Mathematical Statistician and Engineering Applications
ISSN: 2094-0343
2326-9865

Application of Energy-Saving Airflow Technology for Finishing and Strengthening Processing of Thin-Walled Cylindrical Parts

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Article Info
Page Number: 6982-6999
Publication Issue:
Vol. 71 No. 4 (2022)

Article History
Article Received: 25 March 2022
Revised: 30 April 2022
Accepted: 15 June 2022

Abstract

This article examines the results of research on the application of the energy of swirling air flows in the finishing and strengthening processing of thin-walled cylindrical parts. The main goal of the research is the point contact of the ball with the treated surface, which provides high specific pressures on the walls of the part at low loads, the simplicity of the design and the relatively low cost of the tool causes the use of ball rolling for finishing and hardening processing of thin-walled and low-rigid parts with a large ratio of length to the outer diameter and wall thickness. It is hoped that after results obtained from the research will ensure significant advantages such as developing the concept of aerodynamic effect-based production, aerodynamic action of finishing and strengthening processing of thin-walled cylindrical parts, obtaining surface roughness in high accuracy.

Keywords: ball rolling, cylindrical parts, pressure, finishing, hardening, vortex effect, wall thickness, roughness, air flow, forces.

INTRODUCTION

Currently, research is being conducted in the world practice to optimize the use of energy resources, the development of energy-saving equipment and technology and their introduction into production. Taking into account the peculiarities of control and management of technological processes of production in the developed countries of the world, the concept of the development of scientific and technological progress is one of the urgent problems in the development of high-performance reliable, energy-saving, technological equipment in all industries. In this regard, the developed countries of the world, such as the USA, Germany, Japan, South Korea, China, Russia and others have achieved certain achievements in improving productivity, and product quality and ensuring their performance, reducing the cost of manufacturing products [1].

The development of modern mechanical engineering in Uzbekistan requires solving several problems related to increasing the durability and reliability of machines and mechanisms produced by the domestic industry. These problems should be solved through the use of new high-performance progressive technological methods and means of increasing the wear resistance and fatigue strength of parts, improving their quality and accuracy of surface treatment.

Considering that the latest achievements in the field of control systems, both individual automata and their complexes, have been increasingly used in the development of automated technological equipment. However, for several years, the principles of the construction of executive mechanisms have remained virtually unchanged. There are no developments where the actuator would perform its functions without using drive mechanisms [2].

Currently, high performance and reliability requirements are imposed on technological equipment. However, their development and design using non-traditional methods is not at the proper level.

One of the ways to solve this problem is the use of progressive methods, which, along with the automation of the process, make it possible to simplify the design of device elements.

The analysis of the processes of aerodynamic action showed that a method using the energy of swirling air flows is potentially possible. However, to date, well-known developments have not investigated issues related to the use of the energy of aerodynamic flows for the automation of technological processes [3].

In the world, great importance is given to solving the complex scientific and technical problem of ensuring the required level of reliability and reliability of the information, the development and implementation of methods to ensure them, which determines the need of enterprises for technological equipment based on modern management methods. Fundamental research and unconventional design methods occupy a special place in the automation of complex tasks when designing a new type of equipment. Among other important tasks are the design, calculation and development of methods for automating technological equipment of aerodynamic action, providing increased productivity and high reliability, product quality, optimization of parameters of finishing and hardening processing with the help of control, technical and software tools. Upon gaining independence in the Republic, special attention is paid to constantly increase the requirements for reducing energy used and introducing highly efficient machinery and technology into production, increasing their reliability and productivity. Tangible results have been achieved in creating highly efficient control systems and improving the reliability of technological equipment and devices [4]. Therefore, increasing their efficiency is currently one of the priority tasks of production. The results obtained in the research work to a certain extent serve to develop measures for the introduction of high-performance, reliable automated technological processes and aerodynamic equipment into production. The University of Illinois at Chicago (USA), the Louvain Catholic Institute of (Belgium), the University of Canterbury (New Zealand), Hitachi, Mitsubishi Electric (Japan), Siemens (Germany), Wuhan University (China), Samara are actively engaged in research on automation of technological processes with the use of aerodynamic effect Aerospace University, Moscow Power Engineering Institute, Moscow State Technical University, Kazan University (Russia), Fergana Polytechnic Institute (Uzbekistan) [5].

The aerodynamic effect is used in studies on the separation of air into warm and cold in vortex tubes conducted at the Voronezh State Technological Academy (Russia), cleaning the interior of the kinescope from foreign particles at the Lviv Polytechnic Institute (Ukraine), when studying the dynamics of aircraft at the Kharkiv Aviation Institute (Ukraine), when developing devices for assembling cylindrical parts in "ENIMS", "Tsniitmash" (Russia), development of devices for monitoring threaded connections and connections at the Moscow State Technical University "STANKIN" (Russia) [6].

As a result of worldwide research on the improvement and achievements obtained by using the aerodynamic effect, it is considered appropriate to research the automation of technological equipment for processing the internal surfaces of cylindrical parts.

The scientific foundations of automation and control of technological processes and productions are developed and presented in the works of G.A. Shaumyan, L.I. Volchkevich, A.S. Pronikov, A.I. Dashchenko, N.R. Yusupbekov, H.Z. Igamberdiev, Sh.M. Gulyamov, A.M. Mamadzhanov and other scientists.

Automation of finishing and strengthening processing of cylindrical parts is developed and presented in the works of M.A.Balter, I.V.Kudryavtsev, Y.M.Kulakov, V.E.Zotkin, A.G.Odintsovo, Yu.G.Proskuryakova, V.V.Petrosov, D.D.Papshev, T. Yu.Stepanova, M.M.Saverin, V.M.Torbilo, Ya.S.Feldman, Yu.G.Schneider, P. I.Lizardin and other scientists [7-13].

However, scientific publications have not sufficiently considered the issues of finishing and strengthening the treatment of the internal surfaces of thin-walled cylindrical parts.

The use of ball rolling in many cases, despite the lower productivity compared to roller rolling, is due to the absence of a forced axis of rotation and the balls slipping relative to the workpiece. In addition, the point contact of the ball with the treated surface, which provides high specific pressures on the walls of the part at low loads, the simplicity of the design and the relatively low cost of the tool causes the use of ball rolling for finishing and hardening processing of thin-walled and low-rigid parts with a large ratio of length to the outer diameter and wall thickness [14-16].

Currently, ball rolling machines perform rigid and elastic actions, unregulated and adjustable.

RESULTS AND DISCUSSION

Elastic action rolls, the principle of operation of which is based on the elastic contact of the working deforming element with the surface to be processed, are intended only for finishing and strengthening processing, where the accuracy of the shape and dimensions of the hole are provided by pre-treatment. During dimensional finishing, rigid rolling is used, characterized by rigid contact of the working deforming element with the surface to be processed. At the same time, the correction of the shape and the hole occurs within insignificant limits.

The disadvantage of rigid rolling is rather large deformations that spread throughout the section of the part, which sometimes leads to a curvature of the axis of the part, a change in the geometry of the part and uneven roughness of the treated surface.

The main condition for the reliable operation of such rolls is the high accuracy of their manufacture. The location of the axes of all landing surfaces should not exceed 0.005 mm, and the difference in the diameters of the working balls in the kit should not exceed 0.001 mm [8]. The use of rigid action rolls also places increased demands on the accuracy of processing holes for rolling, since even small fluctuations in tension lead to a sharp change in the force and angle of indentation of the balls, which negatively affects the quality of the workpiece. In addition, when the rolling is in hard contact with the workpiece, it is necessary to determine its working size experimentally with great accuracy, as well as assign a very tight tolerance for processing the hole for rolling. Despite these disadvantages, rolling holes with balls and rollers have been widely used in tractors and automotive engineering for processing parts made of non-ferrous metals and alloys. Most often, rolls with ball-deforming elements rigidly fixed on conical mandrels are used. The tool is fed into the hole of the part fixed to the spindle of the machine with guaranteed tension, the part is rotated at a speed of no more than 50 m/min, and the tool is moved with a longitudinal feed not higher than S = 0.01 mm/ rev. Currently, hole rolling is also used in the electronics industry, for example, in the manufacture of film cold cathodes.

To obtain high adhesion of the cold cathode emission film, the surface roughness of the substrate should not exceed the values of Ra = 0.16-0.08 microns with the required geometry. The working surface on the parts is obtained on high-precision machines of model 1И611П using diamond boring and further surface stabilization by rolling with a rotating ball [1].

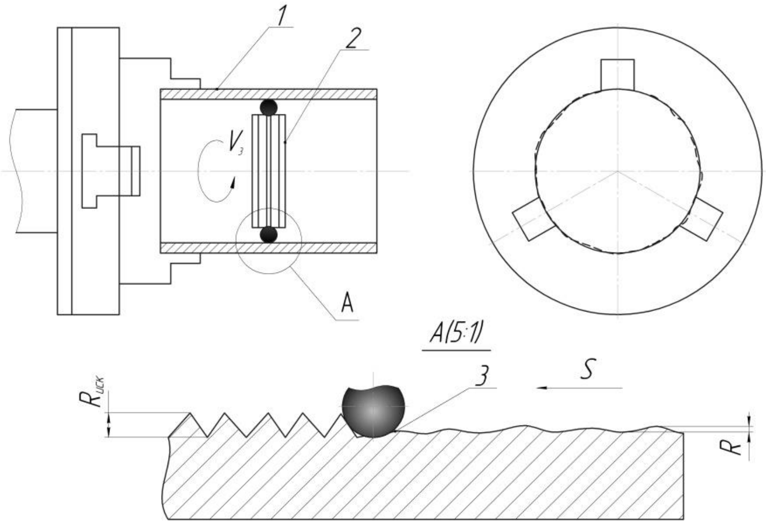


Fig.1. Scheme of finishing and hardening treatment of thin-walled

cylindrical parts by rolling out.

1-part; 2-ball rolling; 3-metal particles stuck to the working part of the rolling

The technological yield of thin-walled cylindrical parts (beryllium film) suitable for manufacturing operations is 60%. At the same time, out of 40% of technological losses, the share of semi-finished boring accounts for 19%, and for finishing cylindrical parts by rolling out a rotating ball about 21%. These losses are caused by the caricature of the surface, the change in the geometry of the part and the uneven roughness of the treated surface. In addition, practice shows that the use of existing technology for viscous steels and alloys (((BT0, BT5, Д16T) leads to the adhesion of the processed material to the working surface of the tool (rollout), which reduces the quality of processing (Fig.1).

Thus, the use of methods with deformation of surface irregularities in conditions of continuous contact of the tool with the treated surface (roller and ball rolling) does not always meet the increased production requirements. This is especially evident when processing the internal surfaces of special products with thin walls (less than 1 mm) when it is necessary to obtain a surface with a roughness of R_a=0,16÷0,08 microns while maintaining the required geometry of the part.

To obtain high-quality parts, the location of micro-dimensions on the surface of the workpiece is also of great importance, since the heterogeneity of shape and size, and the irregularity of their location lead to significant heterogeneity of the properties of the film in various parts of the part. A promising direction in this regard is methods and processes that ensure the formation of surfaces with a more uniform, regular microrelief. One such method developed by Russian scientists is the method of vibration rolling.

The essence of the method lies in the fact that the deforming element (ball) during processing, in addition to the main axial movement, is additionally informed of reciprocating motion along the axis of the workpiece with simultaneous movement perpendicular to the surface being processed with a certain frequency, the change of which is carried out according to a given law. The vibrating element (ball), making a complex movement relative to the treated surface, smoothes the initial micro-dimensions and forms a new micro relief.

The main advantage of the vibration rolling method is that by regulating the process of movement of the vibrating element (ball), it is possible to create a wide variety of microreliefs that differ in shape, relative position and number of them per unit surface. In addition, the complexity in the kinematics of the ball movement during processing makes it possible to significantly reduce the deformation force of the material, which creates conditions for processing thin-walled low-rigid parts.

However, due to the low productivity and cumbersome technical means, the method of vibration rolling has not yet found wide application in the industry.

Solutions to the above problems are possible with the use of progressive methods based on the energy of swirling air flows. A wide range of technological capabilities of aerodynamic flows, taking into account all their advantages, determined the direction of this work related to the development of new methods and devices of aerodynamic action for the automation of technological processes.

To verify the theoretical premises obtained, experimental studies were carried out on specially designed installations using modern measuring and recording equipment. The results of the experimental data were obtained by the methods of experiment planning, processed using the theory of automatic modelling and optimization methods

Existing methods and devices for processing the internal surfaces of cylindrical parts do not provide increased production requirements and are difficult to automate. Obtaining a working surface on thin-walled cylindrical parts, by rolling with a rotating ball, characterized by rigid contact of the working deforming element with the surface to be processed. The disadvantage of rigid rolling is rather large deformations that spread throughout the section of the part, which sometimes leads to a curvature of the axis and a change in the geometry of the part, uneven roughness of the treated surface. The technological yield of thin-walled cylindrical parts suitable for manufacturing operations is 60%. At the same time, of the technological losses, about 19% account for the share of half-finished boring, and 21% for finishing the part with a rolling roller with a rotating ball. These losses are caused by the caricature of the surface, the change in the geometry of the part and the uneven roughness of the treated surface. In addition, practice shows that the use of existing technology for viscous steels and alloys leads to the sticking of the processed material on the working surface of the rolling mill, which reduces the quality of processing. Due to the absence to date of physical and mathematical regularities of the processes occurring in aerodynamic devices, further research was carried out in stages [15-16].

At the first stage of the study, the regularities of the flow of aerodynamic flows in the design scheme chosen by us were determined and the interactions of the flow with a ball freely placed in it, and possible device options were considered, and the basic design for automated technological equipment was selected among them. To obtain a specific dependence that takes into account the influence of controlled factors on the rotation frequency of the ball and its force action on the surface, consider the interaction of the ball with the flow during the operation of the device. Considering that a stable rotating flow has been created inside the device, let us consider in more detail the causes and magnitude of the force acting on the ball placed in the vortex cavity of the chamber.

According to (Fig.2) the diagram of the forces applied to the ball, the gas flow flowing around the ball can be decomposed into two components: the axial $\overline{F}_z$ acting along the axis of the cylindrical pipe and the circumferential $\overline{F}_\tau$ acting tangentially to the cylindrical pipe. Each of them has a different effect on the ball. The axial component moves the ball along the axis of the pipe, the circumferential component causes the ball to rotate with a frequency proportional to the flow velocity and rotation around its own axis.

With a uniform rotation of the ball around the circumference, a component of the centrifugal force the $\overline{F}_{cent.}$ and the Coriolis force of the $\overline{F}_C$ acts on it. In addition, in a rotating flow, with a decrease in the radius, the air pressure drops, and the $\overline{F}_q$ force will act on the ball in the direction of the axis of rotation (Fig.1,2).

The resulting force of these components of the Cutters presses the ball with a certain force against the walls of the cylindrical tube and causes the reaction force to appear at the contact points.

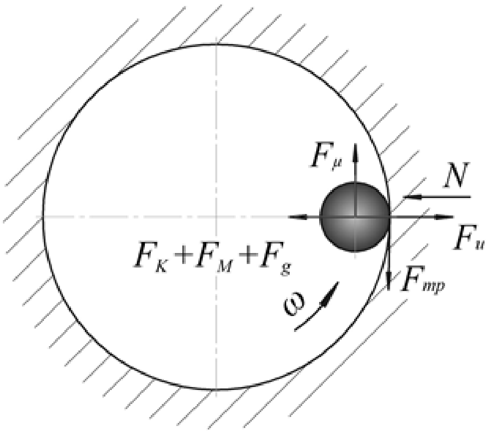


Fig.2. Calculation scheme of forces at the points of contact of the ball with a cylindrical surface

The problem of determining the resultant component of the force $\overline{F}_{res}$ acting on the ball is complicated by the fact that the flow is three-dimensional, high-speed and turbulent.

Therefore, the case was considered when the force exceeds the force of the weight of the ball and a situation of stable equilibrium arises.

The entraining force F_{μ}, acting on the ball from the flow side, can be decomposed into two components: axial and circumferential.

For the case under consideration, taking into account the assumptions, the axial component of the flow is $F_{\mu} \cdot \sin\alpha = P$, where P is the force of the weight of the ball.

In general, from the flow side, the Magnus force F will act on the ball, which is equal to:

$$F_{\mu} = C_x \cdot \pi \cdot r_{\omega}^2 \frac{\rho_n \cdot V_{отн}^2}{2} \tag{1}$$

As a result of the interaction of the ball with the cylindrical tube, a reaction force N will appear at the points of their contact, acting normally to the surface of the pipe in the direction towards the centre of the ball, and a friction force $F_{Тр}$ directed in the direction opposite to the movement of the ball. Rolling friction moments will also act at the points of contact of the ball with the cylindrical tube. Figure 2 shows a diagram of the forces at the points of contact of the ball with a cylindrical pipe in the plane perpendicular to the axis of the pipe.

$$F_{тр} = N \cdot K_{тр.кач} \tag{2}$$

The forces we have identified acting on the ball will be schematically depicted at the moment of contact of the ball with a cylindrical tube (Fig.2).

Based on the analysis of the obtained dependencies, we will compile an equation of forces on the ball for the case of uniform rotation, projecting all forces on the X and Y axes.

In general, the force projection equations on the coordinate axis can be written as:

$$\sum F_y = 0, \qquad F_{тр} = F_{\mu}$$

$$\sum F_x = 0, \qquad N = F_ц - F_k - F_{маг} - F_q,$$

$$N = F_{рез}$$

$$\sum M = 0, \qquad F_{\mu} \cdot r_ш = N \cdot K_{тр} \qquad (3)$$

Substituting previously obtained formulas for forces into equation (3), we obtain:

$$C_x \cdot \pi \cdot r_ш^2 \frac{\rho_п \cdot V_{отм}^2}{2} \cdot r_ш = \frac{m \cdot V_ш^2}{R_{вр}} \cdot K_{тр} \tag{4}$$

Knowing that $V_{отн} = V_п - V_ш$, let's determine the velocity of the ball relative to the flow:

$$V_ш = \frac{V_п}{1 + \sqrt{\dfrac{2mK_{тр.кач}}{C_x \pi \cdot r_ш^3 \cdot \rho_п \cdot R_{вр}}}} \tag{5}$$

The resulting expression (5) allows us to find with what force the ball acts on the treated surface.

The centrifugal force of pressing the ball to the surface can be determined by the formula

$$F_{цен} \cdot \frac{m_ш \cdot V_ш^2}{R_{вр}} = \frac{m \cdot V_п^2}{R_{вр}} \left(1 + \sqrt{\frac{2mK_{тр.кач}}{C_x \pi \cdot r_ш^3 \cdot \rho_п \cdot R_{вр}}} \right)^{-2} \tag{6}$$

With an increase in the flow velocity, the speed of ball movement along the treated surface increases proportionally, which, in turn, leads to an increase in the centrifugal force of ball compression to the surface. To ensure the conditions under which the process of deformation of the surface layer will occur, it is necessary to determine the contact stresses that occur during the contact of the ball with the treated surface.

At the same time, to simplify the task, we will make the following assumptions:

- We consider the surfaces to be absolutely smooth and unpolluted;

- We neglect the axial displacement relative to the surface.

The analysis of formula (4) shows that for the case under consideration, when a ball with a radius of $r_ш$ comes into contact with a cylindrical cavity of radius R, the rolling friction coefficient depends on the diameter of the ball, the ratio of the diameter of the ball to the radius of the workpiece, on the elastic modulus of the contacting bodies, on the force, as well as on the magnitude of the micro-dimensions of the surface layer.

With small contact spots, the boundary of the material flow region is so small that the dislocation mechanism of plastic deformations is disrupted. As a result, the yield strength of the material increases and, as a result, contact stresses at the contact point. In addition, the high speed of movement of the ball on the surface causes instantaneous contact of the ball with the surface and does not allow the flow process to develop. There are overvoltages of the surface layer.

It should be noted that the yield strength of the material during processing increases due to the riveting, which is caused by the high speed of movement of the ball along the treated surface and the presence of micro-impacts of the ball on the surface, resulting from the heterogeneity of the surface layer and turbulence of the vortex flow.

According to the above assumptions, the coefficient of rolling friction (Fig.3a) for the ideal case is equal to

$$K_{тр} = K \cdot a, \tag{7}$$

Where a - the value of the circular contact area;

K - a coefficient that takes into account the position of the resultant pressure force of the ball on the contact area (0<K< 1).

The value of the radius of the circular contact area is determined according to:

$$a = 0,9086 \sqrt[3]{\eta \cdot F_{ш} \cdot r_{п}} \tag{8}$$

Where $r_п$ - the reduced radius of the ball and cylinder at the point of contact, equal to $r_n = \dfrac{R \cdot r}{R - r}$. $F_Ш$ – the centrifugal force of pressing the ball to the surface; n is the elastic constant of the contacting bodies, equal to

$$\eta = \frac{1-\nu_1^2}{E_1} + \frac{1-\nu_2^2}{E_2} \tag{9}$$

Here ν_1, ν_2, и E_1, E_2 are, respectively, the Poisson coefficients and the elastic modulus of the ball and cylinder.

The value of the contact stresses between the contacting bodies can be written as:

$$\sigma = 0,5784 \sqrt[3]{\frac{F_ц}{\eta^2 \cdot r_n^2}} \tag{10}$$

or

$$F_ц = \frac{\sigma^3 \cdot \eta^2 \cdot r_n^2}{(0,5784)^3}$$

Substituting (9) and (10), in (8) we find the radius of the circular contact area

$$\alpha = 0,9086\sqrt{\frac{\sigma^3\cdot\eta^2\cdot r_n^2}{(0,5784)^3}\cdot\eta\cdot r_n} = 1,571\cdot\sigma\cdot\eta\cdot r_n \qquad (11)$$

In general, equation (11), taking into account the dependencies obtained above, can be written as follows:

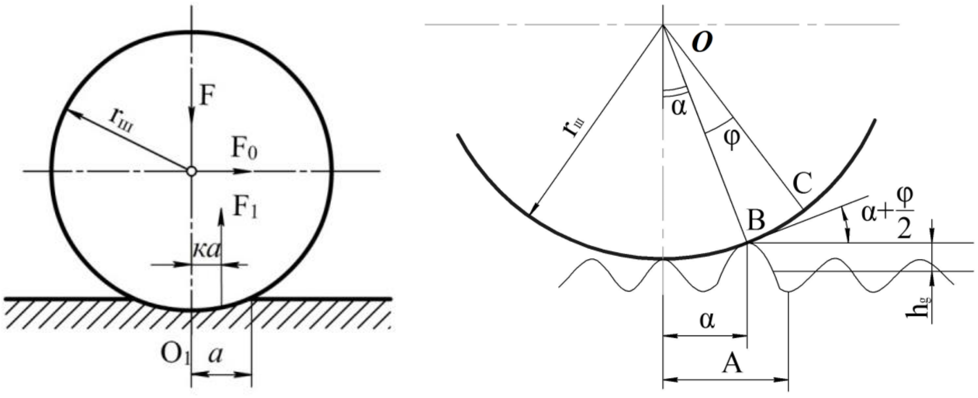
$$\frac{\sigma^3\cdot\eta^2\cdot r_n^2}{(0,5784)^3} = \frac{m\cdot V_n^2}{R\cdot\sqrt{\left(1+\frac{2mK_{тр.кач}}{C_x\pi\cdot r_ш^3\cdot\rho_n\cdot R_{вр}}\right)^2}} \qquad (12)$$

Substituting the value of the rolling friction coefficient in (12), after simple transformations, we obtain a dependence that allows us to determine the contact stresses arising from the interaction of the ball with the surface:

$$\sigma^3 = \frac{6318\cdot V_n^2\cdot r_ш^3}{\eta^2\cdot r_n^2\cdot R\cdot\left(1+\sqrt{58190\frac{K}{R}\sqrt{1.234\sigma\cdot\eta\cdot r_n^2}}\right)^2} \qquad (13)$$

Решение уравнения (13) с применением ЭВМ проводился при следующих параметрах: радиус стального шарика r=0,5÷3,0 мм, с модулем упругости E=2·10^{11} Па, коэффициентом Пуассона ν=0,3 контактирует с цилиндром R=10; 15; 20 мм, E=0,71·10^{11} Па, ν=0,3.

The solution of equation (13) using a computer was carried out with the following parameters: the radius of the steel ball r=0,5÷3,0 mm, with a modulus of elasticity E=2·10^{11} Pa, Poisson's ratio v = 0.3 contacts the cylinder R=10; 15; 20 mm, E=0,71·10^{11} Pa, ν=0,3.



a) b)

Fig. 3. Diagram of the formation of contact of the protrusions of the defective layer with the ball.

a – for the ideal case; b – taking into account the defective layer.

The magnitude of contact stresses during plastic deformation under real conditions is significantly affected by the presence of a defective layer (roughness, contamination of the oxide film, etc.). At the same time, the tops of the micro-dimensions are located at different levels, and the nucleation of zones of plastic deformation does not occur simultaneously in all contact spots.

Let's consider the case of the interaction of a ball with a surface, taking into account the presence of a defective layer, which is closer to real conditions.

Figure 3b shows a diagram of the formation of contact of the protrusions of micro-dimensions with the ball. In reality, due to the presence of dirt and micro-dimensions, the value of the rolling friction coefficient will be much higher than in the ideal case.

According to Fig.3 b, the rolling friction coefficient is equal to:

$$K_{mp} = K \cdot A \tag{14}$$

Where:

К – a coefficient that takes into account the position of the resultant pressure force of the ball on the contact area;

A – the size of the contact area, taking into account the defective layer, is equal in our case to A = R•sin (α+φ) or due to the smallness of α+φ

$$A = R\,(\alpha + \varphi). \tag{15}$$

From the triangle OBC, we find

$$\varphi = \frac{K}{r},$$

where

$$K = \frac{h}{\sin\left(\alpha + \frac{\phi}{2}\right)} = \frac{h}{\alpha + \frac{\phi}{2}} \tag{16}$$

here h - the height of the defective layer, equal to

$h = h_з + h_М$,

where $h_з$ is the height of the contaminated layer; $h_М$ is the height of the micro–dimensions.

In turn

$$\phi = \frac{h}{\left(\alpha + \frac{\phi}{2}\right) \cdot r_n} \tag{17}$$

where r_n - the reduced radius of the ball.

After simple transformations we get

$$\phi = \sqrt{\alpha^2 + \frac{2h}{r_n}} - \alpha \tag{18}$$

Substituting (18) into (15) and knowing that $\alpha = \frac{a}{2}$, we find the value of the contact area taking into account the defective layer:

$$A = \sqrt{a^2 + 2hr} \tag{19}$$

Where:

h - the height of the defective layer;

a - the size of the circular contact area.

Substituting (18) into (19), we obtain the value of the rolling friction coefficient, taking into account contamination and micro-dimensions

$$K_{mp} = K\sqrt{a^2 + 2hr_n} \tag{20}$$

Taking into account (19), equation (21) for the real case can be written as:

$$\sigma^3 = \frac{6318 \cdot V_n^2 \cdot r_ш^3}{\eta^2 r_n^2 R \cdot \left(1 + \sqrt{58190 \frac{K}{R} \sqrt{1,234\sigma^2 \eta^2 r_n^2 + h \cdot r_n}}\right)^2} \tag{21}$$

At h≥1,0 microns, this expression can be simplified:

$$\sigma^3 = \frac{6318 \cdot V_n^2 \cdot r_ш^3}{\eta^2 r_n^2 R \cdot \left(1 + \sqrt{58190 \frac{K}{R} \sqrt{h \cdot r_n}}\right)^2}.$$

Or at r<R (more than 10 times)

$$\sigma^3 = \frac{6318 \cdot V_n^2 \cdot r_ш}{\eta^2 \cdot R \cdot \left(1 + \sqrt{58190 \frac{K}{R} \sqrt{h \cdot r_n}}\right)^2} \tag{22}$$

The solution of equation (22) using a computer was carried out at the following parameter limits: h – from 0.2 microns to 10 microns; $R_{Ш}$ – from 0.5 mm to 3.0 mm. The R values were assumed to be 10, 15, and 20 mm.

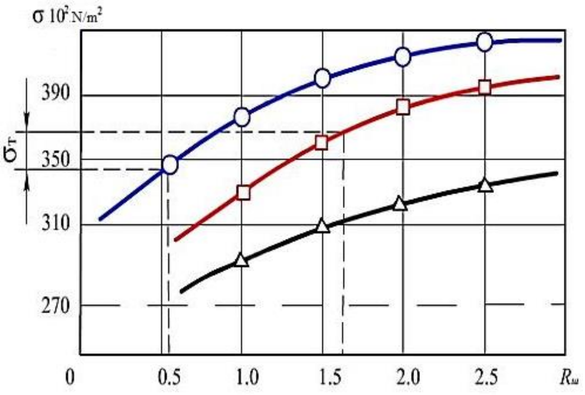


Fig.4. The effect of the radius of the ball on the contact voltage at

$V_{\text{п}}$ =90 m/sec, R=20 mm.

○ - at h= 2.5 microns; □ - at h=5.0 microns;

△ - at h=10 microns

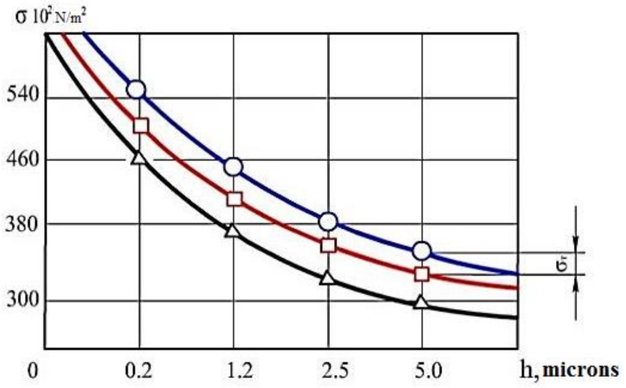


Fig.5. The effect of the defective layer on the contact voltage at $r_{\text{ш}}$ = 1.0 mm.

○ the value is at $V_{\text{п}}$ =100 m/sec; □ - when

$V_{\text{п}}$ =90 m/sec; △ at $V_{\text{п}}$ =80 m/sec.

The effect of the radius of the ball on the contact stresses at the flow rate $V_{\text{п}}$ = 90 m /sec, the radius of the workpiece R = 20 mm and p are shown in Fig.4. As the radius of the ball increases to $R_{\text{ш}}$ = 2.5 mm, its deforming effect increases and, as a consequence, contact stresses increase. As the height of the defective layer h increases, the contact stresses decrease (Fig.5). This is due to the fact that the presence of contamination on the surface of the workpiece, as well as condensation of water vapour of compressed air, creates a film layer on the protrusions of micro-dimensions, which prevents the approach of the contacting bodies. As follows from expression (21), the main parameter affecting the value of the contact voltage is the flow velocity $V_{\text{п}}$. This makes it possible to choose the operating parameters of the finishing and hardening treatment depending on the yield strength of the material and the initial state of the surface layer of the workpiece.

The results of measuring the distribution of static pressure in the nozzle section of the vortex chamber at different values of the inlet pressure show that with an increase in the inlet pressure, the static pressure at the walls of the chamber increases. Increased pressure on the walls of the vortex chamber leads to an increase in the radial gradient of the flow, which, in turn, increases the turbulence of the vortex flow in the zone of rotation of the ball. This phenomenon makes it difficult to carry out the finishing and hardening treatment of thin-walled cylindrical parts due to the increase in impact phenomena during processing. As you approach the axis of the part, the static pressure decreases and becomes negative (below atmospheric). The distribution of negative static pressure (vacuum) along the axis of the cylindrical part at different values of the relative distance from the nozzle section is shown in Fig.6.

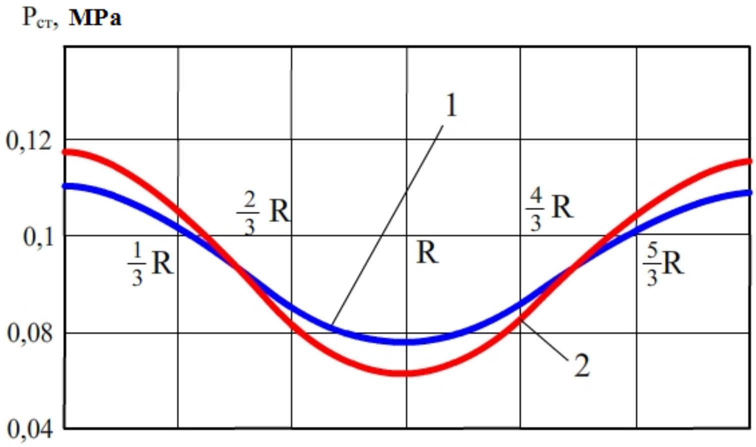


Fig.6. Distribution of static pressure in the nozzle section of the vortex chamber at different values of the inlet pressure

1 - at $P_{вх}$ = 0.2 MPa; 2 - at $P_{вх}$ = 0.3 MPa

The results obtained show that as we move away from the nozzle section, the difference between atmospheric pressure and the pressure on the axis of part ΔP decreases. As can be seen from the graphs, as we move away from the nozzle section, the negative static pressure field tends to equalize. However, this process proceeds relatively slowly at a relative distance from the nozzle section, L/D=5 and the zone of negative static pressure remains. Therefore, in this zone, which occupies 2/3 of the diameter of the part, there will be a suction of air from the atmosphere. This phenomenon has a negative effect on the upward movement of the balls due to the formation of an air damper. To eliminate it during processing, it is necessary to close the central part of the mesh partition by 2/3 of the diameter of the workpiece. Thus, the experiments have shown that the pressure change leads to a redistribution of aerodynamic flows, which in turn should cause a different rotation frequency of the balls along the length of the workpiece. In addition, the presence of deforming balls in the aerodynamic flow will lead to a restructuring of the flow movement, therefore, to a change in the rotation frequency of the balls. As a result, unevenness of processing along the length of the workpiece should be expected.

As studies have shown, with an increase in the length of the part, the rotation frequency of the ball decreases. This is due to the fact that the mass of the ball, the friction force that occurs when the ball comes into contact with the treated surface, reduces the energy of the flow.

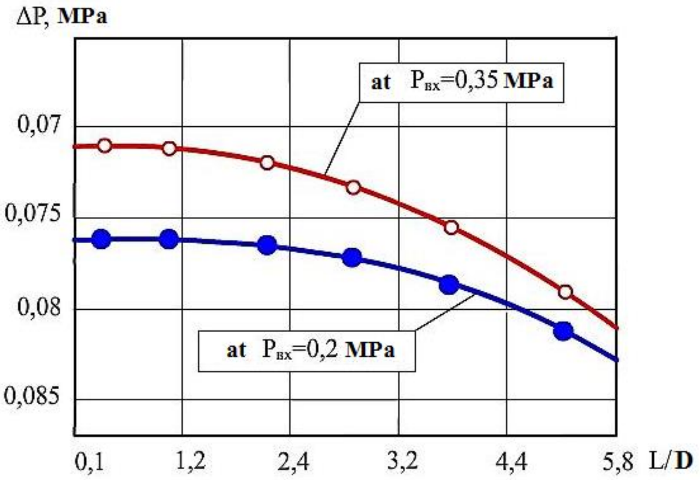


Fig.7. Distribution of negative static pressure along the axis of the cylindrical part at a relative distance from the nozzle section

Obtaining the required quality along the entire length of the part and achieving high performance of finishing and hardening processing is possible only with the simultaneous use of a large number of balls. An excessive increase in the requirements for the surface quality of semi-finished products, although it leads to a reduction in processing time, will significantly increase the costs of previous operations (Fig. 7). For example, for rolling with a rotating ball of the workpiece with a diameter of D_p = 40 mm, length L = 200 mm, the processing time is t_p = 10-12 minutes (rolling modes: n=160÷200 rpm; S=0.075 mm/min, the number of double passes is 2). In our case, for the above-mentioned part, the processing time is only t_p = 3 min. Such a comparison clearly shows the advantages of the attached method not only in terms of mobility and simplicity of the device, as previously noted but also in terms of performance.

In the conditions of scientific and technological progress, there is a revision of views on experimental research in the development of new technological processes. Solving the problem of automation and optimization of technological processes required consideration of the problem of object management, both in statics and dynamics. They are solved quite well with the experimental-static approach when the object was considered as a certain system with certain inputs and outputs. The main operating parameters affecting the output characteristics of the workpiece are the pressure of compressed air at the inlet to the vortex head $P_{ВХ}$, the diameter $d_{Ш}$ and the number of N balls.

Consider a technological process in which the output of roughness (R_a) after processing on the relative length of the workpiece depends on the diameter $d_{Ш}$, the number of balls N and the inlet pressure $P_{ВХ}$. The preliminary experimental studies made it possible to select ranges of variation of the diameter of the balls ($d_{Ш}$ = 1.6 - 3.5 mm) and the inlet pressure ($P_{ВХ}$ = 0.2 – 0.35 MPa).

In order to ensure the required productivity and mobility, and taking into account that the processing time is within 2-3 minutes, a scheme for the layout of parallel-acting technological equipment with the number of positions P = 4 was adopted.

The conducted tests of a pilot industrial sample of aerodynamic technological equipment introduced instead of the existing processing technology (rolling with a rotating ball) showed an increase in the cyclic productivity of one position by 4 times due to a reduction in processing time.

CONCLUSION

The main scientific provisions and the results obtained in the framework of the research are summarized in the following main conclusions:

1. The concept and methodology of automation of technological equipment for machine-building production based on the aerodynamic effect are substantiated and developed.

2. Scientific bases of calculation and design of the automated technological equipment of aerodynamic action of finishing and strengthening processing of cylindrical details, new designs of the automated devices carrying out the loading of flat products, transportation of small piece products, installation of rivets in a hole with a vertical and horizontal axis are developed.

3. It is established that the currently existing methods and means of the blade, finishing and hardening processing of thin-walled cylindrical parts do not allow obtaining roughness on the treated surface (R_a = 0.16-0.08 microns), which requires the development of new processing methods.

4. Methodology, scientific foundations and formalized methods of building automated technological processes and devices have been developed.

5. The theory of the process of contact stresses arising from a series of impacts of the ball on the treated surface is described, taking into account the heterogeneity of aerodynamic flows and the presence of micro-dimensions, which allows us to recommend optimal parameters of technological factors.

6. The interaction of aerodynamic flows with a free ball is theoretically described under the given parameters of the device when the resulting force ($F_{рез}$) exceeds the force of the weight of the ball and a situation of stable equilibrium arises.

7. It is shown that to increase the efficiency and reliability of the gripping organs of automatic manipulators, it is possible to use the effect of a swirling airflow to create a zone of reduced pressure (vacuum).

ACKNOWLEDGEMENT

The authors acknowledge the immense help received from the scholars whose articles are cited and included in references to this manuscript. The authors are also grateful to the authors/ editors/publishers of all those articles, journals and books from where the literature for this article has been reviewed and discussed.
The authors report no conflicts of interest.
The Source of funding is nil.

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