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Development of a Turbine Diffuser for a 50 Kw High-Performance Microgas Turbine Plant

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***Abstract*: The article is devoted to the optimization of annular diffusers of radial-axial turbines of small-sized gas turbine engines. It shows the results of verification of the used mathematical models for calculating the flow using experimental performance charts for annular diffusers. The results of the geometry optimization of the developed diffuser are presented. The final part of the article covers the results of the optimization of the diffuser geometry by the swirl angle of the inlet flow. As a result, a highly efficient diffuser was designed for a 50 kW microturbine under development.**

***Keywords*: diffuser, microturbine, mathematical model, swirl angle.**

I. INTRODUCTION

As part of the development of a 50 kW high-performance small-sized gas turbine engine (microturbine), research was conducted to develop and optimize the diffuser of its radial-axial turbine. The initial design of the diffuser (Figure 1) was obtained at the stage of the preliminary design of the microturbine and subsequently optimized using mathematical modeling [1; 2] of the flow in the diffuser (CFD).

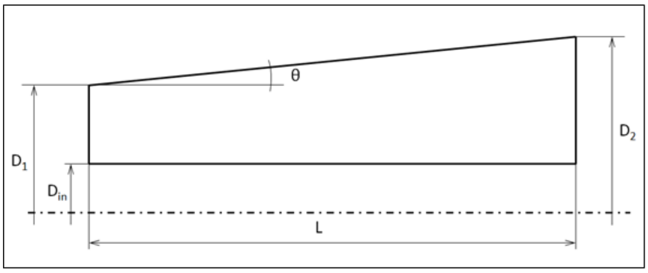

Figure 1. Scheme of the diffuser baseline design

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II. MATERIALS AND METHODS

To assess the performance of the diffuser and optimize its geometry, a three-dimensional mathematical model of the diffuser sector was built to calculate the flow (Figure 2). To verify the used physical models and the resolution of the computational mesh, open-source experimental and calculated data from NASA [3] were used. The SST turbulence model with a near-wall resolution of Y+<1 is widely used to calculate flows with significant pressure gradients, separation and PS connections. Figure 3 shows NASA data comparing the friction coefficient on the wall, obtained experimentally on a flat diffuser, with numerical simulations conducted on meshes of different resolutions and using different models of turbulence.

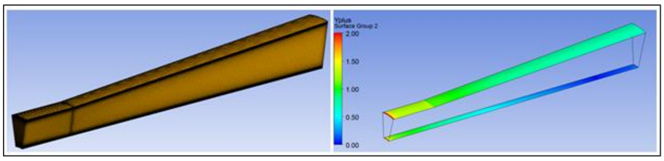

Fig. 2. Computational mesh and dimensionless wall coordinate Y+ of the diffuser mathematical model.

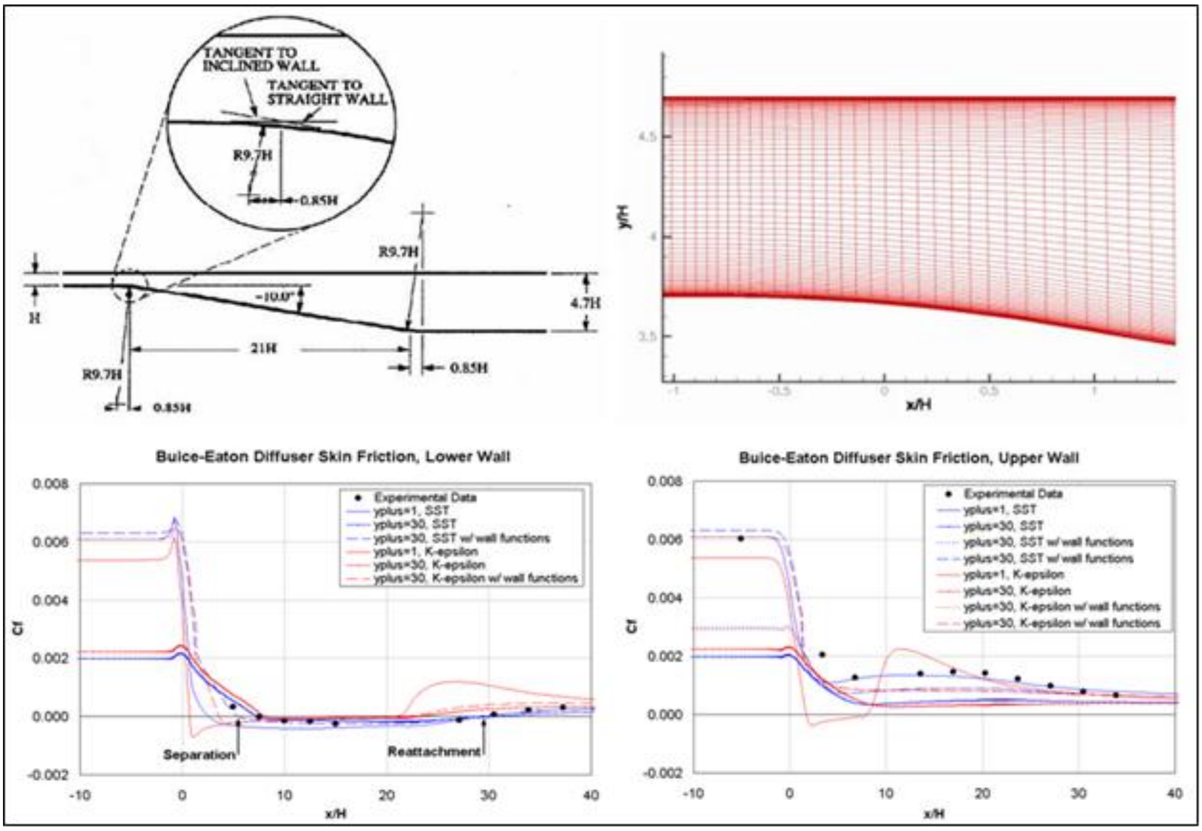

Fig. 3. Comparison of experimental data and mathematical modeling of a plane diffuser (Buice-Eaton 2D Diffuser NASA) [1].

Experimental data confirm the applicability of the SST turbulence model for calculating flow in diffusers. Moreover, in comparison with other standard models of turbulence, SST models simulate the PS separation and attachment more accurately.

The computing model of the diffuser is a sector of the diffuser with a calculated mesh of 350,000 elements of hexahedral topology.

A viscous, turbulent, 3-D flow was simulated in the diffuser. The working medium model was an ideal gas with viscosity, thermal conductivity and heat capacity depending on temperature.

The SST turbulence model and the full energy model including the kinetic energy contribution were used.

The radial profiles of total pressure, total temperature, turbulent kinetic energy and turbulent frequency, obtained from calculations of the turbine stage (Figure 4), were set at the diffuser inlet, the nominal flow rate – at the outlet.

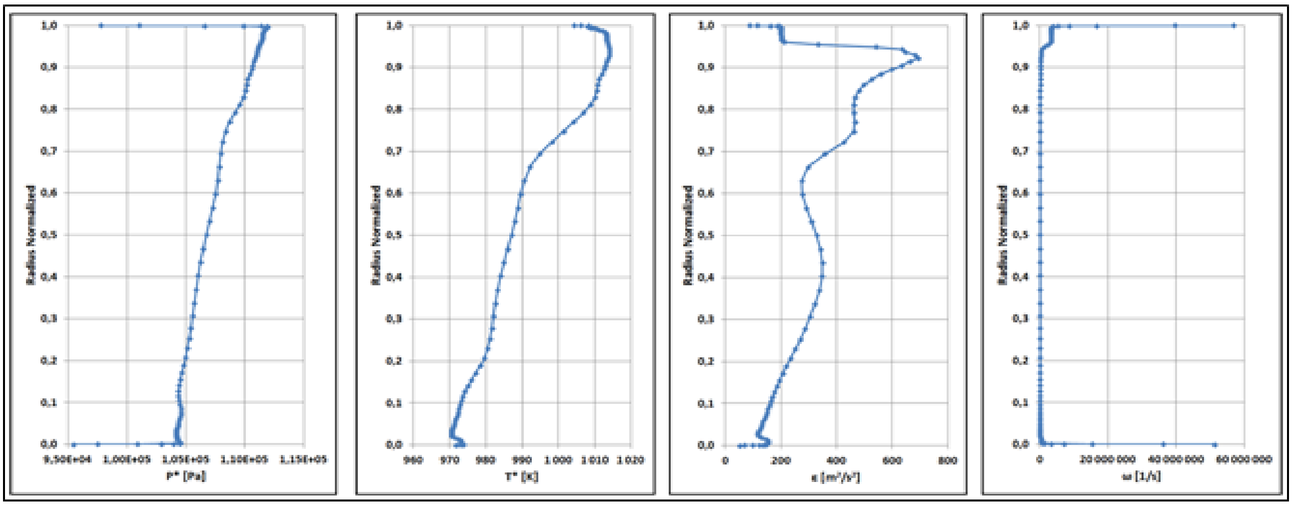

Fig. 4. BC at the inlet of the diffuser – radial profiles of total pressure, total temperature, turbulent kinetic energy and turbulent eddy frequency.

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III. RESULTS

The preliminary geometry of the annular diffuser, obtained at the stage of preliminary design, did not provide high values of the static pressure recovery coefficient (Cp). To optimize the geometry, the well-known performance charts of annular diffusers were used, connecting the main relative sizes of the diffuser with its operating parameters. The operating mode maps were used to determine the range of relative sizes that satisfy the layout constraints and to verify the parameters of the optimized diffuser obtained from CFD. Figure 5 shows an experimental map of the performance characteristics of an annular diffuser [4; 5]. The performance map shows the results of CFD calculations for the original version and the two best options according to the results of optimization (highlighted by the frame). Figure 5 shows that the mathematical model accurately determines Cp and corresponds to the experimental data. Therefore, two candidates for optimal geometry with high Cp and efficiency in the field of favorable (non-separable) modes, differing in axial length, were obtained. A longer diffuser allows achieving large Cp values. The choice between the two options will be based on the engine layout constraints.

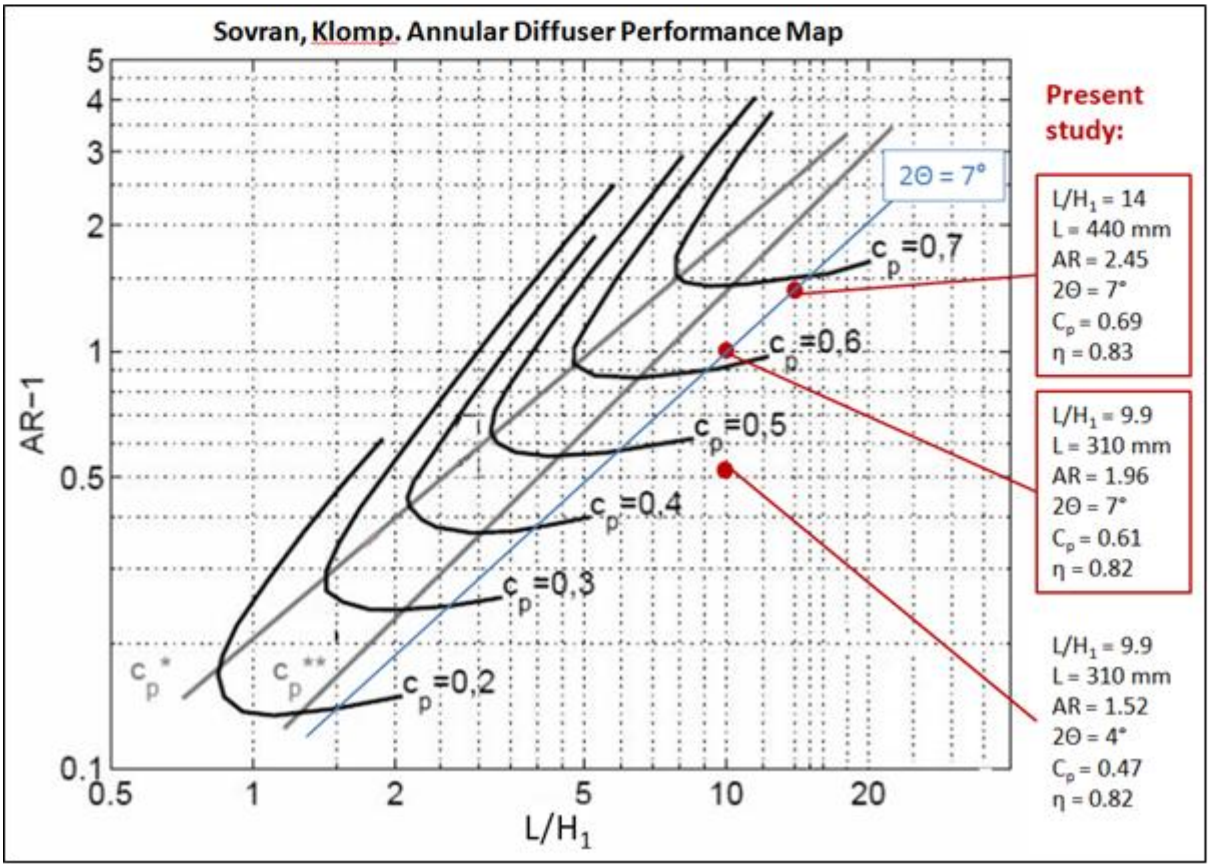

Fig. 5. Experimental performance map of annular diffuser [2; 3].

Optimized diffusers work at the separation boundary in the separation-free area. A further increase in the angle Θ greater than 3.5° leads to the appearance of a PS separation and a significant decrease in the efficiency of the diffuser (Figure 6). This conclusion closely coincides with the results of [6; 7].

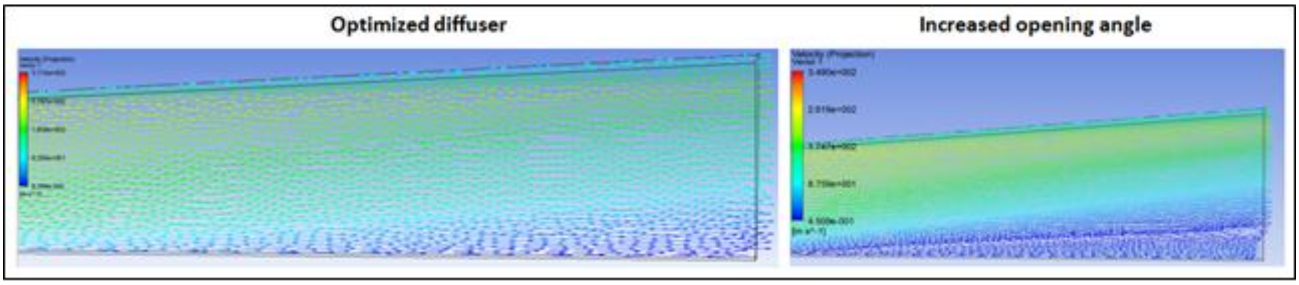

Fig. 6. Flow field in optimized diffuser and diffuser with an increased opening angle.

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IV. EFFECT OF THE FLOW SWIRL AT THE DIFFUSER INLET

It is known that the swirl at the inlet of the diffuser significantly affects the efficiency of its work. The turbine of the designed small-sized gas turbine engine had a swirl at the exit of the stage of about 25° (Figure 7). Swirl at the inlet can have both positive and negative effects on the diffuser flow and in some cases has an optimum, which allows increasing the efficiency of the diffuser up to certain angles. This influence depends on many factors, such as the combination of geometric parameters, the configuration of the diffuser, the flow regime – the Reynolds and Mach numbers.

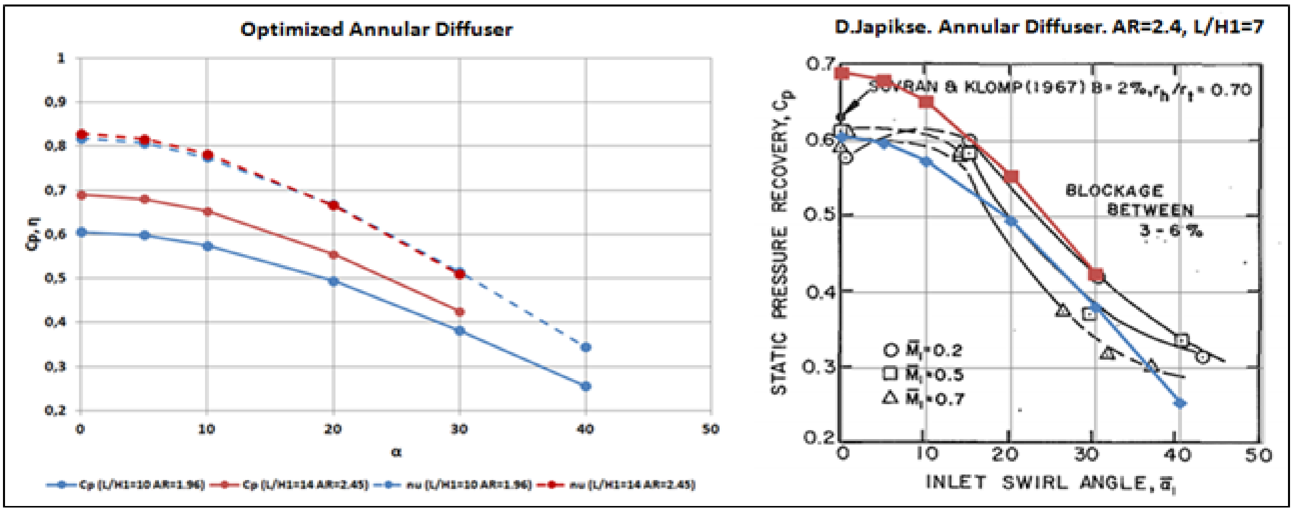

Fig. 7. Dependency of performance of two variants of optimized diffusers on inlet flow swirl angle in comparison with experimental data [7].

The results of mathematical modeling of the flow in two versions of the above-optimized diffuser with an inlet swirl showed that even with the introduction of a small swirl the η and Cp of the diffuser begin to decrease. At swirl angles of 20° and 40°, efficiency decreases by more than 10% and 30%, respectively. This character of the dependence of η and Cp of the annular diffuser on the swirl angle corresponds with the experimental data for diffusers of this configuration (Figure 8) [8].

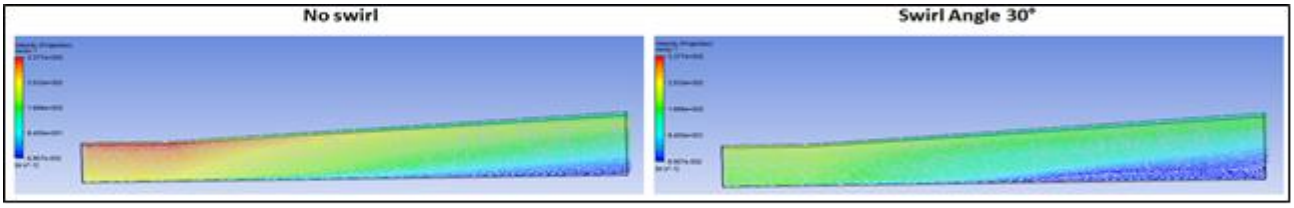

Fig. 8. Flow field in an optimized diffuser with inlet swirl.

Calculations show that such a drop in efficiency is due to the fact that the swirl provokes a tear-off flow on the inner wall of the diffuser (Figure 9).

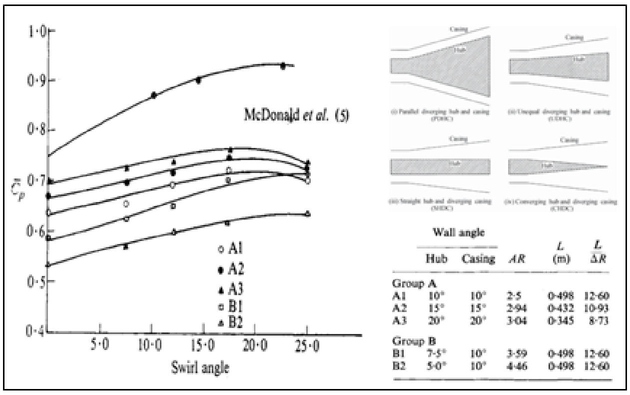

Fig. 9. Swirl characteristic of diffusers of various design [6; 8].

Studies described in the literature show that different configurations of annular diffusers have significantly different characteristics in terms of swirl angle. However, there are configurations that are resistant to the swirl angle of a broad range [9; 10]. This served as a motivation for the study of such configurations of annular diffusers, in particular, a diffuser with the same angles of inclination of the outer and inner forming walls Θ1 and Θ2 (Figure 10).

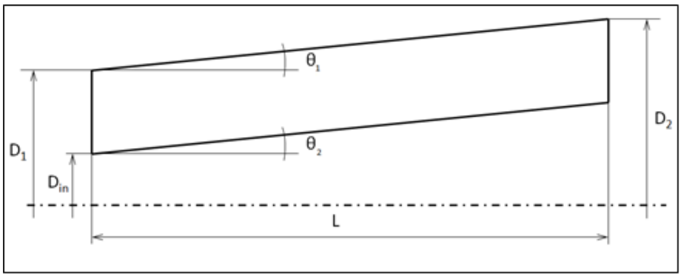

Fig. 10. Scheme of a diffuser with parallel walls.

The relative geometrical parameters of the optimized ring diffuser with Θ2 = 0 were taken and the geometry of the annular diffuser with Θ1 = Θ2 and the same parameters was constructed (Figure 11). Then there was a series of calculations of new geometry with different swirl angles.

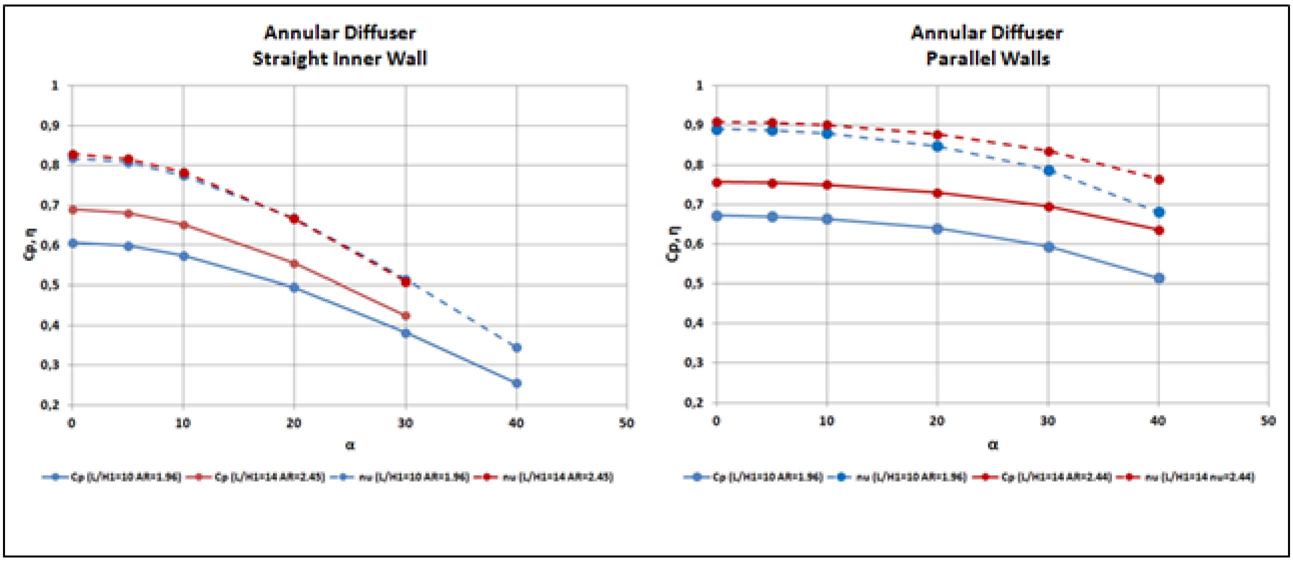

Fig. 11. Swirl characteristic of a diffuser with a straight inner diffusers wall and diffuser with parallel walls for two variants of optimized designs.

The calculations showed that a diffuser with Θ1=Θ2 turned out to be more resistant to the swirl flow at the inlet than a diffuser with Θ2=0 (Figure 11). So, for example, at 20° swirl the efficiency and Cp decreases by only ~ 3%, and at angles less than 10°, there is practically no decrease in efficiency. Note that a diffuser with Θ1=Θ2 is resistant to a swirl angle of a broad range – a decrease of η and Cp by more than 10% occurs only at swirl angles greater than 35°.

V. CONCLUSIONS

This study focuses on the development of a turbine diffuser for a high-efficiency gas turbine engine. During the study, a mathematical model was verified to calculate the flow in the considered diffuser.

The diffuser geometry was optimized. To determine the range of geometric parameters and verify the results, experimental maps of the characteristics of diffusers from the open-source literature were used. As a result of the optimization, it was possible to achieve high-efficiency indicators (83%) and the static pressure recovery coefficient (0.69) of the diffuser.

A special part of the study is devoted to the influence of the swirl angle at the diffuser inlet, which is presented in the developed turbine stage. The optimized diffuser with a straight inner wall was ineffective in terms of swirling inlet flow. To solve this problem, the inner wall of the diffuser was made parallel to the outer one, while preserving the relative sizes obtained in the optimization process. The resulting configuration of the diffuser has a stable characteristic of the swirling of the inlet swirl in a broad range (up to 35°) without significant degradation of operating parameters.

The results of the calculations coincide quite well with the experimental data from the open-source literature, which indicates the reliability of the mathematical model used.

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REFERENCES

1. I. A. Kulikov, A. A. Shorin, S. V. Bakhmutov, A. S. Terenchenko, K. E. Karpukhin, “A Method of Powertrain’s Components Sizing for a Range Extended Electric Vehicle”. SAE Technical Papers 2016-01-8096, 2016.
2. N. Kh. Tuan, K. E. Karpukhin, A. S. Terenchenko, A.F. Kolbasov, “World Trends in the Development of Vehicles with Alternative Energy Sources”, ARPN Journal of engineering and applied sciences, vol. 13(7), 2018, pp. 2535-2542.

3. C. U. Buice, J. K. Eaton, "Experimental Investigation of Flow Through an Asymmetric Plane Diffuser", Journal of Fluids Engineering, vol. 122, 2000, pp. 433-435.
4. G. Sovran, E. D. Klomp, "Experimentally Determined Optimum Geometries for Rectilinear Diffusers with Rectangular, Conical or Annular Cross-Section", in Fluid Mechanics of Internal Flow, G. Sovran, Ed. Amsterdam: Elsevier, 1967, pp. 270-319.
5. P. T. Couey, C. W. McKeever, M. F> Malak, S. Balamurugan, H. Raju Veeraraghava, R. Dhinagaran, "Computational study of geometric parameter influence on aggressive inter-turbine duct performance", Proceedings of ASME Turbo Expo 2010: Power for Land, Sea and Air, 2010.
6. L. A. Kosach, A. S. Gornovskiy, A.V. Kostyukov, "Vyhodnoe ustrojstvo turbiny v malorazmernom gazoturbinnom dvigatele" [Turbine output device in a small-sized gas turbine engine], Naukograd, vol.13, 2017, pp. 21-24.
7. L. A. Kosach, A. S. Gornovskiy, A. V. Kostyukov, K. Yu. Eliseev, "Optimizatsiya turbinnogo diffuzora mnogotselevoy mikroturbiny" [Optimization of a turbine diffuser of a multi-purpose microturbine], Izvestiya Moskovskogo gosudarstvennogo tekhnicheskogo universiteta MAMI, vol. 3(33), 2017, pp. 21-22.
8. D. Japikse, R. Pampreen, "Annular Diffuser Performance for an Automotive Gas Turbine", ASME Journal of Engineering for Power, vol. 101(1), 1979, pp. 358-372.
9. S. N. Singh, V. Seshadri, K. Saha, K. VempatiK, S. Bharani, "Effect of inlet swirl on the performance of annular diffusers having the same equivalent cone angle", Proceedings of the Institution of Mechanical Engineers Part G Journal of Aerospace Engineering, vol. 220(2), 2006, pp. 129-143.
10. A. T. McDonald, R. W. Fox, R. V. Van Dowestine, "Effects of swirling inlet flow on pressure recovery in conical diffusers", AIAA Journal, vol. 9(10), 1971, pp. 71-84.