INFLUENCE OF INNER RIFLING ON THE EFFICIENCY OF A VORTEX TUBE

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The results are presented on experimental studies of cylindrical vortex tubes having inner rifling of the hot end.

The state of the inner surface of a vortex tube has an important influence on the efficiency of the temperature separation of gases. The data available in the literature on this question are scanty and, to a certain extent, contradictory. In [4] it is shown that polishing the inner surface of a vortex tube 8.7 mm in diameter and 36 calibers long made of acrylic resin increases the cooling effect by 10%. The authors of [1] suggest covering the inner surface of a vortex tube with a layer of plastic having a low coefficient of friction to a length of 8-16 calibers from the nozzle cross section to increase its thermodynamic efficiency. The results of an experimental study presented in [2] show a decrease of 10-20% in the efficiency of short vortex tubes 15 mm in diameter at the nozzle cross section having inner rifling of the hot end made in the form of triangular grooves and of a metric thread with pitches of 1.5 and 4 mm. The rifled section has a short length and is adjacent to the nozzle cross section.

At the same time, in [3] it was established that the use of inner rifling 1.5 mm deep (an inner diameter of 18 mm) over the entire length of the hot end allows one to reduce the length of the vortex tube from 30 to 25 calibers while retaining the cooling and heating capacity.

In order to refine the character of the influence of inner rifling on the efficiency of a vortex tube, we made experimental studies of cylindrical tubes 15 mm in diameter without aligning cross pieces and with a rifled surface of various lengths (Fig. 1). The tests were conducted on compressed undried air coming from a compressor. The temperatures of the compressed, cold, and hot air was measured in thermally insulated receivers by mercury thermometers with a measurement accuracy of 0.1°C. The pressure of the compressed air was measured by a manometer with an accuracy class of 0.6. The flow rates of the cold and hot streams were determined with Venturi tubes.

To reduce the heat inflow the frame of the helix was made of organic glass while the single-cut helix itself was made of brass with a rectangular channel in the form of an Archimedes spiral. The hot end of the vortex tube was made of brass with a smoothness of working of the inner surface of $\nabla 5$-$\nabla 6$ and was made detachable, screwed together from individual pieces each 6 calibers long. The section directly adjacent to the nozzle cross section was assembled from individual pieces each 1 caliber long.

The tests were carried out with the successive replacement of the smooth end pieces adjacent to the throttle by pieces of the same length with inner rifling made in the form of an M16 × 1 metric thread (rifling depth 0.54 mm). In the limiting cases either the entire inner surface remained smooth ($L_0 = L$) or it all had threaded rifling ($L_0 = 0$).

In Fig. 1 the results of the studies of vortex tubes with lengths of 18 (curve 1) and 48 (curve 2) calibers with $\pi = 5$ are shown. Similar results were obtained for $\pi = 3$. It was established that the influence of the length L_0 of the smooth section of the tube is not the same for long and short tubes. In a long tube an increase in the length L_0 from zero to seven calibers leads to a constant increase in the coefficient of temperature efficiency η_t. A further increase in the length of the smooth section does not affect the efficiency of the tube.

In a short tube an increase in the length L_0 from 0 to 6-8 calibers causes an increase in the temperature efficiency, as in a long tube. But a further lengthening of the smooth section reduces the coefficient η_t. An entirely smooth short tube has a somewhat lower efficiency than an entirely rifled tube.

Besides the experiments described above, we also studied cylindrical brass vortex tubes 15 mm in diameter and 48 calibers long with the following construction features: 1) inner surface smooth without rifling; 2)

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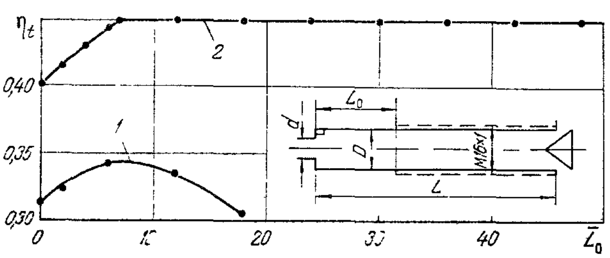

Fig. 1. Dependence of coefficient of temperature efficiency η_t on relative length $\bar{L}_0$ of smooth section of vortex tube. D = 15 mm; $\delta = 0.45$; $\omega = 0.092$; $P_0 = 5 \cdot 10^5$ Pa; $T_0 = 303$°K; 1) $\bar{L} = 18$; 2) 48.

at a distance of 6 calibers from the inlet nozzle there is a section 6 calibers long with an M16 × 1 thread; 3) the initial section 6 calibers long is made of Teflon; 4) the initial section 3 calibers long has an M16 × 1 thread.

The highest efficiency was obtained for vortex tube 3, which agrees well with the recommendations of [1]. Tube 4 proved to be the least efficient. Vortex tubes 1 and 2 have the same temperature efficiency, about 3% less than tube 3 but 10% higher than tube 4.

The results of these studies are in qualitative agreement with those of [1, 2, 4]. A quantitative comparison between the results obtained and those of the enumerated papers did not seem possible because of the considerable difference in the constructions of the test vortex tubes.

The results obtained indicate that the process of temperature separation of the gas occurs mainly in the initial section of a cylindrical vortex tube in a length of 6 to 8 calibers. The rest of the tube plays the role of a kind of vortex brake, reducing to a minimum the radial pressure gradient at the end of the vortex zone of the tube. If the length of the tube is great enough then the additional braking of the flow with the aid of the rifling does not affect the efficiency of temperature separation. But in short tubes the swirled flow is not able to be braked to a sufficient extent by the smooth inner surface of the tube, and in this case rifling on the inner surface leads to additional braking of the flow, having a favorable effect on the operation of the vortex tube. The introduction of rifling is evidently analogous to the use of an aligning cross piece or to lengthening of the hot end of the tube.

But in all cases the inner surface must be made smooth in the initial section 6 to 8 calibers long, which reduces the frictional losses in the main zone of temperature separation and raises the temperature efficiency of the vortex tube.

NOTATION

L, length of vortex tube; L_0, length of smooth section of vortex tube; D, diameter of vortex tube; $\bar{L} = L/D$, relative length of tube; $\bar{L}_0 = L_0/D$, relative length of smooth section of tube; d, diameter of diaphragm opening; $\delta = d/D$, relative diameter of diaphragm opening; $\omega = 4S/\pi D^2$, dimensionless cross-sectional area of helix; $\pi = P_0/P_c$, degree of expansion of compressed air; P_0, total pressure of compressed air ahead of vortex tube; P_c, total pressure of cold air at center of nozzle cross section of tube; $\eta_t = \Delta T_c/\Delta T_s$, coefficient of temperature efficiency; $\Delta T_c = T_0 - T_c$, cooling effect; ΔT_s, calculated air cooling upon isentropic expansion from a pressure P_0 to a pressure P_c; T_0, stagnation temperature of compressed air ahead of vortex tube; T_c, stagnation temperature of cold air; S, cross-sectional area of inlet helix.

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