MULTI-SENSOR APPROACH FOR PULSED EDDY CURRENT TESTING: DESIGN, SIMULATION, AND NON-DESTRUCTIVE TESTING POTENTIAL

TIẾP CẬN ĐA CẢM BIẾN KIỂM TRA DÒNG ĐIỆN XOÁY DẠNG XUNG: THIẾT KẾ, MÔ PHỎNG VÀ TIỀM NĂNG ỨNG DỤNG TRONG KIỂM TRA KHÔNG PHÁ HỦY

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DOI: http://doi.org/10.57001/huih5804.2024.236

ABSTRACT

Pulsed Eddy Current (PEC) testing is a non-destructive testing (NDT) technique that has been widely used in various applications, including the detection and characterization of defects in metallic materials. The measurement of pulsed eddy current signals is essential for this purpose. This study proposes a novel multi-sensor PEC approach for improved defect detection. The proposed approach uses multiple magnetic sensors placed at different locations to measure the magnetic field changes induced by defects on the surface of a metallic specimen. This approach has the advantage of being able to measure at multiple points simultaneously, which can improve the accuracy and reliability of the measurement results. We conducted a simulation of the magnetic field distribution and proposed a structure for a multi-sensor system placed under the excitation coil in a probe. The multi-sensor system will collect electromagnetic signals generated by eddy currents to help identify defects more accurately. The team also investigated and evaluated the effects of several factors on the sensor signal, such as the frequency, amplitude, and pulse width of the excitation source. This study provides a new approach for improving defect detection performance in PEC testing. The proposed approach has the potential to be applied to a wide range of NDT applications.

Keywords: *Pulsed Eddy Current Testing; multi-sensor; multi-point measurement; defect detection; non-destructive testing.*

TÓM TẮT

Thử nghiệm dòng điện xoáy dạng xung (PEC) là một kỹ thuật thử nghiệm không phá hủy (NDT) được sử dụng rộng rãi trong nhiều ứng dụng, bao gồm phát hiện và phân tích đặc điểm của các lỗi trên vật liệu kim loại. Để thực hiện điều này, việc đo tín hiệu dòng điện xoáy dạng xung là rất cần thiết. Nghiên cứu này đề xuất một phương pháp kiểm tra PEC đa cảm biến mới để cải thiện khả năng phát hiện lỗi. Phương pháp đề xuất sử dụng nhiều cảm biến từ đặt ở các vị trí khác nhau để đo sự thay đổi của từ trường do các lỗi trên bề mặt mẫu kim loại gây ra. Ưu điểm của phương pháp này là có thể đo đồng thời tại nhiều điểm, qua đó cải thiện độ chính xác và độ tin cậy của kết quả đo. Nghiên cứu đã tiến hành mô phỏng phân bố từ trường và đề xuất cấu trúc cho hệ đa cảm biến đặt dưới cuộn kích thích trong đầu dò. Hệ đa cảm biến sẽ thu thập các tín hiệu điện từ do dòng điện xoáy tạo ra để giúp xác định lỗi chính xác hơn. Nhóm nghiên cứu cũng đã khảo sát và đánh giá tác động của một số yếu tố lên tín hiệu cảm biến, chẳng hạn như tần số, biên độ và độ rộng xung của nguồn kích thích. Nghiên cứu này cung cấp một cách tiếp cận mới để cải thiện hiệu suất phát hiện lỗi trong thử nghiệm PEC. Phương pháp đề xuất có tiềm năng được áp dụng cho nhiều ứng dụng NDT khác nhau.

Từ khóa: *Kiểm tra dòng điện xoáy dạng xung; đa cảm biến, đo đa điểm; phát hiện khuyết tật; kiểm tra không phá hủy.*

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Received: 20/4/2024
Revised: 18/5/2024
Accepted: 25/7/2024

ABBREVIATIONS

ECT	Eddy Current Testing
NDT	Non-Destructive Testing
PEC	Pulsed Eddy Current
PECT	Pulsed Eddy Current Testing

1. INTRODUCTION

For a long time, in industrial manufacturing industries, monitoring corrosion or detecting cracks in metal parts has played a very important role. PEC has become a reliable and widely used technique in inspecting and detecting the above defects. Scientists are constantly researching to develop this technique to improve its accuracy and applicability in practice. PEC provides an effective screening method, allowing corrosion to be detected without the need to remove coatings or insulating materials from the sample [1]. Initially, the PEC technique was used only with coils and measured the current changes in those coils under different conditions, then used a separate excitation coil and a separate detection coil to detect shows changes in the electromagnetic field [2, 3]. In recently published studies, most use a probe structure consisting of an excitation coil that generates a magnetic field and a magnetic sensor to measure the change in magnetic field due to the effect of PEC [4].

Besides, many methods for measuring pulsed eddy current have been proposed, such as: using two sensors to create a differential signal for noise reduction in PECT for detecting wall thinning in pipes [5], or using multiple sensors in PECT for a more comprehensive assessment of 3D subsurface cracks [6]. In 2011 a publication by Angani, C. S., et al. proposed to create a probe that uses a differential Hall-sensor to detect the defects in a stainless-steel pipe, one sensor placed below and the other placed above inside the excitation coil of the probe [7]. By 2013, Duck-Gun Park et al. have developed a double-D differential probe. Accordingly, the core of the probe is made by connecting two semicircular cylindrical cores together to form a double-D shaped core, a 100-turns copper wire is wound around both cores and connected in series. They used two Hall sensors with similar characteristics placed inside the center of each coil, the difference of the field detected by the two sensors was used as the composite PEC signal [8]. Most recently, in February 2024 Saibo She et al. published a study using 4-coil excitation array ECT with a detection coil located at the center to reduce the influence of lift-off in evaluation of defects depth for metal sheets [9].

In this study, we design and simulate a PECT model to analyze and find the optimized measurement point location with the best signal to place the magnetic sensor. Based on results, we propose a multi-sensor probe structure with an excitation coil and evaluate the application potential for NDT.

2. MODELING THE PECT SYSTEM

Pulsed Eddy Current Testing (PECT) leverages the principle of electromagnetic induction, similar to traditional Eddy Current Testing (ECT). However, PECT differs by employing a rectangular pulse excitation in the primary coil, compared to ECT's single-frequency sinusoidal approach. This allows PECT to be analyzed in the time domain by studying the voltage pulse received by the testing coil or the magnetic sensor.

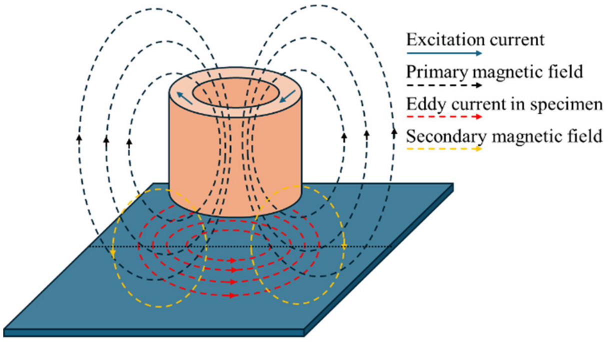
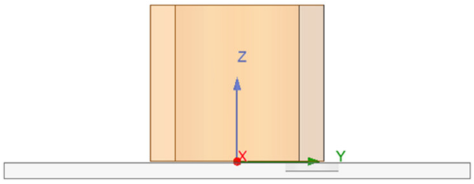


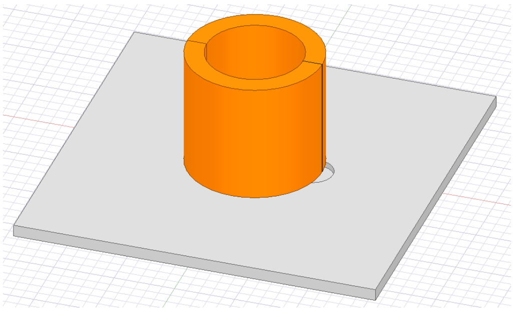
Fig. 1. Principle of ECT

The key advantage of PECT lies in its broad-spectrum excitation. The rising and falling edges of the rectangular pulse induce eddy currents within the test specimen at a wide range of frequencies. This wide spectrum translates to a response containing information from multiple frequency components. Since the penetration depth of eddy currents is directly related to their frequency, a single PECT pulse can gather defect information from a broader range of depths within the material.

We use Ansys Maxwell electromagnetic simulation software to perform models and simulate the PECT system. The model of PECT system is shown in Fig. 1. Include an excitation coil and a specimen is an aluminum plate with a corrosion mark.



a) 2-D view



b) 3-D view

Fig. 2. Model of PECT system

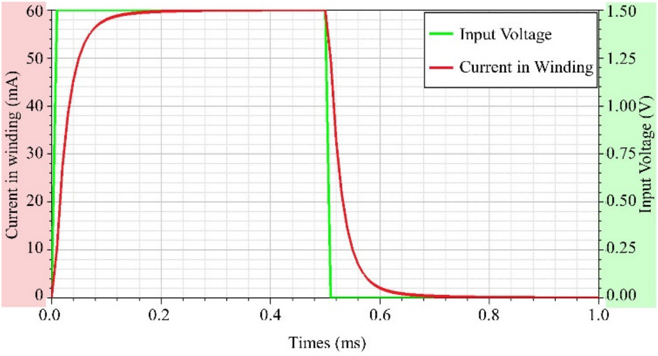
The model parameters of the excitation coil are described in Table 1 and the model parameters of specimen are shown in Table 2.

Table 1. The parameters of the excitation coil

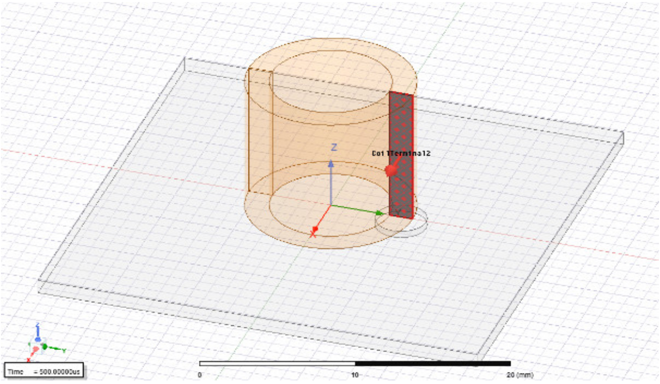
Inner diameter	Outer diameter	Coil height	No. of winding turns
8mm	11.2mm	10mm	320

Table 2. The parameters of the specimen

Length	Width	Height	Material
30mm	30mm	1,5mm	Aluminum



a) Waveform of excitation signal



b) The direction of excitation signal

Fig. 3. Excitation signal

Excitation signal: Applying a square pulse voltage (blue color) to the excitation coil, the coil will receive a waveform current (red color) as shown in Fig. 3a and the direction of excitation current as shown in Fig. 3b. The magnetic field is usually measured by a magnetic sensor (Hall sensor) placed at the center of the exciting coil. In this research, rather than using only a single Hall sensor, we used multiple Hall sensor elements to measure magnetic field simultaneously at different locations to enhance the detectability of the PECT probe.

3. RESULTS OF SIMULATION

When a pulsed current with an amplitude of 200mA and a frequency of 1kHz is applied to the excitation coil, an eddy current appears in the test sample as shown in Fig. 4, eddy current density will be more concentrated and stronger at locations with corrosion.

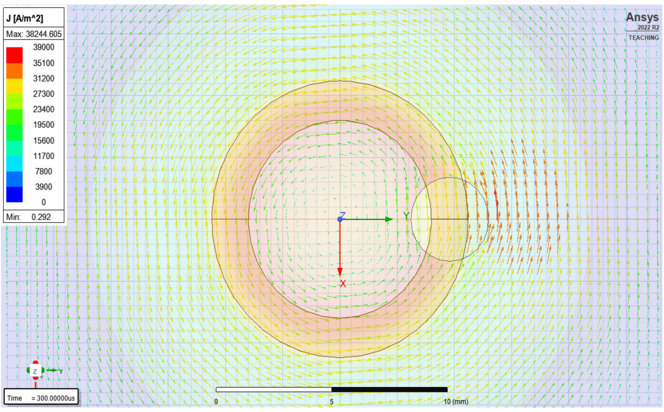
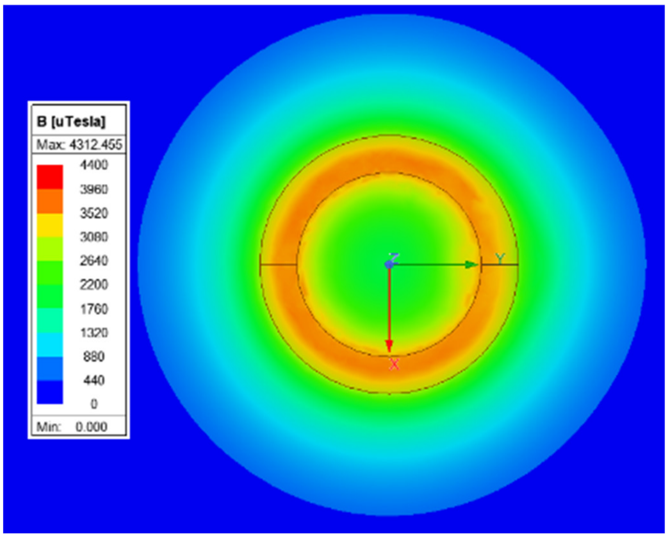
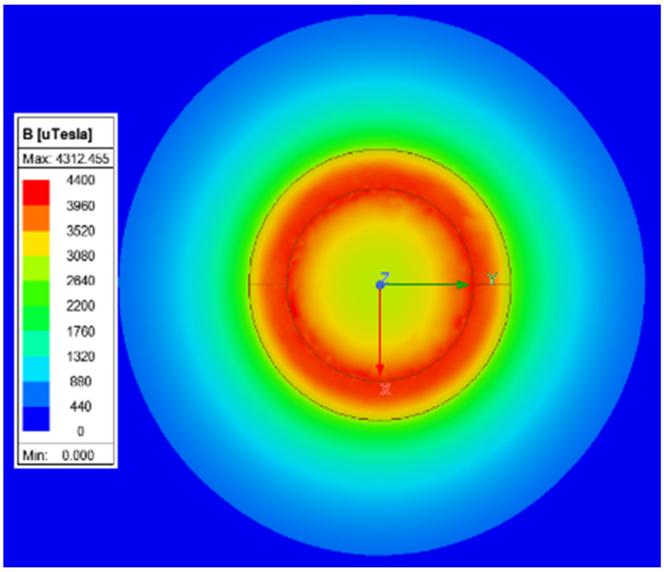


Fig. 4. Eddy current density

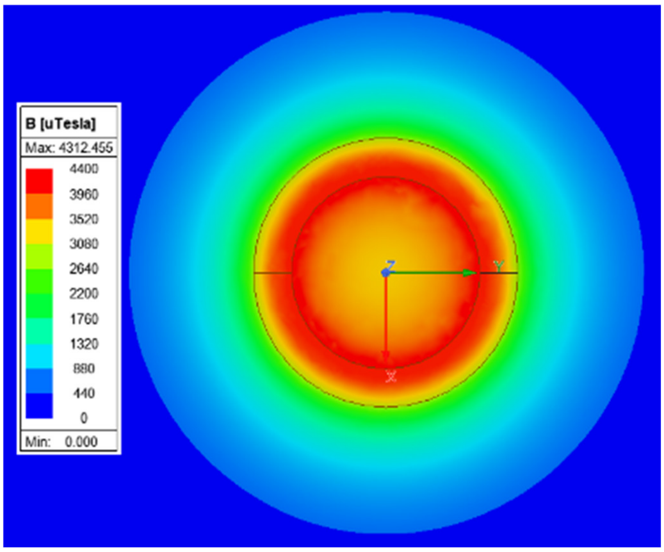
The eddy current will generate a magnetic field called the secondary magnetic field that has the opposite direction to the magnetic field created by the excitation coil. The simulation results of the magnetic field density on the interface plane below the excitation coil at each transient time are shown in Fig. 5.



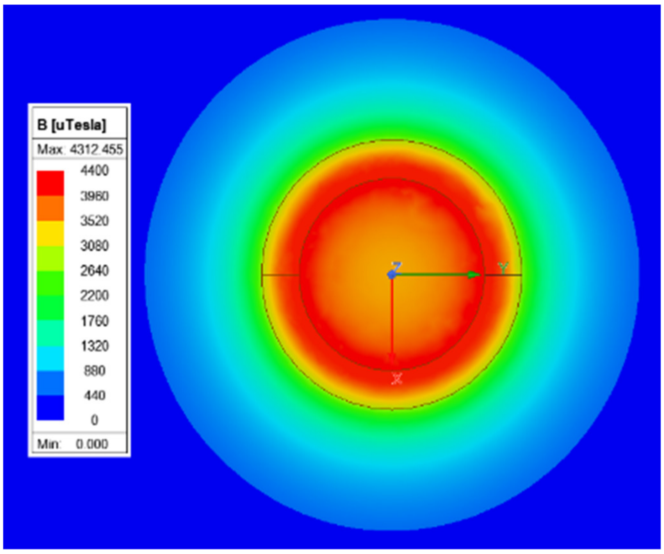
a) 100us



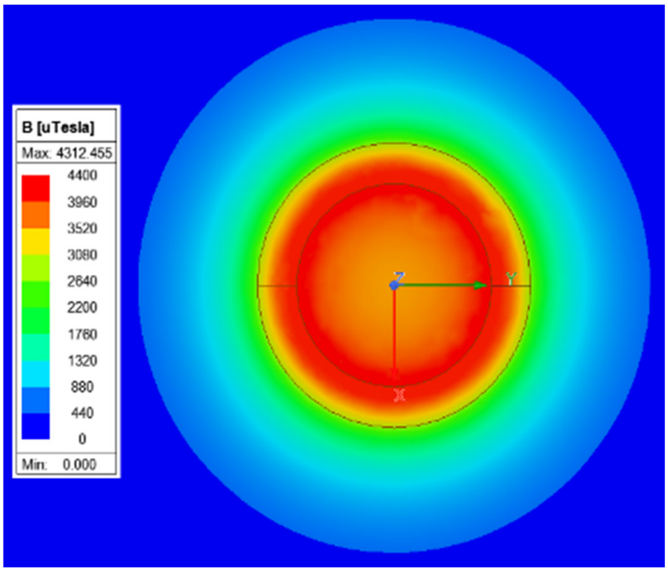
b) 200us



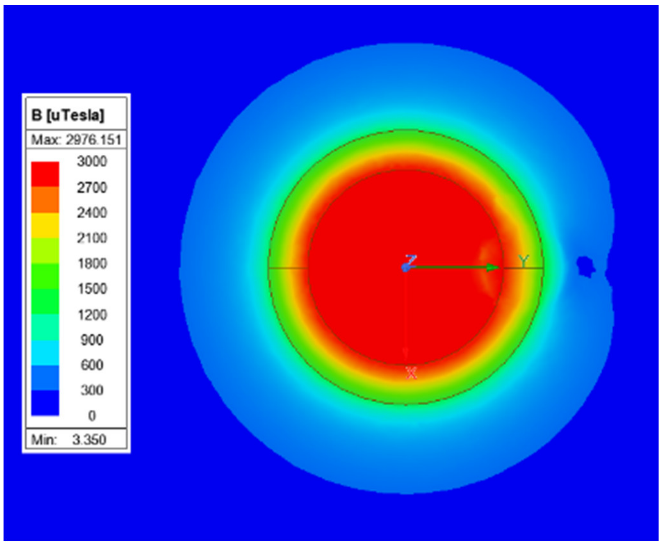
c) 300us



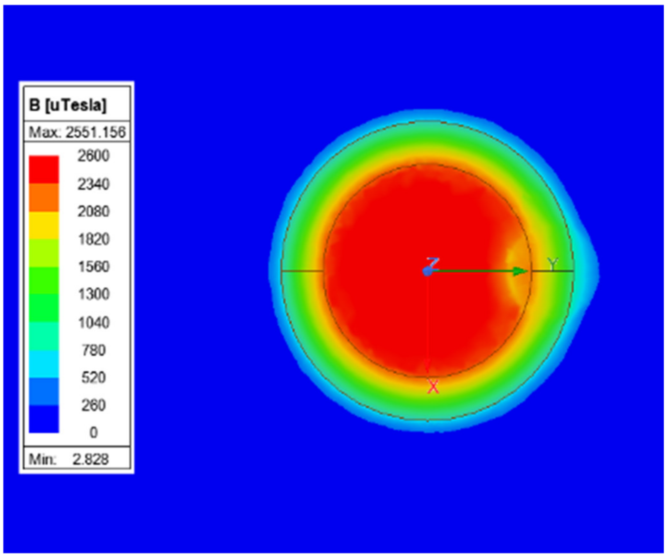
d) 400us



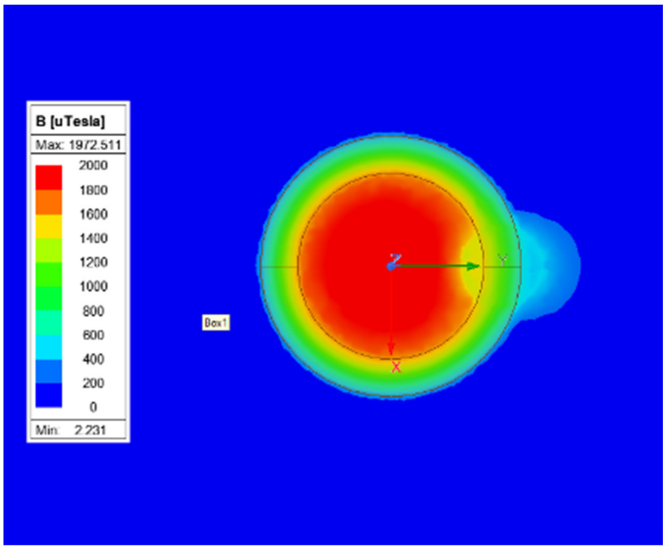
e) 500us



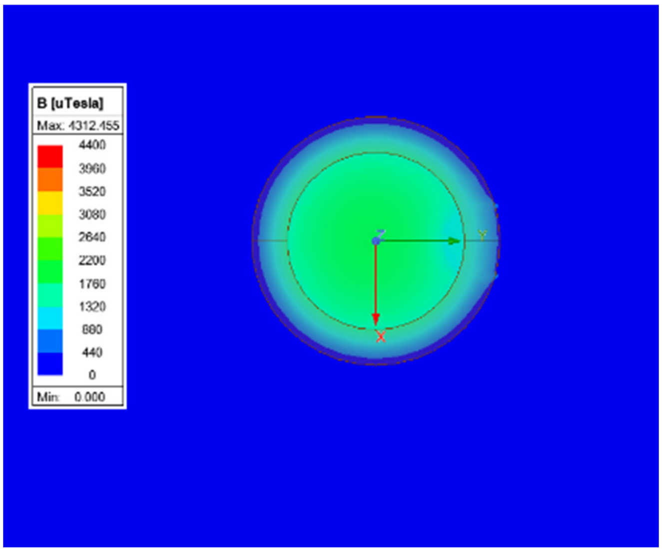
f) 530us



g) 550us



h) 580us



i) 600us

Fig. 5. Magnetic field density on the interface plane below the excitation coil at different transient time

It is easy to see from the magnetic field density simulation image above that during the period of maximum pulse (from 200us to 500us), the magnetic field is concentrated right below the wound coil. When the excitation pulse is on the falling edge (after 500us to 580us), a strong magnetic field appears inside the core of the coil and corrosion marks are clearly visible on the specimen.

From the above results, we tested the new measurement point location. Instead of placing one sensor at the center of the coil core, we placed addition them at the inner edge of the coil where the magnetic field is strongest during the high level of the excitation pulse. Due to the limited size of the probe structure, we decided to place 4 more sensors, and we have a total of 5 magnetic field measurement points placed as shown in Fig. 6. The output measurement results at 5 points are shown in Fig. 7.

Comparing the differences at the measuring points with each other, we can see that the difference between measuring points without corrosion marks is much smaller than when there is a measurement point with corrosion marks. In Fig 8., an orange line is the difference between measurement points 3 and 4 without corrosion marks and a blue line is the difference between measurement points 4 and 5 with corrosion marks. It is observed that the difference signal between sensors 3 and 4 is almost zero indicating no corrosion because the eddy current flow is symmetric between the two sensor locations. This phenomenon is the same if there is lift-off between the PECT sensor and the specimen. Thus, the lift-off effect during operating or scanning of the PECT sensor is minimized. In addition, the difference signal between sensors 4 and 5 is large due to the presence of corrosion in the sensor 5 location. So, we could easily determine the existence of the corrosion. We could further understand the presence of corrosion or multi-corrosion in different locations by analyzing the signal of the multiple Hall sensors which is much improved than the conventional PECT sensor with only one Hall sensor at the center (point 1). Furthermore, the lift-off effect could be minimized by using the difference of the two opposite Hall sensors by the nature symmetric of the eddy current flow in the PECT probe.

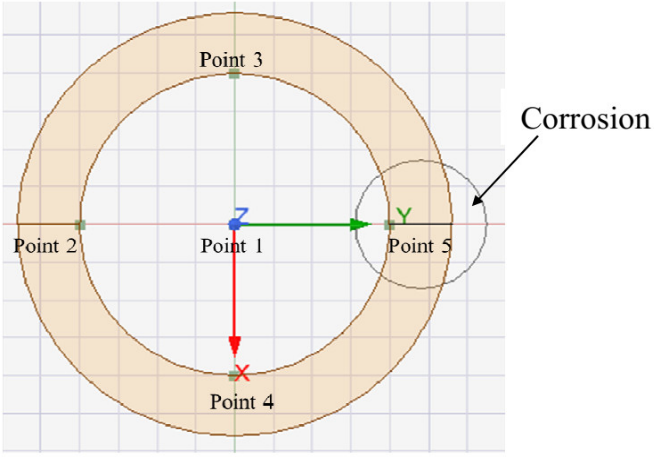


Fig. 6. Measurement point locations

In this study, we have not specifically evaluated the use of a larger number of sensors. However, it can be seen that with the current application of artificial intelligence in data processing, the more data collected will give better results. However, with small probe sizes, installing a large number of sensors will be difficult and the signal collection and preprocessing circuit board will become more cumbersome.

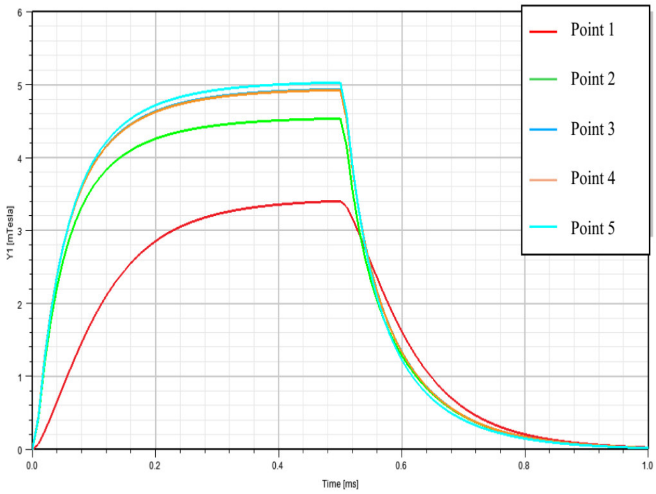


Fig. 7. Output signal at 5 measurement points

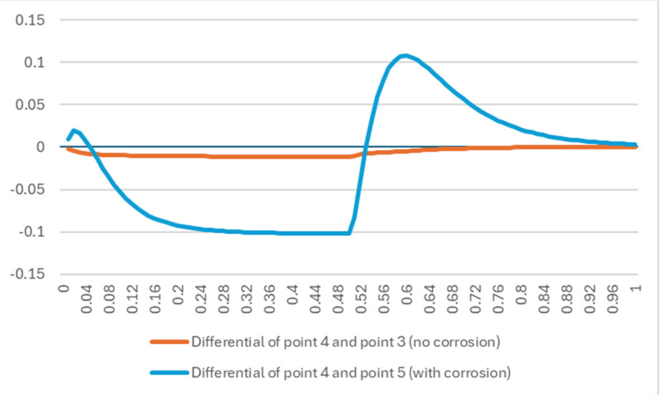


Fig. 8. Differential of two points with and without corrosion

4. CONCLUSIONS

In this report, we performed the simulation of a PECT system and analyzed the magnetic field density. We proposed to position four magnetic sensors at the inner edge below the coil instead of only a single Hall sensor at the center of the coil as in conventional PECT probe. This could help increase confidence in detecting defects/corrosion on metal surfaces and subsurface in NDT applications. Furthermore, using multiple Hall sensors in the measurement eliminates the influence of lift-off during operation. At the same time, making it possible to perform simultaneous measurements at multiple points which can increase the measurement area.

In the next stage of research, we will implement the finding results in the simulation to fabricate a real PECT sensor. We believe that the suggestions for multi-point measurements at the mentioned locations will bring better results in identifying defects in various NDT applications such as aircraft multilayer structure, nuclear power plant's piping systems, oil piping system, etc.

ACKNOWLEDGMENT

This research is funded by Phenikaa University under grant number PU2023-1-A-10.

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THÔNG TIN TÁC GIẢ

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