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Design Optimization Opportunity Of The End Stage Output Plenum Chamber Of The Centrifugal Compressor For Gas Pumping Unit

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Abstract. The purpose of this work is to determine the optimal configuration of a flowing part of the plenum chamber of the centrifugal compressor of natural gas based on numerical experiment. In the research process was the analysis of the gas-dynamic perfection of a flowing part of the compressor plenum chamber, carried out the calculations to determine the parameters and effectiveness of the plenum chamber by methods of computational fluid dynamics. The result of the work revealed the shortcomings of the original design and determine the expected performance and efficiency optimized plenum chamber.

INTRODUCTION

In the context of improving the competitiveness of domestic steel key parameters of compressor energy efficiency of the equipment produced, and above all the efficiency of the machine. Reduced efficiency at an optimal mode due to losses occurring in the output devices varies from 1% to 5% depending on the camera type and destination of the centrifugal compressor.

Department "Compressor, vacuum and refrigeration engineering» SPbPU Peter the Great commissioned and together with LLS " Kompressor complex engineering" have worked to optimize the flow of the output device - an annular collecting chamber of constant cross-section of the centrifugal designed compressor for a linear compressor of gas pipeline station, taking into account technological and design limitations. Restrictions are the diameter of the outer body of the "barrel" misalignment outlet and annular collection chamber and the values of the radius of rounding of the cross-section.

The aim is to determine the optimal configuration of the annular flow collection chamber on the basis of the numerical experiment.

The methodology of the work lies in the computational and analytical study of the running configuration output annular collection chamber. The study analyzed the gas-dynamic flow of perfection when you change elements of the geometric shape of the running, were calculated to determine the parameters of the work and efficiency of the annular collection chamber methods of computational gas dynamics.

As a result of the shortcomings of the original design of the flow revealed a ring collection chamber (Figure 1), and identifies the expected parameters of performance and efficiency of the optimized version of the annular collection chamber.

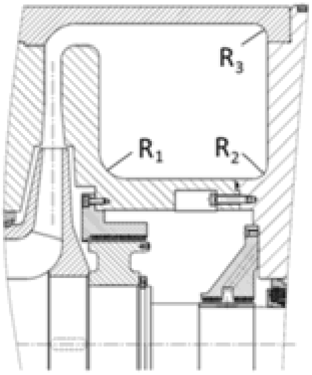


FIGURE 1. General view of the object

SUBJECT OF RESEARCH

Optimum performance annular collection chamber is primarily determined by the shape of the flow, the presence of a full or partial separation edge. According to [1], the introduction of separation edge into the annular collecting chamber, which is installed in the flow in the discharge pipe entrance area, provides improved performance of the camera and stage. A. A. Miftakhov performed experimental and theoretical study of output devices with different length of the separation edge. Theoretical studies have shown that the separation rib elongation reduces uneven velocity distribution on the cross section height. The distribution of average speeds in section along the central angle θ that indicates that at least the edges elongation occurs reducing flow swirling C_u (circumferential velocity component of the flow). Improving the flow structure and the reduction of C_u due to the fact that the edge prevents the formation of backflow and eliminating the recirculating flow.

It is expected that these factors will impact positively on the performance of the annular collection chamber, especially at higher costs. Experimental studies have shown that in all cases, installation of complete and incomplete separation ribs characteristics shifts the annular collection chamber in the region of large values of the angle of the flow between the expenditure component of the velocity and spin α4. This is in accordance with the theoretical analysis, the result is a decrease in average velocity reducing backflow vortex zone and intensity in the inner pipe wall. For optimal operating conditions, according to research by A. A. Miftakhov, reducing the coefficient of loss does not occur. When $\alpha_4 = \alpha_{4opt}$ presence of such fins eliminates the recirculating flow in the annular collection chamber. The installation of the ribs on the one hand, eliminates the additional loss of recycle flow, the other expansion causes a substantial increase in losses and loss of impact occurrence flow through the control section $\theta = 360^\circ$, on edge. Installation edge shifts depending on the pressure in the efficiency and toward higher cost efficiency in this magnitude does not change.

In his studies, W. Hans [2] suggested that the replacement of a symmetrical circular cross-section of the cochlea in the cochlea of the same size, but with minimized side-section should improve the efficiency and the pressure stage. The authors attributed this to a possible increase in the efficiency of reduction of head loss in the cochlea, which should occur as a result of the conversion of the vortex pair in the cross section in the one-sided. F. Krisam [3] by conducting detailed studies stage pumps with non-circular shape volutes misaligned received opposing, compared to [2] results - decrease efficiency of 4%. Results [3] show that the effect of the change in the location of the cross-section of the cochlea with respect to the meridian axis of the preceding item level only achieved in the case of a circular coiled cochlea.

Applied to the annular collection chamber similar study of cross-sectional shapes spent J. N. Zhuravlev. Tests c centrifugal compressor with two different shaped cross sections (circular and rectangular) annular chambers have shown that better performance provided rectangular chamber section. The author explains this unexpected result of a decrease in the intensity of the vortex of the rod (decrease spin flow) in the chamber because of its rectangular cross-section.

Conducted complex investigations output devices by A. A. Miftakhov [1] have established the following:

- In terms of aerodynamic perfection are the best misalignment of circular cross section of the cochlea, and the pressure loss coefficient 1.25-1.4 times less than the rate of loss of the best equestrian center a similar conclusion is given in [6] for centrifugal pumps;
- The direction of the cross-sectional collapse of volutes and annular collection chambers do not have a significant impact on the efficiency of the output device;
- The greatest efficiency of the collection chambers has an annular collection chamber section of a circular shape;
- The effect of the value of integrated cross-sectional area of the collecting chamber I ring on her performance. The optimal value of the I, which is a deviation from the pressure ratio increases. With the increase of I ring characteristics of the collecting chamber becomes less steep and uneven distribution of pressure coefficient in front of the collecting chamber is reduced.

- The same values of I, the greatest aerodynamic efficiency of the collection chamber has a circular or near the cross-sectional shape.

In accordance with the conclusions of the available literature, in this paper, the calculation of annular collection chambers produced at a possible round in cross-section chambers.

For convenience, the data dependencies efficiency losses from the various elements of the computational domain across the compressor will be driven by form factor section Ks, Miftakhov derived and defined by the formula:

$$K_s = \frac{I}{2\pi b_4 tg\alpha_4 \cdot K_{\Pi}} \tag{1}$$

where I - integral calculation section, b4 - width vaneless diffuser outlet, Kp - coefficient taking into account the reduction in mass flow due to the presence of transit flows directly into the discharge pipe.

Loss factor determined by the formula:

$$\zeta^*_{i-i} = \frac{P^*_{in} - P^*_{out}}{\rho_{in}\frac{C^2_{in}}{2}} \tag{2}$$

The share of the loss of efficiency of the compressor, introduced only output device is determined by the following formula:

$$\Delta\eta_{i-i} = \zeta^*_i \frac{\left(C_{in}/U_2\right)^2}{2\psi_t\, z(1+\beta_{fr}+\beta_{leak})}\ , \tag{3}$$

where z-number of compressor stages, β_{fr} is the coefficient of friction disk β_{leak} is the leakage rate.

Determination of the efficiency of the discharge chamber (section (4-4) - (6-6)):

$$\eta_{cham} = 1 - \frac{\zeta^*_{4-6}}{1+\frac{C^2_{out}}{C^2_{in}}} \tag{4}$$

Indexes «in» and «out» means the relevant parameters of the input and output section in each cell of the computational domain.

Figure 2 shows the position of the control cross sections for calculating performance elements of the computational domain, where:

(2-2) - (4-4) - vaneless diffuser
(4-4) - (5-5) - the outlet chamber
(5-5) - (6-6) - discharge pipe
(2-2) - (6-6) - the whole computational domain

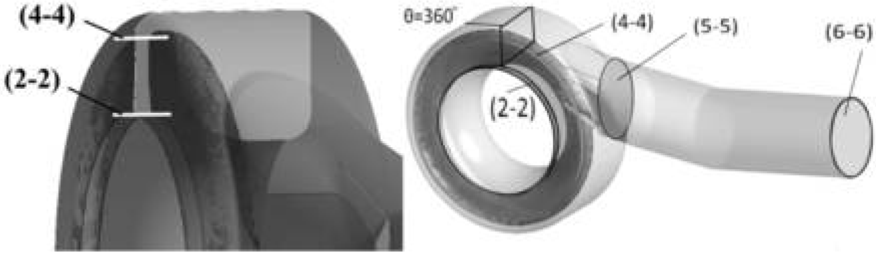


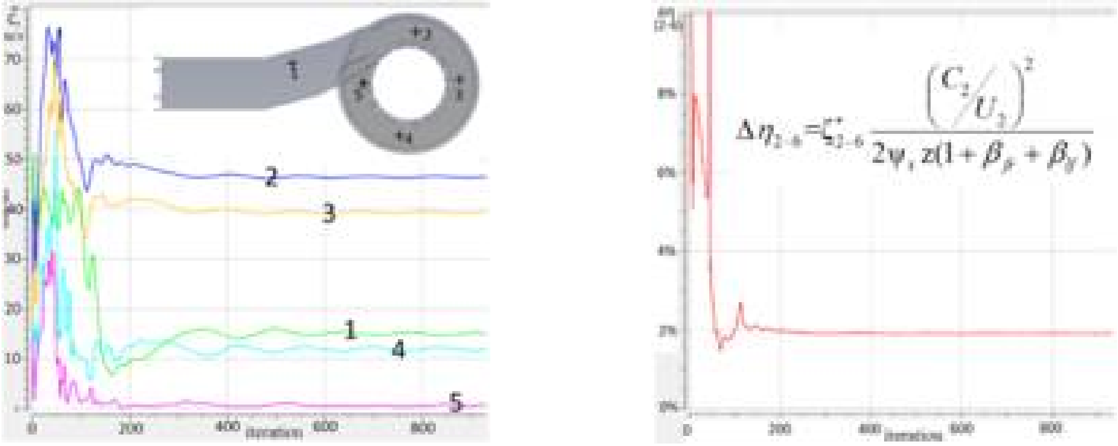
FIGURE 2. The position of the control cross-sections

NUMERICAL CALCULATION

At the entrance to vaneless diffuser section (2-2) for all calculations to set parameters at the outlet of the end compressor centrifugal impeller: beam angle α2 = 34,9˚; total pressure = 7392100 Pa and the total temperature = 311,6K. The output section (6-6) of the mass flow rate corresponding to the optimum mode. Used turbulence model SST (the experience of the Department «Compressor, vacuum and refrigeration engineering» applicable diffuser for turbulent flow). The working medium - actual methane gas.

The calculation was carried out on a computer cluster of the Department «Compressor, vacuum and refrigeration engineering» iteratively in solver CFX-Solver v14.5 after the calculations on the grid independent solutions using the initialization parameters with the less loaded boundary conditions.

The convergence of the solutions was controlled by monitoring standard deviations «residual» (RMS <103), unbalances change the basic equations of conservation of less than 0.5%, and the immutability of the absolute velocity of the monitoring points (Fig. 3, a), and invariably the loss of efficiency of the annular collection chamber to scale only the compressor (Fig. 3, b).



(a) (b)

FIGURE 3. Schedule of convergence a) in the monitoring points; b) efficiency loss across the compressor

Figure 4 shows the distribution of the share of the loss of efficiency of the compressor, introduced only annular collection chamber and its individual elements in an unchanged form an annular collection chamber according to the different shape of the separation edge.

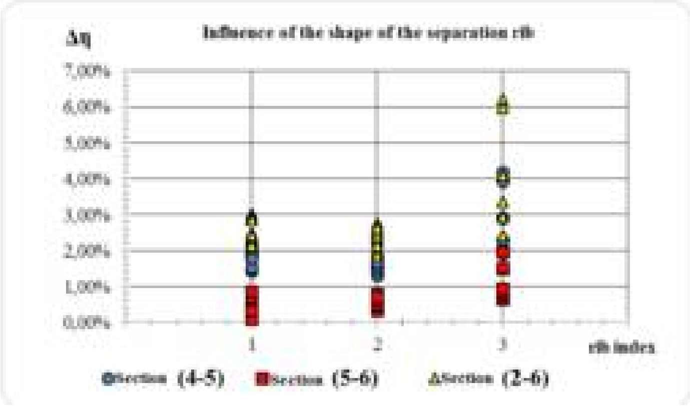


FIGURE 4. Schedule distribution efficiency losses in the annular collection chamber in the compressor scale with 3 forms of separation edge: №1, 2 - incomplete rib number 3 - a full rib.

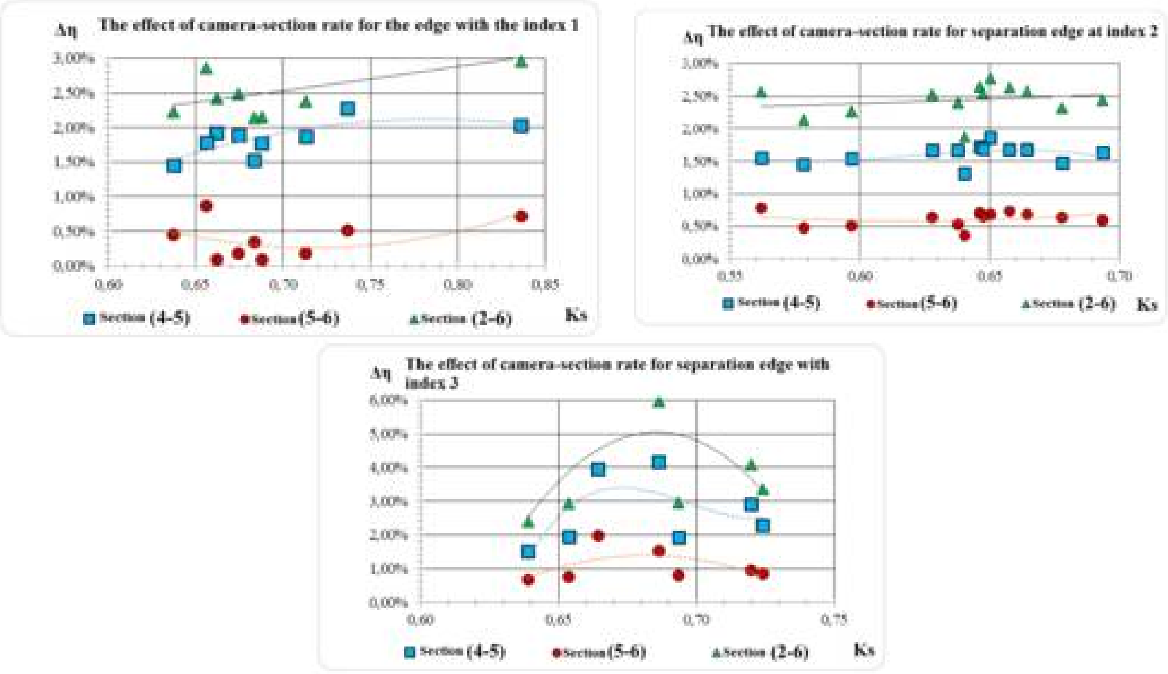
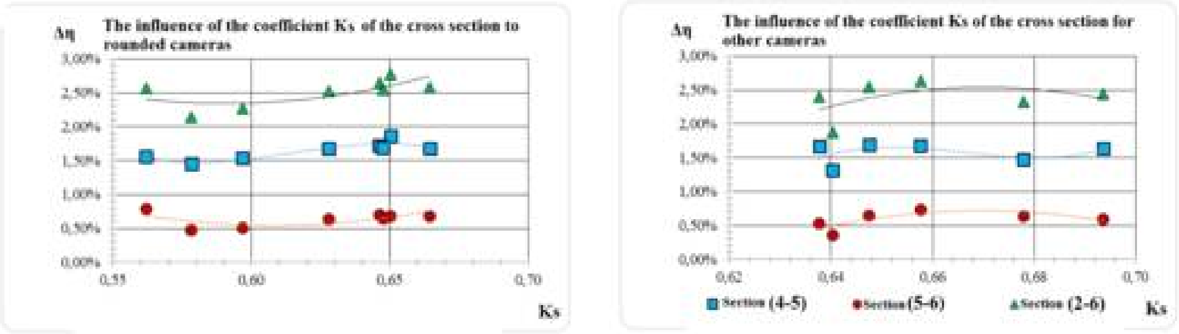


FIGURE 5. Charts distribution options integrated area of the discharge chamber of sections I, through the Ks factor for loss of compressor efficiency in various elements of the calculation region 3 forms the dividing ribs.



a) b)

FIGURE 6. Effect of cross-sectional area of the integral I, the coefficient Ks through compressor efficiency losses in the various elements calculation region for spherical and other forms of cross section of the chamber, with the rib type №2

ANALYSIS OF THE RESULTS OF CALCULATIONS

All calculations are descended stationary solutions, which is determined by the drop in residual level equations and enter the "shelf" options in speed monitoring points (Figure 3, a), and the immutability of values efficiency losses (Figure 3, b). The maximum value of the wall dimensionless coordinate y + = 110,17 corresponds to the chosen model of turbulence flow SST and not more than 300 additional calculations showed insignificant within the computational error variance in the loss factor in the calculation of the ring team to check the impeller impact on the work of the annular collection chamber were held the camera as part of a complete computational model of the compressor full $\zeta^* = 0.297$ and a model ring collection chamber Cams $\zeta^* = 0.300$. Fig. 7 shows the relative error of the integral parameters, depending on the section of the annular collection chamber.

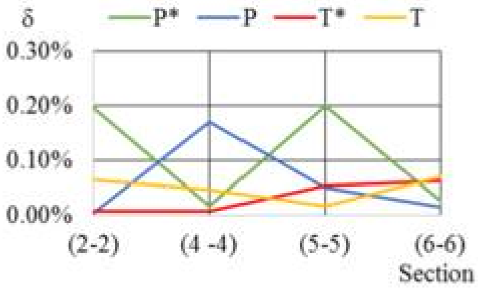


FIGURE 7. Relative error integral parameters depending on the section camera

Character flow in the design section at the central angle θ = 360˚ suggests that the presence of the paired vortex increases energy efficiency by reducing the intensity of the vortex unilateral having higher kinetic energy at the bounding surfaces.

According to a comparative analysis of numerical experiments, the following conclusions:

1. Form vaneless diffuser

New streamlined shape vaneless diffuser with increased channel turning radius with the radial direction in the axial possible to reduce the loss of efficiency on average by 0.1%, bringing the share of losses of efficiency from this site to a value of 0.22%. Form vaneless diffuser shown in the figure. 8.

2. Influence of the installation of complete and incomplete ribs

In this paper, we consider two types of dividing ribs: complete (ind. №3) and incomplete (ind. №1, №2.) That is, with the gap between the beginning of the outlet and the outlet of the annular collection chamber. Incomplete separation rib Ind. №1 №2 and differ in inclination relative to the axis of the outlet fitting.

The used literature [1] pointed out that the installation of a complete rib helps to reduce losses due to the reduction zone recycle flow, but increased loss due to the formation of a stagnant zone at the separation edge. Similar findings for the partial ribs at the same time according to the authors of experimental studies the impact of the installation of complete and incomplete ribs on the effectiveness of the annular collection chamber at the optimum mode is extremely small, and the greatest effect is observed with increasing flow rate (characteristic becomes flatter). It is worth noting that the authors of the study carried out under atmospheric conditions in the air for the cameras with low values of the angle α_2 = 12-15 °, while investigated for camera α_2 = 34,9 ° and the calculation was made under high pressure on a real gas. As a result of numerical studies we found that for a given ring collection chamber the presence of incomplete rib improves flow characteristics. This is due to the positive effect of the recirculating flow in these working conditions

3. Effect of the sections of the annular collection chamber

The graphs in Fig. 5-6 show the distribution of losses according to the results of numerical experiments, depending on the coefficient Ks, is directly dependent on the integral cross-section I. The cameras have different cross-sectional shapes, so the graphs are divided into 2 parts as in Figure 6 a) - with the camera rounded and round shape, and b) - the rest of the camera. The graphs show that for a rounded shape (camera №13,14,15,16,17,18,19,21) there is the presence of the optimum corresponding to the minimum level of losses in the chamber, where it does not coincide with the optimal losses in the pipe. Results for the other chambers in which the predominant presence of a large radius, say that further shift towards lower values of the Ks. Additional influence on the flow configuration has a visor on a diaphragm defining a circumferential flow direction, which allows the flow is divided into two rotating vortex, thereby reducing its kinetic energy and reduce the loss in the absence of a peak contrast, when there is primarily single vortex with high losses. Also, the emergence of a single vortex effect and the shape of sections of the annular collection chamber.

4. Impact of the fillet radius sections of the annular collection chamber

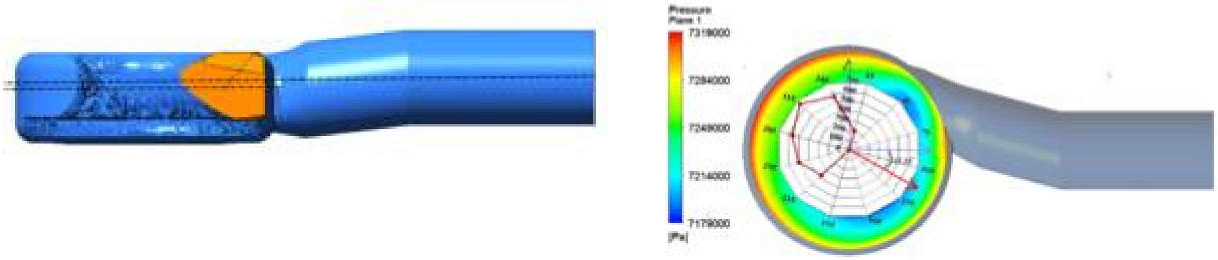
From table 2 it is possible to draw a conclusion, that best option available with technological constraints is the following radius fillets: R_1 = 200 mm, R_2 = 100-150 mm, R_3 = 100. However, given the multifactorial effects on the effectiveness of the camera, you can not specify more precisely the optimum fillet radius, so studied and are rounded values.

Based on the above it obtained the best option Figure 8 (chamber No. 11 in table 2) provides the results of numerical experiments are compared with the rest of the calculated annular collection chambers lowest level of losses, which is $\Delta\eta$ = 1,89%, taking into account losses in vaneless diffuser. Table 1 shows a comparison of the efficacy parameters of optimal variant camera to the base. The radius fillets comprise R_1 = 200 mm, R_2 = 100 mm, R_3 = 100 mm. The resulting camera view with R_1 = 200, probably due to the influence of the outlet, which is due to design restrictions is offset from the axis of the outlet chamber (Figure 9, a). Thus, the flow is biased towards the axis of displacement, which improves the flow patterns in the pipe. It is likely that the coincidence of the axes of the best cross-sectional shape will be circular chamber, as described in many sources, because the round shape studies loss level in the chamber is comparable with the best option, however, they have high losses in the outlet nozzle, probably due to misalignment.

Design constraints for output devices of centrifugal compressors for gas pumping, placed in a barrel, is the small flow area compared with the values obtained in the design to the optimal settings. This causes a higher flow rate as a whole in the annular collection chamber. It is possible to make a preliminary conclusion on the results of a numerical experiment for the case that a single vortex due to the high values of the velocity at restricting wall in cross-section low from the optimal values of the area is greater than the value of friction losses at the walls than doubles vortex generally having lower speed at the inner the chamber walls. It is possible to assume that the optimal discharge chamber section will be at the lowest losses circle section and a single vortex, but this requires an additional check by numerical experiment. The structure of vortex motion in the Central section is shown in table 3.

The magnitude of the radial load acting on the compressor rotor due to circumferential nonuniformity of the static pressure, which is m = 0,212 tons. (Fig. 9, b).

FIGURE 8. Optimum (solid) and the base (dashed) form an annular collection chamber section



(a) (b)

FIGURE 9. a) Offset pipe axis relative to the axis of the annular collection chamber b) A static load vector direction

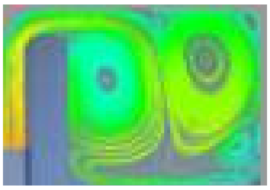
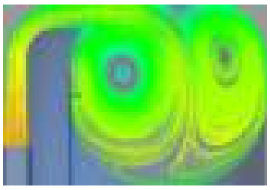
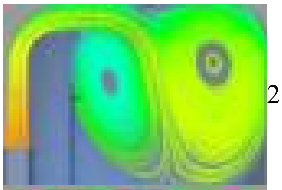
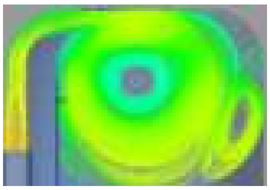
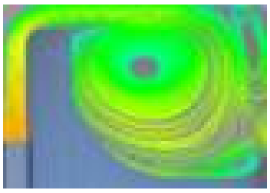
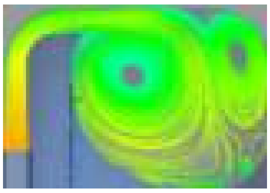
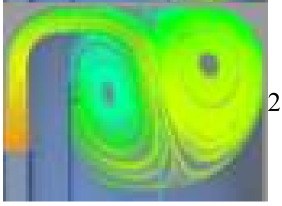
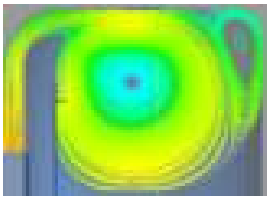
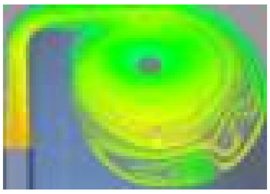
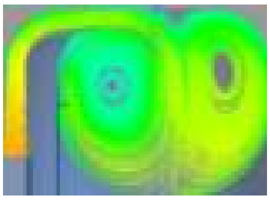
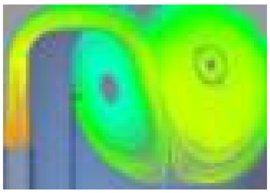
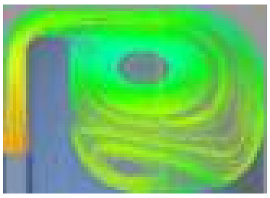
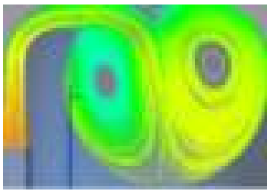
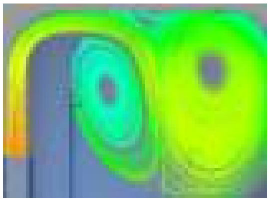
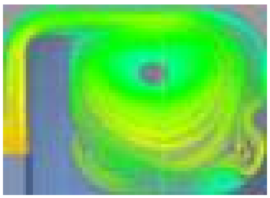
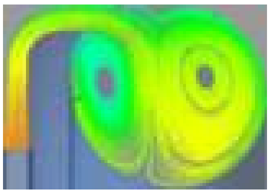
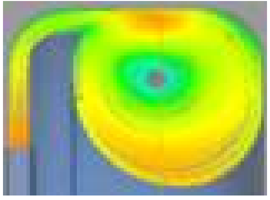
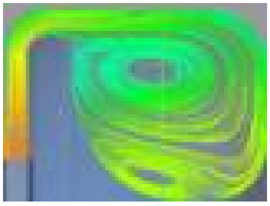
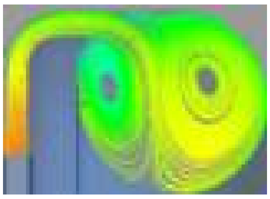
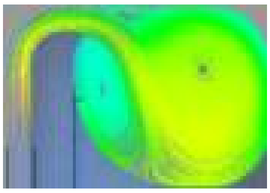
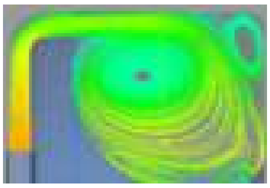
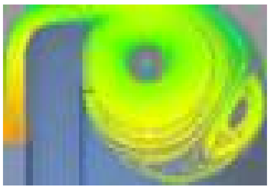
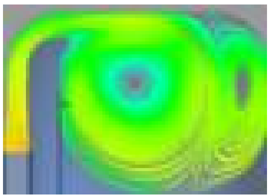
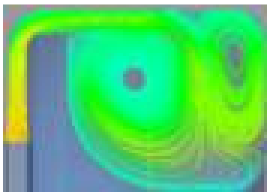
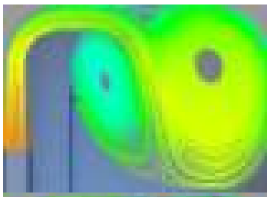
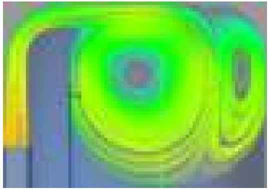
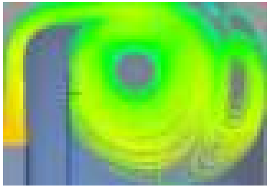
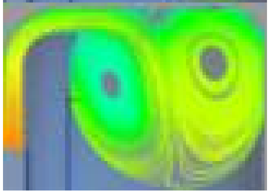
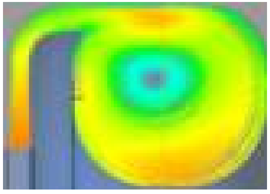
Table 1. Comparative table for the base and the best options

Parameter	**Original**	**Optimal**	**Distinction** $Y_{dif}=\frac{X_{orig}-X_{opt}}{X_{orig}}\times100\%$
Loss factor at full parameters ζ^*	0,293	0,176	40%
The flow rate in the initial section Cinitial, m / s	82,76	81,26	2%
Efficiency - an annular collection chamber, η_{ACC}	0,748	0,847	-13%
Efficiency loss, $\Delta\eta_{2-6}$	0,032	0,018	42%
The relative importance of static pressure drop, Δ_{sp}	0,0104	0,0082	21%
Static load, m, tonns	0,256	0,212	17%

Table 2. Data on the study of the cross-sectional shape of the annular chamber

	Integral	**The deviation of the integral**	**Coef. sections**	**Coef. losses'**	**The loss of efficiency in the elements of the computational domain**				**The radius of the cross section**			
№	**I, m^2**	**δ**	**K_s**	**ζ^*_{2-6}**	**$\Delta\eta_{2-6}$**	**$\Delta\eta_{2-4}$**	**$\Delta\eta_{4-5}$**	**$\Delta\eta_{5-6}$**	**R_1, mm**	**R_2, mm**	**R_3, mm**	**index**
1	0.1180	0.0%	0.74	0.293	3.15%	0.34%	2.28%	0.51%	60	30	30	1
2	0.1101	-6.7%	0.69	0.200	2.15%	0.29%	1.77%	0.10%	200	67	30	1
3	0.1020	-13.5%	0.64	0.207	2.23%	0.32%	1.45%	0.45%	166	166	166	1
4	0.1090	-7.6%	0.67	0.230	2.49%	0.41%	1.89%	0.18%	130	130	130	1
5	0.1134	-3.9%	0.71	0.219	2.38%	0.33%	1.86%	0.18%	100	100	100	1
6	0.1070	-9.3%	0.66	0.225	2.42%	0.40%	1.92%	0.10%	200	100	100	1
7	0.1087	-7.9%	0.68	0.199	2.14%	0.28%	1.53%	0.34%	200	100	100	1
8	0.1320	11.8%	0.84	0.272	2.95%	0.20%	2.03%	0.72%	200	100	100	1
9	0.1069	-9.4%	0.66	0.264	2.86%	0.21%	1.79%	0.86%	150	150	100	1
10	0.1069	-9.4%	0.68	0.215	2.32%	0.21%	1.48%	0.63%	150	150	100	2
11	**0.1058**	**-10.3%**	**0.64**	0.174	**1.87%**	**0.21%**	**1.31%**	**0.35%**	**200**	**100**	**100**	**2**
12	0.1145	-3.0%	0.69	0.226	2.45%	0.22%	1.63%	0.60%	150	150	100	2
13	0.1077	-8.7%	0.65	0.255	2.77%	0.23%	1.86%	0.68%	190	190	100	2
14	0.0990	-16.1%	0.60	0.210	2.27%	0.22%	1.54%	0.51%	190	166	166	2
15	0.0957	-18.9%	0.58	0.198	2.14%	0.22%	1.45%	0.47%	190	166	166	2
16	0.0925	-21.6%	0.56	0.236	2.57%	0.23%	1.56%	0.79%	190	166	166	2
17	0.1041	-11.8%	0.63	0.233	2.52%	0.22%	1.67%	0.64%	220	80	100	2
18	0.1041	-11.8%	0.66	0.238	2.58%	0.22%	1.68%	0.68%	200	150	100	2
19	0.1072	-9.2%	0.65	0.244	2.65%	0.22%	1.72%	0.70%	220	80	100	2
20	0.1058	-10.3%	0.64	0.222	2.40%	0.21%	1.67%	0.53%	100	200	100	2
21	0.1074	-9.0%	0.65	0.235	2.55%	0.22%	1.69%	0.65%	180	100	100	2
22	0.1090	-7.6%	0.66	0.243	2.63%	0.22%	1.68%	0.73%	200	50	50	2
23	0.1041	-11.8%	0.66	0.546	6.21%	0.29%	3.95%	1.97%	200	150	65	3
24	0.1058	-10.3%	0.64	0.223	2.42%	0.21%	1.52%	0.68%	200	100	100	3
25	0.1145	-3.0%	0.69	0.269	2.96%	0.24%	1.92%	0.80%	150	150	100	3
26	0.1069	-9.4%	0.65	0.272	2.95%	0.24%	1.94%	0.77%	150	150	100	3
27	0.1069	-9.4%	0.69	0.492	5.98%	0.28%	4.18%	1.52%	150	150	100	3
28	0.1180	0.0%	0.72	0.306	3.36%	0.22%	2.29%	0.84%	80	150	100	3
29	0.1156	-2.1%	0.72	0.368	4.09%	0.23%	2.91%	0.94%	100	200	80	3

Table 3. Flow Structure in the estimated cross-section θ=360° for the cross-sectional shape

1		10		19		28	
2		**11**		20		29	
3		12		21			-
4		13		22			-
5		14		23			-
6		15		24			-
7		16		25			-
8		17		26			-
9		18		27			-

CONCLUSIONS

As a result, numerical optimization of geometric shapes off the annular collection chamber is increased efficiency of the entire flow of the compressor is estimated at 1.28% on the value of polytropic efficiency for the full parameters. The optimum operating conditions for these were the following main characteristics of execution annular collection chamber. First, the presence of a peak at the exit of the diffuser, which provides the double vortex in cross section, which reduces the friction loss at the chamber walls, in contrast to a single vortex with high speed at the periphery with a reduced flow area because of restrictions barrel diameter. Second, the presence of incomplete separation rib, the gap which recirculates the flow in the circumferential direction, reducing the swirl edge zone and provides for a smoother transition of the flow in the annular portion of the outlet when misalignment. Third, cross-sectional shape with large radius of curvature, including those caused by technological constraints other than the range that reduces the value of the vortex flow velocity at the walls, and a slight increase in the flow cross section. This kind of optimization of control parameters can be used for verified multistage centrifugal compressors [5].

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