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Progression in Designing and Fabrication of Minimum Quantity Lubrication (MQL) System with an Arduino based Controller

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Progression in Designing and Fabrication of Minimum Quantity Lubrication (MQL) System with an Arduino based Controller

Mahros Darsin, M M Firdaus, I Hardiataman, R D H Qoryah, R Sidartawan, A Syuhri, Y Hermawan, H A Basuki, D Djumhariyanto, D Yudistiro

Department of Mechanical Engineering, University of Jember, Jalan Kalimantan 37 Jember 68121, Jawa Timur, Indonesia

E-mail: mahros.teknik@unej.ac.id

Abstract. Using cutting fluids in machining with petroleum-based creates health hazards issues to the machining operator and environmental problems due to the waste. One effort to reduce it is by applying minimum quantity lubrication (MQL). This research aims to develop an MQL system with an Arduino controlled based on the previous design. The main hardware was changed, i.e., pump, power supply, nozzle, sensor, and temperature setting changed from 70 ^{o}C to 150 ^{o}C. The fluid consumption was measured in machining with a depth of cut of 2.3 mm and 2.5 mm and cutting liquid composition of 3:7 and 7:3 (water to dromus cutting fluid). The calculation showed that cutting fluid consumption is mostly more than 1000 ml/h, or it has not achieved a maximum of 500 ml/h. However, compared to the previous design, it has reduced up to half of the former scenario. From the tool deterioration perspective, the depth of cut of more than 2.0 mm results in severe tool deterioration in the form of chipping. The higher the depth of cut, the intense the tool deteriorated. For the next design, we should add an air compressor in the MQL system and solenoid(s) to regulate the spraying.

1. Introduction

Applying cutting fluids in machining is a typical case to increase machinability. A cutting fluid is a mineral oil made of petroleum (crude) oil mixed with some water in a particular proportion. This cutting fluid will be used for a certain period in the machine tools and then drained and thrown away. The used cutting fluids creates environmental issues [1]. Its content - such as sulfur, phosphorus, and chlorine [1] - may also be dangerous for the machining operators when they fumed due to heat generated during machining. Another issue to cope up with the petroleum-based cutting fluid is its sustainability. Therefore, it needs to be replaced by renewable ones.

There are two primary efforts to overcome those issues. On one side, some researchers have made an effort to replace the petroleum-based cutting fluid with renewable ones. They tried some plants based oils such as castor [2], palm oil [3], Karanja [4], and Calophyllum inophyllum [5]. Other researchers concern about reducing the use of cutting fluid by applying minimum quantity lubrication (MQL) in machining [6–9]. Both groups have made significant achievements. Besides, some researchers have tried to apply both. All parties are in a race towards green manufacturing to create a better life for the future.

Applying MQL in machining proved to improve machinability from different points of view. It is reported that MQL results in better machined surface [10–12]. Some scientists claimed that MQL has proved to increase the tool life in different machining applications [13,14]. It also reduced the cutting force in machining [1,11,15]. After all, the MQL is much more economical than using a flooding method due to less cutting fluid needed during the machining cycle.

By default, the MQL system is not an original method of applying cutting fluid in a machine tool. Therefore, researchers have to build their network and combine it with the existing cutting fluid apparatus. Other experimenters use the MQL system by removing or abandoning the current system [16]. There is no published paper describing or presenting a clear portrait of how the MQL system was built. However, there is the same clue to building an MQL system, using a compressed cutting fluid [17–21] to create a mist form and directed it to the interface of tool and workpiece chips formation taking place.

The further reduction of cutting fluid application can be made by adding a controller in the MQL system. The cutting fluid will be gushed as needed only. Our team has succeeded in designing and fabricating the MQL system with an Arduino based controller [22]. The controller can either be time- or temperature- controlled. Applying the new device has proved to reduce tool deterioration and increase the quality of the machined surface. The new system's only weakness is it has not yet achieved the general criteria of an MQL system, i.e., the maximum consumption of cutting fluid is only 500 ml.

This research aims to develop the MQL system to target the plan to fulfill the MQL requirement (less than 500 ml/h). Some hardware weaknesses have been recognized, and the software will be developed to attain the goal.

2. Methods

To build an MQL system, we developed an Arduino based controller. Based on the previous system, there are four major hardware or components, as presented in Table 1. Also, the setting temperature on spraying was changed from 70 ^oC to 150 ^oC considering that the tool's working temperature is up to 600 ^oC with retaining its hardness at 70 HRC [23]. All changes are attempts to comply with MQL criteria. Some components were kept the same as the previous design, using Arduino UNO R3 type (which used atmega 238P). To reduce the DC voltage, it is using LM2596 as shown in Table 1 with notation $\mathcal{P}$ is Previous MQL system [22] and $\mathcal{N}$ is The new MQL.

Table 1: Comparison between the old and the new components used to build the MQL system

No	Component	$\mathcal{P}$	$\mathcal{N}$	Reason for changing
1	Pump	Water Pump	Fuel Pump	More powerful pump
2	Power Supply	Switching DVD (12V / 1A)	CPU (12V/10A)	More durable
3	Nozzle	Freshener spray	Injector	Possible to get a smaller droplet of mist spray
4	Sensor	Sensor DS18B20	Sensor MAX6675	Able to work at wider temperature (from -200^{0}C to 1200^{0}C)
5	Temperature setting	70 ^oC	150 ^oC	To increase the threshold of spraying

The MQL system is then tested in the straight turning of AISI 4340 with a TiAlN PVD carbide coated insert tool. The machining performance was measured by measuring/calculating the amount of cutting fluid used in one hour. Its machinability was measured by observing the tool deterioration and surface roughness of the machined part.

The machining tool was TiAlN PVD coated carbide, which has a working range is depicted in Figure 1a. The workpiece to be machined is a rod of AISI 4340 which have the chemical composition C: 0,34%, Si: max 0.40%; Mn: 0.65%, Cr: 1.50%; Mo 0.23%, Ni: 1.50%; Fe: the rest. The dimension of the workpiece is presented in Figure 1b.

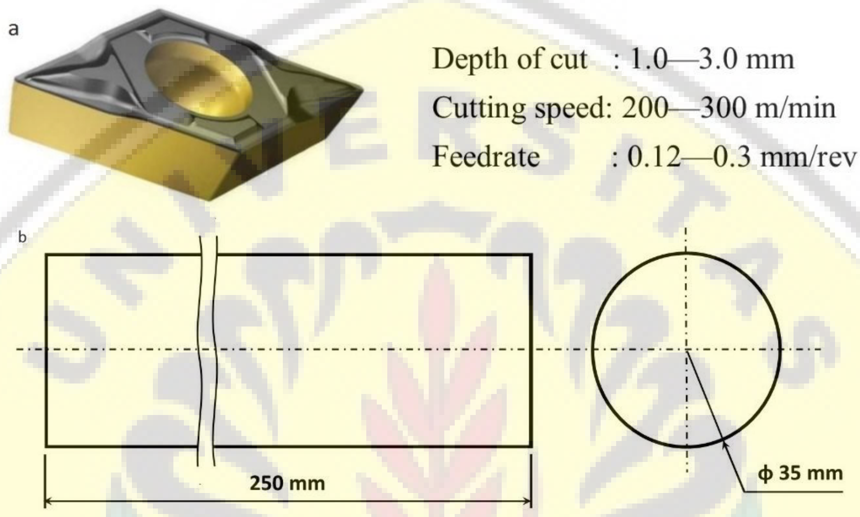

Figure 1: The TiAlN coated carbide tool used in the experiments and its operating range. Also, The workpiece dimension

3. Results and Discussions

The designed MQL system is presented in Figure 2. The sensor was placed 3 mm from the tooltip and then connected to the Arduino controller, where the controller is connected to the pump. When the spindle rotates and the tool comes forward toward the workpiece, the machining process starts. Due to the shearing process of chips formation and friction between the tool-workpiece and tool-chips, the heat is generated during machining. Then the heat will be distributed among the tool, workpiece, and chips. When the sensor detects the tool temperature increase up to 150 ^{o}C, the controller sends a signal to the pump to gush the cutting fluid. Subsequently, the tool temperature drop under 150 ^{o}C controller manages the pump to stop spraying. The temperature and time of the process are monitored and recorded by a laptop.

Some combinations of machining parameters and conditions have been tried for straight turning. As machining is to measure the cutting fluid consumption, we did not try the flood and dry ones. The cutting composition compares the volume of water to the oil (dromus) before machining. Each combination of parameters was replicated thrice. The measured output was the time needed to operate one run. Cutting fluid consumption in ml is measured by subtracting the initial volume to the left offer of the reservoir's cutting fluid. The cutting fluid consumption in ml/h generated by calculation, one example of it is described in the following calculation as look in Table 2 with notation: PR is Parameter combination, $\mathcal{D}$ is DoC (mm), CF_ξ is CF Composition, CF_c is CF consumption (ml), t is Time need in one run (s), and CF_s is CF

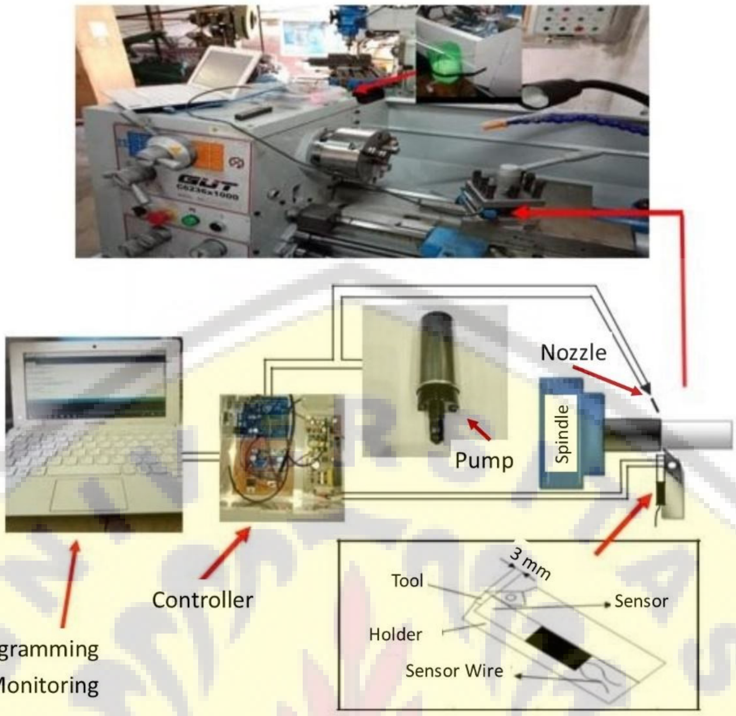

Figure 2: The new MQL system

consumption (ml/h).

$$\text{Total CF consumption} = \frac{3600}{\text{time of one run}} \times \text{CF consumption of one run} \tag{1}$$

For run no 1 of 1^{st} replication

$$\text{Total CF consumption} = \frac{3600}{120.55} \times 40 = 1194.5\text{ml/h} \tag{2}$$

Table 2: Experiments variables and cutting fluid consumption measurements

PR		Results								
		CF_c			t			CF_s		
$\mathcal{D}$	CF_ξ	1	2	3	1	2	3	1	2	3
2,0	5 : 5	40	30	40	120.55	110.30	123.49	1194.50	979.10	1166.06
2,3	3 : 7	70	65	60	120.26	121.61	121.29	2095.40	1924.10	1780.80
2,5	7 : 3	100	90	70	124.46	125.10	117.40	2892.40	2589.90	2146.50

It is evident from Table 2 that all of the results in fluid consumption are more than 1000 ml/h except for combination number 1 of the 2^{nd} replication. It is also evidence that the higher the depth of cut, the more fluid consumption was. Inevitably the depth of cut is the most influential parameter toward fluid consumption. The higher center of the amount means the more volume of material to be removed at a particular time. It is a compound with an oil-rich composition.

Oil-rich composition means the thicker cutting fluids, which means the more difficult it is for the cutting to be sprayed in small droplets. Consequently, it reduced the effectiveness of cutting fluid to cooling down the tool. Therefore, the time needed to spray was relatively high.

However, fluid consumption has been decreased by almost half that of the previous design [22]. Therefore, as research, it is a good enough achievement. Furthermore, there are some other criteria of MQL in terms of the volume of sprayed cutting fluid. One literature mentioned that it is up to 900 ml/h [12], some others said it is maximum of 500 ml/h [1], [17], [24].

Let's observe the tool deterioration following the implementation of the new MQL system. The tool was observed under an optic microscope from a different perspective. The results are shown in Figure 3. The original shape of the device is depicted in Figure 3a. At the DoC of 2.3 and 2.5, chipping is dominant tool deterioration (Figure 3c & 3d), while at DoC of 2.0 tool experienced abrasion (Figure 3b). the dry machining is shown the severest worsening. It is broken (Figure 3e). It evident that the higher the depth of cut resulted in a severed tool deterioration. In our previous design, we tried the maximum depth of cut at 2.0, and a severe tool deterioration in the form of chipping occurred. Whereas, at a depth of cut less than 2.0 mm (1.6 and 1.8 mm), the tool chipping has never been found either with MQL, dry, or flood method [25]. The results contrast with what was assumed by Jiang et al. that the depth of cut has only a small contribution toward tool wear [16]; therefore, they kept cutting low and constant at level 1 mm. In the current experiments, we purposely tried a higher depth of cut to see whether the MQL system works well to protect the tool or not. Therefore, we do not recommend using the depth or amount more than 2.0 mm either machining AISI 4340 with a TiAlN coated carbide tool with MQL or other methods to avoid severe tool deterioration.

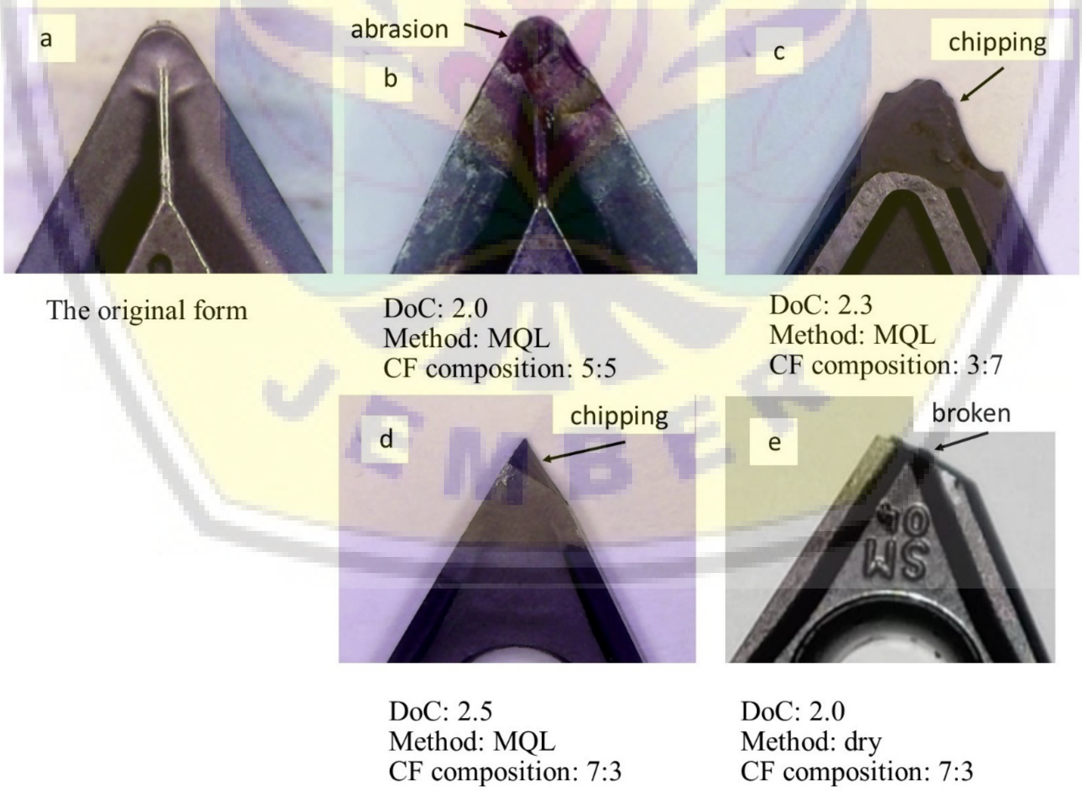

Figure 3: Tool deterioration

Based on measuring/calculating cutting fluid consumption and tool deterioration observation, we learned that the recently built MQL system needs to be improved. The spraying of cutting fluid should be made in smaller droplets to maximize the cooling effectiveness. It may be achieved by adding compressed air. In the next design, an air compressor should be added to the system. We may adopt a similar airbrush approach for painting purposes, spraying the paint smoothly and gently if the compressor in the controller, solenoid(s) will be employed to regulate the spraying.

4. Conclusion

It is concluded that the new MQL system has improved from the previous one, though it has not reached the target. The TiAlN coated carbide tool is not recommended for machining or turning at a depth of cut more than 2.0 mm. For the next design, we will add an air compressor to the MQL system together with solenoid(s).

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