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New method of tip losses reduction in thrusters ducted fan type based on the acoustic resonators separation flow control

A new approach of tip losses control that appeared at the tips region of the rotor blades, as well as in the guide vanes in thrusters ducted fan is proposed. The functional block diagram of acoustic resonators and theoretical approach of calculation of the similar systems is provided.

Introduction

Axial fans are widely used as thrusters at Manned and Unmanned Air Vehicle (UAV), and also at the Vertical Take-Off and Landing (VTOL) Vehicle. Axial fans are widely used as ventilation units at railway transport, and industrial facilities.

Taking into account for technical, and output performance of aircrafts, and also their production costs, one of the main way at the modern aircraft-engine-buildings is axial fans aerodynamic improving. One of the aerodynamic improving approach is reducing of the tip loses that was caused by vertical flows into the air-gas channel of the fans. Approbation of the preliminary studies shows that one of the approaches of their improvement is an active and passive influences methods implementation.

Background

Its well-known that flow separation is one of the factor that leads to rapidly decrease of fans aerodynamic characteristics, and can be a reason of operational range reduced, and as a result reduction of fans efficiency. Flow in the boundary layer of the profile surface characterized by the velocity decreasing and formation its considerable gradients, by means of skin friction. The velocity decrease leads to flow impulse extenuation that defined as production of the working body density at the square of its velocity. One part of the impulse and energy along the profile surface spends to overcome friction forces, another part starts to separate from the profile surfaces, and as a result we have boundary layer separation.

Flow separation can be removed with the help of flow impulse increasing into the area of its location. Impulse increasing can be reached with the use of vortex generators located along the boundary surface [1]. Another well-known approach of flow separation consists in continuous input and suction high-energy flow from the profile surface [2]. Suction above the separation line provides removing part of low-lag flow at the profile surface, and appeared free space at the profile surface became filling by the part of the high-energy flow that was removed above its surface. Presented methods to a certain extent provide flow reattachment by the way of cyclic perturbation to the boundary layer that influences for vortex structures shifting. Moreover, bought of two methods of separation control required an energy saving source, and energy supplying to the profile surface. Practical application of defined methods has a number of restrictions that was caused by their high costs, complicity of construction, and significant mass gain of the system in whole.

In addition, there were researches provided by the different authors [3, 4] of flow separation control in the gas-dynamic channels by the way of acoustics resonators applied. Those researches show the cooperation mechanism of sound wave and separated flow. The results of the researches show that at the beginning of the flow separation appeared natural unstable oscillation and with the help of acoustic resonator sound wave there are oscillation growing, that leads to flow attaching through all profile length, and during switching off separation appeared again. At present, there are restricted numbers of researches at the open literature sources regarding separation flow control at the blades row of axial turbomachinery. However, prospects of using and definition of the optimal characteristics, calculation methodology are very relevant for now.

Main idea and approaches

Principle of proposed method consist in boundary layer improvement and a possibility of prevention its separation, and as a result providing of the high level of aerodynamic blades load, extension of fan exploitation range, and improving of its stall margin with the help of new blade construction.

The engineering solution lies in the fact that for blade surface flow control the resonators was used. A resonator (fig. 1) consists of cavity 1 – volume V, hole 2 – diameter D, throat 3 – height h. Depending on frequency of flow forced oscillation into the fan that depends from design and modes of it operation, calculated the resonator geometric parameters for providing the necessary resonating frequency of natural oscillations, which defined by the formula

$$f_c = \frac{C_0}{2\pi} \cdot \sqrt{\frac{S}{V \cdot h}}$$

where,

f_c – overall resonant frequency of the system natural oscillation, Hz;

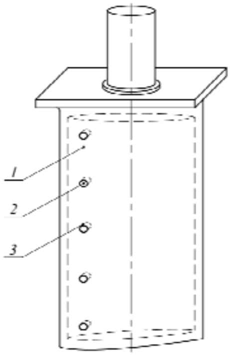
C_0 – acoustical velocity (340 m/s);

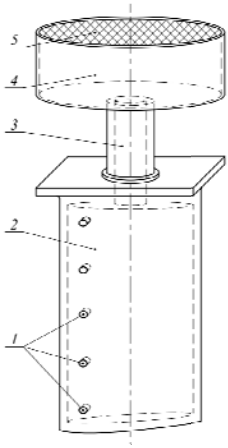
S – cross-sectional area of the cavity throat, m2;

V – resonator volume, m3;

h – hole height, m.

In practice, due to certain structural restrictions of blades, it is not possibility to provide necessary structural dimensions of resonators cavity. For such derestriction, above the blade mounts additional cavity (above the stator) 4 (fig. 2) that locates above the fan case, and works as an additional cavity (volume) for working body energy saving. Then, with the help of transition duct 3, connects with the resonating cavity 2, and provides the systems of connected resonators. System operation can provide by the additional driving element 5 (fig. 2).





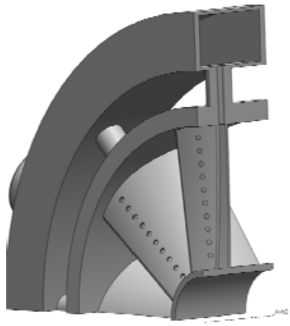


Рис. 1 Рис. 2 Рис. 3

High-energetic flow partially absorbed through the holes, and though hole 2, flows to the internal volume of the cavity 4. Accumulated volume of the working body, due to its own oscillation frequency that was specified by the design of resonator excites the boundary layer of the relative airflow by the exhaust of the air through the holes at the blade surface. Thus, leads to the recirculation of the boundary layer.

One of the system element is acoustic cavity (fig.). The geometric parameters of the cavity should include volume , throat length , and throat cross-section . For the environment parameters, where cavity is locates, can refer flow velocity into the specified volume , and its pressure [5].

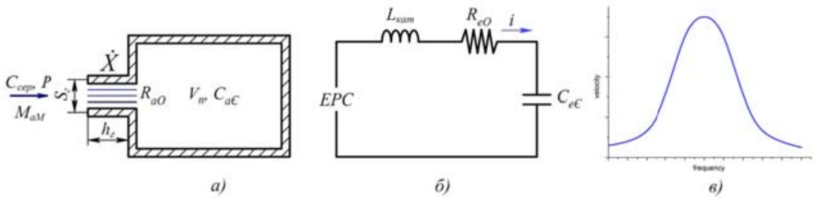


Рис. 4

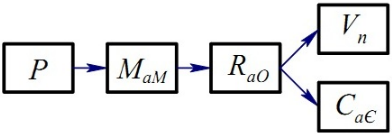


Рис. 5

In acoustic system, pressure p influences for acoustic mass M_{aM}, and acoustic resistance R_{aO} that correspond to the working body resistance into the cavity that connected with the volume V_n that in turn characterize by the acoustic cavity $C_{aЄ}$ (fig. 5)

Conclusion

New approach of acoustic resonators used for tip losses reduction of ducted fan blades leads for filling the velocity diagram of aerodynamic profiles, extend exploitation range of its attached flow, and also increase an stability and efficiency of ducted fans exploitations, and decrease tip losses as a whole.

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