International Engineering Research Journal
Optimization of Vortex Tube by Selecting Different Parameters

A. M. Takane#1, Prof. S. L. Pachpute#

#Department of Mechanical Engineering, D. Y. Patil College of Engineering, Akurdi, Pune-411044, ,Savitribai Phule Pune University, India.

[1]amolmtakane@gmail.com

Abstract

This paper discusses the experimental investigation of vortex tube performance as it relates to cold mass fraction, inlet pressure and L/D ratio. Vortex tube is device used in industry for generation of hot and cold air from single compressed supply of air. Different explanations are proposed for the energy separation in the vortex tube. The effective parameters are geometrical and thermo-physical. The ascertainment focuses on the effect of double inlet nozzle, L/D ratio by changing D (D= diameter of vortex tube) to optimize the geometrical parameters and comparison with previous single nozzle and optimize double inlet nozzle vortex tube.

Keywords: *Vortex Tube, L/D ratio, Cold mass fraction.*

1. Introduction

Vortex tube also known as Ranque-Hilsch vortex tube is device that separate flow of compressed air into hot and cold streams without using any moving part. Vortex tube was invented in 1933 by metallurgist and physicist Ranque. His ideas were not widely read and remained unknown until 1945 when German physicist Hilsch published paper describing the actions of the vortex tube and improved the design. He proposed that the Ranque effect was incarnation of Maxwell's Demon. Hilsch received wide acclaim and now device is known as Ranque-Hilsch Vortex tube. It has one or more inlet nozzles, a vortex chamber, cold-end and hot end orifices. Specially designed vortex tube combined with effect of pressure, creates high rate rotations.

The main part of vortex tube is hollow cylinder, in which compressed air injected tangentially. The hot and cold end provides exhaust at both ends of tube. The hot nozzle is located at periphery while cold nozzle is centrally aligned with the tube. In counter-flow vortex tube exits are placed at opposite ends and at the same ends in uni-flow vortex tube. The compressed air is injected by nozzle tangentially in to tube develops swirling motion. Gas leaving at tube wall gets warmer while at central part it will be cooler. Centrifugal separation of the two split flow elements and their adiabatic expansion causes the energy separation in the vortex tube system.

The vortex tube was useful as a breakthrough device with application throughout the industry. It can be used in many industrial applications such as cooling equipment of computer numerical control (CNC) machines, refrigerators, cooling suits, heating processes, etc., as it is simple, compact, light and quite. Since it has no moving parts, it does not cause to break or wear the unit and therefore it requires little maintenance. There are two types of flow in vortex tube, such as parallel flow and counter flow. The working principle of counter flow can be defined as; a compressed fluid, which is passed tangentially into the vortex tube through nozzle, starts to make circular movement inside the vortex tube at very large speed, caused by cylindrical form of the tube, depending on its inlet pressure. A pressure difference occurs between tube wall and the tube center caused by friction of fluid flowing at high speed, through the radial pressure gradient also is responsible partly for separation of two streams. The speed of fluid near the tube wall is lower than the speed at tube center because of the wall friction. As a result, fluid at center region transfers energy to the fluid at the tube wall, in proportion with the geometric dimensions of the vortex tube. The cooled fluid leaves the vortex tube by moving against the main flow direction after the stagnation point, where as the heated fluid leaves tube in main direction.

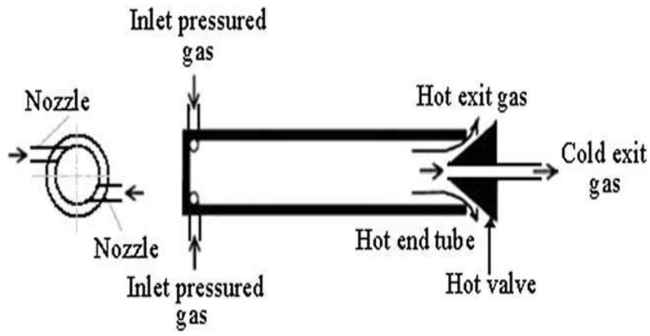

Fig.1 The schematic representation of a parallel flow vortex tube principle

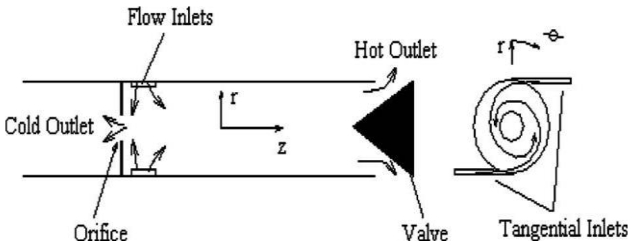

Fig.2 The schematic representation of counter flow vortex tube principle

2. Literature Review

Yunpeng Xue [1] has conducted experimental and computational analysis of counter-flow Vortex tube. He concluded that temperature drop of cold air can be considered to be the result of sudden expansion near the entrance, and temperature rise in hot air might be result of friction of multi circulation near hot exit.

M. Yilmaz [2] overviewed the past investigations of the design criteria of vortex tubes and the detailed information was presented on the design of them. In this article, an overview of the past investigations of the design criteria of vortex tubes was studied, to draw together the mass of literature, and to provide detailed information on the design of vortex tubes.

Volkan Kırmacı [3] tested the vortex tube for L / D = 15 have been tested by using the com-pressed air and five different orifices with different nozzle numbers N = 2, 3, 4, 5 and 6 to obtain the vortex tube performance. He estimated that increasing the vortex tube inlet pressure, the temperature gradient between the cold and the hot outlets was increased. Increasing the orifice nozzle number has decreased the cold and the hot outlet temperature gradient. The combination of high cold mass fraction of air flow and cold outlet temperature produces the maximum cooling capacity. A low cold mass fraction means a less air comes out, which is very cold. In short, the less the air is released, the colder the air will be.

Prabhakaran J. [4] investigated that the main factors affecting the performance of vortex tube are inlet pressure, L/D ratio, cold mass fraction, diameter of nozzle and orifice. In this paper the performance of the vortex tube is investigated with different diameters of orifice and nozzle.

Jiri Linhart et al [5] studied the Vortex tube properties and analyzed that in fluid flow there are basically two causes of pressure variation in addition to the weight effect. These are acceleration and viscous resistance.

Table 1 Properties of various gases

Gas	Prandtl Number	Sp. heat ratio	Molar mass	Gas constant
Air	0.73	1.403	28.97	0.287
CO_2	0.78	1.304	44	0.1889
NH_3	0.85	1.310	20	0.4157

Skye HM. [6] tested the Vortex tube with different L/D ratios, with different orifice sizes, pressures and cold mass fraction of 0.5 to 0.7 with 0.02 increments to obtain the vortex tube performance. The maximum temperature gradient between the cold and hot outlets is obtained when the orifice number is 2. The combination of high cold mass fraction of air flow and cold outlet temperature produces the maximum cooling capacity. Low cold mass fraction means that a smaller volume of air comes out, which is very cold.

In this study, the performance of a counter flow vortex tube is determined in regard to the measured cold outlet temperature and the hot outlet temperature gradient. The difference of this study from the previous studies is to determine the performance of the counter flow type vortex tube with nozzle number 2 by use of the processing conditions such as inlet pressure in a large pressure scale with very small increments, cold mass fraction with small increments, and different L/D ratios.

3. Problem Statement

Vortex tube is an altogether different vortex tube to achieve cooling. Vortex tube is simple in itself. However, its working is quite complex in nature. The thermodynamics and physics behind the vortex tube are yet to be understood completely. Many theories have been suggested to explain the physics of the vortex tube. There are various types of configuration are tested using different gases. However, air is most commonly used as the working medium of the vortex tube. L/D ratio and cold mass fraction are the two important performance parameters of the vortex tube. We need to optimize these parameters to develop vortex tube that can be used as a miniature device for Electronics Cooling. One of the objectives is to develop an ecofriendly and economical refrigerator working on vortex effect to nullify CFC harms.

4. Objective

The objective of work is to investigate the vortex tube experimentally using air as working fluids with double inlet nozzle. Further the performance parameters such as L/D ratio, cold mass fraction, inlet pressure are tested for different values and optimized.

5. Methodology

5.1 Manufacturing of tube

5.1.1 Selection of material

The vortex tubes are manufactured by using various materials like metals, polymer plastic, etc. Plastic is

light in weight and also easy to handle, but it has less machinability than metals. Metals are easily available and have better rigidity. They also have good machinability. We are going to select Brass, as it is cheaper than copper. It can be produced by soldering brass nozzles to tubes directly.
Properties of Brass are,

- Alloy Type: Binary
- Content: Copper (67%) & Zinc (33%)
- Density: 8.3-8.7 g/cm^3
- Melting Point: 900-940 °C
- Hardness: 3-4
- Thermal conductivity: 109 W/mK

5.1.2 Geometric Parameters
Length and diameters are selected for different L/D ratios. Then other parameters are calculated by using relation as below.

$$\frac{\mathrm{Din}}{D} \leq 2 \ldots\ldots\ldots\ldots\ldots\ldots \text{i}$$

$$\frac{\mathrm{Dc}^2}{N\,\mathrm{Din}^2} \leq 2.3 \ldots\ldots\ldots\ldots \text{ii}$$

$$D_c < D - 2D_{in} \ldots\ldots\ldots\ldots \text{iii}$$

Table 2 Vortex Tube Parameters with Specification

Parameter	Specification
Length of tube	170 mm
Diameter of tube	11 mm, 12 mm, 14 mm
Diameter of cold end	3 mm,4 mm, 5 mm
Diameter of inlet nozzle	2 mm
Cone angle of hot valve	45 degree
Number of nozzle	2

6. Experimental study

In this study the vortex tubes with 2 inlet nozzles are used. Three different tubes with different L/D ratios are manufactured and used in experiments. Brass is used as manufacturing material. Brass has good machinability and can be soldered well. Each tube has same outer diameter and length with varying internal diameters.

The inlet pressure and the hot and cold outlet pressures of vortex tube have been measured by pressure gauge. The mass flow rates at hot and cold end outlets are measured by rotameter. The temperature of pressurized air at the inlet and cold and hot outlets were measured by use of digital thermometer with precision tolerance and obtained temperatures values have been converted into kelvins. Temperature probes are placed into hole, which was drilled at the center of the vortex tube and 10 mm away from the cold and the hot outlets. The cavities between the probes and the hole were filled in order to prevent the leakage. A conical valve has been mounted on the hot outlet of the tube in order to adjust the mass flow rate of the hot air. With the help of this valve, cold mass fraction m_c was being adjusted.

Before starting the experimental studies and collecting reading for different pressures, the conical valve on the hot outlet was kept in fully open position. And then the air compressor was started and by use of the throttle valve placed on the vortex tube inlet side, the required pressure value was reached. The compressed air flow is continued, while reaching the constant temperature values at the cold outlet and hot outlet of the vortex tube. At this stage, the mass flow rates and pressures of the air at the cold end and hot end were measured by using rotameters and pressure gauges, respectively. This experimental cycle was made three times for the entire inlet pressures selected 2 to 8 bar with 2 bar increments and for the cold mass fractions with small increments with the different orifices selected with different L/D ratios. The mean values of the measured results have been used to obtain the energy separation. The results will give the optimum dimensions of vortex with better efficiency.

6.1 Experimental Setup

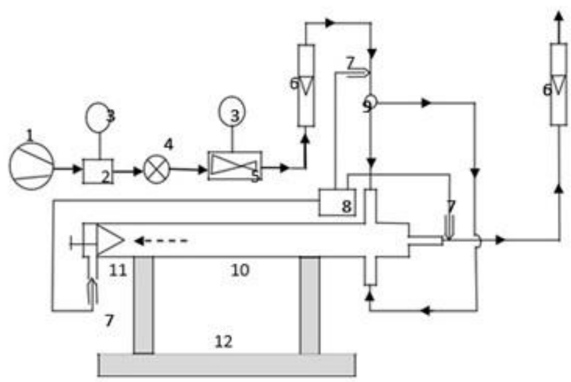

Fig.3 Schematic diagram of experimental setup

1. Compressor
2. Receiver
3. Pressure Gauge
4. Control Valve
5. FRL Unit
6. Air Roatameter
7. Thermocouples at inlet, cold end and hot end
8. Temperature Indicator
9. Pneumatic connector before double inlet nozzle
10. Vortex Tube
11. Conical Control valve at hot end
12. Stand

The schematic diagram of the experimental test facility is shown in Fig.3. Compressed air from the compressor (1) passes through the control valve (4) and pressure regulator filter section (5) and enters in the vortex tube (10) tangentially. To ensure the tangentially entry of the compressed air in the vortex tube to have proper swirling of the air special care was taken. The compressed air expands in the vortex tube and divides in to cold and hot streams. The cold air leaves the cold end orifice near the inlet nozzle while the hot air discharges the periphery at the far end of the tube i.e. hot end (11). The control valve (needle valve) controls the flow rate of the hot air (11). Two rotameters (Eureka made) (6) measures the mass flow rates of the hot and cold air. Thermocouples numbered (7) measure the temperature of the leaving cold and hot air in the vortex tube. The pressure of inlet gas is measured by pressure gauge (2) and the temperature of inlet gas is measured by thermocouple (7). In order to uniformly divide the compressed air, a pneumatic connector is used which divide the incoming stream in to two separate streams and supplies to two nozzles of the vortex tube.

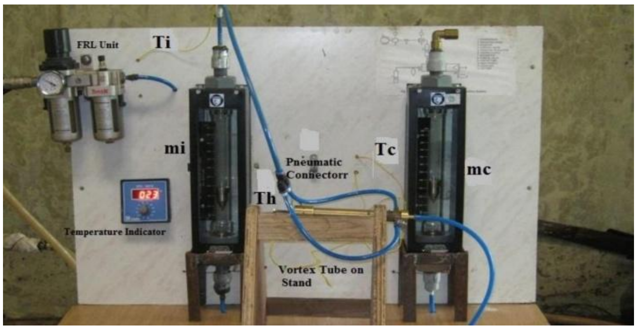

Fig.4 Photograph of experimental setup

7. Conclusion

Experimental analysis will be carried out by using the vortex tubes with L/D ratios of 12, 14, 15.5 for different cold orifice diameters, cold mass fraction and pressures from 2 to 8 bar with 2 bar increments. Results will give the optimum dimensions in L/D ratio, cold orifice diameter for given cold mass fraction at particular pressure.

Nomenclature

D = Diameter of vortex tube
D_c = Cold orifice diameter
D_{in} = Inlet nozzle diameter
N = Number of nozzles
T_i = Inlet Air Temperature
T_c = Cold end temperature
T_h = Hot end temperature

References

1. Xue Y., Arjomandi, Kelso R., (2010), *"A critical review of temperature separation in a vortex tub."* Experimental Thermal and Fluid Science, Vol 34, pg no.1367-1374.
2. Yilmaz M., Kaya M., Karagoz S., Erdogan S., (2009), " *A review on design criteria for vortex tubes."* Heat Mass Transfer, vol. 45, pg no. 613–632.
3. Volkan Kırmacı, Onuralp Uluer, (2009), "*An Experimental Investigation of the Cold Mass Fraction, Nozzle Number, and Inlet Pressure Effects on Performance of Counter Flow Vortex Tube*", Journal of Heat Transfer, Vol. 131 / 081701-1
4. Prabakaran. J, Vaidyanathan. S, (2010), "*Effect of diameter of orifice and nozzle on the performance of counter flow vortex tube"*, International Journal of Engineering Science and Technology Vol. 2(4), 704-707.
5. Jiří Linhart, Mohamad Kalal, Richard Matas, (2005), *"Numerical Study Of Vortex Tube Properties"*, 16th International Symposium On Transport Phenomena, Paper 168.
6. Skye H.M., Nellis G.F., Klein S.A., (2006), *"Comparison of CFD analysis to empiricaldata in a commercial vortex tube."* International Journal of Refrigeration, Vol. 29, pg no.71–80.
7. Nellis G. F., Klein S. A., (2002), *"The application of Vortex Tubes to RefrigerationCycle."* International Refrigeration and Air Conditioning Conference, Paper537.
8. Farouk T., Farouk B., (2007), *"Large eddy simulations of the flow field andtemperature separation in the Ranque–Hilsch vortex tube"* International Journal of Heat and Mass Transfer, Vol. 50, pg no. 4724–4735.