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Machining by Waterless Cooling using Vortex Gun

¹ Rupesh Deshbhratar, ² Pankaj Rawool, ³ Krishna Gaikwad ⁴ Vinay Bhatkar

¹ Assistant Professor, ² Assistant Professor, ³ Assistant Professor ⁴ Assistant Professor

¹Mechanical Engineering Department,

¹Thakur college of engineering & Tech, Mumbai, India

Abstract— In present, the first and foremost important quality of any research or development is its eco-friendly nature, by the virtue of which it fulfils our basic needs without any harm to the nature. Today, environment safety has become an important aspect of the industries and people in common. This paper aims at increase in efficiency of one such eco-friendly system named vortex tube used for industrial spot cooling and process cooling needs, such as Spot cooling, Weld cooling, Plastic slitting, Extrusion cooling, Foodstuffs cooling etc. The commonly used cooling systems use the gas and liquids which either deplete the ozone layer or contribute in the global warming in the same as CO₂ does. Efforts have been made to include various aspects to get the maximum output in terms of C.O.P. (COEFICIENT OF PERFORMANCE) and knowledge about the vortex tube. The report includes detailed explanation of working and construction of a vortex tube with experimental results for a series of different physical, thermal and mechanical conditions. This paper summarizes analysis of cooling and heating effect, temperature difference and C.O.P. with different working conditions and constructional features. This paper also has the tabulated data with experimental values.

IndexTerms - Vortex Tube Cooling , Eco-Friendly Refrigeration ,Coefficient of Performance (COP) ,Industrial Spot Cooling

1 INTRODUCTION

The Vortex Tube is an effective and low cost solution to a wide variety of industrial spot cooling and process cooling needs. We

can say Vortex tube is a device which produces cooling at one end and heating at the other end simultaneously. The general name of vortex tube is cooling tube also, which instantaneously create streams of high and low temperature with respect to the temperature of the air which is used as a feed. The highly compressed air is forcing through a generation chamber, and by the virtue of high pressure and limited volume the pressure head of feeding air is get converted into the kinetic head which generates the centrifugal spin of air along the inner walls of the tube. It is evident that the cooling unit part does not incorporate any moving part if high pressure air is available. It has no moving parts; pressurized gas is injected tangentially into a swirl chamber and accelerates to a high rate of rotations. The Compressed air which is supplied to the vortex tube and passes through nozzles that are tangent to an internal counter bore. These nozzles set the air in a vortex motion. This spinning stream of air turns 90° and passes down the hot tube in the form of a spinning shell, similar to a tornado. Due to the conical nozzle at the end of the tube, only the outer shell of the compressed gas is allowed to escape at that end. The remainder of the gas is forced to return in an inner vortex of reduced diameter within the outer vortex. A percentage of the hot, high-speed air is permitted to exit at the control valve. The remainder of the (now slower) air stream is forced to counter flow up through the center of the high-speed air stream, giving up heat, through the center of the generation chamber finally exiting through the opposite end as extremely cold air. For the performance analysis of this kind of vortex tube is being made on the basis of some series of different-different mechanical, physical and constructional features and the performance of tube depends upon:

(a) Air parameter

(b) Tube parameter

The controlling process of volume and temperature of cold air produced by a Vortex Tube was done by the valve in the hot air exhaust. This volume (Cold Fraction) is the percent of total input air released through the cold exhaust. For example, if the total volume of compressed air input is 15SCFM and the Cold Fraction is 70%, then

10.5 SCFM exits the cold end and 4.5 SCFM exits the hot end. A high Cold Fraction. (i.e., more than 50% of the input air exiting the cold air exhaust), produces the maximum efficiency -- the greatest BTUH out- put. The maximum efficiency condition occurs at Cold Fractions of 60% to 70%, where the amount of air released at the cold exhaust and the temperature drop are optimized. Some industrial operations like cooling machining operations, electronic controls, liquid baths, and workers will require high cold Fractions for maximum refrigeration.

The fluid which rotates in a vortex along the axis may touch the high speed up to **1,000,000 RPM**. And due to this Vortex tubes are able to generate temperatures down to 100°F below inlet air temperature.

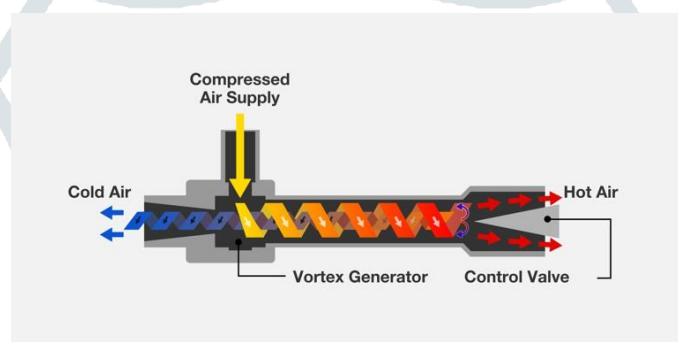


Figure 1: Schematic diagram of Vortex Tube

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 PROCEDURE OF ANALYSIS

The procedure for analysis which have adopted is as follows:

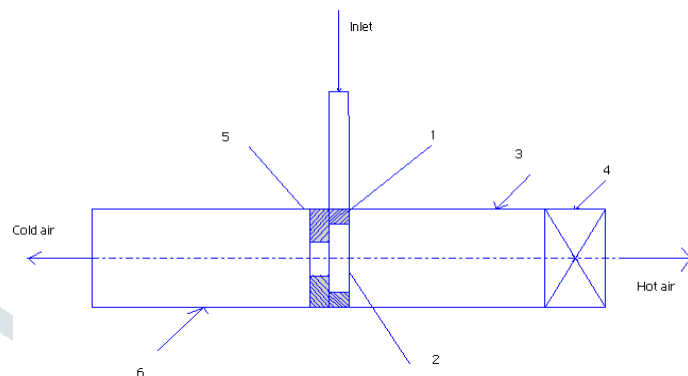


Figure 2: Line diagram

The layout of a vortex tube is given in fig. It consists of following parts:

1. Nozzle
2. Diaphragm
3. Valve
4. Hot air side
5. Cold air side
6. Chamber

Compressed air is admitted to the vortex tube through (1) in the nozzle the air acquires high velocity and enters the chamber. (2) Tangentially where it forms a vortex. (3) This vortex is formed because of the particular shape of the chamber. The vortex travels through the hot side

(4) of the tube through the diaphragm. (5) Part of this air flows back towards the diaphragm (2). It then leaves the tube through the diaphragm (2) and the cold end (3). The hot air passes through the valve. By adjusting the valve opening the quantity of cold air and the temperature drop can be varied. The maximum drop is obtained for a particular opening of the valve. A decrease in temperature drop will result by reducing the valve opening below this opening.

For the analysis of vortex tube following procedure has adopted. For the series of observation, we have to feed air at different-different pressure and temperature that is on different thermodynamic conditions, then apply the formula and find out the value of critical C.O.P. as our aim of analysis.

4 EXPLANATION OF WORKING CYCLE

This basic on which the temperature separation in a vortex tube can be explained is as follows: When compressed air is injected into the tube from the tangential inlet, it forms a highly vertical flow and moves to the end of the tube. The inner part of the flow moves towards the hot end and turns back in front part of the tube.

This part of the flow gets expanded due to the low pressure in the central part of the tube and escapes from the cold nozzle at a lower temperature than the injected air. Small amount of the inner flow mixes with the multi-circulation and forms small vorticities that separate the cold flow and multi-circulations. Due to the pressure gradient in a vortex tube, the lowest

temperature will be found in the central part of the flow near the injection port. After mixing with other cold flow, which has been inwardly turned back, the minimum temperature of the exhausted stream from the cold nozzle will be found to be higher than the lowest temperature inside the tube.

The peripheral part of the airflow escapes from the hot exit at a higher temperature than the inlet temperature and the inner part of the flow is forced back by the plug at the hot end. Due to the increase of the swirl velocity, the centrifugal force of the swirling flow increases and leads to the outwards flow of the central fluid.

On its way to the cold end, the central flow moves outwards, mixes with the peripheral flow, and turns back to the hot end again. In this way, the central flow performs multiple circulations before being exhausted from the hot exit. Because of the strong swirling flow in the hot region of the tube, sub-cycles of the multi-circulation might be found in the principal multi-circulation, which is represented by the dashed line in Figure 2.

The temperature of the peripheral flow arises due to the partial stagnation and mixture induced by the multi-circulation. The maximum temperature should be found at the outwards turn back to the hot end of the central flow. The maximum temperature along the wall was also reported to be some distance from the hot exit.

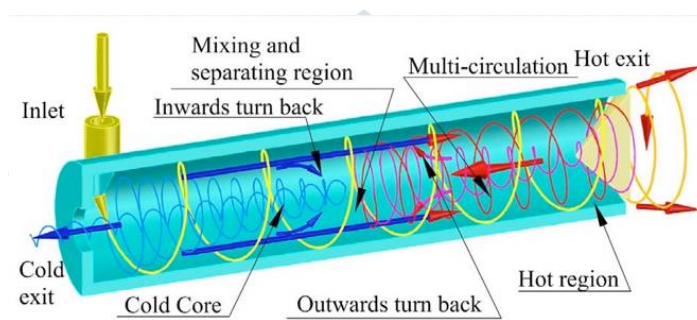


Figure 3: Flow pattern in Vortex Tube

5 SOLIDWORKS MODEL

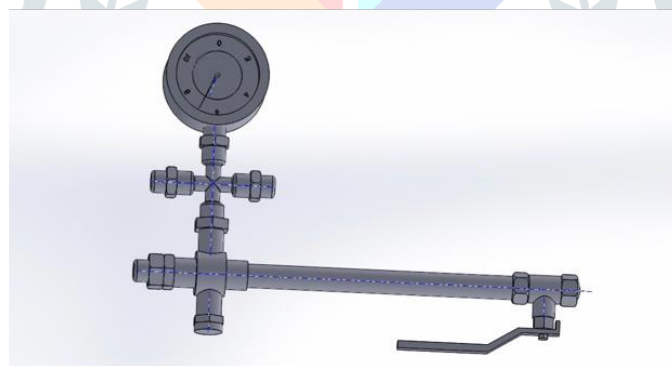


Figure 4: SolidWorks model of Vortex Tube

6 APPLICATIONS

Commercial vortex tubes are designed for industrial applications to produce a temperature drop of up to 71°C (127 °F). With no moving parts, no electricity, and no Freon, a vortex tube can produce refrigeration up to 6,000 BTU/h (1,800 W) using only filtered compressed air at 100 PSI (6.9 bar). A control valve in the hot air exhaust adjusts temperatures, flows and refrigeration over a wide range.

Vortex tubes are used for cooling of cutting tools (lathes and mills, both manually-operated and CNC machines) during machining. The vortex tube is well-matched to this application: machine shops generally already use compressed air and a fast jet of cold air provides both cooling and removal of the "chips" produced by the tool. This

completely eliminates or drastically reduces the need for liquid coolant, which is messy, expensive, and environmentally hazardous.

7 RESULTS

Pressure Temperature graph at optimum valve opening is shown in graph below:

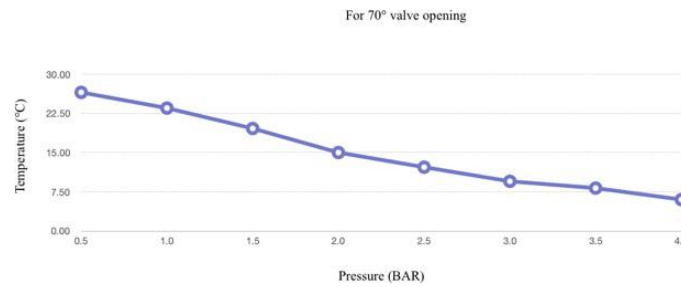


Figure 5: Temperature v/s Pressure diagram

After testing generator with different number of inlet ports including 2, 3, 4 & 6 ports, we achieved the best results with the generator having 3 ports. Figure of generator with 3 inlet ports is as shown.



Figure 6: Front view & Side view of Generator

8 CONCLUSION

Explanations from the literature, which relate to the effect of expansion within a vortex tube, appear relatively more consistent, and from these, it is reasonable to conclude that the expansion, i.e., pressure gradient near the injection point, is the predominant factor underlying the temperature drop. The observation that the maximum value within the temperature gradient of the peripheral flow along the tube, occurs some distance from the hot end, and leads to the novel notion that the flow structure within the rear part of the vortex tube may circulate repeatedly before escaping the tube.

Based on these notions, together with agreement between the computational and experimental investigations, a novel hypothesis for the thermal separation is now proposed. Accordingly, partial stagnation and mixture due to the structure of the multi-circulation in the rear part of the tube, along with the pressure gradient near the injection point, are proposed to be the dominant factors responsible for the phenomenon of thermal separation. The working principle of a vortex tube is described as following: When the compressed air is injected into a vortex tube tangentially, it starts rotating and moving to the other end of the tube. The inner part of the flow moves inwards and turns back in the front part of the tube.

The flow in this region expands due to the lower pressure in the central part of the tube and then escapes from the cold nozzle at a temperature lower than the supplied air. In the meantime, the peripheral flow keeps moving to the hot end. The outer layer of the peripheral flow escapes from the gap between the control plug and the inner wall of the tube at a temperature higher than the supplied air, and the inner part of the peripheral flow is then forced back to the cold end by the plug, through the central region of the tube. Hence, on its way moving to the cold end, the central flow spreads outwards, mixes with the peripheral flow and then turns back to the hot end again. Termed multi-circulation, this specific flow structure was first hypothesised in the present research. The temperature of the peripheral flow rises due to the partial stagnation and mixing induced by the flow structure of the multi-circulation.

In previous experimental investigations, the flow properties inside a vortex tube were measured by inserting a particular measuring device into the vortex tube. Hence, perturbation to the internal flow field would have been induced by the inserted measuring device, which led to unavoidable measurement errors of the actual internal flow.

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