The working principle of a

Ranque-Hilsch Vortex Tube

By

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Abstract

A vortex tube is a Thermo-fluidic device, which generates cold and hot streams from a single injection of pressurized gas. Without any moving parts or chemical reaction within the tube, the interesting phenomenon of energy separation results only from fluid dynamic effects.

The main part of a typical counter-flow vortex tube is a straight tube with a tangential injection, through which compressed gas is injected into the tube. There are two exits, located at different ends of a counter-flow vortex tube, or at the same end for a uni-flow vortex tube. A control plug is positioned inside the tube away from the injection point, which has a smaller dimension than the inner diameter of the tube, and this allows the gas to escape from the small gap between the control plug and the tube. The cold exit is located in the central part of the tube at the same end of the injection, while the hot exit is the gap between the plug and the tube. When the compressed gas is injected into the tube tangentially at a high velocity, two streams with different temperatures will be generated and exhausted from the two exits of the tube. This phenomenon of temperature separation in a vortex tube is known as the Ranque effect.

Several explanations for the energy separation in a vortex tube have been proposed since its invention. However, due to the complex internal flow, the nature of the energy separation in the vortex tube, is still unclear. The proposed hypotheses can only be used to explain part of the phenomenon and they do not cover all the aspects of the temperature separation in the vortex tube. Therefore, to date, there has not been a well-accepted explanation for the thermal separation, and the flow behaviour inside the vortex tube remains unclear.

This thesis presents fundamental investigations on the Ranque-Hilsch Vortex Tube, with the aim to identify the dominant factors underlying in the energy separation phenomenon. This includes a critical review of current explanations, visualization of the flow pattern inside a water-operated vortex tube, accurate

measurements of the flow properties inside an air-operated vortex tube, and a novel analysis based on the experimental data, which has led to a new understanding of the flow behaviour and the process of temperature separation.

Previous research on the vortex tube is summarized in the literature review and included theoretical, experimental and numerical investigations. The various explanations for the temperature separation have been examined and the different factors within these previous explanations were evaluated, and a new hypothesis was proposed.

Flow behaviour inside a vortex tube was visualized in this study. Visualization of the flow direction along a vortex tube indicated the existence of the main stream and oscillation of the vortex flow. For the first time, the flow behaviour inside a water-operated vortex tube was clearly visualized using different methods. It was observed that most of the cold flow came from the front part of the tube, specifically in the cold core. Also, the flow structure in the hot region was first visualized by dye and tracer particles. The visualization results agree well with the hypothesized flow behaviour and provide significant evidence in support of the concept proposed.

The proposed hypothesis is also supported by the results of the obtained velocity profiles. Obtained from the visualization results and measured in the air-operated vortex tube, the swirl velocity distributions near the hot end in both vortex tubes indicate the outwards flow and formation of a flow re-circulation region known as the multi-circulation. Calculations of the volumetric flow rate along the vortex tube indicate the existence and locations of the cold core and the multi-circulation. The axial and radial velocity profiles in an air-operated vortex tube indicate the existence of the cold core. Formation of the multi-circulation is indicated by the 3-D velocity profiles in the rear part of the tube. Thus, the proposed hypothesis is strongly supported by the velocity profiles obtained in this study.

Exergy density analysis in the air-operated vortex tube was performed in this study and offered solid support for the proposed hypothesis. The analysis from this study, as well as the data from other studies, show a slightly decreased peripheral exergy density in the rear part of the tube, which defines the dominant contribution to the temperature rise from the stagnation and mixture due to multi-circulation. The dramatically reduced exergy density in the front part of the tube, together with an estimation of the temperature drop based on the forced vortex assumption, indicate that the pressure gradient in the front part of the tube is the primary factor contributing to the temperature drop.

Based on the proposed hypothesis, discussion of various geometrical effects, such as cold mass flow ratio, tube length, tube diameter and inlet nozzle, on the tube performance has been undertaken. A good agreement between the theoretical and experimental results demonstrates the validity of the proposed hypothesis for the temperature separation occurring within a vortex tube.

As a result of the study presented, a novel explanation for the temperature separation phenomenon inside a vortex tube can be forwarded, and can be supported by the flow visualization, measured flow velocity profiles and exergy analysis inside the vortex tube. The explanation is best described as a pressure gradient near the cold end being the main factor for temperature drop, while stagnation and fluid mixing due to the multi-circulation being the main reason for the temperature rise.

Declaration

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