**Optimization of Parameters of Automatic Devices of Finishing and Hardening Processes using Aerodynamic Flows**

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**Abstract.** Тhe article describes the development, modelling, and optimization of devices designed for automatic finishing and hardening using aerodynamic action, which uses the energy of vortex airflow. It shows the experimental information about the ball motion in the vortex tube, which work without mechanical drives; it is a simplified design of the device of this kind, there is less friction and users check it less often. The focus is on several important pneumatic parameters such as pressure and circumferential flow velocity, and their heavenly effects on the efficiency of the processing. The study also emphasizes the difficulties associated with the random impact of the ball on the workpiece surface, which can impact processing quality. To this end, methods to minimize these influences are suggested, leading to more precise and repetitive surface treatment. Therefore, much of the study is devoted to adjusting vortex flow features to improve productivity and obtain uniform processing of the material being processed. The suggested system targets increasing efficiency at the same time keeping top quality finishing and hardening together with reworking of the air flows (for constitutional, quality and precision). These results can potentially lead to exploring better non-conventional machining techniques for industries that require precision surface grinding and minimal physical wear. This research overall gives insight into the aerodynamic finishing process, offering potential for more effective and long-lasting manufacturing solutions.

**Keywords:** automation, optimization, aerodynamic devices, vortex flows, pneumatic systems, finishing and strengthening treatment, non-driven devices.

**INTRODUCTION**

The concepts of automation of mechanical engineering production as the basis of technical policy are determined by the correct understanding of the content and main focus of automation work. As is known, technological processes are the main part of production processes and all potential possibilities of quality and quantity of manufactured products are laid in them. Therefore, automation of production in mechanical engineering is a complex design and technological task of creating new progressive technology, high-intensity technological processes and high-performance means. They, in turn, must be available for direct implementation by a human being [1-3].

This research was conducted within the advanced manufacturing conditions of “Ferpi Mech-Techno”, a state-of-the-art facility at the Fergana Polytechnic Institute. Equipped with modern CNC machines and designed for applied research in mechanical engineering, “Ferpi Mech-Techno” provided the ideal environment for experimental validation and optimization of automatic finishing and hardening devices utilizing aerodynamic flows. This setting ensured precise experimentation and data collection, enhancing the reliability of the proposed methodologies.

At present, aerodynamic flows are effectively used to transmit rotational motion to a part while maintaining, if necessary, several degrees of freedom.

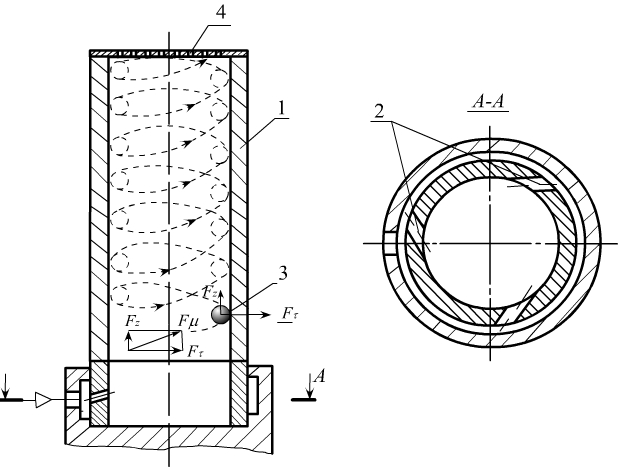
The indicated possibilities of aerodynamic flows are the basis for the development of non-driven automatic finishing and strengthening devices of aerodynamic action.

When selecting a design scheme, it is necessary to create a combination of device parameters that would make it possible to simultaneously impart movement to the ball in the circumferential and axial directions without the presence of any mechanical drive mechanisms.

An analysis of known developments has shown that a potentially possible method for solving the above problem is the use of the energy of swirling flows.

**METHODS**

If a vortex tube is installed vertically, its lower end is closed, and a free ball (balls) is placed inside the tube, then we obtain a device where, during the operation of the latter, the movement of the ball in the circumferential and axial directions is carried out only with the help of compressed air energy (see Fig. 1).



**FIGURE 1.** Calculation scheme of the aerodynamic device

The operating principle of this device is as follows: compressed air, entering the cylindrical pipe 1 through tangential nozzles 2, acquires rotational and axial motion. As a result of the interaction of the rotating flow with the ball 3 freely placed inside the device, which begins to rotate at a speed proportional to the air flow rate. The presence of axial flow velocities directed toward the exit of the cylindrical pipe creates an axial force for moving the ball along the pipe axis without any mechanical drive mechanisms [4-6].

Thus, we have the ability to perform all the above operations: feeding balls into the processing zone, their movement in the circumferential and axial direction only using the energy of the vortex rotating air flow.

If the role of the cylindrical vortex tube 1 is played by the workpiece, then finishing and strengthening treatment of its inner surface occurs.

Due to the absence to date of physical and mathematical laws of the processes occurring in aerodynamic devices for finishing and strengthening treatment, further research must be carried out in stages.

**RESULTS AND DISCUSSION**

At the first stage of the study, it is necessary to determine the pattern of functioning of aerodynamic flows in the chosen calculation scheme and consider the interaction of the flow with a ball freely placed in it. It is also necessary to consider the force action of the ball on the surface. At the second stage of the study, it is necessary to consider possible device options and select a basic option for solving a specific problem - for processing thin-walled cylindrical parts. It should be noted that the theoretical dependencies obtained at the first stage should be acceptable for the analyzed options.

Sequential execution of the specified stages will allow us to develop unpowered automatic aerodynamic devices. In this device, all operations: feeding balls into the processing zone, their movement in the circumferential and axial directions, i.e. the entire processing process should be carried out automatically without any mechanical drives or rigid connections.

Before moving on to theoretical descriptions of the processes in the calculation scheme, it is important to consider the phenomena that occur during the operation of the aerodynamic device.

The analysis carried out during the study showed that the nature of the processing is primarily influenced by aerodynamic phenomena that create forces. In the process of examining the aerodynamic forces of the flow acting on the ball, we encounter a unique problem that is at the junction of solid mechanics and aerodynamics.

An analytical description of such a problem is possible only if we have a solution to the equations of gas dynamics in a domain with a variable boundary.

In addition, it should also be noted that during the operation of the device, due to the heterogeneity and non-stationarity of aerodynamic phenomena and the presence of micro-roughness of the surface being processed, a series of impacts of the ball on the surface may occur. The moments of impact and their force are random quantities; an exact quantitative theory describing the processes of such impacts does not currently exist.

Significant difficulties are also presented by determining both the aerodynamic forces of the flow acting on the ball and calculating the movement of the ball when interacting with the vortex tube.

As is known, a stationary rotating flow moving in a hollow cylindrical pipe can be determined at each point in space by its following main parameters: pressure, velocity components (circumferential , axial , radial ) and flow density ρ.

The specified flow parameters can be determined taking into account the dependencies given in the works [7], [8-9].

Let us make a number of simplifying assumptions:

a) the distribution of the circumferential flow velocity in the nozzle section of the vortex tube is described by the law of a free vortex;

b) the distribution of static temperature along the radius in the vortex cavity obeys the adiabatic dependence

c) the flow of a steady gas stream in a vortex tube is assumed to be isentropic.

In accordance with the accepted assumptions, the circumferential flow velocity is represented as a constant in the range (see Fig. 2)

When in the range under consideration is determined mainly by the speed of air flow from the nozzle holes, i.e. it is assumed that when ,



Taking into account the assumptions, the initial system of equations has the form: Navier -Stokes equation of motion

 (1)



**FIGURE 2.** Schematic diagram of the movement of a ball in a hollow vortex tube.

Energy equation

 (2)

Continuity equation

 (3)

Equation of state

 (4)

The solution of this system is possible under the given laws of change :

- for free vortex;

 (5)

- for a forced vortex.

 (6)

Neglecting the axial velocity of motion, which affects only the perfection of the energy exchange process and taking into account that in the vortex separation zone it is equal to zero and the interaction of the balls with the flow occurs only in the free vortex zone, from the equations of motion (1), which in our case will take the form

 (7)

and expressions (4) and (5) can be used to determine the distribution of static pressure in a free vortex

 (8)

where *M -* the Mach number at the periphery of the free vortex, ;

*P 1 –* static pressure at the periphery of the free vortex in the nozzle section equal to *P*1 = (0.55÷0.60) *P*n;

*R -* current radius in the section under consideration;

*K -* the adiabatic coefficient (for air *K* = 1.2);

- critical flow velocity, equal to the local flow velocity;

*Vn -* air velocity from the nozzle holes;

*q -* gas constant; *Tr –* flow temperature in section *R - r.*

For a known value of static pressure in the section we have chosen, the corresponding flow density is found taking into account the equation of state of the gas and the adiabaticity of the flow and is expressed in the form:

 (9)

In accordance with the accepted assumptions, the peripheral velocity is presented as a constant in the range of the gap *R - r.* In the selected calculation scheme, the number of nozzles is three, therefore, it can be assumed that the velocity in the considered range *R - r* is determined mainly by the velocity of the air flow from the holes - nozzles.

According to [7], the speed of air flow from the holes – nozzles is equal to:

 (10)

where *Pout* - pressure at the outlet of the pipe;

*Pin* - pressure at the entrance to the vortex tube.

Considering that the rotation frequency of the ball in the device mainly depends on the peripheral velocity of the flow, we will find the law of distribution of the peripheral velocity in the rotating flow.

Taking into account the assumptions, the peripheral velocity in the nozzle section of the vortex tube in the range under consideration can be represented as:

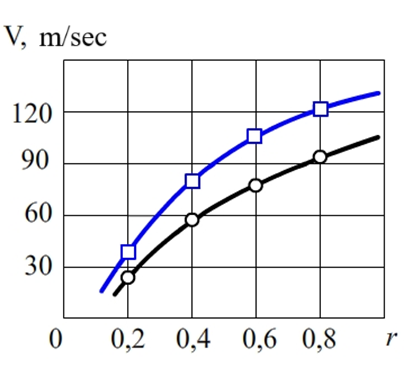
 (11)

Due to the fact that the constant in the range of gaps *R-r* is adopted, expressions ( 5) can be written

 (12)

Analysis of the obtained dependencies shows that in order to find a vortex tube in a specific nozzle section, it is necessary to specify not only the pneumatic parameters of the flow, but also the design parameters of the device.

Formula (3) shows the calculated value in the nozzle section of the vortex tube from the relative radius of the vortex tube with a diameter of the vortex chamber *Dc* = 19 mm, nozzle openings *dn* = 3 × 3.0 mm. As can be seen from the graph (see Fig. 3), the circumferential flow velocity increases with an increase in the relative radius of the vortex tube up to a certain value. A further increase does not lead to a significant increase in the circumferential flow velocity.



**FIGURE 3.** Dependence of the circumferential flow velocity on relative radius of the vortex tube:□- at input pressure *P* = 0.2 MPa; 🌕- at input pressure *P* = 0.3 MPa

Thus, the analysis of the dependencies obtained above allows us to conclude that by varying the design parameters of the device and the pneumatic parameters of the flow, it is possible to obtain such a relationship between them that the maximum circumferential flow velocities can be in the range indicated above.

To obtain a specific dependence that takes into account the influence of other factors on the rotation frequency of the ball, as well as its force impact on the surface, taking into account the specifics of rotating flows, we will consider the interaction of the ball with the flow during the operation of the device.

In this study, a method for automatic finishing and strengthening devices of aerodynamic action was developed and experimentally tested, using the energy of swirling air flows to set a ball in motion inside a cylindrical tube. During the experiments, it was confirmed that aerodynamic flows can effectively transmit rotational and axial motion to the ball without using mechanical drives.

**CONCLUSION**

The study showed that the use of aerodynamic flows in automatic finishing and hardening devices has significant potential for application in mechanical engineering, especially in the processing of thin-walled cylindrical parts. The use of swirling air flows to create rotational and axial movement of the ball opens up new possibilities in the field of automation of finishing processes, eliminating the need for mechanical drives and reducing equipment wear.

The key findings of the work are:

1. Vortex flows are capable of effectively transferring energy to moving particles, ensuring the required speed and uniformity of processing.
2. Control of pneumatic parameters (pressure, flow rate) allows the process to be adapted to different types of materials and part configurations.
3. Current limitations associated with accidental ball impacts can be eliminated by improving the design of the device and optimizing the air flow parameters.

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