DEVELOPMENT OF AN AUTOMATED COOLANT SYSTEM FOR CNC MACHINE

This report submitted in accordance with requirement of the University Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Robotic and Automation)(Hons.)

by

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ABSTRAK

Dalam industri pembuatan masa kini, dua cara penyejukan yang banyak digunakan adalah cara pemesinan kering dan penyejukan basah. Bagaimanapun, kedua-dua cara penyejukan ini mempunyai keburukan yang akan membawa kesan sampingan kepada bahan kerja, peralatan, kesihatan, ekosistem dan persekitaran. Di samping itu, dalam kegunaan cara penyejukan basah, hanya 10% kepada 15% daripada bahan penyejukan dapat memainkan peranan mereka dalam penyejukan bahan kerja manakala penyejukan selebihnya hanya sia-sia. Ini akan meiningkatkan pembaziran dan pengeluaran kos. Oleh itu, satu idea menggunakan PLC untuk mengawal jumlah bahan penyejuk dan masa bekalan bahan penyejukan telah diilhamkan. Jadi, tujuan projek ini adalah untuk membangunkan satu sistem bekalan penyejukan berasaskan masa dan membandingkan prestasi dengan kaedah penyejukan sebelumnya. Struktur untuk projek ini dibahagikan kepada-dua bahagian utama iaitu perkakasan dan perisian. Dalam bahagian perkakasan, PLC disambungkan kepada injap kawalan bekalan dan melaraskan pembukaan dan penutupan. Dalam bahagian perisian, gambahrajah tangga telah dibina. Masa yang ditetapkan untuk menutup injap dan selepas beberapa jumlah masa yang tertentu, injap akan dibuka dan terus membekalkan bahan penyejukan sebelum tertutup semula mengikut masa yang telah ditetapkan. Analisis digunakan dalam kajian ini adalah prestasi ujian penyejuk tanpa dipunggah serta penyejukan berdasarkan masa, di mana keputusannya adalah merujuk kepada kualiti permulaan bahan kerja. Prestasi bagi setiap selang masa bekalan bahan pendingin dianalisis melalui mendapatkan kekasaran permukaan dari setiap bahagian pengilangan. Bacaan kekasaran permukaan diambil dengan menggunakan Mitutoyo kekasaran penguji di Makmal Metrologi. Keputusan yang diperolehi menunjukkan bahawa permukaan kekasaran untuk 5s penyejukan bekalan adalah lebih tinggi daripada teknik penyejukan lazim manakala kekasaran permukaan untuk 10s ke 20s penyejukan bekalan adalah jauh lebih baik daripada teknik penyejukan lazim. Walau bagaimanapun, keputusan kekasaran untuk 25s penyejuk adalah lebih buruk daripada 20s penyejukan bekalan tetapi ia adalah jauh lebih baik daripada teknik penyejukan yang basah.

ABSTRACT

In current manufacturing industry, two types of cooling methods which are widely used are dry machining and wet cooling method. However, both cooling methods consists of the disadvantages which result in bringing detrimental effects to the workpiece, tooling, health ecosystem and environment. Furthermore, with the used of wet cooling method, only 10% to 15% of the coolants are able to play their role in cooling the workpiece while the rest of the coolants are just wasted. This will increase in waste and production cost. Hence, an idea of using PLC to control the amount of coolants and the timing of the coolants supply is inspired. Therefore, the aim of this project is to develop a time-based coolant supply system and comparing the performance with the previous cooling methods. The structure for this project is divided into two core sections which are hardware and software. In hardware part, the PLC is connected to the washing machine inlet control valve and adjusting the opening and closing of the valve. In software part, the ladder diagram is built. The timing is set to close the valve and after some specific amount of times passed, the valve will open and continue supplying coolants before closing again due to the time settling. The analysis applied in the experiment are performance test of unloaded coolants as well as with time-based coolant, where the result will be referring to workpiece surface quality. The performance for each time interval of coolants supply is analysed through the obtaining of the surface roughness from each milling part. The reading of the surface roughness is taken by the used of Mitutoyo roughness tester in Metrology Lab. The results obtained shows that surface roughness for 5s on-off coolants supply is higher than the conventional cooling technique while the surface roughness for 10s to 20s on-off coolants supply is largely improved and much better than the conventional cooling technique. However, the roughness results for 25s on-off coolant supply is worse than 20s on-off coolants supply but it is much better than the wet cooling technique.

DEDICATION

This report is dedicated to my beloved parents, Chee Chin and Yap Siew Chan as well as my caring and supportive family members who has always stood by my side in facing whatever circumstances. Besides that, I sincerely appreciate and show my highest gratitude to grant my project supervisor, Dr Fairul Azni bin Jafar, lecturers and friends who always helped me with useful guidance and show me the correct path from the beginning to the end of the project.

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LIST OF ABBREVIATIONS

CNC	-	Computer Numerical Control
PLC	-	Programmable Logic Circuit
TCA	-	Trichloroacetic Acid
MQL	-	Minimal Quantity Lubrication
AL	-	Aluminium
AISI	-	American Iron and Steel Institute
CAD	-	Computer Aided Design
CAM	-	Computer Aided Manufacturing
G-code	-	Preparatory Code
FEM	-	Finite Element Method
NDG	-	Near Dry Grinding
LED	-	Light Emitted Diode
USB	-	Universal Serial Bus
PC	-	Personal Computer
I/O	-	Input and output
ICS	-	Intelligent Cooling System
DC	-	Direct Current
AC	-	Alternating Current
VDC	-	Volt of Direct Current
CPU	-	Central Processing Unit
2D	-	2-Dimensional
NOTC	-	Normally-open, Timed-closed
NOTO	-	Normally-open, Timed-opened
HSS	-	High Speed Steel

LIST OF SYMBOLS

%	-	Percent
MPa	-	Mega Pascal
Km/h	-	Kilo meter per hour
L/min	-	Litre per minute
ml/min	-	Millilitre per minute
℃	-	Degree Celcius
ml/h	-	Millilitre per hour
mm/s	-	Millimetre per second
rpm	-	Revolution per minute
mm	-	Millimetre
s	-	Seconds

CHAPTER 1

INTRODUCTION

In this chapter, overview of Computer Numerical Control (CNC) machines, which includes the cleaner application techniques and the method to apply coolants (Arduino and Programmable Logic Circuit (PLC)) in machining is discussed. Next, the inspiration of using PLC to replace the conventional method is discussed in the motivation part. The problem statement, objectives, scopes and report structures are also discussed.

1.1 Background

In current manufacturing industry, the seeking of low prising, high efficiency as well as great quality of product are rising. However, high machining speed, small amount of feed rate and large cut depth is directly linked to a high productivity and which will unswervingly cause the heat generation in profusion and high cutting temperature in the machining region. The overheating of the tooling may diminish its incisiveness and accuracy. Also, using unsharpened cutter will eventually lead to extremely high power usage and poor surface finishing. Thus, faster tool wear, low quality machining and low surface integrity of the product is formed. Therefore, cutting oil is needed in machining in order to make the workpiece cool, diminish friction, and rinse away the chips. Vieira *et al*. (2001) stated that cutting fluids plays an ultimately important role in machining process with the intention of rising the productivity. When the cutting fluid is applied, the quality of the machined surface is able to be enhanced and the tool wear is diminished. Also, the cutting forces is minimized and therefore the energy is saved.

In year 2005, nearly 38 manual transmission lubricants are used in machining and probable increase of 1.2% over the forthcoming decade. The highest demand of the cutting oil is mineral-based cutting fluid which is widely used around the world. However, this mineral-based cutting fluid has strong negative impacts to health and environment. Shashidhara & Jayaram (2010) stated that approximately 80% of all work-related contagions of the workers were because of close skin interaction of operator with cutting fluids. Besides that, greatly use of poisonous and less biodegradability cutting fluids can cause severe health problems like respiratory infections, lung cancer, dermatological as well as inherent diseases and also numerous techno-environmental problems (Ozcelik *et al*., 2011).

Moreover, Klocke and Kuchle (2011) said that a special incineration sites is purposely made in order to burn cutting fluid which containing of chlorinate. This is because that the toxic components in the cutting fluid can cause uncontrolled burning. Thus, it is categorised as a risky and dangerous waste to biological life and environment. Salate *et al.* (2008) defined that the discarding of cutting fluids will result in an upsurge of carbon dioxide releases to the surrounding and as a result of global warming occurrence. Besides that, chemical Trichloroacetic Acid (TCA) in cutting fluids is associated with high-level ozone depletion.

Since all the three aspects i.e. health, environment and economy had been seriously affected from the use of coolant fluids, there are methods of application of cutting fluids in CNC machine that were investigated in order to obtain the optimal method of application. The investigation includes the comparisons of dry machining, conventional flood lubrication (wet cooling), and minimal quantity lubrication (MQL) regarding to the tool wear, surface roughness, temperature deviation with the alteration in depth of cut and amount of coolant used.

a) Dry Machining

The theory of dry machining consists of many benefits, for example non-contamination of the atmosphere, surrounding or water, no waste which lead to the lessening of discarding and cleaning cost, no threat and risk to health for example severe skin problem or allergy. Groover (2002) stated that the benefits of using dry machining is able to lengthen the tool life but in the condition of low cutting speed. The low cutting speed leads to a low production rate. Also, dry machining causes negative impact like overheating the tools. Diniz *et al*. (2002) defined that high friction occurs among the tool and workpiece can lead to obviously upsurge of the temperature and eventually results in higher standard of oxidation, abrasion and diffusion. Moreover, Diniz and Micaroni found that the excessive heat occurring in the workpiece will consequently impede the achievement of tight tolerances and metallurgical damage. Hence, in such circumstance, dry machining is considered neither practical nor commercial.

b) Conventional Flood Lubrication (Wet Cooling)

Flood lubrication is the most common application method used in CNC machine. This method delivers a stable flow of fluid to the workpiece or tool chip interface for machining operation (Groover 2002). Imran *et al*. (2013) revealed that using conventional flood lubrication will result in a large degree of surface deformations with high dislocation density in nanocrystalline grain structures. Also, Imran *et al*. concluded that the key wear mechanism for flood cutting were diffusion, abrasion and micro-chipping. In additional, there is an abundant waste of cutting fluids which lead to a high production costs.

c) Minimal Quantity Lubrication (MQL)

Jayal *et al*. (2009) defined that MQL is an environmentally friendly and economically beneficial method. In MQL technique, aerosol concept which is mixing a very small quantity of cutting fluids and air had been used and the mixture is sprayed in the cutting zone with the use of nozzle (Varadharajan *et al*., 1999). The major advantages of MQL are decreasing in cutting fluids consumption, reducing cost, decline of negative influence to the environment, as well as enhanced overall performances in machining operation and apparent quality (Fratila, 2009). Furthermore, several researches had been done to prove that MQL provides better performance than dry and wet machining. Li & Lin (2012) explored that MQL is able to dramatically reduce the surface roughness, improve tool lifespan and burr development. Heinemann *et al*. (2006) noticed that with the non-stop and constant application of MQL in drilling could significantly improve cutting tool life. Moreover, Li and Lin (2012) found that the use of MQL in micro grinding has obtained a remarkably decrease in surface roughness and a significant enhancement in tool life. In addition, low residue of lubricant are left on the chips, workpiece and tool holder hence their cleaning is easier and cheapest. Thus, MQL can diminish both the environmental threats and manufacturing fee.

With the comparison of the three application methods, the concept of MQL application has been chosen to be the basis of this research work. This is because of its vast benefits in enhancing machining performance, reducing the cost related with the removal of used oil and also minimizing the machine-tool cleaning cycle time and energy usage. Elahi *et al*. (2015) had proposed a research named Intelligent Cooling System (ICS) for machining. This system applied MQL method and used integrated Arduino micro-controller in controlling the amount of coolant used. In this system, temperature sensors are used in detecting the cutting zone temperature and once the temperature of the work piece had reached a fixed temperature, the integrated Arduino micro-controller then open the solenoid valve to supply the fluids as a continuous supply for a limited time until the temperature is reduced back. From this research work, an idea on using time-based supply coolant with the help of PLC is inspired.

The goal of this research work is to develop an automated coolant supply system with the help of Programmable Logic Circuit (PLC) to control the amount and the timing of the coolant needed. By using this technique, it is expected that almost similar product quality can be produced, tool wear lifetime is reduced, and more environmental friendly condition can be achieved as regards to current conventional flood cooling technique.

1.2 Motivation

This project is an inspiration from the idea of improving the wet cooling technique. In the past, wet cooling technique with an application of stable flow of coolant to the workpiece and tool chip interface has been widely used. In this system, a large amount of coolants is being projected but just a small amount is able to play their role. However, the coolant has to undergo recycle frequency, which is about 2 to 3 weeks' time. This has leads to a waste in coolants and directly cause the increase of production cost. Hence, due to this particular disadvantages, an idea of using MQL method with the help of PLC is inspired. By using PLC, time-based coolant supply is implemented and it is believed that the coolant recycle frequency is able to be lengthen to 2 to 3 months' time and hence reduce the cost.

1.3 Problem Statement

Currently, most of the conventional CNC machines are using flood cooling method in order to reduce friction between workpiece and tooling, to remove the heat of the workpiece and also rinse away the chips. However there are three major problems exist with the used of wet cooling method and consequently bring result to the development of PLC control based coolant supply (time-based supply). That is with the use of excessive coolant in an extended period, health and environment will be severely affected. Also, the flood cooling method supply a large amount of coolants to cool down the workpiece, however there is only 10% to 15% of the coolant that able to play their role in cooling the workpiece while the rest of the coolants are just wasted. This has caused the increase in waste and production cost. Moreover, machine-tool cleaning cycle time is long and finally leads to a waste of manpower. Thus, in order to minimize the usage of coolants, reduce the production cost, and shorten the machine-tool cleaning cycle time, a PLC control based coolant supply is proposed to eliminate these problems.

1.4 Objective

The objective of this project are:

i. To develop an automated coolant supply system with the used of PLC to control the amount supply and timing of the coolant.
ii. To analyse the performance of the developed system.

1.5 Scope

The scope work of this project are:

i. The system will be operated by using Keyence Programmable Logic Circuit (PLC)
ii. 10mm high speed steel tooling is in used.
iii. Several fixed variables will be set such as 250mm/s feed rate, 1500rpm of spindle speed and 0.5mm depth of cut are in used. These variables are determined by Das *et al*. (2015).

iv. The cutting fluid used is Al Soluble Extra and other types of cutting fluid will not be considered.

v. Workpiece will be AISI 304L only, other type of workpiece material will not be considered. .

1.6 Report Organisation

This report consists of five key chapters which are introduction, literature review, methodology, discussion and conclusion. Some short reviews are discussed in subsequent chapters. First of all, chapter 1 is discussed about the introduction of the whole report. In chapter 1, background of the project, the motivation, objectives, problem statement and scope of study will be covered.

Chapter 2, Literature Review involves of a lot of researches and findings that related to the CNC machine, types of coolants supply and automated supply system will be discussed. Comparisons between five types of cooling techniques had been undergone and the best cooling technique which is MQL has been selected to proceed the project. Also, the benefits and the applications of Arduino microcontroller and PLC had been further discussed.

Next, chapter 3, Methodology shows various types of methods that are used to fulfil and succeed the objective and scope of the project. Project flow is discussed thoroughly with the used of flow chart. Bill of materials had been listed out and each materials in use is discussed. Also, experiment procedure to examine the performance had been covered.

Chapter 4 contains the software and hardware development. For the software development, details of ladder diagram are discussed over while for the hardware development, the specific particulars about the connection of electrical and mechanical parts are covered. Unloaded and loaded testing are undergone in order to analyse the performance of the system.

Chapter 5 concludes the objectives achieved of this project and also discussed on the outcomes of the testing. Also, the recommendations for future works to boost the system are suggested.

Chapter 2

LITERATURE REVIEW

This chapter describes about the details of the research works that had been previously done. In this chapter, history of CNC machine, type of coolant system, and control of automated coolant system will be described thoroughly and the information obtained will become the guideline to proceed and succeed this project.

2.1 Computer Numerical Control (CNC) Machine

CNC machine consists of a mini computer or a microcomputer which performs as the controller unit of the machine. The computer and prepared program of coded alphanumeric data in the machine are used to control, automate as well as monitor the motions and movements of the workpiece or tool. CNC machine also capable in inserting different parameters for example depth of cut, feed rate, speed and also tuning on/off the spindle as well as the functions of cutting fluids on/off. The advantages of CNC machines are:

- Able to perform constant repetitive tasks
- High precision and accuracy in machining process
- Short machining time
- Better manufacturing flexibility and minimized human errors

Nonetheless, Sutherland (2003) claimed that in the year 1960s, had successfully invented and developed the SKETCHPAD system and it can be considered as a great milestone of research achievement in computer graphics. After year of evolution, computer graphic had finally evolve to the development of Computer Aided Design (CAD) but it is just two dimensional drawing and drafting in the early stage. Requicha (1980) stated that the solid modelling emerged to describe three-dimensional products and it has been seen an increase using of solid modellers and three-dimensional CAD systems. Besides that Computer Aided Manufacturing (CAM) has been introduced to manufacture the products. However, there is very little or no linkage and communication between the CAD and CAM (Han, 1996).

Next, computers were known to a manufacturing sector in order to compute and regulate the cutter movements of machine tools however this requires a lot of mastery skills in identifying and interpreting the shape details from engineering drawings. Therefore, a special languages which are able to translate the drawing details into the computer-controlled machine tool were developed (Mortenson, 1985). The CNC machine is programmed by G-code (ISO 6983) which the cutting tool movement is largely altered and moved in terms of the feed rates of axes and position (Taylor *et al*., 2010).

G-code, also known as preparatory code is a well-accepted standard in worldwide. This is a language which guided the machine tools on the path to move, the destination of the tooling, the spindle speed, the feed rates as well as the X, Y, Z for axis motion. Besides that, it is written in sentence-like format and all the programs will be executed and performed by control in step-by-step, successive order. Hence, a distinctive sequence of CNC words are make-up as commands in order to interconnect what the machine is planned to move. Below indicates the types of actions that are able to be performed by the control of G-codes:

- Rapid movement (transport the tool to the set location in very fast pace)
- Controlled feed in a straight line or arc
- Set tool information such as offset, feed rate, spindle speed and etc.

In additional, G-codes is able to be applied in a variety of applications that are milling machine, drill press, lathe, router, grinder, welder, sheet-metal stamping machine, laser, tube bending machine and etc. Thus, with the applications of G-codes in CNC machine, a task with high repetitive, high precision and accuracy as well as high quality is produced. As a result, high productivity is produced. However, heat production and dissipation at the cutting zone because of the friction happened at the clearance face of the cutter and workpiece, friction at the toolchip contact point, as well as the overheating of the tooling is the crucial adverse factor in affecting the quality of products and as a result in decreasing the productivity.

Vieira *et al*. (2001) revealed that cutting fluids plays an ultimately vital role in machining process with the intention of rising the efficiency and productivity. With the application of cutting fluids, heat generation in machining is significantly reduced, distortion of the work piece is minimized and thus the surface roughness is dramatically improved. Davim *et al*. (2007) stated that surface quality is directly linked to the evaluation of productivity of machine tools and mechanical parts. Therefore, cutting fluids is crucially important in machining process. Moreover, there are three types of coolants supply system that help in increasing productivity and decreasing the heat generation. Details of these three different types of coolant system will be discussed in next session.

2.2 Coolant Supply System (Cooling techniques)

The heat and friction produced in machining will result in bringing a deleterious effect to cutter and superficial layer of the work pieces. Therefore, with the use of coolant, a slight decline in temperature between cutter and work material is able to be achieved and in results of extensively enhances the cutter lifespan and surface finish. The characteristics of the cooling techniques at the cutting zone must be clearly understood so that the heat produced in machining can be reduced successfully and it may result in an effective and economic machining. Sharma *et al*. (2009) stated that numerous cooling techniques had been introduced to control the temperature at the cutting zone and in result of productivity is upgraded and the general effectiveness of the process is amplified.

2.2.1 Dry Machining Cooling Techniques

Dry machining is defined as machining without coolants applied to cool down the tool and work piece in machining process. The major benefits of using this method is this method is able to create a healthy and clean environment as it entirely eliminates the cutting fluid. A number of advantages can be achieved with dry machining is it does not trigger any contamination of water resources, air or atmosphere, no occupational danger to health and significant cost reduction as there is no maintenance and disposal cost (Sreejith & Ngoi, 2000). Groover (2010) claimed that dry machining is desirable and optimum when working at lower cutting speed. This resulted in low production rate is formed and tool lifespan is able to be lengthen. Moreover, Sreejith *et al*. (2000) defined that the dry machining is become more widely used because of the lower cost and reduce undesirable influence to the atmosphere, ecosystem and well-being problems in the shop floor.

Table 2.1: Balance of positive and negative impacts in dry machining.

Positive impacts of dry machining	**Negative impacts of dry machining**
Clean and healthy working environment	Productivity reduction
No coolant emissions to environment	Poor product quality
No cost for coolant, its maintenance and disposal	Dry dust generation
Meeting environment regulations	

However, problems like overheating between the tool and workpiece is largely happened. The high friction occurred in dry cutting condition will directly obviously upsurge the temperature and causing in high level of diffusion, abrasion and oxidation. Also, high friction results in dry machining will lead to high tool wear and built-up edge formation, which affects machined surface finish. Hence, due to the maintaining of the great surface quality, the feed rate and speed had to slow down and this directly decline the productivity and rises the production cost. Moreover, the large amount of heat will obstruct the tight tolerances achievement and occur the metallurgical destruction to the surface layer of workpiece (Diniz, 2003). Furthermore, the worsening on the machined superficial layer due to the chip formation, is unable to be washed away. Therefore, Alves *et al*. (2008) explored that eliminating coolants in some machining is impossible.

Figure 2.1: Dry Machining.
(Source: https://www.ctemag.com/news-videos/articles/coolgroove)

As a result, Braga *et al*. (2002) had conducted an experiment to find out the most suitable cutting condition for dry cutting by not affecting the surface roughness of workpiece, obtaining suitable cutting power, and a longer tool life. The experiment is carried out with the used of coated carbide inserts in steel turning process. From the experiment, dry cutting will result in smaller surface roughness. This is due to the dry cutting will affect the temperature of the work materials close to the cutting region and directly result in declining of the hardness and strength. This consequences in the formation of chips become much easier, the cutting force is decreased and therefore the roughness is decreased. The higher the feed rate, the greater the surface roughness. Hence, in order to make the dry cutting process more suitable to be used, the feed rate should be increased.

Moreover, dry cutting obtained a smaller cutting power. This is because the dry cutting will cause the upsurge of the workpiece temperature and consequences the hardness and strength of the workpiece decline. Hence, the decrease of the cutting power occurred. Also, the cutting power will rise when the speed is rise, however the power will be constant or even smaller when the feed is increased. Thus, Braga *et al*. (2002) concluded that the application of dry cutting is applicable when the condition of higher feed and lower cutting speed is applied. From this, tool lifespan will slightly improve, cutting power will largely decline and surface roughness will remain unchanged.