Experimental Setup of Dual Inlet Vortex Tube

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Abstract— Refrigeration and air conditioning has become essential field of research these days due to its vast applications. Thus developing non conventional methods of refrigeration is needed. Our project "Fabrication of experimental setup of vortex tube" can be seen as a optional method for many cooling purpose. In this project we have made a experimental model of vortex tube which divides inlet stream of compressed air into two streams a cold at one side and hot on other, thus providing cooling and heating effect at same time. Aim of our project is to make efficient vortex tube using dual inlet. We have selected proper design of the same by researching on various studies on the same topic and through this research we have selected optimum design and fabricated the same. Details of vortex flow and working principle of the tube is provided. The project has various applications for spot cooling in machining process, for reheating and cooling purposes in process industries where hot compressed gases are exhausted.made to the data, which we store in cloud.

Key words: Dual Inlet Vortex Tube, Fabrication

I. INTRODUCTION

The vortex tube, also known as the Ranque-Hilsch vortex tube, is a mechanical device that separates a compressed gas into hot and cold streams. It has no moving parts. Pressurized gas is injected tangentially into a swirl chamber and accelerated to a high rate of rotation. Due to the conical nozzle at the end of the tube, only the outer shell of the compressed gas is allowed to escape at that end. The remainder of the gas is forced to return in an inner vortex of reduced diameter within the outer vortex resulting in two streams of air.

The Vortex Tube is an effective and low cost solution to a wide variety of industrial spot cooling and process cooling needs. We can say Vortex tube is a device which produces cooling at one end and heating at the other end simultaneously. The general name of vortex tube is cooling tube also, which instantaneously create streams of high and low temperature with respect to the temperature of the air which is used as a feed. The highly compressed air is forcing through a generation chamber, and by the virtue of high pressure and limited volume the pressure head of feeding air is get converted into the kinetic head which generates the centrifugal spin of air along the inner walls of the tube. It is evident that the cooling unit part does not incorporate any moving part if high pressure air is available. It has no moving parts; pressurized gas is injected tangentially into a swirl chamber and accelerates to a high rate of rotations. The Compressed air which is supplied to the vortex tube and passes through nozzles that are tangent to an internal counter bore. These nozzles set the air in a vortex motion. This spinning stream of air turns 90° and passes down the hot tube in the form of a spinning shell, similar to a tornado Due to the conical nozzle at the end of the tube, only the outer shell of the compressed gas is allowed to escape at that end. The remainder of the gas is forced to return in an inner vortex of reduced diameter within the outer vortex. 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.

II. VORTEX TUBE PHENOMENON

Fluid that rotates about an axis like a tornado is called a vortex. A vortex tube creates a vortex from compressed air and separates it into two air streams one hot and one cold.

Compressed air enters a cylindrical generator which is proportionately larger than the hot (long) tube where it causes the air to rotate. Then, the rotating air is forced down the inner walls of the hot tube at speeds reaching 1,000,000 rpm. At the end of the hot tube, a small portion of this air exits through a needle valve as hot air exhaust. The remaining air is forced back through the center of the incoming air stream at a slower speed. The heat in the slower moving air is transferred to the faster moving incoming air. This super-cooled air flows through the center of the generator and exits through the cold air exhaust port.

It is one of the non-conventional type refrigerating systems for the production of refrigeration. It consists of nozzle, diaphragm, valve, hot-air side, cold-air side. The nozzles are of converging or diverging or converging-diverging type as per the design. An efficient nozzle is designed to have higher velocity, greater mass flow and minimum inlet losses. 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. Hot side is cylindrical in cross section and is of different lengths as per design. Valve obstructs the flow of air through hot side and it also controls the quantity of hot air through vortex tube. Diaphragm is a cylindrical piece of small thickness and having a small hole of specific diameter at the center. Air stream traveling through the core of the hot side is emitted through the diaphragm hole. Cold side is a cylindrical portion through which cold air is passed.

The vortex tube is generally classified into two types. They are uniflow type or parallel type and counter flow type. Uniflow type This type of vortex tube has both the cold and hot exit at the far end of nozzle in the same side.

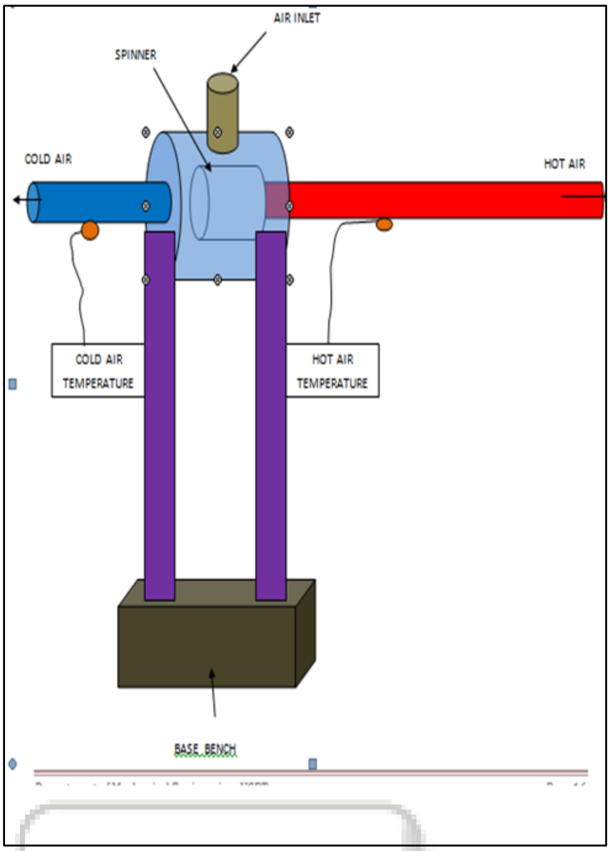

Fig. 1:

A. Components

- Inlet
- Hot tube chamber
- Cold tube side
- Cold orifice
- Hot plug
- Hoses
- Thermocouples

III. WORKING

Air (compressed) enters in the nozzle the air acquires high velocity and enters the vortex chamber. Tangentially where it forms a vortex. This vortex is formed because of the particular shape of the chamber. The vortex travels through the hot side of the tube through the hot pug or diagram. Part of this air flows back towards the diaphragm. It then leaves the tube through the orifice at the cold end. The hot air passes through the plug. By adjusting the valve opening the quantity of cold air and the temperature drop can be varied. The maximum drop is obtained for a particular opening of the valve. A decrease in temperature drop will result by reducing the valve opening below this opening.

IV. GOVERNING PARAMETERS OF PERFORMANCE FOR VORTEX TUBE:-

A. Effect of Inlet Pressure:

The variation of the cold mass fraction (CF) against the temperature different (Th-Tc). These results are obtained for different aspect ratio and one set of hot tube length ratio (L/D = 10). In addition, increasing the inlet pressure (Pi) of the counter-flow Ranque Hilsch vortex tube has increases the temperature gradient between the hot and the cold outlets. This due to the fact that at high pressure, air enters the RHVT with a higher tangential velocity, resulting in higher momentum transfer from the central region of the tube to the tube wall. This offers a bettertemperature separation, providing a higher temperature at the tube surface and a lower temperature in the core region of the tube.

B. Effect of Tube Length:

Optimum length to diameter ratio is important. Energy separation will increase up to critical length, beyond that there is no increase in energy separation. the temperatures gradients between the hot stream and cold stream outlet as a function of cold mass frication,. on the basis of the conclusion made by Chang Eta researchers form China for vortex tube with a cylinder tube, there is a critical length of vortex tube over which majority of the energy transfer takes place. Consequently, the energy separation increase as the length of hot tube increases to a critical length, however a further increase of the hot tube length beyond the critical does not improve the energy separation. It presents that the critical length to the diameter ratio (L/D) is ranged from 25 to 30 under normal experimental conditions. From studies by international journal of engineering studies and technical approach optimum value of length to diameter ratio was found to be 12.35.

C. Effect of Hot Plug Diameter:

The effect of hot plug diameter was studied varying the effective plug diameter by moving the conical valve in and out of the tube by researchers. The coldest temperatures were obtained at about 16.5 mm diameter of hot plug for a pipe of 18 mm internal diameter. Going higher than that value increases the temperature of cold air due to mixing of more hot air to the flow. Higher temperature drops are obtained in vortex tube at 90% hot plug diameter and is due to higher

Hot temperatures rather that low cold temperatures.. It is observed that maximum cooling effect is obtained at hot plug diameter, 90% of Tube inner diameter. efficiency is more influenced by the mass flow rate and the size of the cold orifice rather than the size of the hot plug.

D. Effect of Mass Flow Rate:

During the previous experiments, it was observed that the mass flow rate of air is the main characteristic feature that controls the temperature of cold air produced. Due to sudden expansion of air near outlet of nozzles, there is a low pressure region created just near the diaphragm placed. If the mass flow rate cannot supply enough amount of air there will be a negative pressure leading to suction of air through the cold outlet in all cases, as mass flow rate increases there is increase in temperature. At low hot plug opening, this rise is quite insignificant. But as the diameter of hot plug increases, the rise in temperature is quite dominant.

There is no much effect by either hot plug diameter or mass flow rate. Cold end temperature as well as adiabatic efficiency is more influenced by the mass flow rate and the size of the cold orifice rather than the size of the hot plug.

The pressure and mass flow rate is to be kept at a range for proper operation of tube. The higher range is defined by the strength of tube while lower limit is defined by the tube diameter and hot plug diameter.

E. Draft of Tube:

A 1- 5 O inclination of the inlet orifice towards hot end helped in reducing pressure buildup near the orifices, restricting further flow. A higher inclination increased the axial velocity, reducing the efficiency of operation.

V. SELECTION OF TUBE PARAMETERS

A. Inlet Pressure:

Optimum value of inlet pressure should be in the range of 5-7 bar.

B. Tube Length:

Optimum length to diameter ratio is important. Energy separation will increase upto critical length, beyond that there is no increase in energy separation. From studies by international journal of engineering studies and technical approach optimum value of length to diameter ratio was found to be 12.35.
i.e. Length/Diameter = 12.35

C. Tube Diameter:

Small diameter vortex tube provides more temperature separation when compared to larger tube. Even a very small dia may lead to diffusion of kinetic energy.
Also, according to Euler's equation,

$$T - (V*W*R)/Cp = Constant$$

From standard vortex tube experimented we are selecting, lenght = 110 mm
Therefore now diameter, D = 110/ 12.35 = 9 mm

D. No. of Inlets :

For maximum temperature drop inlet should be such that flow will enter tangentially in vortex tube to increase angular velocity. Standard vortex tubes experimented includes a single inlet.

To improve the tangential flow we are modifying it to dual inlet.

Therefore No. of inlet = 2 (symmetrical)

E. Cold Orifice:

We are using std value for cold orifice, d_3 = 0.6D = 6 mm (range of diameter = 0.4D to 0.6D)

F. Flow control:

Hot end control valve is important component as mass flow rate solely depend upon it. Optimum value for this conical plug = 45^o

G. Cross section divergent:

For better separation tube is made for divergent section up to 3^o divergent.

Therefore, selected dimensions are,
D = 10.20 mm
L = 12.60 mm
d_3 = 6 mm
No. of inlets = 2
Divergent angle = 3^o
Pi = 5 to 7 bar

The following assumptions were made for the ease calculation:

- The entire system is insulated and the processes are adiabatic.
- The outlet pressures are equal to atmospheric pressures.
- The cold end diaphragm and hot end conical valve does not absorb any heat.
- There is no change in performance due to the projecting part of conical valve.
- There is no effect of back pressure in the outlets

VI. PERFORMANCE EVALUATION:

Performance of vortex tube is evaluated by heating effect (ΔTh) and cooling effect (ΔTc)
$\Delta Th = Ta - Tc$
$\Delta Tc = Th - Ta$

Now temperature of air after entering the inlet,
Considering isentropic process
$\Delta Ti = Ta\ [1-(P_{inlet}/P_{tube})^{v-1/v}]$
Considering Ptube is atmospheric we can calculate ΔTi
Now efficiency of isentropic process may be given as,
$\eta_{isentropic} = \Delta T/\Delta Ti$

For refrigeration, $\eta = Ta\text{-}Tc/\Delta Ti$
For heat pump , $\eta = Th - Ta/\Delta Ti$

COP of the system may be found as follows,
$COP_{refrigeration} = Qc / WD$

$$\text{Where } WD = \frac{v}{v-1} * \mathbf{mrt}\left[\left(\left(\frac{Pin}{Patm}\right)^{\frac{v-1}{v}} - 1\right]\right.$$

VII. MATERIAL SELECTION

- Tube body:- Steel
- To deal with varying temperature and provide strength to shell body.\
- Cold orifice:-Steel
- Hot plug:- Steel

VIII. ADVANTAGES OF VORTEX TUBE REFRIGERATION:

- Maintenance free (No moving parts)
- Cools without costly electricity or refrigerants
- Reliable, compact and lightweight
- Low cost application
- Durable - Stainless Steel
- Adjustable temperature
- Instant cold air

IX. APPLICATIONS OF VORTEX TUBE REFRIGERATION:

- Cooling electronic controls
- Cooling machining operations
- Setting hot melts
- Cooling soldered parts
- Cooling gas samples
- Electronic component cooling
- Cooling heat seals
- Cooling environmental chamber

ACKNOWLEDGEMENT

We express esteemed gratitude and sincere thanks to our worthy lecturer guide PROF. DIPAK J. CHAUDHARI, our vocabulary do not have suitable words benefiting to high standard at knowledge and extreme sincerity, deviation and affection with they have regularly encouraged us to put heart and soul in this work.

We are also thankful to our HOD, PROF. V.D.PATEL whose advices and kind co-operation wrought out through discussion provide for completion of this project.

We also convey great thanks to our Honorable Principal Dr.A.V. BHONSALE, who helped a lot for completion of our project.

Our parents and relatives who always bear with us in very critical situation have contributed a great deal in making this for us. As we give expression to our love and appreciation for them our heart infill.

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