APPLICATION OF VORTEX TUBE FOR TOOL COOLING

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Abstract: The environmental pollution and health hazards of traditional tool cooling technique applied for machining processes will be evaluated and compared with new acceptable alternatives, based on six main sustainability aspects: cost, environment impact, energy consumption, waste management, safety and personal health. The innovative technique with the analytical predictive models has to be developed for industrial applications. This technologies show high potential of productivity increasing while assuring sustainability principles. The introduction of dry machining is one of sollution of today’s metal cutting industry that tirelessly endeavours to reduce machining costs and impact from chemicals in the environment. 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.

Key words: Dry machining, air-cooling, principle of work of vortex tube

1. INTRODUCTION

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]. Recently it has been proposed that vortex tubes could be used as components in refrigeration systems replacing the conventional expansion nozzle in order to increase the efficiency [5].

The coolants in refrigeration systems pass through a thermal cycle in which the pressure may well drop below atmospheric.

ADJUSTABLE SPOT COOLER ADVANTAGES

- No moving parts.
- Quiet
- Driven by air and not electricity.
- Small and light weight-portable.
- Low in cost compared to most others
- Superior design and performance
- Maintenance free operation
- Made of durable stainless steel and metal parts, no cheap plastic parts
- Adjustable temperature range
- Generators are interchangeable
- System uses strong magnetic base

Figure 1 shows adjustable Spot Cooler-Compressed air enters at point (A) into the vortex tube component of the spot cooler. The vortex tube splits the compressed air into a hot (B) and cold (C) stream of air. The hot air from the vortex tube is vented to the atmosphere at point (D) after being muffled to reduce noise. Cold air enters into the muffler (E) and then distributed through the hose distribution kit (F) and onto the item being cooled. A strong magnet (G) holds the spot cooler in place. The temperature of the cold air is controlled by an adjustable knob.
2. 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 temperature rises. As you close the valve the cold air end flow increases and temperature drops. 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 as shown in Fig. 3.

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 (A), as it expands, the outer air will be cooled due to its expansion. Consequently, the inner core air (B) will get warm because it is compressed by the expansion of the peripheral air.

2.1 Temperature of hot/cold side on vortex tube

The vortex tube with atmospheric inlet pressure was operated for a variety of cold gas fractions \(Y = \frac{j_c}{j_0}\). The temperature measurements are shown in Fig. 5. Clearly the temperature splitting effect is obtained. The cooling is well developed, but it appears as if the heating is not quite as pronounced. We have lately
become aware that varying the moisture content of the ambient air will change the thermal capacity of this working fluid significantly and hence contribute to variations of the temperature change. This effect could easily amount to several degrees and it should be more pronounced in the hot flow component than in the cold stream.

To put the temperature measurements into perspective several high-pressure curves for the same vortex tube are given in Fig. 6.

3. EFFECT OF AIR-COOLING ON TOOL LIFE

It is known that all the wear mechanisms increased at elevated temperatures reducing the tool life [9]. The application of cold air to the tool tip is shown to reduce the temperature at the tool tip enabling the tool tip to have a longer tool life [10]. The effectiveness of the air-cooled system can be shown when a comparison is made between the wear for a dry cut and an air-cooled cut for one minute and seven minutes of machining. Fig. 7a-d show the flank wear as seen under a microscope.

The development of the flank wear was shown to take longer to develop when the cooled air was applied to the cutting zone as shown in Fig. 7d. After seven minutes of dry machining the top rake face is starting to develop crater wear, at 0.5 mm from the flank face as shown in Fig. 8. Further dry machining will accelerate this rate of wear. At this stage the tool radius shows no sign of wear and the top flank edge has no observable notches.

The air-cooled tool tip shows no visible sign of tool wear on the top rake face and the flank wear is also substantially reduced. Observation of the chips produced during dry and air-cooling indicated that much of the heat was being dissipated from the cutting zone.

Figure 9 shows the chips produced during the dry and air-cooled tool tip test. The left hand chips produced during dry cutting and the right hand produced during air-cooling.

4. CONCLUSION

The results obtained from 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 recorded 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 as shown by Fig. 10. These temperatures were measured 1 mm from the tool interface and for that reason the temperatures recorded at this position are considerably reduced from that of the tool interface.
The most convenient method of determining the effectiveness of the air-cooling is by determining the tool life, as it is known that there is a relationship between tool life and the wear mechanisms that are shown to increase at elevated cutting temperatures. Inspection of the tool tip using a microscope confirmed that the tool wear is reduced when being air-cooled, resulting in longer tool life. The vortex tube air-cooling systems proved to be effective at dissipating the heat from the tool tip, proving that air-cooling is an effective method of cooling tool tips. Therefore, whenever dry machining is the preferred method of metal cutting, aircooling should be incorporated as there are no associated environmental issues and will extend the life of the tool.

Fig. 10. Temperatures recorded at the tool tip for dry and air-cooling [7]

5. REFERENCES

[3] Swirl Tubes Norgren 5400 South Delaware, Littleton, Colorado; Vortex Tubes Exair products, 1250 Century Circle North, Cincinnati, OH, 45246, USA; Vortex Tubes Vortec Corp, Cincinnati OH, USA.

Authors: Miroslav Duspara, Antun Stoić, Mechanical Engineering faculty in Slavonski Brod, e-mail: antun.stoic@gmail.com
Borut Kosec, Faculty of Natural Sciences and Engineering, Ljubljana
Marija Stoić, College of Slavonski Brod
Davorin Kramar, Faculty of Mechanical Engineering, Ljubljana