International Journal of Engineering Studies and Technical Approach
IJESTA
ISSN No. 2395-0900

Numerical Investigation for Optimizing Parameter of Vortex Tube for Sustainable Manufacturing

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ABSTRACT:

Sustainability developed in many countries; it is mainly implemented in engineering design, manufacturing and supply chain management field. Sustainable is defined as meeting the needs of the present generation by not taking the need of the feature generation. Sustainability is more important in today's culture due to the increasing demand for a more eco-friendly society and a growing population. Sustainability is the reconciliation of environmental, society and economic. Vortex tube is used as sustainable tool for manufacturing system. Vortex tubes having no moving part so there is no need for maintence. This work is numerical analysis on optimizing the parameter of the vortex tube for minimizing the temperature at cold end. The length and diameter of the vortex tube are optimized, cold end orifice radios and hot end gap are optimized using numerical tool. The inlet profile of the vortex tube also modified and analyzed. The importance of this work is reducing the cold end temperature of the vortex tube. By reducing the cold end temperature we can use the vortex tube in machining operation alternative for the flood cooling method.

Keywords: —Sustainability; vortex tube; L/D Radio; cold orifice diameter; modified vortex tube generator profile.

1. INTRODUCTION:

The work presented here is modifying vortex tube profile for better cooling temperature and optimizing the parameter of the vortex tube. Environmental, social equity and economic demands it all three pillars of sustainability, sustainable manufacturing is deals with manufacturing method that is nonpolluting the environment, not affecting the human health, economic manufacturing system. The sustainable manufacturing system must use renewable energy resources. Nowadays in developed countries industries are workout the sustainability as important factor along with productivity profitability and competitiveness.

ISSN No. 2395-0900
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Fig 1: EXAIR 3205 Vortex Tube

Vortex tube is a sustainable tool use air as a working medium used for cooling the cutting edge of the tool tip. It separates a hot air and cold air by using compressed air. it was accidently invented by a French physicist named Ranque when he doing his dust separated cyclone project in 1933,the idea was abounded because of its in efficiency and it was redesigned and parameter are modified by germen engineer Rudolf hilsch in 1947. Vortex tube having no moving part no chemical reaction and no electricity is needed no maintence is required. Vortex tube creates a cold air and hot air by forcing a compressed air through generator chamber, which spins the air at high rate of speed into a vortex. The high speed air heats up as it spins along the inner walls of the tube toward the control valve. A percentage of the hot, high speed air is permitted to exit at the valve. The remainder of the air stream is forced to counter flow up through the center of the high speed air stream in a second vortex. The slower moving air gives up the energy in the form of heat and becomes cooled as it spins up the tube. The chilled air passes through the center of the generation chamber finally exiting through the opposite end as extremely cold air. The control located in the hot exhaust end can be used to adjust the temperature drop and rise for all vortex tubes.

Measurement	**values**
Tube inner diameter, D	10.20mm
Tube length/diameter	11.37
Number of nozzle	6
Tangential inlet nozzle width	1.41mm
Hot exit gap	0.3mm

Table 1 Vortex tube Dimension

Control valve used to control the mass flow rate of the vortex tube at hot end side. It is difficult to understand the energy separation phenomenon inside the vortex tube and quite complex. Because the two layer created inside the vortex tube is the reason for the energy separation, swirling flow velocity and larger angular velocity important parameter for the energy separation effect. Eiamsa-ard [1] suggest that for maximum cooling temperature cold mass friction ( ) should be 30% to 40%.but till now The energy separation in the vortex tube is not fully understood. Aljuwayhel et al[2] recirculation nature and high velocity swirling flow is challenge to the traditional and non-invasive flow visualization techniques .Liew et al [3] revealing the relation the RHVT and Maxwell's demon. Yunpenq xuy et al [4] the temperature drop at cold end is because of pressure gradient in the front vortex tube and the temperature rice at the hot end is the multi circulation flow structure in the outer part of the main tube.

2. GEOMENTRY OF THE VORTEX TUBE

Vortex tube having three important component vortex generator, tube and hot end control valve. stoper is used at the cold end of the vortex tube to hold the vortex generator. Vortex generator having the six tangential inlets for creating the vortex flow. The hot end control valve is used to control the mass flow rate of the vortex tube. When the vortex generator assembled in tube that create the vortex chamber for swirling the air this increase the velocity of the air. The physical paramater of the vortex tube are optimized in this work . The length and diameter radio of the vortex tube and hot end control valve position and cold end orifice diameter are modified and analyzed in fluent.

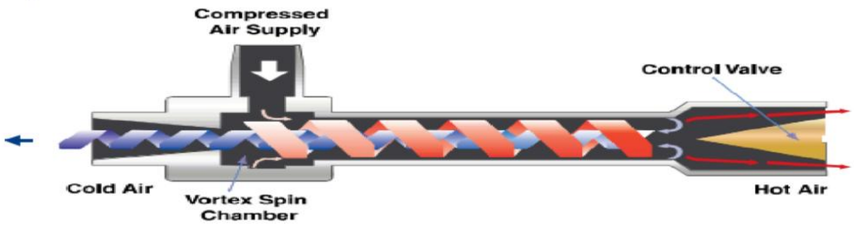

Fig 2 Vortex Tube Energy Separation

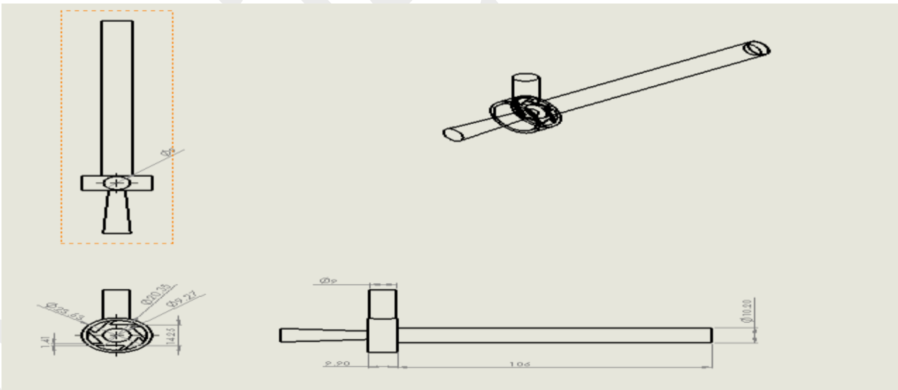

Fig 3 Vortex Tube Fluid Path Geometry

The length of the vortex tube is modified and analyzed in fluent software. The diameter of the main tube in existing model is 10.20mm. nader pourmahmoud et al [5] shows that at 9.3 L/D radio give the minimum temperature at cold end. When compressed air give as input it enters in to the system and creating the swirling motion in vortex chamber and enter in to the The 6 tangential nozzles for creating the turbulence flow. Nozzle width is 1.41mm 0.97mm depth length of the nozzle is 2.9mm and cold orifice diameter is 4.56mm. L/D radio14.21, 12.35 11.37, 10.39, 9.31, 8.33, 7.35, 6.37, 5.39 is taken for analysis. L/D radio 5.39 giving the best energy separation in our case 6 tangential inlet nozzle is used in this CFD model. And different D/d ratio 1.99, 1.64, 2.31, 2.04, 3.4 are analyzed and 1.64 is giving the optimum result.

Fig 4 Vortex Generator And Stopper

3. CFD MODEL

The ICEM is the tool used for the volume mesh generation in the vortex tube model. In fluent two type of solver is used pressure based solver and volume based solver. Pressure based solver is initially written for the low turbulence flow the density based solver written for high turbulence flow, but the pressure passed solver is then improved for the turbulence flow also. the standard k-epsilon turbulence model is used. Skye et al [6] investigate the RNG k-epsilon turbulence model but the result is not correlated with the experimental data, Reynolds stress equation also can't be converge for this simulation walls are consider as no slip boundary condition. the 3D model is meshed with tetra element in icem meshing tool, the velocity along the axial direction is the reason for creating the forced and free vortex zone inside the tube.

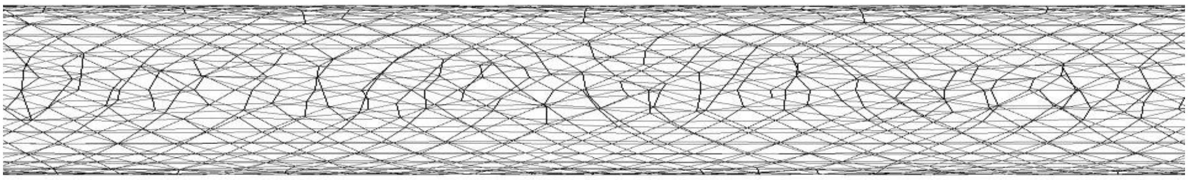

Fig 5 Tetra Mesh Grid Display

Ansys 14.5 and fluent version 6 is used for solving this problem. 3D model is meshed and analysed, density based solver diverged for this vortex tube problem, so pressure based solver is used. Energy equation is on for balancing the energy. K-epsilon model is used 2equation model is used and for finding the wall friction on fluid standard wall function is used. Finding the heat dissipation between the layers can be captured by viscous heating function. Air is used as material body. Because the flow is considered as compressible flow ideal gas equation is used. No interaction between environment and computation domain.

The inlet of the vortex tube is defined as a pressure inlet and cold outlet and hot outlet is defined as a pressure outlet and the atmospheric temperature is given as a input in the model. Wall is assumed as a adiabatic condition. The fluent package solved by mass, momentum and energy equation.

ISSN No. 2395-0900
International Journal of Engineering Studies and Technical Approach

The inlet pressure and inlet ambient temperature is giving as a input, inlet pressure is 5.5 bar and inlet ambient temperature is 27°c.cold outlet pressure is set as environmental pressure and hot outlet is also a environmental pressure. Maurya et al[7] Energy separation in the vortex tube is due to the double swirling flow structure . The back flow because of the pressure variation in the swirling region and hot outlet region and the cold outlet region, the negative pressure created inside the cold end important for back flow. Separation of two layers clearly show the energy transfer between the two layers and the inner layer give it heat energy in the form of kinetic energy.

4. MODIFICATION IN DESIGN

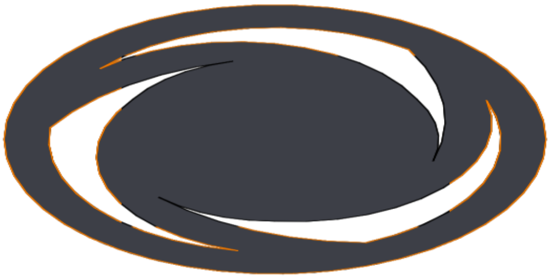

Fig 6 Vortex Generator Inlet 3 Snail Profile

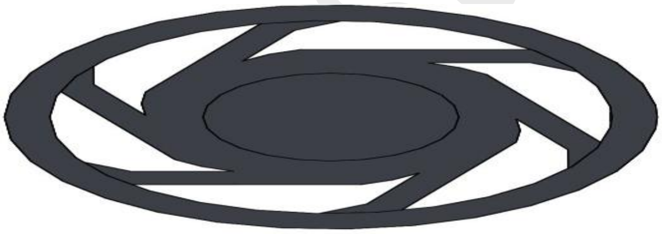

Fig 7 Vortex Generator Inlet Divergent Profile

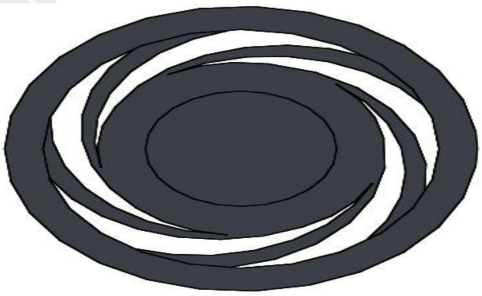

Fig 8 Vortex Generator Inlet 5 Snail Profile

Divergent straight inlet profile gives the same velocity as in straight inlet nozzle the temperature at the cold end also end also remains same.

For L/D ratio 5.39 and 2.22mm orifice radios convergent type vortex inlet is used but it will not give the better cold end temperature. Convergent nozzle reduces the inlet velocity

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Engineering Studies and Technical Approach
ISSN No. 2395-0900

because of the wall friction. Reducing the area of the inlet reduce velocity of the inlet so change in profile of the inlet increasing the temperature at cold end also remains same

5. RESULT AND DISSCUSTION

The various results are obtained from the analysis fluid flow in vortex tube is discussed in this chapter. The temperature at the cold end and hot end is taken as output.

L/D Ratio	Cold end temperature in°c
11.37	7

Table 2 Experimental Result of EXAIR 3205 Medium Model

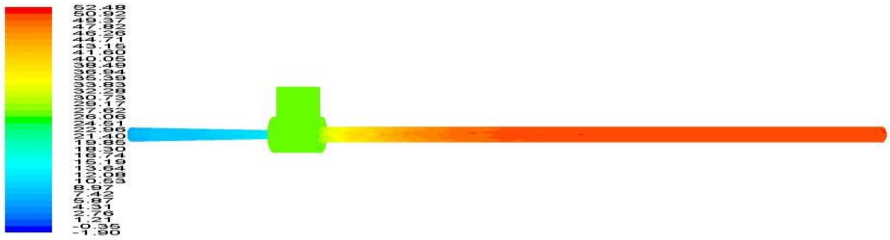

Fig 9 Exair 3205 Model Temperature Contour

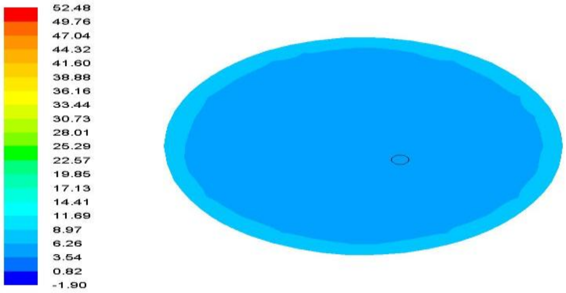

Fig 10 Exair Cold End Temperature Contour

Fig 8 shows that the hot air coming out in one end and cold air coming out in another end for the Exair 3205 medium type vortex tube having the L/D ratio of 11.37

Fig 11 and Fig 12 is the velocity vector of the tube and vortex inlet area it shows that increasing the length of the vortex tube will reduce the velocity in the swirling range. 145mm length vortex tube velocity at near the hot end is 39.44m/s to 59.04m/s. so reducing the vortex tube length gives the better energy separation and better cold end temperature.

L/D Radio	**Cold End Temperature In °C**
14.21	4.47-6.85
12.35	4.96-7.29

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ISSN No. 2395-0900

11.37	3.54-6.25
10.39	5.64-8.47
9.31	4.93-7.26
8.33	3.42-6.12
7.35	3.37-6.07
6.37	2.85-5.56
5.39	2.34-5.05

Table 3 L/D Ratio and Cold End Temperature

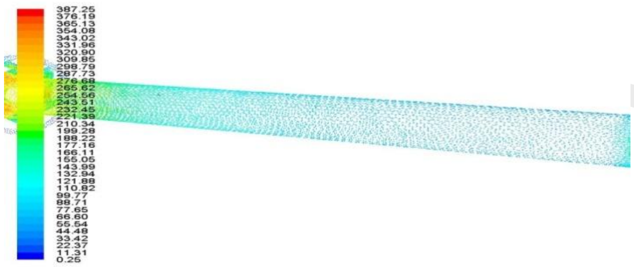

Fig 11 Velocity Vector Of The 116mm Length Vortex Tube

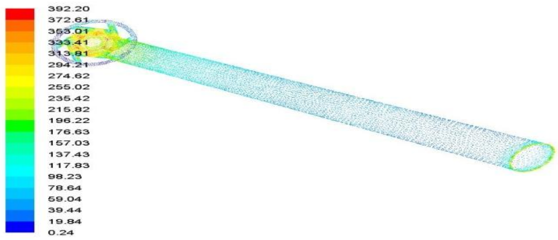

Fig 12 Velocity Vector Of The 145mm Length Tube

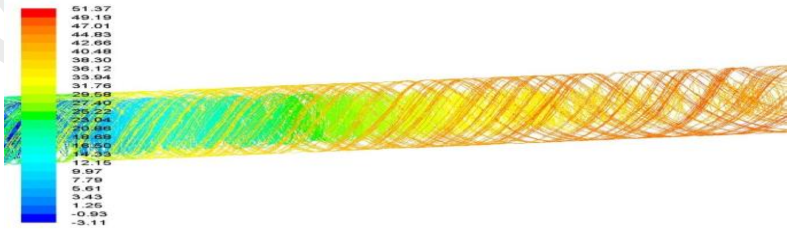

Fig 13 Energy Separation In The Vortex Tube L/D=5.39

The path line clearly shows that flow separation of swirling air inside the vortex tube. The length of the vortex tube is 55mm, reducing the length of the vortex tube below 55mm give the large eddy in nearer to the hot end of the vortex tube. Below this length increase the temperature at cold end.

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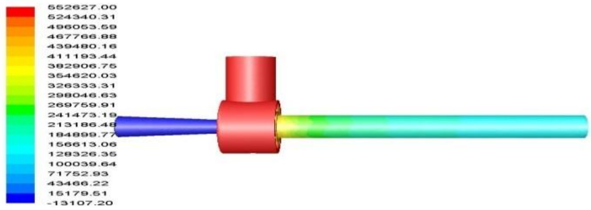

Fig 14 Pressure Contour of L/D-5.39

Fig 14 shows the total pressure contour of the vortex tube .in the cold end negative pressure is created that is the reason for the back flow in the vortex tube.

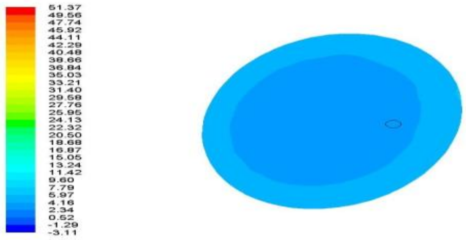

Fig 15 Cold End Temperature Contour Of L/D Ratio- 5.39

The orifice diameter is varied to improve the cold end temperature. Existed vortex tube having the orifice radios 2.56 mm. 3.1mm radios increase the temperature at cold end.

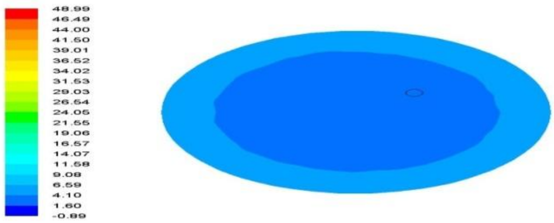

Fig 16 Cold End Temperature Contour Of L/D Radio 5.39 and Orifice Radios 2mm in °c

The hot end gap is 0.3mm for existed model reducing the hot end gap to 0.2mm increase the temperature at cold end. 0.4mm hot end gap gives the minimum cold end temperature 1.31°c.

Orifice radios in mm	Cold end temperature in °c
3	23.67-26.61
2	1.60-4.10
2.5	1.60-4.12
1.5	1.60-4.12

Table 4 Orifice Radius and Cold End Temperature

6. CONCLUSION

This work shows that reduction in length of the vortex tube will reduce the cold end temperature, because reduction in length of the vortex tube will affect the velocity inside the vortex generator and tube. Orifice diameter is modified and analyzed, increasing the orifice diameter increasing the temperature at cold end. Reducing orifice radios to 2mm and 1.5mm give the cold end temperature, reducing the orifice radios below 1.5mm increasing the temperature at cold end. Hot end gap at 0.4mm give the optimum temperature 1.31°c.

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