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Design & Development of Vortex Cooling System

Aniket Bhukele[1], Shubhangi Chavan[2] Yuvraj More[3], Sanjivani Thorat[4]
[1, 2, 3, 4]Dept Of Mechanical Engineering, Savitribai Phule Pune University

***Abstract:** Possibilities for integration of vortex tube with automotive radiator for more effective cooling of automotive engine is the aim of the overview. An automotive radiator/heat exchanger is a device which helps maintain the working temperature of the engine. The vortex tube is a device which provides low temperature and high temperature output with pressure as an input. Because of its compact design and little maintenance requirements, it is very popular in heating and cooling processes. Despite its simple geometry, the mechanism that produces the temperature separation inside the tube is complicated. In addition, thermal and kinetic energy considerations have been used to explain temperature separation. There have also been plenty of numerical analyses that confirm earlier experiments. One fact remains, however. In this study, the past investigations of the design criteria of vortex tubes were overviewed and the detailed information was presented on the design of them. Vortex tubes were classified and the type of them was described. All criteria of vortex tubes were given in detail using experimental and theoretical results from the past until now. Finally, the criteria on the design of them are summarized.*
own text.
***Keywords:** Radiator, Heat exchanger, Vortex tube, Engine cooling, Overheating.*

I. INTRODUCTION

The vortex tube was invented in 1933 by French physicist Georges J. Ranque. German physicist Rudolf Hilsch improved the design and published a widely read paper in 1947 on the device, which he called a Wirbelrohr (literally, whirl pipe).[1] The vortex tube was used to separate gas mixtures, oxygen and nitrogen, carbon dioxide and helium, carbon dioxide and air in 1967 by Linderstrom-Lang. Experiment where free body rotation occurs from the core and a thick boundary layer at the wall.[2] Air is separated causing a cooler air stream coming out the exhaust hoping to chill as a refrigerator.

[3] In 1988 R.T. Balmer applied liquid water as the working medium. It was found that when the inlet pressure is high, for instance 20-50 bar, the heat energy separation process exists in incompressible (liquids) vortex flow as well.

Vortex tube is a simple energy separating device which is compact, simple to produce and to operate. Although intensive research has been carried out in many countries over the years, the mechanism producing the temperature separation phenomenon as a gas or vapor passes through a Ranque-Hilsch vortex tube is not yet fully understood.[4] Numerical simulation of 3D compressible turbulent flow was made using FLUENT software. [5] The temperature distribution in vortex chamber was obtained by numerical simulation and a new explanation of vortex tube energy separation mechanism was proposed. In summary, this approach is based on first-principles physics alone and is not limited to vortex tubes only but applies to moving gas in general.[6]

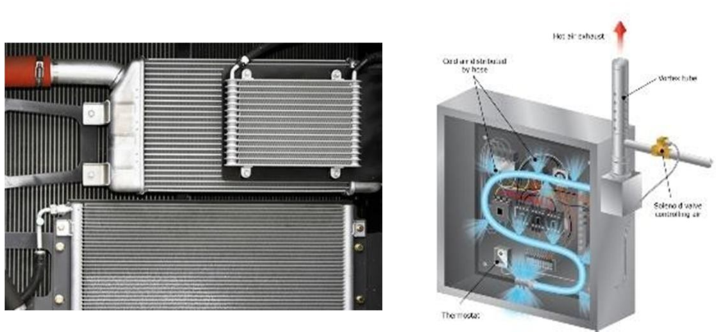

Figure 1. Current Methods using Air

A. Overview of the Project

The vortex tube is a mechanical device that separates single compressed air stream into cold and hot streams. It consists of a nozzle, vortex chamber, separating cold plate, hot valve, hot and cold end tube without any moving parts. In the vortex tube, when works, the compressed gaseous fluid expands in the nozzle, then enters vortex tube tangentially with high speed, by means of whirl, the inlet gas splits in low pressure hot and cold temperature streams, one of which, the peripheral gas, has a higher temperature the initial gas, while the other, the central flow, has a lower temperature.

Vortex tube has the following advantages compared to the other commercial refrigeration devices: simple, no moving parts, no electricity or chemicals, small and light weight, low cost, maintenance free, instant cold air, durable, temperature adjustable. Therefore, the vortex tube has application in heating gas, cooling gas, cleaning gas, drying gas, and separating gas mixtures, liquefying natural gas, when compactness, reliability and lower equipment cost are the main factors, and the operating efficiency becomes less important.

II. LITERATURE REVIEW

1) *Sankar Ram T. and Anish Raj K 'An Experimental Performance Study of Vortex Tube Refrigeration System.*

Investigates temperature distribution in confined rotating gas flows, using a counter-flow vortex tube with tangential nozzle injecting compressed air. Describes rotating air movement in vortex track, separating hot and cold ends.

2) *Mahyar Kargaran and Mahmood Farzaneh-Gord: 'Experimental Investigation the Effect of Orifice Diameter and Tube Length on A Vortex Tube'*

Title Explores vortex tube's ability to separate hot and cold gas streams from an inlet gas stream. Examines the impact of orifice diameter (d / D) and tube length (L/ D) on vortex tube performance. Focuses on industrial applications.

3) *Mahyar Praduman Kumar Yadav, Prof. Dr. Anil Kumar. Department of Mechanical Engineering, Rajshree Institute of Management and Technology Bareilly, UP, India. Abstract- As a working fluid, compressed air or gas could be used in the Ranque–Hilsch vortex tube to make cold.*

This project author had presented result that showed that increasing the nozzle diameter improved the cooling power and temperature separation, but also increased the pressure drop across the device 5 Ramli et al. Experimental investigation and optimization This study investigated the performance of a counter-flow VT for cooling applications. The authors optimized the design parameters, including the nozzle count and cold mass fraction, to achieve maximum cooling power and coefficient of performance 6 Ahyan et al. Machine learning techniques They employed three different machine learning algorithms, viz., support vector regression, artificial neural networks, and decision trees, to develop predictive models which can accurately estimate the VT performance with high R- squared values 7 Manimaran Review This review article discusses the history, working principles, and applications of vortex tubes in various industries, viz., food processing, aerospace, and medical fields. The review also covers the recent developments and future research directions of vortex tubes for sustainable and energy-efficient applications Figure 2a shows the effect of changing the length-to diameter (L/D) ratio of the vortex tube on the cold and hot exit temperatures.

III.PROBLEM STATEMENT & APPLICATION

A. Problem Statement

Engine overheating can lead to a cascade of damaging consequences. Firstly, it can cause detonation, resulting in engine rattling, loss of power, and potential damage to rings, pistons, and rod bearings. Overheating may also cause piston scuffing, where the pistons swell and scrape against cylinders, causing damage. Exhaust valves can stick or scuff, leading to valve, guide, and compression loss issues. Additionally, overheating may cause a blown head gasket due to thermal stress and swelling of aluminium components, leading to leaks and compression issues. Overheating can also cause an overhead cam to seize and break, and stress old radiator and heater hoses, causing bursts. The use of liquid coolant, while traditional, can wash away lubricating oil in machines, reducing their lifespan. Vortex tubes offer an efficient alternative for cooling in situations where liquid coolant is impractical or inefficient. Other cooling methods often require electricity, complex equipment, and time, making vortex tubes a viable option for various cooling needs.

B. Objective

The project aims to develop a highly efficient cooling system using a vortex tube. The key requirements include the absence of moving parts, ensuring low maintenance and high reliability. The system's output should be easily controllable, providing constant temperature without consuming electricity or causing RF interference.

It should be intrinsically safe, eliminating the need for refrigerants or chemicals. The system must be effective for spot cooling, cost-effective, compact, lightweight, and simple in design. It should not require complex control systems or moving parts within the vortex tube. The utilization of compressed air, readily available in factories, keeps initial costs low and working expenses minimal. Maintenance should be straightforward, requiring no specialized labour. The project focuses on developing a practical, economical, and user-friendly vortex tube cooling system that meets these essential criteria.

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IV. PROPOSED METHODOLOGY

A. Block Diagram

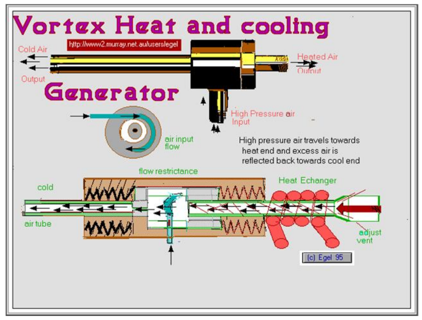

Figure 2. Schematic diagram

Theoretical explanation is given by various papers in different way. They have tried to explain as how the pumping of heat from compressed air temp takes place in absence of a mechanical device. When compressed air is passing through the nozzle in the vortex chamber inside the chamber high velocity swirl motion is created. The air moves as a free vortex from the nozzle plane towards the valve end. As it near the valve, the kinetic energy is converted into the pressure energy giving a point of stagnation. But the stagnation pressure is higher than the pressure in the nozzle plane; thereby the reversal in flow takes place. This reversed flow encounters forward moving free vortex, which causes the reversed vortex flow to rotate with it. Heat exchange takes place between these two flows.

1) *Construction Procedure:* The vortex tube is a remarkable mechanical device designed to separate a single compressed air stream into cold and hot streams without the need for any moving parts, electricity, or chemicals. It's simple and effective construction consists of several key components:
2) *Nozzle:* The compressed gaseous fluid enters the vortex tube through a nozzle, where increasing its velocity.
3) *Vortex Chamber:* The high-speed gas then enters the vortex chamber tangentially, creating a swirling motion inside the chamber.
4) *Separating Cold Plate:* Within the vortex chamber, the swirling gas separates into two distinct streams: the peripheral gas with a higher temperature and the central flow with a lower temperature.
5) *Hot Valve:* The hot air exits the vortex tube from the far side, and its temperature is controlled by a cone valve.
6) *Cold End Tube:* The cold air exits through an orifice next to the inlet, creating an instant cold air stream.

B. Design & Analysis

- Inner Diameter of the vessel (Di) = 500 mm
- Wall Thickness (t) = 20 mm
- Design Pressure (Pi) = 10 MPa

1) *Tangential or Circumferential Stress (σt)*

(σt) = Pi X Di 10Mpa X 500mm
2 X t =2 X 20 mm
= 125Mpa

2) *Analysis*

Tangential Stress (σt): 125 MPa (within permissible limits)
Longitudinal Stress (σ1): 62.5 MPa (within permissible limits)
Factor of Safety (Assuming Allowable Stress = 150 MPa): 1.2

3) *Selection Motor*

50N Total Load But Load Is Divided Into 4 Wheels = 50/4 = 12.5 N

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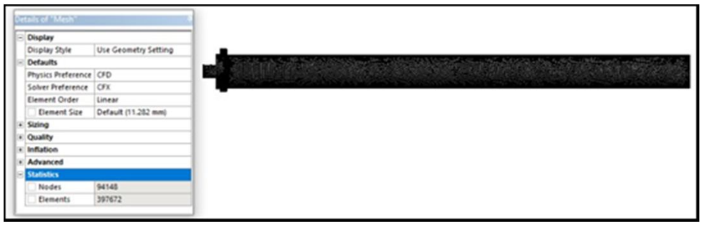

Figure 3. Material Properties of Aluminium

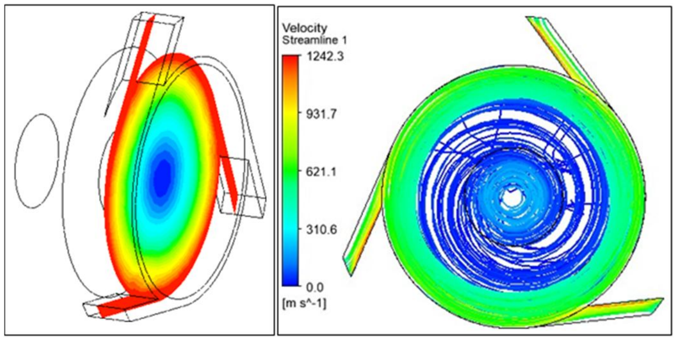

Figure 4. Boundary Conditions

Figure Stress analysis on frame Result.
Torque = ½ Force X Diameter
= ½ X12.5∗ 70 mm
= 437.5 Nmm
= 4.461 Kg/Cm
Diameter = diameter of a wheel (d
= 70 mm) standard available in market.
Force = total
Force including all components (50 N).

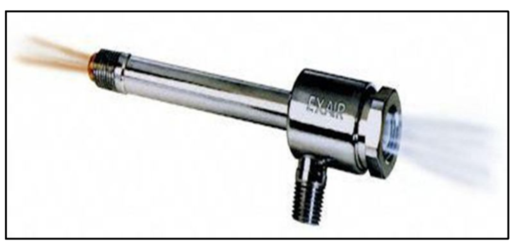

Figure 5. ISO View of Proposed System

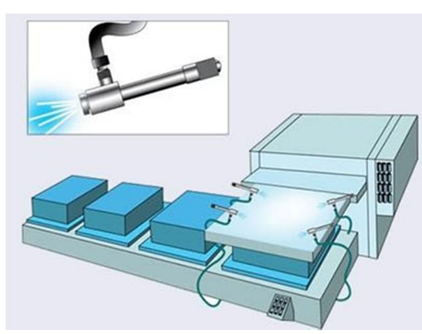
Figure 6. ISO View of 3D Drafting.

V. RESULT DISCUSSION AND CONCLUSION

1) Cold end temperature obtained by CFD = 278 ºK
2) Hot end temperature obtained by CFD = 335 ºK
3) With CFD results we observed the ambient air temperature reduced by 22Deg C whereas hot temperature obtained around 25Deg C.

This proposed CFD model of the vortex tube can be used to analyse the change of temperature and velocity within a vortex tube in a very effective way. The temperature separation within fluid is due to viscosity and turbulence between the peripheral and core vortex.

Temperature drop is mainly due to sudden expansion of air near the entrance. The temperature separation within fluid is due to viscosity and turbulence between the peripheral and core vortex. Secondary circulation close to the cold end is the reason for the heat transfer from core to periphery.

This proposed CFD model of the vortex tube can be used to analyse the change of temperature and velocity within a vortex tube in a very effective way.

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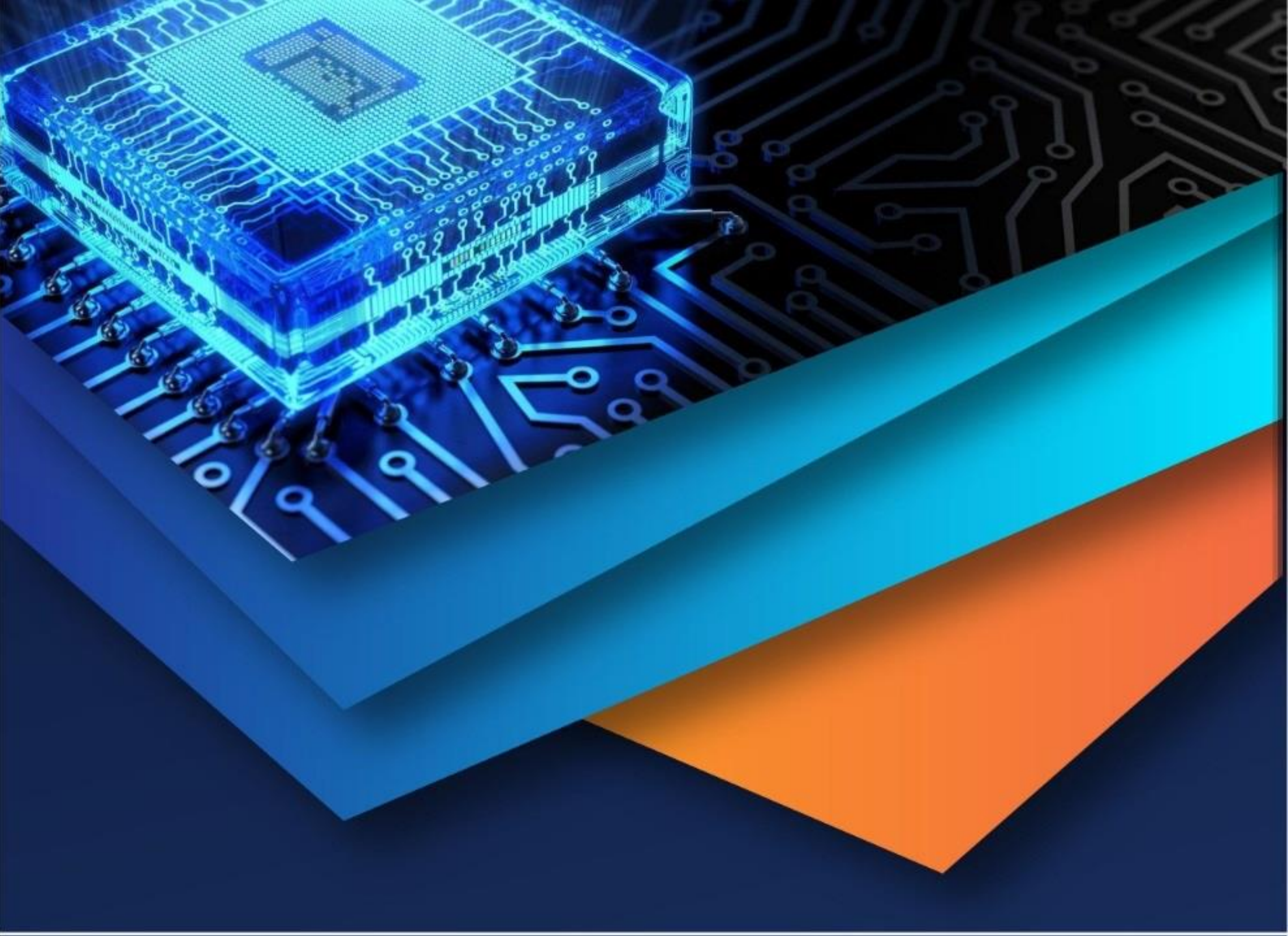

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