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# Investigation of the flow in compressor cascades with active flow control in supercirculation mode

*The paper presents the results of numerical simulation of flow in compressor cascades with active flow control at different angles of attack. It is shown that the active control of flow past the blades affects the value of deviation angle of flow behind the blades. The paper analyzes the influence of the effect of supercirculation on the aerodynamic characteristics of compressor cascades with active control of the flow past the blades.*

Active flow control is an effective way to reduce the intensity of aerodynamic traces behind the blade rims [1, 2]. However, the problems of the effect of active control of the flow past the blades on the aerodynamic characteristics of compressor cascades have not been fully investigated. The aim of the research is to study the effect of active control of the flow past the blades on the deviation angle of flow in cascades of strongly curved profiles using computational aerodynamics methods.

The aerodynamic characteristics of compressor cascades are determined by the nature of the flow in the three-dimensional boundary layer on the surface of the blades at different angles of attack of the profiles. The peculiarity of calculating the parameters of a walled three-dimensional boundary layer in a cascade with active control of the flow past the blades is the need to take into account the interaction of the jet emerging from the slit channel with the flow coming from the upper boundary of the slit channel. Special studies are devoted to the questions of interaction of flows and semi-bound jets in which possible solutions for the jet and near-wall boundary layers are discussed in great detail [1, 2, 3]. To calculate the parameters of the boundary layer in strongly curved channels in the presence of a longitudinal pressure gradient, one of the most complicated tasks is the specification of the velocity diagram and the tangential directions.

To calculate the parameters of compressor cascades with active flow control, an analytical calculation of the integral characteristics of the boundary layer can be used only in the first approximation. More accurate methods of investigating flow in compressor grids with active gas dynamic control are physical and numerical experiments [4]. However, the physical experiment does not always make it possible to see a qualitative picture of the flow, and to study in detail the physical phenomena in a wide range of Mach numbers [5]. Therefore, a numerical experiment was used in the work. The nonstationary system of Navier-Stokes equations was closed by the Menter’s SST eddy-viscosity turbulence model.

The object of the research was a compressor cascade, which has the following geometric parameters: the structural angle of the cascade inlet $\beta_{1k}$=35º, structural angle of the cascade outlet $\beta_{2k}$=60º, angle of profiles $\gamma$=55º, profile chord b=55mm; profile cascade density b/t=0,8, 1,5, 2,0; t – cascade spacing. The location of the slit is chosen taking into account the recommendations presented in the paper [2, p. 51].

The effectiveness of boundary layer control can be estimated by varying the deviation angle of flow. The deviation angle of flow behind the cascade largely determines the efficiency of the compressor cascade, estimated by the angle of rotation of the flow. The results of experimental studies have shown that with an increase in the bending angle of the midline of the profiles, the deviation angle of the flow in the cascade increases; with an increase in the angle of installation of profiles in the cascade, the deviation angle increases; an increase in the cascade density leads to a decrease in the deviation angle.

Figure 1 shows the dependencies between the deviation angle of the flow for different injection rates on Mach numbers in the range M = 0.3...0.7 at the nominal flow mode for cascades with different density.

By the theoretical blowing-in coefficient $C_\mu$ we mean the ratio of the momentum of the gas blown through the slit of the one-second mass of gas $J_b$ to the momentum of the one-second mass of gas in the interlacing channel $J_0$ [2, p. 56]:

$$C_\mu = J_b / J_0$$

Coefficient $C_\mu$ serves to estimate the efficiency of the application of active flow control in cascades with different geometric parameters.

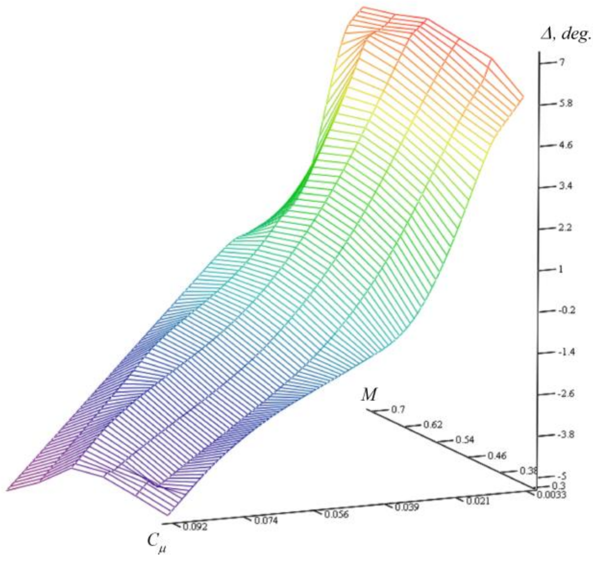



Fig. 1. Dependence of deviation angle of the flow on the Mach number for various control intensities (b / t = 0.8)

The analysis shows that blowing an additional mass of air into the boundary layer leads to a decrease in the deviation angle of the flow, and for certain values of the blowing coefficient, the phenomenon of supercirculation takes place. In this case, the angle of rotation of the flow exceeds the value of the structural angle of the cascade outlet when the outlet angle of the flow is greater than the design angle of the cascade outlet ($\beta_2 > \beta_{2k}$).

Figure 2 shows the dependence of the flow control intensity that provides the zero deviation angle of the flow ($\beta_2 = \beta_{2k}$) on the Mach number for cascades with different cascade densities.

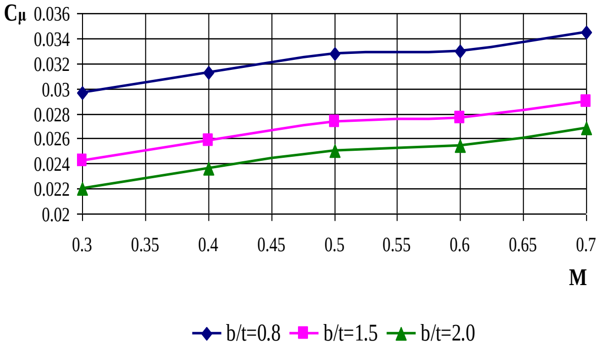
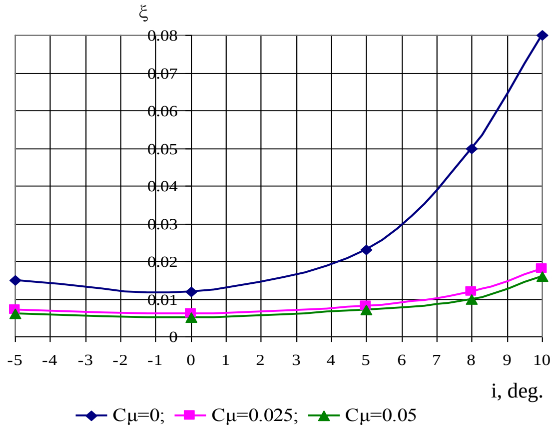



Fig.2. The dependence of the flow control intensity, providing a zero deviation angle of the flow on the Mach number

For cascades with cascade density of b/t=0.8...1.5, in order to effectively use the active flow control, the control intensity should correspond to the blowing factor $C_\mu$=0,022…0,027 for the operating mode corresponding to Mach numbers M=0,3…0,7. For cascades with the cascade density b/t = 2.0, to ensure zero deviation angle of flow for Mach numbers M=0.3...0.7 the blowing pulse coefficient is $C_\mu$=0,03…0,035.

Based on the results of numerical simulation of the flow, the aerodynamic characteristics of the cascades without gas dynamic influence and with active gas dynamic influence were constructed. The calculation was made for the Mach numbers M=0.7.

Figure 3 shows the aerodynamic characteristics of compressor cascade with gas dynamic influence. The results of study of flow in active-controlled compressor cascades at different angles of attack show that, in the operating mode corresponding to the flow control rate $C_\mu$=0,025, there is an increase in the angle of rotation of the flow compared to the zero flow control mode of flow. This is due to the fact that the deviation angle of the flow at the value of the impulse factor $C_\mu$=0,025 is zero. In addition, the level of total pressure loss is significantly reduced. An analysis of aerodynamic characteristics shows that the use of active flow control leads to an increase in the critical angle of attack.



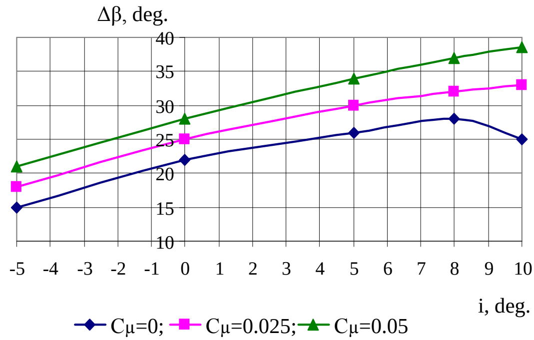




Fig. 3. Aerodynamic characteristics of the compressor cascade with gas dynamic control of the flow past the blades

With an increase in the value of the blowing pulse coefficient to $C_\mu > 0.05$, the effect of supercirculation takes place. The presence of supercirculation leads to the fact that the outlet angle of the flow from the cascade becomes larger than the design angle of the outlet of the cascade. This leads to an even greater increase in the angle of rotation of the flow. At the same time, the value of the total pressure loss coefficient decreases insignificantly, in comparison with the flow at the value of the blowing pulse coefficient $C_\mu$=0,025.

## Conclusions

The results of the research showed that the use of active gas dynamic control of the flow past the blades positively affects the aerodynamic characteristics of compressor cascades. Active control of the flow past the blades allows to increase the maximum angle of rotation of the flow in the cascade with continious flow around the blades. At certain values of the blowing pulse coefficient, the phenomenon of supercirculation takes place when the angle of rotation of the flow exceeds the value of the structural angle of the outlet of the cascade, when the outlet angle of the flow is larger than the design angle of the outlet of the cascade ($\beta_2 > \beta_{2k}$).

The use of active control of the flow around the stator elements (input racks, guiding devices, input guiding devices) may be appropriate to ensure the continuous flow in cascade and increase the maximum aerodynamic loading of the blade rims.

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