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Determination of Axial Forces of Tool Elements for Plastically Strengthening Hole Machining

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***Abstract*—When machining holes by burnishing, there is a direct relationship between the main parameter - the applied force and the geometric elements of the deforming rollers. This relationship can be determined by considering the force balance of the tool during operation. It is determined by the accuracy of the workpiece positioning and tool adjustment, and is expressed in the unevenness of the allowance, both in the transverse and in the proper section of the workpiece. The nature of the errors obtained and their magnitude depend, in addition to the accuracy of the relative position of the workpiece and the tool, on the scheme and operating mode. In order to simplify the analysis, it is necessary to neglect the friction forces during rolling and the magnitude of the elastic recovery of the material after burnishing. The tightness of the deforming elements is formed depending on the prescribed roughness of the surfaces, the type of material being processed and the type of tool. The rate of deformation of the machined holes is limited by the power of the machine and the design features of the deforming separator tool. This publication provides analytical dependencies for determining axial components of the deforming force using roller-ball separator tools for machining holes. Dependencies are derived for determining the optimal number of deforming elements ensuring a given accuracy of machined surfaces.The obtained analytical dependencies allow, under given production conditions, to ensure the necessary quality indicators of processing by changing the number of deforming elements and their radius in the tool design. From the condition for dynamic equilibrium of the support cone, the relationship between the cutting force and the deformation force can be revealed. This is a prerequisite for determining the transmission coefficients of the power chain for the two types of deforming elements - balls and rollers.**

Keywords— axial force, strain elements, holes, quality.

I. INTRODUCTION

The method of surfaces finishing of structural steels is based on strain of microroughness of surface layer of metal, which helps to form quality indicators of parts[1].

By means of burnishing in the conditions of force contact interaction of surface with deforming elements, performing a given movement and having a certain shape and geometry, a significant reduction in height of roughness of the cylindrical holes is obtained[2].[3].[4].The hardness of the metal of the deforming elements must be higher than the hardness of the processed metal and the roughness of the deforming surfaces is less than desired roughness of the processed surfaces[5].

During the force interaction in the contact zone between the strain elements and the processed surfaces, high pressure and stresses arise, which cause elastic and plastic deformations in the surface layer of the processed surface, as a result of this impact, the latter changes its roughness, and the surface layer changes its structure, physical-mechanical and chemical properties[6]. The purpose of this article is to determine the necessary axial force to overcome the friction forces of ball and roller deforming elements of combined tools for machining holes. This will allow the creation of methodologies for optimized technological parameters of burnishing process based on the roughness of the machined surfaces. Through a comparative analysis with the application of recommended and computational modes of cutting and burnishing processing, it is possible to obtain results for the efficiency of the process depending on the length of the tool.

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II. Materials and Methods

The analysis of the burnishing process requires a detailed consideration of force balance of the conical deforming rollers and deforming balls in their interaction with other structural elements of the tool and the machined hole[7].

The deforming elements are rollers and balls from standard rolling bearings[8]. The balls have a diameter of ϕ=8mm and ϕ=10mm. The conical rollers have a slope of 2°30' and 3°, and the large diameter is ϕ=6.5 mm and ϕ=8.2 mm with a length of 10 mm and 15 mm, respectively[9]. The radius of curvature at the deforming end of the rollers is ρ=2.5÷3 mm. The angle of the smoothing part φ_1, depending on the roller setting, is recommended to be minimal, and for steel machining it is 20'<φ_1< 50' φ_1=30' is selected. Standard rollers were used due to the difficulty in producing original ones in the conditions of single production by the factories - implementers of such tools.

The quality of the processed surfaces is also influenced by the type of connection of the deforming elements - rigid, elastic and with self-regulation[10]. For this purpose, when studying the operability of the combined tools, various designs were implemented, combined tools for processing holes.

The support cone and the separator of the tools are made of bearing steel with heat treatment to HRC = 62÷64[11]. The remaining elements are mainly made of medium carbon steel, heat treated to HRC = 40.

The deforming elements perform the role of a movable rest and a vibration damper in the system[12]. When working with such tools, a closed system is obtained, in which the energy of self-excited or forced oscillations is dissipated in the system of the cutting part, deforming part, workpiece and to a significant extent the remaining elements of the technological system are excluded.

III. Results and Discussion

It is known that the friction forces during deformation are determined by the dependence[13]

$$F_{mp} = F_N^{'} tg\varphi_1 = \mu F_N^{'} \tag{1}$$

where $F_N^{'}$ is the radial component of the normal force; μ - the coefficient of sliding friction ($\mu = tg\varphi_1$).

Based on the desire to accurately determine the force factors, the assumption is taken into account that the coefficients of sliding and rolling friction between the deforming rollers and the machined surface - and between the deforming rollers and the support shaft - are not equal to each other, i.e. each of them has a specific, discrete value.

Then it may be written:

$$F_{oв} = F_N^{'} tg\left(\alpha + \varphi_2\right) \tag{2}$$

where α is the angle at the apex of the cone of the deforming rollers; F_N - the normal force to the contact surface between the deforming rollers and the support shaft; $F_N^{'}$ - the radial component of the normal force; F_o - the axial component of the normal force .

The condition for equilibrium of the forces applied along the tool axis has the form

$$F_{oв} - F_{mp} - F_{mp1} = 0 \tag{3}$$

where $F_{oв}$ is the external axial force;

F_{mp} -sliding friction force between the deforming rollers and the processed surface;

F_{mp1} - sliding friction force between the deforming rollers and the separator.

Substituting (1) and (2) into (3), and expressing the external axial force after the corresponding trigonometric transformations:

$$F_{oв} = F_N^{'} \left[\frac{tg\alpha\left(1 - \mu\mu_1\right) + \mu + \mu_1}{1 - \mu_1 tg\alpha} \right] \tag{4}$$

In dependence (4) the denominator and the term in small brackets would have numerical values extremely close to unity and for this reason they can be ignored, in which case the error will not exceed 0.5%. In such a case, dependence (4) takes the form

$$F_{oв} = F_N^{'} \left[\mu + \mu_1 + tg\alpha \right] \tag{5}$$

Conditions (4) and (5) reflect the process of pure sliding of the deforming roller when entering or leaving the machined hole until the completion of the machining. They also make it possible, during the experimental study of the processes, to indirectly judge the magnitude of the normal deforming force by the magnitude of the axial force. This dependence is also valid for tools with cylindrical rollers, in which case it takes the form.

$$F_{oв} = F_N^{'} \left[\mu + \mu_1 \right]. \tag{6}$$

The determination of the forces acting on the deforming element is shown in Fig. 1, *a* - for the deforming element ball, and in Fig. 1, *b* - for the deforming element roller.

From the condition for force equilibrium for deforming elements balls, the following dependencies are obtained:

$$F_c = F_{n1} \sin\frac{\varphi}{2} + F_{n2} \sin\alpha \tag{7}$$

$$F_{n2} = F_{n1} \frac{\cos\frac{\varphi}{2}}{\cos\alpha} \tag{8}$$

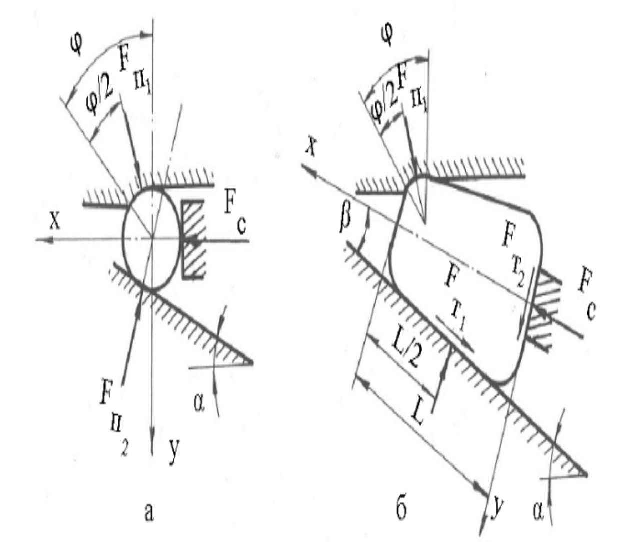

Fig. 1. Loading of the deforming element:a) ball;b) roller.

For deforming elements rollers, the following relationships are obtained:

$$F_c = F_{n1}\sin\left(\alpha-\beta+\frac{\varphi}{2}\right) - F_{n2}\left(\sin\beta + f\cos\beta\right) \quad (9)$$

$$F_{n2} = F_{n1}\frac{\cos\left(\alpha-\beta+\frac{\varphi}{2}\right) - f\sin\left(\alpha-\beta+\frac{\varphi}{2}\right)}{\cos\beta\left(1-f^2\right)-2f\sin\beta} \quad (10)$$

$$F_{n2} = F_{n1}\frac{\cos\psi - f\sin\psi}{\cos\beta\left(1-f^2\right)-2f\sin\beta} \quad (11)$$

$$F_{n2} = F_{n1}\frac{\cos\psi - f\sin\psi}{\cos\beta\left(1-f^2\right)-2f\sin\beta}. \quad (12)$$

From the dynamic equilibrium condition of the support cone, the relationship between the cutting force and the deforming force can be revealed. The loading of the cone is shown in Fig. 2.

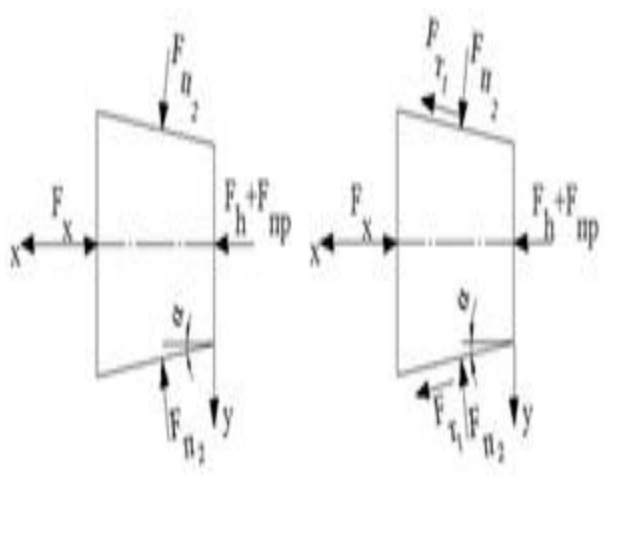

Fig. 2. Loading of the support cone: a) for a ball deforming element; b) for a roller deforming element.

For deforming elements such as balls, this relationship is expressed by the dependence:

$$F_x = zF_{n1}tg\alpha\cos\frac{\varphi}{2} + F_{np} + F_h \quad (13)$$

For deforming elements rollers the dependence has the form:

$$F_x = zF_{n1}\frac{\left(\cos\psi + f\sin\psi\right)\left(\sin\alpha + f\cos\alpha\right)}{\left(1-f^2\right)\cos\beta - 2f\sin\beta} + \quad (14)$$
$$+F_{np} + F_h$$

Here F_{np} is the force from the spring included in the tool;
F_h - the force from the hydraulic system;
z - the number of deforming elements.

From expressions (13) and (14) by differentiation, the transmission coefficients of the power chain can be determined, respectively, for deforming elements balls and rollers:

$$\frac{dF_x}{dF_{n1}} = ztg\alpha.\cos\frac{\varphi}{2} \quad (15)$$

$$\frac{dF_x}{dF_{n1}} = z\frac{\left(\cos\psi + f\sin\psi\right)\left(\sin\alpha + f\cos\alpha\right)}{\left(1-f^2\right)\cos\beta - 2f\sin\beta} \quad (16)$$

Dependencies (15) and (16) can be represented in the form:

$$\frac{\partial F_x}{\partial F_{n1}} = K_c z \quad (17)$$

$$\frac{\partial F_x}{\partial F_{n1}} = K_p z \quad (18)$$

where $K_c = tg\alpha.\cos\frac{\varphi}{2}$

$$K_p = \frac{\left(\cos\psi + f\sin\psi\right)\left(\sin\alpha + f\cos\alpha\right)}{\left(1-f^2\right)\cos\beta - 2f\sin\beta}.$$

From the expressions of the total differential of the functions (13) and (14), by moving to finite increments of F_x and Fn1, we can write:

$$\Delta F_x = \Delta F_{n1}\frac{\partial F_x}{\partial F_{n1}} \quad (19)$$

The permissible fluctuation of the deforming force can be determined from the condition for ensuring the quality of the surface treated with burnishing [2]:

$q = \left(1{,}8 \div 2{,}1\right)\sigma_s$

Therefore, where we can obtain an expression for the permissible fluctuation of the deforming force:

$$\Delta F_{n1} = 0,3\pi\sigma_s \left(r.\sin\varphi\right)^2 \qquad (20)$$

After substituting in (19) the partial derivatives with expressions (17) and (18) and the permissible change of the deforming force in expression (20), we obtain:

$$\Delta F_x = 0,3\pi\sigma_s \sin^2\varphi.r^2.K_c.z \qquad (21)$$

$$\Delta F_x = 0,3\pi\sigma_s \sin^2\varphi.r^2.K_p.z \qquad (22)$$

From expressions (21) and (22) the condition for ensuring the quality of the processed surface can be obtained:

$$zr^2 = \frac{F_x}{0,3\pi\sigma_s \sin^2\varphi.K_c} \qquad (23)$$

$$zr^2 = \frac{F_x}{0,3\pi\sigma_s \sin^2\varphi.K_p} \quad . \qquad (24)$$

The obtained dependencies (23) and (24) allow, under given production conditions, to ensure high-quality processing by varying the number of deforming elements and their radius in the tool design[14].[15].

IV. Conclusions

Based on the derived analytical dependencies for determining the axial force during burnishing of cylindrical surfaces with rolling and ball separator tools, it is possible to ensure specified quality indicators of the surfaces. This is achieved by adjusting the number of deforming elements, providing the necessary friction forces during sliding during burnishing of cylindrical rotational surfaces.

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