LDA Diagnostics of velocity fields inside the Ranque tube

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Abstract. Longitudinal and tangential components of the mean velocity field inside the Ranque tube of square cross section are presented for a central longitudinal section. Measurements are carried at central plane over the entire tube, with 1-2 millimeter step in transverse direction and with 10 millimeter step along the tube. The data is presented in the form of velocity maps.

1. Introduction

The experimental investigation of Ranque tube is carried out by means of LDA method. The nonintrusive diagnostics in the Ranque tube has currently demonstrated certain success. In [1] the large-scale vortex structure of double spiral form in the field of optical phase density is for the first time visualized by means of Hilbert optics. In [2] the same flow is diagnosed by scanning of a part of the central longitudinal plane section, using the LDA method with flow fumigation. In [3] a three-dimensional diagnostics is realized for water droplets in the nitrogen flow in the Ranque tube, and the data with good time resolution is obtained for velocity and size of particles. In [4] the mean velocity field is presented in the central plane of the tube, obtained by means of planar filtered Rayleigh scattering on gas molecules. In [3-4] the tube under investigation had the circle cross section, thus requiring the special correction of optical data out of the central plane. In [1-2] for the convenience of optical diagnostics all along the flow, the tube with square cross section, the so called square tube, was used. This particular tube is the subject of present research, also since it demonstrates large-scale hydrodynamic structure in the flow, observed by Hilbert optics in [1]. The influence of these structures on temperature separation has not been investigated yet. The careful comparison of circle and square tubes was made in [5] in the region of incoming overpressure from 1 to 6 Bar, showing a distinct Ranque effect of temperature separation in the square tube at nearly the same total flow rate, though being about 1.5 times less than that in a circular one with the tube diameter equal to the square side. In the present work the authors continue the investigation of the square tube [1-2, 5] in order to fit the LDA method for obtaining the two-dimensional mean velocity field all over the central plane as a first step. The more detailed data including on incoming pressure variation, measurements out of the center line and three-dimensional diagnostics are provided.

2. The experimental setup.

The actual Ranque tube (Figure 1) includes two-slit swirl apparatus, accelerating the vortex chamber with a planar top cover at one side and a profiled diaphragm at the other side, as well as the working square channel, adjusted to the diaphragm orifice. The cold exit from the tube is made as a cylindrical
channel, passing through the swirler cover, and the hot exit is made as a radial diffuser. Air from the hot exit flows in the buffer volume that has an exit to the atmosphere, regulated by the valve.

The compressed air enters the vortex chamber through two tangential slits with total area of 40 mm$^2$ at the radius $R_1=65$ mm. The diaphragm is hyperbolically shaped that keeps the velocity circulation almost constant up to the entrance into the working channel of the tube. The radius of exit to the channel is $R_2=17$ mm. Thus, the tangential velocity at the entrance of the tube is higher than that at the slit exit. The channel length is 450 mm. Thermal insulation is absent. Sections of the square tube are made of duralumin; each section has two optical glass windows on opposite sides.

The cold fraction $\mu=G_c/G_{in}$ is regulated by the hot exit valve. The gap size between the disks of radial diffuser is 1.5 mm.

The cold exit channel is 10 mm in diameter. The cross section of the working channel is a square with the side of 34 mm.

The flow rates at the entrance and the exits were measured by calibrated [5] orifice flowmeters. The cold fraction $\mu$, was kept equal to 0.24 at the incoming overpressure $P$ being equal to 1 Bar and the incoming flow rate $G_{in}$ equal to 0.02 kg/s. The temperature difference between hot and cold exits was 7K.

![Figure 1. Vortex chamber geometry and coordinate system](image)

The experimental flow kinematics inside the Ranque tube is studied using a laser Doppler anemometer (LDA) with an adaptive temporal selection of the velocity vector (LAD-05). The measuring device was designed and manufactured at the Kutateladze Institute of Thermophysics SB RAS, in Novosibirsk. The diagrams illustrating the LAD-05 complex operation principle and the LAD-05 photo are shown in Figure. 2. (a, b). The optical unit is mounted on a coordinate spacer (positioning device). The laser-optic velocity measuring circuit contains a laser, two orthogonally oriented acousto-optic modulators with traveling waves, a transmitting-receiving optical system, consisting of a series of mirrors and lenses arranged at the optical unit, and a photomultiplier tube (PMT). The photomultiplier tube transmits the signal to the quadroture mixer. The quadroture mixer passes the signal to the Doppler signal processor, which transmits the processed data to the computer. The test volume is scanned by moving the optical unit by a coordinate spacer (positioning device). LAD-05 operates as follows. After passing through the acousto-optical modulators the laser beam is diffracted into the zero and minus first orders. The split beams pass through a series of optical
elements of the system and then are sent to the tested area of the flow by the lenses. Intersecting in that area, laser beams form an interference pattern with the known space-time periodic structure. The particle moving through the intersection area scatters the light. The photocurrent appears at the output of the detector, producing a frequency pulse in the radio range with the Doppler frequency shift, which is the known linear function of particle velocity. The signal duration is equal to the time of particle passage through the volume of intersection. The LAD-05 measures two projections of the velocity vector in the range of 0.001-300 m/s with a relative error of no more than 0.5%. The size of the intersection area is 0.1x0.1x0.5 (mm). The coordinate spacer moves the measurement unit in the area of 250 x 250 x 250 (mm) with an accuracy of 0.1 mm.

3. The experimental results.
Velocity components $V_x$ and $V_y$ are measured in the central OZX plane, as shown in Figure 3. In these measurements, the module of $V_y$ component coincides with tangential velocity.

Figure 2.a. Diagram illustrating the LAD-05 complex operation principle. Figure 2.b. Photo of the LAD-05 measuring complex.

Figure 3. Illustrated measurement of two velocity components in channel cross section (several profiles).
The test points in each cross section were taken with the interval of 1-2 millimeters in Z direction. And the intervals between profiles in X direction were 10 millimeters. In each test point averaging was made on 300 particles for 3-15 seconds.

The results are presented in Figures 4, 5 in the form of velocity level maps.

**Figure 4.** Map of module $V_y$ (tangential velocity, m/s). The white dashed line denotes zero tangential velocity in the center.

**Figure 5.** Map of $V_x$ (m/s) with the white lines denoting zero longitudinal velocity and the boundary of the reverse flow area.

**Conclusion**

The longitudinal and tangential velocities were measured in the cross section of the square Ranque tube at one flow regime (overpressure of 1 Bar, incoming flow rate of 0.02 kg/s, cold flow fraction $\mu = 0.24$, the temperature difference in two exits of 7 K [5]). The maximum of tangential velocity was observed at a distance of one square side caliber from the inlet plane. The boundary of the reverse flow is distinctly shown in Figure 5 by white zero level lines for longitudinal velocity. The reverse flow area reaches the hot exit plane. No circulation areas were observed in the mean flow. The investigation of a variety of flow regimes should be continued. In particular, the three dimensional velocity fields should be obtained by using two LDA-meters simultaneously. A time development of velocity in certain points and PIV investigation of flow patterns will serve to verify and prove the presence of the large scale structures in the flow. The pressure pulsations will show if the rise and development of the large scale structures influence the mean characteristics and temperature separation.

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