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Initial Results on Magnetic Flux Leakage (MFL) Diagnosis Device

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Abstract— Magnetic flux leakage (MFL) is among the famous and expensive technique in large scale oil and gas pipe diagnosis system. This technique apply strong magnetic fields to detect any strange in the inner surface of the pipes such as corroded, crack or other symptoms which is bad to the pipe condition. The aim of this research is to develop a small scale, low cost and portable magnetic flux leakage (MFL) diagnosis system which suitable in to detect the defect the inner side of steel pipe or steel tank structures. Other than industries, the possible application of this research is in the hospital piping and medical tanks. Through this system, the liquid or material inside the pipe or tank no need to take out, and this will not disturb the inside process. This non destructive developed system applies a coil together with Hall Effect sensor that senses the strength of the generated magnetic flux. The detected magnetic flux is then converts to voltage value by the Hall Effect sensor. The value of the converted voltage is different depends on the magnetic flux density, and this flux density will base on the types of the pipe or tank surface. The condition of the surface is then display on the LCD which is also part of the new developed MFL system.

Keywords— Magnetic Flux, Diagnosis System, Hall Effect Sensor

I. Introduction

A non destructive testing (NDT) technique has been applied for a long time period secure structural integrity of complex mechanical systems such as nuclear power plan [1],[2]. MFL (Magnetic Flux Leakage) testing method is on of magnetic NDT method derived from the Magnetic particles inspection, which uses sensing coils and probes substituting the fluorescent particles to detect the flux leakage of the flaw [3]. Other than those industries, the possible application of this research is in the hospital piping and medical tanks. This system is required based on the several situations especially when we need to check condition of the steel plate or wall from one side. This is crucial for situation where the space for measurement is not easily available for both side of the wall like pressure vessel, tank and plant because of factors like pressure, heat and space. Measurement from one side only allows the process to be easy and fast.

There are various techniques that can be used to identify the condition of the steel plate. Most commonly used method today for inspecting is magnetic particles inspection. However a serious problem with this method is its low efficiency and reliability. MFL is used because it more effective for ferromagnetic testing [3]. In this project, we use the magnetic based sensor to measure the condition of the steel plate. Magnetic field characteristics are used to measure the condition of the steel plate. Therefore it needs magnetic sources to produce magnetic field. There are two type of magnetic source either permanent magnetic or inducing magnetic field using coil [4]. The permanent magnet can be in various size, shape and strength. It depends on the direction of the magnetic field would be measure. The coil is generated the field when there is current flow through the coil. For this project we decide to use coil instead of permanent magnet. It is because the magnetic field produce by the coil can easily controlled in term of direction, strength and time.

In MFL, magnets or DC electromagnets are applied in generation of magnetic field in order to magnetize the ferromagnetic specimen under inspection to saturation [5]. If there are any anomalies or inclusions, the magnetic flux lines will leaks outsides the specimen in proximity of the anomalies and the sensor or sensor array will detect the leakage magnetic field, which conceives information on anomalies or inclusions such as corrosion, cracks, grooving, etc [6].

II. METHODOLOGY

A. HARDWARE DEVELOPMENT

In order to finish up the perfect project, the project is dividing in to two part hardware development and software development. The hardware development is consists of the signal conditioning, Hall Effect sensor, the electronic switch for coil, the LCD power circuit, the design of coil with sensor inside and sample preparation.

The magnetic coil is made of wrapping wire. The wire had a conducting size of AWG 30. The conducting material is made of copper. The diameter of the wire is 0.254mm while the resistance is 338.496 Ω per kilometer. It is noted that the maximum ampere for chassis wiring of the wire is only 0.86 amps. The length of the wire is approximately 8 meters with number of turns 80. The current that flow through the wire is approximately 1.2 amps. The coil had an inner diameter of 0.02 meter where the Hall Effect sensor is placed in the center. By using the coil, the magnetic field produced would be in vertical direction when it is being measured by the Hall Effect sensor. The magnetic field of the coil that is measure is in vertical direction. The current flow in the coil is approximately 1.2 Amp. The magnetic field generate by the coil can be calculated by using this formula 3.0

$$B = \frac{u_0 NI}{9\sqrt{L^2+4R^2}}$$

L= length of solenoid
N= number of turn
I = Current, amp
R = radius of solenoid, m
μ= relative permeability of air

The coil can generate the magnetic field approximately 0.05395 Tesla or 539.5 Gauss at the center of the coil. But when the coil is placed on the top of the steel plate, the magnetic field increased because the high permeability of the steel plate. The value of the magnetic field can be observed when it shows on the LCD screen.

When the coil generated the magnetic field the Hall Effect sensor will detect the present of the magnetic field. The magnetic field enters the steel plate according to its direction. Part of the magnetic field is outside of the coil while part of it is inside the coil. The Hall Effect sensor would only sense the magnetic field inside the coil [7]. The magnetic field line inside the coil is assumed to travel through the steel plate. The sensor is located in the middle inside the coil. The figure below shows the magnetic field direction and the placement of the sensor.

The Hall Effect sensor used in this project is SS94A2. This Hall Effect sensor is used to detect the magnetic field or magnetic flux. The sensitivity to the magnetic is 0.1 mV/Gauss. Output of the sensor is ratio metric type.

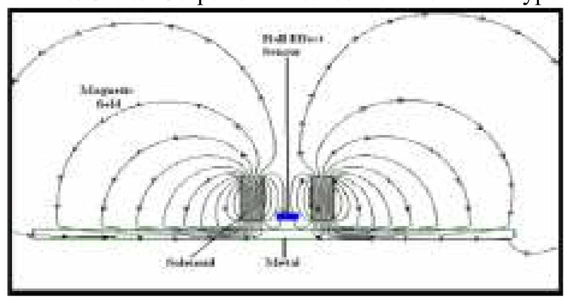

Fig 2: Magnetic Field Direction and Placemen of sensor

The sensor can detect the present of the magnetic field between -500G to 500 G in either direction. The maximum supply current at 25^0 C is 30 mV. The output without magnetic field at 25^0C is 4.00 Vdc. The sensor is placed in the middle of the coil at the bottom position. The distance between the sensor and the plate is approximately 1mm or less. Make sure the sensor not move because it can affect the measurement. The SS9 utilizes a Hall Effect integrated circuit chip which provides increased temperature stability and performance. Laser trimmed thick film resistors on the ceramic substrate and thin film resistors on the integrated circuit reduce null and gain shifts over temperature which results in consistent sensitivity from one device to the next .

The figure below show the sensor jig and the illustration of the coil and the test sample.

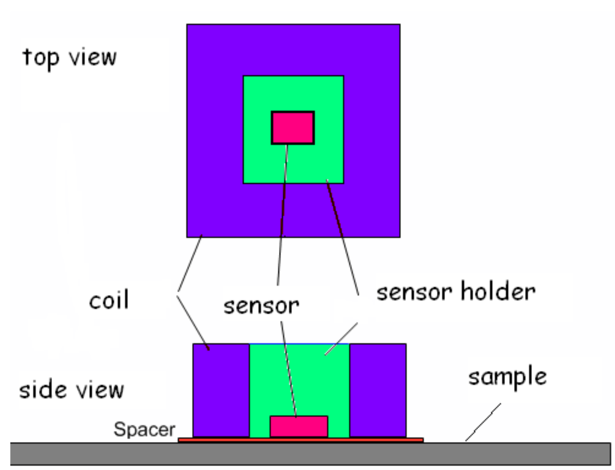

Fig 3: Sensor Jig and Sample Placement

The coil is control by the microcontroller through an electronic switch. This electronic switch consists of MOSFET that received signal from microcontroller to control the current flow into the coil. There is no resistances use between the microcontroller output pin to the gate pin of MOSFET to control to allow the high current into the coil. The 20 kΩ resistors is use between the gate pin to ground. This resistance is use to reduce the current to avoid overheated.

The diode is used in this circuit function as a protector to the MOSFET. The diode is connected to the MOSFET from the brief high voltage produced when the load is switched off. The sudden collapse of the magnetic field induced brief high voltage across the coil which is very likely to damage transistors and ICs. The protection diode allows the induced voltage to drive a brief current through the coil so the magnetic field dies away quickly rather than instantly. This prevents the induced voltage becoming high enough to cause damage to transistors and ICs.

The collected data from the sensor will be displayed on the LCD. On the LCD the type of defect is displaying according to magnetic field captured by the sensor. The ITM 1602A is the model of the LCD using in this project. This LCD module is fabricated by lower power COMS technology, it can display 16 characters in 2 lines with 5x8 dots format. It interfaces with 4-bit or 8-bit MPU.

The LCD had 16 pins where the first 3 pin are used as the power to drive the LCD. It required a 5 V DC power supply to properly operate. The next 3 pins that are pin number 5, 6 and 7 are used to control the display operation of the LCD. The pin is labeled as R/S, R/W and E. Pin number 7 to 14 is used as the data bus for the LCD. The LCD can operate in two mode, 4-bit bus mode and 8-bit bus mode. For 8-bit bus mode, the entire data bus pin is connected. But for 4-bit bus mode, only the last 4 pin is used as the data bus. The first 4 pin is left unconnected to the microcontroller. The LCD had a backlight that can be turn on so that the LCD is easier to see and read. The backlight is connected to pin 15 and 16. Pin 15 is labeled as the anode that is connected to the ground. Pin 16 is labeled as cathode that is connected to 5 V power supply with appropriate resistor value. The resistor use on the cathode pin is 390Ω.

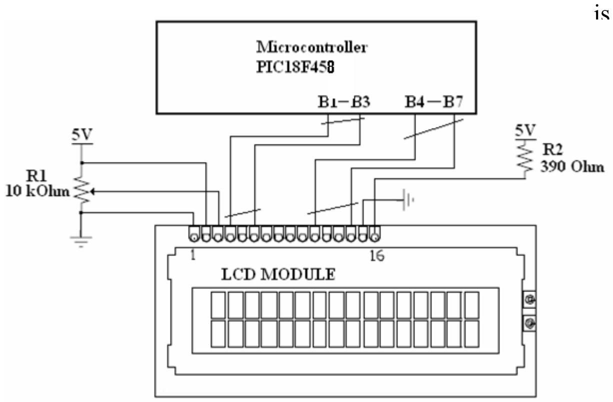

Fig 4: LCD circuit

In this project 5 types of sample were inspected. All 5 types of defect are made up from the same material.

Fig 5: Defect Type A

The type A sample is the one line defect at the center of the plate. The volume loses by the defect is 5.13 cm^3.

Fig 6: Defect Type B

Second sample is one line defect on the center with the volume loses is 2.56 cm^3.

Fig 7: Defect Type C

Third sample is the two line defect with the volume loses is 3.456 cm^3.

Fig 8: Defect Type D

The fourth sample is rectangular defect with volume loses 0.546 cm^3.

Fig 9: Normal

Lastly, the normal defect with no volume loses also tested to check the initial value of the output.

B. SOFTWARE DEVELOPMENT

To interface the data from the sensor and the coil switch circuits, embedded system using PIC 18F458 is use as the central processing unit. The output from the sensor is connected to ADC-analog digital converter module at pin A.2 on port A. The pulse that is use to control the coil switch circuit is connected to pin C.2 on port C. The purpose of integration of the embedded system is to control the switching of coil while sampling the value from the ADC only when the coil is activated. Generally the coil cannot be turned on for a long time because it can lead to the over heat and may damage the circuit because of high current used. This procedure avoids the situation happen [8].

The program is setup to have a small duty ratio. The pulsed is high for 2 ms before it is return to low for 20 ms. The ADC process is done during the time when the pulsed is high. By using the PIC18F simulation IDE the program is identify whether it function or not. The process of inspecting the condition of the plate involves both hardware and software. The software is needed in order to control the coil switch and the ADC process. Furthermore the software is use to do a correct sample of the signal from the hardware and to convert it into represent able form on LCD. When the coil is activated at the same time ADC also activated. The ADC is required approximately 1 ms to finished its sampling process. The coil is activated around 3 ms before it turn off for 20 ms.

The LCD will display the type of the crack. The MPLAB IDE V8.10 is used to program the LCD. The LCD is program using assembly language. According to the program the LCD will display 4 type of crack either type A, type B, type C or type D. PROTEUS 7 professional is used to make sure the program is working as needed.

Generally, all this procedure inspection of steel can be simplify in one block diagram as shown below.

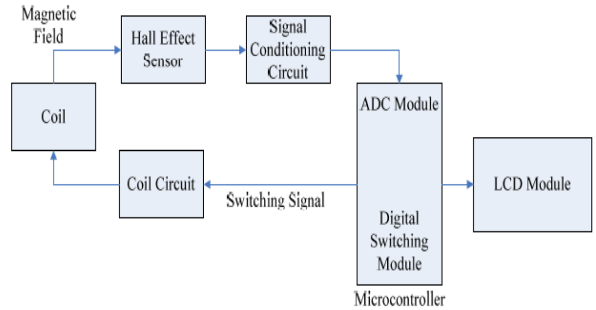

Fig 10: Block Diagram of Magnetic Sensing

III. Result and Discussion

In order to combine the software and hardware together, the testing involved the both part were done. The software and hardware part include pulse for the coil switching, LCD display, sensor power and coil circuit. All this parts need to be tested separately to ensure all the system is in good condition before all the part assembled together.

Firstly the signal from the PIC18f458 is checked using oscilloscope. This pulse is vital to produce the polarity of magnet. The pulsed is called as pulsed width modulation (PWM). When the polarity of the magnet occurs around the coil the magnet field is produce [9]. Others, the pulse are needed to control the current flow into the coil. The purpose of control the current is to avoid the coil being over heated. Figure below show the connection the pic18f458 to oscilloscope

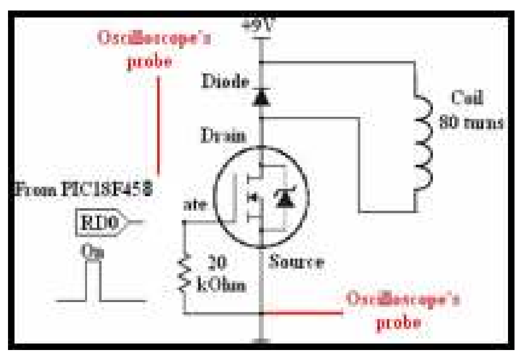

Fig 11: Connection Pic18f458 to Oscilloscope

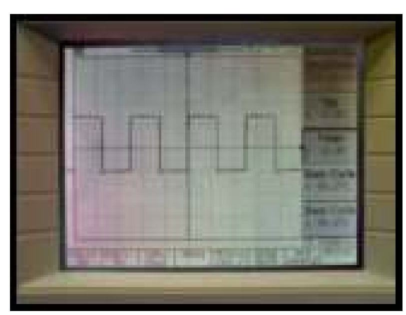

Fig 12: Output from pin port C.2 of PIC18F458

The oscilloscope is connected to the output of the pic18f458 which is port C2.

Table 1: Output from Hall Effect Sensor

Type of defect	Reading 1 (volt)	Reading 2 (volt)	Reading 3 (volt)
Type A	1.7270	1.8892	1.7703
Type B	1.6232	1.6042	1.5085
Type C	1.6085	1.7099	1.5902
Type D	1.5854	1.5018	1.4904
Normal	1.4505	1.4304	1.2350

The value of output in Table 1 is currently change based on the volume loses. When the value of volume of loses increase the value of the output also increased and vice versa.

The LCD will display the type of defect based on the data arrangement. The table below shows the range of volt for each type of defect as in Table 2.

Table 2: LCD display output

LCD Display	**Output Range (volt)**
TYPE A	1.72-1.90
TYPE B	1.59-162
TYPE C	1.63-1.70
TYPE D	1.49-1.58
NORMAL	1.23-1.45

IV. Conclusion

The magnetic flux leakage diagnosis system was developed and archives the initial objective. The objective of this project had been fulfilled as follow:

i) The system able to generate the enough strength of magnetic field which can be detected by the sensor.

ii) The sensors with the amplifier circuit manage to capture the magnetic strength and give the output in volt value.

iii) The system able to detect the 5 different cracks.

V. Acknowledgement

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VI. References

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