International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Design and Manufacturing of Vortex Tube

Mr. P.K.V.S. Subramanyeswara Rao[1], A. Seeta Rama Raju[2], L. Naveen Kumar[3], M. Durga Srinivas[4], K. Joy Livingstan[5], CH. Sai Kiran[6]

[1]Assistant Professor, Department of Mechanical Engineering, Raghu Engineering College, Visakhapatnam, Andhra Pradesh.
[2,3,4,5,6]UG Students, Department of Mechanical Engineering, Raghu Engineering College, Visakhapatnam, Andhra Pradesh.

ABSTRACT:

For many years, the Ranque-Hilsch vortex tube has been employed in a variety of engineering applications. It is widely used in heating and cooling processes due to its small size and little maintenance needs. Despite the tube's straightforward shape, the mechanism that causes the internal temperature separation is quite intricate.

The vortex tube is a mechanical device that divides compressed air into an inner, lower temperature area and an outward radial high temperature region. With simple geometry and no moving elements, it functions as a refrigerator. Commercial applications include cooling suits, freezers, and aircraft. Other real-world uses include laboratory equipment cooling, quick starting steam generators, liquefaction of natural gas, and waste particle separation in the gas sector.

INTRODUCTION:

A vortex tube is a thermo-fluidic device that produces cold and hot streams from a single injection of pressurised gas. The intriguing phenomenon of energy separation is only caused by fluid dynamic dynamics and does not include any moving parts or chemical reactions inside the tube.

A straight tube with a tangential injection, via which compressed gas is injected into the tube, makes up the majority of a standard counter-flow vortex tube. A counter-flow vortex tube has two outlets, which are situated at opposite ends or, in the case of a uni-flow vortex tube, both ends. The gas can escape through the tiny gap between the control plug and the tube because the control plug is positioned within the tube far from the injection point and has a smaller size than the inner diameter of the tube. The hot exit is the space between the plug and the tube, while the cold exit is found in the middle of the tube at the same end of the injection.

LITERATURE REVIEW:

Explanation given by Van Deemeter: Through the nozzle, air enters the main tube and creates a free vortex. When the vortex approaches the throttle valve, the rotation almost comes to a complete stop due to the centripetal acceleration, creating a point of atmospheric pressure where a reverse axial flow begins. The axial stream creates a forced vortex when it comes into contact with the free vortex, which is travelling at an increasing speed. The free vortex at the perimeter provides the energy necessary to maintain the forced vortex in the reversed axial flow stream.

As a result, energy (momentum) is transferred from the air's periphery to the stream of reversed axial flow at the axis. There is a relative sliding between the two adjacent aeroplanes that are travelling in the direction of the valve because the rotational velocity of the free vortex at the perimeter gradually decreases from the plane of the nozzle to the plane of the valve. As a result, energy is continuously transferred from the nozzle's plane to the valve's plane. In light of this, it is now clear why the air warms up as it moves closer to the valve. There is no satisfactory explanation for the energy transfer from the inner core (from the driven vortex region) to the periphery.

Explanation given by Parulekar: Tangentially entering the tube, the air creates a free vortex. Due to centrifugal force, the vortex moves along the wall. Near the valve, the air rotation virtually stops. A reversing axial flow begins when the pressure close to the valve is greater than the pressure outside the diaphragm at the other end. Along the interior surface of the free vortex, this reversed flow makes contact with the forward-moving vortex. The axial stream is forced to rotate because of the free vortex's rapid rotation. Thus, a forced vortex is created by an axial stream. The outer free vortex provides the energy needed to create the forced vortex of the axial stream.

Energy is transferred from the low-pressure area at the axis to the high-pressure area at the periphery as a result of turbulent mixing in the centrifugal field. As previously stated by Van Deemeter, the energy is subsequently transmitted in the form of momentum in the direction of the valve. There is a net transfer of energy radially outward and towards the valve because the radial outflow energy caused by turbulent mixing is significantly greater than the inward flow of energy caused by vortex formation.

As a result, a heated stream emerges from a periphery layer whereas a cold stream emerges from an axial layer. The energy that the hot stream removes from the insulated tube is equivalent to the energy that the cold stream needs.

COMPONENTS OF VORTEX TUBE:

The vortex tube consists of the following parts

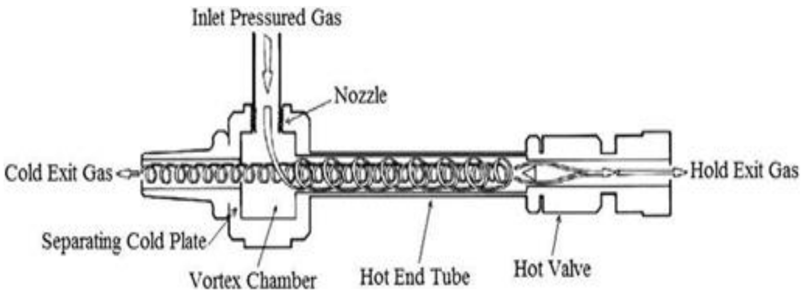
1. Nozzle

2. Diaphragm

3. Control valve

4. Hot air side

5. Cold air side



Schematic Diagram of Vortex Tube

WORKING OF VORTEX TUBE:

Through the air inlet, compressed air is sent through the nozzle. The nozzle in this instance causes the air to expand and pick up speed. In the chamber, a vortex flow is produced, and air moves in spiral motion around the edges of the hot side. The revolving air is then accelerated to 1,000,000 rpm and driven down the hot tube's inside walls.

This flow is limited by the valve. A reversed axial flow through the core of the heated side begins from the high-pressure zone when the pressure of the air near the valve is made greater than the outside by partially closing the valve.

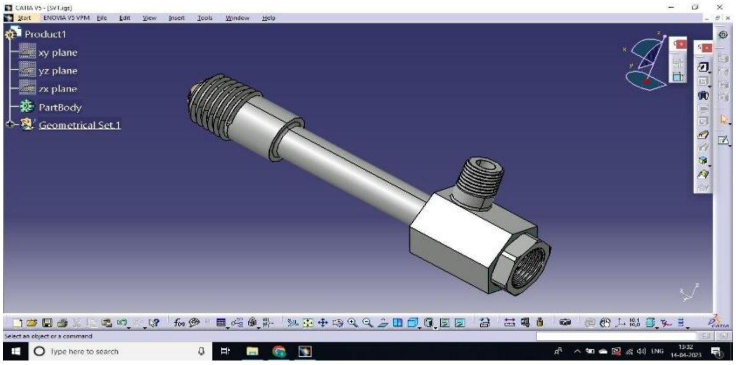
As a result of the energy transfer that occurs during this process between the reversed stream and forward stream, the air flowing through the core is cooled below the air's inlet temperature in the vortex tube while the air flowing forward is heated. The diaphragm hole allows the cold stream to exit into the cold side while the valve opening allows the hot stream to pass through. The amount of cold air present and its temperature can be altered by adjusting how the valve opens. There are a number of ideas that provide a physical justification for how energy moves from a cooler to a hotter area.

DESIGN AND ANALYSIS OF VORTEX TUBE:

Vortex tube creation and design When it comes to applications, vortex tubes are employed in a variety of small-scale enterprises to obtain two different types of gas flow. Regardless of how crucial the application, we are free to use it whenever it suits us. Due to the energy separation effect, it splits the compressed air flow. The primary purpose of a vortex tube is to divide a compressed flow of air into two distinct regions—hot and cold—without moving any mechanical components. A vortex tube is made up of three primary components: a hot control valve and orifice, a cold trminal orifice, and a vortex chamber input nozzle.

It functions so that as fluid enters the tube, it circulates around a vortex-like axis. And the compressed air is spun around in a vortex, which splits the flow into hot and cold air streams. Supercooled air is transported through its middle and delivered through the cold end port. The performance of the Vortex Tube is greatly influenced by the hot end's (nozzle and tube) surface finish.In this research, it is noted that the vortex tube's efficiency is increased by using vortex tubes with significant cylinder hot tube surface roughness values. It causes the vortex tube's C.O.P.

The vortex tube is designed in the cad software



EXPERIMENTATION:

An experimental setup was created using the previously mentioned design to examine the impact of various factors, including inlet pressure, orifice diameter, and L/D ratio, on the functioning of the vortex tube. In order to switch the geometry of the tube from a maximum temperature drop tube design to a maximum cooling effect tube design, the vortex tube components were constructed in this way. The experimental set up diagram is displayed below.

RESULTS:

SPECIFICATIONS OF THE AIR COMPRESSOR:

Compressor H.P	3HP
No of cylinders	2
Diameter L.P cylinder	0.07m
Diameter H.P cylinder	0.05m
Stroke length	0.085 m
Number of stages	2
Coefficient of discharge	0.62
Orifice diameter	0.022 m

EFFICIENCY:

Delivery pressure (bar)	Speed, N (rpm)	Time for 10 rev (Sec)	Theoretical volume flow rate V1 (m3/sec)	Energy input (kW)	Adiabatic Work (J)	Adiabatic efficiency
7	882	86	9.6x10 -3	5.2 3	0.025x1 05	0.4811
6	886	87	9.6x10 -3	5.2 1	0.022x1 05	0.4342
5	888	87	9.6x10 -3	5.1 2	0.019x1 05	0.3837
4	894	88	9.6x10 -3	5.0 1	0.016x1 05	0.2492

FOR VORTEX TUBE READINGS:

Table 1: Results for 1/4 valve opening

Pressure Pi(bar)	Cold Temp Tc(C)	Hot Temp Th(C)	Difference ΔT= Th- Tc (0C)	Cold Tempeature Drop ΔTc(0C)	Hot Temperature Drop ΔTh(0C)	Cold mass Fraction μ	Adiabatic Efficiency	C.OP
2	23	37	14	6	8	0.57	0.569	0.06
3	21	39	18	8	10	0.56	0.568	0.07
4	20	40	20	9	11	0.55	0.525	0.08
5	18	41	23	11	12	0.52	0.540	0.13
6	16	43	27	13	14	0.51	0.583	0.15

Table 2: Results for 1/2 valve opening

Pressure Pi(bar)	Cold Temp Tc(C)	Hot Temp Th(C)	Difference ΔT= Th- Tc (0C)	Cold Tempeature Drop ΔTc(0C)	Hot Temperature Drop ΔTh(0C)	Cold mass Fracti on μ	Adiabatic Efficiency	C.OP
2	25	36	11	4	7	0.63	0.491	0.05
3	22	38	16	7	9	0.56	0.504	0.06
4	21	39	18	8	10	0.55	0.467	0.07
5	20	40	20	9	11	0.55	0.462	0.11
6	18	42	24	11	13	0.54	0.513	0.13

OBSERVATIONS:

Specimen calculations for the inlet pressure of air, Pi = 6 bar

1. Atmospheric pressure, Pa = 1.013 bar
2. Inlet pressure of air, Pi = 2 bar
3. Inlet temperature of air, Ti = 29C
4. Cold air exit temperature, Tc = 25 C
5. Hot air exit temperature, Th = 36C

CALCULATIONS:

1. Cold drop temperature ΔTc = Ti – Tc = 29-25

= 4

2 Hot raise temperature ΔTh = Th – Ti = 36-29

= 7

3. Temperature Drop at the two ends $\Delta T = Th - Tc = 36-25$

   $= 11$

4. Cold mass fraction $\mu = \frac{\Delta T_h}{\Delta T_h + \Delta T_c}$

   $= 0.63$

5. Static Temperature Drop Due To Expansion

   $\Delta T'c = Ti - T'c = Ti[1-(Pa/Pi)(\gamma-1)/\gamma]$

   $=5.1$

6. Relative Temperature Drop ($\Delta Trel$) = $\Delta Tc/(\Delta T'c)$ = 0.78

7. Adiabatic Efficiency (ηab) = $\frac{\text{Actual cooling gained in vortex tube}}{\text{Cooling possible with adiabatic expansion}}$

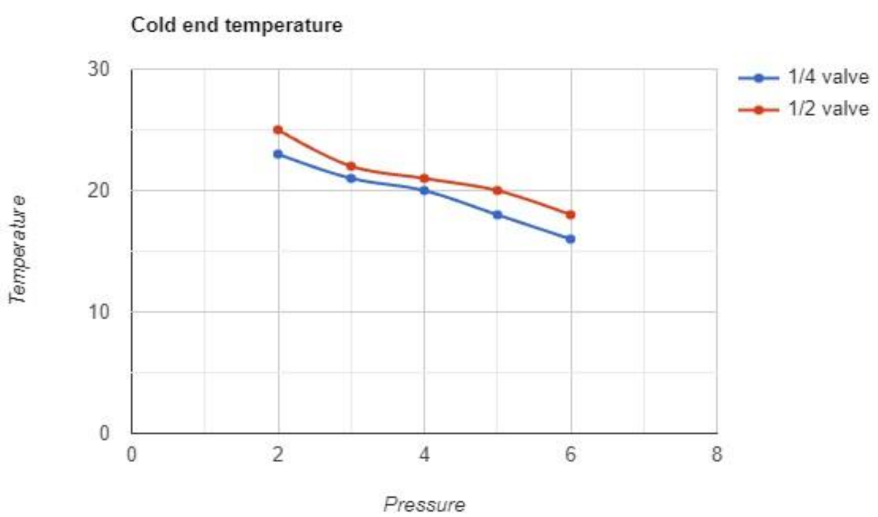
   $= 0.491$

8. Coefficient of Performance (C.O.P) of Vortex Tube

   $C.O.P = \eta ab.\ \eta ac.\ [(Pa/Pi)^{(\gamma-1)/\gamma}] = 0.05$

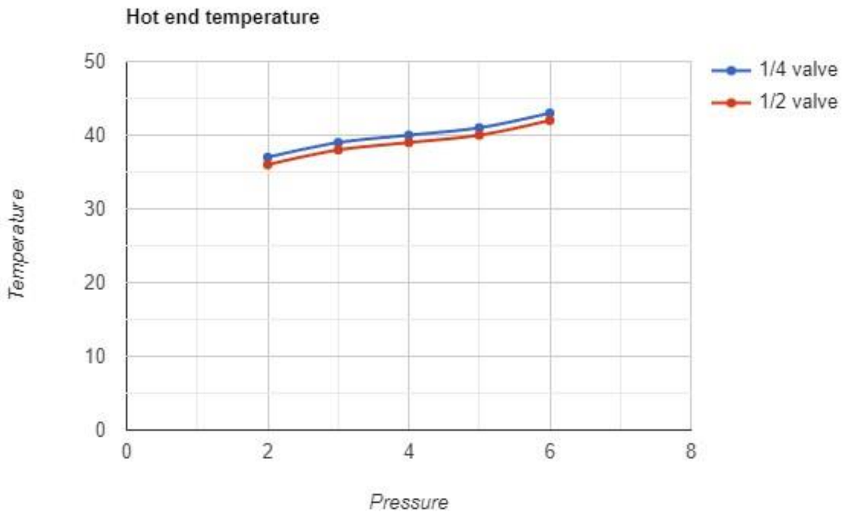
GRAPHS:

COLD END TEMPERATURE VARIATION AT DIFFERENT PRESSURES



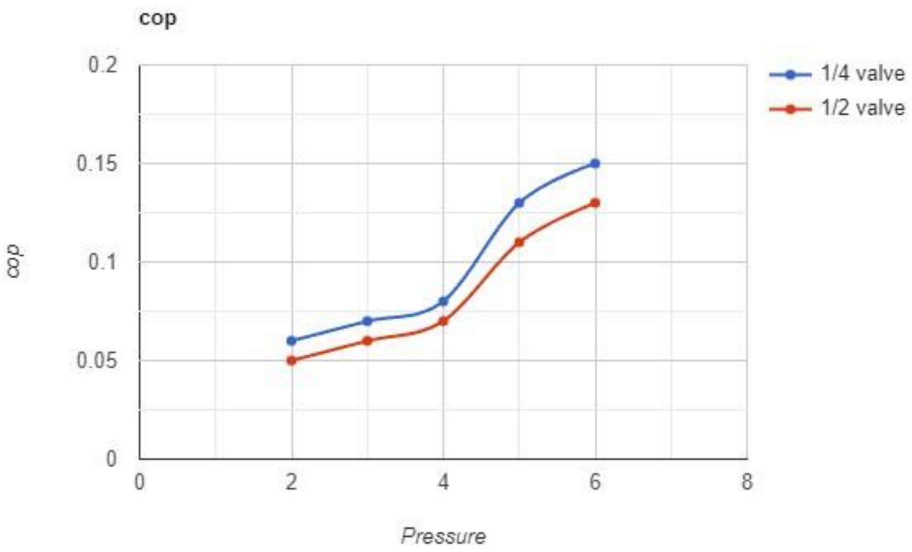
From the above Fig. it is clear that at any given pressure the temperature of the vortex tube of 1/4 valve is better when compared to vortex tube of 1/2 valve and the temperature difference between them is proportional to pressure i.e., the temperature difference is increasing progressively with pressure

HOT END TEMPERATURE VARIATION AT DIFFERENT PRESSURES.



From the above Fig. it is clear that at any given pressure the temperature of the vortex tube of 1/4 valve is better when compared to vortex tube of 1/2 valve and the temperature difference between them is proportional to pressure i.e., the temperature difference is increasing progressively with pressure

COP VARIATION AT DIFFERENT PRESSURES



The above Fig. is plotted for pressure V/s COP. From the graph it is noted that the COP of the vortex tube with 1/4 valve is higher than the vortex tube with 1/2 valve.

From the above three graphs it is noted that the performance of the vortex tube with 1/4 valve is better than the vortex tube with 1/2 valve.

ADVANTAGES OF VORTEX TUBE:

1. It does not have any moving parts, makes it simple in construction.
2. It provides instant cold air in environmental chamber.
3. The cold air temperature can be easily adjusted with the help of valve.
4. The output temperature range and mass flow rate can be easily adjusted
5. No need of electricity if compressed air is available.

6. Not require any refrigerant or chemicals.
7. It is compact; light in weight makes it suitable for aviation application.

DISADVANTAGES OF VORTEX TUBE:

1. C.O.P is very poor compared to conventional refrigeration system.
2. Limited capacity

CONCLUSION:

A examination of the literature demonstrates that no theory is ever perfect enough to describe the vortex tube phenomenon in a way that is satisfying to all scholars. As a result, it was decided to conduct experimental studies to comprehend the properties of heat transport in a vortex tube.

The analysis of the impact of pressure on the decrease in cold temperature, increase in hot temperature, and COP of the Vortex tube yielded the following conclusions.

1. The Cold drop temperature ΔTc increases with increase in inlet air pressure.
2. The Hot temperature raise ΔTh increases with increase in inlet air pressure.
3. The COP of the vortex tube increases with increase in inlet pressure.
4. The optimum end gate valve opening gives the best performance.
5. The effect of nozzle design is more important than the cold orifice design in getting higher temperature drops.
6. The surface finish of the nozzle and the hot tube plays a great role in the performance of the vortex tube, good surface finish leads to the better performance. So, care to be taken while fabrication of the parts to obtain to get good surface finish.

REFERENCES:

1. G J Ranque. Experiments on Expansion in a Vortex with Simultaneous Exhaust of Hot and Cold Air. Le Journal De Physique, et le Radium (Paris), vol 4, June 1933, pp 1125-1130.
2. S.C Arora and S. Domkundwar, A course in refrigeration and air conditioning, Dhanapat Rai & Sons Publications, Seventh edition.
3. C D Fulton. Ranque Tube. Journal of the ASRE, Refrigeration Engineering, vol 58, May 1950, pp 473-479.
4. G W Scheper (Jr). The Vortex Tube Internal Flow Data and a Heat Transfer Theory. Journal of the ASRE, Refrigeration Engineering, vol 59, October 1951, pp 985-989.
5. J P Hartnett and E R G Eckert. Experimental Study of the Velocity and Temperature Distribution in a High Velocity Vortex Tube Flow. Transactions of ASME, vol 79, May 1957, pp 751-758.
6. B Parulekar. The Short Vortex Tube. Journal of Refrigeration, vol 4, 1961, pp 74-80.
7. R B Aronson. The Vortex Tube: Cooling with Compressed Air. Journal of Machine Design, December 1976, pp 140-143.