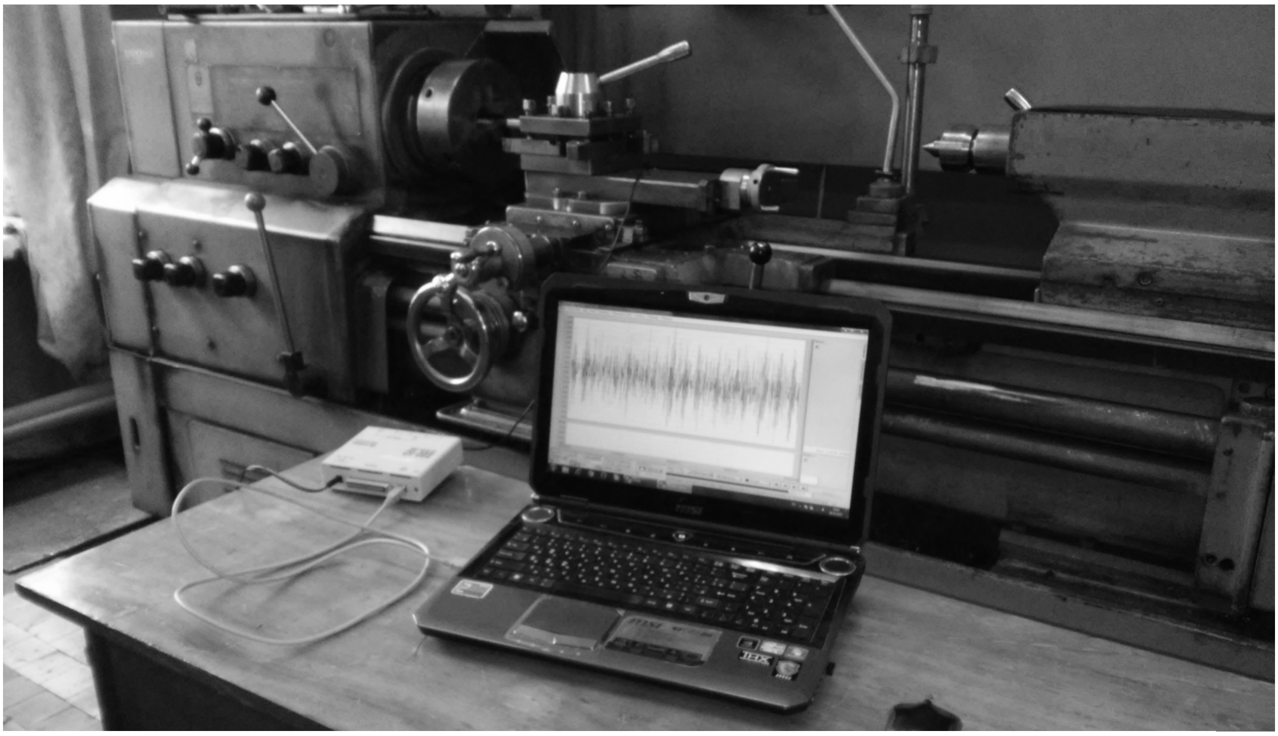


Fig. 1. Booth to implement research

During the research, using the programme LGraph2, the vibration acceleration oscillograph for the support (toolhead) of machine tools were obtained and recorded into a file. An example is the oscillograph at the spindle speed of 200 turn./min. and feed of 0,05 mm/turn. (fig. 2).

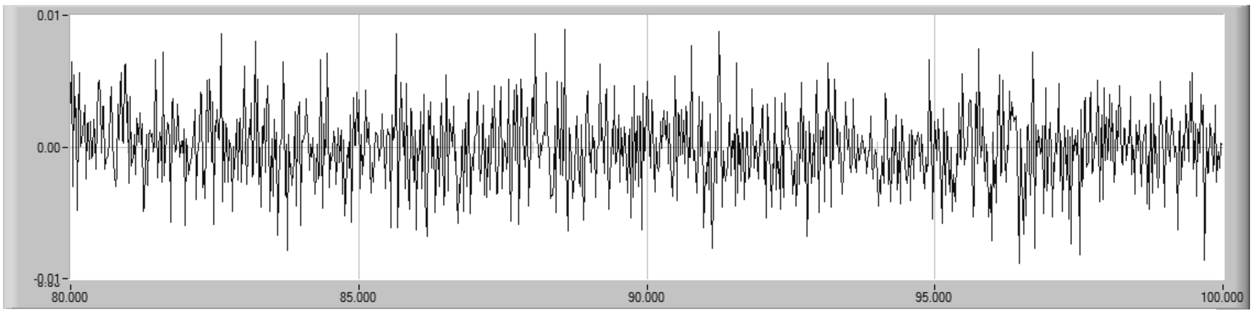


Fig. 2. Vibration acceleration oscillograph at the support displacement speed of 10 mm/min.

As it is well known [13], using the way of integration it is possible to get a vibration speed oscillograph, and using the double integration – the vibration displacement. Therefore in the MATLAB programme due to the visual mathematic modeling SIMULINK the mathematic model was designed to convert vibration acceleration into vibration speed and vibration displacement (fig. 3).

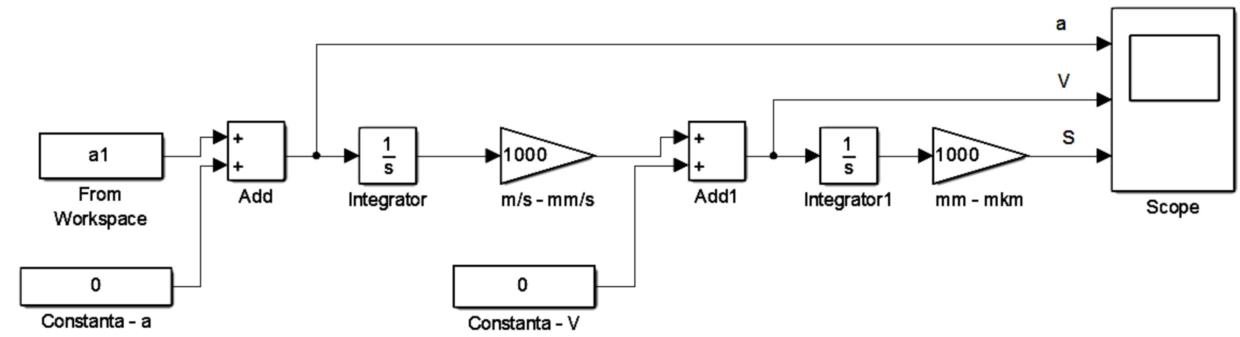
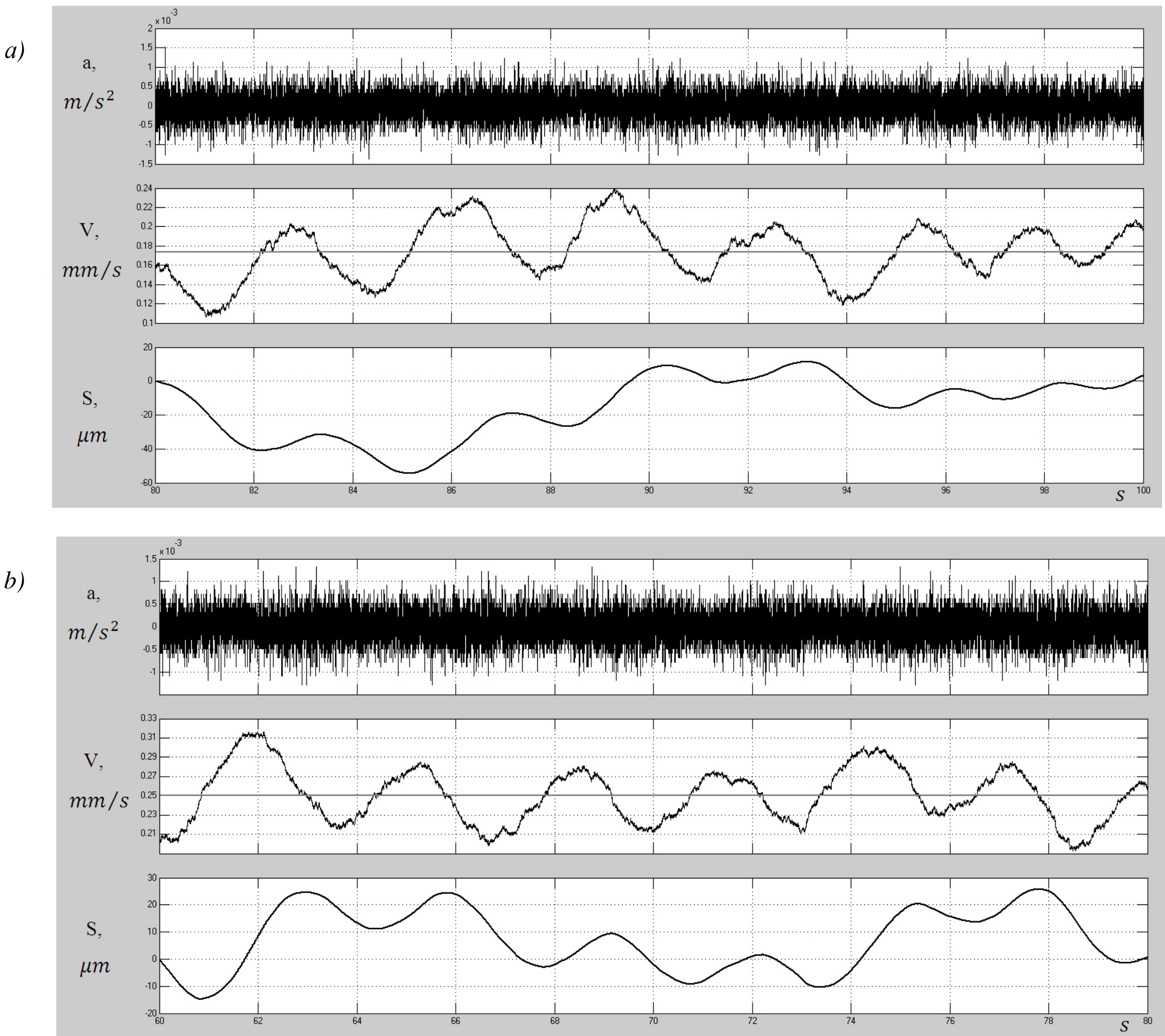
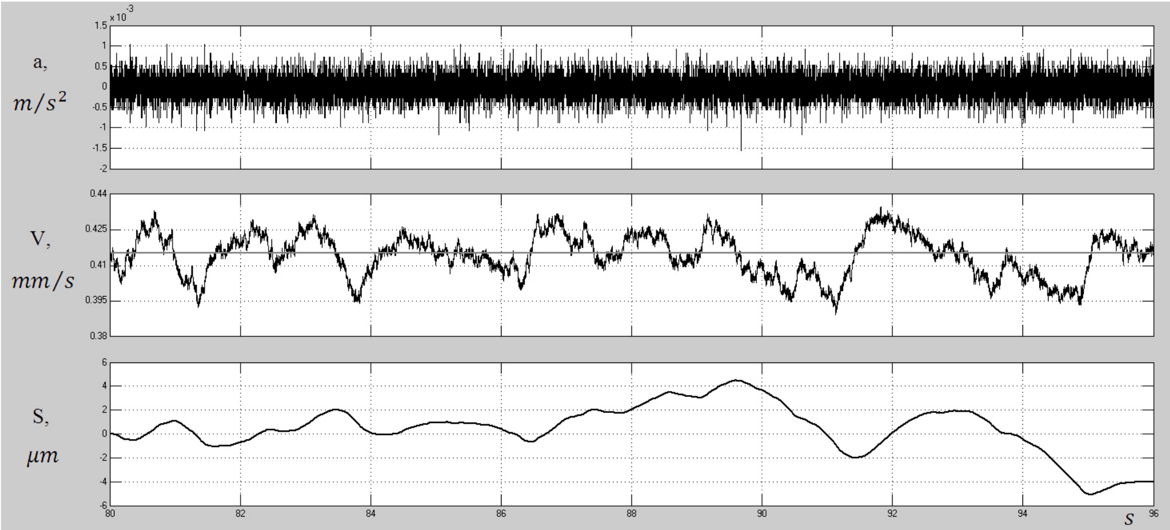


Fig. 3. Mathematic model to convert vibration acceleration into vibration speed and vibration displacement.

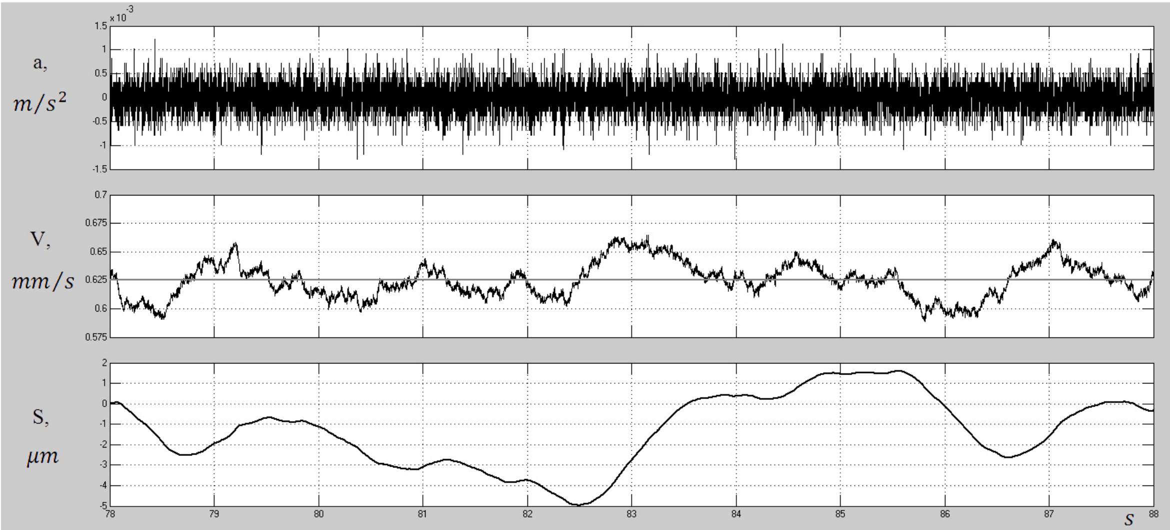
Support nonuniformity motion at different speed records were made with the screw-cutting lathe. The attained results are displayed in the fig. 4.



c)



d)



e)

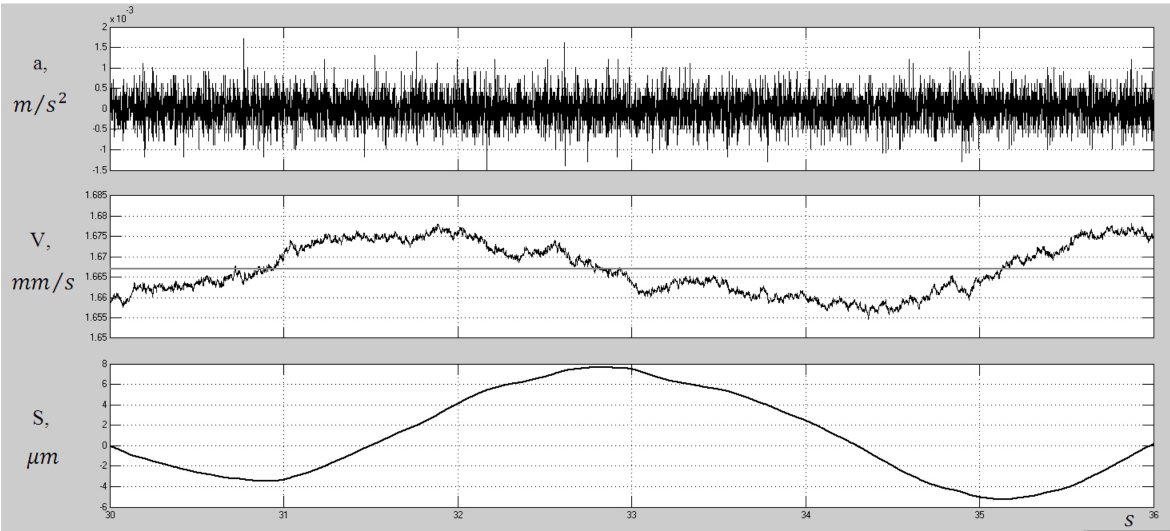


Fig. 4. Oscillographs, obtained with the screw-cutting lathe mod. 16К20 at the support displacement speeds: a) 10 mm/min.; b) 15 mm/min.; c) 25 mm/min.; d) 37,5 mm/min.; e) 100 mm/min.

From these results, it is obvious that at the speed of 10 mm/min., the amplitude of the support jumps reaches

22 microns per one spindle turn, which will significantly degrade the surface roughness. With speed increasing, the amplitude decreases and at 37,5 mm/min. it is within the range of 2–3 microns. At the speed of 100 mm/min. The graphic is smooth, which indicates that the support motion is uniformity.

Due to the formulas (13), (14) we can calculate the determined component of the roughness when turning in the case of the uniformity support motions well as in the case of nonuniformity one, using the received values of a jump per one spindle turnover. The radius at the blade peak should be taken as 0,5 mm. The obtained results are presented in the table 1.

$$R_{Zp} = \frac{S^2}{8R}; \quad (13)$$

$$R_{Zp\phi} = \frac{(S+\Delta S)^2}{8R}, \quad (14)$$

where S – is a feed per a turnover; ΔS – is an average value of feed acceleration per a turnover; R – is a radius at the peak blade.

Table 1

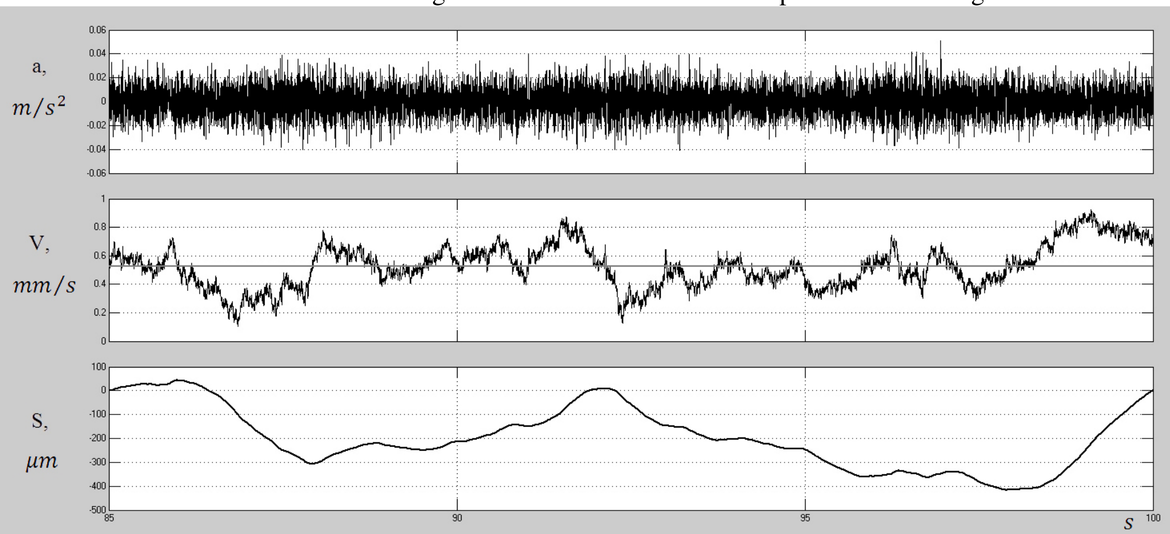
Values for the calculated roughness under the processing with the thread-cutting lathe – 16K20

$S_{min.}$ $\frac{mm}{min}$	n $\frac{turn.}{min}$	S, $\frac{mm}{turn.}$	R_{Zp}, microns	$S+\Delta S$, $\frac{mm}{turn.}$	$R_{Zp\phi}$, microns	Difference between, %
10	200	0,05	0,6	0,062	0,96	60
15	200	0,075	1,4	0,088	1,94	39
25	500	0,05	0,6	0,052	0,68	14
37,5	500	0,075	1,4	0,078	1,52	9
100	500	0,2	10	0,0201	10,1	1

As it can be seen from the calculations, the roughness value on the feed rate up to 20 mm/min. increased by more than 50 %. At the support motion speed more than 20 mm/min. the value increases by 10–15 %, comparing to the roughness under the support uniformity motion.

The records concerning the nonuniformity toolhead motion at the speeds of 1,5 mm/min., 50 mm/min. and 100 mm/min. was made with the thread-cutting lathe. The obtained results are presented in the fig. 5.

a)



b)

c)

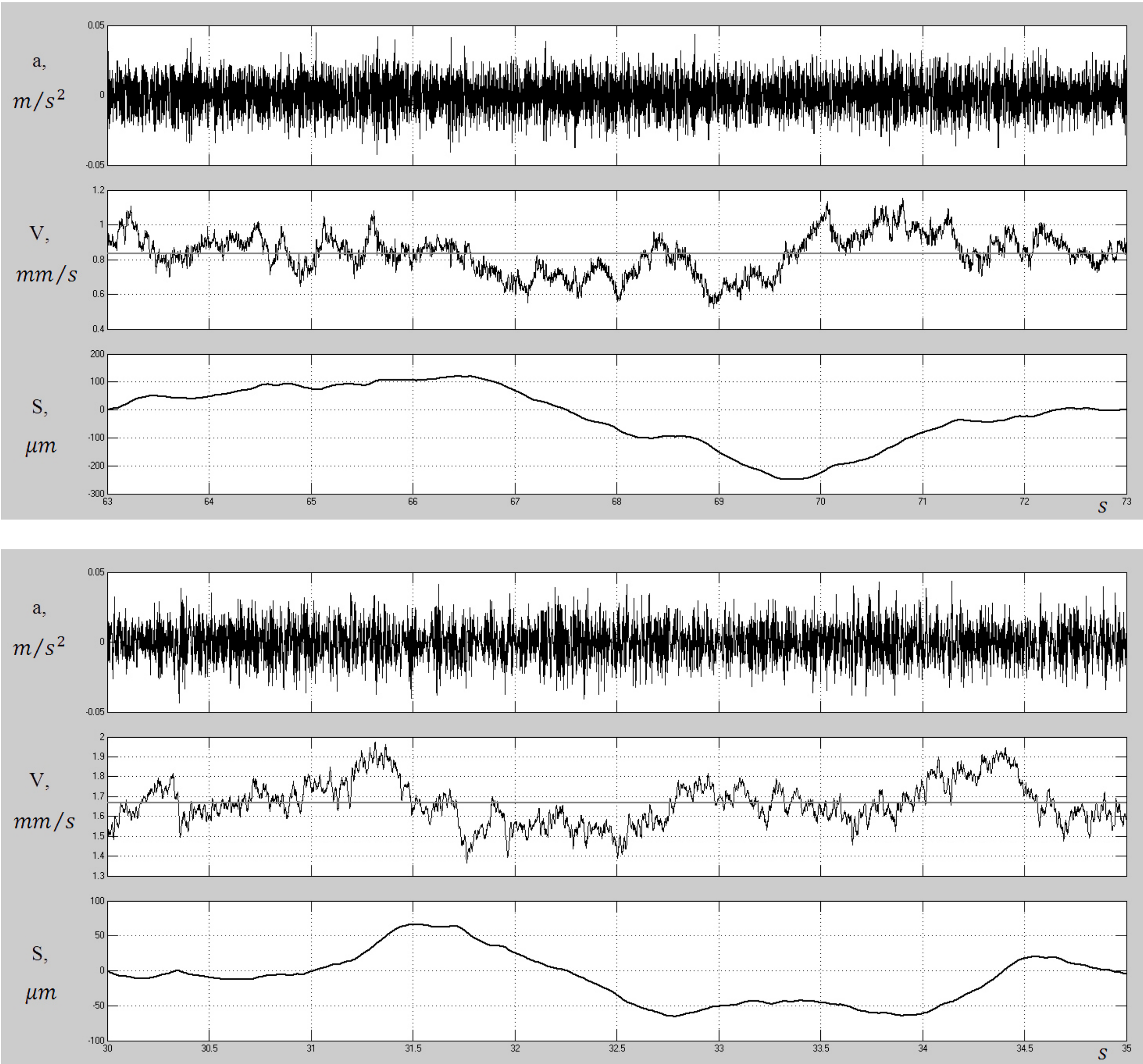


Fig. 5. Oscillograph data, received with the vertical milling machine mod. 6P12 at the speeds of the toolhead motion: a) 31,5 mm/min.; b) 50 mm/min.; c) 100 mm/min.

The results, received with the vertical milling machine, showed that at the toolhead motion speed of 31,5 mm/min. – the amplitude of jumps per a spindle turnover reaches 150 microns, with speed acceleration up to 50 mm/min. – the amplitude reduces up to 100 microns. At the speed of 100 mm/min. the jump per spindle turnover within the range is 40–50 microns.

Moreover, due to the formulas (15), (16) we are able to calculate the determined component of the roughness under the face milling, with the miller with the amount of teeth – 8, entering-cutting angle 45° and minor-cutting angle – 5°, in the case of the toolhead uniformity motion and in the case of nonuniformity, using the obtained values of the jump to the tooth. The received result is presented in the table 2.

$$R_{Zp} = \frac{S \cdot \sin\varphi \cdot \sin\varphi_1}{\sin(\varphi + \varphi_1)}; \quad (15)$$

$$R_{Zp\hat{o}} = \frac{(S + \Delta S) \cdot \sin\varphi \cdot \sin\varphi_1}{\sin(\varphi + \varphi_1)}, \quad (16)$$

where S – is a feed per tooth; ΔS – is an average value of feed per tooth increase; φ – entering-cutting angle; φ_1 – minor-cutting angle.

Table 2

The value of the calculated value for the roughness under processing with vertical milling machine – 6P12

S_{min} $\frac{mm}{min}$	n, $\frac{turn.}{min}$	S, $\frac{mm}{tooth}$	R_{Zp} microns	$S+\Delta S$, $\frac{mm}{tooth}$	$R_{Zp\phi}$, microns	Difference between, %
31,5	100	0,04	3,2	0,057	4,6	43
50	125	0,05	4	0,062	5	25
100	250	0,05	4	0,055	4,4	10

The calculations show that at the toolhead motion speed of 1,5 mm/min., the roughness value increases by 43 %. At the toolhead motion speed of 100 mm/min. The roughness increases by 10 %, comparing to the roughness under the uniformity toolhead motion.

Conclusion. The provided analysis of the experimental results confirmed the hypothesis of a significant influence by the machine nonuniformity operative parts motion on detail surface roughness, processed by the blade tool. Especially this influence is obvious at small (finishing) feed values. Comparing to other surface roughness components (3) this value can be significantly higher.

When turning processing, when feed per a turnover is 0,05 mm/turnover and 200 turnovers/min., the jump value per a turnover is about 20 microns, which indicated that the actual feed per a turnover at some certain period of time can be varied by a value of 0,05±0,02 mm/turnover.

When milling processing, when feed per a tooth is 0,04–0,06 mm/tooth, the jump value per a miller turnover increases 120–160 microns, and per a tooth is 10–15 microns, which changes as well the given values of feed per tooth, thus the roughness is getting worse, and in case of slotting by thin disk millers, it can lead even to their destruction [14].

Eve a this stage of the study, it is possible to provide some recommendations to reduce the detail surface roughness, processed with turning and milling machines:

1. Under the finishing processing, the blade tool with increased radius of curvature at the peak should be used.
2. Do not use minimal (less than 50 mm/min) support (toolhead) feed.
3. To reduce the friction forces and to increase motion smoothness of the operative parts, anti-jumping greasing substances and finishing chemimechanical pulping for guiding parts should be used.
4. The equipment with maximum positive drive for operative parts supply should be used.

Literature:

1. *Dunin-Barkovskii I.V.* Changes and analysis of the surface roughness, waviness and out-of-roundness / *I.V. Dunin-Barkovskii, A.N. Kartashova*. – M. : Mashinostroieniie, 1978. – 232 p.
2. *Isaiev A.I.* Micro geometry of the surface under turning processing / *I.A. Isaiev*. – M.–L., 1950. – 106 p.
3. *Suslov A.H.* Technological provision of the details upper layer state parameters / *A.H. Suslov*. – M. : Mashinostroieniie, 1987. – 208 p.
4. *Lopovok T.S.* Surface waviness and its calculation / *T.S. Lopovok*. – M. : Izdatelstvo Standartov, 1973. – 184 p.
5. *Klimenko S.A.* Microroughnesses formation under surface processing with a blade tool / *S.A. Klimenko* // NAS of Ukraine. Institute of ultrahard materials. – K., 1998. – P. 26–33.
6. *Klimenko S.A.* On the mechanism of surface microgeometry formation under blade processing. / *S.A. Klimenko* // Ultrahard materials. – 1997. – № 5. – P. 43–53.
7. *Zimovnov O.V.* Diagnostic of quality between driving elements for machine tools subject to performance motions nonuniformity on the example of machine feed drives of a turning group: extended abstract of dissertation – PhD in engineering : spec. 05.03.01 "Processes in mechanical and physical-technical processing, machines and tools" / *O.V. Zimovnov*. – Rostov-na-Donu, 1996. – 18 p.
8. *Push V.E.* Small displacements in machines / *V.E. Push*. – M. : Mashgiz, 1961. – 124 p.
9. *Chechuga O.V.* Surface quality improvement under mechanical processing, using rational setting of feeding devices: PhD in engineering : spec. 05.03.01 "Processes in mechanical and physical-technical processing, machines and tools" / O.V. Chechuga. – Tula, 2002. – 24 p.
10. Methodology to calculate joints for machine tools for low speed motions smoothness / *V.A. Kudinov, N.A. Kochieniev, M.I. Ierukhimovich, I.P. Lomako*. – M. : ENIMS, 1972. – 21 p.
11. *Orlikov M.L.* Machines dynamics / *M.L. Orlikov*. – K. : Vyshcha shkola, 1980. – 256 p.
12. *Push V.E.* Machine tools construction / *V.E. Push*. – M. : Mashinostroienie, 1987. – 390 p.
13. *Strutinskii V.B.* Mathemetical modeling mechanical processes and systems : мanual / *V.B. Strutinskii*. – Zhytomyr : Zhytomyr State Technological University, 2001. – 612 p.
14. *Balytska N.O.* Cutting millers capacity increasing: PhD in engineering : spec. 05.03.01 "Processes in mechanical and physical-technical processing, machines and tools"/ *N.O. Balytska*. – Kyiv, 2015. – 25 p.

МЕЛЬНИЧУК Петро Петрович – доктор технічних наук, професор, ректор Житомирського державного технологічного університету.

Наукові інтереси:

– технологія машинобудування.

E-mail: rector@ztu.edu.ua

ВИНОГРАДОВ Олександр Олександрович – доктор технічних наук, професор Житомирського державного технологічного університету.

Наукові інтереси:

– обробка важкооброблюваних матеріалів;

– надтверді матеріали.

ЛОЄВ Володимир Юхимович – кандидат технічних наук, професор кафедри металорізальних верстатів і систем Житомирського державного технологічного університету.

Наукові інтереси:

– технологія машинобудування;

– комплексні і комбіновані методи обробки плоских поверхонь деталей машин;

– конструювання металообробних верстатів та інструментів.

E-mail: loev.vladimir@rambler.ru

ОТАМАНСЬКИЙ Валентин Владиславович – аспірант кафедри металорізальних верстатів і систем Житомирського державного технологічного університету.

Наукові інтереси:

- динаміка механічних систем;
- математичне моделювання;
- конструювання металообробних верстатів.

E-mail: rembrox@rambler.ru

Стаття надійшла до редакції 14.12.2015