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Original scientific paper

Accuracy Control in the Process of Low-Rigidity Elastic Deformable Shafts Turning

Antoni ŚWIĆ, Dariusz WOŁOS, Arkadiusz GOLA, Natalia SMIDOVA

Abstract: The paper focuses on the problem of control of accuracy of forming elastic-deformable shafts with low rigidity. In particular, results of analysis of basic factors affecting the accuracy of machining of low-rigidity shafts such as the stiffness of the technological system, geometry of cutting tool, lathe temperature, degree of cutting tool wear, cutting tool strength, lubrication-cooling fluid and machining parameters are presented. Moreover, the performed analysis encompassed the effect of stiffness of particular elements of the technological system, the analytical relations determining the changes of defined parameters, values of elasticity of the fixed headstock and tailstock, as well as of the stiffness of the machining system from the zones of rigidity of the parts. To analyse appearing errors in the real industrial conditions, the study was realized on the example of manufacturing precision mechanics tooling in two and a single pass, with the application of specific parameters of machining.

Keywords: accuracy; control; flexible workpiece; low rigidity; machining; manufacturing; stiffness; turning

1 INTRODUCTION

Elastic-deformable shafts with low rigidity are more and more frequently used in various mechanisms and machines. In particular, parts with low rigidity find application in the aerospace industry (flexible, elastic and torsion shafts, springs, bolts), tooling industry (jigs and fixtures of various kinds, mechanisms, precision and special tools, drill bits, reamers, screw, taps, boring bars), machine building industry (shafts, turbine and pump rotors, feed screws), agricultural machines (tractor and combine harvester axle shafts), in the automotive industry and related industries [1-3]. Based on the analysis of many industrial products it can be concluded that one half of all machine parts are rotational parts: shafts (over 40%), discs, sleeves, thin wall cylinders, rings, etc. In the machine-building industry, axial-symmetrical parts account for approximately 34%, and among those up to 12% can be classified as shafts with low rigidity [4, 5].

In spite of their diverse functionality and design features of those parts, they can be classified into one group based on a uniform classification parameter – shape (bodies of rotation). Such elements must meet stringent requirements with regard to form accuracy and surface position, linear dimensions and quality of outer surface. Shafts with low rigidity are most often manufactured of non-alloy or alloy steels with high strength. The basic methods of machining of such parts are external longitudinal turning and external grinding. Turning accuracy should correspond to accuracy classes from 8 to 11, with surface roughness of $Ra = 0{,}63 – 2{,}5$ μm, and the grinding operation should ensure accuracy classes 5 – 6 with surface roughness of $Ra \leq 0{,}63$ μm. After the operation of grinding the parts should have no micro cracks, grinding burns or other surface defects. Machining methods that meet these requirements are turning followed by grinding. However, the combination of the non-stable processes of turning and grinding of parts with low rigidity causes the creation of a rather complex machine tool-grip-fixture-tool (MGFT system), the behaviour of which in the process of machining cannot practically be foreseen prior to it [6, 7].

The problem of machining low-rigidity shafts was widely discussed in the literature. There are many publications concerning the problem of stability lobes [1, 8], definition of cutting conditions [9, 10], machining forces and error prediction [11], surface quality modelling [12-15] or chatter suppression [16]. Moreover the problem of simulation of low-rigidity part machining was of special interest of researchers [17-22]. However it is rather difficult to find papers which present both the factors affecting the accuracy of machining shafts with low rigidity and the effect of stiffness of particular elements of the MGFT system, the analytical relations determining the changes of defined parameters, values of elasticity of the fixed headstock and tailstock, as well as of the stiffness of the machining system from the zones of rigidity of the parts.

This paper presents the problem of control of accuracy of forming elastic-deformable shafts with low rigidity, and namely the control of elastic-deformable state of semi-finished product with low rigidity through the effect of additional force factors under conditions of lateral bending, permitting the achievement of uniform stiffness of the shaft at the point of application of machining force, and consequently a significant increase of the accuracy of shaft formation in the course of turning.

2 FACTORS AFFECTING THE ACCURACY OF MACHINING OF SHAFTS WITH LOW RIGIDITY

The accuracy of shaft machining is affected most strongly by the following:

Stiffness of MGFT system. With increase of stiffness of the MGFT system there is a narrowing of the zone of vibrations, their frequency increases and amplitude decreases. The use of various vibration attenuators, with artificial resistance (frictional, hydraulic) of impact-type action, as well as dynamic, does not increase the stiffness of the MGFT system and does not eliminate the possibility of transfer of semi-finished product inaccuracies onto the machined element [23]. The stiffness of the MGFT system can be increased by improving the accuracy of manufacture of the parts and assemblies of the machine tool and by increasing the accuracy of mutual alignment of the cutting tool and the machined part [24, 25]. Increased stiffness and accuracy of machine tools permits an increase, within a certain range, of the reliability and accuracy of machining.

Geometry of cutting tool. Suitable geometry of cutting tool allows solving the problem of formation and breaking of chips in the course of turning. An example of the geometry of a turning tool with plates of sintered carbide, allowing the machining of construction steels with chip fragmentation, is presented in Fig. 1a [15]. Graphs of reliable chip fragmentation, dividing the range of machining parameters into zones of stable (A) and unstable (B) chip fragmentation, are presented in Fig. 1b. Curve 1 was obtained when turning steel X10CrNi18-8 at machining speed of $v_c = 70 - 130$ m/min, and curve 2 – when turning steel C45 at $v_c = 130$ m/min.

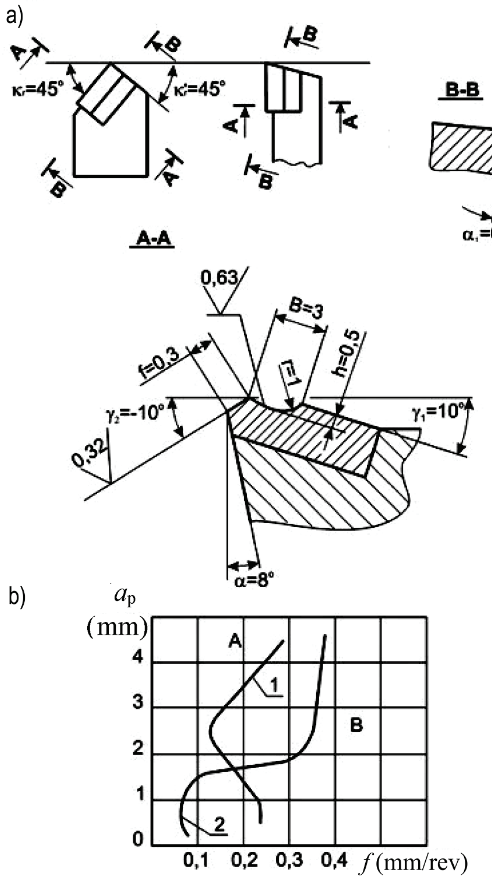

Figure 1 Turning tool edge for longitudinal turning: a) geometric parameter of turning tool edge, b) ranges of reliable chip fragmentation in turning of steels X10CrNi18-8 and C45

Lathe temperature and value of turning tool wear. Lathe temperature (related with the time of its operation) and the value of turning tool wear have a significant effect on accuracy and on errors of geometric form of the machined part. The relation of the error of geometric form of the parts, ΔR, machined on lathes 1K62 (curve 1), 1K625 (curve 2), 16K20P (curve 3), to the time of operation of those machine tools is presented in Fig. 2.

Strength of turning tool. Plates made with the method of layered pressing, followed by sintering of layered semi-finished products, have high strength (1400 – 1500 MPa) and resistance to wear. For additional enhancement of plate strength, on the cutting edges of the plates 0.2 mm chafers are made, with an angle of 20° [6]. The application of nitride and carbide plating increases the strength of the cutting edge as it modifies and strengthens the dislocation structure of the material of steel and tool-making alloys. Increase of the strength of the plastic matrix of cutting tool edge is achieved through preliminary ionic nitration prior to the application of the coatings (three-layer TiC + TiN + T, one-layer TiC) or ionic nitration of plates with the coatings already applied, which allows to increase the durability of the cutting tool from 2- to 5-fold [24].

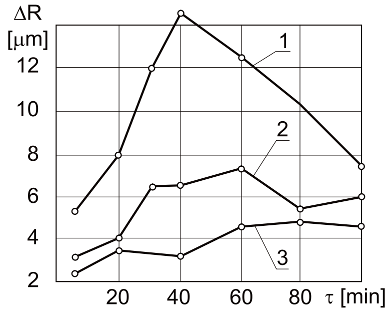

Figure 2 Relations of geometric form errors of parts ΔR to machine tool operation time τ

Lubricating-cooling fluid. The lubricating-cooling fluid has a complex effect on the strength of the cutting part of the turning tool. The application of an oil-based cutting fluid causes an increase of the contact strain σ_n in the vicinity of the cutting edge by from 5 to 10% and a decrease of machining temperature by from 7 to 12%, which increases the working life of the tool. With the using of a water-based cutting fluid, strains σ_n increase by 10% and machining temperature decreases by from 15 to 20%. Synthetic fluids improve machining conditions, reduce the roughness of the machines surface, increase the service life of the tool by from 20 to 200%, and improve the working conditions of the operator [10, 23]. More and more often machining with minimum lubrication is applied, consisting of the application of the cutting fluid in the form of mist, at the rate of 50 ml/h. Research is conducted on the effect of special activating agents added to the cutting fluids on the roughness parameters of the surface of machined parts.

The lubricating-cooling fluid has the strongest effect on increasing the resistance of the tool-part system to vibrations when turning is performed with very small machining depths ($a_p < 0{,}04$ mm). The application of lubricating-cooling fluid causes a decrease of the amplitude of vibrations, friction and machining forces, and deformation of parts with low rigidity [15].

Machining parameters. The importance of the machining parameters increases significantly at low shaft rigidity.

The appearance and intensity of vibrations are related primarily to the thickness of the machined layer (feed f), depth of machining a_p, turning tool geometry, stiffness of the MGFT system, and the lubricating-cooling fluid [25].

During the turning of steel 41Cr4 (Fig. 3), at various feed rates, with increase of the rate of feed f from 0,1 to 0,8 mm/rpm, the amplitude of vibrations decreases rapidly, and at feed rate above 0,5 mm/rpm – practically disappears. With increase of a_p the amplitude of vibrations increases, approximately linearly. However, really small values of a_p (below 0,005 mm) also lead to the appearance of vibrations [24].

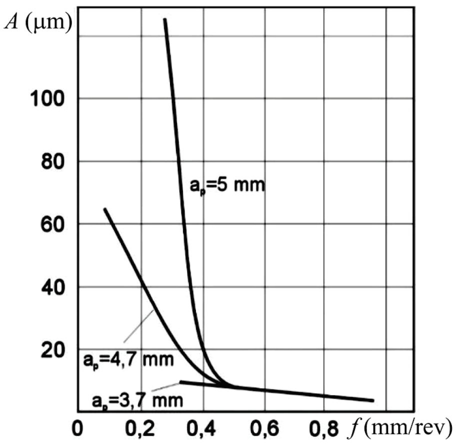

Figure 3 Correlation of amplitude of vibrations with feed rate during turning of steel 41Cr4

Among the elements of geometry of the turning tool edge, the following have a significant effect on the amplitude of vibrations: tool rake angle γ, tool cutting edge main angle κ_r and tool included angle r_ε [10, 23]. Change of tool rake angle γ from –10° to +30° causes a decrease of amplitude from 8- to 10-fold, the greatest effect on vibrations being that of negative tool rake angles as then there is a strong increase in friction forces and in the radial component of the machining force F_p. Decrease of the tool clearance angle α causes a decrease of the amplitude of vibrations. Decrease of the main cutting tool angle leads to an expansion of the zone of vibrations and to an increase of their amplitude, which is determined by increased value of radial force F_p, taking place with a decrease of angle κ_r. Increase of the tool included angle r_ε has an effect on vibrations, similarly to a decrease of the main cutting tool angle κ_r.

3 ANALYSIS OF MACHINING ERRORS

Statistical analysis of machining errors of shafts with low rigidity in the process of turning was conducted at a company manufacturing tooling for precision mechanics. In accordance with the technology of the company, machining of shafts of steel C45 is conducted in two passes on lathe 1604. The following requirements are adopted for the parts: accuracy of machined surface ∅6h9, roughness Ra = 1,25 – 2,5 μm. Machining parameters applied: v_c = 32 m/min, n = 1000 rev/min, a_p1 = 1,75 mm, a_p2 = 0,25 mm, f_1 = 0,125 mm/rev, f_2 = 0,05 mm/rev; turning tool with plates of carbide T15K6, $\kappa_r = 90^0$, r_ε = 0,5 mm.

Taking into account the small batches of machined elements (from 9 to 50 pieces in a batch, which corresponds to the company production program), for the construction of the dot diagrams of form error in the longitudinal section five parts were chosen at random (Fig. 4a – part 1, 4b – part 7, 4c – part 22, 4d – part 30, 4e – part 38). The diagrams were created in accordance with the rule of conventional zero, as which the smallest actual shaft diameter was adopted [23]. After the first pass the form error, in the longitudinal section of the particular parts, was Δd = 0,049 – 0,031 mm. After the second pass it was $\Delta d'$ = 0,015 – 0,01 mm, which corresponds to dimensional tolerance of ∅6h9.

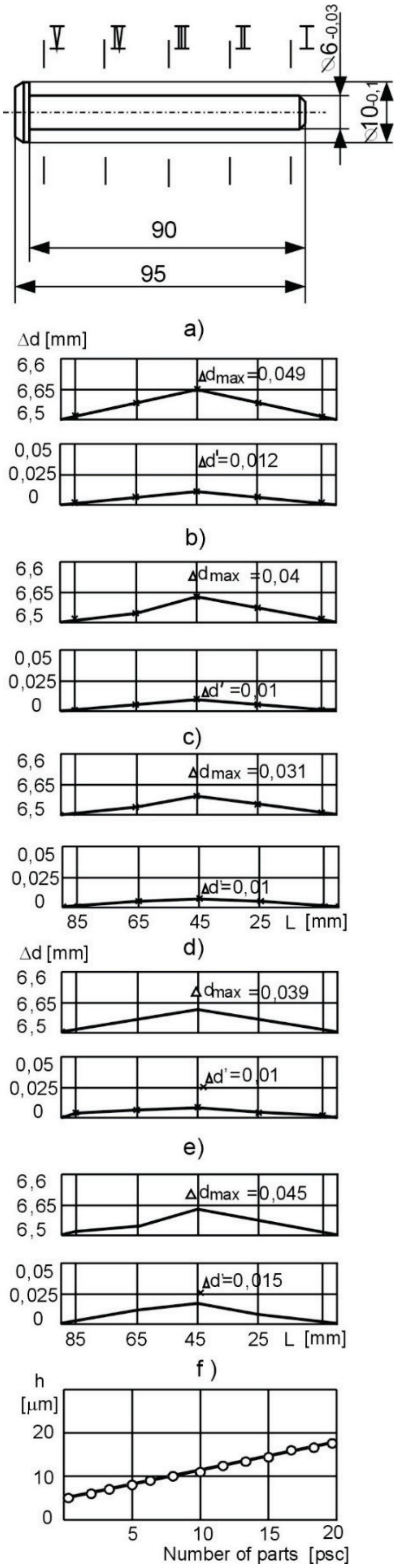

Figure 4 Diagrams of form errors and surface roughness of drive shafts

The diagram of surface roughness is presented in Fig. 4f. Dominant error, both after the first and after the second pass, resulted from changes in lathe settings, mainly elastic deformations of the MGFT system, caused by deformations of parts with low rigidity. During the first pass, the value of elastic deformations of the parts exceeded the required tolerance for machining. With a change of the part numbers, selected at random from the batch of machined semi-finished products, similar results were obtained. The following machining parameters were adopted: $v_c = 30$ m/min ($n = 800$ rev/min), $a_p = 1{,}35$ mm, $f = 0{,}075$ mm/rev, cutting tool with plate T15K6 ($\kappa_r = 90°$, $r_\varepsilon = 0{,}5$ mm), component of machining force, calculated for the given conditions - $F_p = 110$ N.

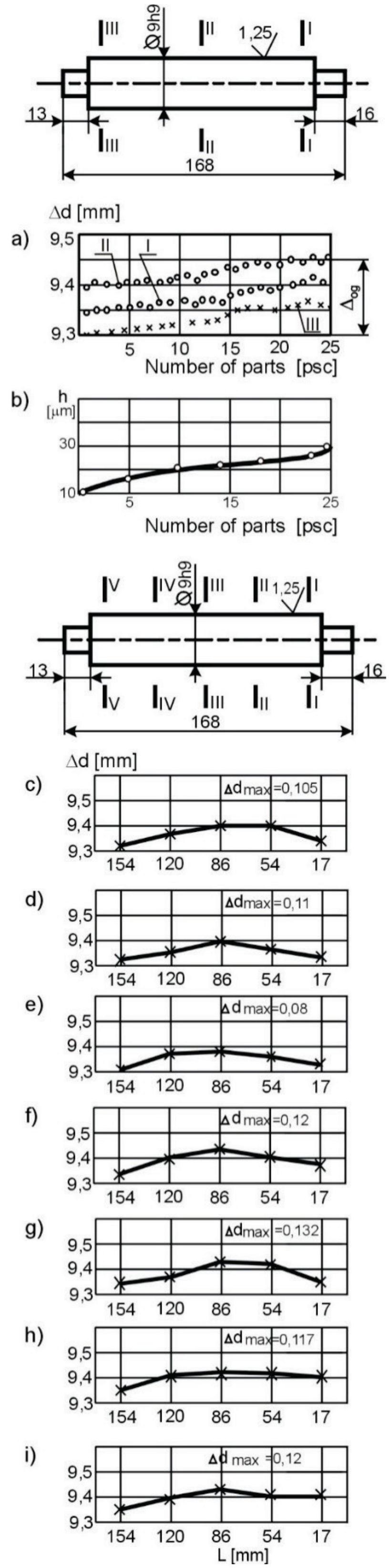

Figure 5 Diagrams of changes in form error and surface roughness of shafts

Analogously as in the case of machining of the batch of the drive shafts (Fig. 4), also for shafts dot diagrams of the area of scatter of dimensions were created (Fig. 5a), a diagram of surface roughness (Fig. 5b), and diagrams of form errors in the longitudinal section of the shafts (Fig. 5c, d, e, f, g, h, i) for seven random selected parts from a batch of 45 pieces. As can be seen in Fig. 5, the overall value of the scatter field was $\Delta_{og} = 0{,}14$ mm, with roughness in the range of $Ra = 3{,}5 - 5$ μm. Form error in the longitudinal section of the particular parts was $\Delta d_{\max} = 0{,}08 - 0{,}132$ mm, as a result of which the parts were forwarded to the grinding operation with non-uniform material allowance exceeding 0,3 mm, which increased the time and cost of machining. Similar repeatability of the results was obtained in the case of samples from other batches of machined parts.

In the second case under analysis the shafts were machined in a single pass, as grinding was adopted as the final operation. The element after turning should meet the following requirements: material allowance for grinding 0,3 mm, surface roughness in the range of $Ra = 2{,}5 - 5$ μm. Diagrams of changes in form error and surface roughness of the shafts are presented in Fig. 5.

In the study of the process of grinding of the shafts with low rigidity, shafts with low rigidity, for electrical micro-machines, were considered as the object of analysis, with geometric parameters of: $d = 2 - 12$ mm, $K = L/d = 15 - 25$, form accuracy (3 – 5 μm).

According to the technical requirements, rotors of the micro-machines should withstand long-lasting, up to 10-fold overload. That requires the achievement of high contact strength of the rolled connections between the shaft and the rotor. The results of industrial and operational tests show that one of the drawbacks of such devices is imperfect tightness of location of the rotor assembly. This leads to the appearance of vibrations and deterioration of technical characteristics of micro-machines.

4 ANALYSIS OF STIFFNESS OF ELEMENTS OF MGFT SYSTEM

Analysis of the effect of stiffness of the individual elements of the MGFT system and of machining parameters on the accuracy of machining in that system was conducted according to the schematic presented in Fig. 6.

Analytical expression of the function of deformations in the case of machining of a shaft in jaws (Fig. 6a) with the action of feed component F_f and thrust (radial) component F_p of the machining force can be obtained from the equation [24]:

$$y'' = -\frac{M(x)}{EI} \tag{1}$$

where: $M(x)$ – bending moments relative to axis x, E – modulus of elasticity, I – moment of inertia of the cross-section.

In this case we take into account the bending moments relative to axis x, because the deformation relative to that axis has the dominant effect on the form error in the longitudinal section of the part.

The need of taking into account the axial component of machining force F_x results from the fact that in the machining of the parts with low rigidity the interactions of component F_f and of the thrust force of the tailstock may lead to the loss of stability. The axial component F_c of machining force causes torsion of the part and in the case under consideration is not taken into account. We only consider the effect of bending on machining accuracy.

The change of the bending moment, in relation to the axial F_f and thrust F_p components of machining force, taking into account the reaction of each of the sections, can be written as:

- section I

$$M(x)_{\mathrm{I}} = -\frac{2F_{\mathrm{p}}(L-a)-F_{\mathrm{f}}d}{2L}x_1 \tag{2}$$

- section II

$$M(x)_{\mathrm{II}} = -\frac{2F_{\mathrm{p}}(L-a)-F_{\mathrm{f}}d}{2L}x_2 \tag{3}$$

where: a – distance from the point of part fixing to the point of action of machining forces

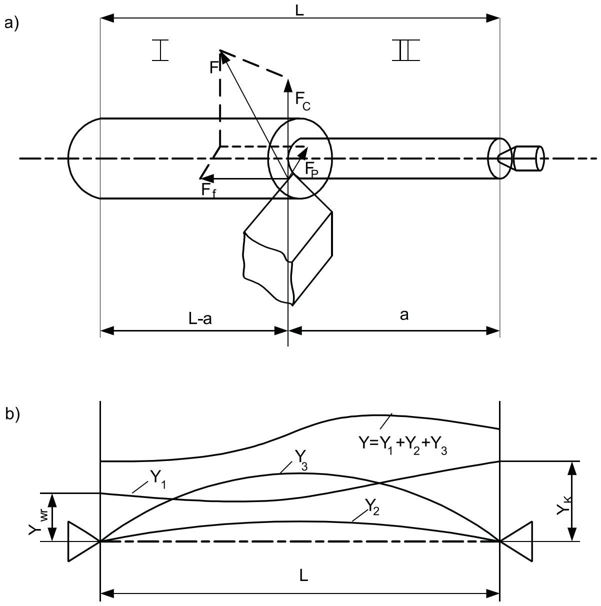

Figure 6 Schematic diagram of forces acting on the part (a) and elastic deformations UT (b) in the process turning

Taking into account Eq. (2), Eq. (1) can be written as:

$$y''(x)_{\mathrm{I}} = -\frac{1}{EI}\cdot\frac{2F_{\mathrm{p}}(L-a)-F_{\mathrm{f}}d}{2L}x_1 \tag{4}$$

After double integration of Eq. (1) we obtain:

$$y'(x)_{\mathrm{I}} = \left(\frac{1}{4}EIL\right)\cdot\left[2F_{\mathrm{p}}(L-a)-F_{\mathrm{f}}d\right]x_1^2 + C_1 \tag{5}$$

$$y(x)_{\mathrm{I}} = \left(\frac{1}{12}EIL\right)\cdot\left[2F_{\mathrm{p}}(L-a)-F_{\mathrm{f}}d\right]x_1^3 + C_2 \tag{6}$$

Integration constants C_1 and C_2 were determined from the boundary conditions which in this case coincide with the initial conditions, at:

$$x=0,\ y(0)=R_k\omega_k,\ x=L,\ y(L)=R_{wr}\omega_{wr} \tag{7}$$

where: $R_{wr} = \frac{2F_{\mathrm{p}}a+F_{\mathrm{f}}d}{2L}$ – reaction in the front support, $R_k = \frac{2F_{\mathrm{p}}(L-a)-F_{\mathrm{f}}d}{2L}$ – reaction in the rear support, ω_{wr} and ω_k – elasticity in the ear and front supports, respectively.

After taking into account Eqs. (3) and (4), the values of the integration constants were obtained:

$$\begin{aligned} C_2 &= \frac{2F_{\mathrm{p}}L-F_{\mathrm{f}}d}{2L}\omega_k \\ C_1 &= \frac{F_{\mathrm{p}}}{L}(\omega_{wr}-\omega_k)+\frac{F_{\mathrm{f}}d}{2L^2}(\omega_{wr}+\omega_k)+\frac{F_{\mathrm{f}}dL}{2EI} \end{aligned} \tag{8}$$

Reducing the point determined by distance x_1 to the point of action of machining forces, the functions of deformations at $x_1 = a = x$ were obtained. Eq. (6), taking into account Eq. (8), can be presented as:

$$\begin{aligned} y(x) = &-\frac{F_{\mathrm{p}}}{6EIL}x^4+\left(\frac{F_{\mathrm{p}}}{6EIL}-\frac{F_{\mathrm{f}}d}{12EIL}\right)x^3+ \\ &+\left[\frac{F_{\mathrm{p}}}{L}(\omega_{wr}-\omega_k)+\frac{F_{\mathrm{f}}d}{2L^2}(\omega_{wr}+\omega_k)+\frac{F_{\mathrm{f}}dL}{2EI}\right]x+ \\ &+\frac{2F_{\mathrm{p}}L-F_{\mathrm{f}}d}{2L}\omega_k. \end{aligned} \tag{9}$$

The introduction of coefficients at x permits the obtainment of the function of deformations in the form of a polynomial:

$$y(x) = Ax^4+Bx^3+Cx+D$$

Where: $A = -\frac{F_{\mathrm{p}}}{6EIL};\ B = \frac{F_{\mathrm{f}}}{6EI}-\frac{F_{\mathrm{f}}d}{12EIL}$ – coefficients taking into account the effect of bending moments, originating from components F_f and F_p of machining forces; $C = \frac{F_{\mathrm{p}}}{L}(\omega_{wr}-\omega_k)+\frac{F_{\mathrm{f}}d}{2L^2}(\omega_{wr}+\omega_k)+\frac{F_{\mathrm{f}}dL}{2EI}$ – coefficient taking into account the effect of elasticity of supports and part; $D = \frac{2F_{\mathrm{p}}L-F_{\mathrm{f}}d}{2L}\omega_k$ – coefficient taking into account the change of position of the main axis of the machine tool, with tool travel from the tailstock towards the headstock.

Effective utilisation of the accuracy of the machine tool requires that the values of elastic deformations of the part do not exceed the values of deformation of the nodes of the machine tool. This means that the following condition should be met:

$$\left|y(x)\right|_{\max} \le y_k \tag{10}$$

which is presented in the graphs in Fig. 6b, where y_k, y_{wr}, y_1, y_2, y_3 – elastic deformations of the tailstock, headstock, lathe and part, respectively.

Analytical relationships of changes of ratio $K = \frac{L}{d}$ and of the value of elasticity of headstock ω_{wr} and tailstock ω_k at $\lambda_1 = \frac{F_\mathrm{p}}{F_\mathrm{f}} = 0,5$ are presented in Fig. 7a.

Their analysis shows that with a reduction of elasticity (increase of stiffness) of elements of the MGFT system, for $d = 2 – 18$ mm, the maximum value of ratio K may decrease by as much as two-fold. This indicates that a part with a given diameter, $K = L/d$, machining forces acting on it, ω_{wr} and ω_k, can be machined with an accuracy that is determined by the characteristics of the machine tool.

Contemporary machine tools are characterised by increased stiffness of particular nodes and of the entire machine tool, and thus increasing values of K will correspond to increasing values of elastic deformations and reduced machining accuracy, which means that a part in a given MGFT system will have low rigidity. Analytical relationships of ratio K and the function of λ_1 (Fig.7b), at ω_k = 0,00004 mm/N, were obtained in an analogous manner.

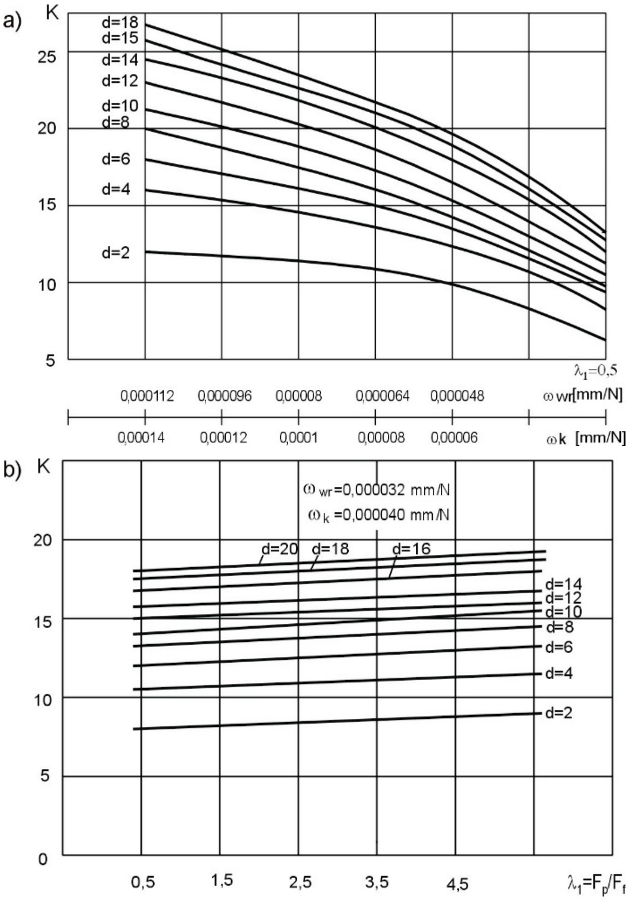

Figure 7 Analytical relations of changes in the maximum ratio $K = L/d$; a) in relation to the elasticity of the elements of the MGFT system $K = f(\omega)$ at λ_1 = 0,5; b) in relation to the machining parameters $K = f(\lambda_1)$

Machining depth $a_\mathrm{p} = 0,5 \div 2$ mm at $\kappa_r = 45°$, $\gamma = 0$, $r_\varepsilon = 0$ and $f = 0,055$ mm/rev affects the machining forces and the ratio of $\lambda_1 = 1,285 \div 1$. At $a_\mathrm{p} = 0,5$ mm and $f = 0,055 \div 1,75$ mm/rev the ratio of λ_1 varied within the range of $\lambda_1 = 5 \div 1,7$. Change of the cutting tool edge angle in the range of $\kappa_r = 45° \div 90°$ at $a_\mathrm{p} = 0,5$ mm, $f = 0,055$ mm/rev causes the change of $\lambda_1 = 1,285 \div 0,38$, and at $a_\mathrm{p} = 0,5$ mm, $f = 1,75$ mm/rev – $\lambda_1 = 5 \div 1,5$. As it follows from the analytical relationships, changes in machining parameters a_p, f, cutting tool geometry, and thus also in the value of λ_1, cause changes of the value of ratio $K = L/d$ from 10 to 12%.

Based on the analysis of the analytical relations (Fig. 7) one can formulate the conclusion that the most effective means of automatic control of the accuracy of forming the given class of parts with $d = 2 – 18$ mm, taking into account the elasticity of the MGFT system, are methods of control of the elastic-deformable state of the parts. The rigidity of the parts. $K_{cz} = \frac{EI \cdot K_i}{L^3}$ (K_i – coefficient dependent on the kind of the supports), is proportional to the fourth power of the diameter and inversely proportional to the cube of the shaft length, and thus, in the MGFT system, it can be estimated through comparison with the stiffness of the supports and the stiffness of the system.

Assuming machining stiffness of $K_{skr} = (0,1 \div 10) \times 10^7$ N/m, support stiffness $K_\mathrm{pod} = 1 \div 10$ N/m, the zones of rigidity of parts with various diameters can be determined from the relations presented in Fig. 8.

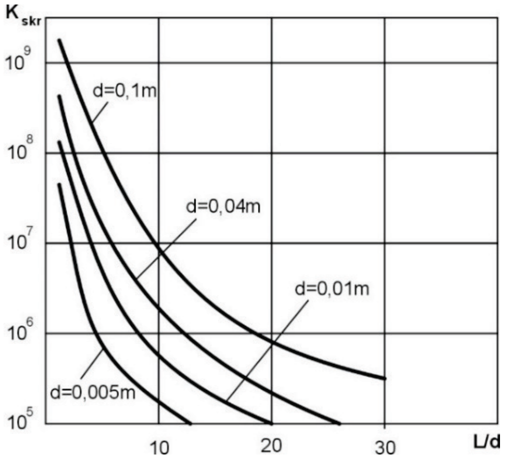

Figure 8 Correlation of stiffness of the system of turning and of the rigidity zones of parts

Increase of machining reliability is achieved as a result of reduction of the machining forces and of elastic deformations of the shafts. The application of multi-pass machining of the shafts with low rigidity, with gradual reduction of the depth of machining, is extremely uneconomical and causes a decrease of efficiency. The technological capacity of the machine tools is not fully utilised, a significant part of the material is turned the chips, the conditions of automated machining of the shafts with low rigidity are difficult, and it is necessary to apply additional means of ensuring safety of machining of those parts.

5 CONCLUSION

The traditional methods of achieving accurate machining of low-rigidity shafts, based on multi-pass machining, lowered parameters of machining, steadies and additional treatments and manual lapping, cause a significant lowering of efficiency, and in many cases preclude the achievement of required reliability; also, they are incompatible with the contemporary requirements of automation, they are uneconomical and inefficient. The provided analysis of machining errors of the drive shafts manufactured in conformance with the company technology shows that even after two turning passes their accuracy was insufficient and grinding was performed at non-uniform material allowance exceeding 0,3 mm, which causes an increase of the time and cost of machining. The tests conducted in the scope of the study (multi-pass and single-pass turning) demonstrated that the multi-pass machining of the shafts with low rigidity, with gradual decrease the depth of machining, is uneconomical – low efficiency.

The accuracy of machining of axial-symmetrical parts is significantly affected by the stiffness of elements of the MGFT system. Effective utilisation of the accuracy of the machine tool requires that the values of elastic deformations of the part should not be higher than the values of deformation of the nodes of the machine tool.

Analysis of the analytical relationships of changes in the value of K ($K = L/d$) and of the values of elasticity of the headstock and tailstock at $\lambda_1 = 0{,}5$ ($\lambda_1 = F_p/F_f$) shows that with a decrease of elasticity (increase of stiffness) of elements of the MGFT system, in the case of analysed diameters ($d = 2 - 18$ mm), the value of K (in relation to the maximum) may decrease even two-fold. Therefore, a part with specific values of diameter, $K = L/d$, machining forces acting on it, elasticity of headstock and tailstock, can be machined with an accuracy resulting from the characteristics of the machine tool.

Based on the study it can be concluded that in the case of the parts with diameters of $d = 2 – 18$ mm, the most effective, with the application of automatic control of the part forming and taking into account the elasticity of the MGFT system, is the control of the elastic-deformable state of the parts. Therefore the future research will be focused on the problem of computer aided control of the accuracy during the turning process. In particular we will try to implement artificial intelligence methods to control accuracy in the process of low-rigidity elastic deformable shafts turning.

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Contact information:

Antoni ŚWIĆ, Professor
Lublin University of Technology, Faculty of Mechanical Engineering,
Institute of Technological Systems of Information,
Ul. Nadbystrzycka 36, 20-618 Lublin, Poland
E-mail: a.swic@pollub.pl

Dariusz WOŁOS, PhD, Eng.
Lublin University of Technology, Faculty of Mechanical Engineering,
Institute of Technological Systems of Information
Ul. Nadbystrzycka 36, 20-618 Lublin, Poland
E-mail: d.wolos@pollub.pl

Arkadiusz GOLA, PhD, Eng.
Corresponding author
Lublin University of Technology, Faculty of Mechanical Engineering,
Institute of Technological Systems of Information
Ul. Nadbystrzycka 36, 20-618 Lublin, Poland
E-mail: a.gola@pollub.pl

Natalia SMIDOVA, RNDr., PhD
Technical University of Kosice,
Faculty of Electrical Engineering of Information, Department of Physics,
Park Angelinum 9, 040 01 Kosice, Slovakia
E-mail: natalia.smidova@tuke.sk