Design and Manufacturing of Vortex Tube

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Abstract: ***The phenomenon of temperature distribution in confined steady rotating gas flows is called Ranque-Hilsch effect. The simple counter-flow vortex tube consists of a long hollow cylinder with tangential nozzle at one end for injecting compressed air. The flow inside the vortex tube can be described as rotating air, which moves in a spring-shaped vortex track. The peripheral flow moves toward the hot end where a hot end plug is placed and the axial flow, which is forced back by the plug, moves in the opposite direction towards the cold end.***

Keywords: Vortex tube; Refrigeration; cooling

1. Introduction

Vortex tube was invented by French physicist G.J. Ranque in 1931 [1]. But due to its inefficiency the patent and idea was rejected and it was highly unpopular. Later in 1947, German engineer R Hilsch modified the design [2]. Henceforth, there had been a lot of research on the energy separation process of the vortex tube but there was no concordance [3]. Vortex tube is a simple mechanical device used for separating a compressed fluid generally air into streams of hot and cold air respectively. Air is commonly used fluid in the vortex tube but it can employ other gases as well. In this analysis air is considered as working fluid. Inlet nozzles are located near the cold end side while hot end is located from the inlet nozzles. An orifice plate is located near the cold end to restrict the flow towards hot direction only. At the hot end of the tube the conical valve is provided to limit the amount of air to be sent to the atmosphere. This conical valve is adjustable. Compressed air is injected tangentially into tube through the nozzles and air is subjected to whirling action creating free vortex due to the periphery of the tube. Since an orifice plate is provided near the cold side of the tube and concentric to hot tube, air is forced to move towards hot side of the tube which partly escapes due to the conical valve while remaining air strikes the valve and returns towards the cold end in linear way [4]. During this process, the central stream loses its energy to the peripheral stream. This phenomenon along with pipe friction is responsible for getting the cold air stream at cold side. The temperature at the hot end can be adjusted by varying the position of the conical valve. The figure 1 reveals the working principle of the Vortex tube [5].

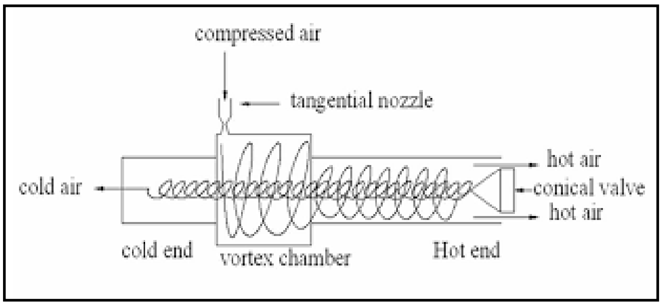


Figure 1: Principle of vortex tube

A. Background

In a vortex tube a stream of air is injected tangentially at high speed through one or several nozzles. The air flow separates into a cold component issued from a small hole on the axis close to the inlet plane and a hot component that leaves through a large orifice at the other end. All reported vortex tubes have been given by a gauge pressure in the range of 2–10 atm.

This ‘temperature separation’ has baffled investigators for over 60 years since heat seems to be travelling in the wrong direction, namely from the cold to the hot part of the flow. The working fluid starts in a plenum chamber at practically zero velocity. It gains kinetic energy and loses temperature as it passes through the inlet nozzle into the vortex tube. It splits into a cold and a hot component which each circle around in the tube and eventually emerge either on the hot side or on the cold side of the device. Typically each flow component then passes through a slowdown section where it must lose all its kinetic energy.

B. Research Aims and Objectives

The main objective of this paper is to showcase the results of the experimental modeling of the vortex tube. Experimenting with changing vortex generator and vortex casing design, are few major newly changes. These alterations affect the outlet exit temperature at hot end and cold end.

2. Literature Review

The vortex tube was invented quite by accident in 1928. George Ranque, a French physics student, was experimenting with a vortex-type pump he had developed when he noticed warm air exhausting 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. However, it soon failed and the vortex tube slipped into obscurity until 1945 when Rudolph Hilsch, a German physicist, published a widely read scientific paper on the device.

Much earlier, the great nineteenth century physicist, James Clerk Maxwell postulated that since heat involves the movement of molecules, we might someday be able to get hot and cold air from the same device with the help of a "friendly little demon" who would sort out and separate the hot and cold molecules of air.

Thus, the vortex tube has been variously known as the "Ranque Vortex Tube", the "Hilsch Tube", the "Ranque-Hilsch Tube", and "Maxwell's Demon". By any name, it has in recent years gained acceptance as a simple, reliable and low cost answer to a wide variety of industrial spot cooling problems.

Some important historical events which are directly related with development of vortex tube are as:

- The separation of gas mixtures, oxygen and nitrogen, carbon dioxide and helium, carbon dioxide and air with the vortex tube (VT) was reported in 1967 by Linderstrom-Lang and in 1977 by J. Marshall.
- In 1979 steam was used as working medium by Takahama.
- In 1979, two-phase propane was used as the working medium by Collins.
- In 1988 Balmer applied liquid water as the working medium. It was found that when the inlet Pressure is high, for instance 20-50 bar, the energy separation effect still exists. So it proves that the energy separation process exists in incompressible (liquids) vortex flow as well.
- In 2004, natural gas was used as working medium and with the VT natural gas was liquefied by Nikolay Poshernev.
- Timothy of I.I.T. Mumbai obtained a drop of 75°C with inlet air at 8 bar and 300 K. Hing and Naganagoudar of IIT Mumbai were able to increase a drop to 83°C.

3. Experimentation in Details

The schematic parts of our vortex tube is being shown in the figure. Geometrical parameters are mentioned below.

A. Geometrical Parameters

The geometrical parameters for our vortex tube set-up are as mentioned below-

Table 1: Geometrical Parameters

Sr. no	*Design Parameters*	*Dimension*
1.	Diameter of vortex generator, D	12.5mm
2.	Diameter of orifice, Dc	5,6.25mm
3.	No. of nozzle	2
4.	Nozzle diameter, Dn	3.2
5.	Dc/D	0.4,0.5
6.	Dn/D	0.256
7.	Length of hot side tube, Lh	10D,20D,30D, 40D,50D
8.	Length of cold side tube, Lc	4D
9.	Inlet pressure (in bar)	4,5,6,7,8,9,10, 11,12

- The following figures show the 3D cut and full sections of the modified vortex tube generator and casing.

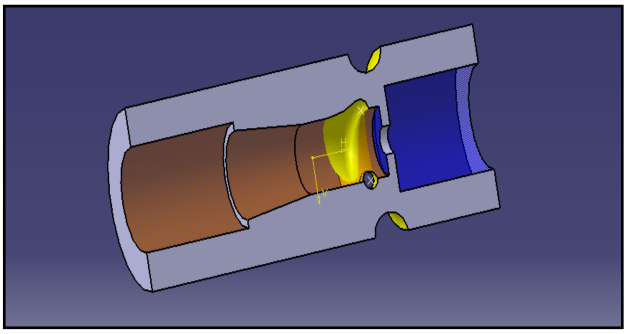


Figure 2: Cut section of vortex generator

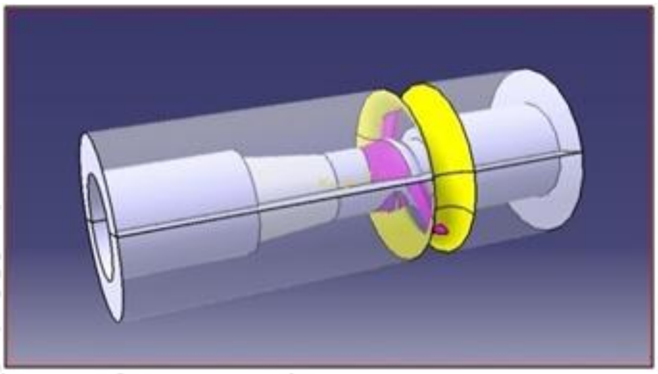


Figure 3: Full section of vortex generator

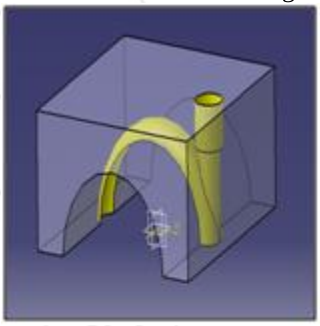
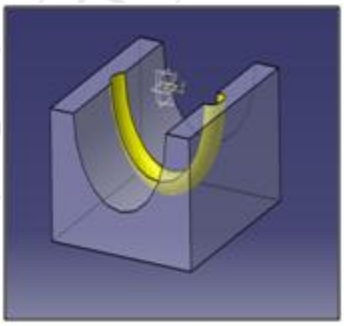


Figure 4: Cut sections of vortex casing



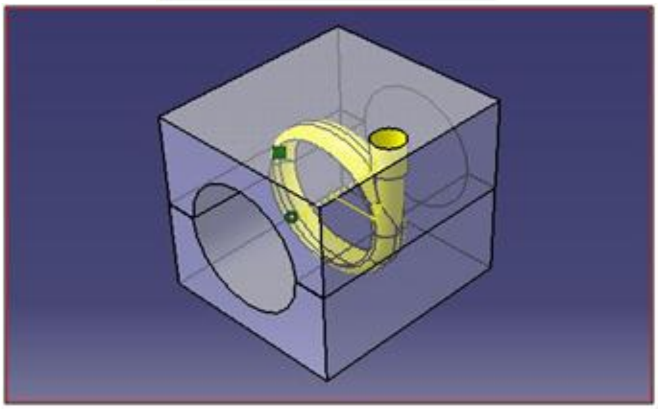


Figure 5: Full section of vortex casing

B. Experimental Setup

The schematic of flexible test rig and measuring equipment's which are used in this study are shown in fig. 6.

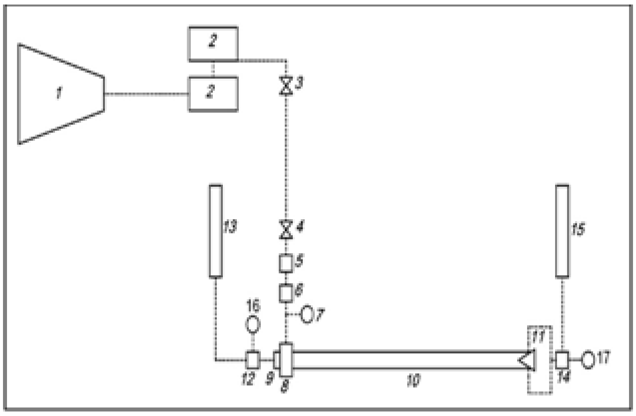


Figure 6: Schematic of the test rig and the arrangement of measuring equipment

1. Compressor, 2. Reservoir tank,
3. Inlet control valve, 4. Regulator,
5. Filter dryer, 6. Inlet thermometer,
7. Inlet pressure gauge, 8. Vortex generator,
9. Cold end orifice, 10. Main tube,
11. Hot end control valve 12. Cold end thermometer,
13. Cold outlet Rota met 14. Hot end collector and thermometer
15. Hot outlet Rota meter, 16. Cold outlet pressure gauge,
17. Hot outlet pressure gauge.

Air is considered as working fluid and a compressor which is connected to the reservoir tanks is used to provide the inlet high pressure stream. Volume flow rate and pressure of inlet stream are controlled by regulating valves 3 and 4. A dryer filter 5 is used to trap the moisture content of inlet flow. Thermometer 6 and pressure gauge 7 measure the temperature and pressure of inlet flow respectively. Pressure gauge 16 and thermometer 12 evaluate cold flow pressure and temperature respectively. Temperature and pressure of hot flow are measured by thermometer 14 and pressure gauge 17 respectively. Volume flow rate of cold and hot streams is determined by two rotameters 13 and 15 respectively.

High pressure inlet air first enter into casing having gradual decrease in cross section through inlet nozzle. This air flow is then directed to the main pipe by two tangential nozzles which make angle of 18^0 with the vertical axis and then this air flows through spiral grooves such that vortex flow is generated inside the vortex generator. The main pipe and cold flow orifice are fitted to the vortex generator. The main tube is made of cast iron. For each tube, Inner surface is perfectly smooth. The results are taken using different length of hot end pipe [10D (125mm), 20D (250mm), 30D (375mm), 40D (500mm), 50D (625mm)] , also by changing the orifice diameter.

4. Observations

Various observations have been obtained for different parameters of the vortex tube. Following table reveals hot end and cold end temperatures for different inlet pressure. Figure 4 and figure 5 shows the variation in ΔTc and ΔTh with the variation in inlet pressure. As the hot end side was kept 30D and better results were obtained. As we advance the cone inside the hot tube kept partially closed to certain level we get optimum temperature range.

Table 2: Observation table

Sr. no	*Inlet Pressure Pi (bar)*	*Cold Temperature Tc(°C)*	*Hot Temperature Th(°C)*
1.	4	9.1	43.1
2.	5	4.3	44
3.	6	2.6	43.5
4.	7	-5.4	46
5.	8	-9.8	49
6.	9	-11.5	50.5
7.	10	-18.4	53

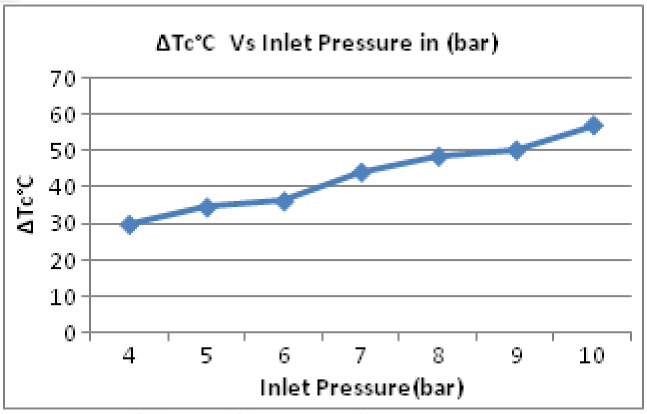


Figure 7: Increase in ΔTc with increase in inlet pressure

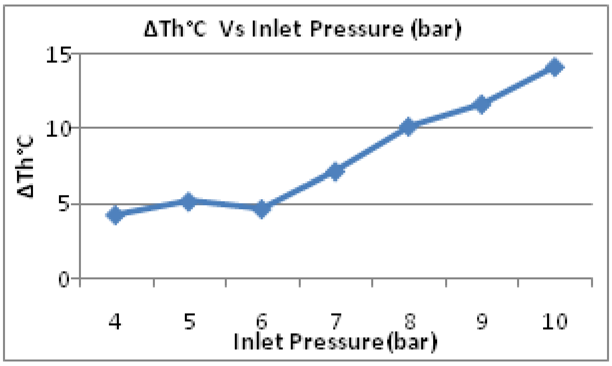


Figure 8 Increase in ΔTh with increase in inlet pressure

5. Results and Discussions

The effect of change in inlet pressure on ΔTc:
Figure 7 shows the effect of change in cold side temperature difference with the change in inlet pressure. It was observed that the temperature difference increased with the increase in the inlet pressure. For an inlet pressure of 10 bar, the cold end temperature (Tc) was obtained as -18.4°C and the cold side temperature difference (ΔTc) was 57.2°C. For an inlet pressure of 4 bar, the cold end temperature obtained was 9.1°C and the cold side temperature difference was 29.7°C

The effect of change in inlet pressure on ΔTh:

Figure 8 shows the effect of change in hot side temperature difference with the change in inlet pressure. It was observed that the temperature difference increased with the slight difference with the increase in inlet pressure. For an inlet pressure of 10 bar, the hot end temperature (Th) was obtained as 53°C and the hot side temperature difference (ΔTh) was 14.2°C. For an inlet pressure of 4 bar the hot end temperature was obtained as 43.1°C and the hot side temperature difference was 4.3°C.

6. Conclusion

The Vortex Tube may be used in a temperature control project & is very effective & economical where the compressed air is readily available. We can't take better advantage of this where the characteristics like weightlessness, cooler cum heater are desired & the compressed air which is the main cost is present with us. We get lowest temperature using 30D hot side length. Using 0.4D (5mm) diameter diaphragm we get lower temperature at cold end, whereas using 0.5D (6.25mm) we get higher temperatures at hot end. Due to the present running research it will certainly take good market & the wide field of applications in near future.

7. Suggestion for Future Work

1) Arrangement of intercooler:- One can provide a heat exchanger in between compressor outlet and vortex tube inlet and study the analysis with different inlet temperature.
2) Short vortex tube: - By fabricating 2-3 hot tubes different length one may study the effects of tube length on the temperature drop obtained.
3) Provision of moisture separator: - By providing the same dry input can be obtained and clogging the cold end due to ice particles can be avoided.
4) Temperature controller: - By inserting a temperature sensor and corresponding actuating circuit one may try for automatic valve opening by servo meter prepare a model providing a constant temperature air output within some range. This successful model may also achieve good market if provision for conditioning the air will be provided.
5) Make the part into single piece:- Due to manufacturing difficulties we made the vortex generator and vortex casing into two halves. If these parts are made into single piece, better results can be obtained.
6) Use of proper material:- To reduce project cost we used cast iron material for the manufacturing of vortex generator and vortex casing. Instead of C.I. Brass material gives better results.
7) Nozzle angle:- We used nozzle angle of 18^0 with vertical plane. If nozzle angle match perfectly with vortex spiral groove will give better results.
8) Spiral Groove:- We made spiral groove up to 180^0 only, if spiral groove extended from 180^0 to 360^0 , it may give better results

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