International Journal of Advance Research in Science and Engineering
Volume No.07, Issue No.04, April 2018
www.ijarse.com
IJARSE
ISSN: 2319-8354

"A Proposed Method of Cooling of Milling Operations by Vortex Tube Refrigeration"

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ABSTRACT

The purpose of this paper is to present the application of a vortex tube in cooling milling operations. This paper emphasis on the comparison of conventional cooling methods and vortex tube cooling application in milling operations. The centre of attention will be regarding temperature of the tool during the cutting operation. The comparison will be done regarding three cooling setups, cutting without coolant, cooling with a water base traditional coolant, and cooling with vortex tube. An Infrared Temperature gun has been used to detect the temperature around the tool during the cutting process. An experiment has been conducted to evaluate the thermodynamic analysis of the vortex tube. During the study the cold mass fraction was varied from 0.2-0.8 for a fix inlet pressure of 4 bar and the inlet pressure was varied between 2 -7 bar for a fix opening of the cone valve. The maximum temperature drop was observed for cold mass fraction of 0.4 and the effective refrigerating effect was observed between the 0.37-0.67 of the cold mass fraction, as the refrigerating effect and heating effect is a function of mass of the cold air and the temperature drop. The results of this study have shown comparative efficient cooling using the vortex tubes than conventional cooling.

Keywords: *Cold fraction, Milling, Temperature gun, Vortex tubes.*

I.INTRODUCTION

Vortex tube is a simple & eco-friendly device, which splits a compressed air into two streams having different temperatures at higher and lower temperatures than the inlet gas temperature without affecting the environment Generally , a supply of compressed air is injected tangentially through the air inlet. The air travels into the vortex spin chamber where it is changed into a turbulence flow and then travels into the hollow cylinder and goes out at the hot air exit located at the periphery as hot dry air. Some of the air is forced back into the hollow cylinder and a second turbulence flow occurs inside the first turbulence flow and goes out at the cold air exit as a cold air. The control valve at the hot air exit controls the amount of air out at both ends. Vortex tube have ability to provide spot cooling at a nominal price and is unique even though their efficiency is low compared to traditional air conditioning. It does not have any moving parts, only it requires is the compressed air, which is available in any workshop, and it delivers a controllable cooling to the tool and work piece . The benefit of using vortex tube is that it helps extend the tool life and thus reduce the setup times, downtime, and lost productivity**.** Traditional coolants present an environment concern, chemical constituents of coolants present several adverse impacts which recently have raised critical concerns about the costs of waste disposal and environmental pollution. Vortex tube, however, cools with no environmental problems and protects the surface layer from thermal defects. Temperatures range from ambient to -40°C for cooling, and from ambient to approximately 110 °C for heating. There are many applications of vortex tube, such as: cooling electronic controls, cooling machining operations, setting hot melts, cooling soldered parts, cooling gas samples, electronic component cooling, cooling heat seals and cooling environmental chamber. In this study, we directed to replace conventional machining coolants by Vortex Tube Refrigeration.This study investigate the temperature of the cutting tool under three different cooling setups including (1) no coolant , (2) cool air introduced using vortex tube, and (3) traditional water base coolant.

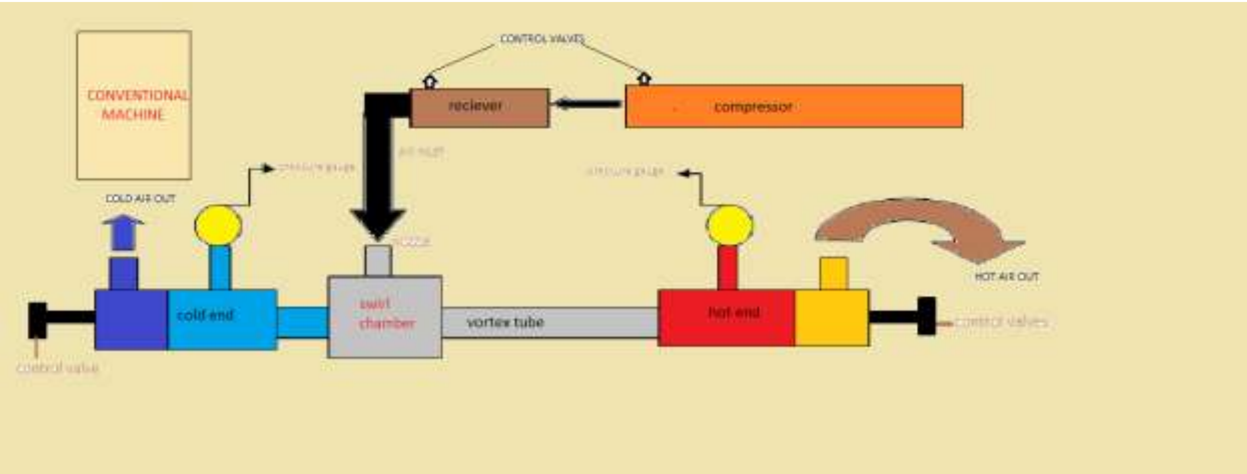

Fig 1:Block diagram of vortex tube Refrigeration

EXPERIMENT SETUP

The experimental setup consists of

- Vortex tube
- Compressor
- IR Temperature Gun
- Inlet Air Regulating Valve
- Conventional Machines

The experiment setup is based on three cooling setups:

1) Cutting without coolant

2) Cutting using a water base coolant

3) Cutting using the vortex tube to cool

Three Gunmetal work pieces were prepared with a diameter of 160 mm each and stainless steel work piece were prepared with 500x340x140mm block size. All work pieces are similar in dimension and experimental setup are produced in the same way to make sure there is no variation among them. This is vital for the conclusion of the experiment.

Milling operation is selected for the experiment. The milling operations were selected as dry milling, cool air cooling milling which produced by a vortex tube and, the fluid cooling milling. Slow speed, feed and small depth of cut are selected to show the extreme scenario. Figure 1 below shows the first cooling setup work piece setup on the milling machine. Figure 1 also shows the Infrared thermometer temperature gun used to note the temperature around the tool.

Fig 2: setup of Cutting without coolant

The three cooling setups are done under the same circumstances to minimize the noise in the results. For the three experiments, the depth of cut is set to 0.4 mm with rotational speed of 450 rpm. The intention is not to deal with higher temperatures, but rather observe the behaviour at the extreme low impact scenario.

The second setup uses a water base coolant as a pool over the work piece surface to ensure the cooling consistency of the tool as well work piece. Figure 2 shows the second cooling setup.

Figure 3: Setup Of Cutting using a water base coolant

In the third setup shown in figure 3, the vortex tube is pointed towards the tool to cool the tool and the workpiece specifically at the cutting area.

Figure 4: Setup of cutting using the vortex tube to cool

In all three setups, an Infrared thermometer temperature gun was directed at the tool and workpiece to get the temperature of the cutting process. Many IR Temperature Gun readings were taken manually and one of each set will be included under the results section to compare the three cooling setups based on the temperature. Five different tests are run for each sample. The values for each sample are averaged to compare the different samples. Results and its analysis are included in the results section. The same setup has been maintained for all three samples to get more accurate and comparable results.

Working of Experimental Set Up

- It consists of a two stage compressor and a receiver as a source of compressed air, auto pressure cut-off switch, an air filter and a counter-flow vortex tube. Compressed air from the receiver of compressor is supplied through a hand operated control valve to control the pressure at the inlet to the vortex tube as shown in figure. The pressure at the inlet to the vortex tube is measured with the help of a calibrated pressure gauge indicator. The temperature of the hot air and temperature of the cold air coming out of the vortex tube is measured with the IR Temperature gun. The temperature of the air is also measured at the inlet to the vortex tube to calculate the temperature drop of the cold. The Infrared thermometer temperature gun along with the digital indicator used in this experiment are calibrated to an accuracy of ±0.1°C.The mass flow rates of the cold air and hot air discharges are measured by calibrated orifice flow meters. The pressure difference across the orifice is measured by a pressure gauge connected to the pressure tapping. A cold mass fraction is changed by regulating the cone-shaped valve opening.
- Now the cooled end of vortex is used for cooling purpose through the channels. And after that we compare this new approach of cooling with other coolant in term of their effectiveness, chemical properties, effect on material tool properties etc. to decide whether our method is feasible to overcome the limitations of traditional methods or not.

II.RESULTS AND ANALYSIS

Thermodynamic analysis:

The cold flow mass ratio (cold mass fraction) is the most important parameter used for indicating the vortex tube performance of RHVT. The cold mass fraction is the ratio of mass of cold air that is released through the cold end of the tube to the total mass of the input compressed air. It is represented as follows

$$\varepsilon = \frac{m_c}{m_i} = \frac{T_i - T_h}{T_c - T_h}$$

Where, *mc* represents the mass flow rate of the cold stream released, *mi* represents the inlet or total mass flow rate of the pressurized air at the inlet. Therefore, ε varies in the range of 0-1. Cold air temperature difference or temperature reduction is defined as the difference between inlet flow temperature and cold air temperature:

$$\Delta T_c = T_i - T_c$$

where *Ti* is the inlet flow temperature and *Tc* is the cold air temperature. Similarly, hot air temperature difference is defined as

$$\Delta T_h = T_h - T_i$$

Had the expansion been isentropic from inlet of the nozzle to the exit pressure and the air to behave like an ideal gas, isentropic efficiency is given by

$$\eta_{is} = \frac{T_i - T_c}{T_i - T_{is}}$$

For isentropic expansion the exit temperature Tis

$$T_{is} = T_i \left(\frac{p_e}{p_i}\right)^{\frac{\gamma-1}{\gamma}}$$

Where, *pe* is the exit pressure of the cold air i.e. atmospheric pressure (*pa*) at outlet. The refrigerating /cooling effect produced by the cold air of vortex tube is give as

$$Q_c = m_c C_p (T_c - T_i)$$

Since cooling and heating streams are obtained simultaneously the heating effect produced by the vortex tube is give as

$$Q_h = m_h C_p (T_h - T_i)$$

Since RHVT can be used as a cooler and heater simultaneously hence both the effect that i.e. cooling effect and heating effects are considered. The COP of the system is calculated accordingly. The coefficient of performance of refrigerator is defined as the ratio of refrigerating effect produced by the system to the work done on the system. In the conventional vapor compression refrigeration (VCR) system work input or power is the work of compression or the compressor work. But, the vortex refrigeration systems are used where compressed air or gas is available.

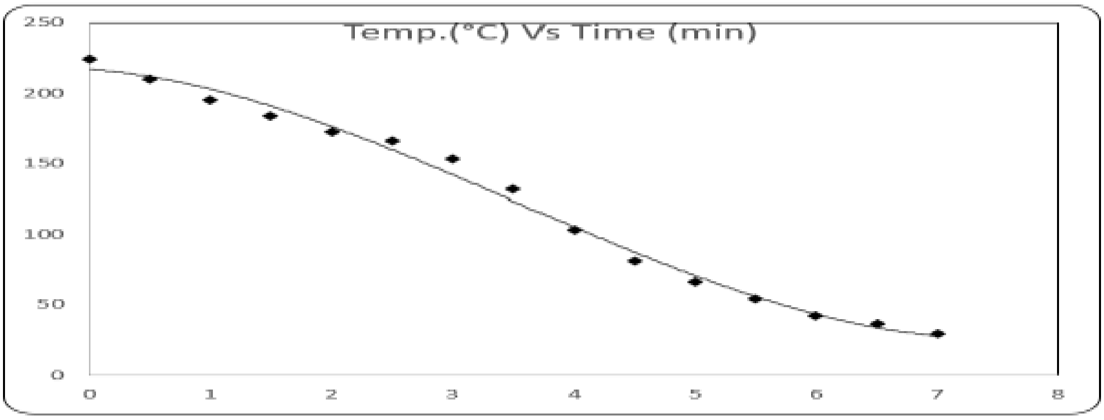

Fig 5: Carbide tool cooling through vortex tube

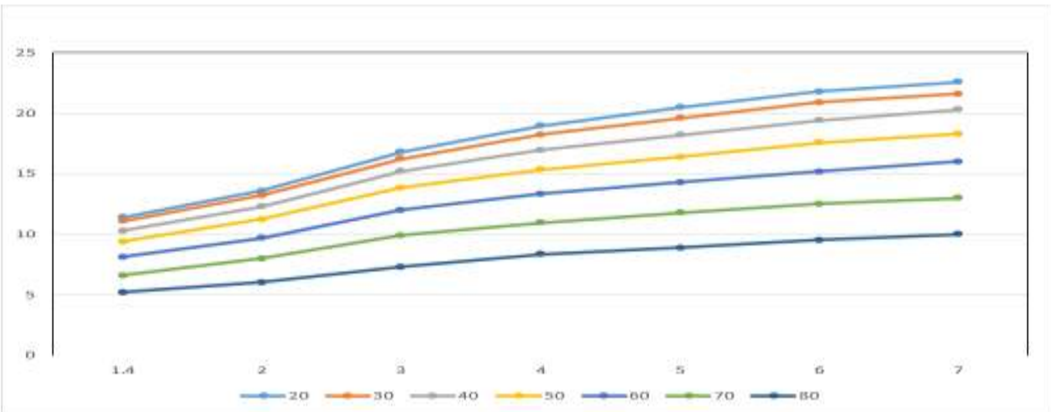

Fig6: ΔT_c vs Pressure

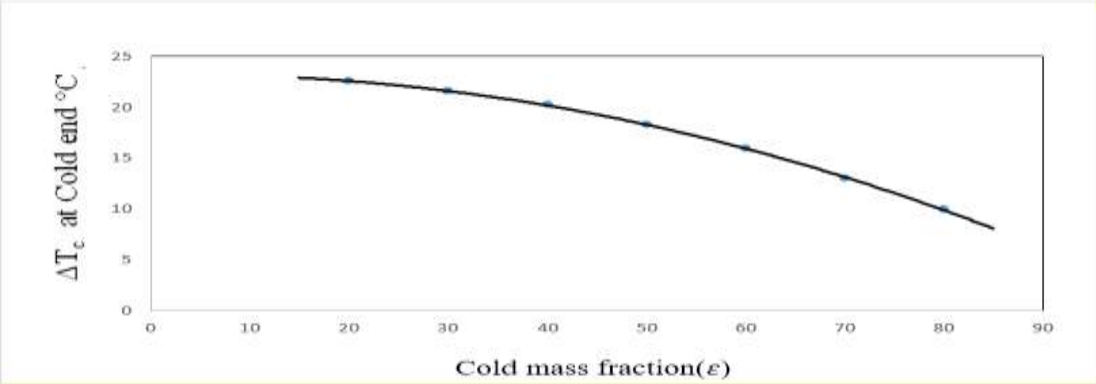

Fig7: Temp. drop at cold end as a function of cold air mass fraction at 7 bar

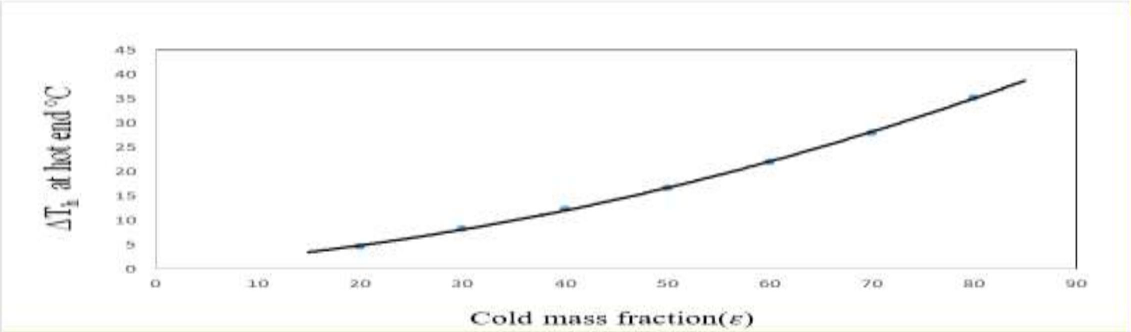

Fig8:Temp. rise at hot end as a function of cold air mass fraction at inlet pressure 7 bar

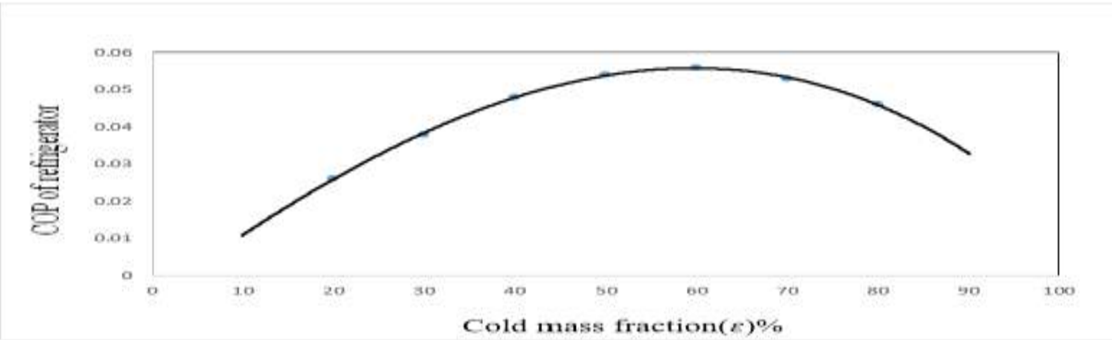

Fig9: COP as a function of cold air mass fraction at inlet pressure 7 bar

After experiments it can be said that vortex tube is a viable means of refrigeration. After analysis of thermodynamic properties the following results were obtained:

- The effect of inlet pressure is more important in getting higher temperature drops, as from graphs it is clear that more the inlet pressure more will be the temperature drop.

- Variation of Temp. drop at cold end T_c v/s cold Mass Fraction µ the experimental results indicate that the value of µ increases T_c starts rising until it attain a certain maximum therefore it starts decreasing until the valve is fully open. It means the results shows where using heating purposes of vortex tube so value of cold Mass Fraction is higher than 0.5 & where using cooling purposes of vortex tube so value of cold Mass Fraction is lower 0.5 .
- The isentropic Efficiency of vortex tube would be maximum when (Cold mass fraction, Temperature drop at cold end) is maximum at a given pressure.
- It has been observed that the constructed vortex tube has been performing best results at inlet air pressure 4.0 bar.
- When vortex cooled air is used as coolant, the temperature of the tip of the cutting tool of lathe machine was found to be 29°C and 31°C for carbide and HSS material tool respectively, which is much lower than the conventional coolants such as Palm kernel oil, etc,.
- We also observe 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.

Future Aspects of Vortex Tube Refrigeration

- Cryogenic cooling in high speed machining (HSM)
- Industrial Application of Multi-purpose Vortex Air Coolers
- Air suits and mask

CONCLUSION

Using compressed air combined with the vortex tube, cooling of tool interface become effective and compares exceedingly well over traditional cooling methods. Using compressed air combined with the vortex tube have shown that 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 solution of today’s metal cutting industry that tirelessly endeavour to reduce machining costs and impact from chemicals in the environment.

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