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"A review on vortex tube refrigeration and Applications"

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ABSTRACT

The vortex tube was discovered by Ranque [1] and first described in detail by Hilsch [2]. Vortex tubes are now commercially used [3] for low-temperature applications, e.g. to cool parts of machines, to set solders, to cool electronic control cabinets, to chill environmental chambers, to cool food, to test temperature sensors, and they are also applied to dehumidify gas samples [4]. Vortex tube is a simple device with no moving parts. It separates inlet high pressure stream of air into two lower pressure streams of cooler temperature at one end and hotter temperature at other end. It is basically of counter flow type and parallel flow type. It has many advantages and wide range of applications, mostly using counter flow owing to better performance than uni flow. Most of the applications reflect the benefits in terms of performance, energy, compactness or as an alternative to the conventional method. Vortex air coolers are preferred for different industrial applications. The personal air suit uses vortex tube to allow workers to work under adverse conditions for longer hours .Modern tool tips are already capable of maintaining their cutting edge at higher temperatures, but even with these improvements in tool materials, the cutting edge will eventually break down. Applying cold air to the tool interface of these modern tool tips will also extend their tool life reducing the cost of metal cutting.

Keywords:Vortex tube, refrigeration, Ranque-Hilschtube ,application , principle of work of vortex tube.

I. INTRODUCTION

The vortex tube was discovered in 1930 by French physicist Georges Ranque. Vortex was the first company to develop this phenomenon into practical, effective cooling solutions for industrial applications. Here's how it works.Fluid that rotates about an axis -- like a tornado -- is called a vortex. A vortex tube creates a vortex from compressed air and separates it into two air streams -- one hot and one cold. Compressed air enters a cylindrical generator which is proportionately larger than the hot (long) tube where it causes the air to rotate. Then, the rotating air is forced down the inner walls of the hot tube at speeds reaching 1,000,000 rpm. At the end of the hot tube, a small portion of this air exits through a needle valve as hot air exhaust. The remaining air is forced back through the center of the incoming air stream at a slower speed. The heat in the slower moving air is transferred to the faster moving incoming air. This super-cooled air flows through the center of the generator and exits through the cold air exhaust port.Vortec's vortex tube products have been solving industrial cooling problems for years. Using only filtered, factory compressed air as a power source, they convert ordinary compressed air into two air streams -- one hot and one cold. At 100 PSIG (6.9 Bar) and 70° F (21°C)inlettemperature, a vortex tube can produce refrigeration up to 6000 BTUH (1512 kcal/H) or

IJARSE
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temperatures to -40° F (-40° C). The circular motion depends on speed and inlet pressure of air. The gas expands through the nozzle and achieves a high angular velocity, causing a vortex-type flow in the tube. There are two exits to the tube: the hot exit is placed near the outer radius of the tube at the end away from the nozzle and the cold exit is placed at the center of the tube at the same end as the nozzle. By adjusting a throttle valve downstream of the hot exit it is possible to vary the fraction of the incoming flow that leaves through the cold exit, referred to as the cold fraction. There is pressure difference and hence speed difference between tube wall and center of tube due to high speed circular motion of air.

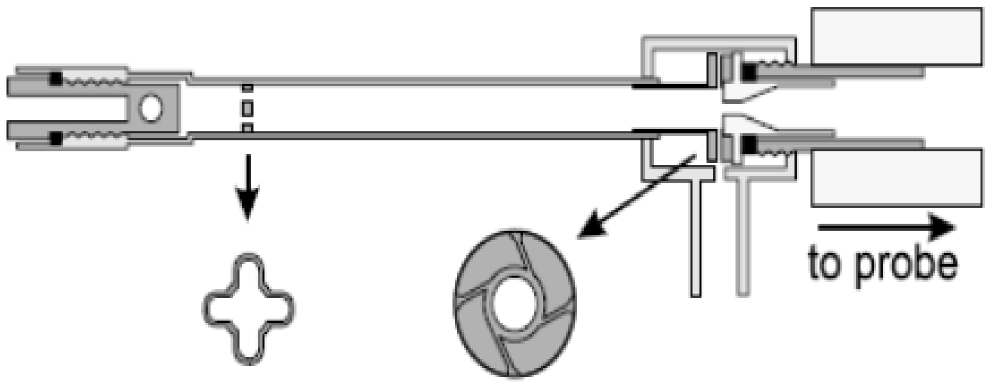

Fig. 1: Vortex Tube Schematic

II. TYPES OF VORTEX TUBES

There are two classifications of the vortex tube.Both of these are currently in use in the industry. The more popular is the counter-flow vortex tube (Figure a). The hot air that exits from the far side of the tube is controlled by the cone valve. The cold air exits through an orifice next to the inlet. On the other hand, the uni-flow vortex tube does not have its cold air orifice next to the inlet (Figure b). Instead, the cold air comes out through a concentrically located annular exit in the cold valve. This type of vortex tube is used in applications where space and equipment cost are of high importance. The mechanism for the uni-flow tube is similar to the counter-flow tube. A radial temperature separation is still induced inside, but the efficiency of the uni-flow tube is generally less than that of the counter-flow tube

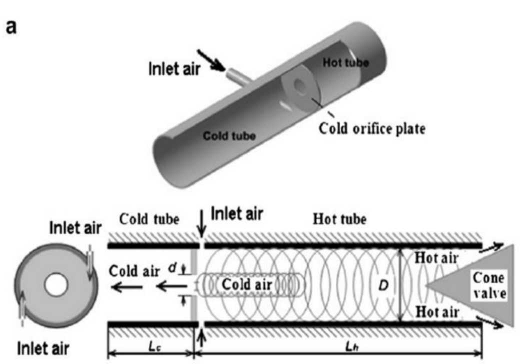

Fig. (a) COUNTER FLOW VORTEX TUBE

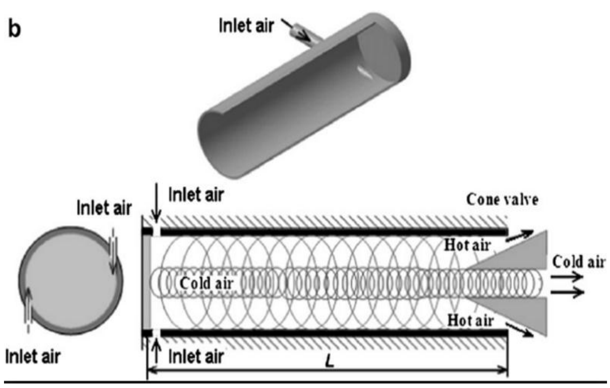

Fig. (b) UNIFLOW VORTEX TUBE

IJARSE
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III. ADVANTAGES OF VORTEX TUBE

There are several advantages of using vortex tube for different applications like there is no leakage problem as it uses only air as the refrigerant; no spark and explosion hazard; it is simple in design and needs only control of valves for appropriate functioning as it has no moving parts; light in weight and portable; requires less space; highly reliable; virtually maintenance free; initial cost is low and at places where compressed air is readily available working expenses are also low. It also does not require expertise attention and has wide variety of applications both for cooling as well as heating. But there are disadvantages also like low COP, limited capacity and not very efficient as cooling device.

IV. FEATURES

- Cool without refrigerants (CFCs/HCFCs) or moving parts for reliable, trouble- free operation.
- Use no electricity -- intrinsically safe, no RF interference.
- Compact and lightweight for easy installation -- even in tight areas.

V. PRINCIPLE OF WORK OF VORTEX TUBE

The flow rate and temperature in a Vortex Tube are interdependent. When you open the adjusting valve at the hot end, the cold air flow decreases and the temperature drops. As you close the valve the cold air end flow increases and temperature rises. The percentage of the total input air that exits the cold end is termed the "cold fraction". Depending on inlet air temperature a cold fraction of between 60% and 80% produces the optimum combination of flow and temperature drop for maximum cooling effect, when using an H generator. Lower cold fractions produce colder air but do not cool as well because of reduced flow. Most industrial applications require the 60% to 80% setting and the H generator for optimal cooling. In some instances such as cooling laboratory samples, testing circuit boards and other "cryogenic" applications, a 'C generator is used which limits the cold end flow rate to lower levels and produces very cold temperatures. To set the Vortex Tube to the desired temperature simply insert a thermometer at the cold end and adjust the hot end valve.The inlet nozzle is tangential to the vortex generator and therefore can provide a high speed rotating airflow inside the vortex generator. Subsequently, there is a radial temperature gradient increasing from the inner core of the tube to the outside wall of the tube. This is primarily because of the potential energy of compressed air converting to kinetic energy due to the forced vortex caused by the external torque near the tangential air inlet. Therefore the high-speed swirling flow inside the tube and away from the walls is created. The existing air inside the vortex hot tube is normally at the atmospheric temperature and so, when the rotating flow enters the vortex tube it expands and its temperature drops to a temperature lower than the ambient temperature. The difference between these two temperatures will lead to a temperature gradient along the tube producing colder peripheral air than the core air. As a result, the central air molecules will lose heat to those in the outer region .It is notable that this system is a dynamic system due to the nature of the airflow in the tube and so will not reach equilibrium. Hence the peripheral air has a higher kinetic energy (hotter) than the inner air (colder). The existence of a major pressure gradient due to the forced vortex in the radial direction will provide a centripetal force for circular swirling and therefore it will lead to a high pressure at the tube wall and low pressure at the centre. When the air enters to peripheral region , as it expands, the outer air will be cooled due to its expansion. Consequently, the inner core

IJARSE
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ISSN (P) 2319 - 8346

air will get warm because it is compressed by the expansion of the peripheral air. Heat is then transferred from the inner core to the outer core . As the inner air is being compressed, it naturally tries to push against the periphery by expanding. Work is therefore done on the outer core air, which then gets heated and the difference in pressures results in the expansion and contraction of the air, which causes work to be done on the peripheral air. Work is therefore done on the outer core air, which then gets heated and the difference in pressures results in the expansion and contraction of the air, which causes work to be done on the peripheral air. Therefore, heat is transferred radially outward as shown in Fig. (2)

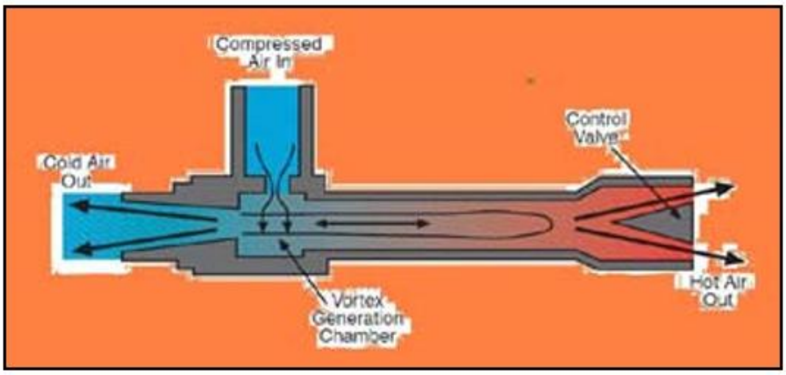

Fig. (2) vortex tube

Applications

(1) Waste Energy Recovery

First step to be taken is to reduce the waste energy production to minimum. This can be done by increasing process efficiency and reducing losses but waste energy below a certain level is unavoidable and thus various techniques are employed for recovery of this waste energy. The technique that should be applied to recover waste heat and pressure energy depends upon the pressure, temperature and quantity of the source and the type of fluid exhausted. The conventional objective of waste energy recovery is electricity generation from high pressure exhaust gases from furnaces and engines. Methods for waste heat and pressure recovery include transferring heat between gases and liquids, transferring heat to the load entering furnaces, generating mechanical and/or electrical power, or using waste heat with a heat pump for heating or cooling facilities and piezoelectric generation. Some common applications of waste heat and pressure energy are listed below:

1. Boiler feed-water preheating
2. Load preheating
3. Power generation
4. Steam generation for mechanical work
5. Space heating
6. Transfer to liquid or gaseous process streams
7. Combustion air preheating

- **Waste Energy Sources**

A large number of industrial processes produce waste heat energy.Some of these which can act as major waste heat and pressure energy sources are tabulated below:

 IJARSE
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ISSN (P) 2319 - 8346

SOURCE	TEMPRATURE (°F)	PRESSURE (bar)	APPLICATION OF WASTE ENERGY
Gas turbine exhaust	700-1000	6-100	Electricity production,
Blast furnace exhaust	1650-3000	6-10	Steam generation for mechanical process
Envelope furnace exhaust	1400-1800	6.5-10	Combustion air pre-heat
Air furnaces, sintering furnaces exhaust	1200	2-5	Furnace load preheating
Geothermal steam	212	6-8	Feed water heating
Thermal power plant gas exhaust	550-900	5-30	Furnace load preheating, Feed-water preheating
Steam boiler exhaust	450-900	3-5	Combustion air preheat
Reciprocating engine exhaust	600-1100	2-5	Transfer to low temperature processes
Cooling water from engines, compressors, furnace doors	80-450	-	Space heating, Domestic water heating

Table 1: Waste Heat and Pressure Sources

(2) AIR SUITS AND MASKS [5]

There are some areas in fields where space conditioning as well as full automation is not possible. In such places, a one piece air-cooled suits for operators is very much helpful. Few places include entering the vessels, the tanks, etc. where there are chances of dust, fumes and toxic environment, or locations like coal mines, foundries, sand blasting, welding, furnaces, etc. This suit protects the workers as well as increases working hours due to conditioned environment given to the body of the worker in the unpleasant or unhealthy working conditions.

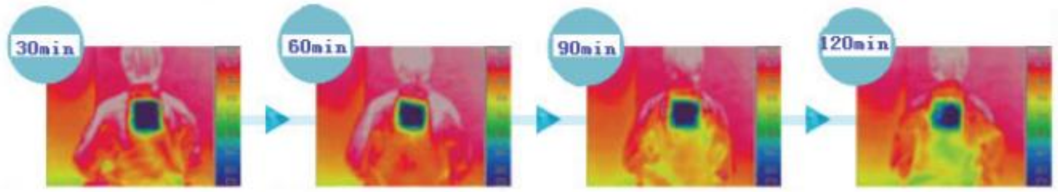

FIGURE 3. The ideal diagram of vortex tubes type of mine cooling jacket

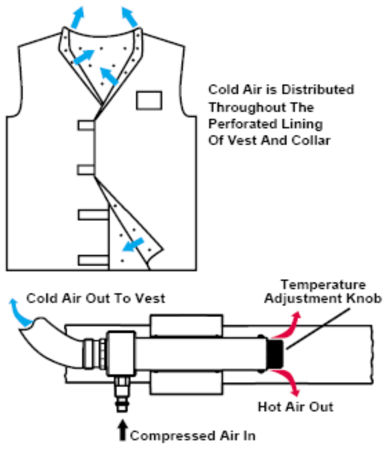

Fig. 4. Air-suit [5]

IJARSE
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ISSN (P) 2319 - 8346

(3) VORTEX TUBE BASED REFRIGERATION

Refrigeration is widely used in different sectors like, agriculture, transportation, domestic, industrial, food, medicine, commercial, etc. Storage of fishes by an average fishermen, medicines and vaccines transportation to villages and remote places, etc can be tried using vortex tube refrigeration system. Industries having facility of compressed air or waste gases at low pressure, etc utilise vortex tube concept to minimise the wastage of their air or gases and get benefited by use of vortex tube for cooling or heating applications. Vortex tube thus find varieties of applications as it is very compact and fail-safe device.

(4) CRYOGENIC COOLING IN HIGH SPEED MACHINING (HSM) [6]

Heat generated during metal cutting affects the quality of a workpiece and limits the life of the cutting tool. Heat is dissipated through the cutting tool, the workpiece, the chip and the cooling fluid. The cooling mechanism is used for circulation of the cooling fluid.Better machining performance can be achieved by using proper workpiece material, cutting tool material, cutting conditions and parameters, also by cooling the cutting tool, freezing the workpiece, cooling the tool-chip and tool-workpiece interface, or with the chip draining the heat away, unwanted heat can be eliminated.Heat dissipations studies through various theories, models and simulations as well as experiments have been attempted by researchers to understand the mechanism and theory behind the temperature built-up during machining for optimising machining procedure, workpiece results and cost effective output. One such attempt is using chilled air or cryogenic cooling. Few researchers have used Ranque-Hilsch vortex tube (RHVT for the cooling purpose for experiments related to metal cutting. Four cooling approaches are found.

a) pre-cooling the workpiece by refrigerated gas and metals which are difficult to machine to be first frozen and cut to shape while in the frozen condition. E.g. chilling aluminium castings prior to machining, can prevent the castings from moving during and after machining.

b) Indirect cryogenic cooling of cutting tool. Cooling isonly attempted at cutters or inserts and no attempt were made on the workpieces.

c) Cryogenic spraying withjet for grinding of cutting tool using cooled air to ensure longer tool life and the lower surfaceroughness compared to that with oil-basedgrinding.Alsousing vortex tube cooling ejectedair and liquid coolant misted by the air while machining could ensure machining hard materials at low cost using TiN coated tools compared to high cost CBN material. Another advantage was achieving dry machining using cold air on interface than wet machining.

d) Direct cryogenic treatment (of cutting tools) reduced cost to about half due to increase of hardness of tool.

Common advantages of machining incorporating cryogenic cooling are retaining of workpiece material properties, cutting temperature according to cooling approach, tool wear reduction and increase in tool life, workpiece surface roughness improved, lower tool/ workpiece friction ratio and cutting forces were affected.

IJARSE
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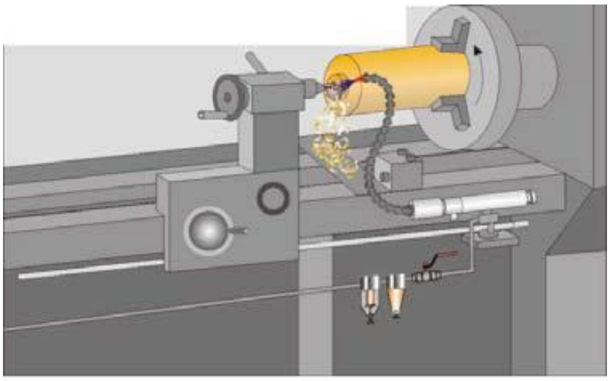

Fig.(5) **Using vortex tube for cooling turning process**

(5) In Micro-Power Generation

vortex tube performance characteristics and the use of vortex tubes to increase the total efficiency of power systems, especially micropower systems. A vortex tube is a device in which compressed air is made to swirl and separate into two low-pressure streams, one with higher temperature than the entry and the other lower.. Vortex tubes are currently used for industrial cooling applications, separation technologies, and chemical analysis It is well known that the temperature difference between the hot and cold sides of the vortex tube scales with the pressure drop. Also, at any pressure drop, the temperatures and flow rates are dependent on the flow fractions between the hot and cold sides. The micro-power systems under consideration include micro-turbines, which evolved out of automotive turbocharger technology. The use of vortex tubes in power systems has received some attention but the use of both the hot and cold streams has never been considered .As an example of an application, the vortex tube is considered in conjunction with a heat recovery steam generator (HRSG). The vortex tube splits the turbine exhaust flow into hotter and cooler streams. The cooler stream is still hot enough to supply all needed heat in the economizer section, leaving the hotter stream to increase the exit temperature from the superheater. In this way both the air leaving the HRSG and going to the steam turbine will have an increased enthalpy and cycle efficiencies are improved. In addition, steam turbine exit quality is increased.

(6) LASER CUTTING OF GFRM USING ASSISTED COOLING-AIR GENERATED BY VORTEX TUBE [7]:

The specimen is fixed on the moving tables by using vacuum adsorptive.For the laser processing of materials, the heat affected zone (HAZ) is an important indicator for themicroelectronics manufacturing.

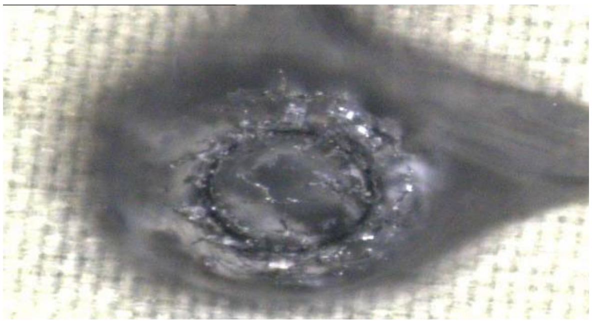

Fig. (6) Laser cutting without any assisted gas [7]

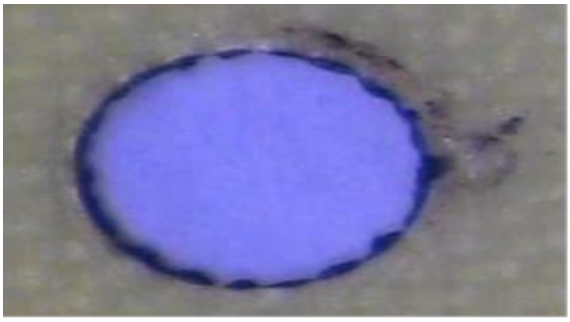

Fig.(7) Laser cutting with the cooling-air [7]

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ISSN (P) 2319 - 8346

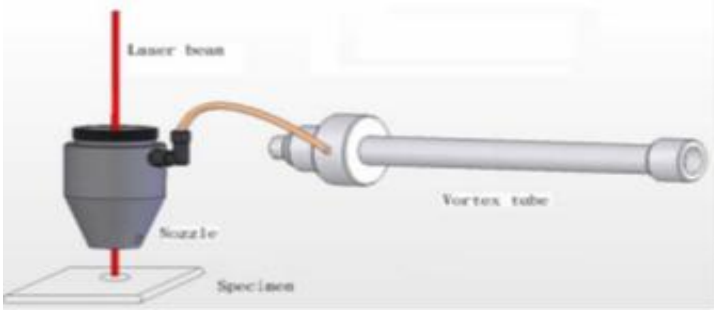

Fig. (8). Low temperature air materialsprocessing used by a vortex tube in the machine tool [7]

The way of laser cutting is using focused beams to heat the surface of the material upto high temperature and melt situation for removal materials. Because melt condition and high temperature generate theburned black droplets and HAZ, the properties of the processing medium are easily influenced. Therefore, decreasingheat affected zone area is a key point of the manufacturing technology. Vortex tube is used as there is no refrigerant requirement, no effect on environment, can generate low temperature cooling-air and can diminish HAZ with the laser cutting for glass fibre reinforced composite materials (GFRM).

VI. CONCLUSION

Using compressed air combined with the vortex tube have shown that using this method of cooling the tool interface is effective and compares exceedingly well with traditional cooling methods. The temperature recoded during air-cooling was found to be 60°C which is 40 °C cooler than that obtained during traditional wet machining and 210 °C cooler than dry machining.vortex refrigeration method is more effective and efficient as large scale temperature drop has been seen as compared to conventional cooling method, hence better cooling rate is observed .In addition to that it also provides large tool life, reduces abrasion and deterioration of cutting tool surface. It also decreases the negative effect of coolant and lubrication which were used in past .This method is also economically feasible and eco-friendly.The introduction of dry machining is one of sollution of today's metal cutting industry that tirelesslyendeavours to reduce machining costs and impact from chemicals in the environment.vortex tube performance characteristics and the use of vortex tubes to increase the total efficiency of power systems, especially micropowersystems.vortex tube can be use for various applictions[8] as cooling solder,cooling machine plastic,setting hot melts, cooling molded plastic ,cooling of gas samples and it also can be use in ultrasonic weld machine .

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