Development of a drive of micro movements of the metal-cutting machine tool with numerical control

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The design of a drive of micro movements for indemnifications of errors of processing on metal-cutting machine tools due to reorientation of the cutting tool concerning processable preparation is offered.

The important problems of mechanical engineering are improvement of quality of products and increase the productivity. One of the basic parameters of quality of products is accuracy. Requirements to increase of accuracy continuously increase. To well-known methods of increase of accuracy of the details processable on technological systems, concern: increase in static accuracy and rigidity of machine tools, the adaptations, the cutting tool and processable details; stabilization of temperature, use of the active control over indemnification of dimensional deterioration of the cutting tool and a number of others.

1 Technical project

As the task at designing a drive of micro movements following parameters are accepted:

Speed of system 2 kHz;
The maximal force of cutting 5 kN;
Size of movement at the maximal congestion of system 100 μm;
Capacity of the engine 14 kW.

2 Development of the block diagram of a drive

The block diagram of a drive is developed for designing system (figure 1). It is accepted, that the task is set in the form of analog signals of sizes of diameter of a site of a shaft which are necessary for receiving owing to processing on a lathe, and horizontal and vertical displacement of a cutting edge of a cutter concerning a theoretical axis of preparation (at processing by round shaped cutters and other cases). Diameter is set by a control panel or operating program on the machine tool with numerical control.

From a sensor control of accuracy of processing signals about the valid size of diameter and displacement of an axis of preparation concerning theoretical position move, then these sizes are compared to the task and their difference, an error, moves on a regulator of accuracy of processing.

The signal from a regulator of accuracy of processing is compared to a signal acting from the gauge of accuracy of positioning of the executive mechanism, and the mistake of positioning acts on an input of a regulator of accuracy of positioning. The regulator of accuracy of positioning submits the pressure proportional to demanded movement of a drive of micro movements. The executive mechanism influences processable preparation which parameters are measured with the gauge of accuracy of processing.

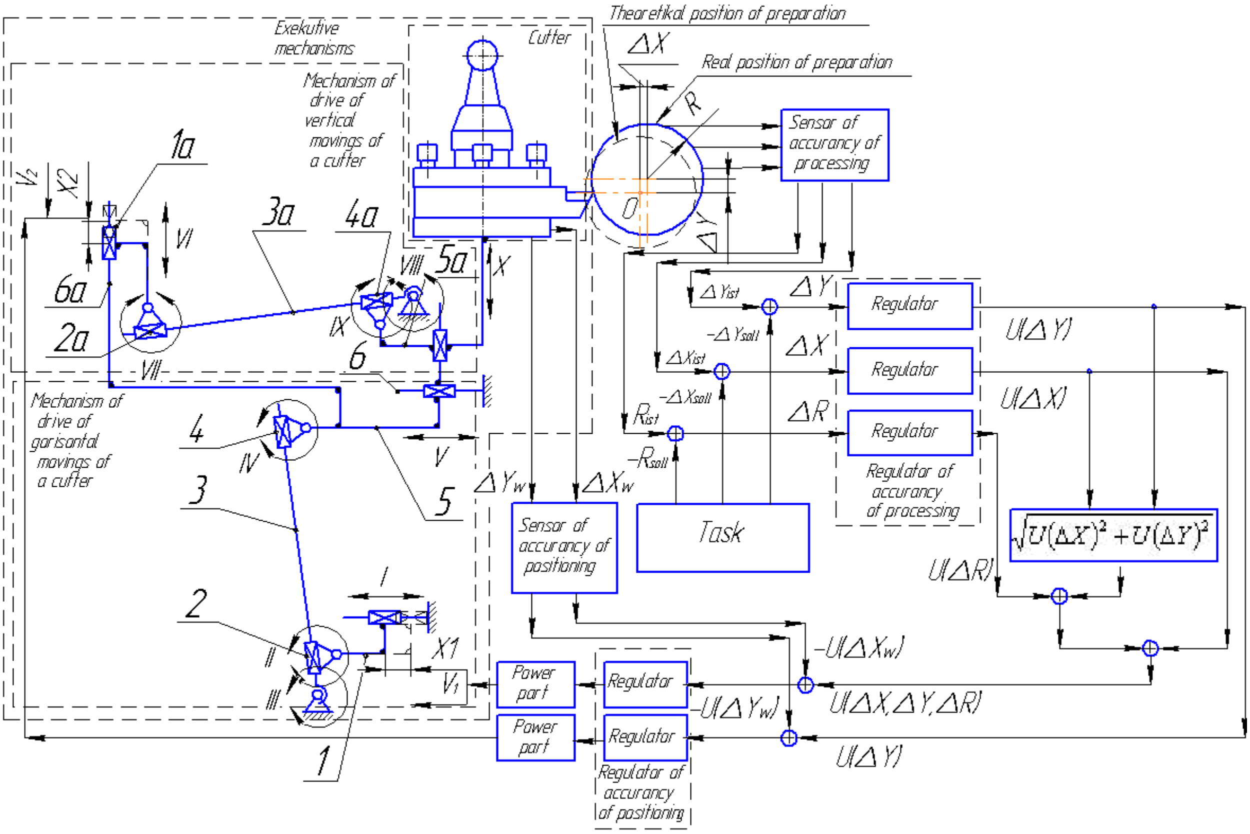

Figure 1. The scheme of system of the active control of accuracy of processing on a lathe.

3 Calculation of the module of multiplication of micro movements

Let's consider the piezoelectric module with lever system of multiplication (fig. 2). The purpose of calculation - definition of key parameters of the module at the set external influences.

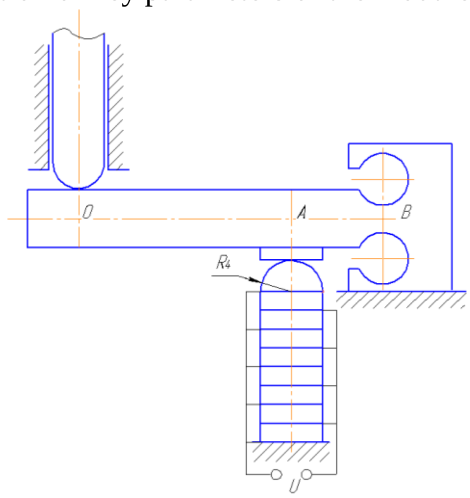

Figure 2. The scheme of the piezoelectric module with lever system of multiplication.

Let's present the settlement scheme of the device in the form of one-dimensional statically indefinable elastic system (fig. 3.a).

For definition of movements we shall use Mor method in view of cutting forces. We shall find movement in a point A, having put to her the individual force 1 directed upwards:

$$\xi_A = -\int_0^a 0\cdot Fx\lambda_1 dx + \int_0^{L_1} 1\cdot(x-a)[P(x-a)-Fx]\lambda_1 dx + \int_{L_1}^{L_1+b} 1\cdot(x-a)[P(x-a)-Fx]\lambda_1 dx + $$
$$+\int_0^{L_1} k\cdot 1\cdot Fy\gamma_1 dx + \int_{L_1}^{L_1+b} k\cdot 1\cdot Fy\gamma_2 dx,$$

where λ_1 - a pliability of section of the first site of a core in length L_1, λ_1 - a pliability of section of the second (thin) site in length b, γ_1 and γ_2-pliabilities of sections at shift of the first and second sites, k - factor of the form of section of a site. Having set by following values of parameters $\lambda_1 = 1{,}6\cdot 10^{-9}$; $\lambda_2 = 1{,}12\cdot 10^{-6}$; $\gamma_1 = 8{,}67\cdot 10^{-11}$; $\gamma_2 = 8{,}67\cdot 10^{-8}$, and having made calculations, we shall receive possible movement a point A at the maximal congestion of system without consideration opportunities movement of piezodrive. $\xi_A = 29{,}32$. µm.

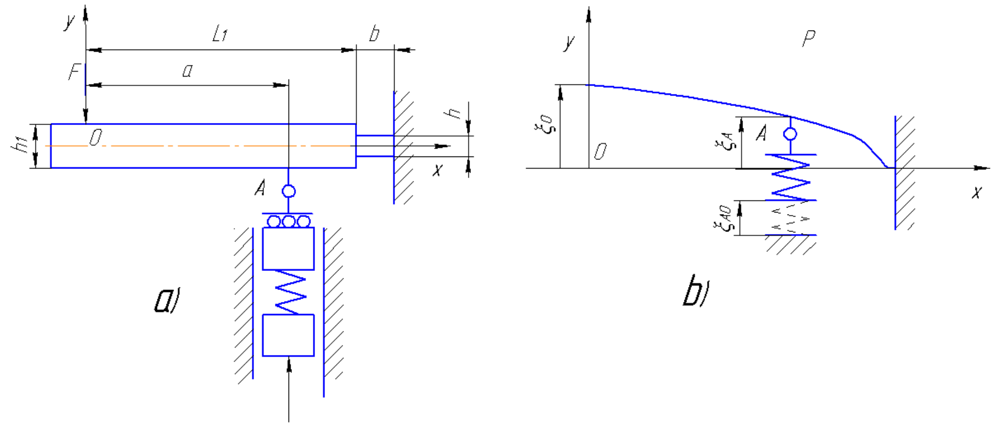

Figure 3. The settlement scheme of system of multiplication: and - the scheme of action of forces: b - the scheme of movements

On the other hand, movement of a working end face the piezoconverter ξ_{A0}, is defined by the formula:

$$\xi_{AO} = \frac{\frac{d_{33}}{h_p}\cdot U - \frac{s_{33}^E}{\Omega_p}\cdot F\cdot k}{1 + s_{33}^E\cdot\frac{\Omega_M}{\Omega_p}\cdot E_M}\cdot L_P$$

Having substituted numerical values it is received $\xi_{AO} = 22{,}82$ µm.

Movement of a point A in view of contact deformations of an insert of the lever and a spherical tip at their squeezing is defined as follows:

$$\xi_A = \xi_{AO} - \xi_K,$$

where ξ_K deformation of an insert of the lever and a spherical tip. Deformation ξ_K not linearly depends on P. Contact deformation is under the formula:

$$\xi_K = \left(\frac{1-\mu_3}{E_{M3}} + \frac{1-\mu_4}{E_{M4}}\right)\iint_\Omega \frac{q}{R_K}d\Omega = \frac{P}{\pi R_K}\left(\frac{1-\mu_3}{E_{M3}} + \frac{1-\mu_4}{E_{M4}}\right),$$

where E_{M3} and E_{M4} - modules of elasticity of an insert of the lever and a spherical tip, μ_3 and μ_4 Puasson factors for a material of an insert of the lever and a spherical tip, q - pressure in a zone of contact, R_K - radius of a spot of contact of a plane with a spherical surface, - the area of a spot of contact.

For a material of an insert of the lever and a spherical tip we shall accept alloy “ВК20”, E=5,3·105 MPa $[\sigma] = 2058$ MPa, hardness HRA 84. The maximal size of contact deformations which influences movement of a point A is equal $\xi_K = 5{,}1\cdot 10^{-6}$ m.

As a result $\xi_A = 17{,}72$ µm. Now by Mor method we shall find movement ξ_0 in a point 0, having put in this point the individual force $\bar{1}$ directed upwards:

$$\xi_0 = -\int_0^a 1\cdot x\cdot Fx\lambda_1 dx + \int_a^{L_1+a} 1\cdot x\cdot[P(x-a)-Fx]\lambda_1 dx + \int_{L_1}^{L_1+b} 1\cdot x\cdot(x-a)[P(x-a)-Fx]\lambda_2 dx -$$

$$-\int_0^a kF\gamma_1 dx - \int_a^{L_1} k(F-P)\gamma_1 dx - \int_{L_1}^{L_1-b} k(F-P)\gamma_2 dx.$$

Having made calculations, we shall receive $\xi_0 = 116{,}9$ µm. In view of contact deformations and the maximal movement piezoceramics it is received $\xi_0 = 105{,}4$ µm.

The maximal force which can develop the compound converter, i.e. blocking force, is defined under the formula:

$$P_{\max} = \frac{d_{33}\cdot\Omega_P}{s_{33}^E\cdot h_P}\cdot U = 66{,}071kH,$$

where U – the greatest possible pressure submitted on piezoceramics, $\Omega_p = \frac{\pi}{4}\left(D_1^2 - D_2^2\right)$ = 0,001982 m^2 – the area of a face surface piezowashers, for the stamp of piezoceramics - “ЦТССт-3” a pliability of piezoceramics – s_{33}^E = 1,8·10-11, the piezoelectric module of piezoceramics at action of an electric pressure in a direction of deformations – d_{33}= 6,0·10-10, h_p = 0,5 *mm* – thickness of piezoceramics washers.

4 Calculation of a compound piezodrive

Let's consider compound piezodrive (fig.4), consisting of a package of piezoceramics washers strapped wire. The pressure moves how is shown on Figure.5.

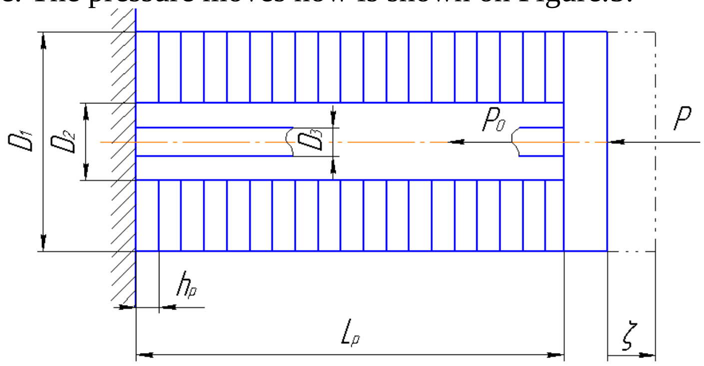

Figure 4. The Settlement scheme of the compound piezoconverter.

Let's calculate movement ξ of working end face of a piezodrive to a static mode. Let thickness of a piezowashers many times less than its diameter. In this case the equation of return piezoeffect will look like:

$$S_3 = s_{33}^E\cdot T_3 + d_{33}\cdot E_3,$$

where S_3 – relative deformation of one washer in an axial direction, T_3 – a mechanical pressure in the axial direction, arising in her, s_{33}^E – a pliability of piezoceramics, d_{33} – The piezoelectric module of piezoceramics, E_3 – intensity of an electric field. In our case the equation of return piezoeffect looks like:

$$\xi = \frac{\frac{d_{33}}{h_p} \cdot U - \frac{s_{33}^E}{\Omega_p} \cdot P}{1 + s_{33}^E \cdot \frac{\Omega_M}{\Omega_p} \cdot E_M} \cdot L_P ,$$

Having substituted numerical values, we shall receive $\xi = 22{,}82$ µm.

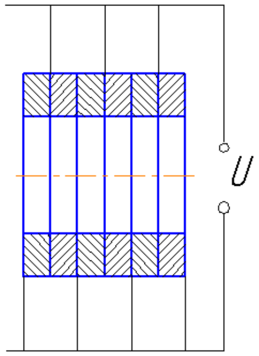

Figure 5. Connection of piezoceramics washers in section.

Piezoceramics – a fragile material, therefore piezowashers it is necessary to check up on durability at compression $T_{3\max} \le [T_3]$, where $T_{3\max} = \frac{P_{\max}}{\Omega_P}$ =33,3MPa – the maximal mechanical pressure of compression, $[T_3]$=400MPa – an admissible mechanical pressure of compression for piezoceramics. Restriction of a pressure is based not on durability of piezoceramics, and on admissible intensity of an electric field *[E3]* at which excess can occur depolarization piezoceramics [3]:

$$U_{\max} \le \frac{[E_3]}{h_p}$$

For the majority of piezomaterials [E_3] lays in a range of 1,0-1,5 kV/mm. The characteristic ξ=f(U) is linear at a working pressure up to 0,3U_{max}, therefore for MMC at thickness of a piezoelement h_p~1 the pressure usually does not exceed mm 300 ÷ 500 V [3]. For a special case when P = 0 we shall receive the maximal movement $\xi_{\max} = 93{,}82$ µm.

The developed principle and design of a piezodrive of micro movements allows raising accuracy of machining of preparations on the metal-cutting equipment with numerical control. The offered system allows compensating the errors connected with elastic properties of system, deformation of the machine tool including thermal, vibrations during machining, deterioration of the tool.

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(conclusions)

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