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DESIGN & FABRICATION AND ANALYSIS OF VORTEX TUBE

Akshay P. Navghare
BE Department of Mechanical Engineering,
Dr. D. Y. Patil College of Engineering & Innovation, Varale, Pune

Irfan M. Ansari
BE Department of Mechanical Engineering,
Dr. D. Y. Patil College of Engineering & Innovation,Varale, Pune

Pratik A. Dalvi
BE Department of Mechanical Engineering,
Dr. D. Y. Patil College of Engineering & Innovation,Varale, Pune

Pranay K.Rane
BE Department of Mechanical Engineering,
Dr. D. Y. Patil College of Engineering & Innovation,Varale, Pune

ABSTRACT—A vortex tube is a simple mechanical device, which splits a compressed gas stream into a cold and hot stream without any chemical reactions or external energy supply. This study presents the results of a series of experiment focusing on various geometries of the "hot end side" for different inlet pressures. Specifically, the tests will be conducted using different hot end plugs. One vortex tube will be designed, fabricated and tested for maximum temperature drop.

An experimental investigation will be performed to realize thorough behaviour of a vortex tube system. A reliable test rig will be designed and constructed to investigate the effect of geometrical parameters i.e. angle of the inline conical valve, tip diameter of the inline conical valve will be changed. During experimentation on short vortex tube, effect angle (30^0, 45^0, 60^0 and 90^0) of a mobile inline conical valve or plug, located at the hot end, will be determined experimentally for best performance. the ratio of the length of the vortex tube to its diameter (L/D) is 1:20.

I. INTRODUCTION

AVortex Tube is a simple mechanical device, which produces cooling effect by separating compressed air into hot and cold streams. The tube is fitted with a central aperture orifice at one end and a throttle valve at the other end. The gas attains maximum velocity of emission as it enters into the tube the shape and size of the nozzle is designed that way. As the gas moves to the end of the throttle valve, it helps to develop the spiraling gas at region, this region has high pressure in the peripheral layers and a region of low pressure in the axis rotation. Therefore a hot stream of gas exits from the throttle end and a cold stream from the orifice. By manipulating the throttle valve, the amount of gas and also the extent of heating and cooling can be controlled.[1]

The vortex tube was invented by Ranque, he was aphysicist and metallurgist who was granted a French patent for the device in the year 1932 and a United States patent in year 1934. The initial reaction of the engineering and scientific communities to his invention wasdisbelief and apathy. The earlier vortex tube was thermodynamically highly inefficient, it was obsolete for several years. Due to interest Hilsch revived the device,he was a German engineer, he reported an account of his own comprehensive experimental and theoretical studies, which aimed at improving the efficiency of the vortex tube. Hilsch systematically examined the effect of the inlet pressure as well as the geometrical parameters of the vortex tube and on its performance and presented a possible explanation of the energy separation process. Following the events of World War II, Hilsch's tubes and documents were discovered, which were later studied extensively. Indicative of early interest in the vortex tube is the comprehensive survey by Westleywhich included over 100 references. Other literature surveys such as Curley and McGree ,Kalvinskas [1].

A device is a low cost and, reliable, maintenance-free and *compact in size* solution to a variety of industrial spot cooling problems. The compressed air used by the device is ordinary, there are two ends of the vortex tube one is hot and other is cold, Compressed air, normally 5.5 - 6.9 Bar, is removed tangentially through a generator into the vortex spin chamber. At up to 1,000,000 RPM, this air stream revolves toward the hot end and from there some escapes through the control valve. The remaining air which don't get chance to escape and is still spinning, is forced back through the center and from there to the hot side, from this side the air exits as cold air. The heat is generated due to kinetic energy which itself is produced due to the inner stream of air while the outer stream exits the vortex tube as cold air. The outer stream exits the opposite end as hot air [2].

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 surroundings. A vortex tube is suitable for this application because compressed air is readily available in workshops, factories, foundaries, mines etc. Preliminary trials 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 of 200 kJ/hr [2].

II. PROBLEM STATEMENT

In present material which is used in the vortex tube the weight of this material is more, therefore to optimize the material density and efficiency, we are replacing the previously used material by Aluminium, Copper and Stainless Steel.

III. LITERATURE REVIEW

The vortex tube was invented quite by accident in 1928, by George Ranque, a French physics student, was experimenting with a vortextype pump he had developed when he noticed the warm air exiting from one end, and cold air from the other. Ranque soon forgot about his pump and started a small firm to exploit the commercial potential for this strange device that produced hot and cold air with no moving parts [1]. However, it soon failed and the vortex tube slipped into obsolete until 1945 when Rudolph Hilsch, a German physicist and engineer, published a widely read scientific paper on the vortex [2]. Ahlbornet al. studied the temperature separation in the vortex tube in a low pressure vortex tube and they state that separation occur due to the secondary circulation [3]. Behera et al. carried out a analytical simulation of vortex tube using CFD [4]. Aljuwayh el. studied the mechanism of stream and energy detachment inside the vortex tube using renormalization group(RNG) k-e and standard-e models. He used a two-dimensional axisymmetric model along with the outcome of the rotational velocity and described that RNG k-e model predicts better the function of the vortex tube [5]. Eiamsa had experimentally studied the effect of the nozzle numbers at the inlet on the performance of a vortex tube [6]. Pinar et al. examined the effects of inlet pressure, nozzle number as well as fluid type factors on the tube vortex performance by means of Taguchi method [7]. Promvonge and Eiamsaard reported the outcomes of the number of inlet tangential nozzles, the cold orifice diameter and the tube insulations on the temperature reduction and isentropic efficiency of the vortex tube [8]. Skye et al. (2006) obtained the inlet and outlet temperatures in experimental and numerical form and compared them with each other [9]. He used a accepted range of two dimensional turbulence k-ε model for simulating. He studied numerically the effect of length to diameter ratio (L/D) and stagnant point occurrence, importance in flow patterns [10].

IV.NOMENCLATURE

Table no. 1. Nomenclature

Sr. No.	Symbol	Description
1	A_N	Area of Nozzle
2	A_T	Area of Tube
3	A_C	Area of Cold Orifice
4	D_N	Diameter of Nozzle
5	D_T	Diameter of Tube
6	D_C	Diameter of Cold Orifice

V. PRINCIPLE THEORY

The theory of the Hilsch vortex tube, that is also known as theRanque-Hilsch vortex tube goes back to the 1930s when French physicist George Ranque invented an early prototype. Around 1945 when the German naziarmy occupied most of France, Rudolf Hilsch, a German physicist made efforts to improveRanque's design to created a better version of the tube. Although the tube was named after the inventors, but most often is credited toHilsch, who made the more notable version.

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 results in the temperature near the tube wall to be higher than that in the central part.

In the middle section of the tube is the inlet for the compressed air which is known as vortex chamber. Note to be taken 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, one can see the middle part which says "spiral chamber in this part. This spiral chamber is the principal component of the tubesince because it is the source of the hot and cold separation of the gas

Looking back for a moment, one can now grasp why the cold outlet valve is much closer to the inlet than that of hot outlet valve. As the molecules moves down the tube, the molecules begin slowly in both the z- and Θ–directions.

This slowing occurs due to reduction in the axial convection of the vortex as it moves down the tube.

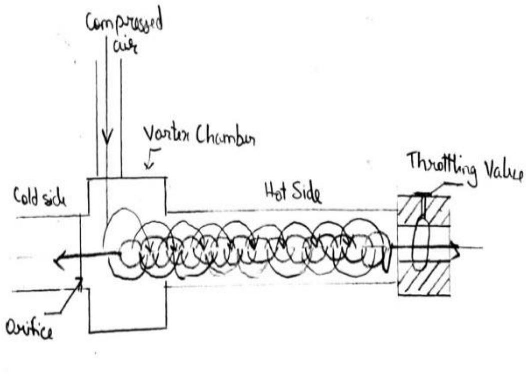

Fig 1: Vortex Tube Schematic

a)Design of vortex Tube

Literature review reveals that there is no theory so perfect, which gives the satisfactory explanation of the vortex tube phenomenon as explained by various researches. There it was thought to carry out experimental investigations to understand the heat transfer characteristics in the vortex tube with respect to various parameters like mass flow rates of cold and hot air, nozzle area of inlet compressed air, cold orifice area, hot end area of the tube, and L/D_T ratio.

b)3D design of Vortex Tube

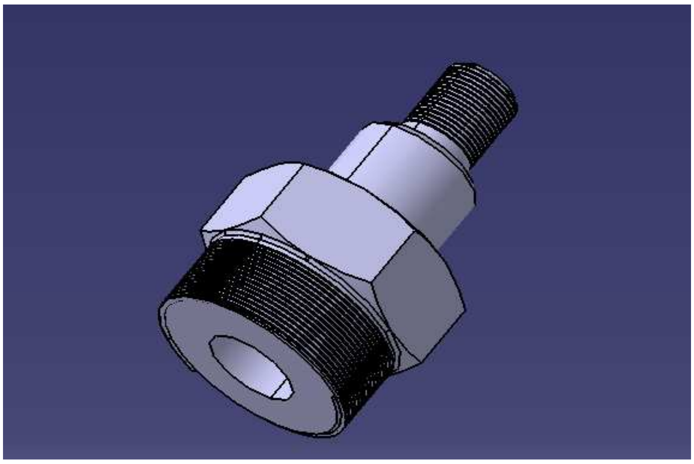

Fig.2: Cold side tube

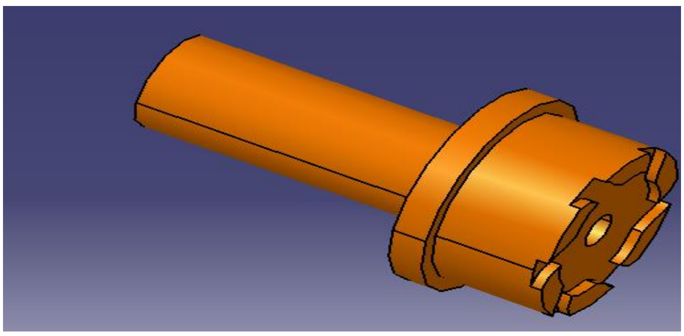

Fig.3: Generator

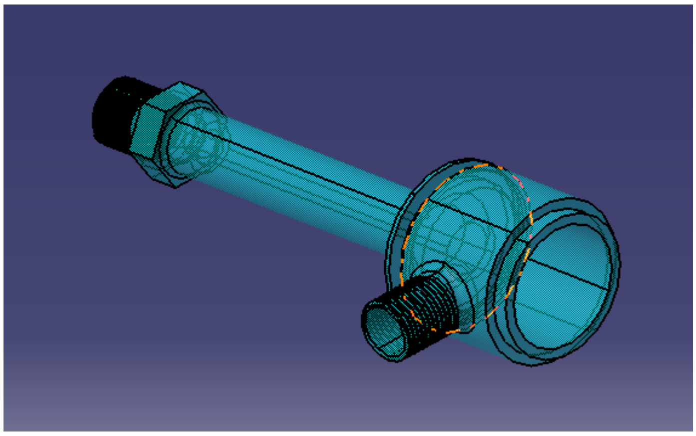

Fig.4: Hot side tube

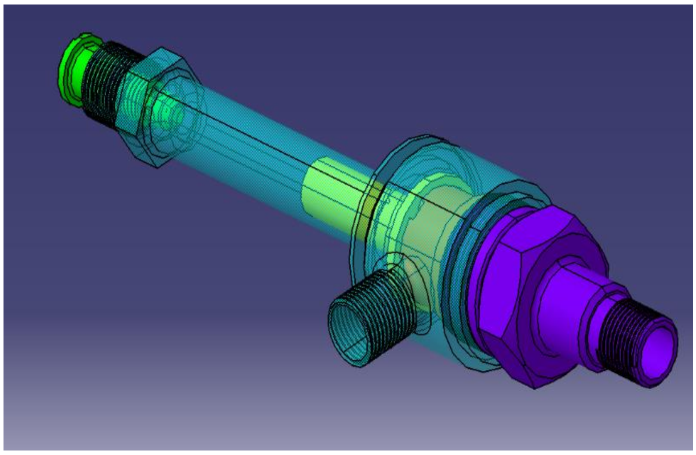

Fig.5: Final Assembly

c)Calculations

As per Soni and Thomson's Correlations
(For Nozzle Diameter)

$$A_N/A_T = 0.11 \pm 0.01$$

Considering the diameter of the Vortex tube D_T = 10mm;

$$A_T = \Pi/4 \times 10^2$$
$$= 78.5398 \text{ mm}^2$$
$$A_N/78.5398 = 0.11 \pm 0.01 \text{(i.e. 0.12 or 0.10)}$$
$$A_N = 9.42 \text{ or } 7.85$$
$$\Pi/4 \times D_N^2 = 9.42$$
$$D_N^2 = 11.9939$$
$$D_N = 3.46 \text{ mm}$$

OR

$$\Pi/4 \times D_N^2 = 7.85$$
$$D_N^2 = 9.6129$$
$$D_N = 3.1 \text{ mm}$$

Finally the Nozzle diameter was selected as D_N = 3.0 mm.

As per Soni and Thomson's Correlations
(For Cold Orifice Diameter)

$$A_C/A_T = 0.08 \pm 0.001$$

Considering the diameter of the Vortex tube D_T = 10mm;

$$A_T = \Pi/4 \times 10^2$$
$$= 78.5398 \text{ mm}^2$$

$A_C/78.5398 = 0.08 \pm 0.001$ (i.e. 0.081 or 0.079)

$\therefore$ $A_C = 6.3617$ or 6.2046

$\therefore \Pi/4 \times D_C^2 = 6.3617$

$$D_C^2 = 8.0999$$

$D_C = 2.83$ mm

OR

$\Pi/4 \times D_C^2 = 7.8999$

$$D_C^2 = 2.81$$
$$D_C = 3.0 \text{ mm}$$

Final Dimensions of short Vortex Tube are as follows:

$$D_T = 10.0 \text{ mm}$$
$$D_N = 3.0 \text{ mm}$$
$$D_C = 3.0 \text{ mm}$$

VI.CONCLUSION

A vortex tube will be investigated experimentally and analytically for best performance with an emphasis on a plug located at the hot outlet. Investigated parameters are, plug location plug tip angle (30^0, 45^0, 60^0 and 90^0), and supply pressure at the inlet (2-5 bar). Four different hot end plugs or inline conical valves will be studied. The vortex tube to be investigated will be length to diameter ratio of L/D = 20.

VII.ACKNOWLEDGMENT

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