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Design Of Vortex Tube And Analysis Of Its Flow Characteristics

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ABSTRACT: Rankque Hitsh Vortex tube takes in compressed gas and produces cold gas. The major reasons attributed to this drop in temperature are sudden expansion, centrifugal effect, secondary circulation, friction. We have fabricated a vortex tube which uses air as working fluid and produces cooling effect. The flow characteristics such as temperature, pressure, discharge, mass flow rate, velocity etc. were measured. Our observations were tabulated and plotted. The values were obtained for input pressure such as 7-6bar, 6-5bar, 5-4 bar and 3-4bar. The vortex tube is used as cooling equipment in CNC machines, spot cooling applications etc. Since no moving parts are involved, this system requires less maintenance. Overall this paper intends to focus broadly on two aspects-geometrical characteristics of the vortex tube and thermophysical parameters involved.

Keywords: **Vortex tube, centrifugal effect, sudden expansion, secondary circulation**

I. INTRODUCTION:

A vortex tube is a thermo-fluidic device, which generates both cold and hot gas from single injection of pressurized gas. Without any moving parts and chemical reaction within the tube, the interesting phenomenon of energy separation results only from fluid dynamic effects.

The main part of vortex tube is a straight tube with tangentially entry, through which compressed gas is injected into the tube. There are two exit located at the different ends of tube. A controlled valve is positioned inside the tube, away from injection point, which has dimension smaller than the internal diameter of the tube and this allows the gas to escape from smaller gap between the tube and control valve. The cold exit is placed in the central part of tube near the injection valve. While the hot exit is the gap between control valve and the tube. When the compressed gas is injected tangentially into the tube hot gas will be exhausted from hot exit and cold air can be exhausted from cold exit. This phenomenon of energy separation in vortex tube is known as Ranque effect.

As vortex tube does not use any harmful refrigerant, it is an Eco-Friendly component. This Eco-friendly nature and its compactness make Vortex tube to finds application in many fields like cooling the tool and workpiece during machining in CNC and lathe.

II. WORKING OF VORTEX TUBE:

A compressed air is passed through the nozzle as shown in figure 2.1. 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 motion along the periphery of the hot side. Then, the rotating air is forced down the inner walls of the hot tube at speeds reaching 1,000,000 rpm.

The control valve restricts this flow. When the pressure of the air near the valve is made more than the outside by partly closing the valve, a reversed axial flow through the core of the hot side starts from high-pressure region. During this process, energy transfer takes place between peripheral flow and axial flow and therefore air flow through the core gets cooled below the inlet temperature of the air in the vortex tube while the air flow in forward direction gets heated. The cold air is escaped through the hole into the cold side, while hot stream is passed through the opening of the control valve. By controlling the opening of the valve, the quantity of the cold air and its temperature can be varied.

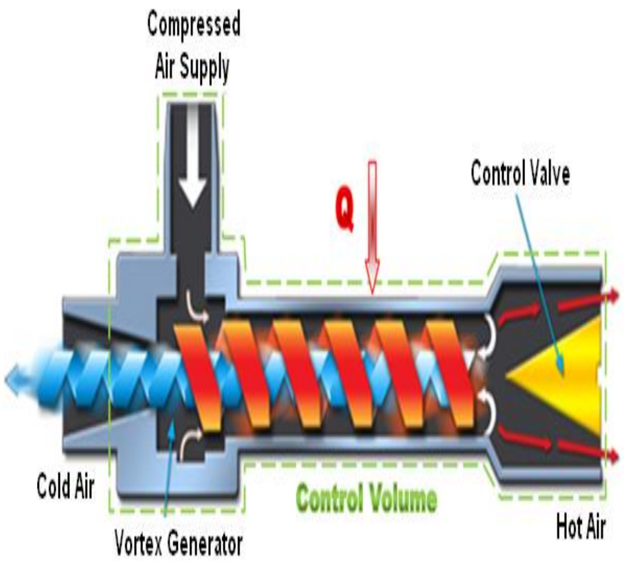

Figure 2.1

III. DIFFERENT EXPLANATION FOR THE PHENOMENON OF TEMPERATURE SEPARATION HAS BEEN PROPOSED:

The angular velocity of inner vortex and outer vortex are same. But according to the **law of conservation of angular momentum** the velocity of inner vortex expected to be increase but the velocity of inner vortex remains the same. Thus the angular momentum has been lost from inner vortex. This lost energy is shown as heat in the outer vortex. Thus the outer vortex become heat and the inner vortex is cold In the vortex tube, the fluid enters the tube along the periphery of the tube and setup a swirling flow which sets up a **centrifugal field and a pressure gradient.** Centrifugal field is responsible for air to flow in vortex motion along the periphery of the tube. Because of the high flow speed requires to set up centrifugal filed, fluid friction results in significant viscous dissipation at the periphery, that is heating, which must be removed. The flow is driven from the periphery to the centre of tube by a pressure gradient that opposes the centrifugal field induced by rotation. When the flow overcomes the centrifugal field by pressure gradient, gas expands and obtain a lower temperature and comes out through cold end.

If one moves a gas pocket from the axis towards the cylinder wall [1to2 in Fig. 3.1(a)], however, the pressure of the gas pocket increases due to compression. If this compression is fast and without heat exchange between the gas pocket and its surroundings, the compression is adiabatic and the temperature of the gas pocket increases [Fig. 3.1 (c)]. Therefore, at point 2, the gas pocket has a higher temperature than its surroundings. The other way around, if one moves a gas pocket adiabatically from the cylinder wall towards the axis (3to1) the gas pocket is expanded and obtains a lower temperature than its surroundings. After compression or expansion, energy is exchanged between the gas pocket and its surrounding gas.

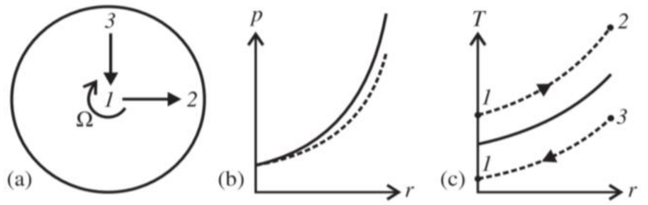

Figure3.1 Rotating cylinder with radial flow. (a) Rotating gas inside cylinder. (b) Pressure as a function of the radial coordinate. (c) Temperature as a function of the radial coordinate.

IV. DESIGN CRITERIA:

1.) Tube length:

The length of the vortex tube affects performance significantly. An efficient tube of either design should be many times longer than its diameter. Optimum L/D is a function of geometrical and operating parameters. The magnitude of the energy separation increases as the length of the vortex tube increases to a critical length, however a further increase of the vortex tube length beyond the critical length does not improve the energy separation.

2.) Tube diameter:

In general, smaller diameter vortex tubes provide more temperature separation than larger diameter ones.

3.) Type and number of nozzles:

The inlet nozzle location should be as close as possible to the orifice to yield high tangential velocities near the orifice. For maximum temperature drop the inlet nozzles should be designed so that the flow be tangentially into vortex tube. For maximum temperature drop the inlet nozzles should be designed so that the flow be tangentially into vortex tube.

4.) Cold end diameter:

Using a small cold orifice yields higher energy separation while a large cold orifice results lower energy separation in the tube. Coaxial orifices have greater temperature separation in compared to the other orifice configurations such as eccentric orifices, diaphragm nozzles, and diaphragms with cross sections other than cylindrical configurations.

V. COMPONENTS OF VORTEX TUBE:

1.Vortex chamber
2.Hot end tube
3.Cold end tube
4.Control valve

1.Vortex chamber

Vortex chamber is a hollow cylinder where inlet nozzle is placed tangentially, an opening for hot side tube and an opening for cold side tube. Vortex chamber is a place where vortex flow is created. Inlet nozzle is placed tangentially by placing the axis of inlet nozzle 10mm away from the axis of vortex chamber. The tangential inlet is cleared shown in the figure5.1

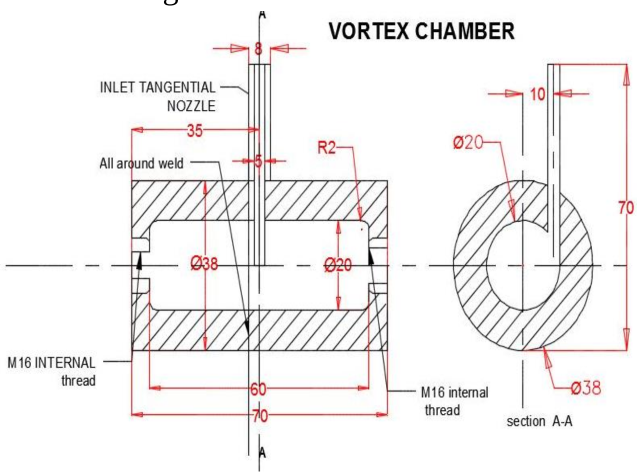

Figure5.1

2.Hot end tube

It is a tube. One end of the tube is connected to Vortex chamber and another side of the tube is connected to control valve. The ratio of length of hot end tube to the diameter of this tube is one of the important parameter while designing the Vortex tube.

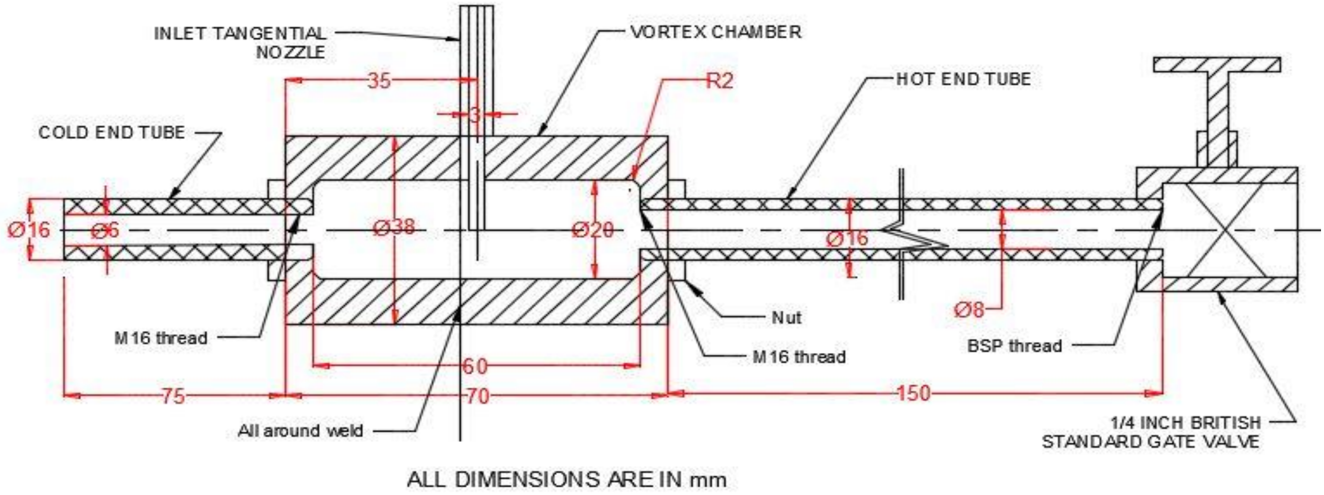

Figure5.2

3.Cold end tube

It is also a tube. One end is connected to Vortex chamber and another end is set free.

4.Control valve

¼" British standard Gate valve is used as control valve. It is connected to another end of hot side tube. Control valve helps in controlling flow rate in the vortex tube.

The 2D representation of vortex tube is shown in the figure 5.2.

S.NO	COMPONENT	DIMENSIONS
1	Inlet nozzle	Inner diameter :3mm Outer diameter :8mm
2	Vortex Chamber	Inner diameter:20mm Outer diameter:38mm Length :70mm
3	Hot end tube	Length :150mm Outer diameter:16mm Inner diameter:12mm
4	Cold end tube	Length :75 mm Inner diameter:6mm Outer diameter:16mm

Table 5.1: Dimensions of vortex tube.

VI. EXPERIMENTAL SETUP:

The experimental set up is shown in figure 6.1.

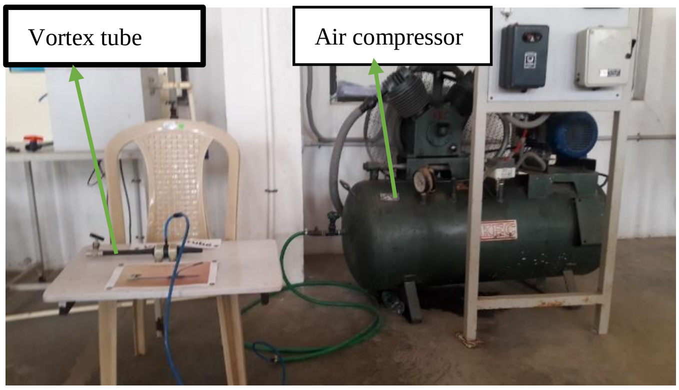

Figure6.1

VII. TABULATION:

S.No	Inlet pressure (bar)	Temperature		Temperature difference ($\delta t=t_h-t_c$) (°c)
		Cold end(°c) (t_c)	Hot end(°c) (t_h)	
1	7-6	4	39	35
2	6-5	8	48	40
3	5-4	10	53	43
4	4-3	14	59	45

Table7.1 Temperature of vortex tube at different pressure

S.NO	Pressure in bar	Inlet		Cold end		Cold flow mass ratio	Cold end temperature (T_c) °c
		Velocity (m\s)	Mass flow rate (ṁ) (Kg/s)	Velocity (m\s)	Mass flow rate ($\dot{m}_c$) (Kg/s)		
1	7-6	28.3	$4.2*10^{-3}$	16.49	$3.8*10^{-3}$	0.9	4
5	6-5	26.8	$3.3*10^{-3}$	15.6	$3.0*10^{-3}$	0.9	8
9	5-4	24.3	$2.5*10^{-3}$	12.7	$1.9*10^{-3}$	0.7	10
13	4-3	20.4	$1.6*10^{-3}$	10.4	$1.2*10^{-3}$	0.76	14

Table7.2 Mass flow rate at cold end

VIII. CALCULATIONS:

Inlet velocity =28.3m/s

Inlet area = $\pi/4\ d^2$ (inner diameter of inlet = 5mm)

$=1.963*10^{-5}\ m^2$

Discharge at inlet Q = area* velocity (m^3/s)

$=28.3*1.963*10^{-5}$

$=5.4977*10^{-4}\ m^3/s$

Density of inlet air ρ= P/RT (kg/m^3)

$=6.5*10^5/287*295$

$=7.6773\ kg/m^3$

Mass flow rate at inlet (ṁ)= Q* ρ (kg/s)

$= 5.4977*10^{-4}* 7.6773$

$=4.2207*10^{-3}$kg/s

Cold end Velocity v =16.49m/s

Area of cold end a $=\pi/4\ (id)^2$ (inner diameter of cold end d=6mm)

$=2.82*10^{-5}\ m^2$

Discharge Qc = velocity* area (m^3/s)

$= 16.49*2.82*10^{-5} =4.650*10^{-4}$ m³\s

Density of cold air ρ= P/RT (kg/m^3)

$=6.5*10^5 / (287) (277) =8.176 (kg/m^3)$

Mass flow rate of cold end ($\dot{m}_c$)= Q* ρ (kg/s)

$=4.650*10^{-4} *8.176$

$= 3.8019*10^{-3}$ (kg/s)

Cold flow mass ratio = mass flow at cold end / mass flow rate at inlet ($\dot{m}_c/\dot{m}$) = $3.8019*10^{-3}/4.2207*10^{-3}$

=0.9

IX FABRICATED SETUP:

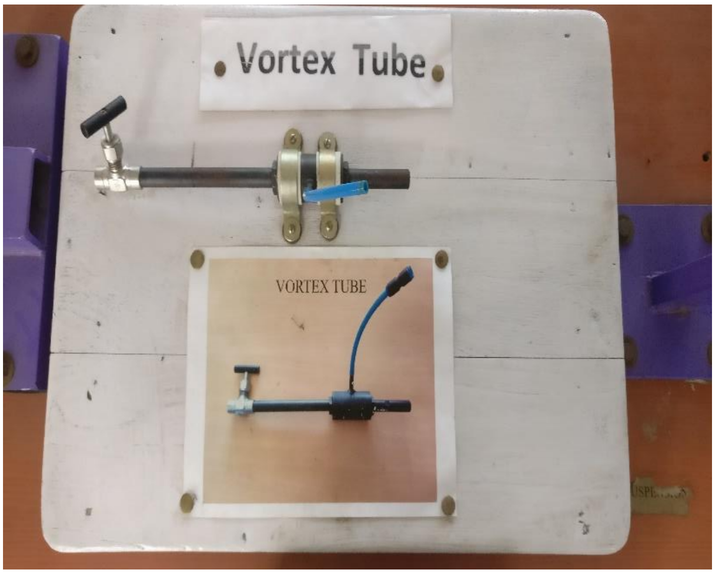

Figure 9.1

The fabricated setup of the vortex tube is shown in the figure 9.1.

X. INFERENCE:

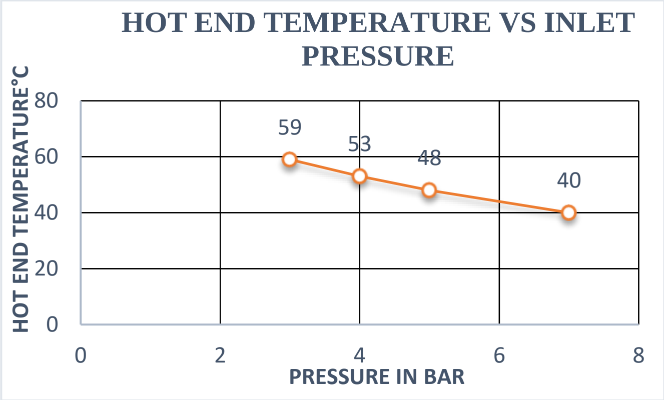

Figure 10.1

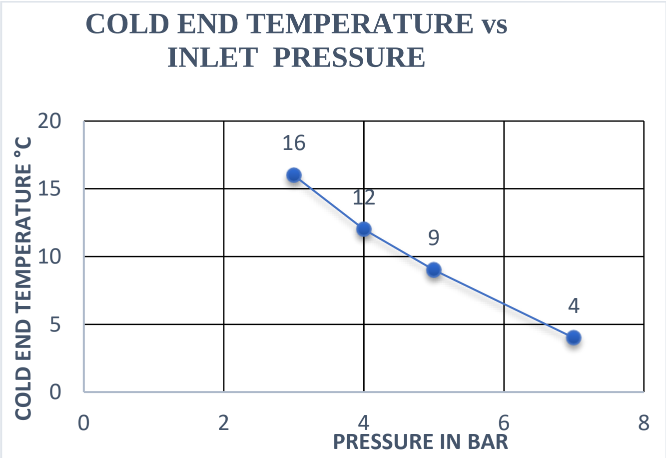

Figure 10.2

The following inferences were made during the analysis of the flow using vortex tube:

- The temperature of the hot end decreases with the increase in pressure
- The temperature of the cold end decreases with the increase in pressure.
- The lowest temperature achieved was 4°c and the height temperature achieved was 59°c.
- Higher temperature drops are obtained in vortex tube made of minimum cold flow temperature design, whereas, more cold fraction and higher adiabatic efficiency are obtained with maximum cooling capacity design.
- Maximum refrigeration occurs when a RHVT operates at 60–70% cold fraction.

XI. CONCLUSIONS:

The cooling effect of vortex tube is high when inlet pressure is high and when the hot end opening is small. It is clear that always the performance of vortex tube is directly proportional to inlet compressed air. Placing a tangential nozzle in cylinder is complicated job, this complication can be avoided by Vortex generator. Vortex generator doesn't need tangential nozzle. Compactness, environment friendly, no wear and tear makes vortex tube to find its application in many places.

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