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INVESTIGATION OF CAPABILITIES OF ELECTROMAGNETIC TOMOGRAPHY FOR PIPELINE IMAGING

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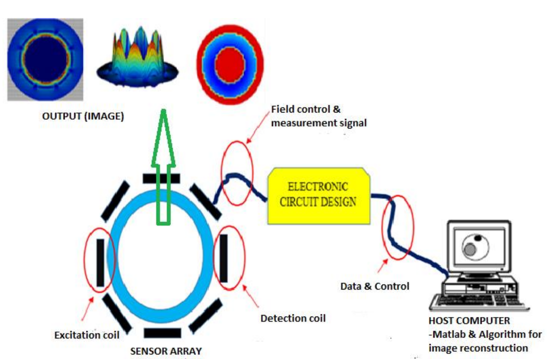
Graphical abstract



Abstract

In industrial process, pipeline leakage often only noticeable pipe condition is critical henceforth causing damages to its internal content. Therefore, pipeline inspection and monitoring work is highly demanding to take early precautions. Electromagnetic Tomography (EMT) is capable to produce images of the internal structure of an object by using external sensors without disrupting it. The coil sensors are placed around the object where the source coil transmits an oscillating magnetic field while the rest acts as receiver and measure the received signals. The measured signal provides the magnetic field distribution of the pipe, and will differ according to the materials' passive electrical properties. In this paper, we investigate the capability of using EMT to identify metallic pipe openings by conducting a finite element analysis simulation study. The design and parameters of the EMT system, as well as the results of using the EMT model to detect various degree of metallic pipe openings is presented. The results confirm that the EMT imaging as a promising tool for inspection of metallic pipelines where the magnetic field of the investigated region differs according to the pipe opening and material of the pipeline.

Keywords: Electromagnetic tomography, region of interest, conductive material

Abstrak

Dalam proses industri, kebocoran saluran paip sering kali hanya diketahui melalui keadaan paip yang ketara kritikalnya dan keadaan ini menyebabkan kerosakan kepada kandungan dalaman paip. Oleh itu, kerja pemeriksaan dan pemantauan saluran paip sangat diperlukan sebagai langkah awal. Tomografi Elektromagnetik (EMT) mampu menghasilkan imej dalaman sesuatu objek dengan menggunakan sensor luaran tanpa mengganggu objek yang sedang diuji. Sensor gegelung diletakkan di sekitar objek di mana sensor gegelung sumber bertindak memancarkan medan magnet, manakala selebihnya bertindak sebagai penerima dan mengukur isyarat yang diterima. Isyarat yang diukur memberikan medan magnet kepada paip, dan akan berbeza mengikut sifat-sifat elektrik pasif bahan yang terlibat. Dalam kajian ini, keupayaan EMT untuk mengenal pasti bukaan paip metalik akan dikaji, dengan menjalankan kajian simulasi analisis *Finite element*. Reka bentuk dan parameter sistem EMT, serta keputusan menggunakan model EMT untuk mengesan pelbagai tahap bukaan paip logam dibentangkan. Hasilnya mengesahkan bahawa pengunaan EMT sebagai alat pemeriksaan paip logam berdasarkan medan magnet di kawasan yang diselidiki adalah berbeza mengikut pembukaan paip dan bahan saluran paip.

Kata kunci: Tomografi elektromagnetik, wilayah kepentingan, bahan kondukti

1.0 INTRODUCTION

An industrial application such as oil and gas industries demanding for a non-invasive and non-intrusive technique to monitor a long pipeline as a transporting channel from one process to another. Tomography is a real-time inspection technique composed of sensors surrounding the object, circuitry unit and imaging facilities to meet the demand without the need for special equipment [1], [2]. Tomography techniques differ based on the working principle of the sensors unit with one sole purpose to measure the internal distribution of contained targeted material [3]. Tomography is a technique that can display an image showing internal structure of an object through the use of penetrating signals such as waves, electromagnetic fields or particles without causing any damage [14]. Electromagnetic Tomography (EMT) is one of the non-destructive, non-hazardous technique that is applicable for industry and medical imaging [15-17]. Therefore, EMT techniques have the potential applications in the industrial process monitoring in situations where the object material contains high contrasts in conductivity and/or permeability [18]. These applications include tracking of ferrite labelled powder in transport separation process, foreign body detection and location, flow regime in column and the multiphase flow in an oil pipeline, food inspection and fault detection of metal components [7], [18-20].

Tomography is a real-time inspection technique composed of sensors surrounding the object, circuitry unit and imaging facilities to meet the demand without the need for special equipment [1], [2]. Tomography techniques differ based on the working principle of the sensors unit with one sole purpose to measure the internal distribution of contained targeted material [3]. Electromagnetic Tomography (EMT) is a magnetic-based imaging modality for electrically conductive medium [4].

Figure 1 depicted the topography of the EMT system composing of electronic circuitry to generate and transmit the magnetic field as excitation source through the excitation coil in the sensor unit. The sensors unit also composed of receiving coils to receive and measure the magnetic field induction. The received signal is measured based on the sensitivity of the sensors toward material with either low or high passive electrical properties (PEPs). The PEPs of material is determined based on the degree of the conductivity (σ), permittivity (ε), and permeability (μ) of the material [5]. Therefore, the received signal differs with the transmitted signal is greatly caused by the PEPs of material. Later on, the measured data from the received signal are processed using MATLAB algorithms to reconstruct the cross-sectional image on a computer [6]. In this paper, a simulative study using EMT system to determine the opening of a metallic pipeline is presented. The modeling design of the EMT system will be first described, then results and discussion of the systems' capability of identifying various pipe openings will be presented.

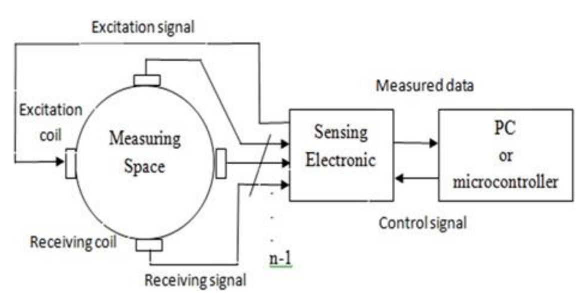


Figure 1 EMT system topology [16]

2.0 METHODOLOGY

The first sub-section will describe the parameter of the coil sensor to increase the sensitivity of the coil sensors unit. The next two sub-section discusses the simulation design process and the modeling of the coil sensor.

2.1 Coil Design for Excitation Channel

Image reconstruction of EMT is suffering from a soft field effect which results in low resolution of the image at the center of the pipeline. However, designing a high sensitivity coil sensors unit can improve the image quality thus increase the performance of the EMT system. There are a few parameters in designing the coil sensor need to be considered, which are [7]-[12]:

- The number of coils used need as it can contribute to a precise and sharp image of the internal distribution of the pipeline.
- The number of turns as strong magnetic field requires a larger number of turns for each coil. However, deciding the number of turns for the coil sensor is depends on the input impedance and the operating frequency of the coil.
- The physical parameter of the coil such as the inner and outer diameter of the coil, the thickness of the coil and the nature of the coil toward self-inductance and resistance.

The working principle of EMT lies in the Eddy current testing. It is crucial to measure the correct data from the Eddy current field. The pattern of the Eddy current field depends on the coil structure, the distance between the excitation and the detection coil, current, and frequency of the coil [13].

2.2 Simulation Design Process

The early stage for the preliminary results is mainly developing the 2D linear Finite Element method (FEM) of 8 coil-channels using COMSOL Multiphysics. The flow of the modeling design is shown in Figure 2.

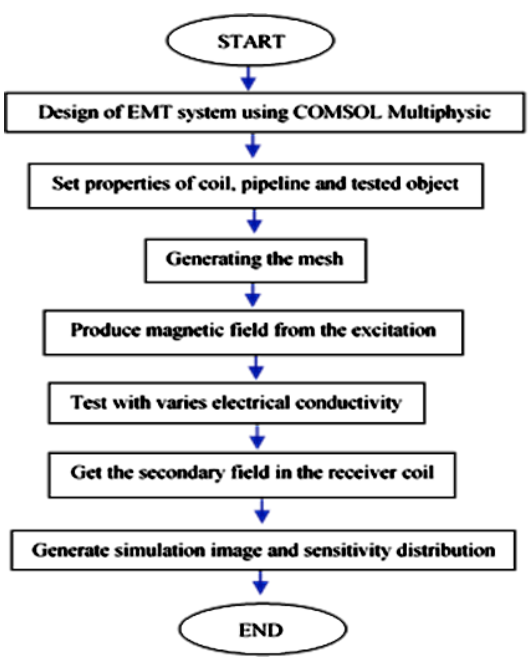


Figure 2 Flow chart of modelling EMT coil sensor

2.3 Modeling of 8-coil channels

Figure 3 demonstrated the modeling of 8-coil channels, where the lines of the magnetic field generated alongside the lines of the electrical field at a single excitation channel. The positions of the sensors are outside of the wall of the pipeline with each sensor arranged in close distance to the adjacent sensors.

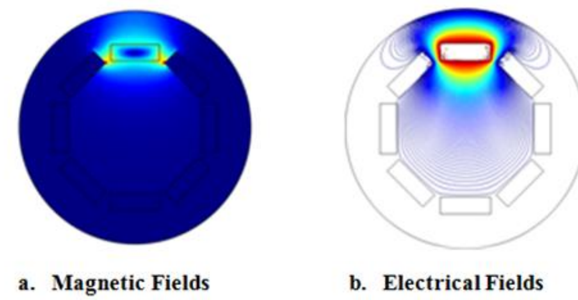


Figure 3 Single excitation of 8-coil channels of EMT

Figure 4 shows the 8-coil channel closely arranged at the outside of the pipeline wall. A fed coil with an alternating current will generate a magnetic field and serve as a transmitter. The remaining channel receives the magnetic field and measures the secondary field caused by the induction of the magnetic field. Then, the next channel will serve as a transmitter, while the remaining channel will serve as the receiver. The same process goes on to complete a full cycle to obtain one frame of a cross-sectional image.

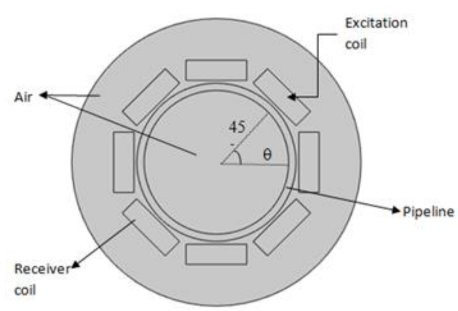


Figure 4 Number of coil channels on EMT

3.0 RESULTS AND DISCUSSION

The material of the object greatly influences the spatial distribution of the magnetic field in the region of interest (ROI). An object with higher electrical conductivity greatly contributes to the pattern of the magnetic field. Figure 5 shows the maximum magnetic field on the ROI with no phantom at sinusoidal wave 20kHz. The far distant of the channels results to the reduced magnetic field strength.

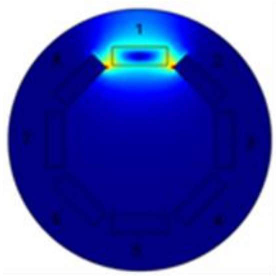


Figure 5 Magnetic field strength for single excited channel

The measured maximum magnetic field strength of the receiving channels, as shown in Figure 6, shows that far distant of the channel reduces the magnetic field strength. The complete sequence of the excitation channels results in 28 independent measurements from the pairing channels, C1-C2, C1-C3. . . C1-C8, C2-C3, C2-C4. . . C7-C8. The sensors are sensitive to the object nearest to the sensor and less sensitive to the object in the middle of ROI, which widely known as the soft-field effect.

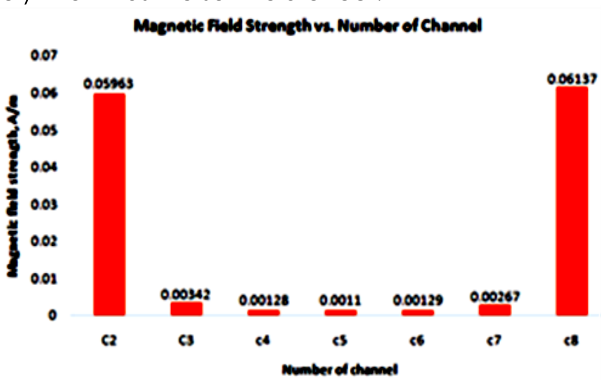


Figure 6 Maximum magnetic field strength values of a single excitation channel

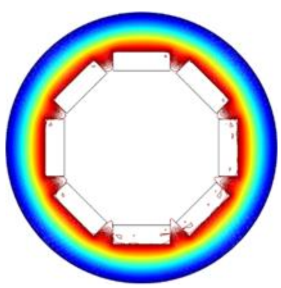
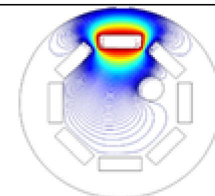
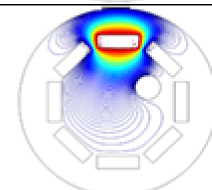


Figure 7 Complete sequence of excitation channels

The generated electrical field lines bend around the object carrying an electrical charge. The placement of a 15mm diameter object shifted the direction of the electric field line, as shown in Table 1. The magnetic and non-conductive object caused the magnetic field line to penetrate the object indicating to no resistance toward the object. The presence of the non-conductive object in ROI will result in a high measurement of the magnetic field strength, as shown in Figure 8. A non-magnetic and conductive object will resist the electrical field from penetrating the object, which results in lower measurement.

Table 1 Parameters of analysis

Characteristic	Types of material	Simulation image from COMSOL
Magnetic and non-conducting	Alloy steel σ:4.032 x 106sm^{-1}	
Non-magnetic and conducting	Aluminum σ: 3.5 x 10^{7}sm^{-1}	

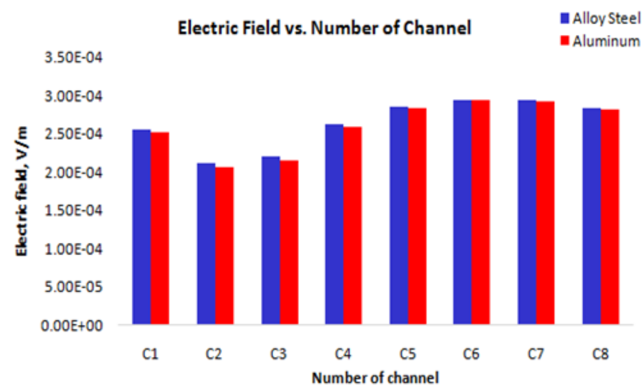
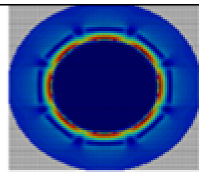
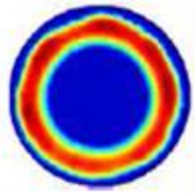
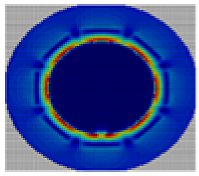
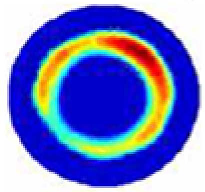
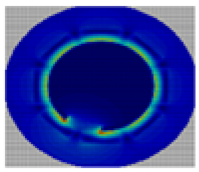
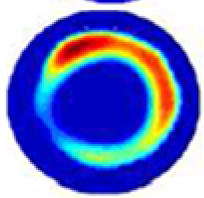
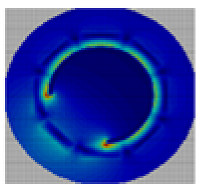
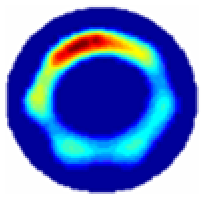


Figure 8 Electric field of alloy steel and aluminium

Several tests are executed to demonstrate the feasibility of EMT technique to detect the different opening size of the pipe. The simulation of the EMT demonstrates its capability to produce the image of the damaged pipe is shown in Table 2. The simulation generated an opening of the pipe at different angles of 0, 10, 45, and 90 degrees producing the sensitivity distribution as in Figure 9. It also shows that the strength of the magnetic field is weaker with the opening area close to the sensor, thus able the sensor to detect the opening of the pipe.

Table 2 Simulated image of pipe at different opening angle

Opening degrees	Simulated image from COMSOL	Reconstruction Image
0°		
10°		
45°		
90°		

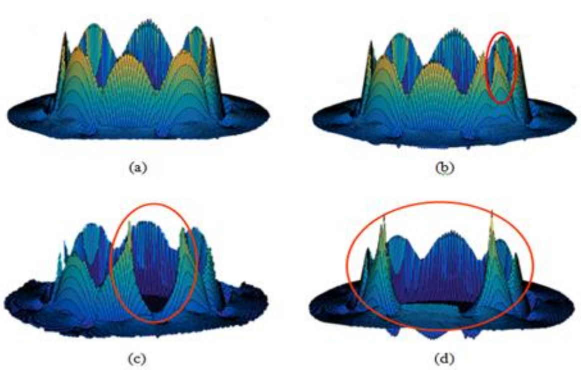


Figure 9 a) Full pipe. (b) Small opening. (c) Large opening. (d) Quarter circle

External wall losses are used to test the developed EMT model with real application of pipeline inspection, indicating the corrosion of the pipe. Therefore, three pipes with different degrees of the damaged area are developed in 3D using Solid Work, as shown in Figure 10. These three pipes have the same inner radius of 25mm and thickness of 6mm. Table 3 shows the comparison between the result of the simulation and the reconstructed image from the experiment, which shows a slight similarity.

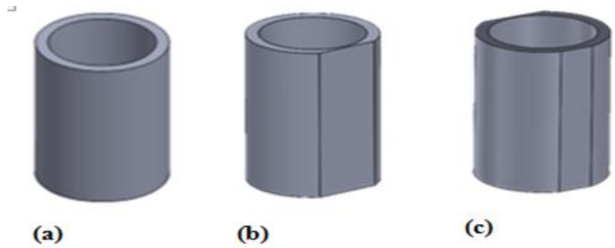
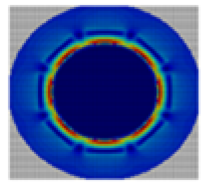
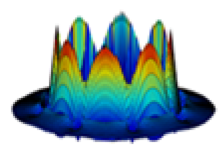
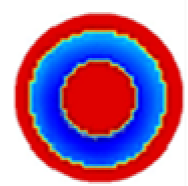
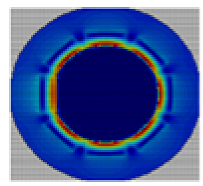
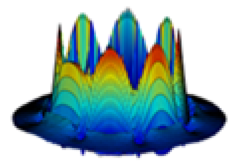
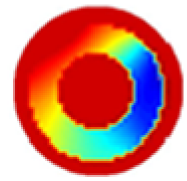
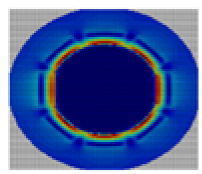
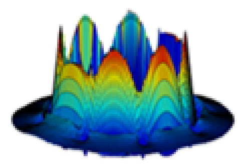
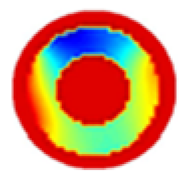


Figure 10 Damaged pipe condition

Table 3 Simulation result of Aluminum pipe inspection

Simulated image from COMSOL	Extracted sensitivity distribution maps using MATLAB	Reconstruction image
		
		
		

4.0 CONCLUSION

This study aims to explore the capability of the developed EMT model in producing the image of the pipeline. The developed model is using 8-coil channel to measure the strength of the magnetic field and tested in a different analytical situation to monitor the performance of the 8-coil channel EMT. The future recommendation in developing the hardware of EMT system is to take full consideration on the parameters of coil sensor design and tested through simulation.

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