DESIGNING ASPECTS OF A VORTEX TUBE COOLING SYSTEM

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Abstract- A cooling system is very important for both man and machine. In general vapour compression refrigeration system and vapour absorption refrigeration system are used for refrigeration purpose. Vortex tube cooling system is a non conventional type of cooling system which is not used widely for cooling purpose. But it has many advantages over the conventional cooling system. This project attempt has been made to construct a counter flow vortex tube and its experimental setup has also been designed. Our objective is to check the performance of counter flow vortex tube by changing the various geometrical parameters such as length and diameter of hot end pipe and cold end pipe and also changing the nozzle number of the orifice so that we increase the COP of the vortex tube. We had also predicted some of the experimental data that are available and observed the performance variation by changing working parameters at inlet such as temperature and pressure. we found that as the pressure is decreasing continuously and we obtained cold air. Also we had determined that we are getting cold air when we used smaller size of hot end pipe.

Keywords: Vortex tube, Temperature Separation, nozzle, Cold Tube, Hot Tube

I. INTRODUCTION

The Vortex tube, also known as the Ranque-Hilsch vortex tube, is a mechanical device operating as a refrigerating or cooling machine without any moving parts, by separating a compressed air/gas stream into a low temperature region and a high one. Such a separation of the flow into regions of low and high temperature is referred to as the temperature (or energy) separation effect. Generally, the vortex tube can be classified into two types. One is the counter-flow type (often referred to as standard type) and another is parallel or uni-flow type. The air emerging from the "hot" end can reach temperatures of 200 °C, and the air emerging from the "cold end" can reach -50 °C. It contains the following parts: one or more inlet nozzles, a vortex chamber, a cold-end orifice, a hot-end control valve and a tube. When high-pressure gas is tangentially injected into the vortex chamber via the inlet nozzles, a swirling flow is created inside the vortex chamber. When the gas swirls to the centre of the chamber, it is expanded and cooled. In the vortex chamber, part of the gas swirls to the hot end, and another part exist via the cold exhaust directly. Part of the gas in the vortex tube reverses for axial component of the velocity and move from the hot end to the cold end. At the hot exhaust, the gas escapes with a higher temperature, while at the cold exhaust, the gas has a lower temperature compared to the inlet temperature.

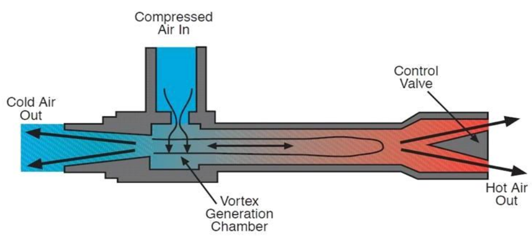

Fig 1:– Vortex Tube

II. WORKING OF VORTEX TUBE

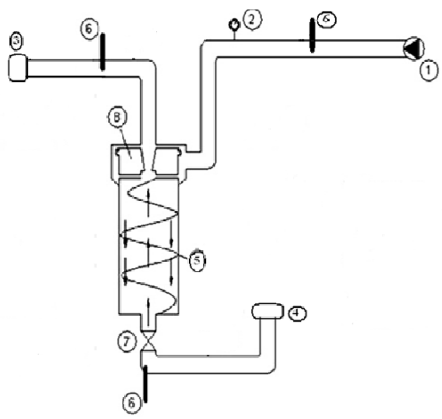

Fig.2 - Working of vortex tube

1- Compressor
2- Inlet nozzle
3- Cold air outlet
4- Hot air outlet
5- Vortex tube
6- Digital temperature indicator
7- valve
8- orifice

Compressed air is passed through the nozzle as here; air expands and acquires high velocity due to particular shape of the nozzle. A vortex flow is created in the chamber and air travels in spiral like motion along the periphery of the hot side. This flow is restricted by the valve. When the pressure of the air near valve is made more than outside by partly closing the valve, a reversed axial flow through the core of the hot side starts from high-pressure region to low-pressure region. During this process, heat transfer takes place between reversed stream and forward stream. Therefore, air stream through the core gets cooled below the inlet temperature of the air in the vortex tube, while air stream in forward direction gets heated up. The cold stream is escaped through the diaphragm hole into the cold side, while hot stream is passed through the opening of the valve. By controlling the opening of the valve, the quantity of the cold air and its temperature can be varied.

III. LAYOUT OF VORTEX TUBE

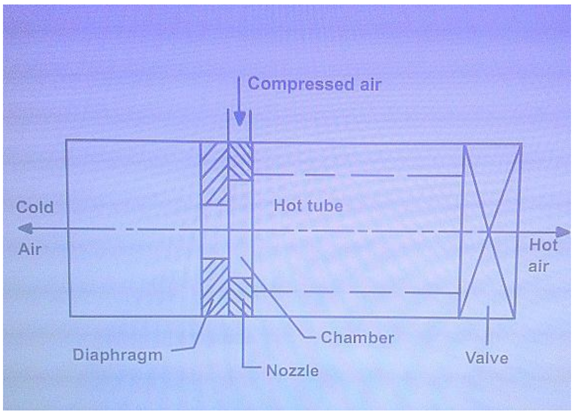

Fig.3- Layout of Vortex Tube

The layout of a vortex tube is given in fig. it consist of following parts:

1. Nozzle: A nozzle is a device designed to control the direction or characteristics of a fluid flow (especially to increase velocity) as it exits (or enters) an enclosed chamber or pipe.

2. Diaphragm: A diaphragm is a sheet of a semi-flexible material anchored at its periphery and most often round in shape. It serves either as a barrier between two chambers, moving slightly up into one chamber or down into the other depending on differences in pressure, or as a device that vibrates when certain frequencies are applied to it.

3. Valve: A device for controlling the flow of fluids (liquids, gases) in a pipe or other enclosure. Control is by means of a movable element that opens, shuts, or partially obstructs an opening in a passageway. Valves are of seven main types: globe, gate, needle, plug (cock), butterfly, poppet, and spool.

4. Hot air side: Hot side is cylindrical in cross section and is of different lengths as per Design.

5. Cold air side: Cold side is a cylindrical portion through which cold air is passed.

6. Chamber: Chamber is a portion of nozzle and facilities the tangential entry of high velocity air-stream into hot side. Generally the chambers are not of circular form, but they are gradually converted into spiral form.

IV. MATERIAL AND DESIGN

Vortex tube generally using three materials for its construction namely:

- Stainless Steel
- Aluminium
- Plastic

It depends on its function to use for cooling purpose or for heating. Generally it is made up of stainless steel because of its high thermal conductivity and better corrosion resistance but because of its heavy weight it lags behind the aluminium. On the other hand aluminium is also used for constructing vortex tube because it may have good thermal conductivity and light weight. Plastic is used where the weight required is very less and the hot fluid temperature is also very less because it may not have high thermal conductivity as compared to the other two.

The Design of vortex tube is not very much complicated because it may not required any moving parts. The design of vortex tube depend on its requirement just like the place where it is used either it is used in vehicles or in mines. But the design aspect is important because we may require more and more cooling so for that we may need to change the ratio of length to diameter because of changing that we may acquire cool air according to our need.

The diameter of the cold tube was taken as D =12.70 mm (0.50 inch) according to Rudolf Hilsch[1]. The length of the cold tube was taken as 10D,hot tube is 45D and the diameter of cold orifice ordiaphragm hole is taken as 0.5D in accordance with Hilsch [1], Pongjet Promvonge and Smith Eiamsaard[2]. The diameter of the nozzle is taken as D/3 according to Guillaume and Jully [3]. The inlet pressure is varied to visualize the variations of temperature drop with pressure drop and a constant mass fraction of approximately maintained by a cone shape. An experimental investigation was made by Kirmaci Volkan [4] to determine the effects of the orifice nozzle number and the inlet pressure on the heating and cooling performance of the counter flow Ranque–Hilsch vortex tube when air and oxygen used as a fluid. Nimbalkar S., Muller M. R. [5] presented the results of a series of experiments focusing on various geometries of the „„cold end side" for different inlet pressures and cold fractions. The experimental results indicate that there is an optimum diameter of cold end orifice for achieving maximum energy separation. Bramo, A. R., Pourmahmoud N. [6] performed computational fluid dynamics analysis in an attempt to investigate the effect of length to diameter ratio on the fluid flow characteristics and energy separation phenomenon inside the Ranque-Hilsch vortex tube

Generally the COP of the vortex tube is very low but we have to increase it by varying the ratio of length to diameter from 8 to 35 so that we get more cooling. And by changing the convergent as well as divergent angle of the control knob we improve the cooling efficiency of vortex tube and it's our aim in this paper.

V. AIR MOVEMENT IN VORTEX TUBE

High pressure air enters into inlet enters the annular space around the generator. It then enters into the nozzle where it loses part of its pressure as it expands and increases the velocity. The nozzle is aimed so that the air is injected tangentially at the circumference of the vortex generation chamber.

All of air leaves the vortex generation chamber and goes into the hot tube. It makes these choices because the opening to the hot tube is always larger than the opening to the cold tube.

Centrifugal force keeps the air near the wall of the hot tube as it moves towards the valve at the end.

By the time the air reaches the valve it has a pressure somewhat less than the exit pressure at the nozzle, but more than atmospheric. It is always true that the pressure just behind the control valve is higher than the cold outlet pressure.

VI. EFFECT OF TEMPERATURE SEPRATION

The air in the hot tube has a complex movement. An outer ring of air is moving toward the hot end of the tube and an inner core of air is moving toward the cold end. Both streams of air are rotating in the same direction. More importantly, both streams of air are rotating at the same angular velocity. This is because intense turbulence at the boundary between the two streams and throughout both streams locks them into a single mass as far as rotational movement is concerned.

The inner stream is a "forced vortex" which is distinguished from a "free vortex" in that its rotational movement is controlled by some outside influence other than the conservation of angular momentum. In this case, the outer hot stream forces the inner (cold) stream to rotate at a constant angular velocity.

In a simple whirlpool a free vortex is formed. As the water moves inward, its rotational speed increases to conserve angular momentum. Linear velocity of any particle in the vortex is inversely proportional to its radius. Thus, in moving from a radius of one unit to a centre point at a radius of 1/2 unit, a particle doubles its linear (tangential) speed in a free vortex. In a forced vortex with constant angular velocity, the linear speed decreases by half as a particle moves from a radius of 1 unit to a centre point at a radius of 1/2 unit.

In the situation above, particles enter the centre with four times the linear velocity in a free vortex compared with a forced vortex. Kinetic energy is proportional to the square of linear velocity, thus the particles leaving the centre of the forced vortex have 1/1 6th the kinetic energy of those leaving the centre of the free vortex in this example.

In other words the air in the vortex tube has a complex movement. An outer ring of air is moving towards the hot end and an inner core of air is moving towards cold end. Both streams of air are rotating in the same direction. More importantly, both streams of air are rotating with same angular velocity. This is because of intense turbulence at the boundary between the two streams and throughout both streams locks them into a single mass so far as rotational movement is concerned. Now a proper term for inner stream would be "forced vortex". This is distinguished from a "free vortex" in that its rotational movement is controlled by some outside influence other than the conservation of angular momentum. In this case the outer hot stream forces the inner (cold) to rotate at a constant angular velocity. This is why hot end temperatures increase as cold fractions increase, and cold end temperatures decrease as cold fractions decrease.

VII. VORTEX TUBE PERFORMANCE

In the vortex tube air that rotates around an axis (like a tornado) is called a vortex. Vortex Tube creates cold air and hot air by forcing compressed air through a generation chamber which spins the air centrifugally along the inner walls of the Tube at a high rate of speed (10, 00,000 RPM) toward the control valve. A percentage of the hot, high-speed air is permitted to exit at the control valve. The remainder of the (now slower) air stream is forced to counter flow up through the center of the high-speed air stream, giving up heat, through the center of the generation chamber finally exiting through the opposite end as extremely cold air. Vortex Tubes generate temperatures down to 40°C below inlet air temperature. A control valve located in the hot exhaust end can be used to adjust the temperature drop and rise for Vortex Tube.

VIII. THERMO DYNAMICAL ANALYSIS OF VORTEX TUBE

The cold flow mass ratio (cold mass fraction) is the most important parameter used for Indicating the vortex tube performance of RHVT. The cold mass fraction is the ratio of mass of cold air that is released through the cold end of the tube to the total mass of the input compressed air. It is represented as follows:

$$E = \frac{m_c}{m_i} = \frac{T_i - T_h}{T_c - T_h}$$

Where, *mc* represents the mass flow rate of the cold stream released, *mi* represents the inlet or total mass flow rate of the pressurized air at the inlet. Therefore, E varies in the range of 0-1.

Cold air temperature difference or temperature reduction is defined as the difference between inlet flow temperature and cold air temperature:

$$\Delta T_c = T_i - T_c$$

Where *Ti* is the inlet flow temperature and *Tc* is the cold air temperature. Similarly, hot air temperature difference is defined as:

$$\Delta T_h = T_h - T_i$$

and the expansion been isentropic from inlet of the nozzle to the exit pressure and the air to behave like an ideal gas, isentropic efficiency is given by

$$\eta_{is} = \frac{T_i - T_c}{T_i - T_{is}}$$

For isentropic expansion the exit temperature

$$T_s\text{-}T_i = \left(\frac{p_i}{p_o}\right)^{\frac{\gamma-1}{\gamma}}$$

Where, p_e is the exit pressure of the cold air i.e. atmospheric pressure (p_a) at outlet.

The refrigerating /cooling effect produced by the cold air of vortex tube is give as:

$$Q_c = m_c C_p (T_c - T_i)$$

Since cooling and heating streams are obtained simultaneously the heating effect produced by the vortex tube is give as:

$$Q_h = m_h C_p (T_h - T_i)$$

Since RHVT can be used as a cooler and heater simultaneously hence both the effect that Cooling effect and heating effects are considered. The COP of the system is calculated accordingly. The coefficient of performance of refrigerator is defined as the ratio of refrigerating effect produced by the system to the work done on the system. In the conventional vapour compression refrigeration (VCR) system work input or power is the work of compression or the compressor work. But, the vortex refrigeration systems are used where compressed air or gas is available. Making analogy to the VCR system, the work of compression from the exit/atmos. i.e. from *pe* to *pi* by a reversible isothermal process, the COP of the system is given as:

$$(COP)_{ref} = \frac{1}{\left(\frac{p_i}{p_o}\right)^{\frac{\gamma-1}{\gamma}} - 1}$$

In the above relation the pressure drop in the supply pipe has been neglected and the pressure at the exit of the cold and the hot air in the vortex tube are assumed to be atmospheric.

IX. EFFICIENCIES OF THE VORTEX TUBE

The various efficiencies of Vortex tube:

1. Thermal efficiencies: The RHVT can be used not only as a cooler, but also as a heater. So the definition of the efficiency should consider both effects. For different applications, different efficiencies are used. The coefficient of performance (COP) of a cooler is normally defined as the cooling power Qc gained by the system divided by the work power P input. So the COP of the cooler, denoted by COP is expressed as:

$$COP = \frac{Q_c}{P}$$

Here the cooling power can be calculated according to the cooling capacity of the cold exhaust gas (e.g. the heat necessary to heat up the cold exhaust gas from the cold exhaust temperature to the applied temperature. Here Tin is chosen.)

$$Q_C = M_C C_P (T_{in} - T_c)$$

2. Carnot Efficiency: The Carnot COP is the maximum efficiency for all heat engines. So, it is also the maximum for the RHVT system. The COPs for Carnot cycles are:

$$COP = \frac{T_{in}}{T_{in} - T_c}$$

CONCLUSION

In this work an attempt is made to focus on the flow behaviour inside a counter-flow vortex tube aiming to locate the dominant reason for the temperature separation in a vortex tube. Variable geometrical parameters have been tested in the experiment, and their effects on the temperature separation in the vortex tube are discussed.

The inner stream is having a forced vortex flow and the outer stream is having free vortex flow. In a vortex flow as the radius is decreasing the linear velocity of the fluid also decreases hence kinetic energy decreases and this decrease in kinetic energy is converted in heat which is dominant reason for the temperature separation in a vortex tube.

We have observed the performance variation by changing working parameters at inlet such as temperature and pressure and found out as is decreasing we obtain colder air. We had determined that we are getting colder air when we used smaller size of hot end pipe.

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