CHARACTERISTICS OF A VORTEX TUBE WITH DETWISTING OF COLD FLOW

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The results of an experimental investigation of a vortex tube with a detwister installed in the cold-flow branch are presented.

The use of a hot-flow detwister in vortex tubes permits reducing to 9...10 units the length of the power separation chamber [1]. In many cases the thermodynamic efficiency of such tubes is no lower than the efficiency of cylindrical tubes 30 units long without a hot-flow detwister [2].

The positive effect of detwisting of a cold flow on the efficiency of vortex tubes was predicted in [3].

A cold-flow detwister, made in the form of a flat plate, can also be employed in order to reduce the noise arising at the outlet of this flow from the tube [4].

In this paper the results of an experimental investigation of an adiabatic cylindrical vortex tube 16 mm in diameter and 190 mm long, equipped with four-lobe hot- and cold-flow detwisters (Fig. 1), are presented.

The power separation chamber of the vortex tube is made of a seamless brass pipe with a wall 1 mm thick. The nozzle inlet, shaped in the form of an Archimedes spiral, and the cold-flow branch are made of plexiglass. The hot- and cold-flow receivers are made of sheet steel in the form of cylinders 100 mm in diameter and 103 mm long. Both cylinders are thermally insulated on the outside by a layer of foam 10 mm thick.

The relative area of the rectangular nozzle inlet $\omega = 0.103$ and the relative diameter of the opening of the diaphragm $\delta = 0.5$. The length of the conical cold-flow branch $L_c = 65$ mm and the cone angle $\gamma = 7°$. The length of the hot-flow detwister $\ell_h = 15$ mm.

The investigations were performed with detwisters 5, 7, 15, 30, and 50 mm long. Preliminary comparative tests of three- and four-lobe detwisters showed that they are virtually equally effective. For this reason, in the main investigations the four-lobe detwisters, which are easier to make, were studied.

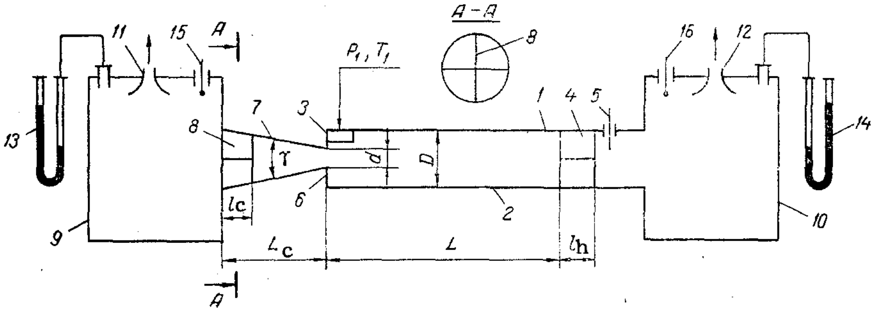

Fig. 1. Diagram of the experimental arrangement: 1) vortex tube; 2) power separation chamber; 3) nozzle input; 4) hot-flow detwister; 5) throttle valve; 6) diaphragm; 7) cold-flow branch; 8) cold-flow detwister; 9, 10) receivers; 11, 12) measuring nozzles; 13, 14) differential manometers; 15, 16) thermometers.

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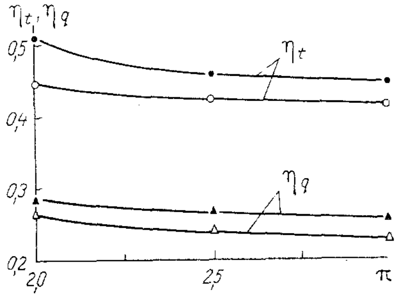

Fig. 2

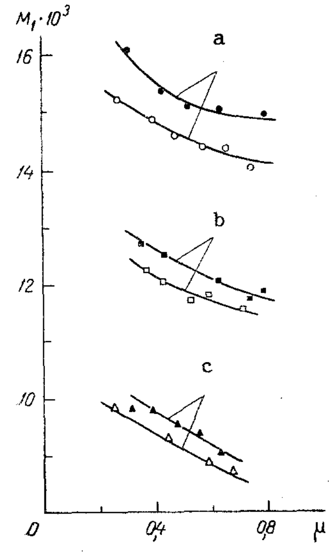

Fig. 3

Fig. 2. Power characteristics of the vortex tube: ℓ_c = 30 mm; light points — with a hot-flow detwister; dark points — with hot- and cold-flow detwisters.

Fig. 3. The flow rate M_1 (kg/sec) of compressed air as a function of μ: ℓ_c = 30 mm; a) $\pi = 3$; b) 2.5; c) 2. The notation is the same as that in Fig. 2.

The air temperature was measured with laboratory mercury thermometers with a scale division of 0.1°C. The pressure of the compressed air in front of the tube was determined with a standard monometer with a precision class 0.4, while the pressure in the receivers was measured with water differential manometers. The rates of flow of the hot and cold air flows were measured with the help of measuring nozzles, installed in the receivers.

The tests were performed on undried compressed air with input pressures p_1 equal to 0.2, 0.25, and 0.3 MPa. For each of these pressures the vortex tube was first studied only with a hot-flow detwister, and then with both detwisters.

In the course of the tests the pressure p_c in the cold-flow receiver exceeded the atmospheric pressure by not more than $2 \cdot 10^{-3}$ MPa.

The results of the investigations, presented in Fig. 2, showed that the thermodynamic efficiency of a vortex tube equipped with a cold-flow detwister is significantly higher. In the range of values of π studied the coefficient of temperature efficiency η_t is 7...15% higher while the adiabatic efficiency η_q is 7...13% higher.

The greatest cooling effect is obtained with a detwister with a length ℓ_c = 30 mm. The vortex tube with such a detwister has for each of the values of p_1 presented above maximum values of ΔT_c, equal to 27, 31, and 36°, respectively (for input temperatures T_1, corresponding to 21, 23, and 26°C, respectively), which is 3...5° higher than the maximum degrees of cooling of a tube with only a hot-flow detwister.

The use of a detwister at the outlet from the cold-flow branch leads, as the experiments showed, to a significant decrease in the radial pressure gradient in this branch; in addition, increasing the length ℓ_c from 5 to 30 mm gives rise to a monotonic decrease of this gradient, which for $\ell_c > 30$ mm remains constant.

Reducing the radial pressure gradient increases the coefficient of restoration of the pressure of the diffusor cold-flow branch, which with constant pressure in the receiver leads to a decrease in the pressure in the axial zone of the nozzle part of the power separation chamber. This last circumstance gives rise to a decrease in the air temperature in this zone, thereby increasing the thermodynamic efficiency of the vortex tube. In addition, decreasing the radial pressure gradient in the cold-flow branch decreases (or completely eliminates) the possibility of suctioning of air from the receiver through the axial region of this branch into the separation chamber, which also increases the efficiency of the temperature separation process.

In all cases when a cold—flow detwister is employed a significant increase was recorded in the total flow rate of air through the vortex tube (Fig. 3). The maximum flow rate, equal to $16.1 \cdot 10^{-3}$ kg/sec, was obtained for a detwister with a length ℓ_c = 30 mm with a pressure p_1 = 0.3 MPa. A vortex tube without a cold-flow detwister has in this regime a flow rate of $15.2 \cdot 10^{-3}$ kg/sec. For this detwister, however, as pointed out above, a minimum radial pressure gradient in the cold-flow branch was obtained and therefore the pressure in the axial zone of the nozzle part of the separation chamber was minimum.

The dependence of the rate of flow of air on the pressure in the axial zone of the nozzle section indicates that the efflux through the nozzle input is subcritical in the range of values of π studied; this corresponds to the results of [1].

It should be noted that the rate of flow of air decreases substantially when μ is increased (Fig. 3); this is associated with the increase in the hydraulic resistance of the diaphragm. The dependence $M_1 = f(\mu)$ must be taken into account in the calculation and design of vortex tubes. The corresponding working equations for the basic types of tubes are given in [5].

In the course of the tests the carry of the jet of cooled air was also determined; for this the cold-flow receiver was removed, which ensured that the jet flowed out freely into the atmosphere.

The carry of the jet was determined with the help of a vane anemometer, placed 0.75 mm from the output section of the cold-flow branch. The greatest carry was obtained for a detwister with a length ℓ_c = 7 mm. In this case, for p_1 = 0.25 MPa and μ = 0.8, the axial velocity of the jet reached 1.5 m/sec at the indicated distance.

If a detwister is not used, the twisted jet of cold air is virtually completely flattened in the surrounding space at a distance of approximately 0.5 m from the outlet section of the branch; this must be taken into account when vortex tubes are used in ventilation systems.

NOTATION

p_1, pressure of the compressed air in front of the vortex tube; p_c, pressure of the cold air at the outlet from the tube; $\pi = p_1/p_c$, degree of expansion; T_1, temperature of the compressed air in front of the vortex tube; T_c, temperature of the cold air at the outlet from the tube; $\Delta T_c = T_1 - T_c$, degree of cooling; $\eta_t = \Delta T_c/\Delta T_s$, temperature efficiency of the vortex tube; ΔT_s, drop in the air temperature with adiabatic reversible expansion with performance of work; $\eta_a = \mu\eta_t$, adiabatic efficiency of the vortex tube; $\mu = M_c/M_1$, relative flow rate of the cold air; M_c, flow rate of the cold air; $M_1 = M_c + M_h$, flow rate of the compressed air; M_h, flow rate of the hot air; $\delta = d/D$, relative diameter of the opening in the diaphragm; d, diameter of the opening in the diaphragm; D, diameter of the vortex tube; ω, relative area of the nozzle input, equal to the ratio of the areas of the nozzle input and the transverse cross section of the vortex tube; L, length of the power separation chamber; L_c, length of the cold-flow branch; γ, cone angle of the cold-flow branch; ℓ_c, length of the cold-flow detwister; and ℓ_h, length of the hot-flow detwister.

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