System Design and Development of MQL Unit for Hard Machining Application: A Review

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Abstract. A well-known technique in machining process is cutting under wet machining. It is widely accepted with benefit of increasing productivity and quality in metal cutting. However, the adverse effect of using cutting fluids in wet cutting is now considered as environmental pollution. An alternative method is needed to hinder the hazardous aspect of cutting fluids. The purpose of this paper is aimed to discuss the system design and development of a minimum quantity lubricant (MQL) that activated based on the evolution of tool wear. The MQL unit is expected to replace wet cutting but maintain its benefit or when possible achieving higher performance than wet cutting. Based on the review of references, this paper confirms the advantages and suitability of MQL system to contribute productivity and cost-reduction due to longer tool life, better surface finish, and besides, the safe and environmentally friendly.

1. Introduction

The cutting process using a lathe is one of the important processes in the manufacturing. One factor that has an important influence in the process of cutting using machines such as lathe and milling is the Machine Cutting Fluids (MCF). Cutting fluid increase productivity and quality of production due to cooling and lubricating during the process of cutting and metal forming [1]. Moreover, cutting fluid functioned as heat transfer on cutting area [2] and it is also remove chip from the cutting area [3]. However, the use of coolant is not only advantage but also disadvantage in production process. Conventional cooling fluids are generally classified into four types: water-based, oil-based, synthetic-based, and solid-based [4].

Approximately 85% of worldwide used coolant is mineral oil [5]. The excessive use of mineral oil may hazardous to the environment and operator health. It was reported that 80% of all occupational work-related diseases were caused by skin contact with coolant [6]. This is due to the presence of hazardous elements in the liquid such as phosphorus, sulfur, chlorine, and zinc which can pollute the environment and make it a flammable material [7]. Although the waste also reported from the use of conventional cooling fluids, in Europe the use of conventional fluids reaches around 320,000 tons per year [8]. The adverse effect of using conventional fluids is environmental pollution. Thus, an alternative method is needed for conventional fluids. Lubrication should replace conventional fluids because it saves energy and environmentally friendly [9]. Lubricant can be applied to workpieces by using a tool. For example, Tamboli et al enabled lubricant with a pressurized air system obtained from a compressor
and uses a spray gun as a nozzle. A gear pump is also used to drain lubricants and it is run by a motor [10]. A compressor can be used to derive pressurized air. The nozzle also functioned as a fuser of the lubricant and compressed air. The oil tanker made from stainless steel is used as a lubricant reservoir. Lubricant is flowed to the nozzle by using compressed air from the compressor. The nozzle stand is used as a buffer nozzle [11].

The MQL nozzle evaluation was designed to improve machine capabilities [12-13]. To this purpose, the application MQL was carried out in experiment at a constant cutting speed, feed, and depth to improve the results. It was found that the fluid can greatly reduce the cutting strength and temperature in machining. The maximum effective flow rate of the lubricant is influenced by cutting speed [13-16].

Furthermore, the MQL spray performance with respect to spray characteristics, cutting force and cutting temperature were determined. It was found that the performance of OD30 nozzle is higher than OD25 nozzle. For the OD30 nozzle shown a wider cone angle, smaller SMD and faster speed, thus it served better cooling effect during the nozzle type turning. The design and position of nozzle has a significant impact on cutting fluid supply [16-19].

In MQL, lubricant and compressed air are fired into the contact within the tool and the workpiece. It reduces the friction between the tool and the workpiece that derives the reduction to temperature and ultimately increases the tool life. The minimum lubrication quantity is now widely used in metal cutting machining areas, and in many areas, it has been established as an alternative to conventional liquid processing. In contrast to flood lubrication, minimum quantity lubrication uses only a few drops of lubrication (about 5 ml to 50 ml per hour) [20].

From various studies, it was proven that MQL is a beneficial and feasible alternative to conventional and dry cooling methods. However, the selection of appropriate MQL parameters should be a consideration for the efficient use of this method. A previous study has reported the development and use of the MQL system to support the machining process [21]. The MQL system was run from the beginning to the end of the machining process, where the tool has reached the end of its useful life. Thus, the use of the MQL system was considered inefficient due to the liquid is emitted from the MQL nozzle from the beginning to the end of the machining process, regardless insignificant of tool wear. By considering the evolution of the tool wear, the gradual phase needs to be conditioned for in this phase, the tool provides the longest performance that determines the quality of the machined surface. Therefore, it is necessary to identify the gradual wear phase as well as the needs of MQL system support.

Based on the background above, this paper reported the system design and development of MQL system that activated based on the evolution of tool wear. The developed MQL unit will be used in the metal cutting manufacturing industry to achieve the possible higher performance. Thus, to achieve this purpose, the following steps are carried out: 1) Designing an MQL system and unit that fits the requirements of hard machining methods; 2) Enriching the MQL system with activation ability based on the evolution of tool wear; 3) Testing the MQL developed unit in the machining of hardened alloy steel (AISI 4340 with a hardness of 50 HRC) by utilization of a cermet chisel.

2. Hard Machining

Hard machining is a machining process with a hardness value above 45 HRC, generally 58 HRC to 68 HRC. The workpieces include seamless alloyed steel, tool steel, hardened alloy steel, nitride steel and hard chrome plated steel, and heat treatment of powder metallurgy. [22]

The hardness of cutting material results the differences characteristics. Hard material has abrasive properties, and high hardness or Young’s modulus ratio. Therefore, the hard lathe process requires the harder and abrasive-resistant cutting tools than the ordinary lathe. The hard lathing process should be carried out on various types of metals such as steel alloys, bearing steel, hot and coldwork tool steel, high speed steel, die steel, and hardened castings steel [23].

The consideration of hard machining industry to use a hard lathe is the ratio between the cost of equipment, especially the age of cutting tool should be increased. Specific materials used for hard lathe are cubic boron nitride (CBN), ceramics, cermet and carbide. However CBN is the hardest material after
the diamond, and is very suitable for use in the hard lathe process. A combination of CBN and titanium nitride powder increases tool life by five times. [24]

3. Dry machining
The emerging of dry machining use in industry is due to the phenomenon of tool failure and problems in cutting fluid, especially on the surface roughness of the workmanship, the accuracy of the product geometry and the mechanism of tool wear and life. Studies reported that used cutting fluid occasionally were stored in containers and then piled in the ground. In addition, there are still many practices that discard used cutting fluid directly into the wild. This will obviously threaten environment sustainability. An alternative for wet machining is dry machining. This technique avoids the used fluid in large quantities resulted from machining process, no haze of cutting fluid particles that endanger the operator and free of contaminated cutting debris. However, the dry machining has several problems related to machining parameters, such as friction between the surface of the workpiece and the cutting tool, the speed of debris removal and high cutting temperature.

Generally, the metal cutting machining industry carries out the dry machining to avoid the adverse effects of cutting fluid in wet machining. This argument is specifically supported by studies that dry machining is free from contamination of the work-environment and haze of cutting fluid particles. Therefore it is necessary to find alternative cutting methods that are environmentally friendly. From ecological perspective, dry machining is called as green machining, for its safety for the environment and reducing the production costs [24].

3.1. MQL in Machining Process
MQL is functioned as a cooling in the form of aerosols. MQL is considered as the latest machining technology for its safety, environment-friendly and reduce the coolant lubricants use [25]. In MQL, a very small amount of lubricant is applied (<30 ml/h) to the pressurized air flow [26]. There are two supply methods in MQL, namely external and internal supply, as shown in Figure 1.

![Figure 1. MQL supply system [15]](image)

3.2. MQL Unit Systems and Construction
The MQL, SKF Lubricant Basic and Smart minimum quantity lubrication system consists of a lubricated reservoir, one or more mixed control units and a lubricant channel with spray nozzles as shown in Figure 2. Compressed air fed into the system to stabilize the lubricant reservoir that was transported separately through the duct system and from the duct to the spray nozzle [19].
3.2.1. **MQL system unit design.** The system design and construction of the minimum unit comprise of components selection, design, and integration of the controller, design and the workings of the tool. Tool testing aims to determine the effectiveness of the following design and parts contained in the spray lubricant. The tools include Pneumatic Air Solenoid Valves, filter regulators, branch tees, regulators, liquid tanks, PGMI injectors, 12V DC motorcycles, fittings, boxes, casing controller boxes, combination nozzles, and magnetic stands as shown in Figure 3.

3.2.2. **MQL system setup.** The general requirement for the main task of the MQL system is to supply the right target lubricant to the cutting edge. A number of different devices for various needs are available for this purpose. For multipurpose machines such as starting, sawing and shaping simple, MQL devices that can be controlled manually with internal and external feeds using different functional modes. This is usually a system with pressure tanks and metering pumps. Modern flexible production systems require very demanding MQL device technology. For this purpose, complex MQL systems have been developed that have integrated components for regulation, control and monitoring. Depending on accessibility to the cutting edge, different requirements apply to the device used. For this reason, a distinction is made between external feed and internal lubrication media, which makes a real difference in the cost of device technology.

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In the case of an external feed, the lubricant is applied by spraying nozzles around the tool. This system is very suitable for the implementation of the entrance level for standard processes (turning, milling, drilling). Through internal feed, the lubricant is transported through the engine spindle system and through the channel to the machining point. This system is used particularly when processing is flexible and a new machine is run, or the high speed cutting (HSC) is demanded. Devices for external feeding transport separate lubricating and atomizing the air near the contact points. This occurs in coaxial or parallel in pipework packages.

At the end of the pipe, the lubricant is atomized with a spray nozzle and fed as an aerosol from the outside. The low and simple reinforcement compared to conventional tools are the main advantages of this system. However, all of these systems have limitation and should be adjusted manually or by
additional position axis; there are also losses due to dispersion and shadow effects. The most important application areas use machine tools with a low degree of flexibility and involve the process of sawing, grinding, forming, drilling and threading.

![Diagram of MQL system](image)

**Figure 3.** An overview of MQL system.

3.2.2.1 *Inlet and outlet.* The inlet of MQL systems with internal feeds allows the proper supply of aerosols directly to the point of contact through the tool. The availability of lubricants is maintained at critical points throughout the entire processing sequence. It makes possible to drill the deep holes and use high cutting speeds. For the media should be fed through the engine shaft, thus the conversion to this system may be expensive. Some systems can be controlled directly by control systems. Lubrication system settings for the amount of oil needed and the value of compressed air can be done automatically in the case of chisel exchange. In an automatic production, the manual system parameter settings are not required.

3.2.2.2 *Nozzle.* The air flow carried out through the coaxial tube is stirred in the lubricant outlet zone (the lubricant exits the capillary tube). The air breaks down the lubricant into very fine granules and sweeps them to the point of lubrication without forming mist. The microdroplet size (200/600 μm) ensures a perfect lubricating layer without atomization. The special design as shown in Figure 5 keeps the jet from expanding and the lubricant is sent to the lubrication point with precise accuracy. As a result, environmental contamination with excess lubrication has been successfully prevented.
Figure 4. Spray nozzle design

Nozzle evaluation was held with the Minimum Quantity Lubrication (MQL) method to improve machine capabilities. [12-13]. The MQL utilization was carried out in constant cutting speed, feed, and depth that greatly improve the cutting strength and reduce the machining temperature. In MQL machining, there was a maximum effective flow rate of the lubricant and is influenced by cutting speed [13-16]. The MQL spray performance was determined for spray characteristics, cutting force and cutting temperature. It revealed that the performance of OD30 nozzle is superior than OD25 nozzle. The OD30 nozzle showed wider cone angle, smaller SMD and faster speed, that overall providing a better cooling effect during the nozzle type turning. The design and position also contributed to a significant influence on cutting fluid supply [16-19].

The testing procedure was carried out as follows. The Compressed air derives from compressors and distributed through pneumatic hoses. Air regulator was used to regulating the pressure entering the system. The compressed air was entering the two different paths. The first path leads to the water solenoid valve which was controlled by Arduino Uno to open and close it. While the second led to the oil tank. Before it entered the oil tank, the pressure was lowered again using an air regulator. Then, the air went out with the oil into the servo-driven valve controlled by Arduino Uno that flowed to the PGMI injector. Then the compressed air and oil enter the combination nozzle that triggers the release of spray lubricant.

3.2.3. MQL system/unit assembly components and materials. The components in the design of the automatic spray control system are as follows: silent compressor and Arduino Uno Microcontroller board and module, Air Tac 3V210-08 Solenoid Valve, Pressure Sensor Transmitter Pressure Transducer 12 Mpa DC 5V G14, pneumatic regulator, housing filter, PGMI injectors, mist coolant spray system, pneumatic hose, pneumatic fittings; relay, 16x2 LCD, push-button, power supply, panel box, other electronic components.
4. Conclusion and Future Works Recommendation

This paper reports the experimental study of system design and development of dry machining unit with minimum quantity lubricant (MQL). The framework of this study is based on the literature review from the previous works on hard machining to confirm the result. The MQL system contribute cost-reduction due to increasing of tool wear life. However the more experimental attempts and details should be keep to identify the further result, either advantage and disadvantage of this system in hard machining process.

The importance of the dry machining with minimum quantity lubricant is an ideal machining system today. It resulted some advantages as previously described in this paper. Although many studies have shown the effective use of MQL system on industry, however the depth investigation is worth to follow up to discover the best method in machining process. Thus, an effort to develop and design a system of that focused to produce the cost with high quality should be continuous in the future works in more detail analysis, parameters, and unit design.

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