Jurnal Polimesin
Department of Mechanical Engineering
Lhokseumawe State Polytechnic
http://e-jurnal.pnl.ac.id/polimesin
e-ISSN : 2549-1999 No : 2 Month : August
p-ISSN : 1693-5462 Volume : 20 Year : 2022

Article Info
Received : 2022-01-18 Accepted : 2022-03-15
Revised : 2022-02-04 Available online : 2022-08-31

Development of MQL (minimum quantity lubricant) automation in applying cutting fluid on lathes

Aris Zainul Muttaqin, Mahros Darsin*, Yohan Rizal Kharisma, Ahmad Syuhri, Muhammad Trfiananto
Department of Mechanical Engineering, University of Jember
Jl. Kalimantan 37, Jember 68121, Jawa Timur, Indonesia
*Corresponding Author: mahros.teknik@unej.ac.id

Abstract

It is normal to apply cutting fluid to machining, but using it excessively will harm the environment. One of the efforts to reduce it is to apply minimum quantity lubrication (MQL). This study aims to minimize the use of cutting fluid by designing a cutting fluid delivery system with Arduino Uno control. The developed MQL system can be controlled both based on temperature and time. This MQL system was a development from the previous system by replacing the limit and temperature sensor, nozzle, and mini compressor with a sprayer. The performance of this new MQL system was compared to a flooded cutting fluid feeding system. The experimental design of Taguchi L9 (3^4) with additional varied factors such as depth of cut, cutting speed, and feed rate. Each factor consisted of 3 levels. The measured output was cutting fluid consumption. S/N ratio analysis showed that the method of giving the cutting fluid most dominantly affected the outcome. ANOVA showed that more than 97.56% of the factors were dominated by the method. The combination of factors that would produce a minimum burst at a rate of 180 ml/hour if applying a combination of factors and a level of depth of cut 1.8 mm and a cutting speed of 120.89 m/min, provision of cutting fluid with the periodic MQL method and feed rate of 0.122 mm/rev. Meanwhile, the metal removal rate (MRR) analysis recommended the use of periodic cutting fluid methods at a depth of cut of 2.2 mm. The development of the new MQL either temperature control or periodic system control, both were able to comply with the MQL criterion, i.e. the maximum spray of 500 ml/h.

Keywords:
Control system, Cutting fluid, MQL Automation, Lathe

1 Introduction

The environment is an aspect that must be considered in a machining process. In the machining process, the use of cutting fluids (dromus oil and water) harms the environment. One method that can overcome the cutting fluid effect on the environment is the MQL method (minimum quantity lubrication [1], [2]. MQL is a method of giving cutting fluid as minimum as possible. There are several different works of literature in determining the maximum limit for the flow of cutting fluid spray that meets the MQL criteria: (i) 900 ml/hour [3], and (ii) 500 ml/hour [4], [5], [6].

In previous studies, an MQL system has been designed with Arduino Uno-based control [7]. The sensors used were the DS18B20 temperature sensor and the MAX6675 thermocouple to read the heat on the tool. These two control system devices have been prior used by other researchers for different applications. The DS18B20 waterproof temperature sensor was used as a monitoring tool and temperature limiter in the fish drying process [8]. Meanwhile, the MAX6675 thermocouple temperature sensor was used to measure temperature by direct contact with the measured object [9].

Further research was carried out by Gardika et al. by using a fuel pump with a DC voltage of 12V, the temperature limit was approximately 100 ^{o}C [7]. In further research, the MQL criteria have not yet been achieved because the fluid composition was less viscous and the influence of the depth of cut was deep. A deep depth of cut could quickly trigger large friction, therefore the workpiece heated up quickly [10]. Another weakness of the two previous studies is the lack of pump power used and the low-temperature limit so the released coolant consumption exceeded the MQL criteria limit. In both of these previous studies, the minimum burst discharge that can be achieved was 1551 ml/hour [7] and 979.5 ml/hour [10], respectively.

The success of the MQL controller system depends on the hot temperature reading on the tool carried out by the sensor and the ability of the valve or pneumatic valve to control the on or off bursts of cutting fluid according to the required criteria. For this reason, further, development is needed to improve the performance of the previously created MQL system.

The objective of this research was to develop an Arduino Uno-based MQL system with a maximum spray target of 500 ml/hour. In addition to fluid consumption, the success of the MQL system would be assessed from the material removal rate (MRR) analysis, a measure of the completion speed of the machining process.

2 Research Method

This research used the experimental method. Designers of cutting fluid tools based on MQL automation used a power supply to regulate the required power in the controller system. Arduino Uno application as a control centre to control the performance of various components such as pneumatic valves, temperature sensors, and the selection of the MQL method in the delivery of cutting fluids. The performance of the tool was measured by measuring and calculating fluid consumption. Variations in cutting fluid consumption parameters used were the depth of cut, cutting speed, feed rate, and method. The method in question was the MQL tool automation system, by temperature control and periodically. Fig. 1 below presents the electronic design of the MQL tool control system used.

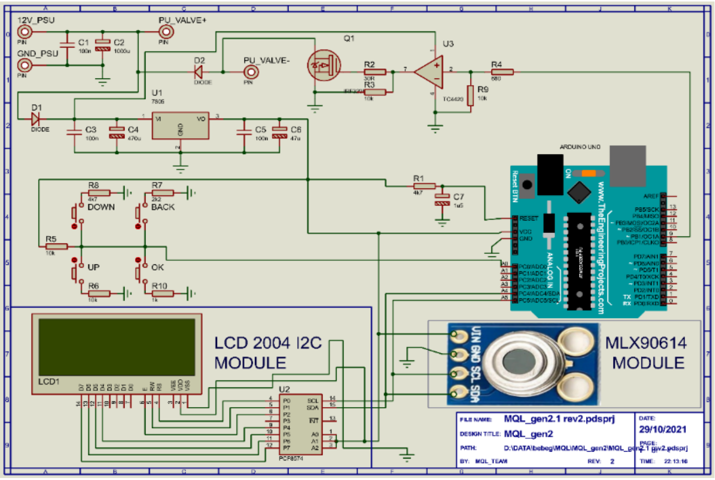

Fig. 1. Electrical and electronic scheme of the MQL tool

The explanation of how the MQL tool works according to the series of Fig.1 above is as follows:

1. The power supply provides power supply with a voltage of 12 Volts to the pneumatic valve (+), TC4420 Mosfet driver, and Regulator 7805;

2. Regulator 7805 lowers the 12V voltage from the power supply to 5 volts which are used as a voltage source for Arduino Uno, button circuit, LCD 2004, and temperature sensor MLX90614;
3. If selecting the MQL mode for temperature control on the system LCD, then when the temperature on the tool and workpiece is equal to or more than 150ºC, pin 9 of the Arduino Uno gives a voltage signal of 5 Volts to the TC4420 MOSFET driver to amplify the voltage to 12 volts to activate the MOSFET driver IRF3205 so the flow can pass through the pneumatic valve and make the valve open so the air can flow into the pen brush;
4. If selecting the periodic MQL mode on the system LCD, then every 4 seconds for 1 second pin 9 of the Arduino Uno gives a voltage signal of 5 Volts to the TC4420 MOSFET driver to amplify the voltage to 12 volts to activate the IRF3205 MOSFET driver so current can pass through the pneumatic valve and make the valve open so the air can flow into the pen brush;
5. After the machining process is complete, the temperature data is taken through the read data program and then connected to the Arduino Ide application on a PC to view the temperature data.

The MQL tool worked based on the selected mode, either temperature controlled or periodic. In MQL controlled, the reference temperature readings were carried out by sensors on the tool and workpiece. When the sensor read the temperature was the same as or has exceeded 150ºC, the pneumatic valve would open and the pen brush would spray the cutting fluid, then when the temperature was below 150ºC, the pneumatic valve would close and the cutting fluid would stop spraying. After programming was complete, the next step was the placement of the sensor, which was based on the specifications of the sensor readings used at a distance of 5 cm from the chisel and higher than the pen brush so as not to interfere with each other.

When the sensor has been placed in the optimal position to take temperature readings and the machining process was also complete, the sensor would send temperature data once every 0.5 seconds on the Arduino Uno and it could be read directly via excel.

In periodic mode, the periodic MQL tool worked based on a predetermined periodic time, every 4 seconds the cutting fluid stopped and then would spray for 1 second. For the flood method, cutting fluid was applied by flushing continuously during the machining process and stopping when the process is complete.

Fig. 2a below shows the position of the pen brush (pointed by the arrow) as a spray medium focused on the contact of the tool and work piece, while Fig. 2b shows the recording of the temperature control MQL experiment time.

(a) (b)

Fig. 2. (a) Spraying pen brush on the tool and workpiece, (b) Example display of temperature control MQL test time reading with cutting depth of 2.0 mm, cutting speed of 120.89 m/min and feed rate of 0.137 mm/put

In this study, three stages were carried out, i.e. the stage of manufacturing, testing, determining the tool replacement, and the workpiece in taking replication and knowing the fluid consumption. Next, the machine set-up installation was carried out in the form of entering or setting several constant parameters such as cutting speed (V, m/mm), feeding motion (f, mm/revolution), and depth of cut (a, mm). After that, the MQL cooling system controller was placed between the tool and the AISI 4340 steel. Finally, the turning process could be carried out using coolant.

The variables used in this study were the independent and the dependent variable. The independent variables included variations in depth of cut, feed rate, cutting speed, and method of fluid application. For simplification, the variable term “cutting fluid delivery method” would be briefly referred to as “method” only. The dependent variable was the value of fluid consumption in the MQL automation method. The independent variables and parameters of the L9 (3^4) orthogonal array data retrieval test can be seen in the following Table 1.

Table 1. Independent variables and levels

		Depth of cut	Cutting speed	Method	Feed rate
		1	**2**	**3**	**4**
L	**1**	1,8 mm	120,89	Periodic	0,107
E	**2**	2,0 mm	141,3	Control Temperature	0,122
V	**3**	2,2 mm	200	Flood	0,137
E					
L					

3 Results and Discussion

3.1 How it Works

This tool worked based on the selected mode, i.e. temperature control and periodic. The temperature control mode worked based on the reference temperature readings made by the sensor on the tool and workpiece. When the sensor read the temperature was the same as or has exceeded 150 ^{o}C, the pneumatic valve would open and the pen brush would spray the cutting fluid, then when the temperature was below than 150^{o}C, the pneumatic valve would close and the cutting fluid would stop spraying.

In the periodic MQL mode, this tool worked based on a predetermined periodic time that was every 4 seconds the cutting fluid stopped and then would spray for the next 1 second and so on during the machining process.

The MQL system controller tool system with its main components is shown in Fig. 3a below. Before testing, the controller was first installed on the machine (Fig. 3b).

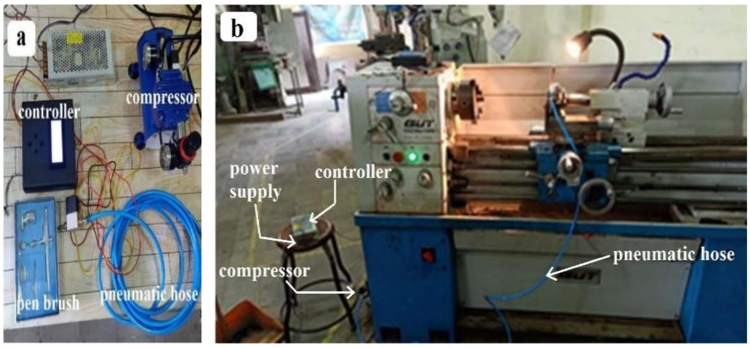

Fig. 3. MQL Controller system tool and its installation: (a) controller main parts and (b) when it is installed on the lathe

3.2 Fluid Consumption Data on Lathe

Testing and data collection of fluid consumption per hour on the lathe process have been carried out based on the L9(3^4) orthogonal array. The steps to determine the results of fluid consumption after the machining process was complete were to ensure the size of the cutting fluid in the measuring cup, recorded the machining process time, put the remainder in the measuring cup, and then calculated the cutting fluid of the first glass minus the remaining cutting fluid, and finally calculated the fluid consumption (FC) per hour with eq. 1:

$$FC\ per\ hour = \frac{FC(ml)}{machiningtime(s)} X3600 \tag{1}$$

Table 2 is the Taguchi experimental design (columns 1-5), along with the results of the machining time measurement in s (column 6), and the cutting fluid consumption for each combination of machining variables (columns 7-9) with three replications.

Table 2. Taguchi L9 (3^4) experimental design and fluid consumption data

No	Control Parameter				Machining Time *(s)*	*Fluid consumption* (ml/hour)			*Means*	*S/N Ratio*
	Depth of Cut (mm)	Cutting speed *(m/min)*	Method	Feed rate (mm/put)		Replication 1	2	3		
1	2	3	4	5	6	7	8	9	10	11
1	1,8	120,89	Periodic	0,107	60	180	180	180	180	-45,1055
2	1,8	141,3	Temperature control	0,122	60	492	480	498	450	-53,8049
3	1,8	200	*Flood*	0,137	60	900	960	900	920	-59,2799
4	2,0	120,89	Tempera-Ture control	0,1-37	70	514	565	540	540	-54,6544
5	2,0	141,3	*Flood*	0,107	70	900	935	900	911	-59,2799
6	2,0	200	Periodic	0,122	60	180	180	180	180	-45,1055
7	2,2	120,89	*Flood*	0,122	72	850	900	900	883	-58,9246
8	2,2	141,3	Periodic	0,137	72	180	180	180	180	-45,1055
9	2,2	200	Temperature control	0,107	72	675	700	660	678	-56,6314

3.3 Taguchi Method and Analysis of Variance

The Taguchi method used the calculation of the S/N ratio as a reference to examine the disturbance to the variations that arise. The response quality characteristic used was *smaller is better* because the less fluid consumption, the better for the MQL criteria, in the sense that it saved costs for the use of cutting fluid. The calculation of the S/N Ratio with the *smaller better* quality criteria is presented in eq. 2 [11].

$$\text{S/N} = -10\ \text{Log}\ (\Sigma(\frac{Y^2}{n})) \tag{2}$$

The S/N ratio could be obtained based on the means price which must also be calculated previously using eq. 3 [11].

$$Means\ = \frac{1}{n}\ \Sigma_{i=1}^{r}\ Y_i \tag{3}$$

The calculation results of the Means and the S/N Ratio are entered into Table 2 in columns 10 and 11. The plot of the results of the calculation of the value of the S/N ratio can be seen in Fig. 4.

The Taguchi method used the calculation of the S/N ratio as a reference to examine the disturbance to the variations that arise. The response quality characteristic used was *smaller is better* because the less fluid consumption, the better for the MQL criteria, in the sense that it saved costs for the use of cutting fluid. The calculation of the S/N Ratio. The calculation results of the Means and the S/N Ratio are entered into Table 2.

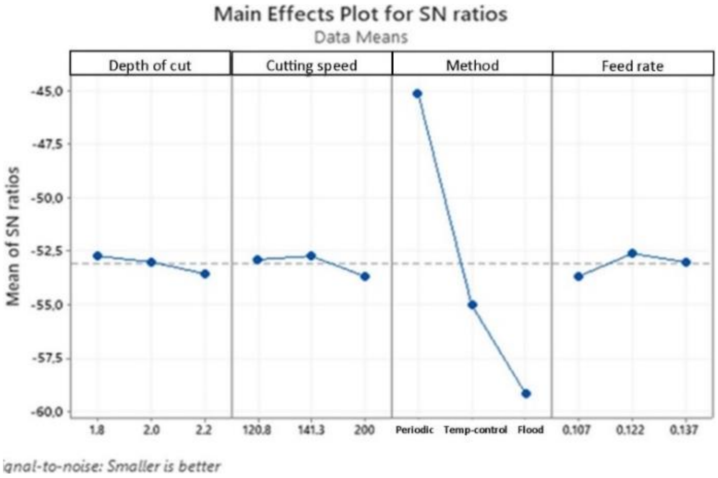

Fig. 4. Plot the average value of the S/N ratio

Analysis of variance (ANOVA) is a statistical procedure to determine whether the arithmetic means of 3 (three) populations or more, are the same or not. The results of the ANOVA calculation in this fluid consumption study can be seen in Table 3 below.

Table 3. ANOVA result for means

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Method	2	795797	97.56%	795797	397898	119.78	0.000
Error	6	19931	2.44%	19931	3322		
Total	8	815728	100.00%				

The contribution percentage shows how much influence these parameters have on the output of the study with a value in the form of a percentage. If the percentage of the residual error contribution is less than fifteen per cent (<15%), then no influential parameter was neglected at the time of the study. If the percentage of the residual error contribution is more than fifteen per cent (>15%), it is assumed that there are parameters that affect the value of fluid consumption in turning but are neglected in this study. The error in this study was 2.44%, which means that there were no neglected factors when designing the experiment. The percentage contribution of each control factor used in fluid consumption is shown in Table 3 in the fourth column.

3.4 Analysis

From data processing using the Taguchi method, it was found that the method factor was a factor that greatly influences the fluid consumption results with the largest percentage contribution compared to other factors, namely 97.56%. The most optimal method factor for the lowest fluid consumption value was using the periodic MQL method and the temperature control method can be used at the lowest depth of cut, namely 1.8 mm. On the other hand, the highest fluid consumption value was the flood method. As for the other 3 factors that had a percentage contribution below 5%, they could be ignored and would not be discussed further in this manuscript.

Then the most optimal machining analysis was carried out from the MRR (material removal rate) review to find out which spraying method was the best. MRR is the volume of wasted material (mm^3) per unit time (min). In machining, a large MRR value is desired, which means that the desired final shape was immediately achieved [12]. To calculate the MRR use eq. 4 [5].

$$MRR = \frac{volume\ of\ wasted\ material\ (mm^3)}{machining\ time\ (min)} \tag{4}$$

$$MRR = \frac{\pi\left({r_0}^2 - {r_f}^2\right).l}{t}$$

Where r_o and r_f, respectively, are the initial and final diameters of the workpiece, the l cutting length, and the t machining time. In the periodic method experiment, which was 180 ml/hour using the highest depth of cut of 2.2 mm and time (t) of 72 s with an MRR value of 66,040 mm^3/min. Meanwhile, the temperature control method that met the MQL criteria was the depth of cut parameter of 1.8 mm, time of 1 minute and the MRR result was 54,485 mm^3/min. From the calculation results of the MRR value above, it can be concluded that the method that was still within the MQL criteria, namely periodic had a better MRR value than the temperature control method because the MRR was higher and the consumption of cutting fluid was more efficient.

From the S/N ratio and MRR analysis, it can be concluded that the method of periodic cutting fluid application was superior in terms of minimum cutting fluid burst with maximum material removal rate. Furthermore, to determine which cutting fluid application method to choose, it was necessary to analyze it from other machinability reviews; (i) tool wear, (ii) surface smoothness, and (iii) chip formation pattern. From the tool wear review, the same conclusion was obtained that the periodic MQL method was more optimum in reducing the deterioration of the tool's physical properties in turning [13]. Meanwhile, from a review of the surface smoothness of the turning results, the best surface was obtained when applying automatic MQL [14].

4 Conclusion

This study has attempted to create a new design for the MQL system of cutting fluid delivery by applying automation with Arduino Mega and adding a mini compressor and a pen brush. The cutting fluid spraying system can be controlled automatically based on the tool temperature set to 150°C or periodically. The tool can work well. Experiments show that the periodic method saves the use of cutting fluid at a spray rate of 180 ml/hour, far below the maximum MQL requirement (500ml/hour). This happens when using a depth of cut of 1.8 mm combined with a cutting speed of 120.89 m/min. Meanwhile, the temperature-based automatic control system is capable of producing a spray of about 450 ml/hour (which also meets the MQL criteria).

Metal removal rate (MMR) analysis showed that the maximum MRR is obtained in the periodic method with a depth of cut of 2.2 mm. So, the periodic MQL method is superior in terms of saving cutting fluid and MRR. However, if the periodic MQL method is applied, the consequence is that the working temperature is not controlled.

References

[1] N. Upadhyay, “Environmentally Friendly Machining: Vegetable Based Cutting Fluid,” *SAMRIDDHI A J. Phys. Sci. Eng. Technol.*, vol. 7, no. 02, pp. 79–86, 2015, doi: 10.18090/samriddhi.v7i2.8630.

[2] A. Shukla, A. Kotwani, and D. R. Unune, “Performance comparison of dry, flood and vegetable oil based minimum quantity lubrication environments during CNC milling of Aluminium 6061,” in *Materials Today: Proceedings*, 2020, vol. 21, doi: 10.1016/j.matpr.2019.11.060.

[3] S. B. Kedare, D. R. Borse, and P. T. Shahane, “Effect of Minimum Quantity Lubrication (MQL) on Surface Roughness of Mild Steel of 15HRC on Universal Milling Machine,” *Procedia Mater. Sci.*, vol. 6, no. Icmpc, pp. 150–153, 2014, doi: 10.1016/j.mspro.2014.07.018.

[4] S. K. Ali, S.M., Dhar, N.R., Dey, “Effect of Minimum Quantity Lubrication (MQL) on Cutting Performance in Turning Medium Carbon Steel by Uncoated Carbide Insert at Different Speed-Feed Combinations,” *Adv. Prod. Eng. Manag.*, vol. 6, no. 3, pp. 185–196, 2011, [Online]. Available: http://maja.uni-mb.si/files/apem/APEM6-3_185-196.pdf.

[5] A. Y. C. Nee, *Handbook of manufacturing engineering and technology*. London: Springer-Verlag, 2015.

[6] B. Basuki, “Analisis pengaruh sistem minimum quantity lubricatin (MQL) terhadap keausan pahat dan benda kerja,” in *Prosiding SNTT*, 2013, pp. 266–271.

[7] G. G. S. Dinata, A. Z. Muttaqin, and M. Darsin, “Rancang bangun dan uji performa sistem kendali pemberian fluida permesinan MQL berbasis arduino,” *Rekayasa Mesin*, vol. 11, no. 1, pp. 97–104, 2020, [Online]. Available: https://rekayasamesin.ub.ac.id/index.php/rm/article/view/634/414.

[8] R. Pramana, K. Ilham, S. Nugraha, M. Otong, and D. Aribowo, “Perancangan Perangkat Pengering Ikan Otomatis Skala Mini,” *J. Sustain. J. Has. Penelit. dan Ind. Terap.*, vol. 8, no. 2, pp. 65–74, 2019, doi: 10.31629/sustainable.v8i2.1436.

[9] M. Aditya and D. E. Myori, “Sistem Sterilisator Otomatis Berbasis Arduino Uno,” *JTEIN J. Tek. Elektro Indones.*, vol. 1, no. 2, pp. 99–109, 2020, doi: 10.24036/jtein.v1i2.49.

[10] M. Darsin, R. D. H. Qoryah, R. Sidartawan, A. Luviandy, A. Z. Muttaqin, and D. Djumhariyanto, “Performance of TiAlN PVD coated carbide tool in machining AISI 4340 with Minimum Quantity Lubrication (MQL) condition,” in *IOP Conference Series: Materials Science and Engineering*, 2021, pp. 1–10, doi: 10.1088/1757-899X/1034/1/012099.

[11] K. Krishnaiah and P. Shahabudeen, *Applied Design of Experiments and Taguchi Method*. New DelhI: PHI Learning Private Limited, 2012.

[12] S. Kalpakjian and S. Schmid, *Manufacturing Engineering and Technology*, 4th ed. Pearson, 2001.

[13] A. A. Putri, “Perubahan fisik pada pembubutan baja AISI 4340 dengan MQL (Mnimum Quantity Lubrication),” Universitas Jember, 2021.

[14] M. B. Ramadhani, M. Darsin, R. D. H. Qoryah, H. A. Basuki, S. Junus, and Y. Hermawan, “Optimizing the Surface Roughness AISI 4340 steel on Turning Process under Minimum Quantity Lubrication (MQL),” in *Board Exposure to Engineering Science and Technology*, 2021, [Online]. Available: https://best.untirta.ac.id/.