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Research Methodology and Applications of Automatic Devices with the Usage of Aerodynamic Effects

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ABSTRACT:It is proved concepts and methodology of automation of technological equipment of machine-building production, is analyzed the scope of traditional methods and tools for finishing – strengthening treatment of internal surfaces of thin-walled cylindrical details, vacuum grippers for handling flat products, automation of installation processes and assembly of rivets in holes with a horizontal axis, application of aerodynamic effect in technological processes, is confirmed the purpose and research problems.It is shown that the existing methods and means of the surfactant treatment, a plastic deformation of internal surfaces of cylindrical parts, do not provide the increased production requirements because of low degree of mobility and it is difficult to automate.

KEYWORDS:finishing – strengthening treatment, vacuum grippers, aerodynamic effect, pneumatics

I. INTRODUCTION

The variety of tasks in the production of engineering products have high, ever-increasing demands for technological devices. In this regard, increasing their efficiency at present is one of the priority tasks of production.
Improving efficiency of manufacturing is primarily based on a more complete use of new high-performance modern technological methods and tools.
One solution to the above problems is the use of advanced methods based on different physical effects using energy swirling air flows (fig.1).

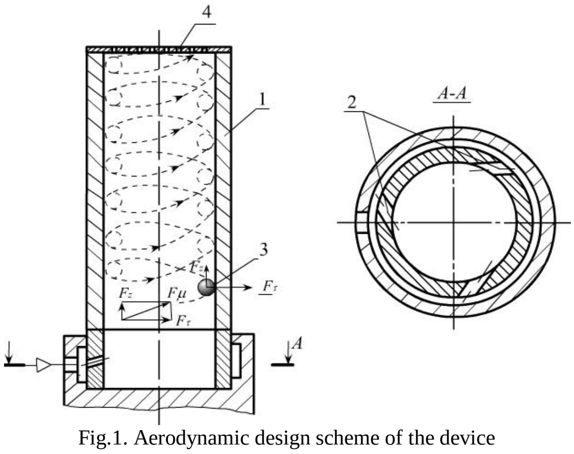

Fig.1. Aerodynamic design scheme of the device

A wide range of technological possibilities of aerodynamic flows, taking into account all their advantages determined the direction of the work associated with the development of fundamentally new methods and devices of the aerodynamic actions for process automation.

II. BACKGROUND

Receiving working surface on the thin-walled cylindrical details, by rolling-off with rotating ball, characterized by rigid contact with a working deforming element with the processing surface. A lack of rigid rolling is rather larger

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deformations extending on all section of details that sometimes lead to axis curvature, change of geometry of details and non-uniform roughness of the processed surface.

Technological yield on manufacturing operations of thin-walled cylindrical parts is 60%. Thus the share of technological losses for semifinished boring accounts about 19%, for fine-tuning the details with rolling-off rotating ball is 21% [1]. These losses are caused by charging of a surface, changing of detail geometry and a non-uniform roughness of the processed surface. Moreover, experience shows that application of existing technology for viscid steels and alloys leads to sticking of the processed material on the work surface of rolling that reduces the quality of processing.

One of the most important operations is largely determined by the performance in production of disks of the car is loading of slabs in technological equipment. For this operation, it is widely used the automatic manipulators supplied with grippers of various types. However the existing designs have restrictions of load-carrying capacity because of insufficient degree of vacuum in capturing area of a sucker.

In chemical industry for incidental pumping of acids, alkalis, easily volatile liquids (gasoline, alcohol, air, etc.) and other aggressive reagents are required mini pumps with a simple design of working bodies, quick launch preparation with frequent stops characterized by ease of maintenance.

Pneumatic transport devices allow to provide higher efficiency in comparison with devices of mechanical type, to save floor spaces, to provide the best working conditions. Known pneumatic transport devices of details with pressure head (delivery) and the ejector (soaking-up) type have poor reliability of work, especially at the turn of transport pipelines, leading to automated equipment. Products are got jammed in turn places, are exposed to a bearing strain, etc.

One of the problematic issues in mechanical engineering and instrument making is automation of assembly processes for piece goods and installation of rivets into holes with a vertical and horizontal axis.

III.PROPOSED METHODOLOGY AND DISCUSSION

In the first phase of the research identified regularities of aerodynamic streams in the chosen design scheme and interactions of a stream with the sphere (fig. 2) which is freely placed in it, optional versions of devices are considered and chosen among them the base for the design, the automated processing technological equipment.

For specific dependencies, considering the influence of controllable factors on the speed of the ball and the force of its impact on the surface we will consider the interaction with the flow of the ball during the operation of the device. Considering that it is created the stable rotating stream in the device, let us consider the causes and magnitude of the force acting on the ball in more detail, placed in a vortex cavity of a chamber.

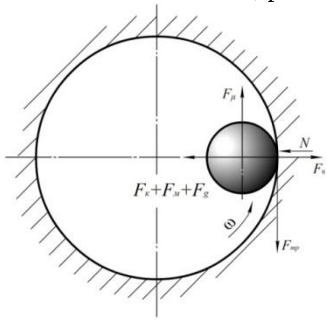

Fig. 2. Design scheme of forces at the points of contact of the ball with a cylindrical tube

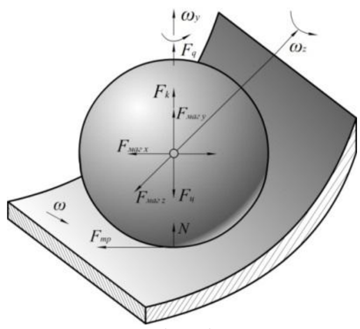

Fig. 3. General scheme of the forces applied to the ball

According to the design scheme (fig. 2), the flow of gas flowing around the ball, can be spread out into two components: the axial $\overline{F}_z$, acting along the axis of the cylindrical tube and a circumferential $\overline{F}_\tau$ acting tangentially to the cylindrical tube. Each of these differently effect on the ball. The axial component of the ball moves along the tube axis, the circumferential rotation of the ball causes a frequency proportional to the flow velocity and the rotation around its own axis.

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With uniform rotation of the ball along the circumference it is acted upon by a centrifugal force component $\overline{F}_{cen}$ and the Coriolis force $\overline{F}_{C}$. In addition, in a rotating flow with decrease of radius the air pressure falls, and the ball will be affected $\overline{F}_{q}$ in the direction of the axis of rotation (fig.2, 3).

The resultant force of these components $\overline{F}_{res}$ presses the ball with a particular force against the walls of the cylindrical tube and causes reaction forces at the contact points.
The problem of determining the resultant force component acting on the ball is complicated by the fact that the flow is three-dimensional, high-speed and turbulent.

Therefore, it is considered the case when the force $\overline{F}_{res}$ exceeds the weight force of the ball and there is a situation of stable equilibrium.
Carried out force F_{μ}, acting on the ball by the flow can be decomposed into two components: the axial and circumferential.
For the considered case axial component of flow with assumptions is $F_{\mu} \cdot sin\alpha = P$, where P - weight force of the ball.
In general, the ball will be affected by force of F_{μ} by the flow which is equal:

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

As a result of interaction of the ball with the cylindrical tube it will be a reaction force N in contact points, acting normal to the surface of the tube in the direction of the ball center, and the frictional force F_{fr} directed in the direction opposite the movement of the ball. In contact points of the ball with a cylindrical tube will act as points of friction bearings. Fig. 2 shows a diagram of the forces at the contact points of the ball with the cylinder tube in a plane perpendicular to the tube axis.

$$F_{fr} = N \cdot K_{ff} \tag{2}$$

The forces revealed by us acting on the ball schematically depict the moment of contact of the ball with the cylinder tube (Fig. 3).
Based on the analysis of the received dependence and knowing that $V_{rl} = V_n - V_b$, we will determine the relative speed of the ball to the flow:

$$V_b = \frac{V_n}{1 + \sqrt{\dfrac{2mK_{ff}}{C_x \pi \cdot r_b^3 \cdot \rho_n \cdot R_{rot}}}}, \tag{3}$$

The received expression (3) allows to find in some force acts on the ball surface to be treated.
Centrifugal force biasing the ball against a surface can be determined by the formula

$$F_{cen} \quad \frac{m_b \cdot V_b^2}{R_{rot}} = \frac{m \cdot V_n^2}{R_{rot}} \left(1 + \sqrt{\frac{2mK_{ff}}{C_x \pi \cdot r_b^3 \cdot \rho_n \cdot R_{rot}}} \right)^{-2} \tag{4}$$

With increase in the flow rate proportionally increases the movement speed of the ball along the surface to be treated, which, in turn, lead to increase of the centrifugal force urging the ball towards the surface.
To provide the conditions under which the process occurs deformation of the surface layer, it is necessary to determine the contact stress occurring during the contact of the ball with the processed surface.
To simplify the task we will make the following assumptions:

- surfaces is considered absolutely smooth and uncontaminated;
- neglect axial movement relative to the surface.

Analysis of the formula (4) shows that for the considered case when the ball is in contact with the radius r_b of the cylindrical cavity of radius R, the coefficient of rolling friction depends on the diameter of the ball, the ball diameter ratio to the radius of the workpiece, the modulus of elasticity of the contacting bodies of the load, and the magnitude of the microscopic roughness of the surface layer.

For small size of the contact points, the boundary of the flow of material is so small that the dislocation mechanism of plastic strains is broken. As a result the yield point of material and, as a consequence, contact pressure in a contact place raises. Besides, high speed movement of the ball on a surface causes the instantaneous contact of the ball with a surface and does not allow develop to flow ability process. There appears overstrains of the surface layer.

It should be noted that the yield stress of the material during processing increases because of work hardening, which is caused by high speed movement of the ball along the surface to be treated and the presence of micro-bumps on the surface of the ball, arising from heterogeneity of the surface layer and the turbulent vortex flow.

In reality due to existence of pollution and micro-roughness the value of rolling friction coefficient will be much higher than in the ideal case.

The equation for the real case can be written as:

$$\sigma^3 = \frac{6318 \cdot V_n^2 \cdot r_b^3}{\eta^2 r_n^2 R \cdot \left(1 + \sqrt{58190 \frac{K}{R} \sqrt{1{,}234\sigma^2 \eta^2 r_n^2 + h \cdot r_n}}\right)^2}. \quad (5)$$

The influence of the radius of the contact stresses at a flow rate $V_п$=90 *m/sec*, radius of the processed detail of *R*=20 *mm* and *p* are given in fig. 3. By increasing the radius of the sphere R_b=2,5*mm* its deforming action increases and, consequently, contact stresses growth. With the rise in the height of the defect layer *h* contact stresses decreases (fig. 5). This results from the fact that existence of pollution on the surface of the processed detail, and also condensation of water vapor of compressed air creates micro-roughness film layer which prevents convergence of the contacting bodies. As it follows from (5), the main parameters affecting to the value of the contact stress is the flow rate V_n.

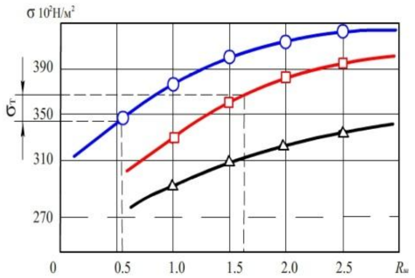

Fig.4. Influence of radius of the ball on a contact stress at V_p=90 *m/sec*, *R*=20 *mm*.
○ - *h*=2,5 *mcm*; □ - *h*=5,0 *mcm*;
△ - *h*=10 *mcm*

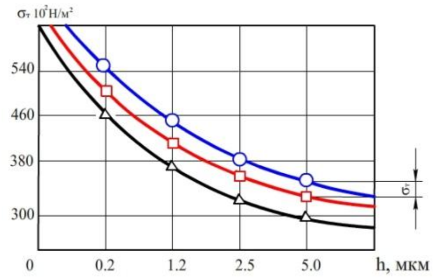

Fig.5. Influence of the defect layer on a contact stress at r_b= 1,0*mm*.
○ - $V_п$=100 *m/sec*; □ - $V_п$=90 *m/sec*;
△ - $V_п$=80 *m/sec*.

From fig. 3 it is seen that contact stresses grow with increase in a flow rate. Such result is natural as the increase in a flow rate leads to increase in a rotation frequency of the ball and therefore, centrifugal force of preload of a ball to a surface.

Another parameter that affects the value of contact stresses, is the radius of the workpiece (fig. 4).

The above received theoretical and experimental dependences allow to estimate impact force of the ball on a surface and to determine contact stresses at interaction of the ball with a surface.

The results of measurement of the static pressure distribution in the nozzle section of the vortex chamber at various values of inlet pressure are illustrated in fig. 6. With increase of inlet pressure static pressure increases in the chamber walls. The increased pressure on the walls of the vortex chamber leads to increase of the radial gradient of the flow, which in turn, increases the turbulence of the vortex flow in the rotation ball area. This phenomenon complicates carrying out the finishing and strengthening treatment of thin-walled cylindrical parts due to the increase of shock effects during processing. As approaching a detail axis static pressure decreases and becomes the negative (below atmospheric).

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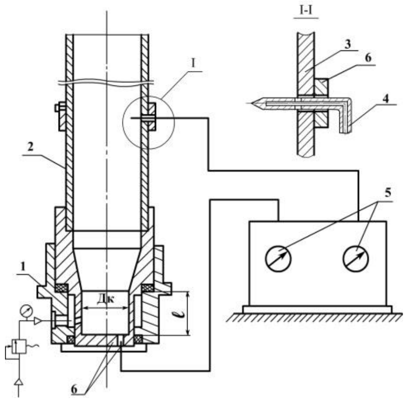

Fig.5. Equipment for measuring static pressure inside the cylindrical part.
1 - pneumovortex head, 2-cylindrical parts, 3- main sleeve, 4 static pressure receiver, 5 manometers, 6 channels for measuring the static pressure in the nozzle section of the swirl chamber and the length of the part.

Distribution of the negative static pressure (depression) on the axis of the cylindrical detail at different values of the relative distance from nozzle section is shown in fig. 7.

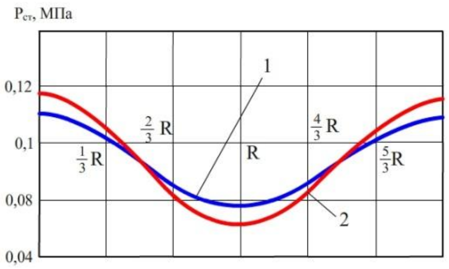

Fig. 6. Distribution of the static pressure in the nozzle section of the vortex chamber at different values of input pressure
1 - $P_{вх}$=0,2 MPa; 2 - $P_{вх}$=0,3 MPa

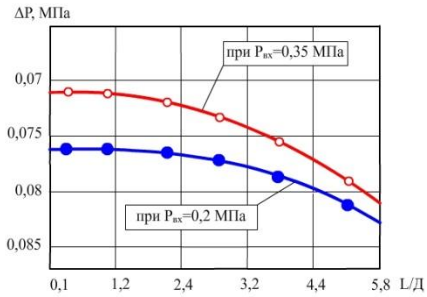

Fig. 7. Negative static pressure distribution along the axis of the cylindrical detail at a relative distance from the nozzle section

The obtained results show that in process of removal from nozzle section, the difference between atmospheric pressure and pressure ΔP upon axes of a detail decreases.

As can be seen from the graphs, in process of removal from nozzle section the field of the negative static pressure tends to flatten out. However, this process is relatively slow at a relative distance from the nozzle section, $L/Д = 5$ and a zone of negative static pressure remains. Therefore, in this zone, which occupies 2/3 of the diameter of the detail, there will be a leak of air from the atmosphere. This phenomenon has a negative effect on the movement of the balls up due to formation of an air damper. For its elimination in processing it is necessary to close the central part of the grid partition on 2/3 diameter of the processed detail.

Thus, the experiments showed that the change in pressure leads to a redistribution of aerodynamic flows, which in turn should cause a different rotation frequency of balls longwise of the processed detail. Besides, the presence of the deforming balls in the aerodynamic flow leads to reorganization of the flow, hence, to change the rotational speed of balls. As a result it is necessary to expect flatness of processing longwise of the processed detail.

As showed researches that with increase in length of the detail the rotation frequency of a ball falls. This results from the fact that the mass of the ball, a frictional force arising at contact of the ball with the processed surface reduce energy of flow.

Obtaining the required quality throughout the length of the detail and the achievement of high performance finishing and strengthening treatment is only possible with the simultaneous use of a large number of balls.

Excessive increase in the quality requirements of the surface of semi-finished products although reduces processing time, but it will greatly increase the cost of the previous operation.

For example, for a rolling with the rotating ball of the processed detail whose diameter D_n=40 mm and length L = 200 mm, the processing time is t_p=10÷12 minutes (rolling regimes: n=160÷200 rev/min; S = 0,075 mm / min, number of double passes - 2). In our case, for the above mentioned detail, duration of processing makes only t_p=3 min. Such comparison obviously shows the advantages of the supplied method not only concerning mobility and simplicity of the device, as previously noted, but also in productivity.

IV. APPLICATIONS AND EXPERIMENTAL RESULTS

Obtained theoretical and experimental results have a general nature, and so they became the basis for the development of automated technological equipment such as vacuum - capture for loading of flat products, transportation of small piece details and their distribution by branch, installations of rivets into the hole with a horizontal and vertical axis.
Ejective ability of the vortex flow allowed to develop a number of a construction. Since the value degree of the vacuum in the gripping area depend on a set of parameters of system "gripper - subject", then to research possibility of their increase requires development of appropriate mathematical models [2].
In operation, when the flat product is captured and adjoins to a face surface of the sucker, which is the supporting surface a vacuum $P_{вак}$. The actual surface is not completely smooth, so the sucker between the surfaces and the flat parts are formed tiny channels passing micro air streams. This in turn reduces the actual load-carrying capacity.
One way to improve the efficiency and reliability of the gripping automatic manipulators is to use an effect of twirled air flow creating in the axial region of the zone of low pressure (vacuum). On this basis a number of designs pneumovortex grippers it was taken into account functionality of a pneumovortex flow, a detail weight and several other factors.

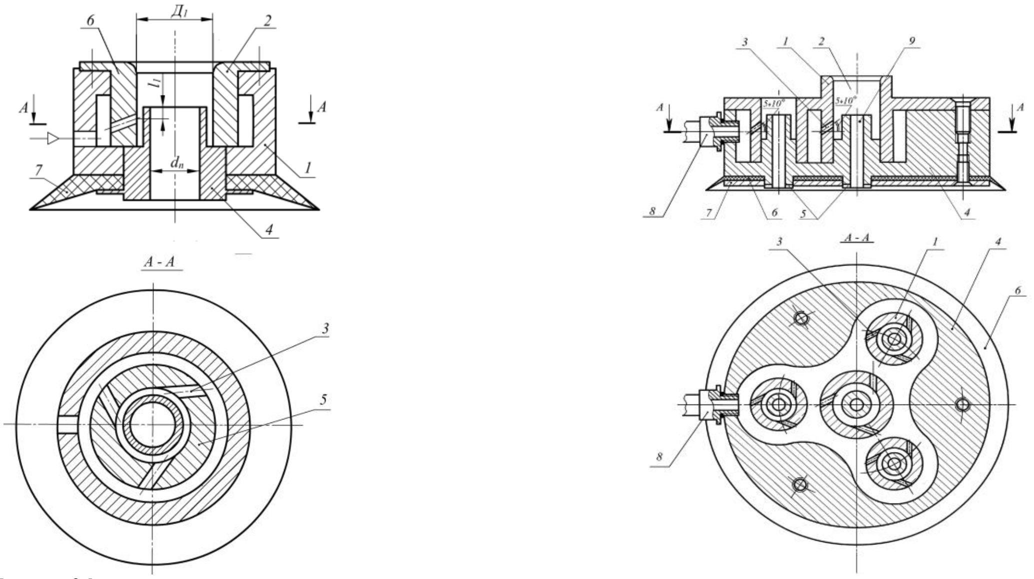

Fig.8. Design schemes of the pneumovortex captures

a)
1-case; 2 vortex chamber; 3- nozzle;
4-cylindrical tube; 5-annular gap;
6- cylindrical tube; 7-rubber sleeve

b)
1-case; 2 vortex chamber; 3- nozzle;
4-cylindrical tube; 5-annular gap;
6-rubber sleeve; 7-prop; 8-nipple

Industrial tests of pneumovortex captures (fig. 8a, b) have shown high reliability. They are easy to manufacture, easy to operate, economical and can capture a wide range of slabs.
Construction with the central capture (fig. 8) is introduced into production line in the cold forming disk of the car.
Besides, thanks to the high suction capacity, the developed vortex device can be applied to suction dust from abrasive, cleaning of working zones from shaving, etc.

For formalized description of pneumatic transportation of piece products, it is advisable to use the research technique, comprising the sequential allocation of system objects. Representation of object facilitates the simultaneous consideration in in total of the deterministic and stochastic aspects of the process. A priori information is the basis on which build the research process.
The nature of distribution of a response time of piece details in the pneumatic transport system which allowed to discriminate hydrodynamic structure of flux in object is investigated. The cell-like mathematical model of statics and dynamics of the studied process is received. The efficiency criterion is justified and the problem of process optimization of pneumatic transportation is solved.
Creating rotating spiral airflow in the transport device can provide capture of products and capture high-intensity supply of them to the working area only by means of compressed air energy. Rotation of all mass of the transported products on the helical direction of flow provides increased reliability of transportation of products and, hence high performance of these devices (fig. 9).
Currently for the distribution of transported goods by branch is used a number of mechanisms of various design (moving mechanical devices, valves, shut off,pneumatic valves, etc.) in the industry.

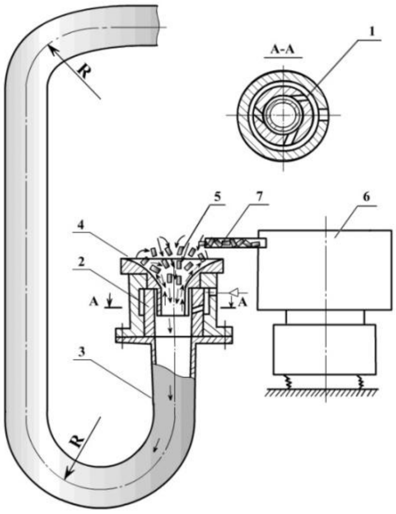

Fig.9.Schematic diagram of the fetch-and-carry device on aerodynamic actions.1-nozzle;2-vortex chamber;3-conduit;4-pipe;5-product;6-vibrating hoppers;7-tray.

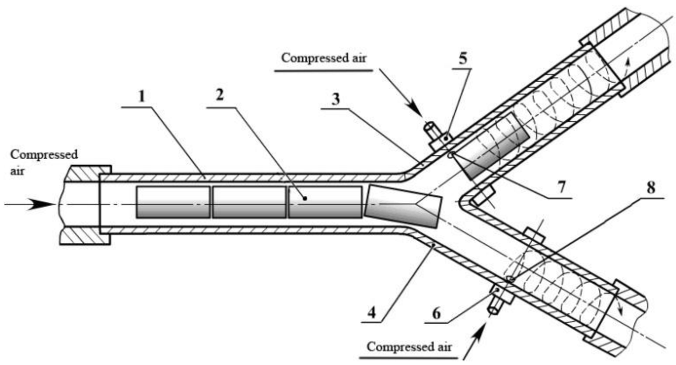

Fig.10. Separating method of the piece parts flow: 1- pipe; 2- piece goods; 3,4-splitting; 5,6- channels; 7,8- whirling head.

In work it is proposed a separating method of distribution of piece goods by splitting, based on the use of energy pneumovortex flow (Fig.9).
Piece goods with continuous flow give a stream of compressed air to a separation place of the transport and splitting where the channels fed jet of compressed air, informing them in a swirling motion branches (highly turbulent spiral flow of air to form in the central zone of the jet area of low static pressure). Products due to effect ejection of the jet are sucked into the vortex branch, where they reportedly processing helical movement in the direction of transportation. Thus, at the initial time, a flow of compressed air, for example, in branch 3, supplies high pressure creating in it larger degree of rarefaction where the first product of a stream will be ejected. Products in turn pass an area of coverage of vortex streams, sequentially close and open a zone of nozzles in branches. As a result, self-governed division of the continuous stream of piece products is carried out.
Changing the input pressure of the streams of compressed air supplied into the pipeline and its branches can be controlled speed movement of the products, and hence the capacity of the pneumatic system. Moreover, communication of products screw processing motion significantly reduce their friction against the pipe wall and adhesion with each other.

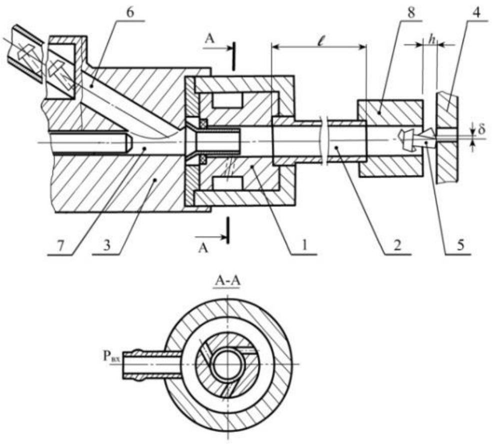

Fig.11 Schematic diagram of the device for installation elements in holes: 1- pneumovortex head;2- tube;3- branch pipe;4- detail;5- rivet;6- channel for feeding rivets;7- channel for passage of the rod of the riveting punch;8- hub.

A rivet coming from the feeder by an ejection effect a vortex stream are soaked up in a zone of nozzles of a pneumovortex head. Here it connects axial rotational movement and search with the necessary force, and torque in the direction of the base member (fig. 11).
The rivet moves along a trajectory, via the nozzle and adjusting branch pipe close to a circle. At the time of contact of the end of the rivet and the basic detail it appears the friction force, promoting increase of search driving of a rivet. Taken together, the rivet performs rotational and vibrational motion relative to holes of the base member. The presence of an axial force of the flow creates rivet skids to a package of a basic detail. It performs a process orientation and sticking of the rivet into the hole.

V. CONCLUSION

On a uniform theoretical basis of aerodynamic effect justified principles of designing technological devices which install rivets into horizontally located holes. Developed without driving device for process automation installation package rivet hole with a horizontal axis, wherein both the rivet and the nozzle imposed rotation by the aerodynamic flow.
It is proposed evidence-based recommendations for application and design of fetch-and-carry unit on aerodynamic actions for inter-operational movement of the products, providing their transportation in the non-contact and hammerless mode, and their distribution on branches.
The results and recommendations, received on the basis of the conducted researches can be used in solving various problems of automation of manufacturing processes, finishing, transportation, loading, assembly, both in machine-building industry, and in the enterprises of other industries.

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