The Effect of Orifice Diameter to the Acoustic Signal at the Hot Tube of a Ranque-Hilsch Vortex Tube

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ABSTRACT

The orifice diameter is one of the parameters that influences the device performance. This study aims to investigate the effect of orifice diameter on the acoustic characteristics produced at the hot side of a Ranque-Hilsch Vortex Tube (RHVT). The orifice diameters were 2 mm, 3 mm, 4 mm, 5 mm and 6 mm. The sound produced is captured by a microphone located outside of the hot tube. The sound signal produced from the tube is transformed into frequency representation using FFT algorithm. Results show that the orifice diameters affect the sound recorded. The frequencies produced by the hot tube remain the same at particular location except when the frequency produced by the orifice is overheard by the microphone. The frequencies obtained from the transformation are then filtered to most significant peaks which are named as frequency signature. Acoustic signatures are obtained from each change in diameter which relate to thermofluid performance of each configuration of the RHVT.

Keywords: *Ranque-Hilsch Vortex Tube, Acoustic Signature, Isentropic Efficiency, Frequency, Orifice.*

Introduction

RHVT (see Figure 1) is a non-conventional method for cooling and heating. Figure 1 (a) shows the drawing of conical valve which is located at the hot

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end of the tube and figure 1 (b) shows the swirl generator which contains inlet nozzles and orifice. When the compressed air is supplied through the inlet to the nozzles, flow with swirling motion is created along the outer periphery of inner tube wall. A fraction of the air exits at the conical valve of the tube with temperature warmer than the inlet temperature. The inner flow of air bounces back and leaves through the orifice with lower temperature than the inlet temperature. This device is capable to increase the air temperature up to 100˚C and decrease the temperature to -40˚C.The tube can be used for spot cooling in a machining operation, electronic panel and circuit cooling [1].

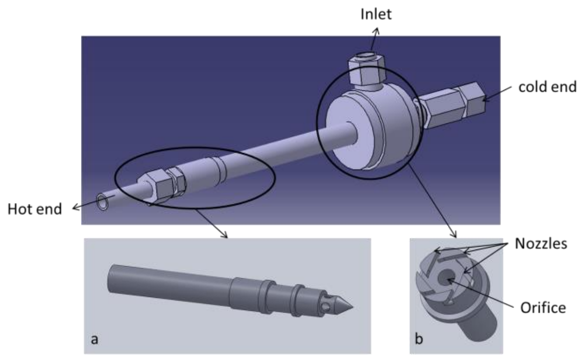


Figure 1: (a) Conical valve and (b) Swirl generator in RHVT

Experimental and simulation analysis have been done to determine the effect of the orifice parameter on the RHVT cooling efficiency. Eiamsa-ard and Promvonge [2] studied the effects of a number of tangential entries, orifice diameter and tube insulation. In the experiment, they mentioned that the cold orifice diameter needs to be 0.5 from the tube diameter in order to achieve maximum isentropic efficiency of 30% to 33%. On the other hand, Nimbalkar and Muller [3] mentioned that there was optimum geometry for orifice to obtain higher efficiency of the RHVT. Ismail *et al*. [4] studied the effect of the orifice diameter and inlet pressure on the RHVT performance experimental and CFD. In the study, they found that 4 mm diameter gave better performance compared to 5 mm of orifice diameter. Devade and Pise [5] said that diameter orifice was more effective compared to the size of the nozzle in terms of isentropic efficiency. Orifice is a small opening for the cold air to exit from the tube. Therefore, it is an important parameter to ensure the optimum efficiency is obtained.

Kurosaka [6] did an analysis of the RHVT effect through acoustic streaming. He said that the temperature separation of the device was related to the flow which created sound 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. This is explained by Fritz and Wolfe in their paper [7] that when a musician blows a rapid jet of air across the embouchure hole, the air flow creates resonances and vibrates. The vibration is released in the form of sound energy out of the end of the holes. Wisnoe *et al.* [8] conducted an experiment on the effect of different nozzles depth to the acoustic characteristic produced by the RHVT. In the experiment, they found that the nozzle depth affected the acoustic signature produced. Nozzle with smaller depth provides a higher signal frequency. He concluded that every parameter change provides specific acoustic signature.

In this paper, experimental study focuses on the effect of the orifice diameter to the acoustic signal produced on the hot side of RHVT and the device performance.

Methodology

An experimental setup was developed to investigate the effect of orifice diameter on the acoustic signal produced by the RHVT. The schematic diagram is shown in figure 2. It was designed to capture the acoustic signal produced by the RHVT and the thermofluid data such as the pressure, temperature and the mass flow rate.

The temperature, mass flow rate and pressure were recorded at 3 different positions which were at the inlet, hot outlet and cold outlet. The air pressure (gage) was controlled by the valve before it reached the inlet. The pressures were set from 10 psi, 15 psi, 20 psi and 25 psi. These pressures were chosen so the mass flow rate produced did not exceed the limitation of mass flow meter. This experiment was held in thermodynamic laboratory at 100.6kPa to 101.1kPa of atmospheric pressure.

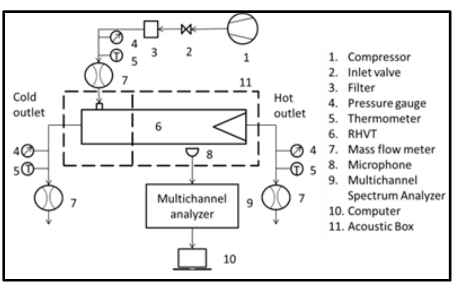
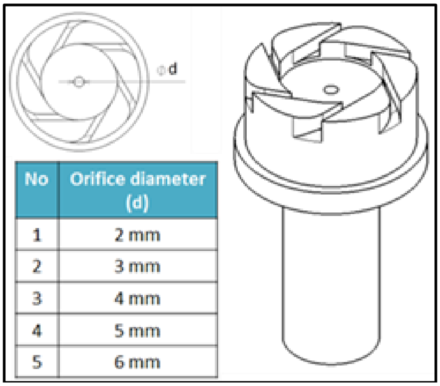


Figure 2: Schematic diagram of the experimental setup



No	Orifice diameter (d)
1	2 mm
2	3 mm
3	4 mm
4	5 mm
5	6 mm

Figure 3: Drawing of swirl generator

Figure 3 shows the diagram swirl generator that was used in this experiment. The difference of these swirl generators was the orifice diameter (d). The diameter was set to be from 2 mm, 3 mm, 4 mm, 5 mm and 6 mm. These 5 swirl generators were able to show the variation of frequency produced in the RHVT.

The thermo-fluid formula used was cold temperature difference; ΔT_c. Cold temperature difference was the temperature difference between cold air, T_c and inlet air:

$$\Delta T_c = T_i - T_c \tag{1}$$

Mass fraction was the ratio between the outlet mass flow rate and the inlet mass flow rate. The formula was given by:

$$\mu_c = \frac{\dot{m}_c}{\dot{m}_i} \tag{2}$$

Isentropic efficiency was calculated using the principal of adiabatic expansion of ideal gas. In this equation, γ was represented by the specific heat ratio (for air, γ = 1.4). Pa and Pi represented the atmospheric pressure and inlet pressure to the vortex tube respectively.

$$\eta_{isen} = \frac{T_i - T_c}{T_i\left(1 - \left(\frac{P_a}{P_i}\right)^{\frac{\gamma-1}{\gamma}}\right)} \tag{3}$$

The acoustic signal was recorded at the hot side of RHVT. The purpose of the microphone's position was to record only sound produced by the hot tube of the RHVT. The location of the microphone was approximately 37 mm from the swirl generator (see figure 4). An anechoic box was created surrounding the RHVT in order to isolate the outside noise while the microphone was used to capture the sound produced by the RHVT. It was divided into two which separated the acoustic signal between the hot side and the cold side.

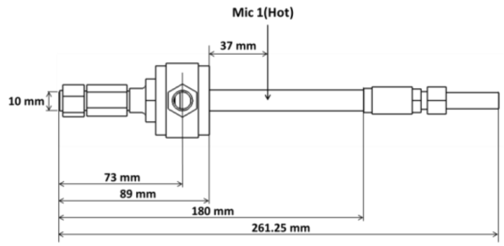


Figure 4: Dimension of RHVT and location of the microphone

The acoustic algorithm used in the experiment was Fast Fourier Transform (FFT). FFT is widely used in engineering. FFT is used to transform the sound signal produced into the frequency domain. This transformation helps in determining the frequency in the signal. Then the frequency representation was replaced by bars for the main frequencies to produce signature of the configuration. Lastly, the signature frequencies were related to the thermofluid data obtained from the device.

Result and Analysis

Effect of orifice diameter to thermo-fluid performance

Performance of thermofluid is referred to the isentropic efficiency, temperature different and mass flow rate. Figure 5 shows the performance of isentropic efficiency and temperature difference against the orifice diameter. Figure 5 (a) shows that the maximum efficiency is obtained at orifice diameter of 4 mm for all inlet pressures. The maximum efficiency obtained is 17.88% at 15 psi. This means that the optimum diameter of the orifice for this device is 4 mm. This optimum diameter also gives maximum temperature differences (figure 5 (b)). The maximum temperature difference is 12.1^{0}C at inlet pressure of 25 psi. From figure 5 (b), it is observed that higher pressure produces higher temperature difference. Note that inlet pressures are limited by the capacity of the mass flow meter; therefore, the maximum performance of the device cannot be achieved.

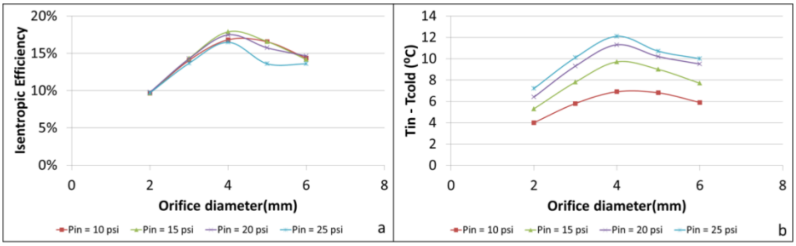


Figure 5 (a): Orifice diameter vs isentropic efficiency (b): Orifice diameter vs temperature difference

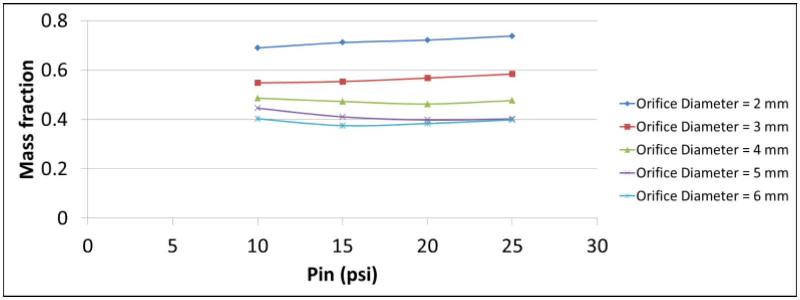


Figure 6: Hot mass fraction vs inlet pressure

Figure 6 shows the relationship of hot mass fraction and the inlet pressure. The variation of mass fraction for each orifice diameter is not significant when the pressure increases. The hot mass fraction decresases while the orifice diameter increases. This is because a larger orifice will allow more air to flow through it. The design of the RHVT consists of 1 inlet and 2 outlets. So, if a small orifice diameter is used to the RHVT, less air is allowed to flow through it. Therefore, more air tends to exit via conical valve.

Effect of orifice diameter on the acoustic signal produced

Figure 7 shows the time representation of sound generated by different orifice diameter. The figure shows the amplitude of the signal increases when the pressure increases. This is because when more pressures acted against the RHVT, the stronger the sound was produced. The signal produced was normally flat as shown in figure 7 (a), (b), (c), (e), (f), (i), (j), (m), (n), (p) and (q). When the compressor is working, the microphone captures the sound of the compressor as shown in figure 7 (d), (g), (h), (k), (l), (o), (r), (s) and (t).

The compressor sound is harder to isolate by the anechoic box since the system is directly connected to the compressor.

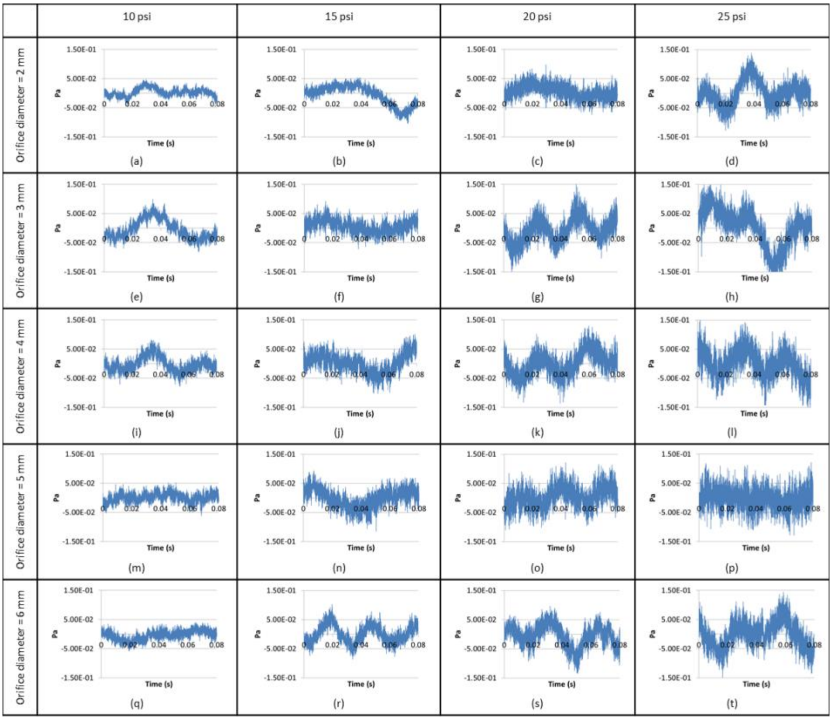


Figure 7: Time-signal representation produced for each orifice diameter.

From time representation, FFT is used to transform the signals into frequency representation. Figure 8 shows the frequency representation produced by the signal recorded. The amplitude of the frequency increases when the pressure increases. It is observed that the frequencies produced have the same set of frequency at a certain location. As shown in the figure, the lines refer to the same sets of frequency areas which indicate the similarity of the swirl generator design and RHVT shape. For 2 mm diameter of the orifice, the amplitude of frequency at the range of 6000Hz shows a high value. This is because of the small diameter of orifice which creates high amplitude of frequency through the small opening when higher air pressure is applied. The microphone has recorded the frequency produced by the opening of the orifice even though the microphone position is far from the source. Therefore, the comparison of the frequencies magnitude can determine the source location.

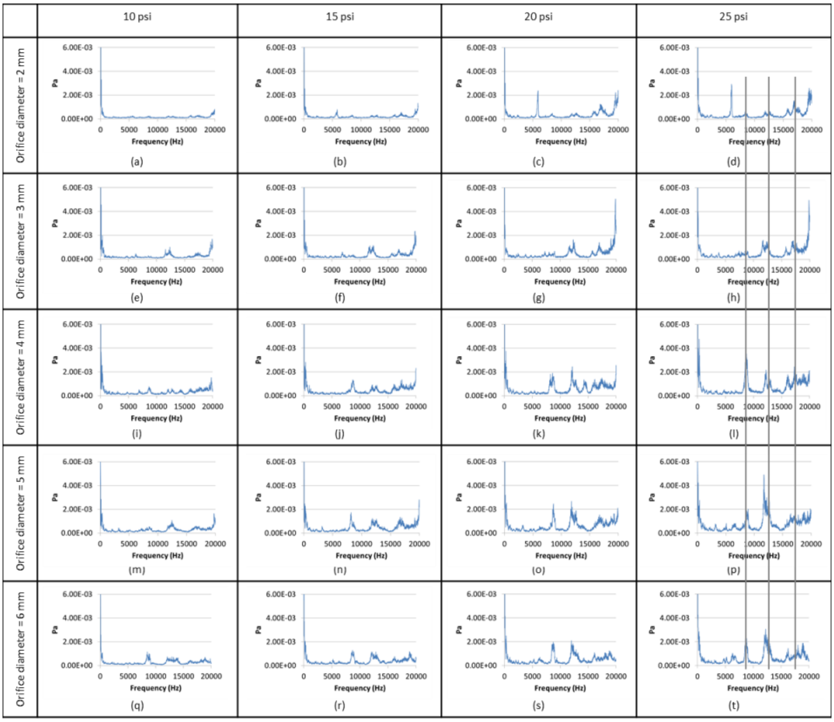


Figure 8: Frequency representation produced for different orifice diameter.

From the frequency representation, the peaks of the frequencies are chosen to form of set of frequency named as acoustic signature for each configuration of the experiment. Figure 9 shows that the significant peaks produced from the frequencies do not change in magnitude but only amplitude when the pressure increases. The acoustic signature is then referred to its cold mass fraction, temperature difference and isentropic efficiency. After correlation, the acoustic signature can be used to indicate the performance of the RHVT.

Conclusion

The effect of orifice diameter of the RHVT to the thermofluid efficiency and its acoustic characteristic are obtained. The maximum isentropic efficiency and temperature difference are given by 4 mm orifice diameter. The maximum efficiency obtained is 17.88% at inlet pressure of 15 psi. For the mass fraction, the smaller the orifice diameter, the smaller amount of compressed air is allowed through the orifice. On the other hand, more compressed air will exit through the hot outlet; therefore, the hot outlet increases when the orifice diameter decreases. The orifice created effects on acoustic characteristic. The smallest diameter orifice creates high amplitude of frequency at 6000 Hz range. The smaller orifice will create a greater turbulence in the tube which creates high amplitude of frequency.

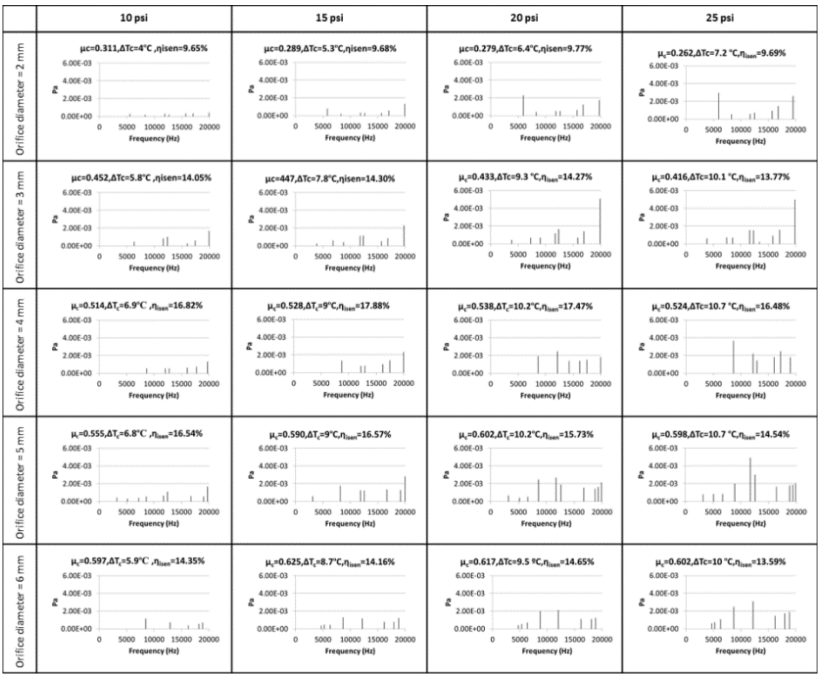


Figure 9: Acoustic signature produced for each different temperature and inlet pressure

It is recommended to use more of the recording device during the study area to determine the exact location of the sound source produced along the tube. Experiments have been conducted with the additional precaution of water droplets in the compressed air. Water droplets were created in the compressor when the air was kept in the tank. Water coming out affected the result of temperature and mass flow rate.

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