



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



DOCTOR OF PHILOSOPHY

2024



Faculty of Industrial and Manufacturing Technology and Engineering

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

اونيور سيتي تيكنيكل مليسيا ملاك
UNIVERSITI TEKNIKAL MALAYSIA MELAKA
Farizan binti Md Nor

Doctor of Philosophy

2024

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

FARIZAN BINTI MD NOR



Faculty of Industrial and Manufacturing Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2024

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 = 135° ; 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 proved through a surface 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 BEROTOMATIK 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° ; 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.

ACKNOWLEDGEMENTS

In the Name of Allah, the Most Gracious, the Most Merciful

First of all I want to thank and praise Allah, the Almighty, my Creator, my Sustainer for everything I have been given since the beginning of my life. I would like to thank Universiti Teknikal Malaysia Melaka (UTeM) for providing the research platform. I am also grateful to Majlis Amanah Rakyat (MARA) for financial assistance and encouragement.

Biggest thanks to my main supervisor Dr. Fairul Azni bin Jafar, Universiti Teknikal Malaysia Melaka (UTeM) for all his support, advice and inspiration. His constant patience to guide and impart invaluable knowledge will be forever remembered. Also my work cosupervisor Associate Prof. Ir. Ts. Dr. Hadzley bin Abu Bakar, Universiti Teknikal Malaysia Melaka (UTeM) who constantly supported my journey. Special thanks to Mr. Hanafiah and Ms. Aisyah as Laboratory Technician for all the help and support I received from them. My special thanks goes to my friends Ms Maimunah, Dr. Rahayu and Ms Hamizah for their assistance and support throughout this challenging journey.

Last but not least, I express my heartfelt thanks to my beloved husband Mohd Ghazali bin Abdul Kadir for his encouragement and who has been my pillar of strength in all my endeavours. My eternal love also to all my children Nur Fatin Najla, Nur Qaisara Humairah, Nur Sofia Khadeeja and Muhammad Waiz Naufal for their patience and understanding. I also want to thank my dear siblings for their endless support, love and prayers. Finally, I want to thank all the people who gave me help, support and inspiration to start my studies.

TABLE OF CONTENTS

	PAGE
DECLARATION	
APPROVAL	
DEDICATION	
ABSTRACT	i
ABSTRAK	ii
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	vi
LIST OF FIGURES	viii
LIST OF APPENDICES	xiii
LIST OF SYMBOLS AND ABBREVIATIONS	xiv
LIST OF PUBLICATIONS	xv
CHAPTER	
1. INTRODUCTION	1
1.1 Background	1
1.2 Motivation	5
1.3 Problem Statement	9
1.4 Research Question	14
1.5 Hypothesis	15
1.6 Objective	16
1.7 Scope/limitation	16
1.8 Thesis Outline	17
2. LITERATURE REVIEW	18
2.1 Introduction	18
2.2 Computer Numerical Control Machine (CNC)	18
2.3 Coolant Supply Method	23
2.3.1 Dry Machining	25
2.3.2 Wet Cooling Method	28
2.3.3 Mist Cooling	31
2.3.4 Minimal Quantity Lubrication	33
2.3.5 Automated Coolant Supply System	37
2.4 Nozzle	42
2.4.1 Effect of Nozzle Types and Shapes in Machining	42
2.4.2 Effect of Nozzle Angle in Machining	44
2.4.3 Effect of Nozzle Distance in Machining	47
2.5 Summary	48
3. METHODOLOGY	52
3.1 Introduction	52
3.2 Overall Methodology	53
3.3 Research Design	55
3.4 System Design	56
3.5 ACS Framework Design	57
3.5.1 Hardware Development	58
3.5.2 Jig Development	69
3.5.3 Software Development	77

3.6	Experimental Setup	80
3.6.1	Experiment I – System Testing (Unloaded and Loaded)	84
3.6.2	Experiment II -Testing ACS System in CNC Turning by the Application of PLC Program	89
3.6.3	Experiment III - Testing ACS System in CNC Milling by the Application PLC Program	98
3.6.4	Experiment IV - Testing System in CNC Milling by the Application of Arduino	110
3.6.5	Experiment V- Optimization by Variable Nozzle Shape, Angle and Distance of Nozzle	116
3.6.6	Experiment VI- Comparison of the System with Flooded, Dry and MQL	119
3.7	Summary	123
4.	RESULTS AND DISCUSSION	125
4.1	Introduction	125
4.2	Development of Automated Coolant Supply System by Application of PLC in CNC Milling and CNC Turning	125
4.2.1	Hardware Development	125
4.2.2	Jig Development	129
4.2.3	Software Development	141
4.3.1	Experiment I – System Testing (Unloaded and Loaded)	149
4.3.2	Experiment II -Testing ACS system in CNC Turning by the Application PLC Program	157
4.3.3	Experiment III - Testing ACS System in CNC Milling by the Application of PLC Program	169
4.3.4	Experiment IV - Testing System in CNC Milling by the Application of Arduino	191
4.3.5	Experiment V - Optimization by Variable Nozzle Shape, Angle and Distance of Nozzle	202
4.3.6	Experiment VI- Comparison of the System with Flooded, Dry and MQL	219
4.4	Summary	225
5.	CONCLUSION AND RECOMMENDATIONS	233
5.1	Introduction	233
5.2	Conclusion	234
5.3	Recommendations	238
	REFERENCES	239
	APPENDICES	253

LIST OF TABLES

TABLE	TITLE	PAGE
3.1	Detail sub experiment for each objective	54
3.2	Component for Electrical Part in The PLC System	65
3.3	Component for Electrical Part in Arduino	67
3.4	Component for the Jig	70
3.5	Material Properties of ABS Plastic	74
3.6	Parameter and Levels for Experimentation (Source: Johnson et al. 2014)	91
3.7	Cutting Parameters for CNC Turning	92
3.8	Cutting Parameters from Taguchi Design Method for CNC Turning	95
3.9	Interval Time for Experiments 1 and 2 in CNC Turning	97
3.10	Cutting Parameters in CNC Milling	100
3.11	Cutting Parameters from Taguchi Design Method for CNC Milling	100
3.12	Interval Time for Experiments 1 and 2 in CNC Milling	102
3.13	Cutting Parameter from Taguchi Design Method	114
4.1	Results from Force 1	133
4.2	Results from Force 2	134
4.3	Results from Force 3	135
4.4	Results from Force 4	136
4.5	Simulation Result on Force 1, Force 2 and Force 3	138
4.6	Result Simulation on Force 4	140
4.7	Feature of Surface Roughness Tester	154
4.8	Average Surface Roughness	155
4.9	Experiment Results for Surface Roughness with Different Cutting Parameters	158
4.10	Surface Roughness Result of Interval Time 2 s to 25 s	161
4.11	Surface Roughness Result of Interval Time 25 s to 2 s	163
4.12	Volume of Coolant for Interval Time	168
4.13	Experiment Results for Surface Roughness with Different Cutting Parameters in CNC Milling	169
4.14	The Optimum Cutting Data	171
4.15	Average Cutting Data for Experiment (2 s – 25 s)	171
4.16	Average Surface Roughness for Experiment (25 s – 2 s)	172
4.17	Average Surface Roughness for Experiment (1 s – 60 s)	174
4.18	Cutting Force for Experiment 1 (1 s – 60 s)	177
4.19	Surface Roughness for Experiment 2 (60 s – 1 s) – Verification Test	181
4.20	Surface Roughness for Flooded Test	181
4.21	Cutting Force for Experiment (60 s – 1 s)-Verification Test	183
4.22	Surface Roughness for Angle 1	185
4.23	Surface Roughness for Angle 2	186
4.24	Cutting Force for Angle 1	187

4.25	Cutting Force for Angle 2	188
4.26	Surface Roughness for Nozzle Distance	189
4.27	Cutting Force for Nozzle Distance	190
4.28	Result of Average Surface Roughness with Different Parameters.	195
4.29	Results of Average Surface Roughness with Different Interval Time	198
4.30	Angle 0°, 90°, 180°, and 270° for Shape 1	204
4.31	Differences Angle from 90° for Shape 1	205
4.32	Distance for Nozzle Shape 1	206
4.33	Angle 0°, 90°, 180°, and 270° for Shape 2	208
4.34	Differences Angle from 90° for Shape 2	209
4.35	Distance for Nozzle Shape 2	209
4.36	Angle 0°, 90°, 180°, and 270° for Shape 3	211
4.37	Differences Angle from 90° for Shape 3	212
4.38	Distance for Nozzle Shape 3	213
4.39	Surface Roughness for 3 Types of Nozzle for Angle 0°, 90°, 180°, and 270°	214
4.40	Surface Roughness for 3 Types of Nozzle for Angle from 90°	216
4.41	Surface Roughness for 3 Types of Nozzle for Distance of Nozzle	217
4.42	Result of Experiment 3	218
4.43	Surface Roughness for 4 Cutting Conditions	220
4.44	Cutting Force for 4 Cutting Conditions	221
4.45	Overall Result of Experiments	230



اونيورسيتي تيكنيكل مليسيا ملاك

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	Heat Generation During Machining Operation (Raval et al., 2016)	2
1.2	Techniques Used to Reduce Heat Generation during Turning Operation (Sharma et al., 2009)	3
1.3	Sustainability Elements of Manufacturing Processes (Muhammad and Ibrahim, 2017)	5
1.4	The Motivation for Implementation of Automated Coolant Supply for Green Manufacturing	7
1.5	Fishbone Diagram Showing Cause and Effect in MQL-Assisted Machining (Upadhyay et al., 2012)	11
1.6	Fishbone Diagram Showing Cause and Effect of Machining Parameters in Machining Performance (Kuram et al., 2011)	12
2.1	CNC Machine	19
2.2	CNC Machine Input, Process and Output (Abdallah, 2014)	20
2.3	Block Diagram for CNC Machine (Ansar et al., 2016)	22
2.4	Heat Generation during Machining (Salman et al., 2019)	24
2.5	Dry Machining Process (https://precisionmetalspinning.com/benefits-dry-machining)	25
2.6	Benefits of Dry Machining (Safian et al., 2009)	26
2.7	Flooded Coolant Technique (https://www.firetrace.com/fire-protection-blog/importance-of-coolants)	30
2.8	Distribution of Manufacturing Costs for Wet Machining (Ekinovic et al., 2014)	31
2.9	Mist Cooling Techniques (Source: http://www.easycutoil.eu/en/photo-gallery/)	32
2.10	Basic Concepts of MQL System (Sen et al. 2021)	35
2.11	Block Diagram of PLC (Kopte and Pai, 2015)	38
2.12	Comparative Analysis Based on Web Search (Kaswan et al. 2020)	40
2.13	Arduino Application Areas	41
2.14	Various Types of Nozzle Coolant	43
2.15	Nozzle Position Relative to Tool Entry Position and Workpiece End Milled Face (Mulyadi, 2013)	45
2.16	Nozzle Position Relative to Spindle Axis (Mulyadi, 2013)	45
2.17	Nozzle Position in Controlled Cutting Fluid Impinging Supply System (Cut-List) (Gariani et al. 2017)	46
3.1	Overall methodology of ACS System	53
3.2	Fundamentals of ACS System	55
3.3	Diagram for ACS Design	56
3.4	Flowchart for Design of Nozzle System and Development of Program	58
3.5	Tier-time Up Box 3D Printer	59
3.6	ABS Filament for 3D Printer	60

3.7	Proportional Flow Control Valve (Source: http://www.xetremotecontrol.com/index.php?ws=showproducts&products_id=606555&cat=WASHING%20MACHINE%20SPARE%20PARTS&subcat=INLET%20VALVE)	62
3.8	Nozzle Sketch	63
3.9	(a) Nozzle System, (b) Nozzle System With Valve and Nozzle	63
3.10	Nozzle With Size of (a) Circular Shape, (B) Rectangular Shape 1, (C) Rectangular Shape 2	64
3.11	Steps Involve to Develop The Jig	69
3.12	Assembled Jig	71
3.13	Jig Attached at Spindel CNC Milling Machine	72
3.14	Flow Chart for Jig Simulation	73
3.15	105° Positioning Angle of Jig Design	75
3.16	Inclination Angle of Jig (45°)	75
3.17	Four Forces Pointed in Different Locations for Analysis Strain and Stress	76
3.18	Experiment I (Loaded and Unloaded Testing for CNC Milling and Turning)	80
3.19	Experiment II (Testing on CNC Turning by the Application of PLC Program)	81
3.20	Experiment III (Testing on CNC Milling by Application of PLC Program)	82
3.21	Experiment IV (Testing on CNC Milling by the Application of Arduino Program)	83
3.22	Experiment V (Optimization)	83
3.23	Experiment VI (Comparison with Dry, Flooded and MQL)	84
3.24	Process Diagram for Unloaded Coolant Testing	85
3.25	Process Diagram for Loaded Coolant Testing	87
3.26	Workpiece of Aluminium Alloy 1014	88
3.27	Process Diagram for Optimum Cutting Parameter	90
3.28	Step to use Taguchi Method	92
3.29	(a) Taguchi Level and Number of Factors and (B) Number of Experiment Runs	93
3.30	Cutting Parameters and its Value Added	94
3.31	Combination of Speed, Feed Rate and Depth of Cut	94
3.32	Process Diagram for the Best Interval Time at Optimum Cutting Parameter in CNC Turning	96
3.33	Process Diagram for the Best Interval Time at Optimum Cutting Parameter in CNC Milling	99
3.34	Process Diagram for the Best Interval Time at Optimum Cutting Parameter in CNC Milling	101
3.35	Process Diagram for the Relationship Between Surface Roughness and Cutting Force f of ACS in CNC Milling	103
3.36	Kistler Dynamometer 5070	104
3.37	Process Diagram for Effect of Nozzle Angle	106
3.38	Position of Nozzle for Experiment 1	107
3.39	Position of Nozzle for Experiment 2	107
3.40	Process Diagram for Effect of Nozzle Angle	109
3.41	Distance of Nozzle	110
3.42	Process Diagram for Unloaded Coolant Testing	111

3.43	Process Diagram for Loaded Coolant Testing by the Application of Arduino	113
3.44	Process Diagram for the Best Interval Time by the Application of Arduino Program	115
3.45	Process Diagram of Optimization by Variable Nozzle Shape, Angle and Distance of Nozzle	117
3.46	Three Types of Nozzle Shape	118
3.47	Process Diagram for Optimization by Variable Nozzle Shape, Angle and Distance of Nozzle	120
3.48	Experiment for Flooded	121
3.49	Experiment for Dry	122
3.50	Experiment for MQL	122
3.51	Position of Nozzle for Flooded, Dry and MQL	123
4.1	Electrical and Wiring Part of the System	126
4.2	Electrical Circuit of the System	127
4.3	(a) 8 mm Tube Fitting for One Hole and (B) 8 mm Tube Fitting with Two Holes	128
4.4	Connection of the Mechanical Part	128
4.5	Fabricated Part A	129
4.6	Fabricated Part B	130
4.7	Fabricated Part C	130
4.8	Fabricated Part D	131
4.9	Assembled Jig	131
4.10	Force 1	132
4.11	Force 2	133
4.12	Force 3	134
4.13	Force 4	135
4.14	Designed jig bend and break	141
4.15	Work Flow of the PLC System Construction	142
4.16	Flowchart of Development of Ladder Diagram	143
4.17	Ladder Diagram Schematic in CX-Programmer Software	144
4.18	Results When the Start Button is Switched On	146
4.19	Result When Timer 1 is Activated	146
4.20	The Coding Used in the Experiment	147
4.21	Example of Success Verifies Shown in the Arduino Software	148
4.22	Coolant from the Nozzle is Precisely Dispersed to the Tooling	149
4.23	The Coolant Stop Disperse from the Nozzle	150
4.24	The Coolant Start to Disperse from the Coolant at 0.00 s Time Period	151
4.25	The Coolant Stop Disperse from the Coolant at 0.05 s Time Period	151
4.26	The Coolant Start to Disperse from the Coolant at 0.10 s Time Period	152
4.27	The Coolant Start to Disperse from the Coolant at 0.15 s Time Period	152
4.28	Milling Process is Undergone on the Aluminium Block of 100 mm Long	153
4.29	Average Surface Roughness for 3 Trial Experiments	155
4.30	(a) The Cutting Workpiece for the Best Combination of Parameter for 2 s to 10 s and (b) The Cutting Workpiece for the Best Combination of Parameter for 15 s to 25 s	158
4.31	Average Surface Roughness with Different Cutting Parameters	159
4.32	Graph Surface Roughness Versus Interval Time for 2 s to 25 s	162
4.33	The Clamping of Workpieces	162

4.34	Graph Surface Roughness Versus Interval Time for 25 s to 2 s	163
4.35	Graph of Surface Roughness for Interval Time 25 s to 2 s and 2 s to 25 s	164
4.36	(a) Surface Roughness for 2 s and (b) Surface Roughness for 3 s	165
4.37	Tool Bit before Experiment	166
4.38	Tool Bit after Experiment 1	167
4.39	Tool Bit after Experiment 2	167
4.40	Graph Coolant Volume Versus Interval Time for 2 s to 25 s	168
4.41	Average Surface Roughness with Different Cutting Parameters in CNC Milling	170
4.42	Graph Plotted Based on the Average of the Overall Experiment (2 s - 25 s)	172
4.43	Graph Plotted Based on the Average of the Overall Experiment (25 s - 2 s)	173
4.44	Graph Plotted Based on the Average Surface Roughness of the Overall Experiment (1 s - 60 s)	175
4.45	Result of Measured Cutting Forces in x, y and z-Axis at 23 s Interval Time	178
4.46	Graph Plotted Based on the Average Cutting Force of the Overall Experiment (1 s - 60 s)	179
4.47	Graph of Surface Roughness Versus Interval Time for 60 s to 1 s	182
4.48	Graph of Surface Roughness Versus Force for 1 s to 60 s	184
4.49	Position of Nozzle for Angle 1	184
4.50	Effect of Nozzle Angle 1 on Surface Roughness	185
4.51	Position of Nozzle for Angle 2	186
4.52	Surface Roughness for Position of Nozzle for Angle 2	187
4.53	Cutting Force for Position of Nozzle for Angle 1	188
4.54	Cutting Force for Position of Nozzle for Angle 2	189
4.55	Effect of Nozzle Distance on Surface Roughness	190
4.56	Cutting Force for Distance of Nozzle	191
4.57	Coolant from the Nozzle is Precisely Dispersed to the Tooling by the Application of Arduino at 0.08 s	192
4.58	The Coolant Stop Disperse from the Nozzle by the Application of Arduino at 0.18 s	192
4.59	Image of Mechanical Part Installed on CNC Machine.	193
4.60	Image of Coolant Supplied Precisely Toward the Cutting Tool.	194
4.61	Aluminium Block Cut Under Unloaded Coolant with Different Parameter.	194
4.62	Graph Plotted Based on the Data for Different Parameters	196
4.63	Milling Process is Performed on the Aluminium Block using Time Interval from 1 s to 60 s	197
4.64	Milling Process is Performed on the Aluminium Block Using Time Interval from 60 s to 1 s	197
4.65	Graph Surface Roughness Versus period (1 s - 60 s)	199
4.66	Graph Surface Roughness Versus period (60 s -1 s)	199
4.67	Graph Plotted Based on Table 4.29	200
4.68	Cutting Tool used for Experiment (1 s - 60 s)	202
4.69	Cutting Tool used for Experiment (60 s - 1 s)	202
4.70	Nozzle Shape	203
4.71	Surface Roughness for Angle 0°, 90°, 180°, and 270° for Shape 1	204

4.72	Angle of Nozzle for Second Test	205
4.73	Surface Roughness for Differences Angle from 90° for Shape 1	206
4.74	Surface Roughness for Distance for Shape 1	207
4.75	Surface Roughness for Angle 0°, 90°, 180°, and 270° for Shape 2	208
4.76	Surface Roughness for Distance for Shape 2	210
4.77	Surface Roughness for Angle 0°, 90°, 180°, and 270° for Shape 3	211
4.78	Surface Roughness for Differences Angle from 90° for Shape 3	212
4.79	Surface Roughness for Distance for Shape 3	213
4.80	Comparison Surface Roughness for Angle 0°, 90°, 180°, and 270°	215
4.81	Comparison of Surface Roughness for Differences Angle from 90°	216
4.82	Comparison of Surface Roughness for Distance for 3 Types of Nozzle	218
4.83	Comparison of Surface Roughness for 4 Cutting Conditions	220
4.84	Comparison of Cutting Force for 4 Cutting Condition	222
4.85	(a) SEM (Scanning Electron Microscope) Images of the Surface Morphology with Dry Cutting (b) Flooded cutting (c) Minimum Quantity Lubrication (d) Automated Coolant Supply System (ACS)	223



LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Part to Connect Between Fitting and Solenoid Valve	253
B	Stress Strain Analysis (Force 1)	254
C	Stress Strain Analysis (Force 2)	260
D	Stress Strain Analysis (Force 3)	266
E	Stress Strain Analysis (Force 4)	272
F	Average Surface Roughness for Loaded Testing (Experiment 1)	281
G	Average Surface Roughness for Loaded Testing (Experiment 2)	282
H	Average Surface Roughness for Loaded Testing (Experiment 3)	283
I	Roughness Reading for Combination of Parameter	284
J	Roughness Reading for Angle Nozzle Shape 1	285
K	Roughness Reading for Angle Nozzle Shape 2	287
L	Roughness Reading for Angle Nozzle Shape 3	289
M	Roughness Reading for Interval Time 1 s to 60 s	291
N	Average Surface Roughness of Angle 1	295
O	Average Surface Roughness for Angle 2	296
P	Average Surface Roughness for Nozzle Distance	297
Q	Result of Average Surface Roughness with Different Parameter	298
R	Average Surface Roughness with Different Interval Time (1 s-60 s)	299
S	Average Surface Roughness with Different Interval Time (60 s -1 s)	300
T	Average Surface Roughness for Dry, Flooded & MQL	301

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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
$^{\circ}$	-	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. Machinability 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

Conference Proceedings

Fairul Azni, J., Mohd Hadzley, A.B., Vanessa, L.H., **Farizan, M.N.**, Nurul Azma, Z, Ahamad Zaki, M.N, December 2020. CNC turning performance under automated coolant supply system. *Proceedings of Innovative Research and Industrial Dialogue 2020*, (pp. 2-3). IRID.

Farizan, M.N., Fairul Azni, J., Tan, J., Mohd Hadzley, A.B., 2018, November. Arduino based automated coolant supply system for CNC machining. *In Proceedings of Symposium on Electrical, Mechatronics and Applied Science 2018 (SEMA '18)* (pp. 23-24). SEMA '18.

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).

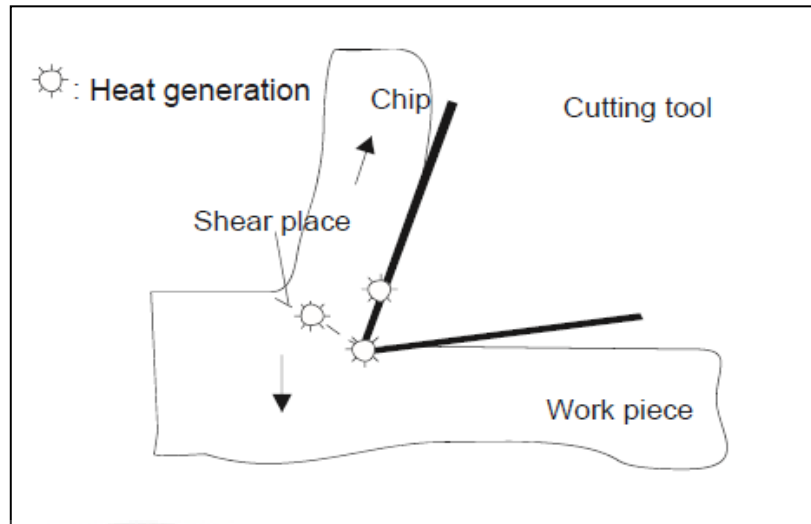


Figure 1.1: Heat Generation During Machining Operation (Raval et al., 2016)

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.

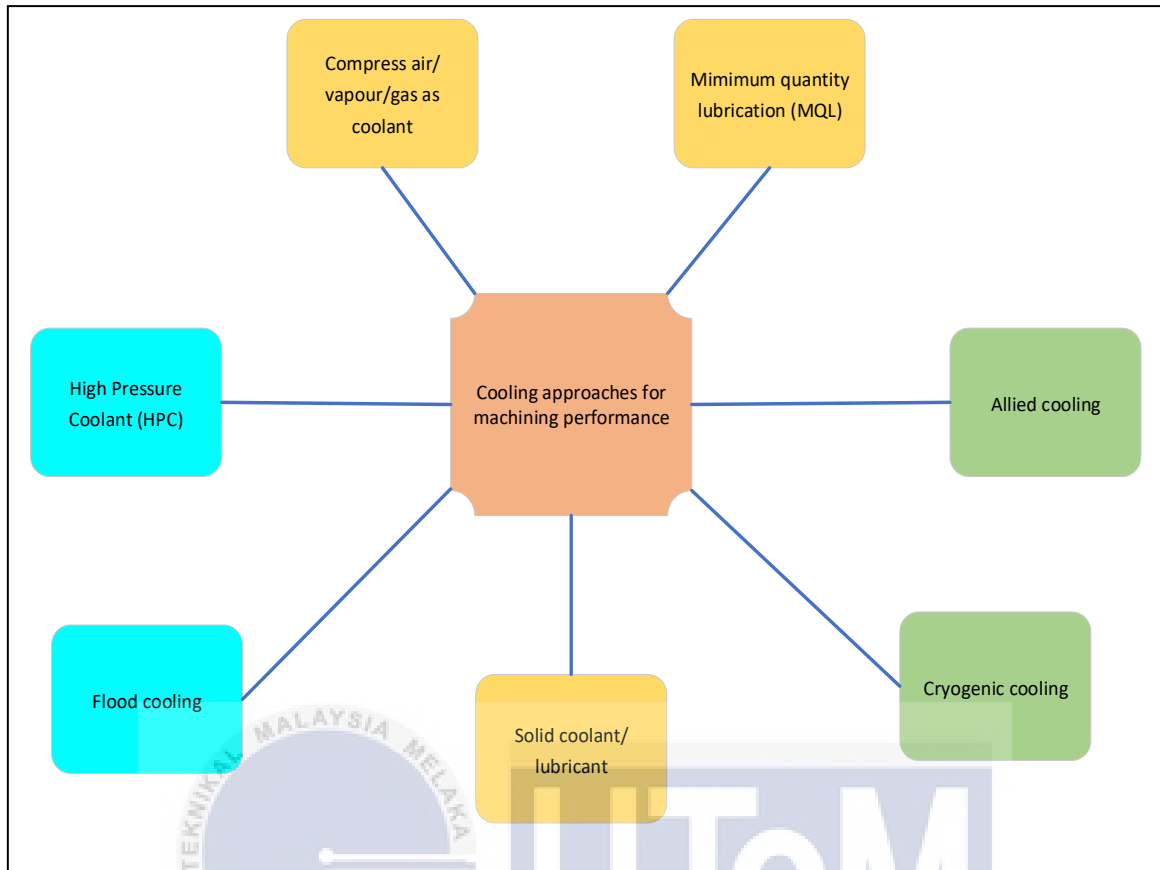


Figure 1.2: Techniques Used to Reduce Heat Generation during Turning Operation (Sharma et al., 2009)

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).