GREEN MANUFACTURING: EFFECT OF VORTEX TUBE ON MACHINABILITY OF MILD STEEL

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ABSTRACT

This research presents a study on the effect of chilled air application through Vortex Tube during dry machining on the machinability of mild steel. Through the full factorial design of experiment, there is a total of 36 experiments had been conducted for two levels of spindle speed (100rpm and 215 rpm), three levels of depth of cut (1mm, 2mm and 3mm) and three levels of freed rate (0.10 mm/rev, 0.18 mm/rev and 0.28 mm/rev) under both traditional dry machining and chilled air dry machining condition by lathe machine with coated carbide cutting tool. The power consumption, surface finish and tool life is measured as the output of material's machinability justification with the used of equipment such as power analyzer, surface profiler and optical video measurement system. The results showed that the better power efficiency had been obtained by the application of Vortex Tube which lowered the temperature by 11.17% in average; even it increased power consumption by 2.87% in average but decreased specific energy consumption by 22.11%. The performance of dry machining in tool life is better and 15.11% better in surface roughness compare to Vortex Tube. This happen due to the cooling effect of Vortex Tube that reduce machining temperature, lowered specific energy consumption but formed rapid harden strain on machined surface lead to higher value of surface roughness, while the surface material of coated carbide tool is easier to detached as the adhesive bond formed by removed chip and tool is stronger than the bond within base material of tool due to cooling effect which lead to tool wear easier. Recommendation of higher spindle speed and freed rate selection for this research had been proposed to observe the effectiveness of Vortex Tube on the performance of tool life and surface finish.

ABSTRAK

Projek ini membentangkan kajian tentang kesan aplikasi udara sejuk melalui Tube Vortex semasa pemesinan tanpa pelincir terhadap keluli. Melalui rekaan eksperimen kaedah factorial penuh, sejumlah 36 eksperimen telah dijalankan untuk dua peringkat kelajuan gelendong (100rpm dan 215 rpm), tiga peringkat kedalaman pemotongan (1mm, 2mm dan 3mm) dan tiga peringkat kadar suapan (0.10 mm / putaran, 0.18 mm / putaran dan 0.28 mm / putaran) bawah dua cara pemesinan tanpa pelincir iaitu tradisional dan udara sejuk dengan alat pemotongan bersalut karbida. Kuantiti penggunaan kuasa elektrik, kualiti permukaan dan hayat alat pemotongan diukur dengan peralatan seperti penganalisis kuasa, alat pengukuran permukaan dan pengukuran optic secara video sistem. Hasil kajian menunjukkan bahawa kecekapan kuasa yang lebih baik melalui penggunaan Tube Vortex yang mampu merendahkan suhu pemesinan sebanyak 11.17%, walaupun pengggunaan kuasa elektrik bertambah 2.87% tetapi kuasa specifik pemesinan dikurangkan sebanyak 22.11%. Prestasi pemesinan tanpa pelicir secara traditional adalah lebih baik daripada pengunaan Tube Vortex dari aspek kualiti permukaan iaitu 15.11% lebih licin dan hayat alat pemotongan yang lebih panjang. Keadaan ini berlaku disebabkan oleh kesan penyejukan dari Tube Vortex, kesan ini mampu mengurangkan suhu pemesinan, menurunkan kuasa specifik pemesinan tetapi menghasilkan kesan lesat yang lebih menonjolkan di permukaan keluli yang menyebabkan permukaan lebih kasar, manakala hayat alat pemotong lebih singkat juga disebabkan oleh kesan penyejukkan dari udara sejuk ang membentuk ikatan yang lebih kuat antara cebisan potongan dan alat pemotongan daripada ikatan asal sesama bahan alat pemotongan yang menjadikan tinggalan bahan dari alat pemotongan. Cadangan pemilihan kelajuan gelendong dan kadar suapan yang lebih tinggi bagi kajian masa depan untuk mengkaji keberkesanan Tube Vortex terhadap hayat alat pemotongan dan kualiti permukaan bahan.

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$$\mathrm{N(rotational\ speed, rpm)} = \frac{\mathrm{v(cutting\ speed)}}{\pi \times \mathrm{D_o(original\ diameter\ of\ wokpiece)}}$$

2.2
$$\mathrm{f(feed\ rate, mm/min)} = \mathrm{Nf_f(freed\ rate)}$$

2.3
$$\mathrm{d(depth\ of\ cut, mm)} = \frac{\mathrm{D_o(original\ diameter)} - \mathrm{D_f(final\ diameter)}}{2}$$

2.4
$$\mathrm{T_m(machining\ time, min)} = \frac{\pi \mathrm{D_o L(length)}}{\mathrm{fv}}$$

2.5
$$\mathrm{MRR(material\ removal\ rate, mm^3/min)} = \pi \times \mathrm{D_{avg}} \times \mathrm{d} \times \mathrm{f_r} \times \mathrm{N}$$

2.6
$$\mathrm{V(cutting\ speed)} \times \mathrm{T^n(time\ with\ consant\ n)} = \mathrm{C(onstant)}$$

2.7
$$\mathrm{V} \times \mathrm{T^n} \times \mathrm{f^{n_1}} \times \mathrm{d^{n_2}} = \mathrm{C(constant), n_1 n_2 n_3\ all\ constant}$$

2.8
$$\mathrm{V} \times \mathrm{T^{0.36}} \times \mathrm{f^{0.31}} \times \mathrm{d^{0.13}} = 310$$

2.9
$$\mathrm{R_a(surface\ roughness, \mu m)} = \frac{\mathrm{a + b + c + d} + \cdots}{\mathrm{n}},$$
$$\mathrm{a, b, c = ordinates, n = number\ of\ readings}$$

2.10
$$\mathrm{R_a(surface\ roughness, \mu m)} = \frac{\mathrm{f^2(feed\ rate)}}{8 \times \mathrm{R(nose\ radius)}}$$

2.11
$$\mathrm{R_q(surface\ roughness, \mu m)} = \sqrt{\frac{\mathrm{a^2 + b^2 + c^2 + d^2} + \cdots}{\mathrm{n}}}$$

2.12
$$\mathrm{P_c(power\ at\ tool, kW)} = \mathrm{F_t(tangetial\ force)} \times \mathrm{V_c(cutting\ speed)}$$

2.13
$$\mathrm{P_c(power\ at\ tool, kW)} = \mathrm{Q(material\ emoval\ rate)} \times \mathrm{K_p(power\ constant)}$$

2.14
$$\mathrm{P_c(power\ at\ tool, kW)} = \frac{\mathrm{T_c(torque)} \times \mathrm{n(spindle\ speed)}}{9549}\mathrm{kW}$$

2.15
$$\mathrm{U(specific\ energy\ consumption, N.\frac{m}{mm^3})} = \frac{\mathrm{F_t(force)}}{\mathrm{d(depth\ of\ cut)} \times \mathrm{f(feed)}}$$

2.16
$$\mathrm{U(specific\ energy\ consumption, N.\frac{m}{mm^3})} = \frac{\mathrm{P(machine\ power)}}{\mathrm{MRR}}$$

2.17
$$\frac{\mathrm{P}}{\mathrm{MRR}}\left(\mathrm{N.}\frac{\mathrm{m}}{\mathrm{mm^3}}\right) = \frac{\mathrm{F_t V_c}}{\mathrm{d} \times \mathrm{f} \times \mathrm{V_c}}$$

3.1
$$\mathrm{Full\ factorial\ design} = \mathrm{level\ of\ factor}^{\mathrm{number\ o\ factors}}$$

4.1 $$\mathrm{T_{avg}(average\ temperature, {}^\circ C)} = \frac{\mathrm{T_1 + T_2 + T_3 + T_4 + T_5}}{5}\ \mathrm{{}^\circ C}$$

4.2 $$\mathrm{Power\ consumption, kWh} = (\mathrm{P_{final}} - \mathrm{P_{initial}})\mathrm{kWh}$$

4.3 $$\mathrm{R_{a_{avg}}(surface\ roughness, \mu m)} = \frac{\mathrm{R_{a_1} + R_{a_2} + R_{a_3} + R_{a_4}}}{4}\ \mathrm{\mu m}$$

4.4 $$\mathrm{U(specific\ energy\ consumption, N.\frac{m}{mm^3})} = \frac{\mathrm{P}}{\mathrm{MRR}}\ (\mathrm{N.\frac{m}{mm^3}})$$

4.5 $$\mathrm{MRR(material\ removal\ rate, mm^3/min)} = \pi \times \mathrm{d} \times \mathrm{D_{avg}} \times \mathrm{f} \times \mathrm{N}$$

LIST OF ABBREVIATIONS

AVG	Average
AA	Ambient Air
DOC	Depth of Cut
HSS	High Speed Steel
MQL	Minimum Quantity Lubrication
MRR	Material Removal Rate
MWF	Metal Working Fluid Machining
RHVT	Ranque-Hilsch Vortex Tube
SEC	Specific Energy Consumption
TiNC	Titanium Nitride Coated Tungsten Carbide Insert
VT	Vortex Tube
WC	Tungsten Carbide

CHAPTER 1

INTRODUCTION

1.0 Introduction

A general overview of the project entitled with “Green Manufacturing: Effect of Vortex Tube on Machinability in Dry Turning” is provided throughout this chapter. Vortex Tube for spot cooling during manufacturing process had been started to be implement widely among industry. The purpose of this project is to study on the effectiveness of Vortex Tube on improving the performance of machined product and cutting tool with the consideration of environmental issue and utilization of resources such as carbon footprint.

This chapter started with the brief description on the background of the study, followed by the problem statement. The objectives aimed to be achieved in this project and the scope of the project being extended is discussed and documented in this chapter. The main vision of this project is to have a detailed investigation on the effect of Vortex tube on the machinability of material in terms of power consumption, surface roughness and tool wear in dry machining.

1.1 Project Background

Heat was generated during manufacturing process at the cutting point of three sources which are primary shear zone where the major part of energy converted to heat, secondary deformation zone at the chip-tool interface where further heat generated due to rubbing between tool-chip interface and third is the worn out flank which generated by rubbing between tool and finished surface. The possible detrimental effects of high temperature on cutting tool are: rapid tool wear, plastic deformation of cutting edge, thermal flanking and fracturing of cutting edge, dimensional inaccuracy of workpiece and surface damage by oxidation or rapid corrosion (ME IIT Kharagpur, 2009).

During turning operation, high temperature was generated in the region of tool cutting edge which defined as summation of plastic deformation of involved in chip formation, friction between tool and workpiece and friction between tool and chip. Cutting tool become softens at high temperature, thus thermal dependency tool wear is easily formed and the surface finish of product is affected. The amount of heat loss in cutting edge region is depending on the thermal conductivity of tool and cooling strategy being applied (Sreejith and Ngoi, 2009).

In order to reduce heat generated for the purpose of quality improvement and cost effectiveness, new cooling approaches had been introduced such as near dry machining, cryogenic cooling and compressed air cooling. Thus, as for the environment protection and fulfillment for legislative ISO 14000 Environment Management System in balance with the industrial benefit, the used of chilled air to replace traditional lubricant which to eliminate adverse effect to environment and as improvement for traditional dry machining for better surface quality and prolonged tool life. The used of Vortex Tube for spot cooling had been preferred by industry for its cost effective, user friendly and flexibility of installation compare to other non-lubricant cooling method.

Align with the concept of green manufacturing that encourage the principle of energy resource utilization and environment sustainability improvement, the main measurement being used for the evaluation on effectiveness of different machining condition applied is the energy efficiency. Theoretically, the power efficiency of a machining process is a ratio of absolute minimum energy required (usually refer to the carbon-footprint) for a task to the total amount of removed material. As for experimental measurement, efficiency of machining is also defined as specific energy which refers as the ratio processing power and material removal rate (Dietmair and Verl, 2009).

1.2 Problem Statement

The main core issue being studied in this project is the performance of selected cooling strategy which is the cooling air by Vortex Tube applied in the dry turning compared with the purely dry turning without any cooling strategy in the context of material’s machinability, especially power consumption.

From the background study, the study on effects of cooling strategy had mainly measured by tool wear and surface roughness which cause the insufficient data for comparison of the performance on power consumption and energy utilization. There is a need for a clear defined power consumption measurement method to be established and become standardized judgment for the evaluation of the cooling strategy effects in the context of energy utilization.

This paper present the complete experimental set up for two different cooling strategies used which traditional dry machining and chilled air dry are machining through Vortex Tube with the main measured output in the context of specific energy consumption obtained through formula. The experiment is run under various cutting parameters such as spindle speed, freed rate and depth of cut. The data being collected and analyzed through comparison between both output data from two different cooling strategies with the descriptive statistical tool. This study aims to perform an energy efficiency comparison between the two different cooling strategy implemented during turning process under varying cutting parameters. Other than that, the surface roughness and tool wear also being measured in order to obtain the overall performance comparison and evaluation of material’s machinability for the different cooling strategy chosen in this research.

1.3 Project Objectives

The objectives of the study are:

1. To investigate effect of Vortex tube on power consumption.
2. To investigate effect of Vortex tube on tool wear and surface roughness.
3. To investigate the trend of both cooling method for varying cutting parameters inputs (cutting speed, freed rate and depth of cut).

1.4 Project Scopes

The scopes of the study are:

1. The experimental material is mild steel.
2. The tool material is titanium coated carbide.
3. The measured manufacturing process is turning process.
4. The cooling method is only cooling air dry turning and open air dry machining.
5. Machinability of material is only measure by surface roughness, power consumption and tool wear.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

This chapter presents the academic study on the performance of vortex tube air cooling under varying cutting parameters on the machinability of material from the aspect of power consumption surface roughness and tool life in dry turning compare with environment air dry machining. This chapter starts by defining green manufacturing then follows by the academic review on the vortex tube, workpiece material which is mild steel and machining process, dry turning which involved this project. The machinability of material in the aspect of surface roughness, power consumption and tool life are reviewed in general. Lastly, reviews of previous study that have been conducted on the effects of varying cutting parameter towards machinability of material and the impacts of different cooling method used in machining on the machinability of material are discussed briefly.

2.1 Green Manufacturing

Green manufacturing model defined as a modern manufacturing model to achieve the objectives of environmental protection and resource optimization which consider both product life cycle process and logistics transformation process from start till end of product. The development of green manufacturing technology is not only improving the ecology environment but also bring significant economic benefits through optimizing resource (Liu, 2012).

In a study done by Deif in year 2011, he had developed and proposed a green manufacturing system in order to better understanding certain kinds of systems, their subsystems and their interactions with related system that consists of four stages. Stage one that starts with accessing current situation with quantitative analysis that use to identify the level of greenness of plant. Stage two is development of improvement plan for areas to be improved in the green level without negatively affecting the production in terms of material, energy, process and technology. Stage three is the implementation of plan which to promote the smooth executing of green improvement plan at machine, process and material through energy improvement plan, process improvement plan and technology improvement plan. Stage four is the maintenance of the green level in manufacturing through policies and guidelines. The full overview of the green manufacturing system illustrated in flow chart in Figure 2.1.

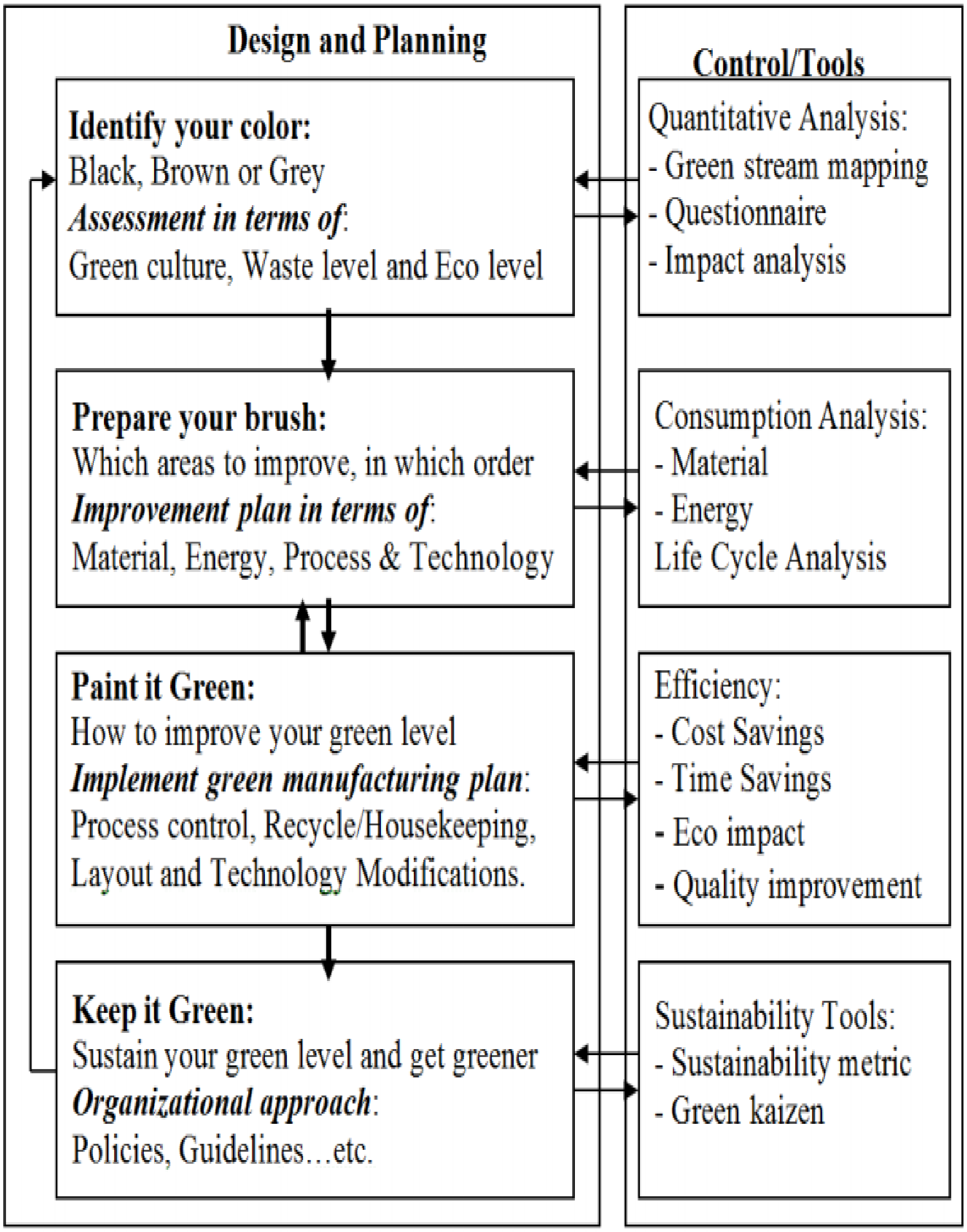

Figure 2.1: Green Manufacturing System

Source: Deif, 2011

A model of green machining strategy had been proposed and designed by Anderberg et. al. in year 2011 correspond to the green manufacturing model in order to assists the manufacturing industry to advance more environmental friendly production. The developed green manufacturing strategy had provided a guideline for industry and researchers in both short terms prospective which refer to the process planning and long term prospective which refers to research and development. In the process planning phase, knowledge about the specific cutting forces and green manufacturing as the entry ticket toward green manufacturing, the process planning phase having primary interface with research and development phase the reviewed on the material properties database, cooling techniques, capability knowledge and tool material development. As it move nearer to the greener machining strategy, it had totally enter the long term perspective which is the completely research and development phase that focus on the machine tool development and machining dynamic damping. The green machining strategy had been illustrated in Figure 2.2.

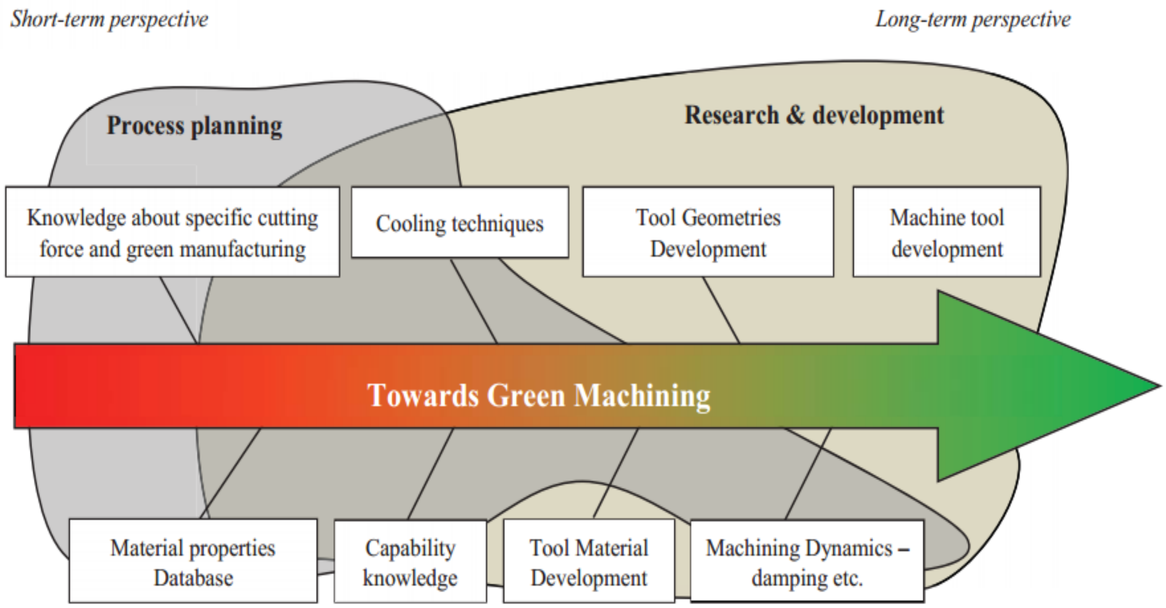

Figure 2.2: Green Machining Strategy

Source: Anderberg at. el,2011

From the green machining strategy it shows the importance on the specific cutting force and cooling method as an input data for consumption analysis in the context of energy consumption for the evaluation of green level of a plant as suggested in the stage two of green manufacturing model proposed by Deif, 2011. In manufacturing process, the energy saving from the entire operational period of machine is one the most needed sustainability factors. In estimation the energy requirement for material removal by machining process with the use of cutting tool, the specific energy is often used. While the cutting energies for machining can depend on many factors such as workpiece properties, presence of cutting fluid (alternative cooling method in the case of no cutting fluid being applied), the cutting tools and the process variable during machining (Davim, 2013). Thus, in this chapter, a review on each affecting factors (workpiece, cutting tool, cooling method and cutting parameters) provided for understanding of its relation towards energy consumption.

2.2 Vortex Tube

The vortex tube is a mechanical device that operates by using an ordinary supply of compressed air as power source, and then separates compressed air into outward radial high temperature region and an inner lower temperature region which creates two streams of air, one hot and one cold without any moving part.

2.2.1 Types of Vortex Tube

There are two classification of vortex tube which are counter-flow vortex tube and uni-flow vortex tube, both of them are using in the industry.

The more popular type of vortex tube being use is counter-flow vortex tube. This type of vortex tube with the working principal that the hot air exits from the far side of the tube is controlled by the cone valve and the cold air exits through an orifice next to the inlet (Vera, 2010). The working mechanism as described was illustrated in Figure 2.3.

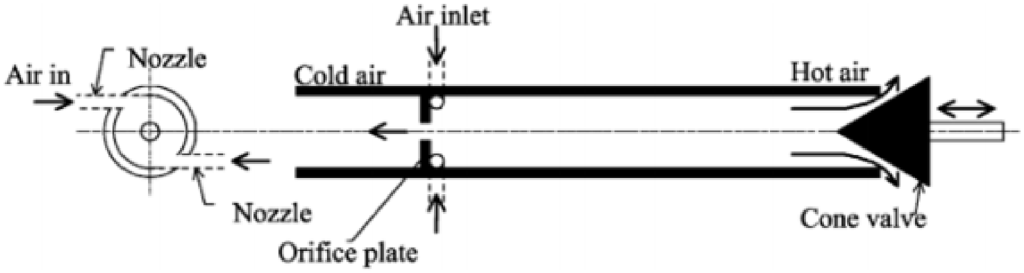

Figure 2.3: Working Mechanism of Counter-Flow Vortex Tube.

Source: Vera, 2010

Another type of vortex tube is uni-flow vortex tube which does not have its cold orifice next to the inlet. Instead the cold air comes out through a concentrically located annular exit in the cold valve. The mechanism for uni-flow tube is similar to the counter-flow vortex tubes the radial temperature separation is still induced inside but the exit of cold air is at the same place of hot air. In general, the sufficiency of it is lower than the counter-flow vortex tube. This type of vortex tube is used in applications where space and equipment cost are of high importance (Vera, 2010).The working mechanism as described was illustrated in Figure 2.4.

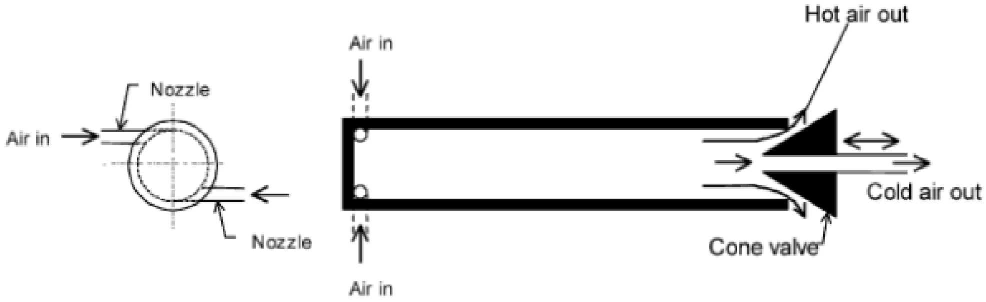

Figure 2.4: Working Mechanism of Uni-Flow Vortex Tube.

Source: Vera, 2010