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Original scientific paper

APPLICATION OF PULSED EDDY CURRENT TECHNIQUE FOR INSPECTION OF INSULATED PIPES

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Abstract: In this paper the use of Pulsed Eddy Current (PEC) technique is analyzed for inspecting insulated pipes, commonly used in industries such as power generation, petrochemical, and oil and gas. PEC technique uses pulsed electromagnetic fields to generate eddy currents in the conductive material, allowing detection in wall thickness and material integrity. In the experimental part an insulated pipe is investigated with the PEC technique for corrosion or wall thinning defect of the material, without the need to remove the insulation. The paper involves experimental testing on insulated pipe of structural steel with composite insulation and the results show the potential of PEC as a reliable tool for maintenance and inspection, especially for reducing operational costs and downtime associated with insulation removal.

Key words: insulated pipes; pulsed eddy current; non-destructive testing; corrosion

ПРИМЕНА НА ТЕХНИКАТА СО ВИОРНИ СТРУИ ЗА ИСПИТУВАЊЕ ИЗОЛИРАНИ ЦЕВКИ

Апстракт: Во овој труд е анализирана примената на методот со пулсирачки виорни струи (PEC) за испитување изолирани цевки, често употребувани во енергетската, петрохемиската и нафтената индустрија. Техниката PEC користи пулсирачко електромагнетно поле кое генерира виорни струи во спроводлив материјал, овозможувајќи детектирање промена во дебелината на ѕидот и интегритетот на материјалот. Во експерименталниот дел изолирана цевка е предмет на истражување со помош на техниката PEC за детектирање на дефекти од корозија и промени на дебелината на ѕидот без да се отстранува изолацијата. Овој труд вклучува експериментално тестирање на изолирана цевка изработена од конструктивен челик со композитна изолација и резултатите го прикажуваат потенцијалот на PEC како сигурна алатка за одржување и инспекција, особено за редуцирање оперативни трошоци и прекини предизвикани со отстранување на изолацијата.

Клучни зборови: изолирани цевки; пулсирачки виорни струи; тестирање без разорување; корозија

1. INTRODUCTION

Non-destructive testing (NDT) plays a crucial role in ensuring the safety and integrity of industrial components, especially in the process and power industries. Between the different NDT techniques, Pulsed Eddy Current (PEC) technique is used for detecting corrosion and other defects in ferromagnetic materials with insulation. PEC technique uses the principles of electromagnetic induction to generate eddy currents within conductive materials, to evaluate the wall thickness of the material and to identify defects without the need of expensive disassembly of the insulation of the inspected components [1, 2]. One of the key advantages of PEC technique is the ability to penetrate into the material, allowing detection of defects beneath the insulation without the need to remove it. This capability is essential for maintaining operational efficiency and minimizing downtime. Recent developments in PEC technology have improved its sensitivity and accuracy, making it a preferred solution for in-service inspections [1, 2]. This method has been proven to be effective in identifying corrosion and localized defects, providing accurate measurements of wall thickness and detect corrosion defects in ferromagnetic pipes [2, 3]. Furthermore, with the integration of advanced signal processing, PEC techniques improved the interpretation of data allowing more precise defect analysis [4].

Besides its advantages, the application of PEC testing experiences certain challenges. Factors like the electromagnetic properties of the materials and the influence of external conditions can impact on the accuracy of the measurements [1, 5]. This paper aims to provide a comprehensive overview of the application of pulsed eddy current testing for the inspection of insulated pipes and identify a localized defect in the wall thickness of the material. By recent research findings and advancements in PEC technology, this study aims to contribute to the reliability and effectiveness of NDT methods in industrial applications.

2. PRINCIPLES OF PULSED EDDY CURRENT INSPECTION

The pulsed eddy current (PEC) inspection is part of a non-destructive testing (NDT) technique and uses the principles of electromagnetic induction to detect defects in conductive materials. The method is especially effective for inspecting insulated pipes and other components where traditional inspection techniques may be limited or expensive to use.

The basic principle of PEC inspection is based on electromagnetic induction, where a time-varying magnetic field is generated by passing an alternating current through a coil. When this coil is placed near a conductive material, such as metal, it induces eddy currents within the material. These eddy currents flow in closed loops perpendicular to the magnetic field and are influenced by the electrical conductivity and magnetic permeability of the material [6, 7].

The conventional eddy current testing uses sinusoidal excitement, but PEC technique uses short-duration pulses of current. This short-duration pulses of current generates a broad spectrum of frequencies, allowing for deeper penetration into the material and improved sensitivity to defects located under surface layers or insulation (Figure 1) [8, 9].

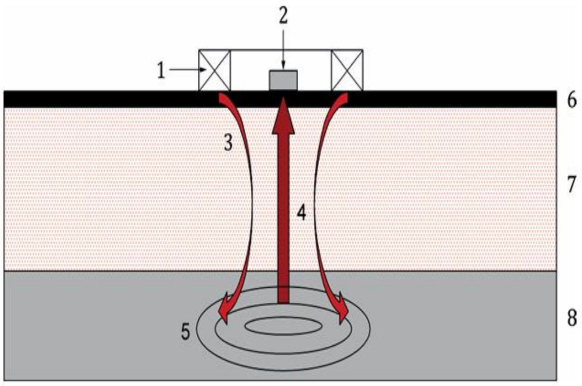


Fig. 1. Basic principle of pulsed eddy current testing technique [10]
1– sender coil, 2 – receiver devices, 3 – primary magnetic field, 4 – secondary magnetic field, 5 – eddy currents, 6 – cover/sheeting, 7 – insulation, 8 – tested component

The presence of defects, such as cracks or corrosion, interrupts the flow of eddy currents, leading to changes in the induced magnetic field. These changes can be detected by the sensor that measures the results of the electromagnetic field variations [11, 12]. The degree of eddy current flow disturbance is closely related with the size and nature of the defect [6, 12]. With the advancement in the field of signal processing, Fourier transformation and pattern recognition algorithms are used to analyze the data and to enhance defect characterization [13, 14]. The ability to accurately interpret these signals is crucial for determining the integrity and location of defects within the inspected material.

PEC inspection is particularly successful for evaluating insulated pipes, as it can penetrate insulation layers without requiring their removal (Figure 2).

This capability minimizes operational downtime and reduces the risks associated with traditional inspection methods, which may involve extensive disassembly of the insulation [8, 9]. The effecttiveness of PEC in detecting corrosion and other defects in insulated pipes has been demonstrated in various studies, highlighting its potential as a reliable NDT method in industrial applications [13, 15].

Fig. 2. Examples of PEC inspected insulated pipes

3. EXPERIMENTAL WORK

For the experimental work a pipe is inspected using PEC method (Figure 3). The pipe material and dimensions are given in Table 1. The PEC system generates a series of electromagnetic pulses and the PEC sensor detects variations in the magnetic field caused by anomalies such as corrosion, thinning of the material or cracks within the pipe. The data from the sensor is recorded and analyzed. Calibration using reference samples of known thickness is performed allowing the accuracy of the results. The experimental results provide critical information on the condition of the pipe, enabling decisions for maintenance or repair.

Fig. 3. Segment of pipeline that is subject of investigation

Table 1

Technical data of tested material

Material (mm)	Structural steel
Diameter of the pipe	323.9
Length	1420
Nominal thickness of the wall	10.3
Thickness of the composite insulation	10

The step of the probe is calculated with the following equation:

$$FP = (0.65\cdot LO) + FP_0 = (0.65\cdot 10) + 35 = 41.5\ \text{mm},$$

where:

LO – thickness of the insulation,

FP_0 – probe surface (for the selected probe (PEC-025) = 35 mm).

Calibration was performed on a segment of the pipe which did not suffer any damage during its operation, on a segment with a nominal thickness of the pipe wall. The experimental work steps are given in Table 2. The initial scan is performed on the entire length of the insulated pipe using the first chosen PEC probe. The probe is moved along the pipe, maintaining a consistent speed and ensuring complete coverage of the pipe. After obtaining the data from the initial scan an analysis is performed to locate the potential areas with defects. The second scan is performed with the same probe only on the damaged segment in dynamic mode (higher resolution) to determine the defects dimensions. For accuracy and error analysis a third and fourth scan is performed with high resolution probe on the same damaged segment to compare data and assess the accuracy of defect characterization.

Table 2

Experimental work steps

Scan	Measurement area	Probe	Resolution
First	Pipe	PEC-025	Reduced resolution
Second	Detected segment	PEC-025	Increased resolution
Third	Detected segment	PECA-HR	CWT ready option
Forth	Detected segment	PECA-HR	High resolution

4. RESULTS AND DISCUSSION

The inspection is performed in two different scans of the pipe. The first scan is performed on the entire surface of the pipe, in order to locate the damaged segment of the component. Scanning is performed in dynamic mode with reduced resolution (signal acquisition points) in order to quickly inspect and locate the defect. After the scan, the received signals are analyzed, and the following results are obtained, as shown in Figure 4. The minimum thickness measured with the first initial scan is 6.4 mm, while the maximum thickness is 11 mm.

Located reduced wall thickness during the initial scan is shown in Figure 4, marked in yellow. The second scan is performed in order to obtain precise data on the degree of damage. The second scan is performed with the same probe, in dynamic mode, but with increased resolution. The dimensions of the damaged segment covers an area of 800×200 mm.

Analyzed results obtained from the second scan of the damaged segment gives the following measurement: the minimum thickness of the material measured by pulses eddy currents is 6.3 mm, while the maximum thickness is 10 mm (Figure 5).

To continue with the analysis of the damaged pipe the next step in this research is to scan the damaged pipe segment with a high-resolution probe. The proposed approach is performed to compare the accuracy and error rate between the probes. The minimum material thickness obtained in the third scan with the CWT ready option is 5.8 mm (Figure 6), and the minimum material thickness obtained with the fourth scan with high-resolution option and the high-resolution probe is 5.5 mm (Figure 7). Summary of the obtained measurements are given in Table 3.

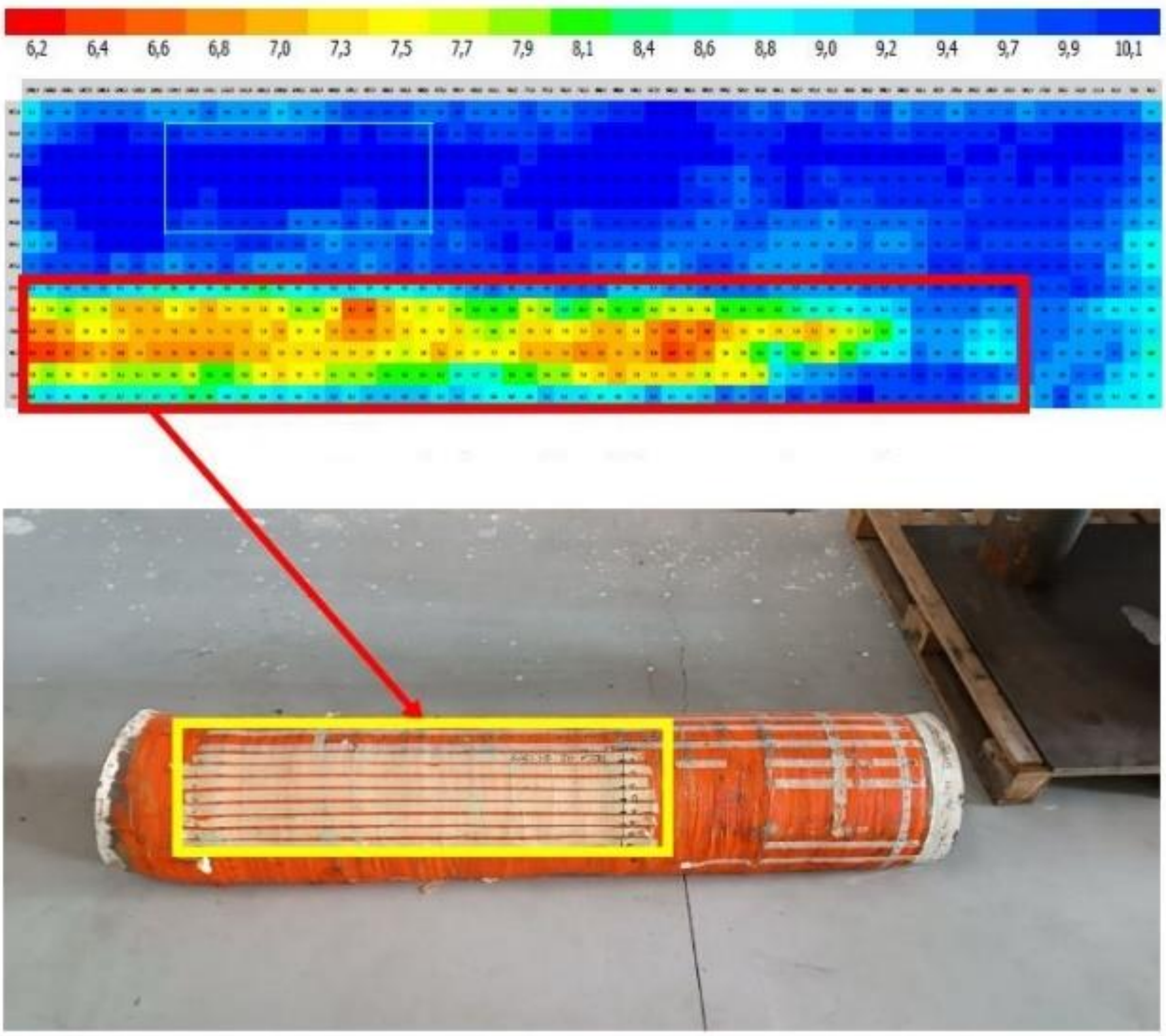


Fig. 4. Obtained results and location of the damaged pipe zone

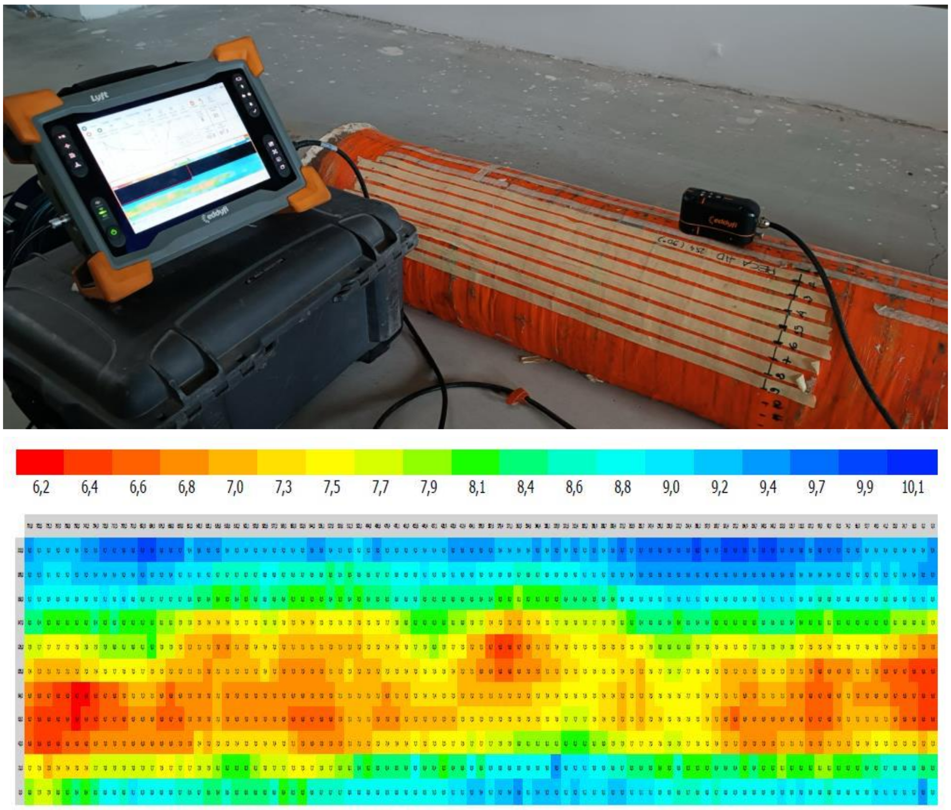


Fig. 5. Scan of the reduced thickness segment and results obtained

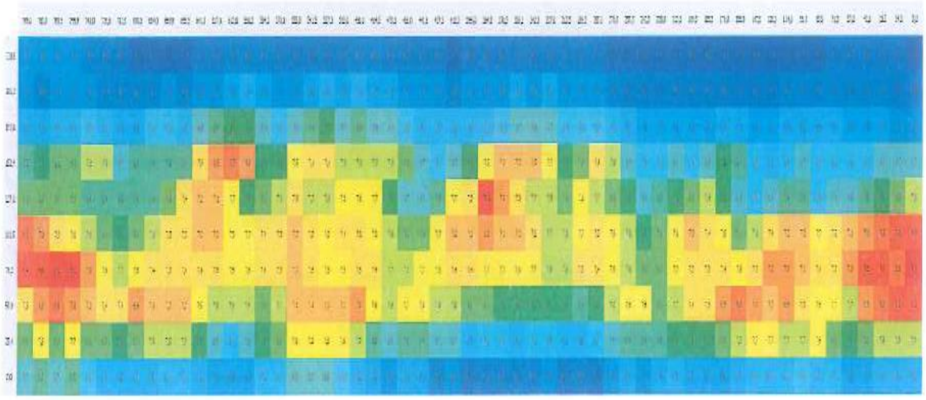


Fig. 6. Material thickness with CWT ready option

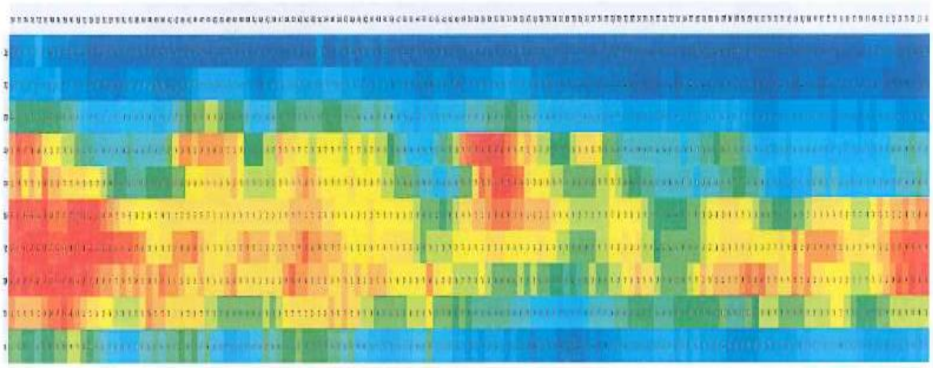
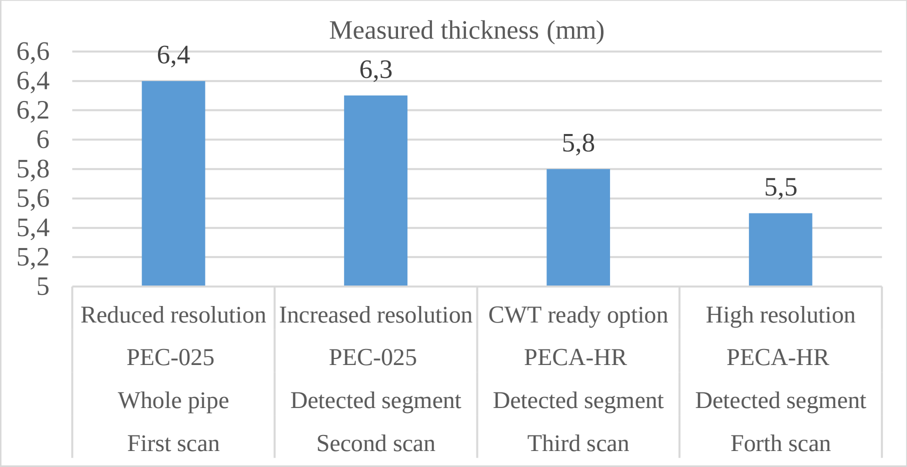


Fig. 7. Material thickness with high resolution option

Table 3

Measurement variations of detected defect with different probe and resolution



The difference in results between the PEC-025 single element probe and the PECA-HR high resolution probe is 0.8 mm. The time required to inspect the damaged segment is increased during scanning with the high-resolution probe. To confirm the values obtained by the inspection of pulsed eddy current, as well as the accuracy of the damaged location, an inspection of the inside of the pipe is carried out. As shown in Figure 8 the measured thickness of the pipe is 5.8 mm. After inspecting the inside of the pipe, it can be noted that the eddy current testing technique provides reliable information about the location of damage that can occur under the insulation of the pipelines. It can also be noted that they provide accurate material thickness data, with small deviations between the measured and actual minimum pipe wall thickness.

Fig. 8. Damaged location inside the pipe and measured minimum thickness in the damaged segment

5. CONCLUSIONS

The experimental investigation conducted in this paper was on a pipe with composite insulation and with the application of pulsed eddy current technique where its effectiveness was demonstrated in detecting defects such as corrosion and wall thinning without the need to remove the insulation. PEC technique can penetrate the composite insulation and accurately identify the variations in pipe wall thickness and material integrity. The technique proved to be useful for inspecting insulated pipes where conventional inspection methods would require costly and time-consuming insulation removal. According to the study the PEC technique can penetrate into insulation materials, including composites, while providing reliable defect detection. This technique presents a valuable solution for non-destructive testing in the industrial sector, offering a practical and efficient method for ensuring the safety of insulated piping systems.

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