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Thermofluid-Acoustic Analysis of a Ranque-Hilsch Vortex Tube

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Abstract

This paper aims to present analysis of sound produced from a Ranque-Hilsch Vortex Tube. A microphone was used to record the sound produced close to the hot tube. It is observed that, for one configuration of RHVT, the sound produced contains a specific set of frequencies. When the inlet pressure is varied, these frequencies remain almost the same, however, the magnitude changes. The RHVT produces different set of frequencies when using different swirl generator. These sets of frequencies-magnitudes represent signatures for each configuration. Different swirl generator nozzles were tested and presented. Frequency signatures with their related thermofluid performance are obtained.

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Keywords: Ranque-Hilsch Vortex Tube; Acoustic Analysis; Thermofluid Performance; Fast-Fourier Transform; Frequency Signatures

1. Introduction

Ranque-Hilsch Vortex Tube (RHVT) (see figure 1) is a mechanical device that is capable of separating compressed air into hot and cold streams. Compressed air is supplied at the inlet and flows through the swirl generator that creates swirl motion of the flow along the tube towards the conical valve. The swirl flow at the outer periphery near the tube wall exits through the valve with higher temperature than the inlet temperature. The center part of the flow hits the conical valve and bounces back toward the orifice producing lower temperature than the inlet temperature.

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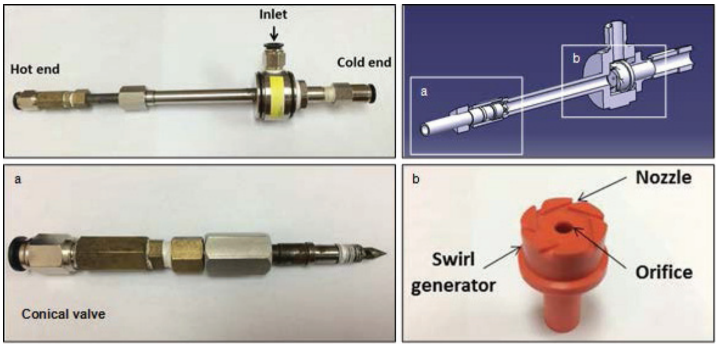

Fig. 1. RHVT and its main components.

Even though the process seems to be simple, the phenomena that occur inside the tube are still difficult to explain. How the temperature can be separated is still not well known. Many empirical studies have been conducted by researchers around the world. They studied mainly on the effect of RHVT parameters to the performance of the device. There are many parameters involved on the performance of the RHVT, such as the shape of swirl generator, the number of intake nozzles, the nozzle area, the shape and the opening of conical valve, the orifice diameter, etc. Mohammadi and Farhadi [1] conducted experimental analysis to optimize the number of nozzles and their diameters. They observed that with high number of nozzle the flow became more turbulent that mixed the hot and cold flows that led to the decreasing performance. The maximum isentropic efficiency obtained in their experiment was 6.8%. Wisnoe et al. [2], Ismail et al. [3] performed experimental investigation on the effect of conical valve shape, swirl generator, orifice diameter and inlet pressure on the performance of the RHVT. They obtained maximum isentropic efficiency of 33.6% when smallest nozzle and medium conical valve were used. Kandil and Abdelghany [4] investigated the effect of orifice size and the length to tube diameter ratio on the performance of the tube. They conducted computational fluid dynamics analysis and concluded that the orifice diameter needed to be lowest to obtain maximum cooling. Aydin and Baki [5] concluded that higher inlet pressure was needed to obtain greater temperature difference.

Measurement of thermofluid parameters of RHVT consists of measuring temperature, pressure and mass flow rate. Measurement devices are usually tapped directly at the inlet and outlets of RHVT to obtain the readings. This type of measurement allows obtaining output readings without observing the process inside the tube. Gao [6] conducted an experiment on the flow inside the RHVT using hot wire to measure the velocity at the cold end. Introducing hotwire inside the tube may disturb the swirl flow behavior as the presence of the hotwire creates blockage to the flow. This disturbance may be neglected when the blockage ratio is small enough. But as the size of RHVT is usually small, the blockage ratio becomes significant. Aydin and Baki [5] visualized the swirl flow pattern inside the tube. They did not specify the visualization technique used, but it looks like they used air bubbles in water medium. It is understood that water is an incompressible fluid. On the other side, the temperature separation in RHVT can occur only if compressible fluid is used. Hence, no quantitative data can be extracted from the visualization results. Kurosaka [7] attempted to analyze the RHVT effect through acoustic streaming. He found that the temperature separation was related to the flows which created acoustic wave known as whistle effect. The whistle effect occurs when the air flows through a blockage which makes the air to vibrate. This phenomenon can also be explained by the acoustic of flute. When a musician blows a rapid jet of air across the embouchure hole the air flow creates resonances and vibrate. The vibration is released in form of sound energy out of the end of the holes. This is explained by Fritz and Wolfe [8] in their paper. Another study on acoustic signals in an RHVT has been conducted by Istihat and Wisnoe [9]. They presented the wavelet transform of the acoustic signals recorded at the outlet of cold and hot tubes.

In this paper, the effect of swirl generator nozzle area (or nozzle depth) on the thermofluid performance of an RHVT and acoustic sounds produced close to the hot tube at different inlet pressure is presented. This is to observe the frequency signatures of the RHVT for different configuration.