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Detection Ability Of Discontinuities In Tank Floor Made From Two Types Of Carbon Steel By Magnetic Flux Leakage

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***Abstract*—Most oil refinery factories possess various liquid tanks for large amount of storage or transportation. If there is a damage, it may create losses for both lives and assets. In this research, it shows a flaw test by the MFL method using Floor Map 3Di models. Three sets of the experiment have been carried out. The first set was consisting of 2 types of carbon steel: SA283 Gr.C and SA516 Gr.70 that have a thickness of 6 mm. This is done by using the same calibrated plate which is SA283 Gr.C. Pitting and uniform corrosion by various sizes and depths are simulated by milling for the natural corrosion. The examination is performed both on the top and bottom sides in which a test for flaws with different shape is also conducted. The second experiment is performed through coated acrylic plates with thickness of 2 mm., 4 mm. and 6 mm. The results show that. The result of the 1st experiment can be concluded that the machine can detect pitting corrosion of both side of testing plate, but it cannot indicate that it is the pitting corrosion and the machine can indicate that there are only 3 groups of damage resulted from loss of metal substance. The 2nd experiment, it is found that the machine can detect uniform corrosion on the top and bottom side. This can indicate that the top uniform corrosion signal is higher than the signal at the bottom. The detected signal will be decreased when the coating thickness is increased. The 3rd experiment, the different shapes that have effect to the signals that are detected by the machine.**

Keywords—Magnetic flux leakage, Tank floor, Carbon steel

1.INTRODUCTION

Damage of storage tank may cause losses to both lives and assets. In order to reduce the chance and to prevent the damage, inspections for the mentioned tanks must be performed to make sure good working conditions and safely use during the operation. Normally, the tank floor may have the surface coating such as paint coating and fiberglass reinforced plastic coating by which the purpose is to prevent corrosion occurred from the deposit accumulation. For a corrosion problem at the product side is not the main problem in the industry in general because it can be checked with the eye sight, but the real problem is the corrosion at the soil or bottom side. This corrosion occurred from the chloride reaction at the tank floor which is therefore hard for the inspection because it cannot be checked with the eye sight.

In the present, the MFL tank floor test is well accepted and popular throughout the world in which it has an advantage that it does not take a lot of test time comparing to the Ultrasonic test [6,7,10,12,13], although this method provides the sensitivity that is not as high as the Ultrasonic test. Alicia et al [1] designed an experiment to test sampling signals that generate defects for both top and bottom sides. After the experiment is conducted, the results are every similar and indistinguishable signal. Later Silver wing developed an operation system for tank floor testing equipment which is called “Surface Technology Air-Gap Reluctance System” or STARS [2,3]. This system can detect signals from the test and at the same time separate the obtained signals whether the location is at the top or bottom plate. This is done using a basic principle that is “The surfaces at the defected locations of the top and bottom are different (Skin effect)” until it leads to the magnetic flux density between the top and the bottom defects that have different densities of the magnetic field. As a result, this system can detect and compare until the defect locations are separated. It was indicated that the discrimination using the Surface Topology Air-gap Reluctance System in conjunction with a Hall effect sensor in order to supplement the discrimination technology (STARS) by 64 sensors [3,13]. This causes the machine to be able to test the paint up to 6 mm. depending on the plate thickness. The principle operation of the censor is that during the plate calibration, the machine recognizes a reluctance value that is a reference value in case that there is a change of the plate thickness. If there is a corrosion at the top surface of the item, it means that the air-gap will be increased resulting in the increase of the reluctance value.

In addition, factors effecting to the signal amplitude are also studied including the flaw depth, flaw volume, flaw shape or profile, flaw aspect ratio (length to width), material permeability, material thickness, magnet system (strength, lift-off, reluctance and magnet material) and sensor systems (types and lift-off) that are used [4,6,8,9,11,12]. However, in practice, the MFL test displays the result in colors using the calibrated plate as the reference in which if the referenced plate contains different chemical compositions, the result may be erroneous. In general, the test in a general work site will test only the uniform corrosion without the pitting corrosion test.

This research will test the effect of type of material of the tank floor that differs from the calibrated plate. Moreover, it will conduct the pitting test by milling at various sizes, depths and distances representing the actual pitting that occurs in the nature both at the top and the bottom sides. In addition, the detection ability due to the different shape of defect will be compared.

This is to check the ability to present the result by which all tests will be conducted through coating that has different depths. The research result can be applied for the real works of the tank floor used in the industrial factories.

2. THEORIES

2.1 Magnetic Flux Leakage Technique

MFL technique is one of the world most widely use Non-destructive testing method using for corrosion detection and evaluation at storage tank floors. Basic principle of this technic is the permanent magnetic transmits magnetic flux to conductor and make it saturate with magnetic flux. The saturated conductor will have magnetic flux density *(B)*. This magnetic flux density obtained from permanent magnetic is compared as a source that input magnetic field to the conductor. equation (1)

$$B = \frac{\emptyset}{A} \qquad (1)$$

Where *B* is the magnetic flux density in Wb/m^2, Ø is the magnetic force in Wb, A is the area perpendicular with magnetic field in (m^2).The magnetic flux density that depend on permeability of material.

2.1.1 Magnetic Permeability

$$\mu=\mu_r\mu_o \qquad (2)$$

where μ_r is Relative permeability of material, μ_o is Permeability of free space

Magnetic susceptibility and permeability data		
Material	Permeability,μ(H/m)	Relative permeability, max μ/μ_0
Carbon steel	1.26×10^{-4}	100
Air	1.256×10^{-6}	1
Wood	1.256×10^{-6}	1

Fig. 2.1 Show Magnetic Susceptibility and Permeability Data

Relative permeability of different materials always represents different number. Non-ferromagnetic materials have ability of permeability at rate of 1. For this project, the block up material is carbon steel in different grades and different carbon value percentage. The different carbon value percentage results effect to permeability of each material. In addition, the magnetic flux density result is slightly different. Figure 2.2 shows the permeability of ferromagnetic μ_f which is the Permeability of ferromagnets, μ_p is Permeability of diamagnets, μ_0 is the Permeability of free space $4\pi \times 10^{-7}$ henry/m

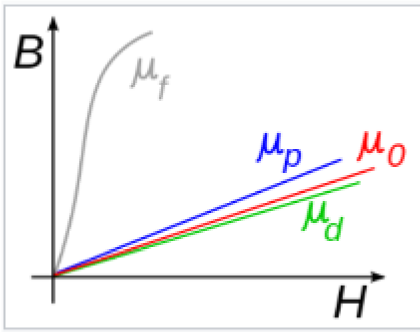

Fig. 2.2 Show Permeability of Different Material

Basic principle of transmission of magnetic flux density (H) to the conductor is to go through air, coating or other material that cover the conducer skin and have similar condition with permeability of free space. By the time, if the magnetic flux density that is able to transmit through ferro-coating, is able to increase number of magnetic flux density [14]. Equation (3)

$$B = \mu \text{ H} \qquad (3)$$

Where H is the magnetic field in A/m, B is magnetic flux density in $Wb.m^2$, μ is relative permeability

2.1.2 B-H Curve

Figure 2.3 shows the relation between *B* and H In addition that the conductor that saturate with magnetic flux density (*B*), adding more number of magnetic field is unable to increase number of flux density.

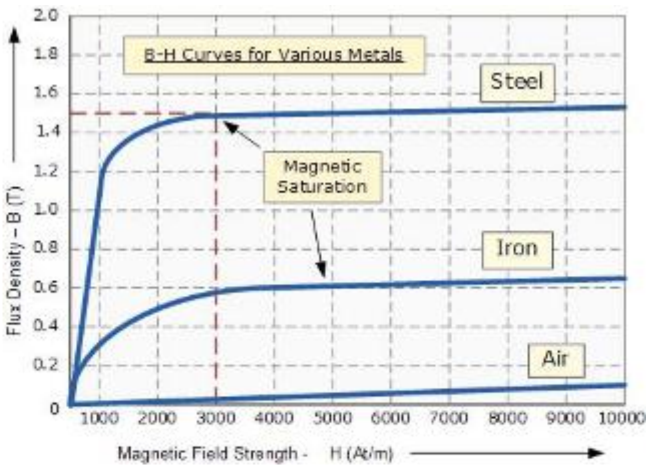

Fig. 2.3 Show Relative of Material between B-H

2.1.3 Hall Sensor

The hall sensor principles that measure of magnetic flux density as change [13,14]. When using floor scan machine test on corrosion area that sensor can measure of magnetic flux density change when compare with calibration plate. That sensor change form magnetic volume to electric volume as call "Hall voltage" equation follow (3)

$$V_H = R_H\left[\frac{I}{b} \times B\right] \quad (3)$$

Hall effect co-efficient equation as follow (4);

$$R_h = -\frac{1}{ne} \quad (4)$$

Where V_H is hall voltage in Volts, R_H is Hall effect co-efficient in ($A^{-1}.s^{-1}$), *I* is current of electric in ampere,(A), b is sensor thickness in mm., *B* is magnetic flux density in Wb/m^2, e is the charge on the electron(-1.6x10^{-19}C), n is the electron concentration

2.1.4 Eddy current sensor

The properties of eddy currents (EC) in particular the principle of the skin effect the air-gap distance is a function of the reluctance as other parameters such as the permeability within the air-gap can be considered constant [4,13]. A brief formulation of the theory is now discussed. The definition of magnetic reluctance can be expressed as:

$$R = \frac{F}{\o} \quad (5)$$

Where F is the magneto-motive force)MMF (and ø is the magnetic flux in Wb .The reluctance of a magnetic field can also be calculated is given by:

$$R = \frac{l}{\mu 0\ \mu r A} \quad (6)$$

Where *l* is the length of the air-gap portion of the circuit in meters, μ_0 is the permeability of free space, μ_r is the relative magnetic permeability of the material and A is the cross-sectional area of the circuit in meters squared.

Therefore, as the length *l* varies, and the magneto-motive force remains constant, then the reluctance can be calculated from the magnetic flux .In the approach presented here, the density of the magnetic flux is measured and a relationship between the lift-off can be calculated when equations (5) and (6) are rearranged to the following:

$$\o = \frac{F\ \mu 0\ \mu r A}{l} \quad (7)$$

2.1.4 Tank Floor Inspection

MFL Technique is one of the world most widely used Non-destructive testing method using for corrosion detection and evaluation at storage tank floors [5]. The advantage of MFL technique is it use less time to inspect less than Ultrasonic technique. However, MFL technique have weakness at sensitivity that lower than Ultrasonic technique. In general, tank storage users particularly in Thailand apply standard API 653 as a maintenance. Making practical use of API 653, user have to comply instruction with understanding of acceptant value calculation. Below is equation of acceptant value of thickness. (8)

$$MRT\ ) = \text{Minimum of } RT_{bc} \text{ or } RT_{ip} - (O\text{r }) StP_r\ + UP_r) \quad (8)$$

Where O_r is the in-service interval of operation)years to next internal inspection(
RT_{bc} is the minimum remaining thickness from bottom side corrosion after repairs; RT_{ip} is the minimum remaining thickness from internal corrosion after repairs; StP_r is the maximum rate of corrosion not repaired on the top side .StP_r =0 for coated areas of the bottom .The expected life of the coating must equal or exceed Or to use StP_r =0; UP_r is the maximum rate of corrosion on the bottom side .To calculate the corrosion rate, use the minimum remaining thickness after repairs .Assume a linear rate based on the age of the tanks .UP_r =0 for areas that have effective cathodic protection

Despite of thickness evaluation, detecting defect at floor of tank storage can cause leakage. This experiment therefore set model of different group of defect in different sizing, depth, length, location and shape. Here upon, this experiment set condition of material that coated with different thickness.

3. EXPERIMENTAL SETUP

Following details introducing testing equipment, "Silver Wing Model Floor map 3Di" Fig.3.1, calibration plate regulates by standard SA283 Gr.C Fig.3.2, block up plate Fig.3.3, coating substitutional which is acrylic plate at size 2-6 mm. Fig.3.4.

Fig. 3.1 Show Floor Scan Machine Model 3Di

Fig. 3.2 Show Calibration Plate

Fig. 3.3 Show Block up plate

Fig. 3.4 Show Acrylic Plate

Experimental setup can be divided into three parts which will be called models. Calibration plate is a principle part for this experiment as it is used to set the accurate defect reference. Therefore, machine calibration is required before testing. For this experiment machine is calibrated comply with plate thickness and coating thickness of block up plate. As per Fig.3.5-3.8

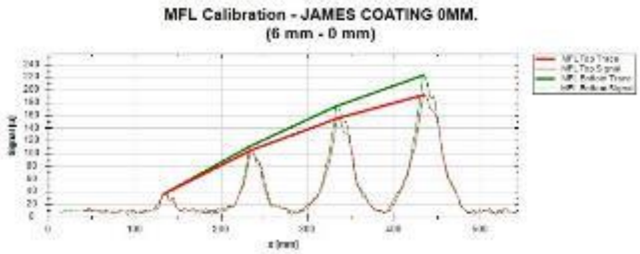

Fig. 3.5 Calibrate plate 6mm. thickness

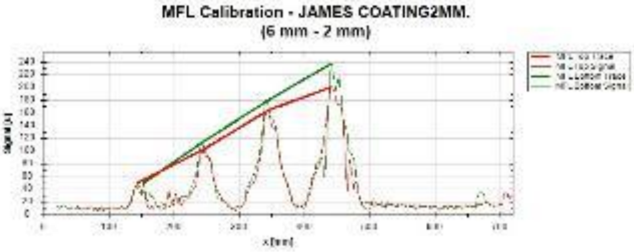

Fig. 3.6 Calibrate plate 6mm. with Acrylic thick 2mm.

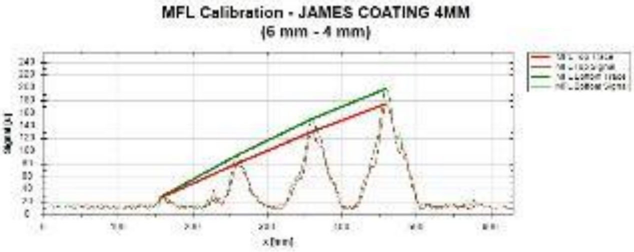

Fig. 3.7 Calibrate plate 6mm. with Acrylic Thick 4mm.

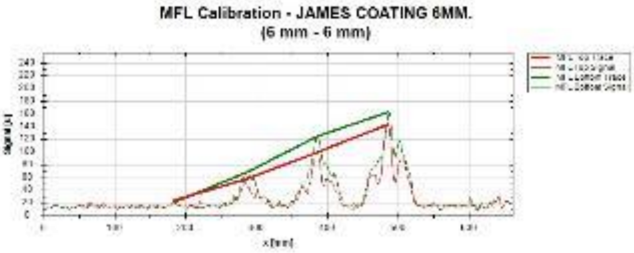

Fig. 3.8 Calibrate plate 6mm. with Acrylic Thick 6mm.

3.1 Model 1. is to study the detection and evaluation of holes appear in different grade of carbon steel and pitting varied in size and depth. For this experiment carbon steel which of type SA283 Gr.C and SA 516 Gr.70 by diameter of pitting sizing at 1mm, 2mm and 3 mm. with 10 levels of depth were used. The depth of each level is gradually increased 10 percent respectively. The gap distance between hole is 2 mm. as illustrated in Fig.3.9.(Remark: These holes are substituted of pitting, in this experiment is referred to pitting defect.)

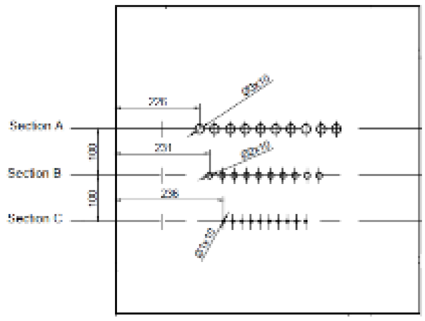

Fig. 3.9 Block up model 1

3.2 Model 2. is to study the detection and evaluation of holes appear in different depth by adjusting diameter of holes at 5mm. Distance are divided into 4 levels of depth varied from 20 percent to 80 percent. Gap between each holes are 50 mm. Depth of coating reference are 2mm, 4mm and 6mm. as shown in fig.3.10. This model to be performed on 2 sides which are “top side” and “bottom side” and the test is conducted through 3 coating thicknesses of 2 mm., 4 mm. and 6 mm (Remark: These holes is substituted the uniform corrosion defect.)

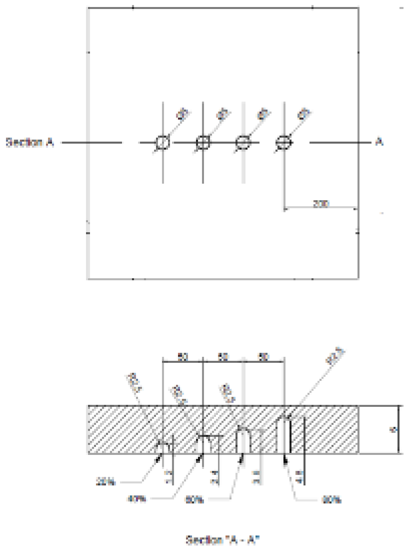

Fig. 3.10 Block up model 2

3.3 Model 3. is to study the effect of the defect shape. There are 3 shapes of defects which are 1. Cone shape 2. Square shape and 3. Circle shape. Each defect has the diameter of 5 mm. and the distance from each other is 50 mm. The depth of each defects are 80 percent of plate thickness. The gap between each holes are 50 mm. Depth of coating reference are 2mm, 4mm and 6mm. as exhibited in fig.3.7. Test results of these 3 models are set to be performed 5 times per and the take the average. Each model plate performed on 2 sides which are “top side” and “bottom side”. Results of every experiment are collected and sorted for the average value as a final result.

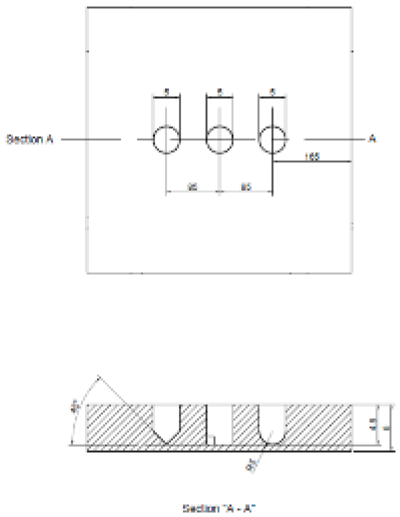

Fig. 3.7 Block up model 3

4. RESULTS AND DISCUSSION

The results as per figure that show the percent of flux density that are detected by MFL machine.

4.1 Experimental Data Model 1

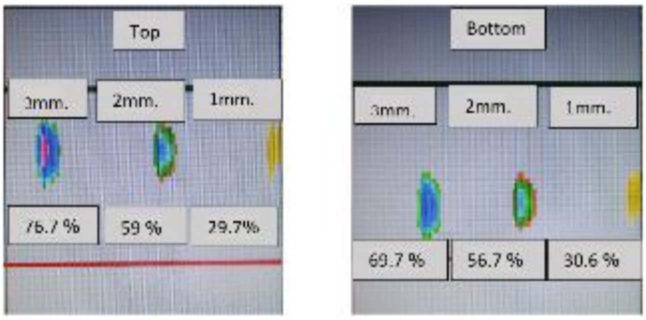

Fig. 4.1 Results of the model 1 SA283 Gr.C of Top and Bottom

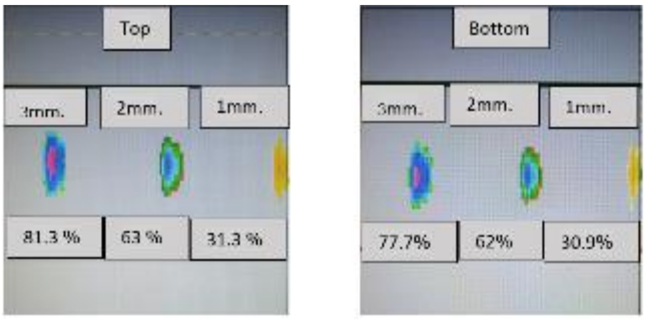

Fig. 4.2 Results of the model 1 SA516 Gr.70 of Top and Bottom

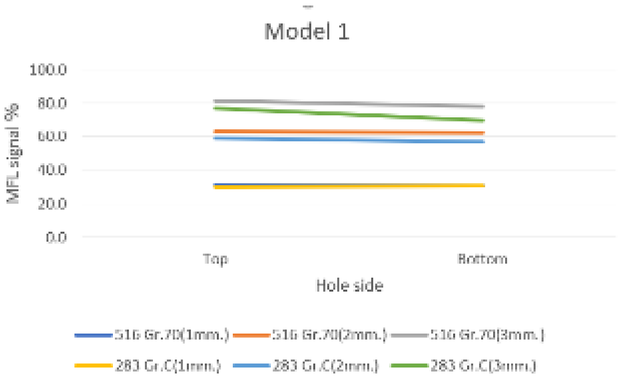

Fig. 4.3 Graph shows Relation MFL signal and Hole Side

The result of the 1st model can be concluded that the machine can detect round hole of both side of testing plates, but it cannot indicate that it is the round hole and the machine can indicate that there are only 3 groups of damage resulted from loss of metal substance. They have different amplitude signals depending on the size of the round hole in which it is found that the SA516 Gr. 70 carbon steel produced higher signal than the SA283 Gr. C carbon steel.

42. Experimental Data Model 2

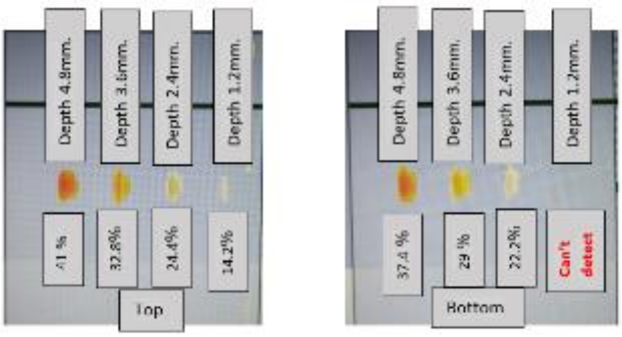

Fig. 4.4 Model 2 No Coating

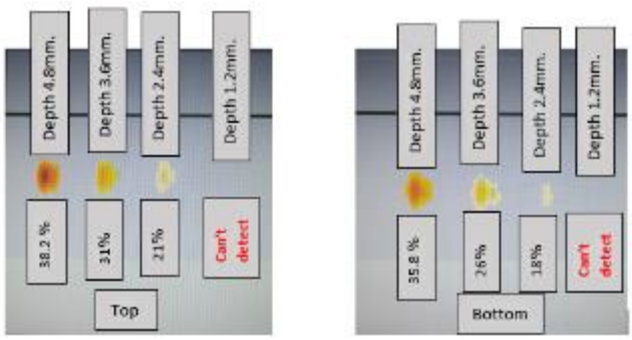

Fig. 4.5 Model 2 thickness of coated 2mm.

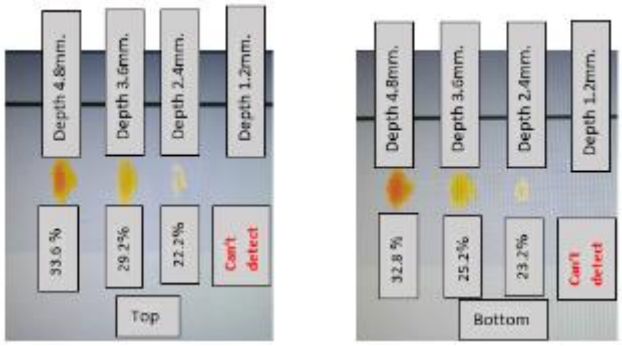

Fig. 4.6 Model 2 thickness of coated 4mm.

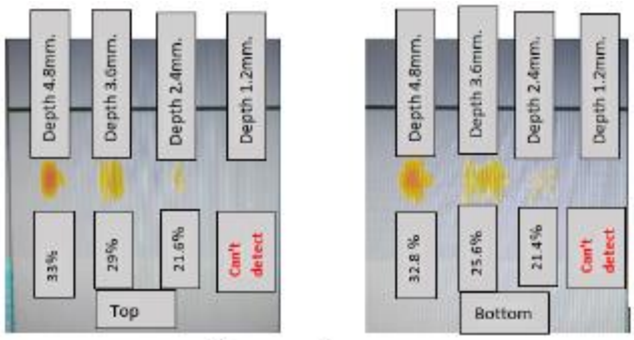

Fig. 4.7 Model 2 thickness of coated 6mm.

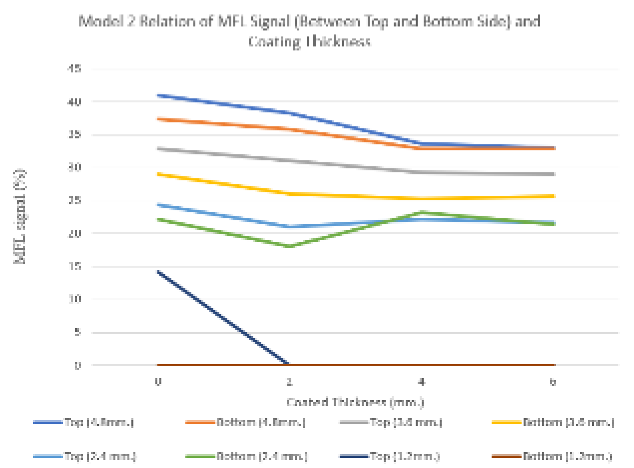

Fig. 4.8 Graph Shows Relation MFL signal (Top and Bottom) and Coating Thickness

The 2nd experiment shows that when the uncoated testing plate is tested on both sides, it is found that the machine can detect all 4 round holes on the top side. However, when the round holes at the bottom side are tested, it is found that the machine can detect only 3 holes. This can indicate that the top round hole signal is higher than the signal at the bottom. After that the experiment was conducted through coating by thicknesses of 2 mm., 4 mm. and 6 mm. in which it is found that the machine can detect the round holes by only 3 holes position and is unable to detect the round holes with the depth of 1.2 mm. or 20 percent metal loss of plate thickness. (Fig.4.4 to 4.7) The detected signal will be decreased when the coating thickness is increased The experiment can be concluded that the flaw positions at the top and the bottom, and the thickness of the coating effect on the signals that are detected by the machine. (Fig.4.8).

4 3.Experimental Data Model 3

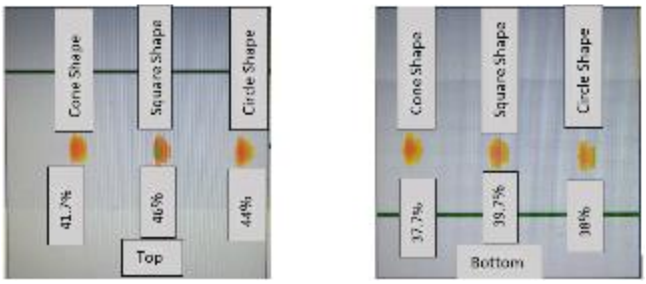

Fig. 4.9 Model 3 Show Signal of Top and Bottom Side

For the 3rd experiment, it is found that the machine can detect round holes in various shapes by which the amplitude signals measured by the machine are slightly different in which the highest signal that the machine can detect is from the square shape, circle shape and cone shape respectively. This can be concluded that the different shapes of the round holes effect to the signals that are detected by the machine (Fig. 4.9)

CONCLUSIONS

5.1. The result of the 1st experiment can be concluded that the machine can detect pitting corrosion of both side of testing plate, but it cannot indicate that it is the pitting corrosion and the machine can indicate that there are only 3 groups of damage resulted from loss of metal substance. They have different amplitude signals depending on the size of the pitting in which it is found that the SA516 Gr. 70 carbon steel produced higher signal than the SA283 Gr. C carbon steel.

5.2. The 2nd experiment shows that when the uncoated and coated testing plate is tested on both sides, it is found that the machine can detect uniform corrosion on the top and bottom side. However, This can indicate that the top uniform corrosion signal is higher than the signal at the bottom. The detected signal will be decreased when the coating thickness is increased.

5.3. The 3rd experiment, the different shapes of the round holes that effect to the signals that are detected by the machine.

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