Visualization in the Ranque-Hilsch vortex tube using high-speed video recording

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Abstract. Visualization via video recording was carried out in a Ranque-Hilsch vortex tube with a square cross-section. Video files were captured at recording speeds from 1000 to 10 000 frames per second. The best video files were obtained at a shooting frequency of 7600 frames per second with an input pressure of 1 bar. The video confirmed the presence of a double helix in the flow core in the second section of the tube. The video files showed the presence of a circulation zone between the flow core and the periphery, which is constantly changing over time. It can be clearly seen the angle at which the particles move in the peripheral flow.

1. Introduction
The vortex effect, also known as the Ranque-Hilsch effect, has been known for about 100 years. But up to date, it has not received generally recognized justification of the effect. The difficulty is that the flow inside the Ranque tube is strongly swirled. In this connection, there is a problem of studying the flow inside this vortex tube. Any sensor introduced directly into the stream distorts it greatly. And a lot of non-contact measurement methods have appeared nowadays. There are quite a few experimental studies of the flow inside the tube. Vortex tubes have been used in industry for a long time and studying the mechanisms of thermal separation can help increase the efficiency of vortex tubes.

The surfaces of the cylindrical tube distort the optical rays. The visualization of the flow, as well as the measurement of velocities by non-contact methods inside the tube is a time-consuming task. It was decided to use a Ranque-Hilsch vortex tube with a square cross-section. This tube was developed in the laboratory number 6.3 of the Institute of Thermophysics SB RAS. In 1997, visualization of a double helix propagating radially from a diffuser was obtained in this tube [1]. Also in [2], it was showed that the replacement of a round flow with a square tube does not influence on the effect. However, the effect becomes 2 times weaker.

2. The task of the experiment
The purpose of this experiment is to obtain a video recording that would allow us to see stable large-scale structures in the stream in the future.

Therefore, the first task is to find suitable tracer particles that this camera can see for 10000 frames per second. Such a shooting frequency is estimated to be necessary so that the movement of particles in the final video is lower than 1 cm during 1 frame capture.

The second task is to choose a light source that could be suitable for such a high frequency of video recording.
As a result, it is necessary to obtain a well illuminated video of the process occurring in the Ranque tube, where it is possible to observe the movement of particles less than 1 cm during frame capture, to estimate the period of large-scale structures.

3. Experimental stand and measurement methods

Figure 1 shows an experimental stand. Air is supplied to the installation through the swirler (section A-A). After that, the flow enters the chamber with a diameter of 78 mm through 2 tangential slits with a size of 40 mm². The swirled flow enters the square-section channel through a hyperbolic transition (B-B). This hyperbolic transition allows an increase in the speed of rotation of the air as compared to the exit from the slits. The channel consists of 3 sections with a size of 130 mm. The internal cross-section of the channel is a square with a side of 34 mm. The sections are equipped with optical windows with a size of 90*34 mm. At the hot end of the tube, a radial diffuser is used. The narrow band of the radial diffuser can be changed; in this work the width of 1.5 mm is set. The air enters the buffer volume tank, and then exits. From the cold end of the installation, the air exits through a round diaphragm with a diameter of 15 mm. The pressure of the input compressed air is regulated by a valve. Also, the ratio of cold exit flow rate and hot exit flow rate can be adjusted not only by the width of the slit of the radial diffuser, but also by the valves at the hot and cold exit, which the installation is equipped with. In all experiments, the cold fraction was 0.25.

Flow control is carried out by the pressure drop measurement on the flow meter orifices Gin and Gc, Gh. The flow meters are equipped with differential pressure sensors. The stand is equipped with temperature sensors (Tc, Tin, Th, Troom). The stand is equipped with pressure sensors (Pin, Ph, Pc). The more detailed description of the stand can be found in [5].

![Figure 1. Experimental stand with a vortex tube.](image)

The Evercam 2800c high-speed camera was used as a video recording tool. The maximum video recording frequency was 10000 frames per second with a resolution of 312*160 images. As a light source a red 100-watt diode, a green laser, a blue diode, and a red laser of 100 Wt were used.

4. Experiment with video recording

The first task was to find suitable tracers for the flow seeding, so that they could be clearly seen by the camera. Initially, there was an attempt to use the smoke from incense sticks. But the camera could not capture these particles. It is impossible to use glycerin smoke in the setup, since glycerin immediately
begins to settle on the channel optical windows in the form of a liquid rivulet, thereby making normal visualization impossible. Gypsum and titanium dioxides were also tested. The choice was made on titanium dioxide particles. They are sufficiently small (250-300µm) to move along with the flow and at the same time reflect light well.

All visualization experiments were carried out in the second section of the working channel.

Experiments on the selection of tracers were made using a white 100-watt diode. But at 5000-6000 frames per second, almost nothing was possible to see.

Then a red laser was tested. The experiment also failed at a speed of over 2000-3000 frames per second.

Then a green laser was taken, which showed the most successful results in visualization. With this laser, it was possible to see particles at a speed of 10000 frames per second, as expected.

It is known that the camera perceives red color well and an attempt was made to use red photodiodes with the power of 100 Wt in the amount of 2 pieces, but the result was worse than that obtained with a green laser. The best result from the available light sources was shown by a green laser knife. The images obtained via a green laser knife are shown in figure 2. A video recording at 10000 frames per second is a video with the maximum frequency at which it was possible to distinguish the flow of air. In these videos, you can already see the movement of particles at the periphery of the flow and in the inner core, but the flow pattern turned out to be indistinguishable. It was decided to choose the most successful frequency for this lighting and camera. It was important to maintain a balance of video quality and sufficient slowing down of the stream.

**Figure 2.** The images obtained using a green laser at an input pressure P=1 bar are excessive. The video recording speed is 10000 frames/s.

At a frequency of 7600 frames per second, the most successful videos were captured. Figure 3 shows the frames made using high-speed video shooting at 7600 frames per second and an excess input pressure of 1 bar. The light source was a green laser knife. At the moment, these are the best data obtained.
Figure 3. Characteristic frames of high-speed video shooting obtained at the speed of recording of 7600 frames per second. The excess pressure at the inlet is 1 bar.
In the video, you can see the rotating and precessing core of the flow, representing the double helix obtained in [1], which was carried out in the same tube in the 3rd section. The spiral obtained in this paper is shown in figure 4. The video also shows the circulation zone between the flow core and the periphery, moving in different directions. It can be seen that in this flow there are no stable boundaries between the periphery, the circulation zone and the flow core.

![Double Helix Visualization](image)

**Figure 4.** Visualization of a double helix using the shadow method. The exposure time of each frame is 250 µs.

5. **Conclusion**

The resulting video files show how the flow core precesses on the axis of a square-section vortex tube. The video confirmed the presence of a double helix in the core of the flow in the second section of the tube. The video files show the presence of a circulation zone between the flow core and the periphery, constantly changing over time. You can also clearly see the angle at which the particles move in the peripheral flow. The experiment is complicated by very rapid contamination of the tube. At the same time, it is necessary to increase the light power even more in order to shoot the stream at the highest possible shooting speed. It is important to continue video shooting to see large-scale structures in the vortex tube, which in turn will help to study those fragments of the flow that will be most significant for studying.

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