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Design analysis of vortex tube of different material for optimum performance and it's fabrication

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ABSTRACT

A Vortex Tube is a mechanical device, which produces cooling effect by separating compressed air into hot and cold streams without using any moving part. The tube consist tangential inlet port for entry of pressurized air and two outlet ports namely hot end and cold end outlets. The shape and size of the nozzle at hot end outlet 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 air a region of high pressure in the peripheral layers and a region of low pressure in the axis rotation. Thus separation of flow in hot and cold streams takes place. By comparing three materials namely stainless steel, copper and aluminium for manufacturing vortex tube using ANSYS Software results are discussed and presented.

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I. INTRODUCTION

The vortex tube was firstly developed by Ranque, a metallurgist and physicist who was granted a French patent for the device in 1932 and a US patent in 1934. Since the vortex tube was thermodynamically inefficient hence not economical. further development in vortex tube made by Hilsch, a German engineer, who reported an improvement in efficiency of vortex tube. He systematically examined the effect of the inlet pressure and the geometrical parameters of the vortex tube on its performance. After World War II, Hilsch's tubes and documents were studied majorly.

The purpose of the present work is to study the effect of cold fraction at the same temperature on Ranque-Hilsch Vortex Effect and Maximum temperature drop. In the present study, three vortex tubes were studied by CFD analysis in CATIA software from which optimized vortex tube is manufactured. During experimentation on short vortex tube, for best performance different materials namely stainless steel, copper and aluminium are compared and effect of supply pressure 2-6 bar was studied.

The scope of this project is to provide use of vortex tube cooling effect for industries. Based on literature, case studies and interviews, the use of cooling effect are studied to address required applications. The project is focused to check efficiency and application of vortex tube for industries. The vortex tube is used for instant cooling purpose, where we required dry coolant. So that applications not get damaged. So, application where we need cooling for small application, we can use vortex tube. It is use in ultrasonic welds for cooling purpose. Cooling blow molded fuel tanks and also use for spot cooling and use for cooling for turbine rotor blades. Vortex tube are an effective, low cost solution to wide variety of industrial spot and processes cooling needs, with no moving parts. Vortex tube has a very wide range application for spot cooling on machine assembly, lines and processes. The scope for vortex tube is to cool machine operation, cool cutter blade, keep electronics cool, cool heat seat operation, thermal test sensor, cooling environmental chambers

II. LITERATURE REVIEW

Saidi and Valipour presented on the classification of the parameters affecting vortex tube operation. In their work, the thermo-physical parameters such as inlet gas pressure, type of gas and cold gas mass ratio, moisture of inlet gas, and the geometry parameters, i.e., diameter and length of main tube diameter of outlet orifice, shape of entrance nozzle were designated and studied. Singh et al. reported the effect of various parameters such as cold mass fraction, nozzle, cold orifice diameter, hot end area of the tube, and L/D ratio on the performance of the vortex tube. They observed that the effect of nozzle design was more important than the cold orifice design in getting higher temperature separations and found that the length of the tube had no effect on the performance of the vortex tube in the range 45– 55 L/D[1].

Gao et al. used a special pitot tube and thermocouple techniques to measure the pressure, velocity and temperature distribution inside the vortex tube which the pitot tube has only a diameter of 1mm with one hole (0.1mm diameter). In their work, the influence of different inlet conditions was studied. They found that rounding off the entrance can be enhanced and extended the secondary circulation gas flow, and improved the system's performance[2].

The work by Smith Eiamsa-ard and Pongjet Promvonge was aimed at gaining understanding of the physical behaviors of the flow and temperature separation process in a vortex tube. To investigate the cold mass fraction's effect on the temperature separation, the numerical calculation was carried out using an algebraic Reynolds stress model (ASM) and the standard k-model. The modeling of turbulence of compressible, complex flows used in the simulation is discussed[3].

E. H. Otten concluded after performing the several experiments that a cooled tube (water jacketed) has a greater effect of the cold fraction exceeds 0.4. There is no cooling effect for the uncooled tube at the cold fraction equal to zero and one, whereas the cooled tube still has an appreciable cooling effect at the cold fraction equal to one i. e. when all inlet air escapes through the diaphragm, the maximum efficiency of about 20% occurs with a value of cold fraction 0.8 for an uncooled tube at 6 atm. On the other hand, in the case of cooled tube the maximum efficiency of 24% occurs with a higher value of cold fraction 0.9[4].

Davood Majidi, Hashem Alighardashi, Fatola Farhadi conclude that reducing inlet feed temperature of vortex tube, separation ability of vortex tube decreased[5].

III. DESIGN FEATURES

In general, there are two design features associated with a vortex tube, namely,

(A) Maximum temperature drop tube design for producing small quantity of air with very low temperature.

(B) Maximum cooling effect vortex tube design for producing large quantity of air with moderate temperatures.

In the present study, out of these two design considerations first has been used. In the present investigation, a nozzle area to tube area ratio of 0.11+0.01 for maximum temperature drop and a ratio of 0.084+0.001 for achieving maximum efficiency has been considered, as suggested by Soni and Thomson. Further, they suggested that the ratio of cold orifice area to tube area should be 0.08+0.001 for achieving maximum temperature drop and it will be 0.145+0.035 for attaining maximum efficiency. Also the same researchers suggested that the length of the vortex tube should be greater than 45 times the tube diameter but no upper limit was specified.

Final Dimensions of short Vortex Tube are as follows:

DT = 10.0 mm

DN = 3.0 mm

DC = 3.0 mm

IV. CFD ANALYSIS

CFD analysis is carried out in ANSYS Workbench 16.0 Software in Fluent domain. The temperature distribution obtained as follows:

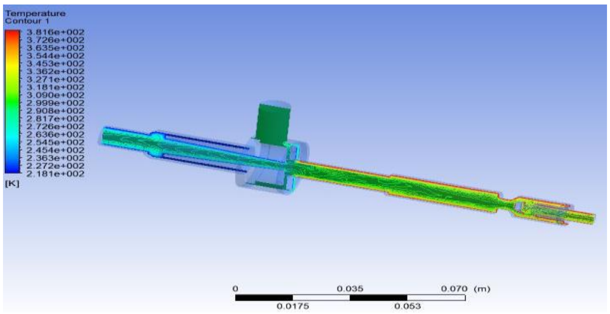

Fig: temperature distribution of ss vortex tube

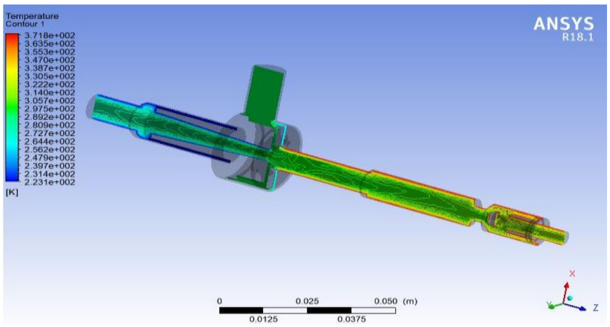

Fig: temprature distribution of copper vortex tube

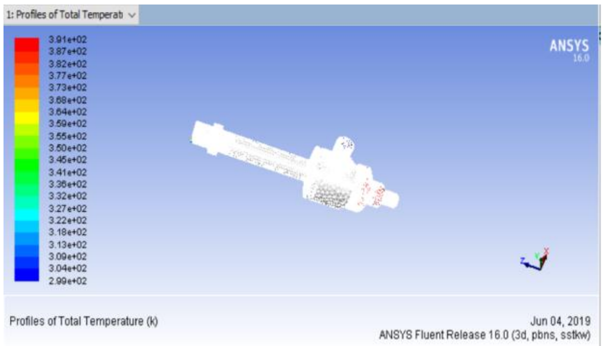

Fig: temprature distribution of aluminium vortex tube

V. EXPERIMENTAL VALIDATION

To ensure the results obtained from CFD Analysis in ANSYS Workbench 16.0 are practical and obtained same in reality prototype of most optimum material vortex tube is manufactured. i.e. Stainless Steel Vortex Tube.

The prototype manufactured was tested for its working on compressor of 6 bar capacity. The results obtained are recorded and compared with results of CFD analysis.

The results obtained experimentally are approximately similar deviated with acceptable limit.

VI. RESULT TABLE

Material	Temp. of hot air(K)		Temp. of cold air(K)		Δ(Theo.)	Δ(Exp.)
	Theo.	Exp.	Theo.	Exp.		
Aluminium	373	_	318	_	55	_
Copper	338	_	256	_	82	_
Stainless steel	345	344.6	254	265.2	91	79.4

VII. CONCLUSIONS

The heat transfer from fluid medium to vortex tube body is maximum in materials having good thermal conductivity. Heat transferred to vortex tube body is dissipated to atmosphere.
The maximum temperature drop is observed in Stainless steel material in comparison with copper and Aluminium after performing CFD analysis.
Hence, Stainless steel proven optimized material for vortex tube over Copper and Aluminium.

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