

## Wavelet Transform Of Acoustic Signal From A Ranque-Hilsch Vortex Tube

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**Abstract.** This paper presents the frequency analysis of flow in a Ranque-Hilsch Vortex Tube (RHVT) obtained from acoustic signal using microphones in an isolated formation setup. Data Acquisition System (DAS) that incorporates Analog to Digital Converter (ADC) with laptop computer has been used to acquire the wave data. Different inlet pressures (20, 30, 40, 50 and 60 psi) are supplied and temperature differences are recorded. Frequencies produced from a RHVT are experimentally measured and analyzed by means of Wavelet Transform (WT). Morlet Wavelet is used and relation between Pressure variation, Temperature and Frequency are studied. Acoustic data has been analyzed using Matlab<sup>®</sup> and time-frequency analysis (Scalogram) is presented. Results show that the Pressure is proportional with the Frequency inside the RHVT whereby two distinct working frequencies is pronounced in between 4-8 kHz.

### 1. Introduction

The invention of Vortex Tube by Georges J. Ranque was begun since 1933 and further developed by Hilsch 1947. Some explanation on the temperature separation has been stated by the inventors [1] but the real phenomena still a curious dispute to the others. Figure 1 shows the schematic of RHVT.

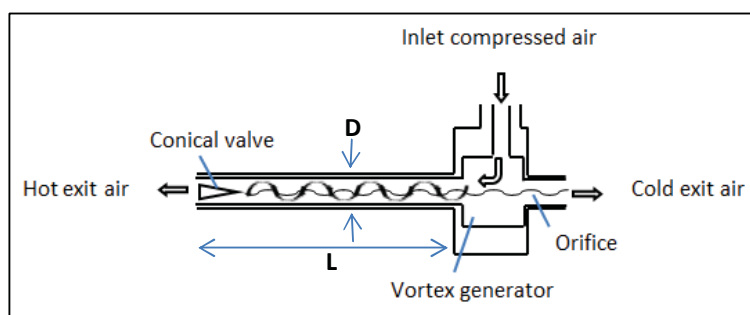


Figure 1 Schematic representation of a RHVT operating principle

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The compressed air flows through the RHVT's inlet and went out through the hot and cold exits [2]. Swirling generator located at the inlet chamber initiate a swirl flow inside the tube. This swirling flow will creates temperature distribution along the tube [3]. The compressed air was injected tangentially in the inlet and moving air near the peripheral will release at hot exit to produce hot air. Conical valve will reflect the moving air in the core side, bounced back and pass through the orifice as cold air at the cold exit.

Increasing the supply pressure, L/D ratio and number of nozzles will increase the performance of RHVT [4]. Aydin et. al [5] introduced a new geometry which called "helical swirl flow generator" for the cold end side for the improvement of RHVT performance meanwhile Wisnoe et. al [6] determined that the conical valve shape, pressure source and swirl generator influence the cold air at cold outlet, the mass cold fraction and the isentropic efficiency of RHVT.

Flow behaviour in RHVT consists of energy separation due to viscous friction as result of interaction between layers. Besides generating heat, the phenomena produce some noise can be heard clearly. Kurosaka et al. [7] conclude about the mechanism of energy separation in RHVT is due acoustic streaming induced by the vortex whistle. Yunpeng et al. [8] study the flow structure in a counter flow vortex tube by measuring velocity distribution and has come with velocity fluctuation by time domains. Chang-Soo & Chang-Hyun [9] concluded that vortex tube has two distinct kinds of frequency, low and high frequency periodic fluctuations.

The main objective of this paper is to do a preliminary analysis of acoustic signal produced from flow inside RHVT using Wavelet Transform (WT). The aim is to obtain the relation between pressure, frequency, temperature and time of the flow.

## 2. Experimental Setup

The schematic diagram of experimental setup is shown in Figure 2. The intention of this study is to record acoustic signal from RHVT using two microphones located at hot and cold exits of RHVT. The RHVT and microphones were placed in a special box which is appropriate to diminish surrounding noise.

Data Acquisition System (DAS), Multi-Channel Spectrum Analyser (PULSE System Type 3560D) has been used to acquire wave data. Five inlet pressures 20, 30, 40, 50 and 60 psi were supplied to the system so that temperature, flowrate and acoustic signal can be recorded. Sampling frequencies of 51200 Hz and 4096 wave data was captured for each microphone within 80 miliseconds. Method of renaming and processing raw data was referring to Istihat Y. et. al. [10]. The experiment was held in the thermodynamics lab at 1006 mbar atmospheric pressure, 23.7°C of room temperature and 72% humidity.

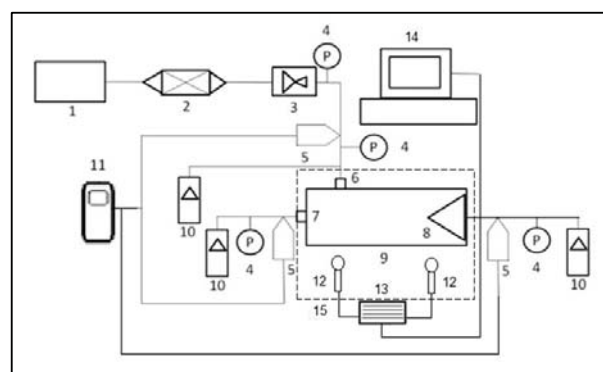


Figure 2 Schematic diagram of experimental setup. 1) Compressor 2) Dehumidifier 3) Pressure regulator (source) 4) Pressure gage 5) Thermocouple 6) Inlet 7) Orifice (cold end) 8) Conical valve (hot end) 9) Vortex tube 10) Flowmeter 11) Thermometer 12) Microphone probe 13) Data Acquisition System (DAS) 14) Computer 15) Box

### 3. Wavelet Transform (WT) and Matlab Setup

The Wavelet Transform (WT) is a method for time-frequency analysis. Richard (2007) [11] found that the continuous wavelet transform (CWT) of acoustic signals is a promising method to obtain the time-frequency energy distribution of a signal. The time-frequency analysis was originated from further study of frequency domain. Frequency domain is a useful technique to identify frequency at a given time domain using Fourier Transform (FT) but it has poor localization in both time and frequency [12].-The WT of a signal  $x(t)$  is a time-scale decomposition obtained by dilating and translating along the time axis of a chosen analysing function (wavelet). The CWT is defined as:

$$W_{\psi}(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} x(t) \psi^* \left( \frac{t-b}{a} \right) dt \quad (1)$$

where  $b$  is the parameter localising the wavelet function in the time domain,  $a$  is the dilation parameter defining the analysing window stretching  $\psi^*$  is the complex conjugate of the basic wavelet function. In other words,  $x(t)$  is the acoustic signal given in the time domain and  $W_{\psi}(a,b)$  is the WT result as a function of  $a$  and  $b$ . The wavelet function used in this study is Morlet Wavelet which is defined as:

$$\psi(t) = \frac{1}{\sqrt{2\pi}} e^{i\omega_0 t} e^{-\frac{1}{2}t^2} \quad (2)$$

where  $\omega_0$  is the wavelet frequency.

The computation is executed using Matlab<sup>®</sup> command `tfrscal` [13].

## 4. Results and Analysis

### 4.1 Experiment Results

Data for experiments was tabulated in Table 1. Temperature different between hot and cold exits was calculated as Delta T (°C) and graph of temperature profiles within working inlet pressure was draw in Figure 3.

Table 1 Experimental data

| Pressure (psi) |         |          | Temperature (°C) |         |          | Delta T (°C) | Flowrate (lpm) |         |          |
|----------------|---------|----------|------------------|---------|----------|--------------|----------------|---------|----------|
| inlet          | out-hot | out-cold | inlet            | out-hot | out-cold | Th - Tc      | inlet          | out-hot | out-cold |
| 20             | 0       | 0        | 23.6             | 36.9    | 7.1      | 29.8         | 70             | 70      | 50       |
| 30             | 0       | 0        | 23.3             | 42.0    | 0.5      | 41.5         | 80             | 100     | 68       |
| 40             | 0       | 1        | 23.3             | 43.9    | -2.0     | 45.9         | 105            | 135     | 70       |
| 50             | 3       | 1        | 23.4             | 38.4    | -1.5     | 39.9         | 125            | 172     | 80       |
| 60             | 7       | 10       | 23.6             | 32.4    | -0.1     | 32.5         | 100            | 235     | 45       |

From the graph, pressure of 40 psi gives more significant temperature different (45.9°C). Inlet temperature has a constant value around 23°C and no changes with the increment of pressure. For the out-hot (hot exit) temperature, the line's profile is same with the Delta T (temperature different). The value is increase gradually and meet a peak value at 45.9°C during 40 psi reading. Lines profile turn to negative slope until last reading of pressure at 60 psi. For the out-cold (cold exit) region, temperature was detected decrease from 7.1°C to -2.0°C at 40 psi and the value is increase to -1.5 and -0.1°C at 50 and 60 psi but in small ammount.

Figure 4-6 designate signal analysis of wave data for 20, 40 and 60 psi of hot and cold exits of RHVT. There are 2 rows of frequency at around 5 and 8 kHz (except for P = 60 psi out-cold, there are 3 area of frequency). Table 2 show the correlation of parameter studied with frequency. From the scalogram observation, the higher frequency is more visible in out-hot (hot exit) of the tube. This frequency does not have constant amplitude but it oscillates at several periodic times. For 20 psi out-hot, a peak reading was detected at 62 ms. Pressure 40 and 60 psi gives peak values at 36 and 10 ms.

The lower frequency is more visible in cold side. From 20 to 60 psi reading, the peaks for each oscillation was charted at 18, 12 and 40 ms. All readings were not constant and this is due to unsteady flow inside the tube.

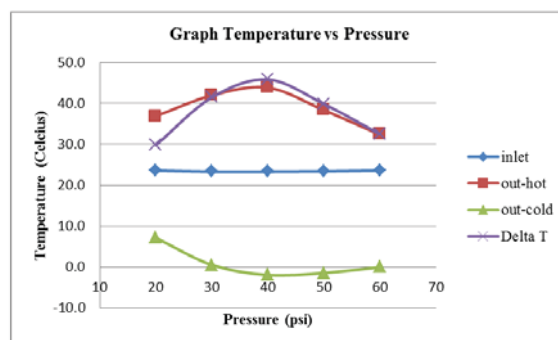


Figure 3 Graph Temperature versus Pressure

#### 4.2 Scalogram of acoustic signal

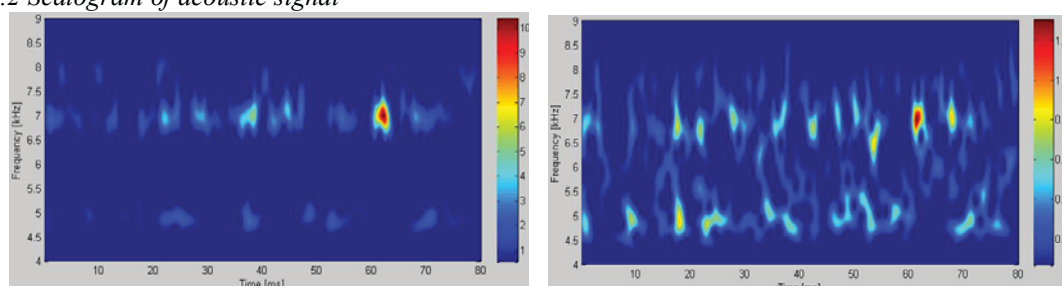


Figure 4 Scalogram for P = 20 psi out-hot & out-cold

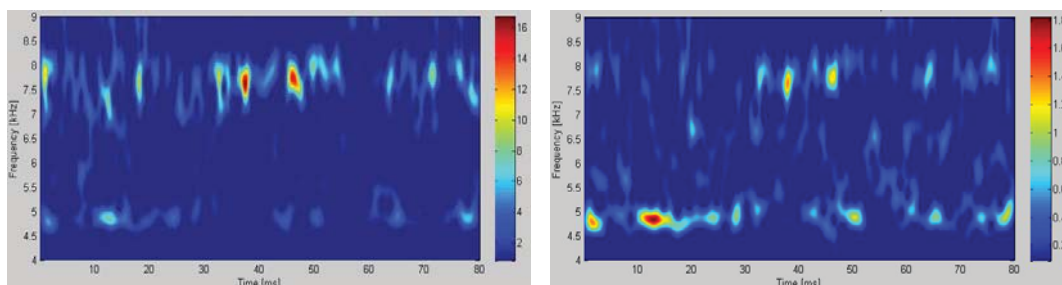


Figure 5 Scalogram for P = 40 psi out-hot & out-cold

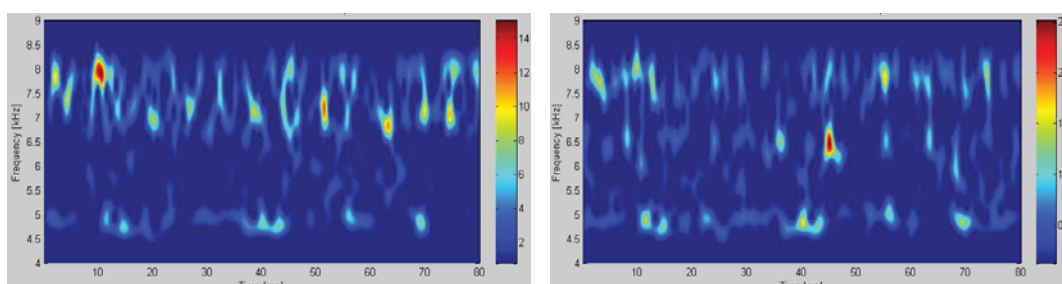


Figure 6 Scalogram for P = 60 psi out-hot & out-cold

Table 2 Correlation Data of Pressure, Temperature, Temperature Difference and Frequency

| P(psi) | Temperature (C) |          | Delta T (C) | $f_{hi}$ (Hz) | $f_{lo}$ (Hz) |
|--------|-----------------|----------|-------------|---------------|---------------|
| inlet  | out-hot         | out-cold | hot - cold  | freq-high     | freq-low      |
| 20     | 36.9            | 7.1      | 29.8        | 7.0           | 4.8           |
| 30     | 42.0            | 0.5      | 41.5        | 7.5           | 4.8           |
| 40     | 43.9            | -2.0     | 45.9        | 7.7           | 4.8           |
| 50     | 38.4            | -1.5     | 39.9        | 7.8           | 4.7           |
| 60     | 32.4            | -0.1     | 32.5        | 8.0           | 4.8           |

The higher frequency is related to the swirling flow in the hot tube and has a close agreement with Chang-Soo & Chang-Hyun (2006). They found that a RHVT has two distinct kinds of frequency, low and high frequency periodic fluctuations. Low frequencies are actually consistent with the calculated Helmholtz frequency and high frequencies are due to precession oscillation by the offset of swirl centre with geometric centre.

Figure 7 shows the curve of frequency versus pressure. It can be observed that pressure is proportional with frequency. Pressures influence the high frequency (freq-high) in a sense of the value is increased to 1 kHz (from 7-8 kHz). On the other hand, pressure does not influence the low frequency (freq-low) and can be classified as negligible effect.\

Figure 8 shows the relation of temperature with frequency-high among out-hot, Delta T and out-cold. The optimum value of pressure for this study is 40 psi. Frequency-high for out-hot and Delta T increase with the temperature. The values were decrease after this point. But for the out-cold, it gives a vice versa effects.

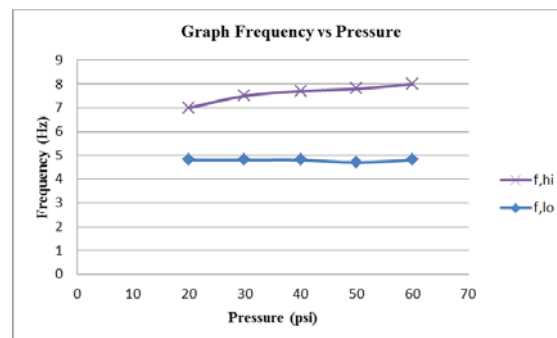


Figure 7 Graph Frequency versus Pressure

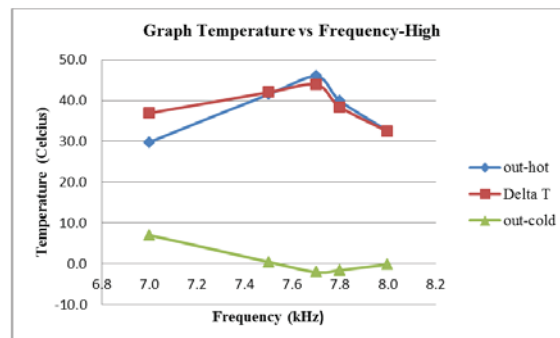


Figure 8 Graph Temperature versus Frequency-high

## 5. Conclusion and Recommendation

This paper shows swirling frequency inside the RHVT was studied and analysed by using WT. From the observation it can be concluded that the swirling frequency oriented were laid in between 4-8 kHz. Pressure of 40 psi was an optimum working pressure to generate high temperature different. Scalograms of all analysis signals were presented and it characterizes the frequency for each hot and cold exits.

For the recommendation, a box divider between hot and cold section should be arranged. The idea is to get pure frequency tone from each section. Attached microphones should be able to capture two different tones from hot and cold region. Further investigation is required to observe the relation between the frequencies observed with the flow in hot and cold region.

## 6. Acknowledgment

Authors would like to thank the Malaysian Ministry of Higher Education (MOHE), the Research Management Institute (RMI) and the Faculty of Mechanical Engineering, Universiti Teknologi MARA (UiTM) for providing fund and support for this research under Fundamental Research Grant Scheme (FRGS) 600-RMI/ST/FRGS 5/3 (74/2014).

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# Corrigendum: Wavelet Transform Of Acoustic Signal From A Ranque-Hilsch Vortex Tube

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CORRIGENDUM TO: 2015 IOP Conf. Ser.: Mater. Sci. Eng. **88** 012005

In the original paper equations 1 and 2 were corrupt, the correct equations are as followed:

$$W_{\psi}(a, b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} x(t) \psi^* \left( \frac{t-b}{a} \right) dt \quad (1)$$

$$\psi(t) = \frac{1}{\sqrt[4]{\pi}} e^{j\omega_0 t} e^{-t^2/2} \quad (2)$$