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Numerical Investigation of Centrifugal Compressor Radial Inlet

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Abstract. Efficient compressors designs reduce the overall energy consumption of industrial buildings. The inlet chambers for turbocompressors have a significant influence on the whole stage operation. An uneven flow in the inlet of an impeller can turn up to be the cause of stage efficiency drop, and also it is able to narrow down the range of its operational stability which in turn is an essential negative factor. Currently, there is no clear methodology of the design of the inlet radial chambers which makes it difficult to design the compressor. The purpose of this work is to develop recommendations for the designing problem formulation of the centrifugal compressor radial inlet chamber and also modify the existing design method for inlet chambers. During the previous research, the most acceptable model of the inlet chamber was obtained with the help of real and numerical experiment. In this paper, different geometric parameters of the inlet chamber are changed and then calculated by means of numerical experiment. Their influence on the inlet chamber loss coefficient, relative velocity distribution and static pressure coefficient is investigated.

Keywords: Radial Inlet, Centrifugal Compressor, Design Method, Computational Fluid Dynamics.

1 Introduction

Compressors are the power machines and they are widely used in different spheres of industry. The more efficient the compressor machine is the more economic effect it can give to the industrial buildings. The centrifugal compressor adiabatic efficiency of the stage for stationary machines it can't be higher than 0.75 - 0.85 and for transport machines it can't exceed 0.60-0.80.

According to the latest research the main attention when developing the stage is mainly paid to the dynamic part of the compressor (impeller) and fixed elements such as: a diffuser, reverse direction device. Thus the question of the flow in the inlet chamber is not a widely spread topic for the investigation.

Nevertheless, inlet chambers cause a significant impact on the stage operation of the power machine. For example, the uneven flow in the outlet of the inlet chamber can cause the stage efficiency reduction by 4-5%, and also can lead to the characteristic drop to the lower mass flow area, which, in its turn, decreases the stage pressure. Careful design process of the inlet chamber flowing part can lead to the loss and unevenness of the flow reduction before the stage and, thus, to the whole machine efficiency rise [1-6].

Nowadays there are formulized recommendations on how to design inlet chambers. However, there is no clear method that would be based on the efficiency criteria in order to for it be able to design these kinds of compressors parts. During the design process a lot of questions on how to design various parts of the inlet chambers appear [7]. In this paper, different geometric parameters of the inlet chamber are changed and then calculated by means of numerical experiment. Their influence on the inlet chamber loss coefficient, relative velocity distribution and static pressure coefficient is investigated. With the help of the received results, the recommendations for the designing problem formulation of the centrifugal compressor radial inlet chamber are formulated.

During the previous research [8-11], the most acceptable model of the inlet chamber was obtained with the help of real and numerical experiment. This chamber became the object of this paper investigation.

2 Investigation

As it was said before, during the inlet chamber design process some geometric parameters of the chamber are accepted approximately, without any recommendations. Such geometric parameters are: the diameter of the nozzle part D_c and the fillet radius of the spiral chamber sections R_f . In this paper we present the investigation of these parameters influence on the chamber efficiency parameters. The solution of grid independence was also investigated in order to determine the minimum number of elements providing an acceptable accuracy of the solution. All numerical studies were carried out using the ANSYS CFX 19 software package [12].

When designing the chamber, it should be divided into three parts: curved axisymmetric nozzle, spiral chamber and inlet channel. The sections where the fillet radius R_f was changed are shown in (see Fig. 1).

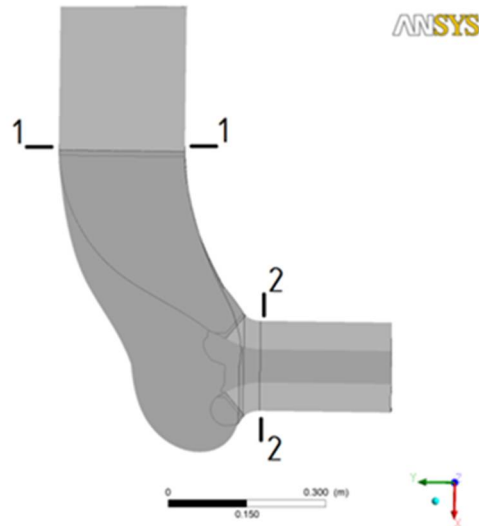


Fig. 2. Cross-sections 1-1 and 2-2 placement

3.1 Grid independency investigation

ICEM CFD program was used to build the grid. With its help, 13 variants of computational grids were built. The computational grid is unstructured, the grid cells in the core of the flow were tetrahedral. The elements were condensed near the inlet and outlet edges of the grid edges [13]. 10 layers of prismatic elements were created near the solid walls to describe the boundary layer [14-18]. The variants of grids differed from each other by the number of elements in the grid are presented in table 1. According to these data, the inlet radial chamber loss coefficient dependence from the computational grid density was constructed (see Fig. 3 a)

Table 1. Results of grid independency numerical investigation.

Number of elements, mln	1	2	2.5	3	3.5	4	4.5	5	6	7.5	8.0	10.5	12.5
$\zeta, 10^{-2}$	6	5.4	5.4	4.9	5.1	5	5.6	5.6	5.4	5	4.7	4.7	4.7

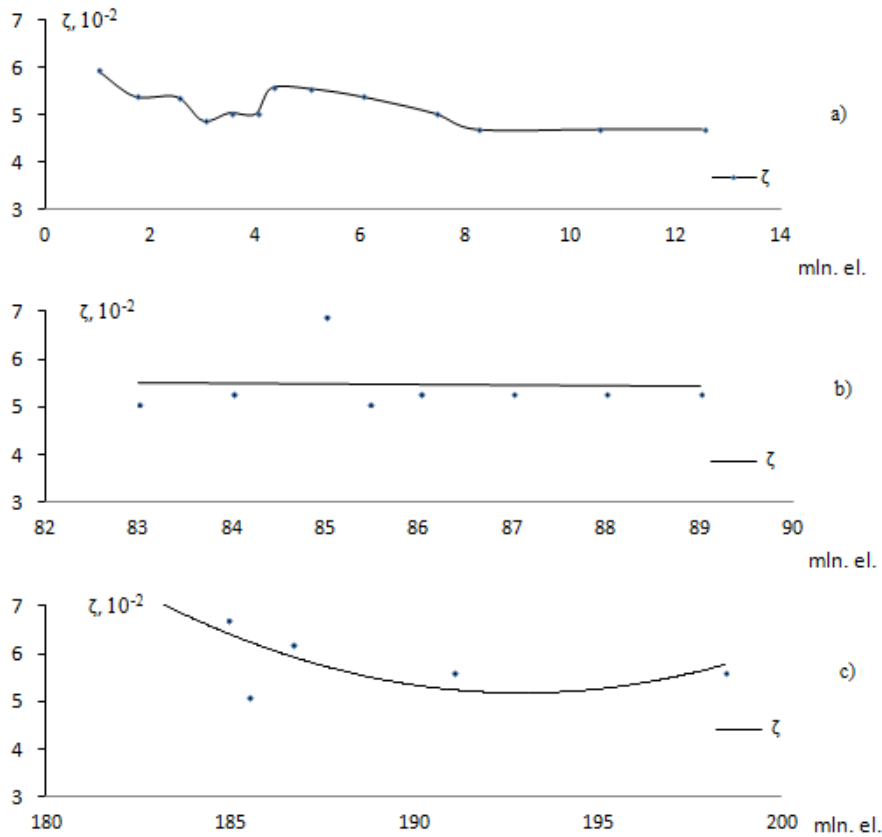


Fig. 3. Loss coefficient dependence a) from the number of grid elements; b) from the fillet radius dimensions; c) from the nozzle diameter dimensions

As it can be seen in table 1 and fig. 3, with the increase in the number of elements from over 8 million elements the change of the inlet chamber loss coefficient occurs with a lower intensity. With the improvement in the grid quality, as expected, the values of the resulting residuals fall, indicating better convergence of the calculation. The calculation with very rough grids gives the residuals convergence only by the order of 10^{-4} , which is insufficient. Finally, the grid with parameters corresponding to the variant with 8.2 million elements was adopted to calculate the inlet chamber characteristics.

3.2 Grid independency investigation

The spiral chamber consists of 6 sections with different fillet radiuses. The sections where the fillet radius R_f was changed are shown in figure 1. Eight different configurations of the fillet radius dimensions were investigated. The results are shown in table 2 and figure 3.

Table 2. Loss coefficient dependence from the fillet radius dimensions.

R_f , mm	83	84	85	85.5	86	87	88	89
ζ , 10^{-2}	5.1	5.3	6.9	5.1	5.3	5.3	5.3	5.3

Table 2 and figure 3 b show that the fillet radius dimensions don't make a lot of influence on the inlet chamber loss coefficient. But other different forms of inlet chambers should be investigated further.

3.3 The nozzle diameter influence investigation

Seven different configurations of the nozzle diameter D_n dimensions were investigated. The results are shown in table 3.

Table 3. Loss coefficient dependence from nozzle diameter dimensions.

D_n , mm	182.1	183	185	185.6	186.7	191.1	198.5
ζ , 10^{-2}	7.7	7.2	6.7	5.1	6.2	5.6	5.6

The results (see Fig 3 c) show that the nozzle diameter has a significant influence on the inlet chamber loss coefficient. And the more the nozzle diameter dimensions are the less is the loss coefficient. But the nozzle diameter has restricted values because of the geometric dimensions of the chamber, so the maximum affordable value of the nozzle diameter should be chosen. Also other different forms of inlet chambers should be investigated further.

4 Results

To sum up, the investigation of different parameters influence on the chamber efficiency parameters is presented in this work, such as: grid independency, the diameter of the nozzle part D_n and the fillet radius of the spiral chamber sections R_f [19-21]. The nozzle diameter has a significant influence on the inlet chamber loss coefficient. And the more the nozzle diameter dimensions are the less is the loss coefficient. But the nozzle diameter has restricted values because of the geometric dimensions of the chamber, so the maximum affordable value of the nozzle diameter should be chosen for each chamber. The fillet radius dimensions don't have a lot of influence on the inlet chamber loss coefficient [22-26].

The results of the work were obtained using computational resources of Peter the Great Saint-Petersburg Polytechnic University Supercomputer Center.

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