Cross-sectional: AUTOMATION AND COMPUTER INTEGRATED TECHNOLOGIES

SUBSTANTIATION OF DESIGN PARAMETERS OF BERNOULLI GRIPPERS WITH AUTOMATED CONTROL OF THE SIZES OF OBJECTS OF MANIPULATION

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Abstract: The advantages of using jet gripping devices with integrated function of size control of objects of manipulation in robotic systems are substantiated. Rational designs of gripping devices are proposed, which allow to measure the diameter of the object held by them, their design parameters are substantiated. The interaction of air flows flowing from the annular nozzle and measuring ejector nozzles in the gap between the outer surface of the jet gripper and the inner surface of the object of manipulation is carried out. Reynolds-averaged Navier-Stokes equations of viscous gas dynamics, SST-model of turbulence and γ-model of laminar-turbulent transition were used for this purpose. As a result of numerical simulation in the Ansys-CFX software environment, the influence of the spatial location of the measuring nozzles on the load capacity of the jet gripper, the range and accuracy of measuring the diameters of manipulation objects was determined.

Keywords: *Bernoulli gripping device, object manipulation, air gaging, nozzle, industrial robot, RANS, SST-model of turbulence*.

1. Introduction

One of the main requirements for technological equipment of flexible automated production systems is a combination of high productivity with precision operations. Effective provision of these requirements is achieved by the maximum concentration of technological operations in a unit of technological equipment using an automatic control system [1-2]. One of the promising ways to increase the productivity of automated production systems is the integration of transport and loading operations with operations to control the parameters of transportation facilities [3-4].

In addition, in modern machining there is a need to organize the modes of optimal and adaptive processes, which are implemented using methods of active control of the parameters of the objects of manipulation (OM). The obtained information about the parameters of the OM is used for further calculations of the most efficient processing modes.

Robotization of transport and loading operations using Bernoulli grippers creates additional opportunities for automation of a number of ancillary operations. The advantage of these grippers is that they carry out contactless capture and retention of OM, the air flow has the ability to clean the surface of the object from various contaminants, can work with objects heated to high temperatures, and create opportunities for pneumatic control and orientation. objects. Design and operational features of jet grippers provide the following advantages over classical methods of measurement by pneumatic means: accurate centering of OM relative to the axis of the gripper in the measuring position, control of axisymmetry and taper OM, increased measurement accuracy, increasing the range of measured dimensions and others. [5-12].

Determination of manipulation object's mass during the robot's handling operations creates a number of additional opportunities for automation of the following processes: sorting of objects of production according to weight or control of a deviation of weight from necessary; definition of the inertial force operating on OM connected with acceleration (braking) of links of the manipulator that allows regulations of power characteristics of a gripping device and to carry out its reorientation for the purpose of decrease in energy consumption [13-20].

The pneumatic method of measurement was widely used for control of the linear sizes [21-23]. This method of measurement provides high accuracy, allows to exercise remote control in hard-to-reach spots. The pneumatic method of measurement allows to control without contact easy to break and fragile details and also details with coverings which can be damaged by mechanical contact. It is easy to automate and operate air measuring devices, they have high reliability and durability of work.

However the typical pneumatic method of measurement has considerable inertance that reduces measurement speed. For speeding up and the accuracy of a pneumatic method of measurement it is necessary to minimize volumes of flowing cameras, to use an ejector nozzle and modern high-precision and low-inertia pressure sensors.

2. Methodology

Fig. 1 shows a BGD circuit that combines the functions of capturing, centering relative to its own axis and conducting active non-contact control of the inner diameter of the OM with the inner blind hole. The jet gripper is structurally simple and provides high operational indicators on reliability and durability of work at preservation for all time of its service of constantly high accuracy of measurement.

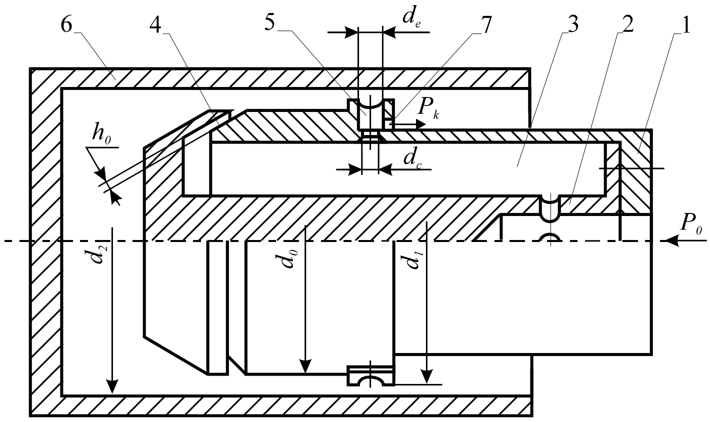


Fig.1 Structural diagram of the jet device for capturing and controlling the inner diameter of the object of manipulation

The device consists of a housing 1, in which the insert 2 is fixed, forming with it a closed chamber 3 for the supply of compressed air. Between the outer chamfer of the housing 1 and the inner chamfer of the insert 2, an adjustable annular conical slit 4 is formed for the release of compressed air from the chamber 3 into the atmosphere. In the body of the housing 1 in the direction of air flow from the annular conical slit 4, perpendicular to its axis is made an even number of symmetrical ejector nozzles 5. To ensure high measurement accuracy and load-carrying capacity of the jet gripper, it is necessary that the active surfaces of the ejector nozzles 5 protrude relative to the side surface of the housing 1 at a distance $\delta=(d_1-d_0)/2$. Their 2-row arrangement for measuring the conicity of the OM surface and 2-pair placement of symmetrical nozzles in a row when measuring axisymmetry in mutually perpendicular diameters are allowed. In the nozzles 5 perpendicular to their own axis made holes 7, which are mounted sensors for converting pressure into voltage (not shown). Piezoceramic transducers, which best meet the requirements of sensitivity and small size, are the most suitable for conversion.

The device in gripping mode works on the following principle. Compressed air from the main, which flows through the slit 4 into the atmosphere, is supplied to the chamber 3. When gripping OM 6, the air in the annular gap between the side surface of the housing 1 and the inner surface of OM forms a continuous annular flow causing due to ejection lowering the absolute pressure p_1 at the end of the insert 2 to less than atmospheric. Under the action of aerodynamic force, the workpiece is attracted to the end of the insert 2 and in the process of movement is centered by an annular flow of air relative to the axis of the gripping device. In this case, the inner cylindrical surface of the OM overlaps the ejector nozzles 5, causing them to increase the absolute pressure to the level of p_k.

The value of the pressure p_k depends on the design parameters of the nozzle, the main pressure p_0 and the interval h_2 formed by the end of the nozzle and the inner surface of the OM and equal to $h_2=(d_2-d_1)/2$. By measuring the value of the pressure p_k in the ejector nozzle and taking into account the dependence $p_k(h_2)$, the inner diameter d_2 OM 6 is determined. The pressure value p_k is directly measured in a transducer of the converter type, the output signal of which is the voltage $U_D=f[p_k(h_2)]$, which is converted by an analog-to-digital converter into a digital code. It is further processed by the processor and transferred to the local control system of technological equipment.

In order to select the optimal design parameters of the BGD that would provide the greatest load capacity and measurement accuracy, it is necessary to simulate air flows in the intervals between the interacting surfaces of the gripper and OM. The solution of this problem is based on the approaches of computational hydrodynamics and information technology for simulation of numerical modeling by the finite element method (FEM). FEM allows to determine with high accuracy the distributions of pressure, velocities, to obtain flow lines and other flow parameters. Modeling of various design options for BGD measuring nozzles was performed using the Ansys CFX CFD package, which is designed to model the flow of liquids and gases.

The mathematical model of course of air in radial interval between the interacting surfaces of BGD and OM is based on Navier-Stokes's (Reynolds averaged Navier-Stokes equations) equations (RANS) average according to Reynolds [24, 25]. Neglecting mass forces the system of the equations will have the following appearance:

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho \cdot V_j)}{\partial x_j}=0, \tag{1}$$

equation of continuity of stream:

$$\rho \frac{\partial V_i}{\partial t} + \rho \cdot V_j \cdot \frac{\partial V_i}{\partial x_j} = \frac{\partial P_{ji}}{\partial x_j}, \tag{2}$$

energy equation:

$$\rho \frac{\partial E}{\partial t} + \rho \cdot V_j \cdot \frac{\partial E}{\partial x_j} = -\frac{\partial q_j}{\partial x_j} + \frac{\partial}{\partial x_j}\left(P_{ji} \cdot V_i\right); \tag{3}$$

ideal gas law equation:

$$\rho = \frac{p_a + p}{R \cdot T}; \tag{4}$$

where *i*, *j* - indexes, accept values 1, 2, 3; ρ - firmness of air; *t* - time; *x* - coordinate; *V* - vector of speed of the movement of air; *p* - excessive pressure of air; **P** - tensor of tension; *E* - total energy of air; *q* - the vector of firmness of heat flux considering transfer of heat due to heat conductivity and diffusion; *R* - gas constant; *T* - absolute air temperature.

Turbulence modeling is one of the most important aspects of CFD modeling, and choosing the right turbulence model is key to receive reliable results. Since our working gaps are quite small, namely between the measuring nozzle and the surface of the manipulation object, we chose the SST model of turbulence [26-28] and the γ-model of the laminar-turbulent transition [29], as they better describe near-wall flows.

The γ-model of a laminar-turbulent transition is described by one differential equation for the coefficient of interference γ:

$$\frac{\partial(\rho\gamma)}{\partial t} + \frac{\partial(\rho V_j \gamma)}{\partial x_j} = P_\gamma - E_\gamma + \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\gamma}\right)\frac{\partial \gamma}{\partial x_j}\right] \tag{5}$$

where ρ - air density; *t* – time; *x* – coordinate; *V* – vector of air velocity; P_γ, E_γ - respectively generative and dissipation members of managing directors of laminar and turbulent transition; μ - molecular dynamic viscosity of gas; μ_t - turbulent dynamic viscosity of gas; $\sigma_\gamma = 1.0$ - model constant.

In the γ-model of the transition, the modified SST model equations are used:

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_j}(\rho V_j k) = \tilde{P}_k + P_k^{\lim} - \tilde{D}_k + \frac{\partial}{\partial x_j}\left((\mu + \sigma_k \mu_t)\frac{\partial k}{\partial x_j}\right) \tag{6}$$

$$\frac{\partial}{\partial t}(\rho\omega) + \frac{\partial}{\partial x_j}(\rho V_j \omega) = \alpha \frac{P_k}{v_t} - D_\omega + Cd_\omega + \frac{\partial}{\partial x_j}\left((\mu + \sigma_\omega \mu_t)\frac{\partial \omega}{\partial x_j}\right) \tag{7}$$

where k - kinetic turbulent energy; ω - the specific speed of dissipation of kinetic energy of turbulence; P_k, D_k - original generation and dissipation of the SST model; $P_k^{\lim}$ - the additional part, which provides the correct gain of turbulent viscosity in transitional area at very low level of turbulent viscosity of the running stream; v_t - turbulent kinematic viscosity of gas; σ_k, α, a_1 - empirical constants of model.

3. Results of the investigation

The jet gripper, depending on the design and location of the measuring nozzles, has different operating characteristics (holding force OM, range of measured diameters, measurement accuracy). In order to improve the operational characteristics of the SZP with an integrated control function of the diameter of the OM, a number of structural schemes of grippers (Fig. 2) with different arrangement of measuring nozzles are considered. In particular, the use of measuring nozzles inclined relative to the axis of symmetry of the BGD at an angle of 30… 45 ° (Fig. 2b, c) allows to increase the load capacity of the gripper. The displacement of the active peripheral surface of the measuring nozzle relative to the basic active cylindrical surface of the BGD provides it with a more efficient mode of operation, as it achieves higher measurement accuracy and load capacity.

To compare the presented design variants, we analyze the influence of the interval $h_2=(d_2–d_1)/2$, which characterizes the change in the diameter of OM, on the load capacity of these grippers and on the measuring characteristic $p_k(h_2)$. The following design parameters of BGD are accepted: h_0=0,1 mm, d_0=32,62 mm, δ=0,25 mm, d_c=0,5 mm, d_e=0.79 mm. The load capacity of the BGD is directly proportional to the vacuum of $p_{в1}$ created by it in the cavity of the gripped OM

$$F = p_{в1}\,\pi d_2^2 / 4, \tag{8}$$

therefore, we will analyze how the change in the annular interval h_2 will affect this rarefaction.

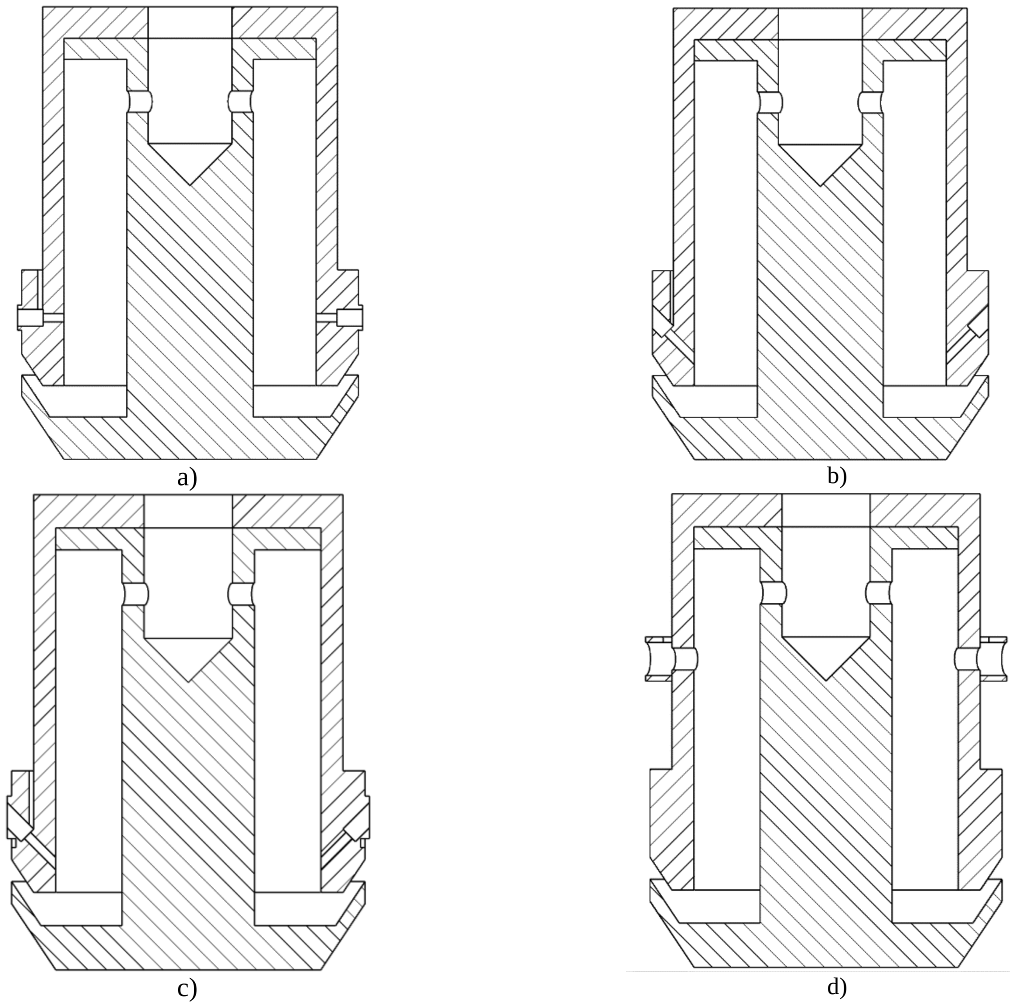


Fig. 2 Variants of Bernoulli gripper designs with the function of controlling the diameter of the object to be manipulated

Construction of characteristics $p_{в1}(h_2)$ and $p_k(h_2)$ for each circuit presented in Fig. 2, was performed on the basis of the mathematical model presented above and the accepted assumptions using the Ansys CFX package, which is designed to model the flow of liquids and gases.

An example of a geometric model of air flows with a scheme of finite element partition of the calculation area is shown in Fig. 3, and the calculation scheme of the model after setting the boundary conditions in Fig. 4. These models correspond to the structural scheme presented in Fig. 2d. Similar models were built for other structural schemes, and the value of the interval h_2 varied within 0.1…0.7 mm. Grids were built either in the CFX-Mesh package application or in the universal ANSYS ICEM CFD network package.

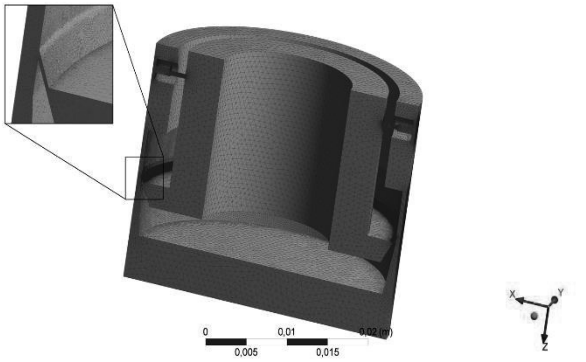


Fig. 3 Geometric model of air flows and the scheme of finite-element partition of the calculation area

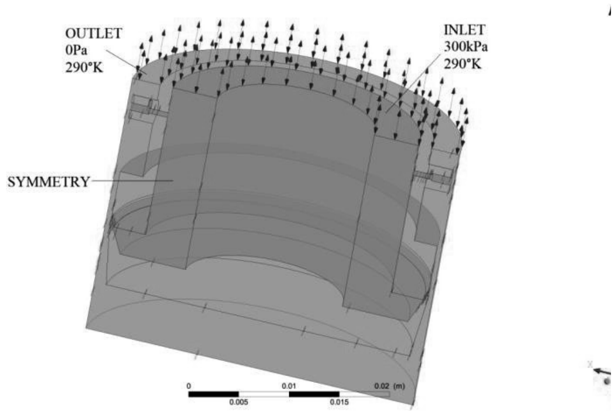


Fig. 4 Calculation scheme of the model after setting the boundary conditions

As a result of modeling the air dynamics in the intervals between the interacting surfaces of the BGD and OM, the values of pressure and velocities for all elements of the flow were obtained. As an example in fig. 5 and 6 present the simulation results in the form of pressure contours and flow lines with color notation of specific values. This graphical representation of the simulation results allowed for a deeper understanding of the interaction of flows and to develop approaches to the rational spatial arrangement of the nozzles and profiling of the active surfaces of the BGD.

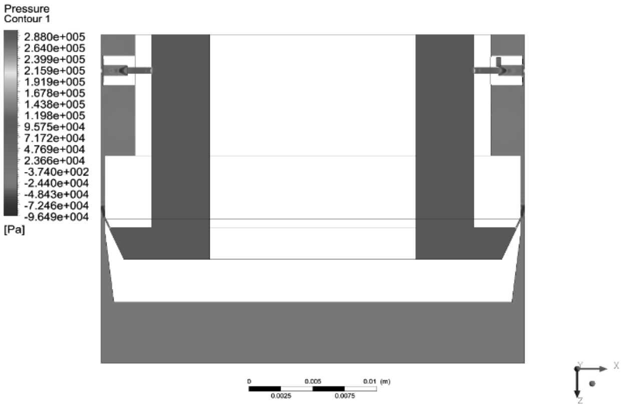


Fig. 5 The results of modeling the pressure circuits

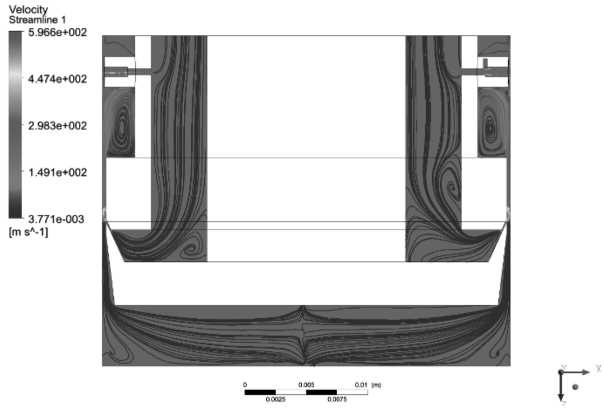
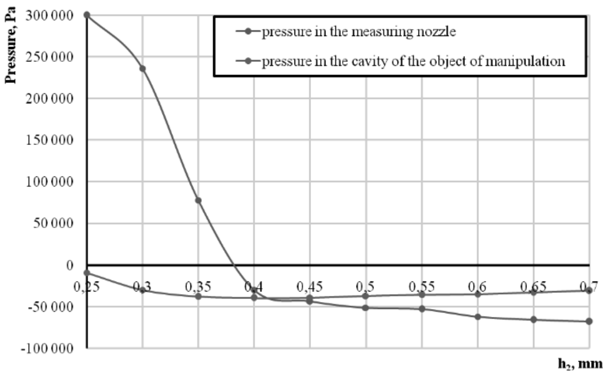
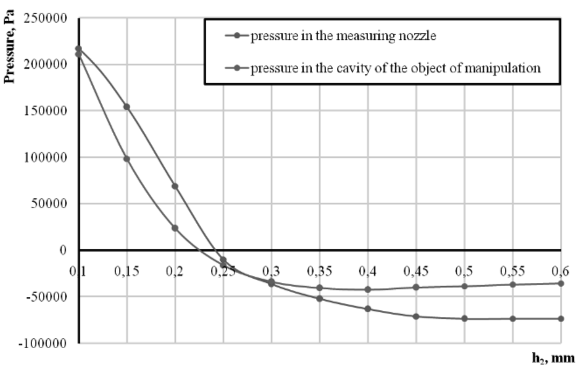


Fig. 6 Results of modeling of flow lines and velocity distribution (Fig.5)

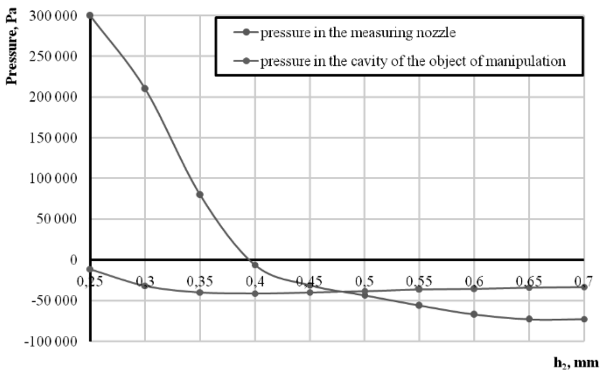
The results of modeling the operational characteristics of BGD (Fig. 2) are presented in Fig. 7.



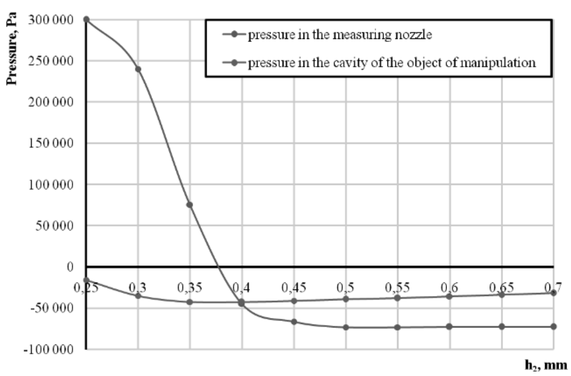
a)



b)



c)



d)

Fig. 7 The results of modeling the performance of Bernoulli grippers with the function of controlling the diameter of the manipulation object (graphs in Fig. a correspond to the design of Fig. 2a, etc.)

As can be seen from the presented graphs, design options (Fig. 2b, c) with inclined relative to the axis of symmetry of the BGD measuring nozzles can increase its load capacity by 5…12%. The displacement of the active surfaces of the measuring nozzles relative to the base cylindrical surface of the BGD by the value of δ=0.2…0.25 mm allows more efficient operation of this device, as in this case the range of maximum load capacity corresponds to the linear part of the measuring characteristic diameters.

To select rational structures of BGD it is necessary to determine their load capacity according to formula (8) and the sensitivity of their measuring characteristics. Sensitivity is defined as the tangent of the angle of inclination of the linear part of the measuring characteristic

$$s = \frac{\left| p_{k\max} - p_{k\min} \right|}{h_{2\max} - h_{2\min}}, \tag{9}$$

where $p_{k\max}$ and $p_{k\min}$ are the maximum and minimum values of the pressure on the linear part of the measuring characteristic, corresponding to the maximum and minimum values of the annular gap $h_{2\max}$ and $h_{2\min}$.

In the presented graphs, the central point of the linear part of the measuring characteristic corresponds $h_2 \approx 0.35$ mm. At this point, the load capacity of the presented structures of the BGD is also almost maximum. Accordingly $h_{2\min} \approx 0.3$ mm and $h_{2\max} \approx 0.4$ mm. For these points, the load capacity and sensitivity of the measuring characteristics were determined. The results are summarized in the table.

Table 1

The results of load capacity and sensitivity of different structures

Type of construction	Lifting capacity, [N]	*s*, [kPa/mm]
Fig. 2a	36,2	2650
Fig. 2b	41	1350
Fig. 2c	37,7	2150
Fig. 2d	37,7	2840

As can be seen from the table, the set of characteristics is best to use structures with measuring nozzles located perpendicular to the axis of the BGD.

4. Conclusions

It is proved that the use of Bernoulli grippers of industrial robots with an integrated function of controlling the size of manipulation objects increases the productivity of technological processes.

Based on numerical simulations in the Ansys-CFX software environment, it was found that the designs of Bernoulli grippers that use measuring nozzles inclined relative to their axis of symmetry have a 5…12% higher load capacity.

The displacement of the active surfaces of the measuring nozzles relative to the base cylindrical surface of the Bernoulli gripper by 0.2…0.25 mm allows operating this device more efficiently, as in this case the range of maximum load capacity corresponds to the linear part of the measuring characteristic. .

It is established that the jet gripping devices have best aggregate operational characteristics in which the measuring nozzles are located perpendicular to their axis.

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