Design, Simulation and Fabrication of Vortex Cold Air Gun

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Abstract— A vortex tube is a compact energy device which splits a compressed air stream into hot and cold streams at opposite ends. This paper presents an insight on Ranque-Hilsch Vortex Tube (RHVT) with divergent nozzle, stream of compressed air to swirl in swirl chamber, conical projection and a diaphragm. The principle of vortex tube is used in vortex air gun for the purpose of cooling a work piece during machining operation. Various models are designed by varying the dependent parameters and the simulation of all the models is done. The model which gave the desired results is then fabricated. The vortex tube testing setup is made and testing of the fabricated model is done in order to verify the simulation results.

Key words: Ranque-Hilsch Vortex Tube, Divergent Nozzle, Swirl Chamber, Temperature Separation Mechanism

I. Introduction

The vortex tube is a simple mechanical device which was introduced by George Ranque in 1933. It was reintroduced by Rudolph Hilsch in 1945 during the world war II. Hence it is known as Ranque-Hilsch vortex tube [1]. According to the study, when a high pressure gas is tangentially injected into the vortex chamber via the inlet nozzle, a swirling flow is created inside the vortex chamber. When the gas swirls to the centre, it is expanded and cooled. The stream which is at the centre strikes on conical projection and it is reflected back towards cold end and the hot air which is at the periphery of tube flows out from the hot exit. The temperature at cold exit is lower compared to the supply air and temperature at hot end is higher than the supply. The advantages of a Vortex tube are that, it is simple in design with no moving parts, small and light weight, low maintenance. In this paper, we are mainly focusing on optimization of tube by varying various parameters using CFD analysis. Parameters to be varied are inlet pressure, angle of conical projection and diameter of nozzle. The effect of these parameters is seen on the temperature output of the cold end side. The obtained optimized model is fabricated and tested.

II. Vortex Air Gun

Cold air guns are used in various industrial processes, fabrication, assemblies as a versatile spot cooling device. It uses filtered compressed air and vortex tube technology. Cold air machining eliminates mist coolants and heat related parts growth while improving tool life, surface finish quality and parts tolerance. Most popular applications involve cooling during the machining of metals, plastics, wood, rubber, ceramics and other materials. Cold air gun provides effective cooling for most of the dry machining operations, allowing an increase in speed and feed rates. It is widely used in milling, drilling, turning and other metal working operations as well as setting hot metals and adhesives.

Cold air gun eliminates the costs of buying and disposing cutting fluids and worker related health problems from breathing airborne coolant.

A. Principle

Vortex tube was a fascinating and disputed device from its introduction. With features as no moving parts, simplicity of manufacture and obvious applications to direct heating and cooling, the success is obvious in environments with an existing compressed air source.

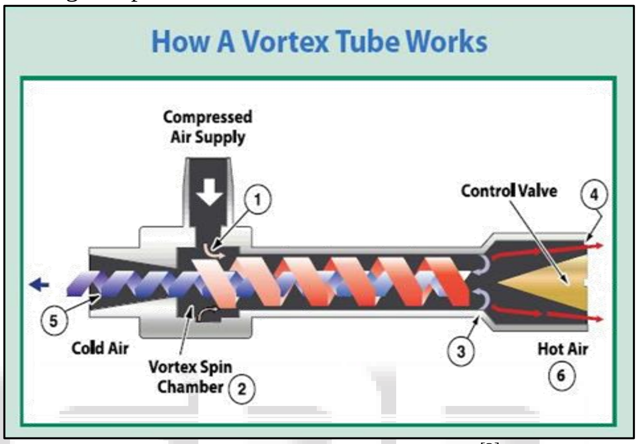

Fig. 1: Principle of Vortex tube [2]

1) A stream of compressed air is injected tangentially through a nozzle into the swirl chamber. As it is injected tangentially, a swirl is created and the stream gains a lot of kinetic energy. This stream has an obstruction on one side and hence, it proceeds on the other side where it encounters a conical projection. The conical projection has a steep angle which reflects a small amount of the compressed air stream in the opposite direction. This inner stream rejects heat to the outer stream while coming out from the opposite end.
2) A paper presents a theory for explaining the phenomena of temperature separation. The injected compressed air creates a swirl inside the tube. This stream is at a very high velocity of about 1,000,000 rpm. But the reflected inner stream has a smaller velocity compared to the outer stream. This causes friction in between the streams. Ranque himself explained the effect. According to him, the rotating air stream produces region of increased pressure near the wall inside the cylinder by adiabatic compression and region of decreased pressure near the axis. Hence, the temperature is increased near the wall and decreased near the axis.
3) A study showed that a centrifugal field is generated inside the tube which is helpful in separating the gas molecules according to their molecular weights. Naturally, the molecules with higher molecular weight will be gathered at the periphery while those with lower weight will be gathered at the axis of the tube. As,

$F_c = \frac{m*V2}{r}$ which implies $F_c \alpha$ m. therefore, it is expected that the stream coming out of the hot end will be rich in high molecular weight components and the stream coming out of the cold end will be rich low molecular weight components. Thus, mass separation also takes place.

1) Scope

This project provides an optimized model by simulation, fabrication, analysis and experimentation of the vortex tube. We have been focusing on its application, "vortex cold air gun". It is used in workshops for spot cooling.

B. Types of Vortex Tubes

1) Based on the direction of flow [3]

a) Counter flow vortex tube

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.

b) Parallel flow vortex tube

The cold air comes out through a concentrically located annular exit in the cold valve. This type is used in applications where space and equipment cost are of high importance. However, the efficiency of former is better than the latter.

2) Based on the temperature drop:

Maximum temperature drop vortex tube which has a small cold end orifice diameter and very low temperature Maximum cooling effect vortex tube for producing large quantity of air with moderate temperature.

III. SIMULATION

Various models were made and then each model was simulated using the ANSYS Workbench software. The analysis of model was done in transient state of the fluid body and the fluid was used under ideal gas condition. The k-epsilon energy equation is used with Tetrahedron elements and the condition of proximity. The results of best model amongst all the models are shown. Since the main purpose of vortex tube is to give cold air, the temperature simulation over the plane is shown.

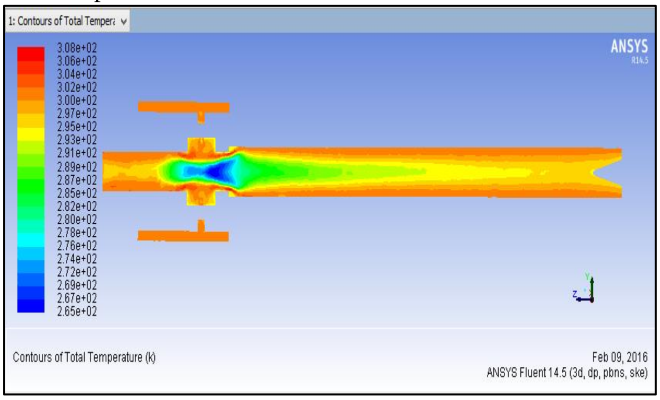

Fig. 2: Temperature contour at centre plane

Fig.2 shows the contour of the distribution of total temperature inside the vortex tube. The temperature separation phenomenon is clearly evident in contour plot.

The temperature obtained near the nozzle is around 265K and at the hot end 304 K is obtained.

Simulation results of various models are listed below.

Sr. no	Pressure at the inlet (Bar)	$\frac{L}{D}$ ratio	No. of nozzles	Angle of the conical projection (deg)	Temperature at the cold end (K)	Temperature at the hot end (K)
1	6	10	6	30	265	302
2	6	10	6	60	274	311
3	6	10	4	60	284	306
4	6	20	4	25	297	301
5	6	25	4	60	297	300

Table 1: Simulation Results of the Various Fabricated Models

The fig-3 shows temperature v/s position graph. The white line shows the temperature along the center line. Yellow color line and maroon color line shows the temperature 4 mm above the center line and 4 mm below the center line respectively.0.02 m position is the point at conical projection. Origin represents the hot outlet surface and 0.14 m position represents the cold end surface.

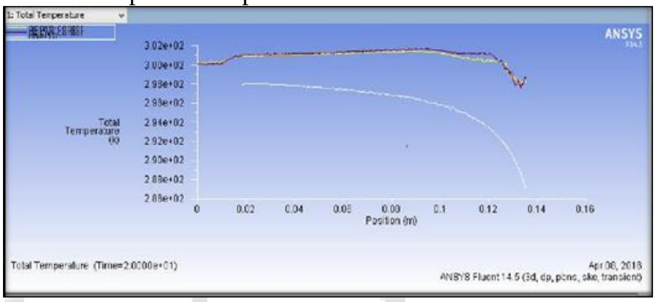

Fig. 3: Temperature v/s position graph

IV. DESIGN

The Fig.4 shows a model of vortex tube. A model on AUTODESK inventor was made at the very beginning considering a set of dimensions which seemed visually close. But the results were not as expected.

To optimize the model, some important parameters affecting the cold end temperature were varied over some range. The parameters include L/D ratio, number of nozzles and angle of the conical projection.

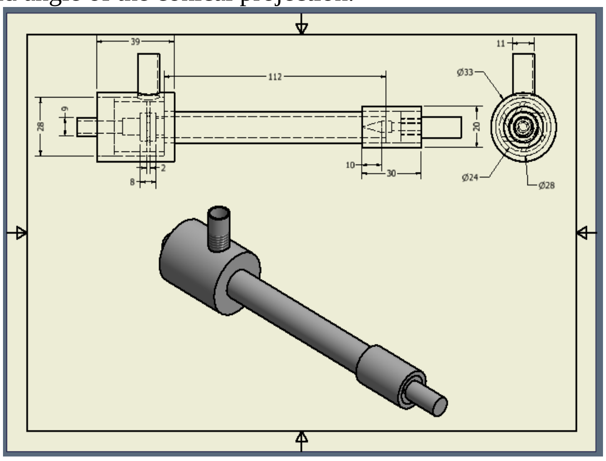

Fig. 4: Drawing of vortex tube

The L/D ratio was increased at first but as it gave an increase in the value of cold end temperature, L/D ratio decreased. An increase in number of nozzles showed a decrease in the cold end temperature. Angle of the Conical projection possess similar characteristics as that of L/D ratio.

The parts of the vortex tube are Main tube, Outer cylinder, Nozzle, Connector, Conical Projection and Vortex generator.

V. FABRICATION OF THE MODEL

The fabricated model of the vortex tube is based on the design given above. All the components are fabricated using Mild Steel.

A. Main Tube

For fabrication of main tube (Fig.5), Lathe machine is used. Main tube is connected to the main cylinder. The swirling action is taking place in main tube. This tube accommodates conical projection as well.

Fig. 5: Main tube

B. Vortex Generator

Vortex generator(Fig.6) is having 6 nozzles on it. These nozzles are tangential. The main purpose of these slots is to give tangential flow to the air coming from the compressor.

Fig. 6: Vortex Generator

C. Outer Cylinder

The outer cylinder(Fig.7) fabricated by using drilling and lathe machine operation. It accommodates Vortex generator, nozzle and main tube.

Fig. 7: Outer Cylinder

D. Nozzle

The nozzle is used for providing entry to compressed air from compressor.

E. Connector

Connector (Fig.8) is used for providing path to conical projection.

Fig. 8: Connector

F. Conical Projection

Conical projection (Fig.9) is made up of mild steel and it has slots and threads on periphery. The angle of cone is 30^0.

Fig. 9: Conical Projection

G. Assembly

All the above parts are joined together as shown in Fig.10. Teflon tape is provided to avoid leakage. Compressed air outlet and nozzle is connected through pipe and pneumatic port to avoid leakage.

Fig. 10: Assembled vortex tube

VI. EXPERIMENTAL SETUP

Experimental set up is made as shown in Fig.11. A Compressor, filter and dryer arrangement is connected to the vortex tube. Due to the dryer and filter arrangement, the moisture is removed from the compressed air. The inlet of the tube is connected to a pipe which is connected to the outlet of the compressor. The compressor pressure is kept at 6 bar. This air is supplied to the tube by actuating a valve in 90^o. The tube is fixed in a vice for avoiding heat transfer to the environment and by human contact.

Thermocouple is used for measuring temperature. Proper connections are required for the use of thermocouple. NI LABVIEW software is used for the display of temperature. The setup includes a laptop, DAQ 9219, wires for connection, thermocouple and a power source as shown in Fig.10

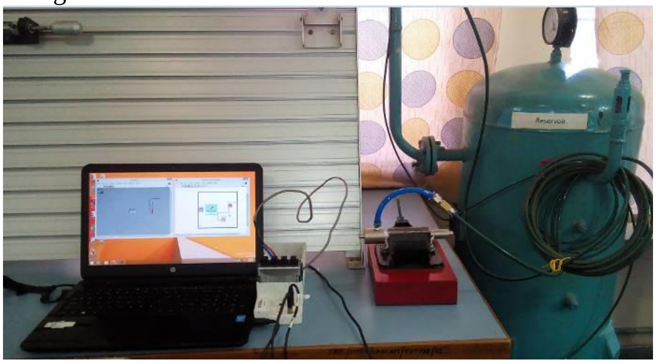

Fig. 11: Experimental setup

VII. RESULTS

After testing the experimental setup, the readings of the temperatures of hot and cold ends are recorded which are as follows:

Temperature of air at the cold end= 17°C
Temperature of air at the hot end= 34°C
For the specifications,

- L/D ratio= 10
- No. of nozzles =6
- Angle of conical projection = 30°

VIII. CONCLUSION

- The experimental results are not exactly similar to the simulation results.
- The cold air tube can be used for spot cooling process with the available cold air temperature as well.

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