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Modeling, Optimization & Manufacturing of Vortex Tube and Application

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ABSTRACT : *The vortex tube is a simple device, having no moving parts, which produces hot and cold air streams simultaneously at its two ends from a source of compressed air. Literature review reveals investigations to understand the heat transfer characteristics in a vortex tube with respect to various parameters like cross section area of cold and hot end, nozzle area of inlet compressed air, cold orifice area, hot end area of the tube, and L/D ratio. As such there is no theory so perfect, which gives the satisfactory explanation of the vortex tube phenomenon as explained by various researchers. Therefore, it was thought to perform experimentation.*

Keywords *- – Heat transfer rate, VT Nozzle area, VT L/D ratio, C/S area of hot end, Orifice area of VT*

1. INTRODUCTION

The vortex tube is a device which generates separated flows of cold and hot gases from a single compressed gas source. The vortex tube was invented quite by accident in 1933 by George Ranque and later developed by Hilsch (1947).In memory of their contribution the Vortex tube is also known as Ranque-Hilsch vortex tube (RHVT).It contains the parts: inlet nozzle, vortex chamber, cold-end orifice, hot-end control valve and tube.

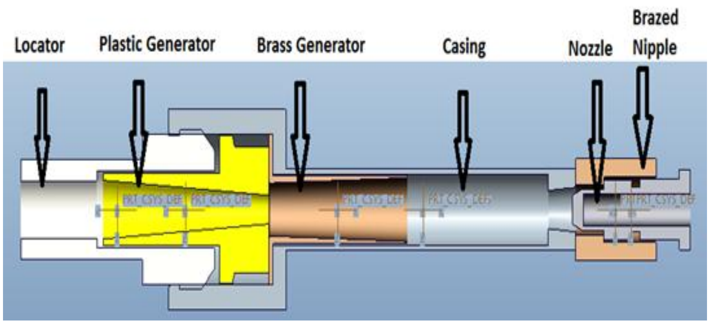

Fig. 1. Schematic diagram of vortex tube

The working principle of the vortex tube is as shown in Fig.1. Compressible fluid is tangentially introduced into the vortex tube through the nozzles, due to the cylindrical structure of the tube and depending on its inlet pressure and speed, leads a circular movement inside the vortex tube at high speeds. A pressure difference between the tube wall is lower than the speed at the tube center, because of the effects of wall friction. As a result, fluid in the center region transfers energy to the fluid at the tube wall. The cooled fluid leaves the tube by moving against the main flow direction after a stagnation point, whereas the heated fluid leaves the tube in the main direction. The RHVT is widely used for both cooling and heating purpose.

2. THE INTERNAL FLOW FIELD

The investigation of the flow field inside the VT began with flow-visualization techniques such as liquid injection and smoke. In 1950 Roy injected colored liquid into the RHVT system to investigate the flow pattern. In 1959, Lay injected water inside the RHVT system, but nothing could be seen. In 1962, Sibulkin used a mixture of powdered carbon and oil. In 1996, Piralishvili used kerosene with the mass ratio of 1:30. In 1962, Smith used smoke. With the injection of liquid, all investigations concentrated on tracking the flow trail on the end wall and using a lucite tube as the vortex tube for tracking the liquid elements visually. From the flow trail on the end wall, the gas velocity distribution shows solid body rotation in the center which is similar to the Rankine vortex motion. Visualization by means of smoke shows the flow path inside the tube along the axis. The velocity distribution also shows the similarity with the Rankine vortex motion. From the flow pattern inside the tube, the two different parts of the swirling flow can be distinguished: with an axial motion towards the hot end is the peripheral region and with axial motion towards the cold end is the central region. With these visualization techniques, the advantage is that it is very easy to qualitatively determine the flow field inside the tube. The disadvantage is that it is not possible to obtain quantitative information of the flow and to find the temperature field inside the tube. The visualization techniques can only give us a qualitative description of the flow field inside the vortex tube. For more detailed flow information, like the pressure, temperature, and velocity fields inside the system, probes are required. Sheller in 1957, Lay in 1959, Holman in 1961, Smith and Sibulkin in 1962, Reynolds in 1962, Takahama, Ahlborn in 1997, Gao in 2005 all used a Pitot tube for pressure measurement and thermocouple to measure the temperature. The probes used by Sheller, Lay, Holman, Smith, Reynolds and Takahama have large size compared to the system geometry.

The error introduced by the probes cannot be neglected and the velocity in the center cannot be measured. The probe used by Ahlborn is small, but in his work the probe is not calibrated, and the error can be up to 25% . The probe used by Reynolds was not calibrated either, so the results can only be used for qualitative analysis. More detailed descriptions about these techniques will be given in later sections. In summary, the purposes of all these experimental investigations are: first of all, to find empirical expressions which can be used for optimizing the RHVT system; secondly, to apply the RHVT for wide application purposes, like cooling and heating, cleaning, purifying and separation, etc.; finally, to investigate the internal process and to understand the mechanism of the energy separation. In the past, a lot of experimental studies have been published. The improvements of the RHVT performance due to the geometric adjustments could not be explained completely.

Furthermore the experimental techniques have some limitations and need to be improved. In this thesis, we employ a specially designed Pitot tube, thermocouple and a hot-wire anemometry for fluctuation measurements, turbulence and spectra analysis.

2.1 Controlling Temperature and Flow in a Vortex Tube

Cold airflow and temperature are easily controlled by adjusting the slotted valve in the hot air outlet. Opening the valve reduces the cold airflow and the cold air temperature. Closing the valve increases the cold airflow and the cold air temperature. The percentage of air directed to the cold outlet of the vortex tube is called the "cold fraction". In most applications, a cold fraction of 80% produces a combination of cold flow rate and temperature drop that maximizes refrigeration, or Btu/hr. (Kcal/hr.) output of a vortex tube. While low cold fractions (less than 50%) produce lowest temperatures, cold airflow rate is sacrificed to achieve them.

Most industrial applications, i.e., process cooling, part cooling, chamber cooling, require maximum refrigeration and utilize the 3200 series Vortex Tube. Certain "cryogenic" applications, i.e., cooling lab samples, circuit testing, are best served by the 3400 series Vortex Tube.

Setting a vortex tube is easy. Simply insert a thermometer in the cold air exhaust and set the temperature by adjusting the valve at the hot end. Maximum refrigeration (80% cold fraction) is achieved when cold air temperature is 50°F (28°C) below compressed air temperature

3. TEMPERATURE SEPARATION EFFECT

The Vortex Tube Creates two types of vortices: free and forced. In a free vortex (like a whirlpool) the angular velocity of a fluid particle increases as it moves toward the Center of the vortex-that is, the closer a particle of fluid is to the center of a vortex, the faster it rotates.

In a forced vortex, the velocity is directly, proportional to the radius of the vortex-the closer the center, the slower the velocity. In a vortex tube, the outer (hot) air stream is a free vortex. The inner (cold) air stream is a forced vortex. The rotational movement of the forced vortex is controlled by the free vortex (hot air stream). The turbulence of both the hot and cold air streams causes the layers to be locked together in a single, rotational mass. The inner air stream flows through the hollow core of the outer air stream at a slower velocity than the outer air stream. Since the energy is proportional to the square of the velocity, the cold air stream loses its energy by heat transfer. This allows energy to flow from the inner air stream to the outer air stream as heat creating a cold inner air stream.

4. DESIGN AND CONSTRUCTIONAL FEATURES

In general, there are two design features associated with a vortex tube, namely, maximum temperature drop vortex tube design for producing small quantity of air with very low temperatures and maximum cooling effect vortex tube design for producing large quantity of air with moderate temperatures. These two design considerations have been used in study for increasing the heat transfer rate during forward motion for swirl air and reversed flow of axial air . The parameters investigated in the study, to understand their inter-relationships and their effect on the performance of the vortex tube are:

- Nozzle diameter
- Cold orifice diameter
- Length of the tube
- Area at the hot end

The material for cold end (inlet cap) is MS, while the hot end is manufactured in Brass for its good thermal conductivity and rest of part are manufactured in mild steel for reducing its overall cost and machining cost. A vortex tube of size 11.04 mm diameter of MS was selected. The casing of the vortex tube was a 27 mm long MS cylinder. Two sets of nozzles were made and each set consisted of two nozzles. The first set of nozzles had a 32.7 mm diameter hole and was 21 mm long, whereas the second set nozzles had a 33.0 mm Outer diameter and was 12 mm long. Similarly, two cold orifices are used having taper hole diameters from 4.5 mm to 9.0 mm, respectively. A conical valve made of mild steel was provided on the right hand side of the tube to regulate the flow.

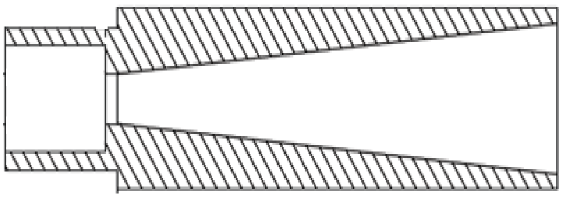

Fig. 2. Modified casing of vortex tube

4.1. Problem Statement

In the present work it is contemplated to experimentally verify the performance of vortex tube in atmospheric conditions for a good range of various working and geometrical parameters to obtain dependence of temperature and refrigeration effect. For this new geometry of helical convergent nozzle is used in which helical nozzle converge from 8mm to 3mm diameter and allowed to escape to vortex diameter 12.5mm tangentially. The intention behind this modification is to pre whirl the air during inlet and also increases the swirl intensity of the air. Different parameters are experimentally tested for 6 no. of nozzles at different pressure i.e.2 bar, 3bar, 4bar, 5bar.

5. PERFORMANCE EQUATIONS FOR VORTEX TUBE

The governing parameters of the operation of a counter-flow RHVT are described below:

The performance of the vortex tube is marked by cooling effect (ΔTc) and heating effect (ΔTh) which is defined as follows:

$$\Delta Tc = T_a - T_c \tag{1}$$

$$\Delta Th = T_h - T_a \tag{2}$$

Adding equations (1) and (2), the total temperature difference is obtained as the in the following:

$$\Delta T = T_h - T_c \tag{3}$$

For isentropic process calculating the temperature difference:

$$\Delta T_{is} = T_a(1 - (\frac{P_1}{P_2})^\wedge \frac{\gamma - 1}{\gamma} \tag{4}$$

Where P_1, P_2, γ are the inlet air pressure, the atmospheric pressure and the specific heat ratio, respectively.
As the air flows into the vortex tube, the expansion in isentropic process occurs. The isentropic efficiency can be written as follow:

$$n_{is} = \frac{\Delta T}{\Delta T_{is}} \tag{5}$$

The vortex tube can be considered as both a cooling and a heating. The efficiency of a cooling can be expressed in terms of coefficient of performance (COP) explained as follows:

$$COP = \frac{Q_c}{W} \tag{6}$$

Where as Q_c = Discharge
W = Work done

6. DIMENSIONS USED BY OTHER RESEARCHERS OF VORTEX TUBE

Table 1.Vortex tube dimensions used by other researcher

Author	Length L (inch)	Inner diameter D (inch)	Generator Nozzle		Cold end orifice diameter d_c (inch)	$d_r = \frac{d_c}{D}$
			Equivalent Diameter (inch)	Year		
Takahama	317	2	0.5	1980	-	-
Reynolds	48	3	0.12	1985	1.27	0.42
Ahlborn	24	1	-	1997	0.328	0.33
C. Gao	8	0.63	0.12	2005	0.16	0.25
Ninmbalkar	10	0.75	0.162	2011	0.38	0.50

7. CONCLUSION

The following conclusions have been drawn from the experimentation:

1. The maximum temperature difference of 27°C is obtained in cold end side while 18°C is obtained in hot end side.
2. With increase in inlet pressure, COP, cooling effect and isentropic efficiency of the vortex tube increases. Maximum COP and Maximum isentropic efficiency obtained is 0.376 and 23% respectively.
3. At 5 bar inlet pressure, 45° valve and 90° valve give the best result.
4. The result with helical convergent nozzle is with divergent tube is compared with literature available and it is found that results are in good agreement with previous work.
5. Hence, vortex tube can be used for any type of spot cooling or spot heating application

REFERENCES

[1] J. Prabakaran., S. Vaidyanatha., Effect Of Orifice And Pressure of Counter Flow Vortex Tube, *IJST*, 3(4), (2010), 374-376.

[2] Q. Chang, Q. Li, G. Zhou, Q. Li, Experimental Investigation of Vortex Tube Refrigerator with a Divergent Hot Tube, *International Journal of refrigeration*, 34 (1), (2011), 322-327.

[3] R. Shamsoddini, A. H. Nezhad, Numerical analysis of the effects of nozzles number on the flow and power of cooling of a vortex tube, *International Journal of Refrigeration*, 33 (4), (2010), 774–782.

[4] S. Nimbalkar and M. R Muller., An experimental investigation of the optimum geometry for the cold end orifice of a vortex tube, *Applied Thermal Engineering*, 29(2-3), (2009), 509–514.