Small-disturbance temperature diagnostics in vortex tube with a square cross-section

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Abstract. The temperature diagnostics in the Ranque-Hilsh vortex was based on the scanning with the special temperature sensor of small size. The temperature profiles in different cross-sections were recorded. The temperature profiles were also measured in the swirler chamber. The difference in temperature at cold and hot outputs was about 50 °С. Three measurement series carried out for each profile show that the temperature profiles in the Ranque tube is significantly nonstationary.

1. Introduction
The vortex effect in the Ranque-Hilsch vortex tube (RHVT) was investigated. This effect discovered by G.J. Ranque [1] doesn't have good physical explanation yet. The reason is the absence of veracious experimental data describing temperature profiles inside the RHVT. The detailed experimental temperature profiles measurements inside the RHVT are in great demand.

The sensors mounted inside the RHVT make great disturbances in the original flow. Experimental methods that do not perturb the flow should be investigated. For this purpose, optical techniques are the most suitable. It should be noted, that the optical methods application for the vortex effect investigation have been found in a relatively small number of works [2-4]. This is connected with the fact that the RHVT are sufficiently complex objects for precise optical measurements. In most optical techniques it is necessary to ensure the straightness of the optical ray paths. This constraint should be also applied to the shadow methods, the laser Doppler anemometry and other optical methods. Even optically transparent cylindrical tube surfaces are cylindrical lenses. They introduce phase distortion of optical wave fronts, which is unacceptable for accurate optical diagnostic methods. The creation of corresponding optical compensators is possible, but it is extremely complicated. In order to use optical methods the vortex tube with square section was applied.

Optical temperature measurements are rather difficult. And calibration of these methods required test measurements. In this work preliminary temperature measurements are provided that will be a basis for future optical temperature measurements technique development.

2. The experimental setup
The experimental setup was designed and constructed for the internal flow structure investigation in the entire volume of RHVT via optical methods. The setup circuit is shown in Fig. 1
The experimental Ranque tube (Fig. 1a) consists of the swirler (1), the working channel (2) with square cross section, the diffuser (3) and an outlet orifice (4). The swirler chamber diameter was 70 mm. The side of the square in cross-section was 34 mm. Compressed air was supplied through the nozzle 12 (Fig 1. c) to the annular channel 5, from where it entered through tangential slits 13 into the swirler chamber 1 with hyperbolic shape of a top wall. In such a vortex chamber the circulation value varies insignificantly downstream the entrance of the working channel. This fact allows increasing the
circumferential velocity at the entrance, as compared to the velocity in the slits. The number of slits in the swirl chamber may differ from 1 to 4. Working channel consists of three sections of the length \( L_1 = 130 \) mm. The channel length is 390 mm. These sections have two transparent walls 6, 7 (Fig. 1.d), which are made of optical glass, specially adopted for the optical methods of diagnostics. At the hot output of the channel, radial diffuser was used with a gap width between flange 8 and disk 9 varying from 0.5 mm to 1.5 mm to regulate the ratio of flow rates in the cold and hot outputs. Also the optical window 10 was placed on the hot output. The cold flow (Fig. 1b) flows through the orifice (11) which is disposed in the flat top end of the swirler chamber. In the described Ranque tube the Ranque effect was stably reproduced [5, 6], the effectiveness being slightly reduced in comparison with the vortex tube with circular cross section of 34 mm diameter.

![Diagram](image)

**Figure 2.** The experimental stand circuit (a) and the RHVT photo (b).

The temperature diagnostics was based on the flow scanning with the small-sized special temperature sensor. The process of scanning did not affect the output temperature. Sensors were made on the basis of direct heating semiconductor thermistors STZ-4v with a nominal impedance of 2.2 ohms. The sensors had the following characteristics: temperature resistance coefficient of 3.2 ... 4.2\% per °C at a nominal temperature of +20 °C, and the nominal temperature range varied from -60 to +125 °C. The semiconductor thermistor soldered in the glass was mounted in front of the glass needle. The needle was mounted into the Teflon sleeve in which electrical signal cable was longitudinally moved. The sensors were pre-calibrated and linearized (fig. 3). In this work the experimental setup was modernized. The signal from temperature sensors were collected via synchronized analog to digital converter LCARD E144. This measurement device allow to collect temperature measurements from 8
channel simultaneously. Also the coordinate system was used to improve the spatial displacement accuracy up to 0.1 mm.

\[ T = -25.801 \ln(R) + 38.047 \]

**Figure 3.** Calibration curve of temperature sensor.

The temperature distribution was measured in a swirler chamber. The temperature in the swirler was measured under the overpressure of 1, 2, 3, 4 bar (fig. 4). The temperature profiles are non-symmetrical. The temperature near the slit is colder rather in the other swirler space because of adiabatic expansion.

**Figure 4.** The temperature sensor in the swirler (a) and the temperature profiles in the swirler (b).
Figure 5. The illustration of nonstationary temperature distribution inside the vortex tube.

For each point several series of measurements were carried out which show that the temperature distribution in the vortex tube is significantly nonstationary. The difference in temperature measurement is about 4 K (fig. 5.).

Figure 6. The temperature contour maps in different sections under pressure Pin = 2, 4, 6 bar.
The temperature distributions in the cross-sections at several points along the vortex tube, were experimentally investigated (Fig. 6). The difference in temperature at cold and hot outputs was about 35 °C.

Conclusion
The temperature diagnostics inside the RHVT was carried out. The temperature distribution was experimentally investigated in the cross-sections at several points along the axis of the RHVT. The temperature distribution was also measured in a swirler chamber. The difference in temperature at cold and hot outputs was about 50 °C at inlet pressure of 6 bar. For each point several series of measurements have been carried out; they show that the temperature distribution in the vortex tube is significantly nonstationary.

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References
[1] Ranque G J 1993 *J. Physique Radium* 7 12–120
[2] Escudier M P, Bornstein J, Zehnder N 1980 *J. Fluid Mech* 98 49–63
[3] Schlenz D 1982 "Kompressible strahlgetriebene drallstromung in rotationssymmetrischen Kanalen", PhD thesis. Technische Fakultat Universitat of Erlangen-Nurnberg.
[4] Liew R, Zeegers J C H, Kuerten J G M, Machalek W R, 2013 *Experiments in Fluids* 54 1416–32
[5] Arbusov V A, Dubnishev Yu N, Lebedev V N, Pravdina M Kh, Yavorsky N I 1997 *Letters to the Journal of technical physics* 23 84–90
[6] Dubnishev Y N, Meledin V G, Pavlov V A, Yavorsky N I 2003 *Thermophys. and aeromech* 10 587–98