Implementation of an FPGA-Based Sensor System for Oil Mist Lubrication

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***Abstract*—This paper deals with an FPGA-based lubrication monitoring system that can supply vaporized oil at a fixed time to a specific area correctly, as well as monitor its state. The system includes a lubrication IP, a communication IP, and an oil mist sensor IP. The lubrication IP can set the pump discharge time and standby time of the system. It has a function for detecting the lubricant level and an interface so that it can transmit signals to an external controller. The oil mist sensor IP can receive the illuminance value of the vaporized lubrication oil from up to 8 sensors. The communication IP transmits measured data to the main computer's graphical user interface (GUI). This sensor system can be used in high speed operating machines with real time processing.**

***Index Terms*—lubrication, FPGA, oil mist, monitoring system**

I. Introduction

Lubrication is defined as the action of an intervening material between two working objects to facilitate movement. By forming a lubrication membrane in an area that transmits the load, the friction between metals is minimized to prevent wear and fatigue in the areas of friction. By transferring the heat generated, circulating lubricants keep the temperature of the friction surface constant and prevent deterioration of the lubricant [1]. By reducing the mechanical noise of friction parts through lubrication, a machine can be operated in optimum conditions at all times and prevent rust and corrosion. Therefore, the condition of the friction surface should be monitored, and the right amount of clean lubricants should be used in a timely manner.

In early machinery, lubrication points were lubricated directly at any time by an expert operator. However, a disadvantage of lubrication by the operator is that the timing of the lubrication is irregular. Later, a lubrication tank was installed in machines, and lubrication oil flowed through cloth or a pipe. However, with this method, it is difficult to maintain the cleanliness of the equipment due to the excessive amount of lubrication. There have been many improvements in lubrication systems. The problem of lubrication timing and proper amount of lubrication was solved by using timers and mechanical methods. Lubricators can be divided into several categories. Some lubricators use oil, and some use grease. Recently, an oil mist lubricator has been used [2]. Grease is generally used in cases of high load on the friction parts of mechanical equipment or long periods of lubrication. Oil is used in cases of high temperature or high-speed rotation of friction parts. Oil lubrication method can be divided into forced circulation lubrication, which reuses the lubricating oil, and proportional (quantitative) lubrication, which does not reuse the lubricating oil once discharged. The latest high-speed rotary machines use oil mist lubrication devices [3].

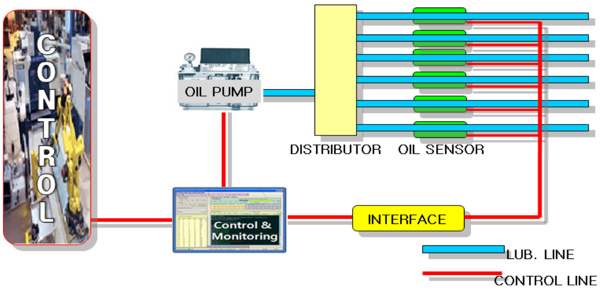

Figure 1. Oil mist lubrication system.

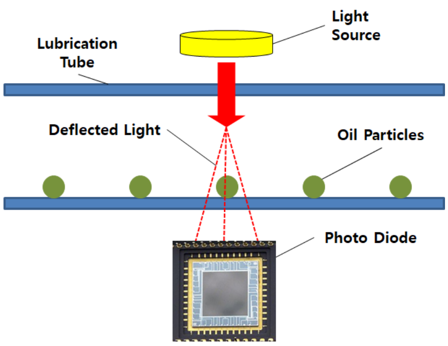

Figure 2. Oil mist lubrication sensor theory.

In oil mist and metered lubrication methods, a small amount of lubricant is used over time, so accurate lubrication time control and lubrication confirmation are essential. It is necessary to develop a new monitoring system to measure the vaporized oil since it cannot be measured by previous flow measurement methods. Fig. 1 shows the oil mist lubrication system. To develop an oil mist lubrication system, it is essential to develop an accurate oil pump control system, a lubrication sensor, and monitoring system. We developed an FPGA-based lubrication system that is suitable for oil mist lubrication

Manuscript received March 30, 2020; revised November 3, 2020.

doi: 10.18178/ijmerr.9.12.1573-1578

sensor control, which is unlike previous oil pump control systems [4].

II. Oil Mist Lubrication System

A. Principle of Oil Mist Lubrication Sensor

Fig. 2 shows the principle of the optical oil mist lubrication sensor that was used in this study. If vaporized oil is sprayed in a transparent lubrication pipe, the light transparency changes according to the oil concentration, and by measuring it, it is possible to easily determine whether or not the vaporized oil has been sprayed [5].

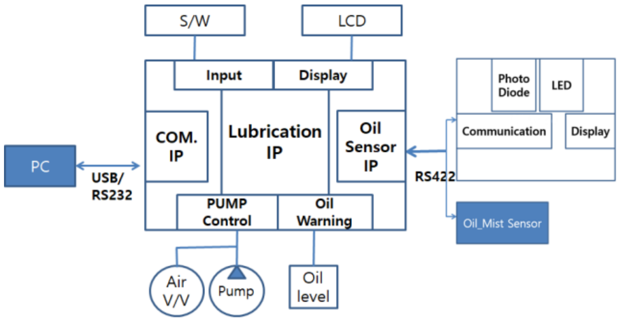

Figure 3. Block diagram of oil mist lubrication.

Fig. 3 shows the oil mist lubrication sensor connected to the lubrication pump control system using RS422. It operates under the command of the lubrication control system. When the lubrication pump starts to discharge, it measures whether the vaporized oil is sprayed inside the lubrication pipe. The measured results are sent to the lubrication control system, and the lubrication control system transmits the values measured by the oil mist lubrication sensor up to 8 points to the computer.

B. Oil Mist Lubrication Sensor System

The oil mist lubrication sensor system includes a lubrication IP, a communication IP, and an oil mist lubrication sensor IP in Fig. 3. The lubrication IP consists of a lubrication pump control unit for lubricating oil, an air valve for spraying vaporized oil, a low surface level sensor for detecting lubricating oil, a switch input unit, and an LCD unit. The oil mist lubrication sensor IP receives data input from eight oil mist lubrication sensors. The communication IP transmits oil mist lubrication sensor data and pump control data to the master computer.

C. Oil Mist Lubrication Sensor

In An ATMEGA8 [6] was used as a processor for the oil mist lubrication sensor. The processor is compact and supports I2C, RS232 communication, and A/D conversion, and it has internal EEPROM. An LCD circuit was used for experimentation in the initial development version, and in the final version, it was removed for miniaturization of the system. The RS422 communication unit uses MAX485, which is connected to TXD and RXD of the processor. In the initial development, RS232 was used. When RS422 communication was completed, the RS232 was removed. To illuminate the illuminance sensor inside the lubrication sensor, the LED for illumination is driven by a FET, and the lubrication operation state is indicated using red and green LEDs to indicate the normal operation of the sensor.

D. Pump Control State

Fig. 4 shows the The Lubrication pump control state diagram. The lubrication system always checks whether the lubricating oil is insufficient by using an oil level sensor and sets the lubricating oil discharge time and standby time.

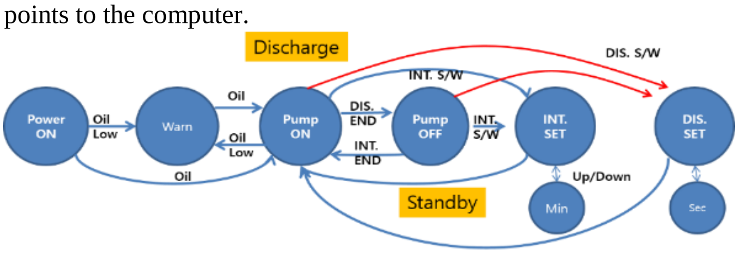

Figure. 4. Lubrication pump control state diagram.

The lubricant discharge time is set in minutes or seconds, and the standby time is set in minutes or hours. An air valve is controlled according to the operation time of the lubricating oil pump to supply air for spraying.

III. IP Simulation

A. Lubrication IP

An XC3S200 from the Spartan 3 device family was used for the system configuration. The lubrication IP consists of seven states: delay, motor_on, motor_off, dis_sw_on, int_sw_on, feed_on, and warn.

When the system starts up, it always starts with a delay state including the initialization process and then converts to motor_on for driving the pump and to motor_off without driving the pump after a certain discharge time. Once the system is running, motor_on and motor_off are repeated until the system is stopped or no control inputs are available. Fig. 5 shows the initialization state, and Fig. 6 shows a simulation of repeated motor_on (discharge) and motor_off (standby) states.

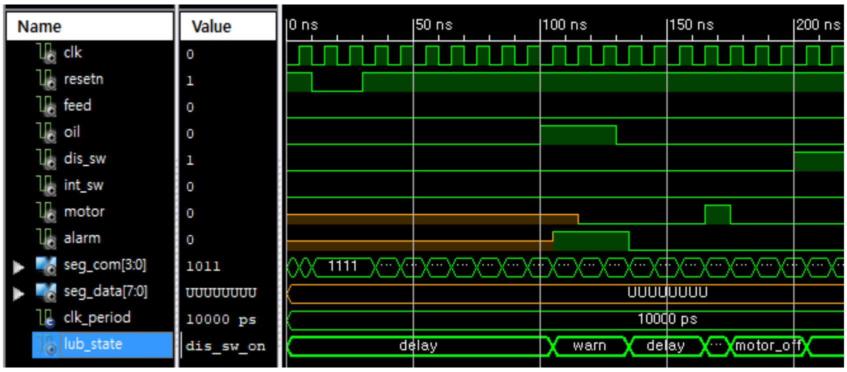

Figure 5. Lubrication IP initialization.

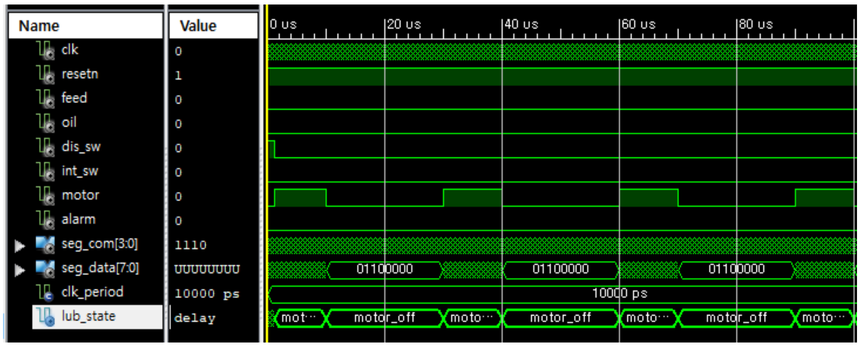

Figure 6. Lubrication IP motor_on/off.

B. *Oil Mist Lubrication Sensor IP*

Fig. 7 shows a simulation of the oil mist lubrication sensor IP. The value of the vaporized oil measured by the lubrication sensor is input through RS422 serial communication and transmitted to the lubrication IP inside the FPGA. The system can be connected to up to eight lubrication sensors, but the simulation shows waveforms connected to one sensor.

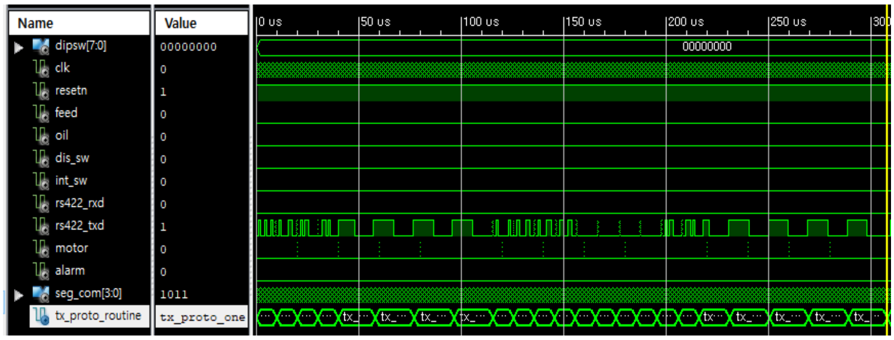

Figure 7. Oil mist lubrication sensor IP simulation.

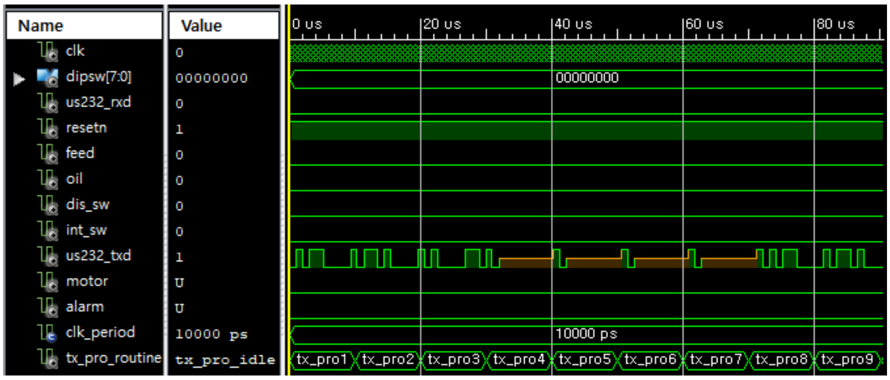

Figure 8. Communication IP simulation.

C. Flow IP

Fig. 8 shows the simulation for the communication IP. The data input from the oil mist lubrication sensor is transferred to the communication IP through the lubrication IP, and the communication IP is configured to transmit it to the master computer. The communication IP converts the RS232 signal into a USB signal from outside of the FPGA and transmits it to a computer.

D. Lubrication Control Packet

Fig. 9 shows the packet format between the master computer and the lubrication pump control system. All packets start with a sync byte "\r" and end with a sync byte "\n". The rest consists of each sensor number and a four-byte data area. Fig. 10 shows the Oil mist lubrication sensor packet. And Fig. 11 shows the Oil mist lubrication sensor data packet.

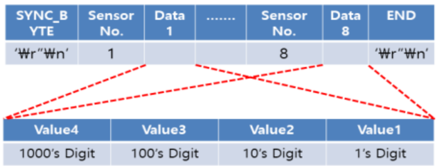

Figure 9. Master computer data packet.

SYNC_BYTE	Sensor No.	END
M: 'I' S: 'O'	1~8	'₩r"₩n'

Figure 10. Oil mist lubrication sensor packet.

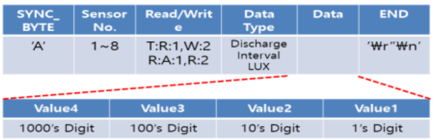

Figure 11. Oil mist lubrication sensor data packet.

The ADC operates from a 2.7 to 5.5-V supply, has two channels of 24-bit ADC. The first four bits indicate the indication, selection channel, output range, and conversion status information. The next 24 bits are data bits. It displays from the MSB to the LSB.

IV. Experiments and Results

A. Lubrication Pump Control

When the lubrication pump is turned on, the lubricating oil level is measured. If there is no lubricating oil, a warning buzzer sounds, and an error is displayed on the LCD. The standby time can be set through the switch input. The standby time can be set between 1 minute and 1 hour and 59 minutes, and the pump operating time can be set as 1 to 99 seconds. Depending on the type of pump, the standby time can be set in units of hours or minutes. A manual discharge switch was installed to enable manual lubrication control.

B. Oil Mist Lubrication Sensor

Fig. 12 a) shows a manufactured oil mist lubrication sensor and PCB. The PCB size is 30 mm * 20 mm, and an oil mist lubrication sensor is 30 mm * 35 mm * 15 mm.

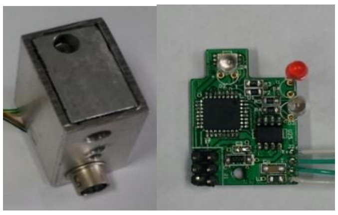

Figure 12. a) Oil mist lubrication sensor & PCB

Fig. 12 b) shows the manufactured oil mist lubrication sensor system.

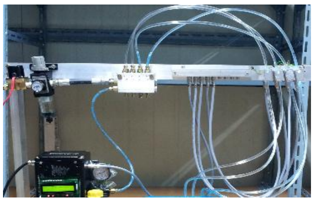

Figure 12. b) Lubrication sensor system.

Fig. 13 shows the manufactured oil mist lubrication sensor circuit.

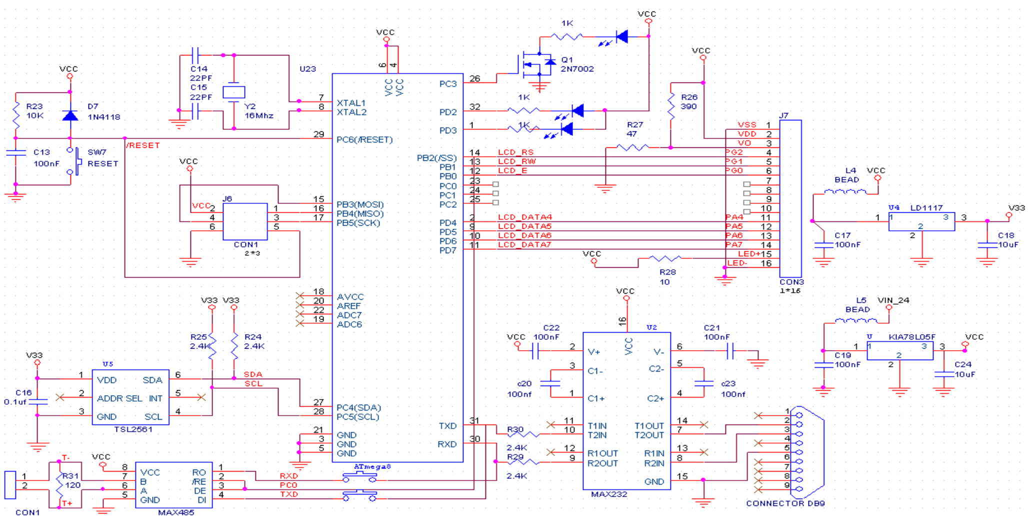

Figure 13. The manufactured oil mist lubrication sensor circuit.

C. Graphical User Interface(GUI)

The USB-RS232 method was used between the lubrication pump and the master computer. In Fig. 14, the upper left shows the transmission data contents, and in the port area, the COM port number, communication baud rate, stop bit, and parity bit can be set.

The length of the transmitted/received byte is shown in the operation area, the send data contents in the send area, and the receive data contents in the receive area. At the bottom of the screen, eight illuminance values input from the oil mist lubrication sensor can be displayed. . In the pump control area, the operating time and standby time of the pump can be set.

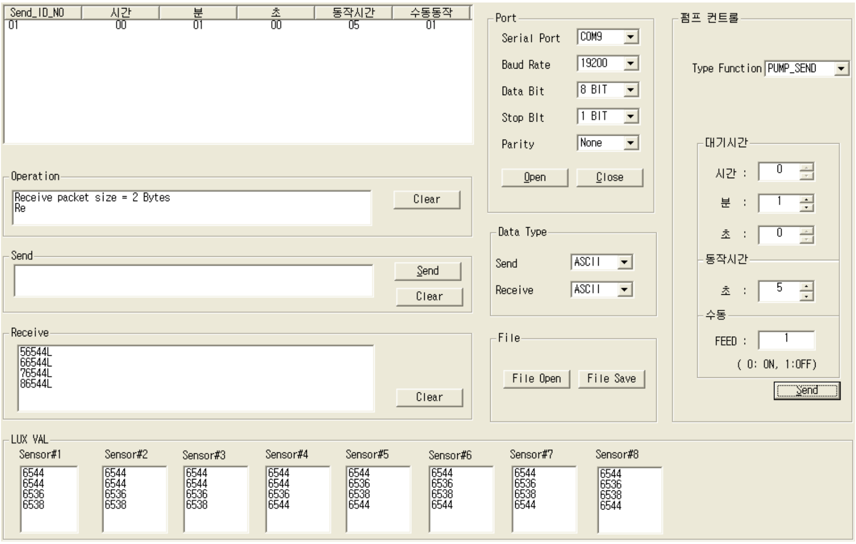

Figure 14. GUI of the oil mist lubrication sensor system.

D. Oil Mist Lubrication Sensor Experiment

The accuracy of the illuminance sensor used in the oil mist lubrication sensor was measured by comparing it with an illuminometer (KONICA MINOLTA CL-200), as shown in table I. The measured value of the fluorescent lighting condition of the laboratory was 325 lux when measured by an illuminometer and 325 – 326 lux when measured by the manufactured lubrication sensor. When the fluorescent lamp was turned off, the illuminometer and the lubrication sensor both showed 6 lux. The measured illuminance value of the fabricated oil mist lubrication sensor and the value measured by the illuminometer were less than 1% different. The illuminance of the transparent vinyl pipe used in the experiment was 522 ±5 lux.

TABLE I. MEASUREMENT OF ILLUMINATION

	CL-200	Oil mist lubrication sensor
1	6LUX	6LUX
2	325LUX	325~326LUX

E. Oil Mist Lubrication Illuminance Experiment

When the air pressure for generating the vaporized oil was set to 1 kgf/cm^2, and 100 cc of lubricating oil was supplied per minute, the measured value was 470 ±5lux. and 100 cc of lubricating oil was supplied per minute, the measured value was 490 ± 5lux. That is, an average difference of 0.5 lux was shown for each 1 cc of lubricant. When the amount of lubricant supplied was fixed at 100 cc and the air pressure was changed to 1-7 kgf/cm^2, the results were 470 lux at 1 kgf/cm^2, 460 lux at 3 kgf/cm^2, and 438 lux at 7 kgf/cm^2.

When 2 g of blue dye was added to 1 L of lubricating oil, the result was 518 lux before discharge started. The vaporization oil was measured by connecting 1 kgf/cm^2 of air to a pump, which discharged 100 cc per minute when the discharge started. The measured value was 325 ± 5 lux, and the average difference in illuminance was 0.23 lux per 1 cc. Fig. 15 shows the measurement of colored Oil Mist Lubrication Illuminance.

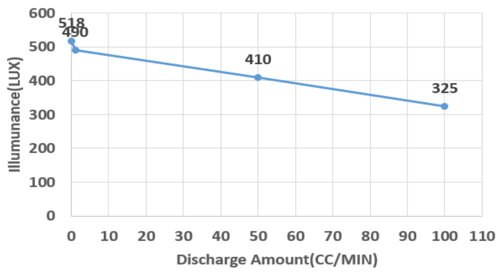

Figure 15. Measurement of colored oil mist lubrication illuminance.

V. CONCLUSION

The developed oil mist lubrication sensor system can set the lubricating oil discharge time from 1 to 99 seconds and standby time from 1 to 99 minutes. It can connect to up to 8 oil mist lubrication sensors through RS422 serial long-distance communication.

It was designed to transfer various data to a computer through USB. In addition, the discharge time and standby time of the pump can be set on the computer. The oil mist lubrication sensor accurately measured the illuminance value. However, the measurement value showed many deviations according to the type of oil.

Lubricant Viscosity CST46 oil is easy and accurate to measure because of the change in illuminance value of 20 lux or more when the discharge amount is over 100 cc. However, it was not possible to measure it at 1 cc/min or less. 2 g of blue lubricating oil dye was added per 1 L of oil. The oil mist lubrication system should be commercialized separately for a small-scale precision control system and mass proportional control system.

In addition, the pressure relief valve inside the pump must be operated correctly to maintain the pressure in the pipe at 0 kgf/cm^2 after discharge. Accurate measurement was possible only when the sprayed oil inside the pipe was completely removed. When the pressure relief valve did not operate correctly, it was necessary to clean the inside of the pipe by supplying additional pure air for 5 to 10 seconds after the lubricating oil was discharged.

Conflict of Interest

The author declares no conflict of interest.

Author Contributions

Cheol Hong Moon composed the whole paper.

Acknowledgment

This study was conducted by research funds from Gwangju University in 2020.

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