SYSTEM CONFIGURATION OF AUTOMATED COOLANT SUPPLY FOR OPTIMAL SYSTEM AND SURFACE FINISH IN CNC MILLING OPERATION

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A thesis submitted
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Doctor of Philosophy

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DEDICATION

To Mohd Ghazali,

My amazing husband,

Whose sacrificial care me and our children,

Made it possible for me to complete this research work,

My beloved children, Nur Fatin Najla, Nur Qaisara Humaira, Nur Sofia Khadeeja and Muhammad Waiz Naufal

My adored siblings, Faizul, Fariza, Fairuzi, Faridah, Fadilah, Fauziyah, Norihah, Faizah and Norhayati...

For endless support, cooperation, encouragement and understanding

Thank You from the bottom of my heart and Love You forever

ABSTRACT

During the machining process, flood cooling is mostly utilized to cool and lubricate the interface between the cutting tool and the work piece. The negative health impacts of coolant use combined with the possible financial benefits of utilizing greener machining techniques are forcing manufacturers to change and create alternative lubricant application techniques. Dry machining and Minimum Quantity Lubricant (MQL) machining have emerged as alternatives to flood cooling. Dry machining saves energy by eliminating fluid, but might be less effective for high efficiency, superior surface finish, and demanding cutting conditions. MQL is a coolant-supply technology that improves surface finish, cutting temperature, cutting force, tool life, and dimensional precision by supplying a very small amount of coolant to the cutting zone. Inspiring by the MQL concept, a good surface finishing can be achieved with small amount of coolant. Therefore, this research work is focusing on developing an Automated Coolant Supply (ACS) system in CNC Milling and Turning where Programmable Logic Controller (PLC) system and Arduino are used to control the amount of coolant used during machining by using timer to supply coolant intermittently to achieve a better surface finishing.The automated coolant supply system consists of two main design components. The first core is the design of the nozzle system and the second core is the development of the program. The mechanical part combines jig, piping, nozzle, valve, coupling, and pneumatic fittings. While in the electrical part, all the electrical components such as relays, lighting socket, voltage regulator and valve are linked together to perform the system. The results of this research work showed that the optimal setting for ACS system are cutting speed = 1600 RPM ; feed rate=150 mm/rev ; depth of cut = 0.6 mm ; angle position of nozzle = 135º ; interval time = 23 s ; distance of nozzle 80 mm with the use of nozzle rectangular 1 (5 mm x 1 mm). The best surface roughness and cutting force are achieved at this optimal condition with 0.4787 µm and 9.8488 N respectively. This value is the lowest compared with dry, flooded and Minimum Quantity Lubrication method and it is prooved through asurface morphology observation. By applying this new ACS system, higher machining precision would be obtained, production costs and coolant consumption during machining will be reduced and a greener environment will be achieved. To achieve a better surface roughness, it is recommended that the effect of different interval time settings when turning the coolant ON and OFF (e.g. 5 seconds on and 10 seconds off) should be studied. Additionally, controlling the interval time settings from a smartphone for this system should also be considered and developed as an element of IR4.0.

SISTEM KONFIGURASI BEKALAN CECAIR PENYEJUK BERAUTOMATIK UNTUK SISTEM OPTIMUM DAN KEMASAN PERMUKAAN DALAM OPERASI PENGISARAN CNC

ABSTRAK

Semasa proses pemesinan, penyejukan banjir kebanyakannya digunakan untuk menyejukkan dan melincirkan antara muka antara alat pemotong dan bahan kerja. Kesan kesihatan negatif penggunaan penyejuk digabungkan dengan kemungkinan faedah kewangan menggunakan teknik pemesinan yang lebih mesra alam memaksa pengeluar menukar dan mencipta teknik aplikasi pelincir alternatif. Pemesinan kering dan Pemesinan Kuantiti Minimum (MQL) telah dipilih sebagai alternatif kepada penyejukan banjir. Pemesinan kering menjimatkan tenaga dengan tidak menggunakan cecair, tetapi mungkin kurang berkesan untuk kecekapan tinggi, kemasan permukaan yang unggul dan keadaan pemotongan yang tertentu. MQL ialah teknologi pembekalan penyejuk yang memperbaiki kemasan permukaan, suhu pemotongan, daya pemotongan, hayat alat dan ketepatan dimensi dengan membekalkan sejumlah kecil penyejuk ke zon pemotongan. Diilhamkan oleh konsep MQL, kemasan permukaan yang baik boleh dicapai dengan jumlah penggunaan penyejuk yang kecil. Oleh itu, kerja penyelidikan ini tertumpu kepada pembangunan Sistem Bekalan Sejuk Automatik (ACS) dalam Pengisaran CNC dan pelarikan CNC di mana sistem Pengawalan Program Logik (PLC) dan Arduino digunakan untuk mengawal jumlah penyejuk yang digunakan semasa pemesinan dengan menggunakan pemasa untuk membekalkan penyejuk secara berselang-seli. Objektif kerja penyelidikan ini adalah untuk mencapai kemasan permukaan yang lebih baik dengan aplikasi sistem ACS. Sistem bekalan penyejuk automatik terdiri daripada dua komponen reka bentuk utama.Teras pertama ialah reka bentuk sistem muncung dan teras kedua ialah pembangunan program. Bahagian mekanikal menggabungkan jig, paip, muncung, injap, gandingan, dan kelengkapan pneumatik. Manakala di bahagian elektrik pula, semua komponen elektrik seperti relay, soket lampu, pengatur voltan dan injap disambungkan bersama untuk melaksanakan sistem. Hasil penyelidikan ini menunjukkan bahawa, tetapan optimum untuk sistem ACS : kelajuan pemotongan = 1600 RPM ; kadar uluran = 150 mm/rev ; kedalaman pemotongan 0.6 mm ; kedudukan sudut muncung = 135^o ; masa selang 23 s ; jarak muncung = 80 mm, dengan penggunaan muncung segi empat tepat 1 (5 mm x 1 mm). Kekasaran permukaan dan daya pemotongan terbaik dicapai pada keadaan optimum ini dengan 0.4787 µm dan 9.8488 N masing-masing. Nilai ini adalah yang paling rendah berbanding kaedah pelinciran kering, banjir dan pelinciran kuantiti minimum. Dan ia dibuktikan dalam pemerhatian morfologi permukaan. Dengan menggunakan sistem ACS baharu ini, ketepatan pemesinan yang lebih tinggi akan diperolehi, kos pengeluaran dan penggunaan penyejuk semasa pemesinan akan dikurangkan dan persekitaran yang lebih hijau akan dicapai. Untuk mencapai kekasaran permukaan yang lebih baik, adalah disyorkan untuk mengkaji kesan tetapan masa selang yang berbeza apabila melakukan pelarikan semasa menghidupkan dan mematikan penyejuk (contoh : 5 saat dihidupkan dan 10 saat dimatikan) perlu dikaji. Selain itu, pengawalan tetapan masa dari sebuah telefon pintar seharusnya dipertimbangkan dan dibangunkan sebagai satu elemen IR4.0.

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LIST OF SYMBOLS AND ABBREVIATIONS

D,d	-	Diameter
s	-	Cutting speed
π	-	Phi (3.142)
mm	-	Milimeter
MPa	-	Mega pascal
N	-	Newton
s	-	Second
µm	-	Mikrometer
RPM	-	Revolution Per Minute
m	-	Meter
^{o}	-	Degree
AISI	-	American Iron and Steel Institute
CAD	-	Computer Aided Design
CAM	-	Computer Aided Manufacturing
CNC	-	Computer Numerical Control
LED	-	Light-emitting Diode
MQL	-	Minimal Quality Lubrication
NC	-	Numerical Control
PCB	-	Printed Circuit Board
PLC	-	Programmable Logic Controller
STL	-	Standard Template Library

LIST OF PUBLICATIONS

Indexed Journal

Farizan, M.N., Fairul Azni, J., Chee, K.S., Mohd Hadzley, A.B., Ahamad Zaki, M.N., 2019. The Effect of Automated Coolant System on Surface Roughness during Machining Aluminium Alloy. *International Journal of Recent Technology and Engineering (IJRTE)* pp.5960-5964, Vol. 8 – 2. Blue Eyes Intelligence Engineering & Sciences Publication.

Non-Indexed Journal

Farizan, M.N., Fairul Azni, J., Mohd Hadzley, A.B., Wan Nur 'Izzati, W.M.H., 2019. Surface Roughness Performance during Machining Aluminium Alloy using Automated Coolant System. *International Journal of Recent Technology and Engineering (IJRTE)* (Vol. 8-4, pp. 11025-11028). Blue Eyes Intelligence Engineering & Sciences Publication.

Farizan, M.N., Fairul Azni, J., Aisyah, J., Wan Nur 'Izzati, W.M.H., Mohd Hadzley, A.B., 2020. PLC Based Automated Coolant Supply System for Machining AISI 304L in CNC Milling. *Intelligent Manufacturing and Mechatronics (*pp.0-13). Springer Nature Singapore Pte Ltd.

Wan Nur 'Izzati, W.M.H., Fairul Azni, J **Farizan, M.N.,** Fairul Azni, J., Ahamad Zaki, M.N.,2019. Machinibility Performance of CNC Turning Based on Automated Coolant Supply System. *International Journal of Innovative Technology and Exploring Engineering (IJITEE)* (Vol.8-10, pp.3953-3957). Blue Eyes Intelligence Engineering & Sciences Publication

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Lecture Note

Farizan, M.N., Fairul Azni, J., Aisyah, J., Wan Nur 'Izzati, W.M.H., Mohd Hadzley, A.B., 2020. PLC Based Automated Coolant Supply System for Machining AISI 304l in CNC Milling. *Lecture Notes in Mechanical Engineering* pp. 569-579. Elsevier B.V.

CHAPTER 1

INTRODUCTION

1.1 Background

Machining is defined as a controlled process that transforms the raw material into the desired final shape and size through a process such as cutting, abrasive process and non-traditional machining. An excellent dimensional tolerance, sharp corners, grooves, fillets, different geometry and good surface finish can be achieved through machining processes (Susmitha et al., 2016). Numerous variables affect surface finish and vibration during machining operations, such as workpiece materials and feed rate, cutting tool, spindle speed, cutting depth, coolant, tool nose diameter, tool edge angles and tool design (Lawal et al., 2016). In addition, optimal cutting conditions can reduce the time and expenses of manufacturing costs and boost surface finishing.

During the machining process, the quality of the product is an essential factor. The surface finish is vital to a material's reliability, affecting functional properties such as wear resistance, fatigue strength, corrosion resistance and friction (Raju et al., 2013). High temperatures are produced at the cutting edge and the workpiece during machining, affecting the cutting tool's wear rate. There are also frictions between the chip and the cutting tool, which minimize tool life and reduce the surface finish quality. Figure 1.1 shows heat generation during the machining operation at the cutting zone. The maximum amount of heat produced is the sum of the heat generated by the plastic deformation of the chip, the friction between the tool and the chips, and the friction between the tool and the workpiece. The chips retain an enormous amount of heat created (about 80 percent) out of all the heat generated and the rest is distributed between the workpiece and the machine (Thakur and Gangopadhyay, 2016).

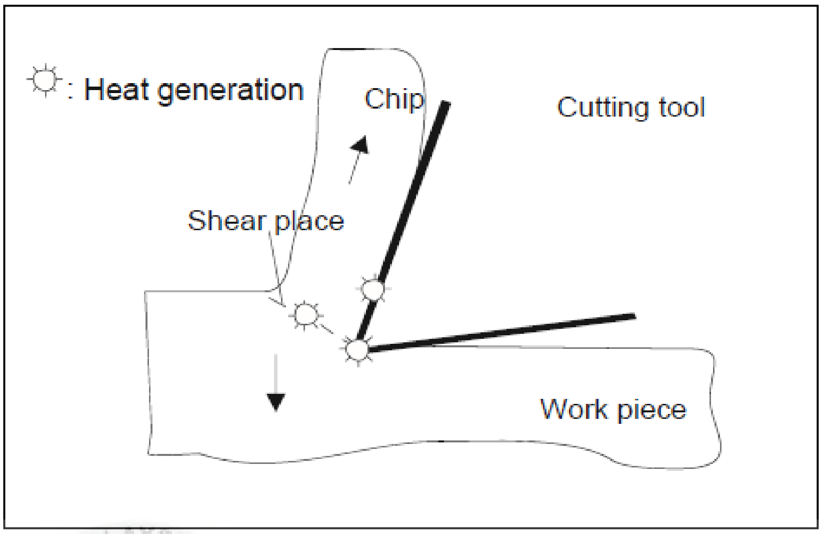

Figure 1.1: Heat Generation During Machining Operation (Raval et al., 2016)

Therefore, the cutting fluid is used during the machining process to remove heat by extracting it from the cutting tool and the workpiece interface and thus prevents the tool from reaching its critical temperature range (Sharma et al., 2014). Their consumption in the machining sector is rapidly increasing due to the benefits of cutting fluids. The quantity of cutting fluids used in machining was recorded as close to 38 Mt in 2005, with an estimated 1.2 percent increase over the next decade (Debnath et al., 2016). The objectives of fluid-cutting applications for metal cutting have been identified as cooling and lubrication. In addition, cutting liquids can help to remove chips from the hole, control the formation of chips and reduce the contact length between the chip and the tool. This condition has a beneficial impact on breaking the chip and enhancing tool life (Narayanan et al., 2014). They also carry chips away from the machining area, minimize the built-up edge (BUE) and defend machine components and parts of machine tools from corrosion. Figure 1.2 shows some techniques to reduce heat generation during the turning operation.

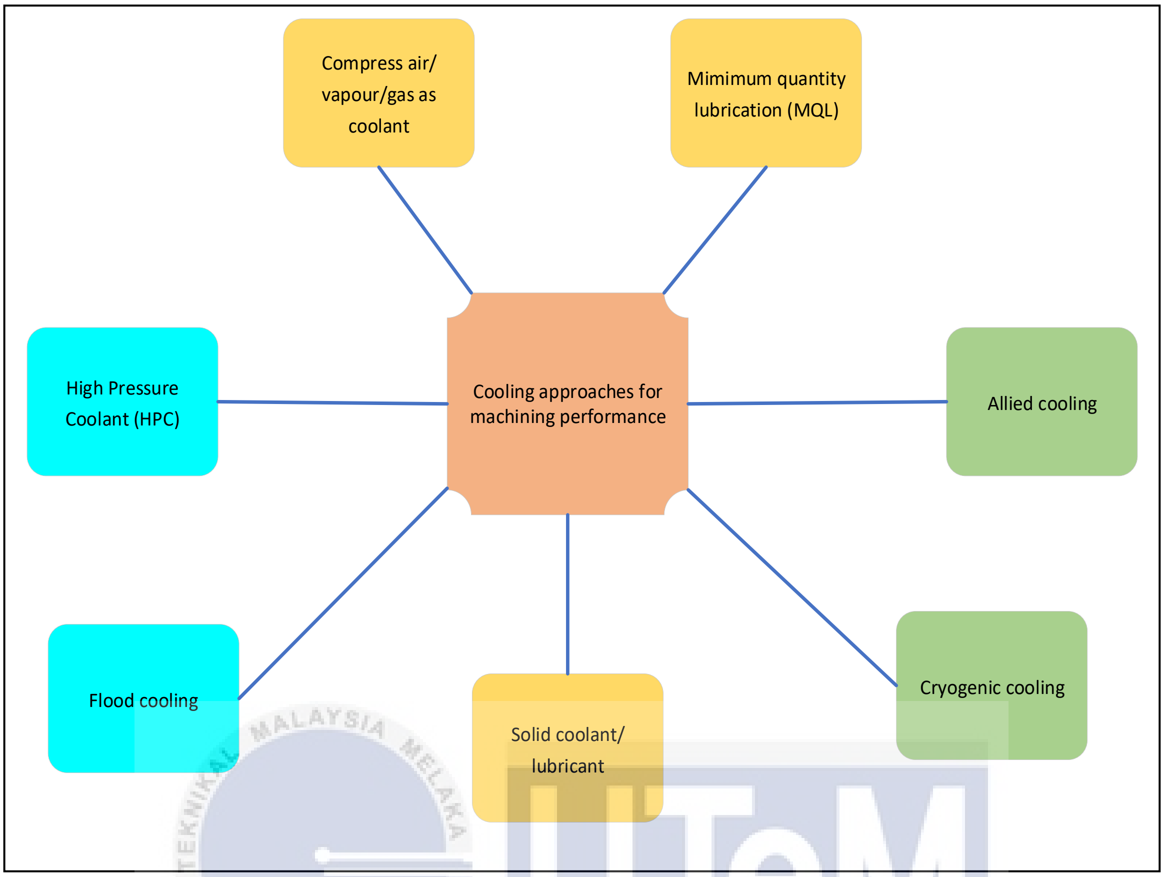

Figure 1.2: Techniques Used to Reduce Heat Generation during Turning Operation (Sharma et al., 2009)

Conventional wet cooling techniques usually execute the operation of hard turning and milling. This technique delivers a steady flow of cutting fluids to the cutting tool resulting in heat reduction, removal of the chip from the workpiece and lubrication to prevent corrosion. Cutting fluids provide numerous advantages, including mechanical and chemical lubrication, which decreases friction, work and tool cooling, improves dimensional stability, prevents chip welding that further stabilizes dimensions, flushing chips that enhance surface finishing and also improves tool performance (Boubekri and Shaikh, 2014).

Despite the benefits, there are several environmental problems related to the properties of coolant, such as toxins on the shop floor, harmful effects on operators, local storage requirements and water pollution (Raj et al., 2016). Therefore, to overcome these problems, eliminating and minimizing the use of cutting fluids during machining operations were executed by many researchers during machining processes (Goyal et al., 2014).

Sustainability has been applied in several areas, including infrastructure, manufacturing and development. Due to competition, the metal machining industry is under increasing pressure in the manufacturing sector. Manufacturers are increasingly concerned about sustainability because sustainability in machining processes leads to improved economic, environmental and social outcomes. Some sustainable lubrication methods have been developed by researchers, such as minimum quantity lubrication (MQL), dry machining, cryogenic machining and high-pressure cooling. These new techniques help reduce costs and prevent health and environmental issues usually caused by conventional cutting liquids, which is aligned with the statement given by the U.S. Department of Commerce, where sustainable manufacturing is produced using procedures that can minimize adverse effects on the environment, preserve energy and natural resources, are secure for staff, communities and customers and are economical (Janez and Franci, 2009; Rosen and Kishawy, 2012). Figure 1.3 shows the sustainability elements of manufacturing processes (Muhammad and Ibrahim, 2017).