ANALYSIS OF SPINDLE COOLING SYSTEM

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ABSTRACT

Modern technology has shown that machine tool has played great roles in technology advances and is an ever-increasing productivity and competency throughout ages. The vital developments in industrialize machining was the usage of high speed machining which includes the motorized high speed spindle in manufacturing industries. This development has break the problems regarding delayed time and lower output in production line. However, heat was the primary enemy in this research. Overheating or excessive heat generation has caused lack in accuracy and precision in machining, exposure to wear and fatigue was the result of inefficient cooling system in the spindle cooling system. Thus, an analysis on the spindle cooling system through three parameters; different spindle operating speed, type of coolant and number of radiators has experimented. The result shows that higher operating speed produces more heat around the spindle. Moreover, results also demonstrate higher thermal stability in Ethylene glycol and water (EGW) compared to water at the peak of 6^{th} and 12^{th} hour respectively. In addition, EGW has a significant percentage of efficiency approximately 10% by using single and more than 15% using dual radiator at the minimal speed and astonishing efficiency of more than 39% and 52% for single and dual radiators respectively at speed, 18,000 rpm. In contrast, water only has below 10% of efficiency in any condition of experiment. In conclusion, EGW with single radiator is economically sufficient to remove heat generated in the spindle with efficiency of between 10% and 39% with lower power consumption of 6 Watts.

ABSTRAK

Teknologi moden telah menunjukkan bahawa alat mesin telah memainkan peranan yang besar dalam kemajuan teknologi dan merupakan produktiviti yang semakin meningkat dan kecekapan sepanjang zaman. Perkembangan penting dalam industrialisasi pemesinan adalah penggunaan mesin kelajuan tinggi yang merangkumi spindle bermotor pada kelajuan tinggi dalam industri pembuatan. Perkembangan ini telah menyelesaikan masalah kesuntukan masa dan output yang rendah di barisan pengeluaran. Walau bagaimanapun, haba adalah musuh utama dalam kajian ini. Penjanaan haba terlampau panas atau berlebihan telah menyebabkan kekurangan dari segi ketepatan dan kejituan dalam pemesinan. Pendedahan kepada haba yang terlampau menyebabkan kehausan dan kerosakan akibat ketidakcekapan sistem penyejukan. Oleh itu, analisis pada sistem penyejukan spindle melalui tiga parameter; kelajuan operasi spindle yang berbeza, jenis penyejuk dan pengunaan radiator. Hasil kajian menunjukkan bahawa kelajuan operasi yang lebih tinggi menghasilkan lebih banyak haba sekitar spindle. Selain itu, keputusan juga menunjukkan kestabilan terma yang lebih tinggi dalam etilena glikol dan air (EGW) berbanding dengan air di puncak jam ke-6 dan ke-12 masing-masing. Di samping itu, EGW mempunyai peratusan kecekapan kira-kira 10% dengan menggunakan satu radiator dan lebih daripada 15% menggunakan dwi-radiator pada kelajuan minimum. Manakala, kecekapan menakjubkan lebih daripada 39% dan 52% untuk radiator satu dan dwi-radiator pada kelajuan maksima 18,000 rpm. Sebaliknya air hanya mempunyai kurang daripada 10% daripada kecekapan dalam mana-mana eksperimen. Kesimpulannya, EGW dengan satu radiator adalah memadai dari segi ekonomi untuk mengeluarkan haba yang dijana dalam spindle dengan kecekapan dalam lingkungan 10% dan 39% dengan penggunaan kuasa yang rendah pada 6 Watt.

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α	Thermal Expansion Coefficient
ρ	Density
Δ	Difference or Changes
C_p	Specific Heat Capacity
K	Thermal Conductivity

ABBREVIATIONS

AC	Alternating Current
CNC	Computer Numerical Controller
DC	Direct Current
DOC	Depth of Cut
EDM	Electrical-Discharge Machining
EGW	Ethylene Glycol and Water
ETVE	Environmental Temperature Variation Error
ISO	International Organization of Standards
LBM	Laser Beam Machining
MQL	Minimum Quantity of Lubricant
PAO	Polyalphaolefin
PGW	Propylene Glycol and Water
RE	Radial Engagement
SOP	Standard Operating Procedure
USM	Ultrasonic Machining
VFD	Variable Frequency Drive Inverter

CHAPTER I

INTRODUCTION

1.0 INTRODUCTION

This chapter introduces readers for a better understanding of this project. This chapter compromise of research background, problem statement, research objectives and research scope.

1.1 RESEARCH BACKGROUND

Manufacturing constitutes the economic background of an industrialized nation and, is the key factor in industrial and equipment evolution, and as such, sustaining a country's economic position and improving man's quality of life. Throughout the centuries, machine tools have been manufactured, evolved and perfected to meet a current market challenge which is seen as a catalyst for changes in manufacturing technologies and system.

In the past thirty years, machines have been revolutionized with the incorporation of numerical control, which is a treat to traditional machines, such as lathes, milling machines, grinders and etc. However, with highly sophisticated knowledge-based systems, these traditional machines have evolved into a more capable multi-task machine of milling, grinding, drilling turning and etc., all in one system (López L. N. and Lamikiz A., 2009). Through rapid developments of machine tools, the lathe was evolved through time, developments and numerical control into a more functioning milling machine based on the spindle axis itself. As of today, the vertical milling machine is the most commonly used machinery in manufacturing industry compared to the horizontal, boring and lathe milling machine and etc.

Moreover, industries have shifted towards high speed machining and advanced machining for a more advanced digital control, higher speeds, precise accuracy and greater flexibility that encourages technological competitiveness of productivity and manufacturing processes. Besides that, importance of high speed machining (HSM) is assumed to assist industries in striving to raise their production demand and revenue by increasing the machineries cutting speed and manufacturing processes in the same amount of time.

Motorized high speed machining has help industries to overcome many problems with low output on production floor. Long operating hours on machining has become a common aspect in manufacturing industries, however, the risk in shorting the lifespan of the machine is at stake. In various milling machine operations, the spindle functions to shape the work piece into desired designs of products. However, to meet tight datelines, the motorized high speed spindles operating continuously causes excessive heat generation and thermal deformation in spindles.

Nevertheless, excessive heat generation and thermal deformation in spindles contributes to low accuracy and precision in machining, lack of flexibility, and reduces lifespan of the bearings and the whole spindle system. A spindle cooling system is the solution to this dilemma. A spindle cooling system is divided into air-cooled and liquid-cooled system. Liquid cooling system has proven advantages and contribution over air-cooled system.

A research on liquid-cooling system based on three parameters; different operating spindle speed, type of coolant and number of radiators are studied to overcome this heat generation build-up in motor spindle to fully-utilized the usage of spindle in machining.

1.2 PROBLEM STATEMENT

A common problem in manufacturing industries is the heat generated in motorized components, for example, the heat generation motorized high speed spindle in milling machine operation. The spindle works to shape and perform material removal on raw materials by computer numerical control (CNC) system into desired end products. However, operating at long hours puts the spindle in risk of spindle failure (Zitney E., 2012). Thus a research to study and optimize the spindle cooling system with standard parameters is required. Moreover, experimental researches on the effect of different operating speed with radiator are investigated. Then, a conclusion is drawn to validate the efficiency of the optimum spindle cooling system.

1.3 RESEARCH OBJECTIVES

The objectives of this research are as follow;

- To conduct a fundamental studies on milling machine operations.
- To study the spindle cooling system in milling machine.
- To develop an optimum result of liquid-cooled spindle cooling system using suggested parameters.
- To test the water-cooling system's efficiency.

1.4 RESEARCH SCOPE

The spindle cooling system is the primary focus of this research. The spindle structure and spindle cooling system were investigated. Next, experiments based on suggested parameters are considered. The proposed parameters; such as medium of fluid-cooling system, different operating speed (rpm) and usage of radiators were tested experimentally to study the effects on increasing spindle speed with temperature rise. Moreover, the outcomes validated were the trend of temperature rise, optimum medium of fluid in liquid-cooled spindle cooling system and percentage efficiency of the liquid-cooling system.

CHAPTER II

LITERATURE REVIEW

2.0 INTRODUCTION

Today's development and prosperity of the world was governed and judged by transformation, improvement and upholding of the standard of living and challenges in manufacturing industries. Manufacturing activities has contributes to a country's economic position; which now becomes a modern rivalry in technology development.

Manufacturing process is as a value added processes where raw materials are removed into high utility and valued products with distinct shape and sizes, surface quality and functionality. Manufacturing incorporates a variety of processes which includes casting, molding, forming, machining, joining, rapid manufacturing and etc.

2.1 MACHINING IN MANUFACTURING PROCESSES

Machining is one of the most important elements in manufacturing processes as it drives the economic system towards mass production with increasing demands from consumers. Traditional machining and advanced machining has embark on a journey for better precision, quality and functionality as the industry faces challenges to fulfill consumers requirements and specifications. By definition, machining is one of the various processes of material removal of raw materials into desired shape and sizes in the form of chips, and was collectively themed as subtractive manufacturing.

Apart from that, conventional machining started back in the 18th century when an Englishman, John Wilkinson's "boring mill" that was water-powered; over time, this space for improvement gives alternatives for machines to be steam-powered, leather belts gearing system and finally electric-powered. The next important development in machining was the milling machine. As machining process improves, processes such as; turning, boring, drilling, milling, broaching, sawing, shaping, planning, reaming, and tapping became more essential.

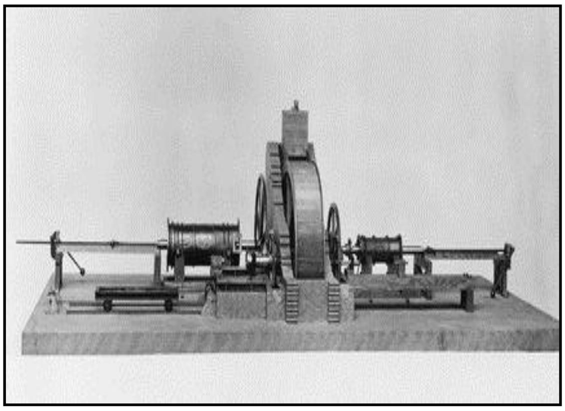

Figure 2.1: Boring mill from Wilkinson's iron works, Bersham, Wales, 1775

Source: Science & Society (2012)

By contrast, the advent of new technologies makes advanced machining seem slightly valuable as industries begin strive to escalate their production and revenue. One of the importances of advanced machining is the need to machine newly developed materials with special properties into intrinsic part geometries, without having surface damages that can be found through conventional machining. To be precise, advanced machining processes includes Electrical-Discharge Machining (EDM), Laser Beam Machining (LBM), Ultrasonic Machining (USM), Water jet Machining, Photochemical machining and etc.

Figure 2.2: Electrical-Discharge Machining (EDM)

Source: CIM Industries (2010)

2.2 MILLING MACHINE

The milling machine was one of the most important developments in the history of machine tools. The milling machine was evolved from the practice or rotary filing in the headstock of a lathe which, dated back in 1760. Between 1912 and 1916, Eli Whitney was the first to invent and developed the true milling machine to produce interchangeable musket parts with the help of power feed, but there were limitations towards Whitney's milling machine; the lack of provision to lift the worktable and lack standardization of measurements at that moment.

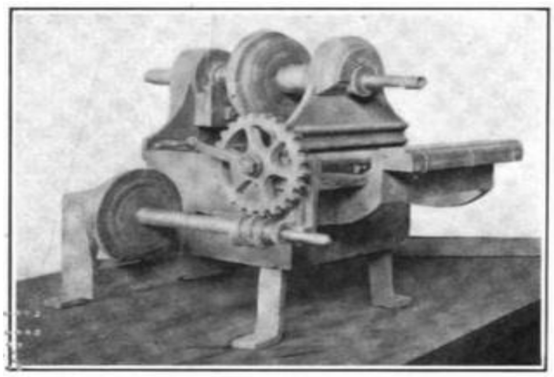

Figure 2.3: Eli Whitney milling machine dated back to circa 1818

Source: www.robinsonlibrary.com (2012)

Besides the limitation's on Whitney's design, the milling machine had an advantage of duplicating the part that could not been manufactured using a file; which was, maintaining the accuracy and uniformity of the design. The advent of technologies have brought a wide varieties of cutting operations on the milling machine, which made the milling machine to have more variations compared to any other family of machine tools.

In addition, improvements and development of the milling machines and components have made the milling machine to improvise on material removal rate (MRR), high accuracy and precision, increasing quality finishing, minimizing errors, and reducing component wear life.

2.3 MILLING OPERATIONS

According to the National Machine Tool Builders Association (2011), milling machine is sold nearly 80 percent in North America as milling is the central issue in machining. As of today, the milling machines can perform a wide range of tasks compared to their primary duty, which was to create flat and square surfaces. Moreover, they shape metal by rotating the cutter and moving it along an axis through the work piece manually. As of today, there are 12 common operation that are divided into four main types; facing, profiling, drilling and boring as explained below.

2.3.1 FACE MILLING

Face milling is the most basic operation in milling machine operation. Basically, face milling is a process of cutting a flat surface using end of the cutter teeth by lowering the cutter below the working surface to the depth of cut (DOC), then setting the engaging of work at a given portion of it diameter, called radial engagement (RE). The most desirable RE is at 66 percent to lengthen the tool life.

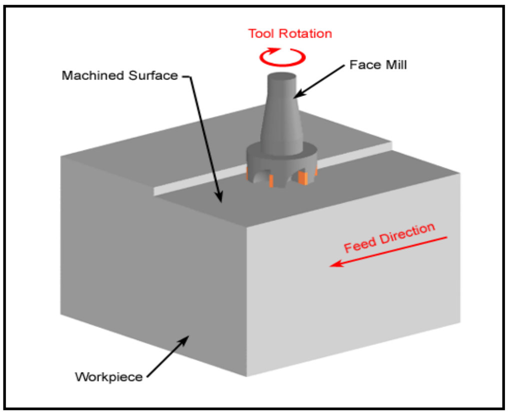

Figure 2.4: Face milling operation

Source: CustomPart.Net (2009)

2.3.2 PROFILING

Peripheral cutting is also known as profiling. Profiling is a process of cutting around the outside or inside surface of the workpiece or a part by using the side teeth of the cutter. Usually, end mill is used as the cutter in any profiling milling operations.

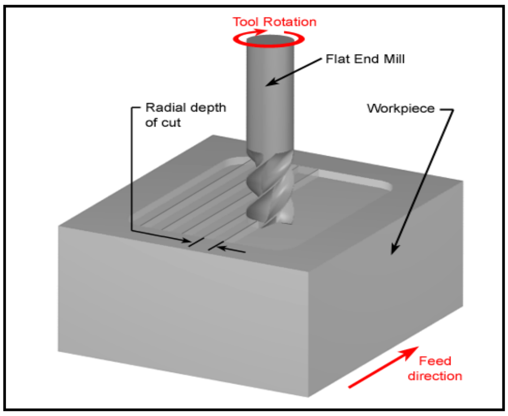

Figure 2.5: Profiling or Peripheral Cutting

Source: CustomPart.Net (2009)

2.3.3 DRILLING

Drilling or reaming is a process of performing a hole or hollow opening. Hole-drilling is usually performed on the milling machine when the hole's position tolerance is tighter than the drill press accuracy. The advantages using the milling machine to drill is that the mill spindles are more rigid compared to drill press and it does not require a center drill to aid the location accuracy as the position of work piece are lock onto the working table.

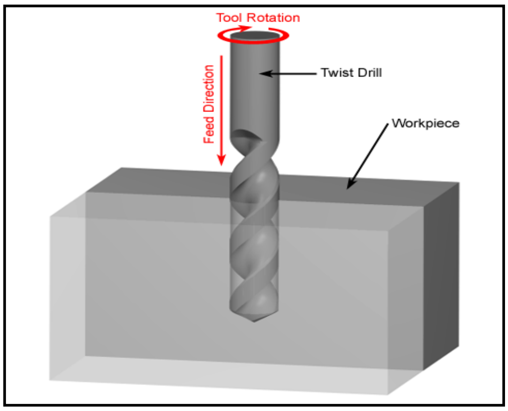

Figure 2.6: Drilling operation

Source: CustomPart.Net (2009)

2.3.4 BORING

Boring is a process done after drilling to give the best location solution by using a rotating, adjustable cutter called boring head. In this operation, a hole is first milled or drilled, then workpiece are taken by dialing the boring tool outward to a bigger radius, then machining passing through a hole. A single-point tool and several passes are used to eliminate out-of-roundness and mis-positioning of the rough hole as boring process tends to machine the hole precisely on the location, very round and straight through the work, without wandering from initial position.

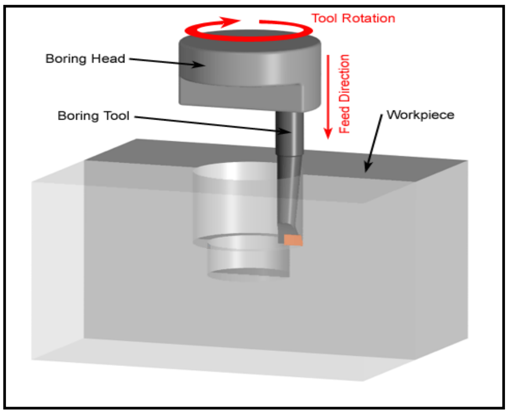

Figure 2.7: Boring operation

Source: CustomPart.Net (2009)

Besides that, the milling machine has other operational methods; such as, step and pocket milling, angular cutting, forming cuts, arbor cutter work, indexed and spaced work, and rotary table work. Moreover, this machine operation can be done over the horizontal or vertical milling machine.

2.4 TYPE OF MILLING MACHINE

Milling machines are difficult to classify as there are various categories of milling machine, and the machines tends to merge within one another. However, they are basically classified into horizontal and vertical milling machine based on the axis of the milling machine spindle.

In horizontal spindle milling machine, the cutters are fit onto an arbor mounted in the milling machine on an axis parallel to the working table. Multiple cutters can also be mounted onto the spindle for some machining operations. However, cutters on the vertical spindle milling machine are placed perpendicular to the working table; but on some occasions, the spindles can be tilted to perform angular cutting operation on the milling machine.

The milling machine are also classified into groups as bed-type, knee-type, ram-type and planer-type milling machines. These machines have their own self-sufficient electric drive motor, coolant system, variable spindle speed and power operated table feeds.

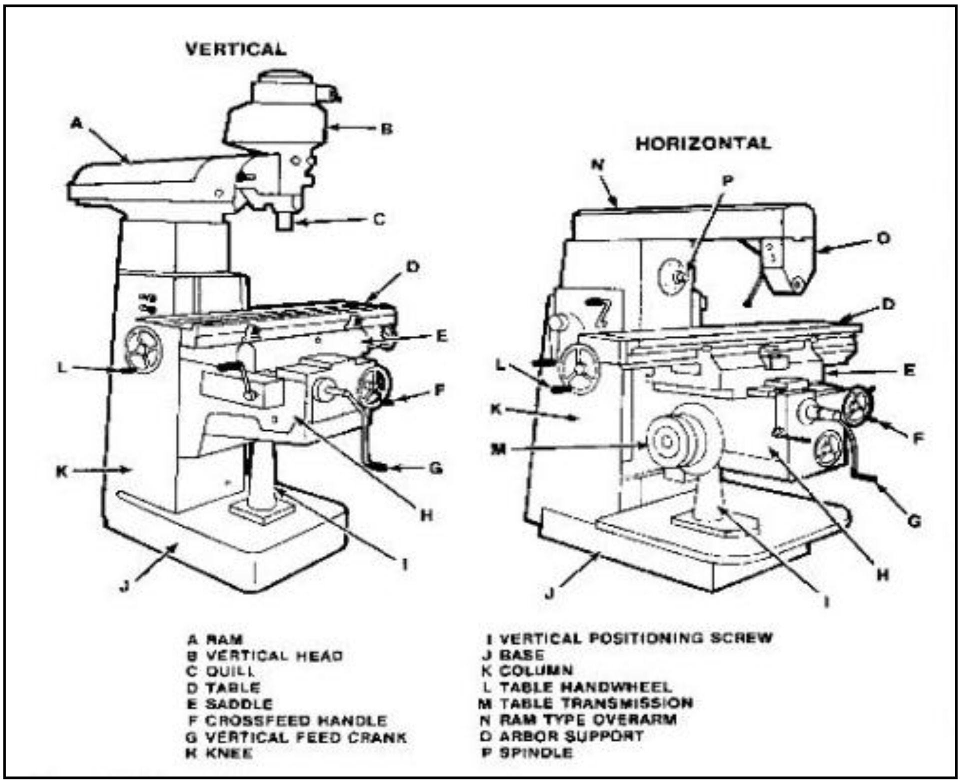

Figure 2.8: Vertical and Horizontal Milling Machine

Source: American Machine Tools Corporation (2012)

2.4.1 MILLING MACHINE CONSTRUCTION

The principle parts of a milling machine (See Figure 2.8) are as follow;

- **Base**. The base serves as the foundation member for all parts that rests on it. It also carries the column at one end while in some machines; the base is left hollowed and works as a reservoir for cutting fluid.

- **Column**. The box shaped that mainly supports the frame that is mounted vertically on the base. The column is heavily ribbed on the inside and houses all