DESIGN AND FABRICATION OF VORTEX TUBE FOR COOLING PURPOSE IN LASER CUTTING

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Abstract:- *Vortex tube is a simple device with no moving parts. It separates inlet high pressure stream of air into two lower pressure streams of cooler temperature at one end and hotter temperature at other end. It is basically of counter flow type and parallel flow type. It has many advantages and wide range of applications, mostly using counter flow owing to better performance than parallel flow. Most of the applications reflect the benefits in terms of performance, energy, compactness or as an alternative to the conventional method. Few applications are highlighted in this paper. Variable temperature system uses vortex tube along with liquid nitrogen cooled heat exchanger to maintain lower temperature as the biochemical samples are prone to change properties in unconditioned environment. In case of high speed machining tools, vortex tube cooling improves the performance and tool life along with better finish of workpiece. Laser cutting system uses vortex tube cooling to minimize heat affected zone. Vortex air coolers are preferred for different industrial applications. The personal air suit uses vortex tube to allow workers to work under adverse conditions for longer hours. Vortex tube refrigeration is alternative way to the conventional refrigeration in some applications.*

Key Words:- Vortex tube, Temperature Separation, nozzle, Cold Tube, Hot Tube

1. INTRODUCTION

The vortex tube is a device without moving mechanical parts, which converts a gas flow initially homogeneous in temperature, into two separate flows of differing temperatures. It separates compressed gas stream into a low total temperature region and a high one. The vortex tube contains the following parts: one or more inlet nozzles, a vortex chamber, a cold-end orifice, a hot-end control valve and a tube. The most well-known names are: vortex tube, Ranque vortex tube (first discoverer), Hilsch vortex tube or Ranque–Hilsch vortex tube (who improved the performance of the vortex tubes after Ranque), and Maxwell–Demon vortex tube (derived from the name of Maxwell and Demon group who together studied the molecule of hot air moving within the tube) The vortex tube effects were first observed by Ranque, a French metallurgist and physicist about 1930. Thereafter, the vortex tube disappeared for several years, until Rudolph Hilsch studied it and published his findings in the mid-1940s. In 1947, Hilsch systematically examined the effect of the inlet pressure and the geometrical parameters of the vortex tube on its performance and presented a possible explanation of the energy separation process. In 1954,

Westley published a comprehensive survey entitled "A bibliography and survey of the vortex tube", which included over 100 references. In 1951 Curley and McGree, 1956

Kalvinskas , in 1964 Dobratz , in 1972 Nash , in 1979 Hellyar made important contribution to the RHVT literature by their extensive reviews on the vortex tube and applications A low cost, reliable, maintenance free solution to a variety of industries spot cooling problems. Using an ordinary supply of compressed air as a power sources, vortex tubes create two streams of air, one hot and one cold, with no moving parts. e.g. rotating or piston cylinders. It consist of piston tubes, which a high pressure gas streams enters tangentially, and splits leaves the tube through a central orifice near the nozzle, while hot gas streams flows towards regulating valves and leaves the tube. The Ranque-Hilsch vortex tube has been used for many decades in various engineering applications. A number of observations and theories have been explored by divergent investigators concerning this phenomenon.. One of these studies showed that acoustic streaming caused by vortex whistle plays a large part in the Ranque-Hilsch. In addition, thermal and kinetic energy considerations have been used to explain temperature separation. There have also been plenty of numerical analyses those concern earlier experiments. One fact still remains, however. There is no unifying theory that explains the temperature separation phenomenon inside the vortex tube. Vortex tubes can produce: Temperature from -50 to +260f (-46 to +127)Flow rates from The vortex tube was discovered by Ranque, a metallurgist and physicist who was granted a French patent for the device in 1932 and a United States patent in1934.The initial reaction of the scientific and engineering communities to his invention was disbelief and apathy. The ability to separate air into streams of different temperature is highly applicable to many areas of chemical engineering, particular for refrigeration purpose. Moreover, to separate air efficiently without using any moving parts or power source would be a breakthrough for the air conditioning industry as well as any other area that would require heating or cooling of compressed air. The most economical method of making a person comfortable while. working in hot surroundings is to provide a personal supply of cool air rather than conditioning the entire surrounding. A vortex tube is suitable for these applications because compressed air is readily available in workshops, factories, foundries, mines etc. Preliminary trails revealed that it is adequate to provide cool air for the upper portion of the body, i.e. above waist, and the cooling load is of the order kj/hr.
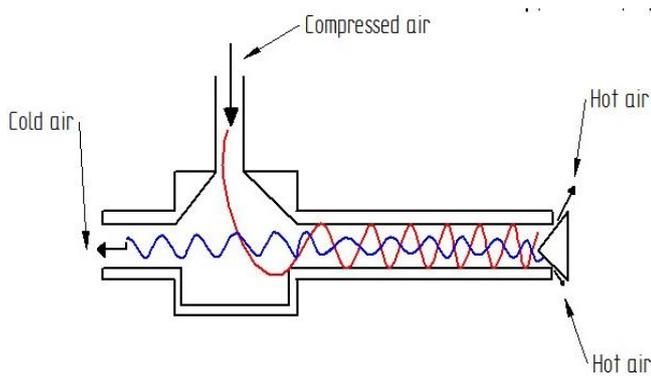
Fig.1- Vortex Tube

1.1 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 semiflexible 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 airstream into hot side. Generally the chambers are not of circular form, but they are gradually converted into spiral form

1.2 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. 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, Pongjet Promvonge and Smith Eiamsaard. The diameter of the nozzle is taken as D/3 according to Guillaume and Jully. 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 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. 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. 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.
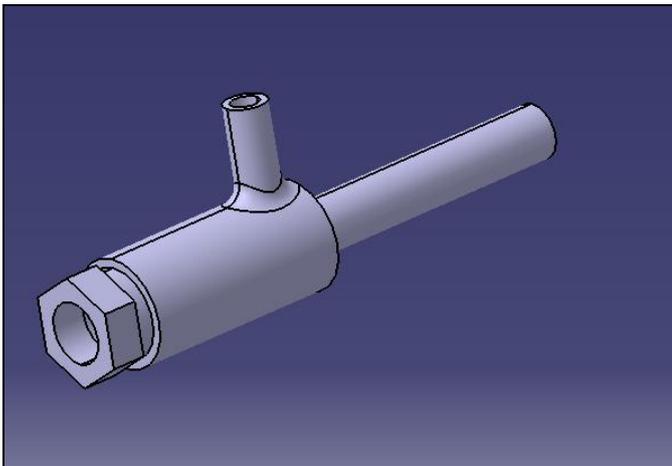
1.3 CATIA MODEL OF VORTEX TUBE:

Fig.2

2. 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, m_c represents the mass flow rate of the cold stream released, m_i 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 T_i is the inlet flow temperature and T_c 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 p_e to p_i by a reversible isothermal process, the COP of the system is given as:

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

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.

2.1 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:

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

3. PROBLEM STATEMENT:

While performing laser cutting operation , material gets heat up to high temperature which leads to formation of Heat affected zone on the material which reduces its performance and it takes much time to cool the material.

4. OBJECTIVE:

To optimize vortex tube for maximum temperature difference from previous investigations. To experimentally investigate the performance of this new optimized vortex tube.

To decrease the time required for cooling material after laser cutting operation and to find out the maximum temperature difference of vortex tube.

5. 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. Vortex flow as the radius is decreasing the linear velocity of fluid also decreases hence kinetic energy decreases and this decrease in kinetic energy is converted in heat which is dominant for the temperature separation for vortex tube. Have observed the variation by changing parameters of working at inlet temperature and pressure is decreasing we obtain colder air.

6. FUTURE SCOPE:

The simplicity of this apparatus has been alluring to many research workers. The mechanism of this experiment is still obscure. Vortex tubes have the potential to be utilized in a compact air separation system that can extract and liquefy oxygen for many purposes including onboard propellant generation for rocket vehicles.

REFERENCES

1. A. Secchiaroli, R. Ricci, S. Montelpare, V. D'Alessandro, Numerical simulation of turbulent flow in a Ranque–Hilsch vortex tube, Int. J. Heat Mass Transfer 52 (2009) 5496–5511.

2. H. Skye, G. Nellis, S. Klein, Comparison of CFD analysis to empirical data in commercial vortex tube, Int. J. Ref 29 (2006) 71–80.

3. T. Farouk, B. Farouk, Large eddy simulations of the flow field and temperature separation in the Ranque–Hilsch vortex tube, Int. J. Heat Mass Transfer 50 (2007) 4724–4735.

4.　Yilmaz, M., Kaya, M., Karagoz, S. and Erdogan, S. ''A review on design criteria for vortex tubes'', Journal of Heat Mass Transfer, 45, pp. 613–632 (2009).

5.　Eiamsa-ard, S. and Promvonge, P. ''Review of Ranque–Hilsch effects in vortex tubes'', Renewable & Sustainable Energy Reviews, (2007).

6.　Eiamsa-ard, S. and Promvonge, P. ''Numerical prediction of vortex flow and thermal separation in a subsonic vortex tube'', Journal of Zhejiang University Science A, 7, pp. 1406–1415 (2006).

7.　Saidi, M.H. and Valipour, M.S. ''Experimental modeling of vortex tube refrigerator'', Applied Thermal Engineering, 23, pp. 1971–1980 (2003).

8.　Aydın, O. and Baki, M. ''An experimental study on the design parameters of a counterflow vortex tube'', Journal of Energy, 31, pp. 2763–2772 (2006).

9.　Aljuwayhel, N.F., Nellis, G.F. and Klein, S.A. ''Parametric and internal study of the vortex tube using a CFD model'', International Journal of Refrigeration, 28, pp. 442–450 (2005).

10.　Gao, C. ''Experimental study on the Ranque–Hilsch vortex tube'', Ph.D. Dissertation, Department of Applied Physics, Eindhoven University of Technology, The Netherlands (2005).