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Studying the thermal effect in a swirled acoustic flow

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Abstract. The mechanism of generation of acoustic oscillations associated with the formation of stable vortex structures in a moving medium is considered on the example of impact swirl flow. A self-regulation effect was detected for condition, when the limiting flow rate of a swirl flow has been reached. This effect is expressed in resonance amplification of the amplitude of the natural frequencies of the hydro-mechanical system due to the absorption of the component of the spectrum of acoustic oscillations generated by the vortex structure of the flow. A redistribution mechanism for the energy of an open system at resonance, associated with the influx of air from the external medium is considered. Temperature distributions on the lower surface of the obstacle were obtained using the thermal imager, and the energy losses associated with the flow cooling due to expansion were estimated.

An experimental investigation of the thermal effect in a swirled acoustic flow was carried out within the framework of studying the effect of self-regulation of acoustic oscillations in a hydromechanical system in the pre-resonance and resonance regimes [1]. A detailed description of the experimental setup is given in [2]. The vortex chamber was a rigid metal vessel with plexiglass upper surface with central hole through which a swirled air stream was flowing out. To organize the impact character of the flow above the outlet opening, made in the form of a confuser, an unfixed barrier in the form of a flat disc was placed. During the measurements, the amplitude-frequency characteristics of acoustic oscillations were recorded; they carried information about the change in the local pressure field, visualization patterns of the vortex structure and the inhomogeneities of the flow, as well as the temperature field on the lower surface of the barrier [3].

With the help of thermal imaging measurements, it was found that the formation of a stable large-scale spiral-vortex structure in the form of a torus with a double rotation in the region of the expiration of an impact swirled jet occurs with the conversion of thermal energy into mechanical energy (Fig.1).

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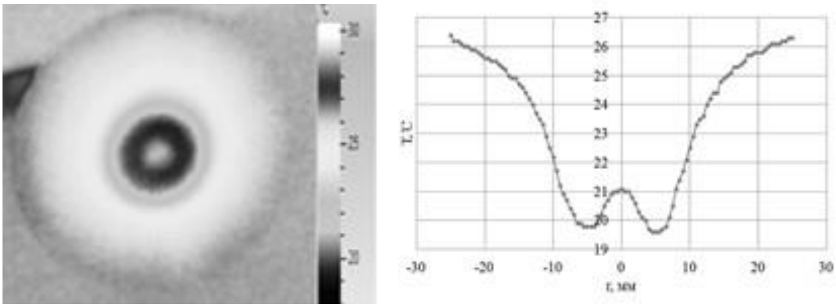
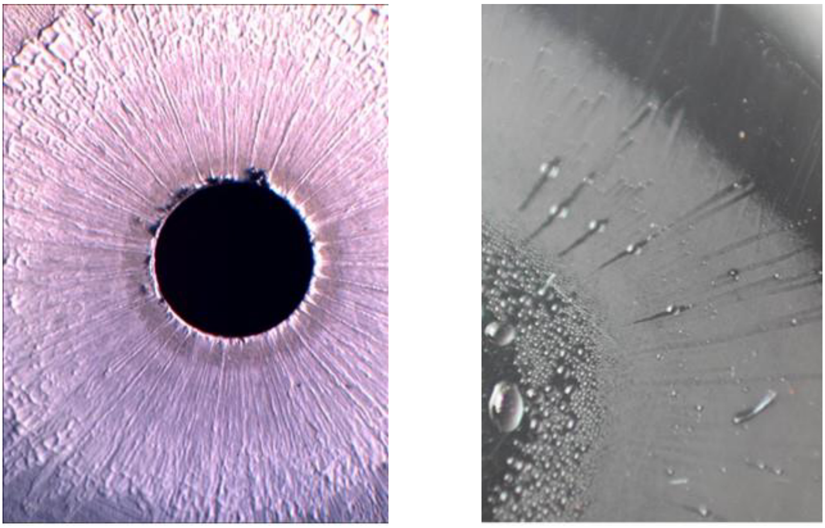


a) b)

Fig.1. Temperature field on the bottom surface of the plexiglass obstacle with a diameter $D = 50$ mm (a) and the temperature dependence on the radius (b) with the outlet port diameter of the vortex chamber $d_0 = 5$ mm and the flow rate $G = 1.3 \cdot 10^{-3}$ m^3/s.

The calculation shows that the temperature drop in the region of the toroidal vortex formed above the edge of the nozzle outlet from the vortex chamber (the dark annular layer in the central part of the barrier in Fig. 1a) is 6.4^0 C, which corresponds to a local decrease in temperature in the region of the vortex ring with a change of the radius in the range: 4 mm $\leq$ r $\leq$ 10 mm (Fig.1b).

The registration of the amplitude-frequency characteristics of the flow under critical flow conditions allowed clearly distinguishing two characteristic frequencies of harmonic oscillations corresponding to the angular frequency of rotation of the swirled flow and the rotation frequency in coherent screw-helical vortices. In this case, the swirled jet, leaving the vortex chamber opening in the region of sharp rotation and radial spreading of the flow due to the presence of an obstacle, was divided into thin spiral vortices, which is confirmed by the picture of the visualization of a vortex track (Fig. 2a). A sharp decrease in pressure in this region, thanks to the vortex formation, provided the transition condition through the dew point (Fig. 2b) with the formation of drops of condensed moisture.

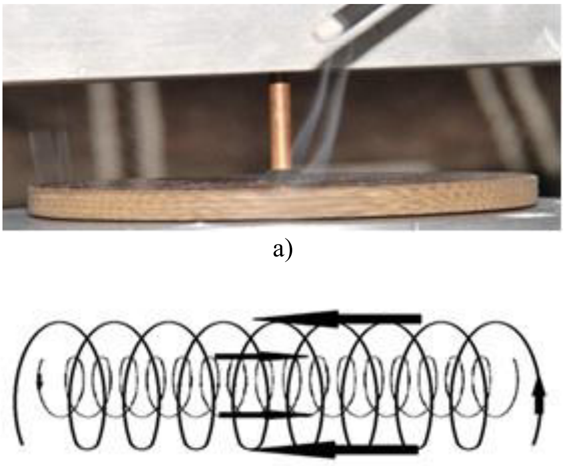


a) b)

Fig. 2. Visualization of the flow field in the resonant flow regime: a) formation of longitudinal helical vortices on the bottom surface of the gap; b) condensation of water droplets on the lower surface of the obstacle (the upper surface of the gap) in the regions of vortices localization.

The theoretical analysis carried out in [1], using of Lissajous figures corresponding to the ratio of two clearly defined harmonic oscillations, allowed proposing a physical model explaining the mechanism of energy redistribution in an open system at resonance. The first harmonic oscillation with frequency f_1 is associated with the formation of longitudinal helical vortices whose transverse scale is determined by the width of the slit. The frequency of the second fundamental harmonic oscillation is the frequency of rotation of the flow around the axis of the vortex chamber f_2. The air flow can perform several oscillation cycles until its energy becomes sufficient to release into the ambient medium.

Experimental observations have shown that, since the air before the vortex chamber entrance is preliminarily dried, the complicated topology of the vortex formation upon the expiration of the impact swirl flow is associated with the influx of air from the external medium. It can be seen from Fig. 2b that the arrangement of water droplets resulting from condensation after spreading of the flow corresponds to the arrangement of thin spiral air vortices (Fig. 2a), which ensures the air flow evacuation from the vortex chamber during the apparatus operation. Since, as already mentioned above, moist air in the work area could come only from the outside, a logical explanation for the observed condensation effect can be the assumption of a two-layer structure of spiral vortices (Fig. 3b). Under conditions of resonance regime of the impact flow, such a structure continues to exist for some time after the flow of the working fluid through the vortex chamber is cut off. The existence of the inlet airflow from the external medium into the space under the obstacle was experimentally proved by visualization with the help of a smoke jet (Fig. 3a).


a)

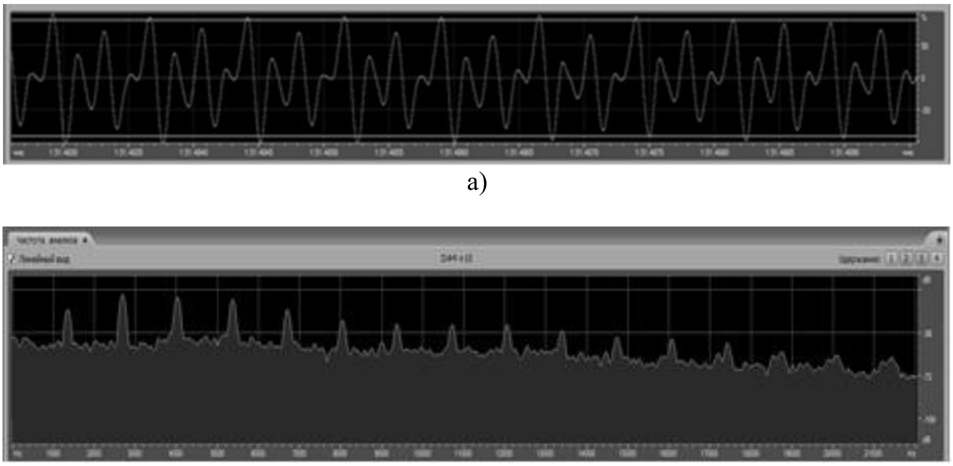
b)

Fig. 3. Visualization of air inflow into the space under the obstacle from the external medium by means of a smoke jet (a) and a flow pattern in the longitudinal helical vortex (b).

As can be seen in the photo (Fig. 3a), the smoke jet is drawn under the obstacle, thus demonstrating that an additional inflow of mass from the external medium is observed when the critical airflow from the vortex chamber outflows. To explain the mechanism by which additional flow entrance carried out under the obstacle, it is assumed that the vortex jets to which the impacted swirling flow is divided have a complex two-layer structure (Fig. 3b).

The vortex chamber is a rigid metal cylindrical vessel with a glued elastic plexiglas cover, through the hole in which a swirl air jet flows out. Having a large kinetic energy the air flow from the vortex chamber, excites vibrations of the elastic surface, which leads to fluctuations in the volume of air under the obstacle. As a result, when the speed of rotation in a spiral vortex coincides with the natural oscillation frequency of the elastic cover, the air outflow leaves the space under the obstacle in one cycle of oscillations, without returning to the center of the obstacle. The described process corresponds to the condition of acoustic resonance, accompanied by a sharp increase in acoustic oscillations at a frequency that coincides with the natural frequency of the oscillatory system.

The time sweep of the acoustic wave presented in Figure 4a also indicates the existence of a two-layer structure in a separate spiral vortex. The amplitude-frequency response corresponding to this time sweep is shown in Fig. 4b. This picture illustrates the experimental dependence, where the first peak with the low amplitude corresponds to the frequency of the external vortex f_1 in Fig. 3b, while the second peak with the higher amplitude corresponds to the frequency f_2 and rotational speed of the internal vortex with the opposite direction of rotation.



a)

b)

Fig. 4. Time scan of the acoustic wave (a) and frequency spectrum (b) for the obstacle diameter D = 30 mm and the flow rate $G = 2.85 \cdot 10^{-3}$ m^3/s.

Thus, the recording of the shape of the sound wave, shown in Fig. 4a is the resultant graph of two antiphase oscillations.

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References

1. O.V. Mitrofanova, I.G. Pozdeeva, Fluid Dynamics **50** 646 (2015)
2. O.V. Mitrofanova, I.G. Pozdeeva, A.B. Kruglov, V.B. Kruglov, Nuclear Phys. Eng. **3** (2012)
3. O.V. Mitrofanova, I.G. Pozdeeva, *Power balance at generation of acoustic fluctuations in the impact swirl flow* Materials of the International Conference "Nonlinear problems of the theory of hydrodynamic stability and turbulence" (2014)