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Development of Thermo Acoustic Device for Cooling Effect in Machining Process.

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Abstract

Different types of coolant are used in machining process to reduce heat and friction between the tool and the work piece, to improve the surface finishing and to increase tool life. But long term exposure to these kinds of working fluids can present with some health hazards. To eliminate these types of coolant in the manufacturing process, a Thermo Acoustic Refrigerator (TAR) generated air coolant is developed.

This technology uses high intensity acoustic waves in a pressurized gas tube to pump heat from one place to other to produce a refrigeration effect. In this study, an electromagnetic loudspeaker is used to generate the acoustic input inside an acoustically insulated tube filled with inert gases inside and with little or almost no moving parts which making the system highly efficient. Cooling effect produced by TAR will be applied in machining process as coolant. The result shows a promising window of application for thermo acoustic refrigerator coolant in machining process.

Keywords: Thermo Acoustic, Cooling effect, machining processes.

1. Introduction

Intense heat generated in machining processes like milling, turning, grinding due to relatively high frictional effects impairs work piece and quality by inducing thermal damage. Therefore, cooling and lubrication play a decisive role in machining process [1-3]. Liquid coolants in flood form have been the conventional choice to deal with this problem. Long term exposure to this kind of fluid can present with many health hazards for the operators. Also relatively high surface speeds of the wheel and large contact area between the wheel and work piece cause a stiff boundary layer to form around the wheel periphery, which restricts the flow of cutting fluids into the grinding zone [4]. To solve these problems, A Thermoacoustic refrigerator (TAR) is realized which produces cold air that can be used to replace the usage of liquid coolant.

Thermoacoustic refrigerator is a cutting edge technology which uses sound effect to convert mechanical energy into temperature differential. They consist of a loudspeaker, attached to one end of an acoustic resonator (tube), which is closed at the other end and contains inert gas inside. Advantages of using TAR are simple and clean mechanical system which doesn't use pistons, cranks and lubricants as the conventional refrigerator or air condition cooling systems [5-6].

TAR was first discovered by European glass blowers in the 19th century when it was noticed sound generated when a cold glass tube was placed next to a hot glass stem [7]. In the mid-1800s, Rijke and Sondhaus made

numerous discoveries significantly progressing the study of thermoacoustics. Rijke determined that a large vertical tube, open at both ends, emitted sound when heat was place at one quarter of the tube length. Additionally, Sondhaus described how a tube closed at one end will produce sound when the closed end is heated. In 1975, Merkli and Thomann were able to observe sound producing a temperature difference. Rott researched these effects and developed the mathematics describing oscillations in a tube with a temperature gradient. These results confirmed the connection between sound and heat [8].
Aim of this study is to investigate the effect of cold air on surface roughness in machining process like turning. Cold air absorbs the heat produced due to friction between the work piece and cutting tool. Cold air is produced with the help of a Thermoacoustic refrigerator. For completion of the study a TAR is designed, fabricated and tested under different frequencies of sine wave for its optimum performance; then the optimal condition is used for conducting the surface roughness testing.

2. Design and Construction of TAR

Figure 1 shows the construction of a simple thermoacoustic refrigerator. It contains a resonator tube made of PVC pipe and Copper tube and it contains the inert gas as working fluid. A loud speaker is used to produce the necessary acoustic power to drive the system. A stack, the heart of the TAR which is a porous medium is placed inside the resonator to increase the gas solid interaction and contact surface to exchange heat. Heat exchangers are used in both sides of the stack. A thermocouple is used to determine the temperature difference between hot and cold air. Figure 2 shows the components of the experimental setup. The brief description of the components is given below:

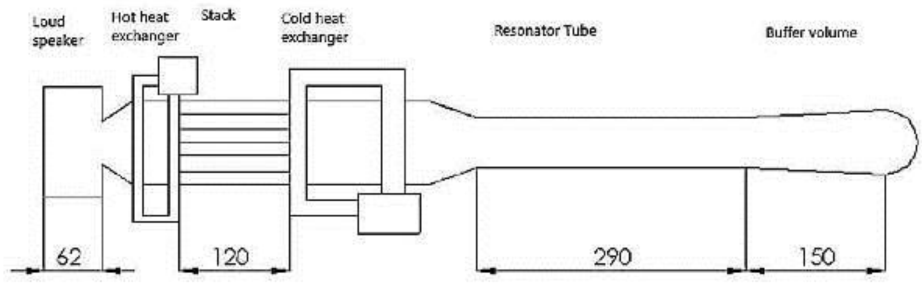


Fig. 1. Schematic Diagram of TAR

Loud speaker

Loud speaker supplies the required acoustic power to drive the system. It should be compact, powerful and light weight. For these reasons an R-2430, 100 watt, 3.5 inch, 3 way speaker was used. The speaker was kept inside a PVC made speaker housing as PVC was readily available and thermally insulating.

Speaker Housing

It is made of PVC. Speaker is inserted inside it. Two holes were drilled at the back, one for electrical wiring of the speaker and another for charging the gas.

Stack

It is the heart of Thermoacoustic refrigerator. It is a porous medium that increases the heat exchange surface area. To guarantee low thermal conductivity of the stack Mylar sheet was chosen. A spiral stack of Mylar sheet is constructed wounding around a PVC dowel of 1.5 inch diameter. A channel structure between the layers is realized with the help of .25 mm fishing lines. Fishing lines were attached to the Mylar sheet with the help of Glue gun and glue sticks. For the first 200 lines a distance of 1 cm was maintained and for the rest a distance of 3 cm up to the diameter of the stack became 3.5 inch. Then it was inserted inside the stack housing. Housing is made of 3.5 inch PVC pipe. PVC material is chosen for its low thermal conductivity and insulation.

Resonator Tube

Resonator tube is the body of the thermoacoustic refrigerator in which the sound wave propagates. It consists of three major parts. First part consists of a large diameter PVC pipe called stack housing which contains the stack, followed by a smaller diameter Copper tube and the last part is the Buffer volume. Copper tube has relatively higher thermal conductivity and its diameter is 2 inch and 29 cm in length.

Buffer Volume

The buffer volume is to be used to simulate open-end resonator. It is a conical shaped copper tube with a taper angle of about 9^0 and a diameter of 2.35 inch and gradually increasing up to 2.85 inch. The total length of this buffer volume is 15 cm.

Heat Exchanger

Two heat exchangers are made of 0.25 inch Copper coil. These are placed in both sides of the stack.

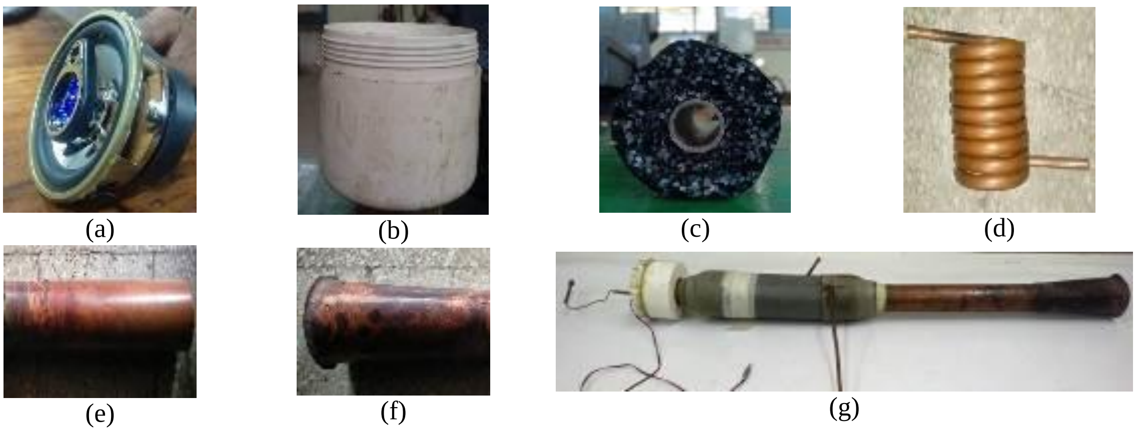


Fig. 2. Different components of TAR; (a) Speaker, (b) Speaker Housing, (c) Stack, (d) Heat Exchanger, (e) Resonator Tube, (f) Buffer Volume, (g) Assembled view

3. Working Principle and Process Flow Chart

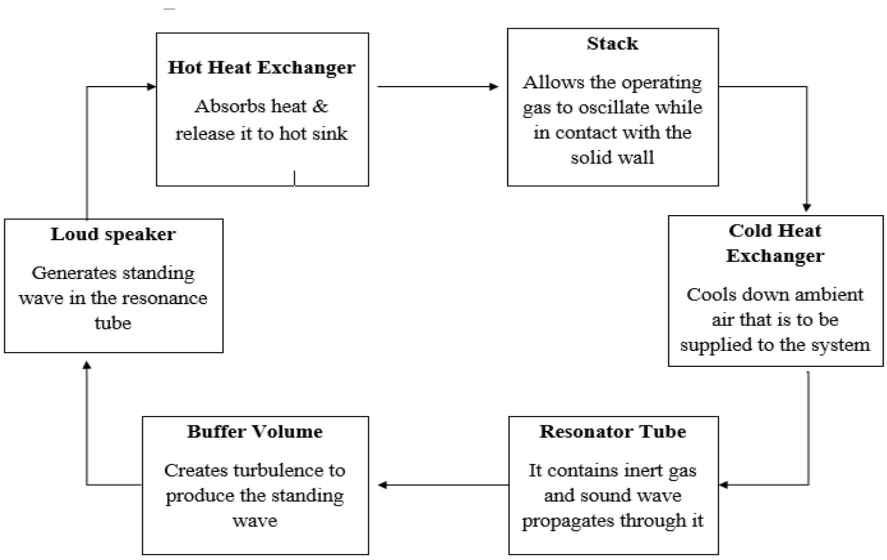


Fig. 2. Process Flow chart

Figure 3 shows the process flow diagram of the working process of TAR. The main principle of Thermoacoustic is the sound waves act like the pressure waves while propagating through a medium. In our device loud speaker generates the standing wave which propagates through the gas causing molecular collisions. These collisions produce a disturbance in the gas which creates constructive and destructive interference by turn. Compression of the molecules is caused by constructive interference and expansion of molecules is caused by destructive interference. As the gas molecules are compressed, pressure increases as well as temperature. On the other hand, where gas molecules are expanded, pressure decreases as well as temperature. As a result, a temperature difference is obtained at both sides of the stack inside the resonator tube.

A hot heat exchanger is used to absorb heat from the hot side of the stack and release it to the hot sink. Main component of TAR is stack. It allows the operating gas to oscillate while in contact with the solid wall. The channel like structure of the stack allows gas particles to propagate through it and increase the gas solid interface and hence enhance heat exchange. A spherical or conical shaped buffer volume is attached to the resonator tube which creates turbulence to produce standing wave.

A cold heat exchanger is used to cool down ambient air that is to be supplied to the machining process as a replacement of coolant

3. Research Methodology

In this study we have conducted two different types of tests: (a) Temperature Testing of TAR and (b) Surface Roughness testing using TAR as coolant

Temperature Testing

Figure 4 shows the temperature testing arrangement for the experiment. Temperature testing commenced with pressurized Argon gas in the TAR. A CIE 305 portable thermometer was used to measure the temperature difference between air at the inlet and outlet of the cold Heat exchanger. The speaker was driven at frequencies form 50 Hz to 1000 Hz in the form of sine wave. Data was taken after driving the speaker for 10 minute. A portable blower (model PB-20) was used to draw air from the inlet to the outlet of the heat exchanger. The velocity of air at the outlet was 0.6 m/s. ΔT was tested after Argon gas was inserted at 1 atm (14.7 psi) & 1.5 atm (22psi).

Speciation of the Blower

Power	:	335 watt
Frequency of A/C current	:	50 Hz
Voltage-Current	:	220V-1.6A
Flow rate	:	2.3 m^3/min

Fig. 3. Experimental set up for Temperature Testing

Surface Roughness Testing

The Centre lathe used for the machining process was manufactured by Gate Inc. (model L-1/180). A contact profilometer Mitutoyo SURFTEST SJ-210 was used to measure the surface roughness of the machined surface.A carbide insert was used in the turning operation. Table 1 shows the parameter used for the experiment. Moreover, figure 5 shows the experimental setup and measuring devices. These parameters were selected arbitrarily and kept constant throughout the process to compare the results obtained under the same condition.

Table 1. Process Parameter

Feed rate (mm/rev)	Depth of cut (mm)	Spindle Speed (rpm)	Cutting speed (mm/min)
0.095	0.50	220	22.11

Job Piece Specification

Material	:	Mild Steel
Initial diameter	:	32 mm
Final Diameter	:	30mm

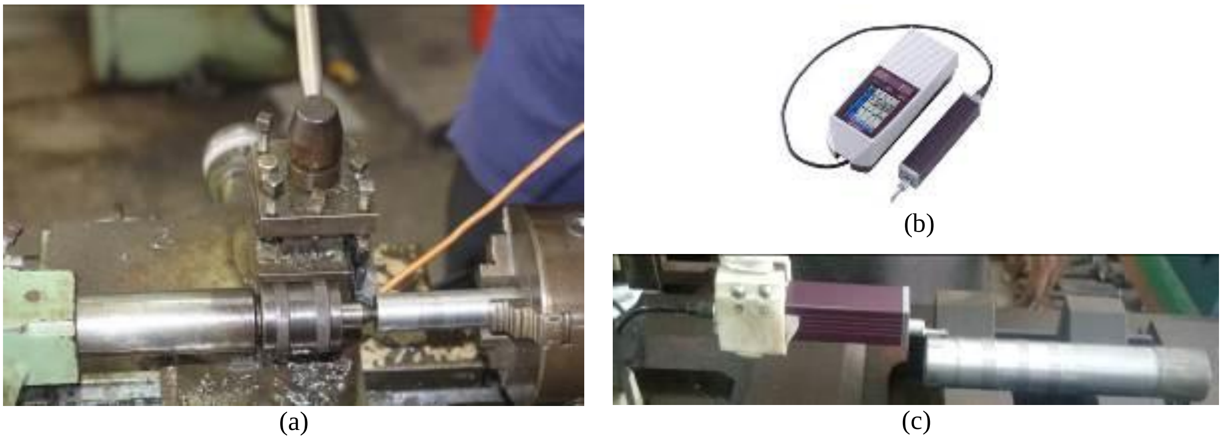


Fig. 4. (a) Experimental Set up for Surface Roughness Testing (b) Mitutoyo SURFTEST SJ-210 contact profilometer (c) Surface roughness measurement

4. Result & Discussion

Temperature Testing

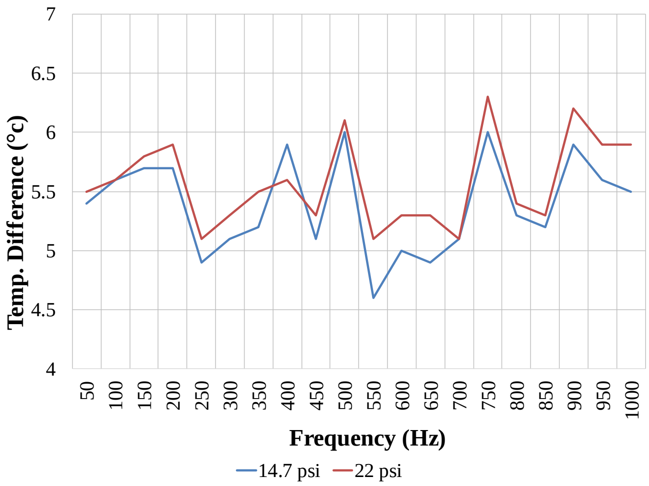


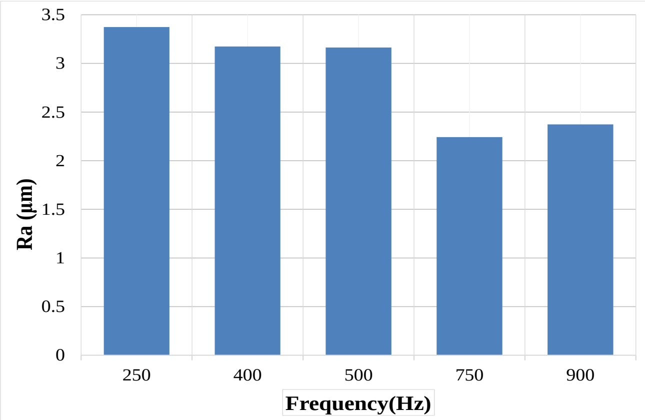
Fig. 5. Effect on Temperature at different frequency

Figure 6 represents the temperature gradient with respect to different sound frequencies at 1 atm (14.7 psi) and 1.5 atm (22 psi). A maximum temperature difference of 6°c was observed at a frequency of 750 Hz when the gas was pressurized at 1 atm. Repeating the same process for 1.5 atm pressure a maximum temperature difference of 6.3^{0}c was obtained at the 750 Hz.

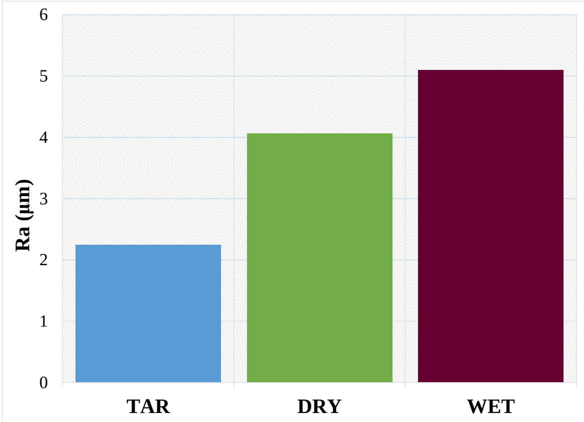
It has been observed that the effect of different frequencies of sound wave is not as significant as the effect of pressure of the gas inside the tube. This may be due to the increase of gas density inside the tube resulting more interference of the gas particles. But the increase in pressure incorporates with increased chance of leakage.

Surface Roughness Testing

Figure 7(a) depicts the results obtained from the different experiments under same process parameter for the Lathe under different Frequencies of sound in TAR. The best surface finishing was obtained at 750 Hz with a profilometer reading of 2.242 μm which is then compared to Dry and Wet Matching keeping the process parameters constant. Figure 7(b) illustrates the comparison among Dry, Wet and TAR cooled Machining process.



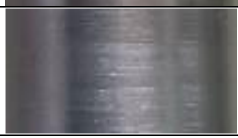
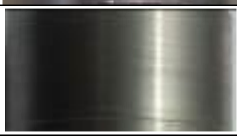
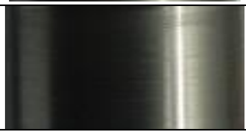
(a)



(b)

Fig. 7. (a) Effect on Surface Roughness; (b) Comparison among Dry, Wet & TAR cooled Machining Process

Table 2. Data Chart for Surface Roughness Testing

		Surface roughness (µm)	**Image of Surface**	**Surface Roughness data**
Frequency Used in TAR (Hz)	**250**	3.373		
	400	3.174		
	500	3.163		
	750	2.242		
	900	2.373		
Dry		4.065		
Wet (with coolant)		5.107		

It has been observed from Fig.7. and Table 2 that with the increase in the frequency of sound wave used in the TAR, surface roughness progressively decreases. The quality of TAR cooled machining is better in comparison to other dry and wet machining as well.

5. Limitations & Scopes of TAR

At present the efficiency of the prototype of thermoacoustic refrigerator is comparatively lower than that of the vapor compression cycle. Also system working on thermoacoustic principle is not yet ready for commercial use because of its low efficiency, design constraints, sealing and unavailability of different components. The main drivers to encourage to uptake this technology once they become commercially available in different application of refrigeration cycle like food sector in domestic and industrial scale. Prohibition on the use of HFCs due to environmental consideration and limits imposed on the amount of flammable refrigerants in self-contained refrigerator cabinet promote the study of alternative refrigeration cycles like Thermo acoustics. In depth study on the behavior of thermo acoustic refrigerators and its different parameters may lead this technology to an efficient and feasible alternative to the conventional refrigeration system.

6. Conclusion & Recommendation

In conclusion, the effect of frequency change in sinusoidal wave and gas pressure inside the resonator tube on the performance of the thermoacoustic refrigerator and the effect of cold air in the machining process was studied in this study. It was found that with the increase of frequency and gas pressure the performance enhances. Also when conducting the surface roughness testing, it was observed that cold air produced by TAR gives the best quality of surface in comparison to dry and conventional machining under same condition. Although Thermoacoustic seems to be a promising technology, significant effort is required to make an efficient one that can be used commercially in large scale. For future work, the material selection and design of the resonator tube should be such that it can withstand the high pressure gas without leaking. A high power full speaker should be used to drive the system and create higher acoustic energy in the resonator tube.

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