Analysis & Testing of Vortex Tube by Optimization of Material

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Abstract - The *vortex tube is a simple device, having no moving parts, which produces hot and cold air streams simultaneously at its two ends from a source of compressed air. It is a mechanical device with no moving parts. As such there is no theory so perfect, which gives the satisfactory explanation of the vortex tube phenomenon as explained by various researchers. Therefore, it was thought to perform experimentation. So we increase efficiency of such vortex tube for industrial spot cooling, process Cooling, Weld Cooling etc. The experiment results indicated that these modifications could remarkably improve the performance of vortex tube. effort have been made to get maximum output in terms of C.O.P. This paper focused analysis of cooling and heating effect temperature difference and C.O.P with different working condition.*

Key Words: Hot & Cold Air, Cooling & Heating Effect, Temperature Difference, L/D Ratio

1. INTRODUCTION

The vortex tube is device which generates separated flows of cold and hot gases from single compressed gas source. The vortex tube was invented quite by accident in 1933 by George Ranque & later developed by Hilsch (1947).

Fig -1: Schematic Representation of Vortex Tube

The tube is fitted with a central aperture orifice at one end and a throttle valve at the other end. The shape and size of the nozzle is such that the gas attains maximum velocity of emission as it enters into the tube. In the process of movement of the gas inside the tube towards the throttle end, there develops in the spiraling gas a region of high pressure in the peripheral layers and a region of low pressure in the axis rotation. Thus a hot stream of gas comes out through the throttle end and a cold stream through the orifice. By manipulating the throttle valve, the amount of gas and also the extent of heating and cooling can be controlled.

A low cost, reliable, maintenance-free and compact size solution to a variety of industrial spot cooling problems. Using an ordinary supply of compressed air as a power source, vortex tubes create two streams of air, one hot and one cold, with no moving parts. Compressed air, normally 80-100 PSIG (5.5 - 6.9 Bar), is ejected tangentially through a generator into the vortex spin chamber. At up to 1,000,000 RPM, this air stream revolves toward the hot end where some escapes through the control valve. The remaining air, still spinning, is forced back through the center of this outer vortex. The inner stream gives off kinetic energy in the form of heat to the outer stream and exits the vortex tube as cold air. The outer stream exits the opposite end as hot air.

2. LITERATURE REVIEW

In 2012, Yunpeng Xue, Maziar Arjomandi and Richard Kelso [1]. This Paper presents detailed measurements of the flow properties inside a counter-flow vortex tube. The three dimensional velocity distributions inside the vortex tube lead to a new understanding of the flow behavior in the vortex tube. It is noted that in the central region of the tube, the irrotational vortex at the hot end was transformed to a forced vortex near the injection and kinetic energy is only transferred outwards from the hot end to the cold end.

In 2017, R C Venkatesh, S Vishal, N Arun kumar [2] Performance evaluation of the Ranque, Hilsch vortex tube has been carried out theoretically. There is a value of cold mass fraction at which vortex tube has the highest temperature drop for all the given pressures at the L/D ratio of 17.5. The maximum cold end temperature drop is obtained at cold mass fraction of 60%. For the given L/D ratio, as the gas pressure increases, cold end temperature difference increases but the optimum value of cold mass fraction remains same.

In 2015, Dr. Ajoy Kumar [3] There is every possibility to improve the low COP of vortex tube which may enable the wide use of it in industries for the purpose of cooling of cutting tools, air –craft refrigeration, air suits, cooling of turbine blades and year round air conditioning etc.

In 2006, Y T Wu, Y Ding, Y B Ji, C F Ma, M C Ge [4] Optimized the design of nozzle and rectifiers, selected the optimum length of hot end tube. The results of experiments show that the developed vortex tube has better performance than that of conventional vortex tube.

In 2016, Taparia N, Ritesh Kumar C, Kanwar L and Verma D [5] Increases the L/D ratio, we can get more temperature difference between cold end and hot end side. The maximum temperature difference in pipe. A between cold end and hot end with initial temperature of the air is 10.6 and 9.8 respectively.

In 2012, Rajarshi Kar, Oindrila Gupta, Mukunda Kumar Das [6] The huge amount of work done in the field of Ranque-Hilsch Vortex Effect, it shows that this is quite important for academic and industrial purposes. Even after so many works done in this field, there still remain some questions about topics unanswered. Moreover, the fair numbers of applications of this Vortex tube like mass separation of gases, measurement of velocities of airplanes etc. show huge scope of this subject.

3. PRINCIPLE AND THEORY

The theory of the Hilsch vortex tube, also known as the Ranque-Hilsch vortex tube dates back to the 1930s where French physicist George Ranque invented an early prototype. Around 1945 when the German army occupied most of France, Rudolf Hilsch, a German physicist improved Ranque's design to created a better version of the tube. The tube was named after the inventors, but most often is attributed to Hilsch, who made the more notable version.

The device itself is illustrated below in Figure, below. As you can see it is a fairly simple piece of equipment with only a few parts.

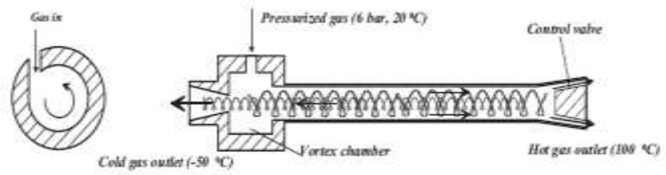

Fig- 2 : Schematic of the Hilsch Vortex Tube

Following the introduction of the compressed working fluid into the vortex tube tangentially, the linear momentum of the working fluid is converted to the angular momentum. Because of the centrifugal characteristics of the forced vortex flow, the peripheral fluid led to the annular space has a higher angular momentum, therefore kinetic energy, than that of the fluid in the central region. Naturally, this fact results in the temperature near the tube wall to be higher than that in the central part.

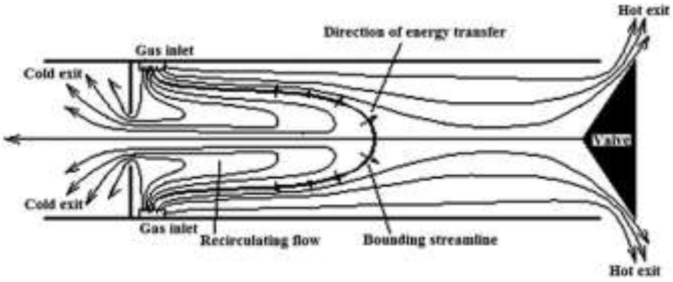

Fig- 3: Flow pattern and Schematic Drawing of Vortex Tube

In the middle section of the tube is the inlet for the compressed air. Note that the inlet is much closer to the cold outlet than the hot outlet. There is a very important aspect of the tube related to this feature which will be discussed shortly. From Figure, one can see the middle part which says "spiral chamber in this part." An enlarged cross-sectional depiction of that spiral chamber is shown on the next page in Figure. This spiral chamber is the essential component of the tube because it is the source of the hot and cold separation of the gas. How it works is based primarily on the physics of rotational motion and on Maxwell's law of random distribution.

Maxwell's law states is the basis of the kinetic theory of gases, which in turn helps explain fundamental properties of gases such as diffusion and pressure. Usually the law refers to velocity, but can also be applied to molecular momentum. In this particular case, we are focusing on velocities of all the molecules in the spiral chamber. From the law scientists can create what are known as Maxwell-Boltzmann distribution functions, which have importance in physics and chemistry.

4. WORKING OF VORTEX TUBE

Compressed air source is connected to vortex tube. The opening is a jet nozzle, which is connected to the compressed air source – Compressor. This jet is arranged to inject the air into the tube at a tangent to the outside circumference of the tube.

Due to design of jet and high pressure of the air, the air swirls rapidly around inside the long length of the tube. To opening are at or near atmospheric pressure. The temperature of air as it leads through tube will be greatly reduced. Temperature Below 0°C is obtained with this device.

A compressed air passed through the nozzle. Here air expands acquires high velocity due to the particular shape of the nozzle. Vortex flow is created in the chamber and air travels spiral like motion along periphery of hot side. The valve restricts the flow. When the pressure of air near the valve is made more than the outside by partly closing the valve a reverse axial flow through the core of hot side starts from high pressure to low pressure region.

During this process energy transfer takes place between reversed stream and forward stream and therefore air stream through the core gets cooled below the initial temperature of the air in vortex tube. While the air stream in the forward direction gets heated up. The cold stream is escaped through the diaphragm hole into cold side while hot stream is passed through opening of valve or orifice. By controlling opening of the valve (orifice size) the quantity of cold air and its temperature can be varied.

5. METHODOLOGY

A vortex tube design methodology has been outlined. Steps of the design process include:

- Design calculation
- Modelling of vortex tube
- Details and assembly drawing of vortex tube
- Analysis of vortex tube
- Selection of material
- Selection of standard parts from manufacturers catalogue
- Manufacturing of tube

6. FINAL CAD MODEL OF VORTEX TUBE

The vortex tube is designed in CATIA V5R20 software. There are 3 main components in vortex tube. The generator is connected to the 3 parts i.e. 1) cold section 2) Hot section 3) Inlet section. In vortex tube we can achieve maximum temperature drop upto -50°C to 200°C Following fig. shows the detailed drawing of vortex tube.

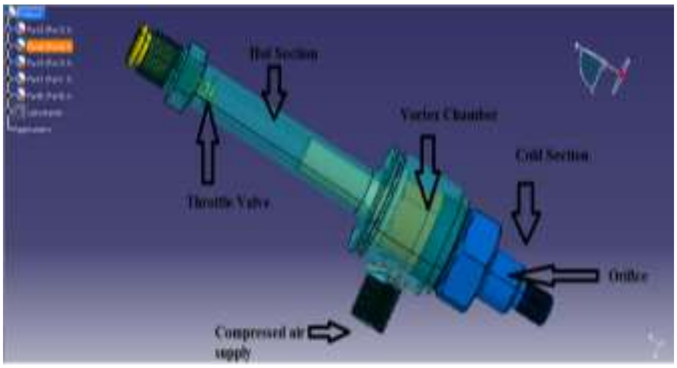

Fig-4: Detailed assembly drawing of vortex tube

7. ANALYSIS OF VORTEX TUBE

We have analyzed the vortex tube by using ANSYS software for selection of better material to achieve maximum difference We have analyzed two material i.e. copper & Stainless steel for vortex tube.

Below table shows analyzed result of that two materials at particular sections.

Table-1: Result for copper

Parameters\Materials	Copper		
	G	C	H
Velocity (m/s)	3.04e^2	10	1.955e^2
Pressure (pa)	6.059e^5	3.88e^5	3.88e^5
Temperature (K)	2.975e^2	2.231e^2	3.718e^2
Streamline Velocity (m/s)	10	10	2.13e^2

Table-2: result for Stainless Steel

Parameters\Materials	Stainless Steel		
	G	C	H
Velocity (m/s)	8.48e^1	10	2.125e^2
Pressure (pa)	6.059e^5	3.863e^5	3.88e^5
Temperature (K)	2.99e^2	2.27e^2	3.81e^2
Streamline Velocity (m/s)	10	10	2.065e^2

Where,

G = Generator

C = Cold Section

H = Hot Section

According to above results we can conclude that stainless steel is better to be used for manufacturing of vortex tube to achieve maximum temperature drop.

8. EXPECTED OUTCOMES

- Increase in COP.
- Maximum temperature difference.
- Maximum cooling effect.
- Reduce the size of the Tube.

9. CONCLUSIONS

The current phase of our research project described in this paper is to be manufacture the vortex tube which can give maximum temperature drop with high COP then conventional vortex tube. For this we have analyzed the vortex tube by using two materials & compared with conventional available vortex tube.

From result we have selected stainless steel for manufacturing of vortex tube because of vortex tube performs better with stainless steel compare to copper owing to its high molecular weight low specific heat ratio.

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