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V. V. Kalchenko[1],
orcid.org/0000-0002-9072-2976,
V. I. Kalchenko[1],
orcid.org/0000-0002-9850-7875,
S. D. Tsybulya[1],
orcid.org/0000-0002-7843-6061,
A. V. Kolohoida[1],
orcid.org/0000-0002-1742-2686,
Ye. Yu. Sakhno[2],
orcid.org/0000-0002-9789-7242

1 – Chernihiv Polytechnic National University, Chernihiv, Ukraine, e-mail: kolohoida@gmail.com
2 – Chernihiv State Institute of Economics and Management, Chernihiv, Ukraine

SIMULATION OF THE PROCESS OF MILLING AND GRINDING CYLINDRICAL SURFACES BY AN ORIENTED TOOL IN ONE SETUP

Purpose. Improvement of schemes for processing the cylindrical surfaces of the shafts of gearboxes and transmissions of large-sized equipment. Development of modular spatial models of the processes of milling and grinding of the cylindrical surfaces of the shafts of gearboxes and transmissions of military and civil vehicles. Development of a model for dressing a grinding wheel with a diamond tool.

Methodology. Creation of general and particular modular mathematical models of the processes of removal of allowance and shaping during rough and finish milling and finishing grinding of non-rigid cylindrical surfaces was carried out using a matrix apparatus for transforming coordinate systems. This made it possible to describe the treatment process using standard matrices. The calculations were carried out in the mathematical package Mathcad. To obtain a graphic display of the mathematical model of the instrumental and machined surfaces, the standard functions of the software package and the developed logical blocks were used.

Findings. A technique for processing cylindrical surfaces of revolution with an oriented tool is proposed. Roughing, finishing and polishing are carried out in one setup. Roughing and finishing are carried out with an oriented cutter with replaceable multifaceted carbide inserts. The angle of orientation of the cutter is selected from the condition of maximum loading of the end section. Thus, the roughing stock is removed by the end face and by the finishing periphery, while the maximum component of the cutting force is directed along the axis of the part and does not cause deformations in the radial direction. Final finishing is carried out with a wide grinding wheel. The angle of orientation of the grinding wheel is selected from the condition of uniform distribution of the allowance along the periphery. A scheme for dressing the working surface of a grinding wheel with a diamond pencil with a constant feed is proposed.

Originality. Modular spatial models of the processes of milling and grinding of the cylindrical surfaces of the shafts of gearboxes and transmissions of military and civil vehicles were developed. A model for dressing a grinding wheel is proposed. The use of the proposed models makes it possible to conduct a more detailed analysis of the processes of stock removal and shaping.

Practical value. Dependencies are proposed for choosing the optimal angles of orientation of the cutter for roughing and finishing milling and the grinding wheel for finishing. The accuracy of parts is increased due to the elimination of the resetting error. The cost of manufacturing is reduced due to the maximum full use of cutting carbide inserts, by turning them and operating the worn finishing edge in the rough milling mode, as well as by increasing the resource of the grinding wheel.

Keywords: *cylindrical surface, three-dimensional modelling, milling, grinding, indexable inserts, space cutting wedge*

Introduction. A significant number of the parts of machines and mechanisms are represented by surfaces of rotation. Most often, these are rectilinear and curved surfaces of shafts. In military and civilian transport, various shafts are widespread, which are components of engines, gearboxes, transmissions, etc. The peculiarity of their work is the rotation with significant speeds. So, the parts with insufficient parameters of accuracy and roughness is causing significant vibrations, which leads to premature destruction of the elements of the car systems.

In addition, these parts have a large axial dimension with small radial dimensions, which determines their low rigidity. Insufficient radial rigidity imposes significant restrictions on the choice of cutting modes, because the increase in cutting depth causes an increase in cutting forces, vibration and as a consequence of a decrease in machining accuracy.

Therefore, the creation of new improved schemes for processing the cylindrical surfaces of the shafts of gearboxes and transmissions of large-scale equipment, including military, is an urgent task.

Literature review. Considerable attention is paid to methods for modeling cutting processes [1, 2], materials and tools [3] and spatial processing schemes [4]. The created models allow software analysis of properties and determination of various processing parameters [5], including cutting forces [6] and dynamic characteristics [7]. A comprehensive analysis of the processes of removal of allowance and shaping during grinding and milling of rotating surfaces is given in [8, 9]. General three-dimensional models of the tool surface and details are offered.

In [9] the peculiarities of milling of support necks and cams of camshafts are investigated. It is offered to carry out processing by a milling cutter in which car-bide and ceramic indexable inserts alternate. The disadvantage of this method is the special design of the milling cutter. In addition, the cost of ceramic indexable inserts exceeds the cost of carbide, which increases the cost of processing.

In [10], the process of rough and final grinding of cylindrical surfaces with an oriented wide wheel is considered. At this, on the peripheral section of the wheel the rough, finishing and calibration sections are combined. The scheme of editing of a wheel by an impregnated diamond tool is offered where feed per revolution of the single-point diamond is changed. This improves the operating conditions of each of the sections of the grinding wheel.

Machining centers, multi-operational and multi-spindle machines are becoming widespread in the industry [11, 12]. Their use allows increasing productivity of production of details and accuracy.

Unsolved aspects of the problem. Despite the large number of studies in the field of spatial modeling of processing methods, insufficient attention is paid to the peculiarities of the handling of non-rigid parts of gearboxes, transmissions and other components of civil and military transport. Methods of simultaneous roughing and finishing milling as well as subsequent finishing grinding on multi-spindle machines are unexplored. However, the use of these methods significantly expands the technological capabilities for the manufacture of shafts and increases their accuracy. In addition, there is no general modular spatial model that describes both the milling and grinding processes at the same time. Also, the main criteria for choosing the angles of orientation of the tools in order to improve the quality of processing and reduce its cost are not studied.

Purpose. To offer new ways of roughing, finishing and polishing of shafts of gearboxes, transmissions and other components of civil and military transport. To develop general and partial modular models of tool surfaces, the process of removal of allowance and shaping, as well as the profile of the part for the case of roughing and finishing milling and finishing grinding for one institution on a multi-spindle machine. To propose calculated dependences to determine the optimal orientation angles of tools in the machining process

Results. The work proposes a new method for processing the cylindrical surfaces of the shafts of gearboxes and transmissions of military and civil road transport. In order to increase accuracy and productivity, it is proposed to perform processing on a multi-spindle machine at one location. The accuracy of processing is increased by eliminating the error of permutation, because roughing, finishing milling and polishing are carried out by changing the tool. The productivity of obtaining high-precision cylindrical surfaces of the shafts of gearboxes and transmissions of military and civilian transport is ensured by eliminating the technological time for relocation of the part.

Rough processing and finishing of a cylindrical surface are carried out according to the scheme shown in Fig. 1. As an example, there is chosen treatment of cylindrical surfaces of the shaft of the gearbox of the military armored personnel carrier (the figure shows part of the shaft). As a tool it is proposed to use a milling cutter model S890 SSB D125-20-40-R13 [13, 14]. Its outer diameter is 125 mm, height – 20 mm, and the diameter of the landing hole is 40 mm. The mill is combined with indexable inserts. The number of cutting teeth is 14. Plates are used of type S890 SNMU 1305PNTR [15] – quadrilateral, double-sided. The number of cutting edges is 8. The length of a cutting edge is 13 mm.

According to the proposed scheme of processing (Fig. 1), the shaft 1 is installed in the centers and rotates around its own axis $O_{sh}Z_{sh}$ with angular velocity ω_{sh}, and performs an axial feed S_z along the same axis. Processing is carried out by a mill *2* with indexable inserts *3*. The milling cutter rotates around an axis O_mZ_m with angular speed ω_m. The end surface of the tool and the peripheral one take part in the process of removing the allowance and forming. The end cutting surface is formed by rotating a number of edges *4* of the indexable inserts *3*, which are directed along the radius of the cutter. The peripheral part is also formed by the edges *5* of the carbide indexable inserts *3*, but the direction of the cutting edges coincides with the axis O_mZ_m. In order to combine roughing and finishing on one pass, the cutter is oriented relative to the part. The orientation angles of the milling cutter are chosen based on the maximum load of the end part of the tool surface. In this case, to ensure the presence of the calibration section, i. e. to increase the accuracy of the final milling, the axis of rotation of the cutter is shifted by a certain distance from its end surface. When the finishing edge is worn to a length of l_i, it is rotated R_i around its own axis by 90°, so that it continues to operate in black milling mode.

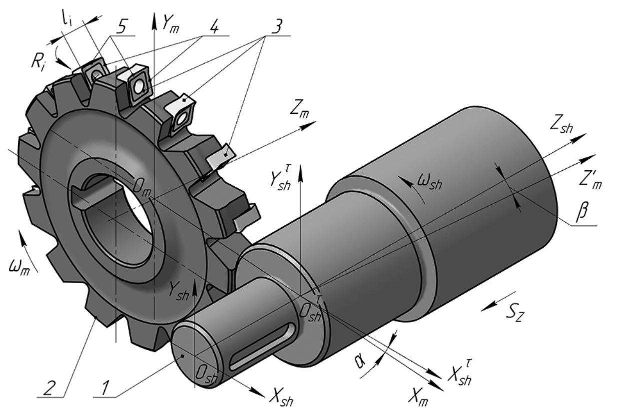


Fig. 1. Scheme of roughing and finishing milling of a cylindrical surface of a shaft

To improve the working conditions of the indexable inserts and increase the accuracy of processing, the tool is rotated around the axis O_mY_m at an angle α and around the axis O_mX_m at an angle β (Figs. 1, 2). The scheme for calculating the relationship between the angles of rotation of the cutter relative to the axes O_mY_m and O_mX_m is shown in Fig. 2.

In Figs. 2, *a*, *b*, line 1 is the nominal diameter of the surface to be treated, line *2* is the initial diameter of the shaft, and *t* is the allowance for processing. A square carbide indexable inserts *3* with the length l_i of the cutting edge, is rotated around a line that is parallel to the axis O_iZ_i and passes through a point O_{ic}. Point O_{ic} is at a distance l_c from the lower edge of the indexable inserts *3*. The length of the segment l_c determines the size of the calibration area on the cutting edge of the indexable inserts. The initial length of the working part of the end cutting edge without taking into account the radius of curvature is l_w. When rotating the plate in the horizontal plane around point O_{ic} (Fig. 2, *a*) at an angle O_{ic}, the working length of the cutting edge increases to l'_w. At the same time point A' – a conditional top of an indexable inserts, goes deep into material of a detail on size l_{adx}. The length of the working part of the cutting edge l'_w after rotating the milling cutter can be determined

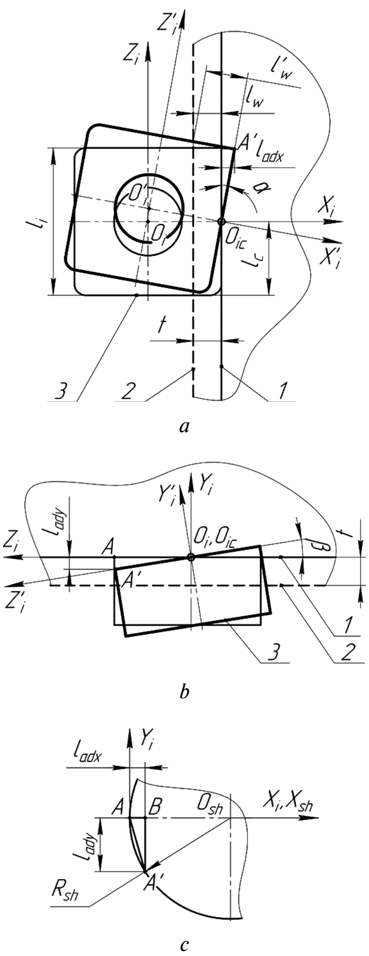
$$l'_w = \frac{(l_w + l_{abx})}{\cos\alpha}, \qquad (1)$$

where $l_w = t$ is the initial length of the working edge, mm; l_{adx} is the amount of deepening of the conditional vertex in the material of the part, mm

$$l_{adx} = (l_i - l_{ic}) \cdot \sin\alpha, \qquad (2)$$

where l_i is the length of the edge of the indexable inserts, mm; l_{ic} is the length of the calibration section of the indexble inserts, mm. Assume $l_{ic} = 0.5 \cdot l_i$, so (1) taking into account (2) can be written as

$$l'_w = \frac{t + 0.5 \cdot l_i}{\cos\alpha}.$$



a

b

c

Fig. 2. The scheme of determining the angles of rotation of the milling cutter:

a – orientation angle α*; b – orientation angle* β*; c – determining the value* l_{ady}

As mentioned above, when turning the milling cutter at an angle α, the top of the indexable inserts cuts into the part, thereby causing an error in size. To prevent this, the milling cutter is additionally rotated around the axis O_mX_m at an angle β (Fig. 2, *b*). The angle of rotation β is determined

$$\sin\beta = \frac{l_{ady}}{(l_i - l_{ic})} = \frac{l_{ady}}{0.5 \cdot l_i},$$

where l_{ady} is the distance along the axis O_iY_i by which it is necessary to lower the top of the indexble inserts, for its removal from the part, mm. According to the scheme (Fig. 2, *c*) l_{ady} is defined as the length of the leg BA' of the triangle $BA'O_{\text{sh}}$. In this case $A'O_{\text{sh}} = R_{\text{sh}}$ is the radius of the cylindrical surface of the processed shaft, mm; the length of the leg $B'O_{\text{sh}}$ is less than the radius of the shaft by l_{adx}, therefore $R_{\text{sh}} - l_{adx}$, mm. So

$$l_{ady} = \sqrt{R_{\text{sh}}^2 - (R_{\text{sh}} - l_{adx})^2}.$$

Then the orientation angles of the milling cutter around the two axes are related by the ratio

$$\sin\beta = \frac{\sqrt{R_{\text{sh}}^2 - (R_{\text{sh}} - (l_i - l_{ic}) \cdot \sin\alpha)^2}}{0.5 \cdot l_i}.$$

In order to build a general model of removal of allowance and shaping during milling of cylindrical surfaces of shafts of gearboxes and transmission of motor transport, we will write the equation of an instrumental surface.

When the milling cutter rotates, the cutting edges of the indexable inserts form a cylindrical surface. Moreover, this surface contains the end and peripheral parts. The three-dimensional model of the working surface of the cutter can be described using coordinate transformation matrices. It will contain two linear displacements describing the position of the point along the radius and along the periphery of the milling cutter. And one angular displacement that forms a continuous cylindrical surface. Therefore, the working cylindrical surface has two independent parameters, the linear coordinate *j* of the profile point and the angle of rotation θ_m of the current profile point around the axis O_mZ_m of rotation of the cutter

$$\overline{r}_m(\theta_m, j) = M3(Z_m(j)) \cdot M6(\theta_m) \cdot M1(R_m(j)) \cdot \overline{e}4, \qquad (3)$$

where *M*3, *M*1 are single-coordinate matrices of transformation of the coordinate systems describing, respectively, movement along the axes O_mZ_m and O_mX_m; *M*6 is a matrix that describes the rotation around the axis O_mZ_m.

The dependence of the current coordinate $Z_m(j)$ and radius of the work surface $Z_m(j)$ at the j^{th} point of the profile can be written using the Heaviside function

$$Z_m(j) = j \cdot (1 - \Phi(j - j_\rho)) + (j_\rho + \rho) \cdot \Phi\left(j - \left[j_\rho + \rho \cdot \frac{\pi}{2}\right]\right) + \\ + \left(j_\rho + \rho \cdot \sin\frac{j - j_\rho}{\rho}\right) \cdot \left[\Phi(j - j_\rho) - \Phi\left(j - \left[j_\rho + \rho \cdot \frac{\pi}{2}\right]\right)\right]; \qquad (4)$$

$$R_m(j) = R \cdot \left(1 - \Phi(j - j_\rho)\right) + \\ + \left[R - \rho - j + \left(j_\rho + \rho \cdot \frac{\pi}{2}\right)\right] \cdot \left(j - \left[j_\rho + \rho \cdot \frac{\pi}{2}\right]\right) + \\ + \left[R + \rho \cdot \left(\cos\frac{j - j_\rho}{\rho} - 1\right)\right] \cdot \left[\begin{matrix} \Phi(j - j_\rho) - \\ \Phi\left(j - \left[j_\rho + \rho \cdot \frac{\pi}{2}\right]\right) \end{matrix}\right], \qquad (5)$$

where *j* is the current coordinate on the cutting surface of the milling cutter along the axis O_mZ_m, mm; j_ρ is the coordinate of the starting point of the radial section on the indexble inserts along the axis O_mZ_m, mm; ρ is the radius of rounding of the indexable inserts, mm.

In (4 and 5), the first term describes the peripheral section of the cutting surface of the milling cutter, the second – the end, and the third – the transitional radial edge of the indexable inserts. The Heaviside function determines the position of each section on the coordinate plane.

After milling the cylindrical surfaces of the gearbox shaft, they are polished. Grinding (Fig. 3) of the shaft *1* is carried out by a grinding wheel *2* with height *H*. In the process of polishing, similarly to the previous scheme, the part rotates around its own axis $O_{\text{sh}}Z_{\text{sh}}$ with an angular velocity ω'_{sh} and performs the feed movement S'_z. The grinding wheel is spaced away from the workpiece x_{gr} and rotated at an angle φ about the axis $O_{gr}X_{gr}$. The tool rotates around the axis $O_{gr}X_{gr}$ at an angular velocity ω'_{gr}.

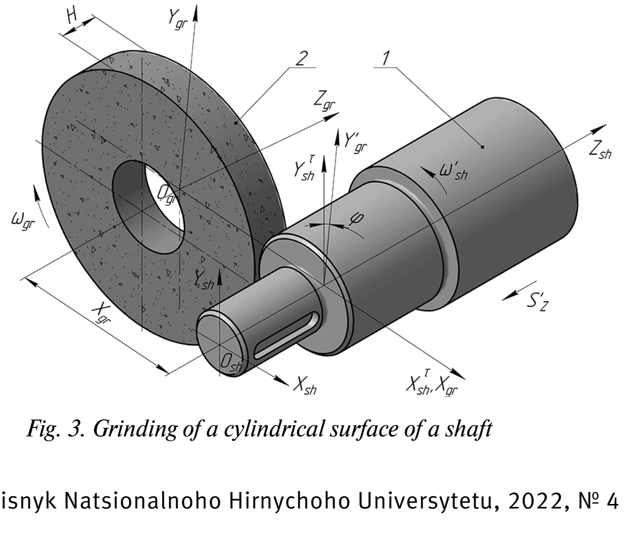


Fig. 3. Grinding of a cylindrical surface of a shaft

The angle φ of orientation of the grinding wheel is selected from the condition of uniform distribution of the allowance along the entire periphery [8]

$$\varphi = \arcsin\frac{\sqrt{(R_{\text{sh}} + t_f)^2 - R_{\text{sh}}^2}}{\acute{I} - C},$$

where R_{sh} is the radius of the cylindrical surface of the processed shaft, mm; t_f is the depth of cutting for grinding, mm; H is the height of a profile of a grinding wheel, mm; $C = 0.3 \cdot H$ is the size of the calibration section, as well as the distance from the end of the grinding wheel to the axis of its rotation, mm.

Even distribution of the allowance along the periphery reduces the wear of the wheel profile. In addition, it changes the shape of the worn area, so that the profile of the wheel is almost unchanged. This increases the working time between edits, and accuracy is ensured by entering a radius adjustment factor.

The equation of the tool surface for the polishing installment is similar to the milling (3), but since the profile of the grinding wheel is straight, the value of its radius is constant for any point on the profile

$$\overline{r}_{gr}(\theta_{gr}, z_{gr}) = M3(z_{gr}) \cdot M6(\theta_{gr}) \cdot M1(R_{gr}) \cdot \overline{e}4,$$

where R_{gr} = 100 mm is the radius of the grinding wheel; θ_{gr} is the current angle of rotation of the point on the profile of the grinding wheel, rad; z_{gr} is the current linear coordinate of the point on the periphery of the wheel, mm.

The radius vector of the part during its roughing, finishing and polishing looks like

$$\begin{gathered}\overline{r}_{\text{sh}}(\theta_{\text{sh}}, \theta_t, z_t) = M3(\theta_{\text{sh}} \cdot p_t) \cdot M6(\theta_{\text{sh}}) \cdot M1(x_t) \times \\ \times M5(\lambda_t) \cdot M4(\gamma_t) \cdot M3(C_t) \cdot \overline{r}_t(\theta_t, z_t),\end{gathered} \tag{6}$$

where θ_{sh} is the current angle of rotation of the part, rad; p_t is parameter of screw movement of a detail, depends on giving ($p_m = 0.5 \cdot S_z/\pi$ – for a case of milling processing, $p_{gr} = 0.5 \times \times S_z'/\pi$ – at polishing), mm/rad; x_t is the distance between the axes of the tool and the part, mm; λ_t, γ_t are tool orientation angles, for milling $\lambda_{gr} = \alpha$, $\gamma_t = \beta$, for polishing $\lambda_{gr} = 0$, $\gamma_t = \varphi$, rad; C_t is position of the axis of rotation of the tool relative to the end of the tool ($C_m = l_c$, $C_{gr} = C$), mm; $\overline{r}_t(\theta_t, z_t)$ is the equation of the radius vector of the tool.

Forming condition is

$$\left(\frac{\overline{r}_{\text{sh}}(\theta_{\text{sh}}, \theta_t, z_t)}{\partial\theta_t} \cdot \frac{\overline{r}_{\text{sh}}(\theta_{\text{sh}}, \theta_t, z_t)}{\partial z_t}\right) \cdot \frac{\overline{r}_{\text{sh}}(\theta_{\text{sh}}, \theta_t, z_t)}{\partial\theta_{\text{sh}}} = 0. \tag{7}$$

Equations (6, 7) are a general three-dimensional model of the process of forming and removing the allowance for milling and grinding the shafts of gearboxes and transmissions of military and civilian transport.

To ensure the required accuracy of the profile of the grinding wheel, we perform its editing by an impregnated diamond tool whose working surface is described by a space cutting wedge [10]

$$\overline{r}_d(\delta, \gamma) = M4(\delta) \cdot M2(\rho_d - r_d) \cdot M6(\gamma) \cdot M2(r_d) \cdot \overline{e}4,$$

where δ, γ are the current angles of rotation of the point of the impregnated diamond tool, rad; r_d is the radius of curvature of the tip of an impregnated diamond tool, mm; ρ_d is the radius of curvature of the cutting edge of a tool, mm.

Editing the grinding wheel is carried out with a constant feed, to ensure a uniform line of the wheel profile.

In the case when the capabilities of the machine do not allow one to perform milling and grinding for one setup. A slightly higher allowance should be provided for finishing. And when editing the grinding wheel, one should provide for the finish and the calibration area.

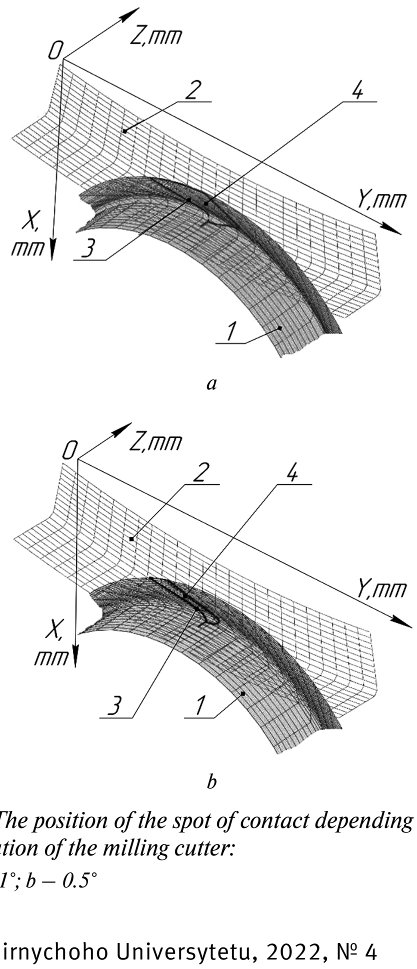
On the basis of the offered three-dimensional models of processes of removal of the allowance and shaping at milling and grinding of shafts of engines, gearboxes, transmissions of military and civil transport, research on parameters of process of processing is carried out.

The graphic display of models is constructed (Figs. 4, *a*, *b*). There is a cylindrical surface of the shaft 1, a working tool surface of the milling cutter *2*, a line of contact of the milling cutter and part *3* and a spot of contact *4*. It is determined that the optimal angle of rotation of the milling cutter is approximately 1°. The spot of contact *4* takes a value close to the maximum (Fig. 4, *a*). At a smaller angle of 0.5° (Fig. 4, *b*), the area of the spot of contact decreases. The same thing happens with a further increase in the angle α of inclination.

So, the rough allowance is removed by the end face of a milling cutter and finishing by its periphery. Therefore, the maximum value of the cutting force component is directed along the axis of the part and does not cause deformations in the radial direction. This allows you to use the proposed processing scheme for non-rigid parts, such as when processing the support necks of camshafts. Reduction of the prime cost of processing is reached at the expense of the fullest use of indexable inserts, by their turn and work of the worn-out finishing edge in the mode of rough milling.

Finishing grinding of the shaft according to the proposed scheme improves the geometric roughness of the part. A uniform distribution of the allowance along the periphery of the grinding wheel reduces its wear. The process of straightening the wheel with a diamond pencil with a constant feed improves the performance of the wheel and increases its life. At the same time, modeling an impregnated diamond tool using a space cutting wedge is common to many cutting methods.

Conclusions. A method for processing of cylindrical surfaces of rotation by the oriented tool is offered. As an example, the processing of shafts of gearboxes and transmissions of military and civilian transport is considered. It is proposed to carry out roughing, finishing and polishing on one machine. Machines with several spindles are used now. In order to carry out the polishing, the tool is changed by changing the spindle. This eliminates the error of relocation of the part, which increases its accuracy.



a

b

Fig. 4. The position of the spot of contact depending on the orientation of the milling cutter:
a – 1°; b – 0.5°

An oriented milling cutter with indexable inserts carries out roughing and finishing. The orientation angle of the milling cutter is chosen from the condition of maximum loading of the end section. Thus, the rough stock is removed by the end face of the milling cutter and the finish by the periphery. So, the maximum component of the cutting force is directed along the axis of the part and does not cause deformation in the radial direction. This allows one to use the proposed processing scheme for non-rigid parts, such as when processing the support necks of camshafts. Reduction of the prime cost of processing is reached at the expense of the fullest use of indexable inserts, by their turn and work of the worn-out finishing edge in the mode of rough milling.

A grinding wheel makes polishing. The angle of orientation of the grinding wheel is selected from the condition of uniform distribution of the allowance along the periphery. The scheme of editing the working surface of the grinding wheel with an impregnated diamond tool with a constant feed is proposed.

Modular spatial models of processes of milling and grinding of cylindrical surfaces of shafts of gearboxes and transmissions of military and civil transport are developed. The model of editing of a grinding wheel is offered, thus the impregnated diamond tool is described with use of a space cutting wedge.

References.

1. Fedorovich, V., Pyzhov, I., Ryazanova-Khitrovskaya, N., & Voropai, V. (2018). Dynamic mathematical modeling of the diamond burnishing process. *Modern technologies of engineering, 13*, 142-152.

2. Fedorovich, V., & Pyzhov, I. (2017). 3D modeling of the stress-strain state of the diamond grinding process. *Cutting & tools in technological systems, 87*, 172-180.

3. Fedorovich, V., Pledge, V., Pyzhov, I., Krivoruchko, D., & Fedorenko, D. (2016). Methodology of 3D modeling of processing of difficult materials. *Modern technologies in mechanical engineering, 11*, 208-232.

4. Brechera, C., Wellmanna, F., & Epplea, A. (2017). Quality-predictive CAM simulation for NC milling. *Procedia Manufacturing, 11*, 1519-1527.

5. Denkena, B., Grove, T., & Suntharakumaran, V. (2020). New profiling approach with geometrically defined cutting edges for sintered metal bonded CBN grinding layers. *Journal of Materials Processing Technology, 278*, 64-73.

6. Jamshidi, H., & Budak, E. (2020). An analytical grinding force model based on individual grit interaction. *Journal of Materials Processing Technology, 283*, 116700.

7. Kilic, Z., & Altintas, Y. (2016). Generalized mechanics and dynamics of metal cutting operations for unified simulations. *International Journal of Machine Tools and Manufacture, 104*, 1-13.

8. Kalchenko, Vitalii, Kolohoida, A., Kuzhelny, J., & Morochko, V. (2018). One-pass finishing grinding with crossed axes of a wheel and a cylindrical part. *Technical sciences and technologies, 4*(14), 9-17.

9. Kalchenko, Vitalii, Kalchenko, Volodymyr, Sira, N., Kalchenko, O., Vynnyk, V., Kalchenko, D., & Morochko, V. (2020). Development of the single-setup milling process model of the shaft support necks and cams. *Eastern-European Journal of Enterprise Technologies, 1*(106), 48-54. https://doi.org/10.15587/1729-4061.2020.208579.

10. Kalchenko, Vitalii, Kalchenko, Volodymyr, Kalchenko O., Sira, N., Kalchenko, D., Morochko, V., & Vynnyk, V. (2020). Development of a model of tool surface dressing when grinding with crossed wheel and cylindrical part axes. *Eastern-European Journal of Enterprise Technologies*, (3), 23-29. https://doi.org/10.15587/1729-4061.2020.202441.

11. Ermolaev, V. (2017). Modern grinding machines: new methods of abrasive processing. *RHYTHM of machine building, 10*, 28-33.

12. Altintas, Y. (2016). Virtual High Performance Machining. In: *Procedia CIRP, 46*, 372-378.

13. AKKO (2021). *Cutting and Connection Systems. Catalogue*. Retrieved from https://www.akko.com.tr/download_dosya/akko-cutting-tools-2021-products-catalogue.pdf .

14. ISCAR (2019). *Complete Machining Solution. Rotating tool lines. Milling. Hole Making. Tooling Sysytems. Catalogue*. Retrieved from https://www.iscar.com/Catalogs/publication-2019/rotating-tools-2019-milling-tools_ua.pdf .

15. ISCAR (2019). *Complete Machining Solution. Milling inserts. Catalogue*. Retrieved from https://www.iscar.com/Catalogs/publication-2019/rotating-tools-2019-milling-inserts_ua.pdf.

Моделювання процесів фрезерування та шліфування циліндричних поверхонь орієнтованим інструментом за один установ

В. В. Кальченко[1], *В. І. Кальченко*[1], *С. Д. Цибуля*[1], *А. В. Кологойда*[1], *Е. Ю. Сахно*[2]

1 – Національний університет «Чернігівська політехніка», м. Чернігів, Україна, e-mail: kolohoida@gmail.com
2 – Чернігівський державний інститут економіки і управління, м. Чернігів, Україна

Мета. Удосконалення схем обробки циліндричних поверхонь валів коробок передач і трансмісії великогабаритної техніки. Розробка модульних просторових моделей процесів фрезерування та шліфування циліндричних поверхонь валів коробок передач і трансмісії військового й цивільного транспорту. Створення моделі правки шліфувального круга алмазним інструментом.

Методика. Створення загальної й частинних модульних математичних моделей процесів зняття припуску та формоутворення при чорновому й чистовому фрезеруванні та фінішному шліфуванні нежорстких циліндричних поверхонь проводилось із використанням матричного апарату перетворення систем координат. Це дозволило з використанням стандартних матриць описати процес обробки. Проведення розрахунків здійснювалось у математичному пакеті Mathcad. Для отримання графічного відображення математичних моделей інструментальної та обробленої поверхонь використовувались стандартні функцій програмного пакету й розроблені логічні блоки.

Результати. Запропонована методика обробки циліндричних поверхонь обертання орієнтованим інструментом. Чорнова, чистова й фінішна обробка здійснюється за один установ. Чорнову й чистову обробку здійснюють орієнтованою фрезою зі змінними багатогранними твердосплавними пластинками. Кут орієнтації фрези обирається з умови максимального завантаження торцевої ділянки. Таким чином, чорновий припуск знімається торцем, а чистовий периферією, при цьому максимальна за величиною складова сили різання направлена вздовж осі деталі та не викликає деформацій у радіальному напрямку. Фінішна обробка проводиться широким шліфувальним кругом. Кут орієнтації шліфувального круга обирається з умови рівномірного розподілу припуску вздовж периферії. Запропонована схема правки робочої поверхні шліфувального круга алмазним олівцем із постійною подачею.

Наукова новизна. Розроблені модульні просторові моделі процесів фрезерування та шліфування циліндричних поверхонь валів коробок передач і трансмісії військового й цивільного транспорту. Також модель правки шліфувального круга. Це дає можливість проведення більш детального аналізу процесів зняття припуску та формоутворення.

Практична значимість. Запропоновані залежності для вибору оптимальних кутів орієнтації фрези при чорновому й чистовому фрезеруванні та шліфувального круга при фінішній обробці. Підвищується точність деталей за рахунок виключення похибки переустановки. Зменшується собівартість виготовлення за рахунок максимально повного використання ріжучих твердосплавних пластин шляхом їх повороту й роботи зношеної чистової кромки в режимі чорнового фрезерування, а також у результаті збільшення ресурсу шліфувального круга.

Ключові слова: *циліндричні поверхні, просторове моделювання, фрезерування, шліфування, багатогранна пластинка, просторовий ріжучий клин*

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