International Journal of Future Generation Communication and Networking
Vol. 13, No. 2s, (2020), pp. 995–1004

Design, Manufacturing and Testing of Vortex Tube

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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 experiments focusing on various geometries of the ''hot end side'' for different inlet pressures. Specifically, the tests were conducted using different hot end plugs. Three vortex tubes were designed, fabricated and tested for maximum temperature drop.

An experimental investigation has been performed to realize thorough behavior of a vortex tube system. A reliable test rig has been 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.

Keywords *— Vortex tube, Refrigeration, Cooling, Nozzle*

I. INTRODUCTION

Vortex 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 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.

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].

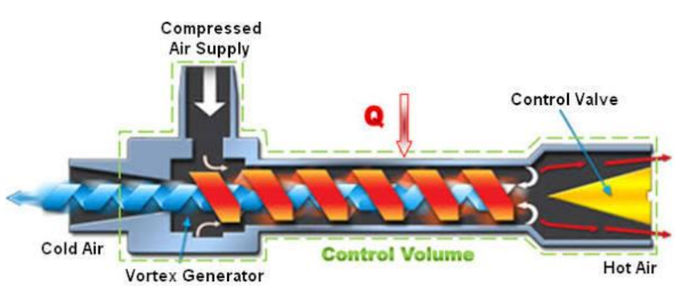

Fig. 1 Flow through the Hilsch Vortex Tube

ISSN: 2233-7857 IJFGCN

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, two vortex tubes were manufactured namely simple vortex tube and Short vortex tube. The performance all the two vortex tube was studied experimentally. During experimentation on short vortex tube, effects of tip diameter (3 mm) and angle (30^0 , 45^0 and 60^0) of a mobile inline conical valve or plug, located at the hot end, were determined experimentally effect of supply pressure 2-5 bar was also studied.
The internal diameter (D) of the vortex tube used in the experiments was 10 mm; the ratio of the length of the vortex tube to its diameter (L/D) was 10. Four different plugs were studied. The maximum difference in the temperatures of hot and cold streams were obtained for the plug diameter of 3mm, tip angles of 30^0 , 45^0 and 60^0 and by keeping the plug location at the hot end.

A. Advantages of Vortex Tube Refrigerator

Vortex Tube Refrigerator has several advantages, which are as follows:

1) It only uses air as refrigerant, so there is no leakage problem.
2) Vortex Tube is simple in design and it avoids control systems.
3) There is complete absence of moving parts in Vortex Tube.
4) It is light in weight and requires less space.
5) Initial cost is low and its working expenses are also less, where compressed air is readily available.
6) Maintenance is simple and no skilled labor is required.
7) No electricity or chemicals employed.
8) Durable – Stainless steels, Stainless steel, Brass,
9) Instant cold air.
10) Adjustable temperatures
11) Interchangeable generators

B. Limitations of Vortex Tube Refrigerator

Given such desirable features, why isn’t the vortex tube more widely used? There are basically two problems with the device which are explained below:

1) The thermal power of the vortex tube is limited.
2) The efficiency of the vortex tube, measured as (power out) / (power needed to compress inlet air) is diabolical. E.g. a typical vortex tube and compressor arrangement achieves a coefficient of performance of around 0.08 when operated as domestic refrigerator.

C. Applications of Vortex Tube Refrigerator

1) Cooling an Ultrasonic Weld
2) Cooling Blow Molded Fuel Tanks
3) Cooling Small Parts After Brazing
4) Cooling Vacuum Formed Parts
5) Air suits
6) Aviation
7) Cooling of Gas Turbine Rotor Blades
8) Laboratory Sample Cooler
9) Shrink Fitting
10) Cutting Tools

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11) Spot Cooling
12) Incentive Testing

II. LITERATURE REVIEW

A. Chronological Survey

Vortex flows or swirl flows have been of considerable interest over the past decades because of their use in industrial applications, such as furnaces, gas-turbine combustors and dust collectors. Vortex (or high swirl) can also produce a hot and a cold stream via a vortex tube. The vortex tube has been used in industrial applications for cooling and heating processes because they are simple, compact, light and quiet (in operation) device. Several researchers put a lot of efforts to explain for the phenomena occurring during the energy separation inside the vortex tube. Research studies about these phenomena were formed mainly into two groups. The first one performed the experimental work (geometrical and thermo-physical parameters) and then through the value of their results attempted to explain the phenomena. The second performed the studies in qualitative, analytical and numerical ways in order to help in the analysis of the mechanisms present in the vortex tube.

Table: 1 Summary of Experimental studies on Vortex tubes

Year	**Investigator**	**Dia. (D)mm**	**Pi (bar)**	**Th - Ti**	**Tc - Ti**	**μ**
1933	Ranque	12	7	38	-32	-----
1947	Hilsch	4.6	11	140	-53	0.23
1950	Webster	8.7	-----	-----	-----	-----
1951	Scheper	38.1	2	3.9	-11.7	0.26
1956	Hartnell and Eckert	76.2	2.4	3.5	-40	-----
1956	Martynovski and Alekseev	4.4/28	12	-----	-65	-----
1957	Scheller and Brown	25.4	6.1	15.6	-23	0.506
1958	Otten	20	08	40	-50	0.43
1959	Lay	50.8	1.68	9.4	-15.5	0
1960	Suzuki	16	5	54	-30	1
1960	Takahama and Kawashima	52.8	-----	-----	-----	-----
1962	Sibulkin	44.5	-----	-----	-----	-----
1962	Reynolds	76.2	-----	-----	-----	-----
1962	Blatt and Trusch	38.1	4	-----	-99	0
1965	Takahama	28/78	-----	-----	-----	-----
1966	Takahama and Soga	28/78	-----	-----	-----	-----
1968	Vennos	41.3	5.76	-1	-13	0.35
1969	Brunn	94	2	6	-20	0.23
1973	Soni	6.4/32	1.5/3	-----	-----	-----
1982	Sclenz	50.8	3.36	-----	-----	-----
1983	Stefan et al.	17.6	6	78	-38	0.3
1983	Amitani et al.	800	3.06	15	-19	0.4
1988	Negm et al.	11/20	6	30	-42	0.38
1994	Ahlborn et al.	18	4	40	-30	-----
2001	Guillaume and Jolly III	9,5	6	-----	-17.37	0.4
2003	Saidi and Valipour	9	3	-----	-43	0.6
2004	Promvongue and Eiamsa	16	3.5	-----	33	0.33
2005	Aljuwayhel et al.	19	3	1.2	-11	0.1

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Table. 2 Summary of Numerical studies on Vortex tubes

Investigators	Flow considered	Model	Method or software used	Results compared with measurements
Linderstrom-Lang (1971)	Incompressible	Zero-equation	Stream-function	Poor but just trend
Schlenz (1982)	2D compressible	Zero-equation	Galerkin's technique	Poor but qualitative Trend
Amitani et al. (1983)	2D compressible	Neglected	Finite difference	Fair but assumptions in Doubt
Borissov et al. (1993)	Incompressible	-------	Velocity field induced by helical vortex	Qualitative agreement
Guston and Bakken (1999)	2D compressible	k– ε model	FLUENT™ code	Fairly good
Frohlingsdorf and Unger (1999)	2D compressible	k– ε model	CFX code	Fairly good
Promvonge (1999)	2D compressible	ASM and k– ε model	Finite volume	Good
Behera et al. (2005)	3D compressible	k– ε and RNG k– ε models	Star-CD code	Fairly good
Aljuwayhel et al. (2005)	2D compressible	k– ε and RNG k– ε models	FLUENT™ code	Fairly good
Skye et al. (2006)	2D compressible	k– ε and RNG k– ε models	FLUENT™ code	Fairly good
Eiamsa-ard and Promvonge (2006)	2D compressible	ASM and k– ε model	Finite volume	Good

III. DESIGN, MANUFACTURING AND TESTING

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.

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.

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(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 uses. 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.

B. Maximum Temperature Drop Tube Design

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

$A_N/A_T = 0.11\pm0.01$

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

$A_T = \Pi/4 \times 10^2$

$= 78.5398\ mm^2$

$A_N/78.5398 = 0.11 \pm 0.01$(i.e. 0.12 or 0.10)

$\therefore A_N = 9.42$ or 7.85

$\therefore \Pi/4 \times D_N^2 = 9.42$

$D_N^2 = 11.9939$

$D_N = 3.46$ mm

OR

$\Pi/4 \times D_N^2 = 7.85$

$D_N^2 = 9.6129$

$D_N = 3.1$ 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 $D_T = 10$mm;

$A_T = \Pi/4 \times 10^2$

$= 78.5398\ mm^2$

$A_C/78.5398 = 0.08 \pm 0.001$ (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

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

$D_C^2 = 2.81$

$D_C = 3.0$ mm

Final Dimensions of short Vortex Tube are as follows:

$D_T = 10.0$ mm
$D_N = 3.0$ mm
$D_C = 3.0$ mm

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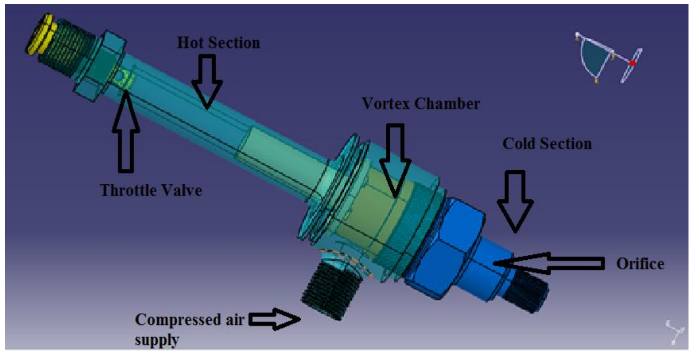
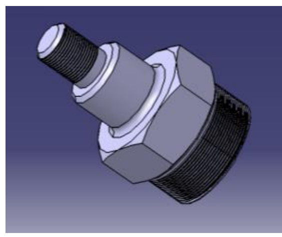


Fig. 2 Newly designed Vortex Tube [Assembly]



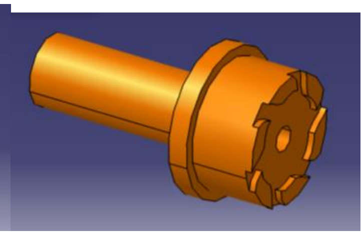
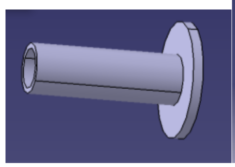


Fig. 3 Cold Section

Fig. 4 Generator



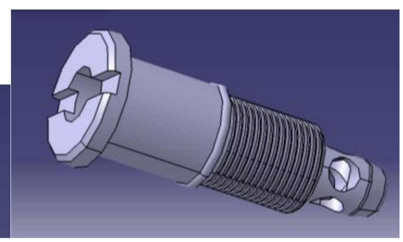


Fig. 5 End Pin of Generator

Fig. 6 Hot End Throttle Valve

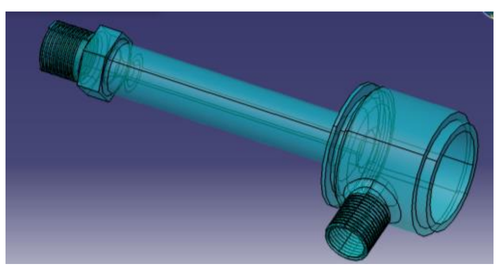


Fig. 7 Outer Tube of Vortex Tube

C. Manufacturing method of Short Vortex Tube:

For the design of vortex tube there are essential components are cold end, cold end orifice diameter cap, hot end and inline conical valve.

1. We take stainless steel rod of dimension Φ 30 mm x 90mm and is drilled at the center Φ 10 mm throughout the length in order to produce a tube.
2. Hole of Φ 3 mm drilled on the periphery at near to one end of the end, which is done very carefully using fixture.

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3. A taper of 1 in 10 is produced 32mm away from one end inside the tube of 10mm length.
4. External threading is prepared on both end for holding cold orifice diameter cap on one side and hot end holding inline conical valve inside on other side, so manufactured vortex generator.
5. Again, we taken stainless steel rod of Φ 40mm x Φ 35mm which drilled throughout a hole of Φ 4mm for cold orifice diameter.
6. Halfway drilled of hole Φ 16mm on cold orifice and then tapped thread to matching external thread on cold end of vortex generator.
7. Step of length of Φ 10mm from outside so that completes the manufacturing of cold orifice diameter cap.
8. For inline conical valve Stainless Steel of Φ 30mm x Φ 40mm is drilled a hole of Φ 15mm upto distance 35mm and remaining 15mm length is tapped of Φ 5mm then tube is drilled no. of holes Φ 3mm on the periphery and side which completes the manufacturing of hot end.
9. Three conical valves are produced with different cone angles of 30^0 ,45^0 & 60^0 with same tip diameter of 3mm. So, we complete manufacturing of inline conical valve

D. Testing of the Vortex Tube

The schematic of the experimental apparatus and measuring devices which is used for the determination of the energy separation in a vortex tube is shown in Fig. Compressed air is passing through the inlet valve and filter section, since then it is conducted tangentially into the vortex tube. The compressed air expands in the vortex tube meanwhile is divided into cold and hot streams. The cold air leaves the central orifice near the entrance nozzle, while the hot air discharges the periphery at the far end of the tube. The control valve (needle valve) may control the flow rate of the hot air. Two rotameters namely 9 and 6 measure the mass flow rates of the hot and cold air, respectively. Thermocouples numbered 5 and 8 measure the temperature of the leaving cold and hot air in the vortex tube, respectively. The pressure of inlet gas is measured by pressure gauge (Pi) and the temperature of inlet gas is measured by thermocouple. To investigate the effect of geometrical parameters on the operational characteristics of vortex tube, vortex tubes with different tube sizes and different number of nozzle intakes were constructed and examined.

The experimental tests of the vortex tube were performed with the variation of the pressure of the inlet air, Pi – 2 to 7 bar, and the cold air mass ratio μ. The temperature obtained was in the range of -10 ^{0} C to 22^0 C.

Fig. 8 Final Product

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Fig. 9 Temperature Results

IV. FUTURE RESEARCH AND DEVELOPMENTS

A. Further Research

1) Compressed Air
2) Creating Clean Water
3) Reversing System of Heat
4) Increased Vortex Efficiency

B. Future Developments

1) Use of Silencers and Mufflers
2) Design of Warm Tube End
3) Design of Outer Tube
4) The Cold Orifice or Diaphragm

C. Recommendations:

Based on the fact that the device had very poor cooling capacity as compared with industry standard refrigeration devices, it would not be a good substitute for commercial purposes. Significant redesign of the device may in the future better the cooling capacity to a point where it may be usable in the refrigeration industry, but for now, all this device can be reasonably used for the spot cooling and perhaps providing a quick and simple way to cool or heat a pressure stream.

Since the device has specific length and diameter restrictions, one cannot significantly alter the design of the tube. The reason it has certain length restrictions is that too short of the tube would not give the hot stream enough time to heat up and too long of a length would cause the vortex within the tube to depressurize and collapse. Likewise, too large a tube diameter will also collapse the vortex flow, so there are tight restrictions on tube design. Increasing pressure will help to enlarge these dimensions, but only slightly and pressurizing the air could get costly depending on the scale up.

V. CONCLUSIONS

Newly design vortex tube we conclude following things:

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Inlet port is perfectly tangential to the circumference of vortex generator we get more temperature drop, it generates vortex effect perfectly, tip angle of conical valve also effects the efficiency of vortex tube. According to it, maximum temperature drop is at 45^0 tip angle.

It is clear that inlet pressure is the necessary to driving force of energy separation experiment show that higher the inlet pressure the greater temperature difference of the outlet stream.

Using vortex tube, we get cold air instantly, so that it can apply on hot surfaces.
Newly designed vortex tube is so compact, so that used in anywhere (compress air need upto 2 to5 bar).

A vortex tube was investigated experimentally 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 supply pressure at the inlet (2-5 bar). Three different hot end plugs or inline conical valves were studied. The vortex tube investigated had a length to diameter ratio of L/D = 10. Length of the tube has no effect on the performance of the tube.

ACKNOWLEDGEMENT

I take this opportunity to thank all those who have contributed in successful completion of this Project Stage -1 work. I would like to express my sincere thanks to my guide Prof. M. E. Nimgade who have encouraged me to work on this topic and provided valuable guidance wherever required. I also extend my gratitude to Dr. N. P. Sherje (H.O.D Mechanical Department) who has provided facilities to explore the subject with more enthusiasm.

I express my immense pleasure and thankfulness to all the teachers and staff of the Department of Mechanical Engineering of Smt. Kashibai Navale College of Engineering for their co-operation and support.

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