

# Gas Pipeline Corrosion Mapping Using Pulsed Eddy Current Technique

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**Abstract:** Oil and gas transmission pipelines are critical items of infrastructure in providing energy sources to regions and countries. Steel pipes are commonly used which can be subject to both internal and external corrosion. This paper presents an advanced nondestructive inspection technique for detection of oil-gas pipeline corrosion defect. The Pulsed Eddy Current (PEC) method has been successfully applied in corrosion detection of unburied gas pipeline without removing the insulation. First, the principles of pulse eddy current method is pointed out then, the pulsed eddy current test on a pipe is simulated by Maxwell software to obtain optimum test parameters. To test the new technique, some artificial defects are fabricated on the inner surface of a gas pipe to simulate different corrosions phenomena in practice. Three isolation layers are applied to the pipe in order to show the efficiency of PEC in the detection of wall thinning areas without removing the insulation.

**Keywords:** Maxwell Software, Pipe Corrosion, Pulsed Eddy Current, Signal Analysis

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## 1 INTRODUCTION

Non-Destructive Testing (NDT) is application of science and technology without disturbing current condition of structural components. It allows testing and examining their integrity. Eddy Current Testing (ET) is one of the various methods of non-destructive testing which follows electromagnetism principles, and its application in non-destructive test is growing increasingly. In conventional ET method, a sinusoid signal is used to excite the driving coil. The impedance of test specimen is measured with a pick-up coil concentric to the driver coil. Pulsed Eddy Current (PEC) method is a new NDT technique which originated in 1971. In contrast to conventional ET method, the PEC used broadband pulses to excite the probe's driving coil. This stimulation pulse is scattered in sample. Since field first influence on the surface, signal time limit analysis should be used in order to gain information on underside defect [1, 2]. Currently, the potential application of PEC for corrosion detection and characterization relies on the signal features such as amplitude, time-to-peak, or time-to zero crossing that are defined graphically in Fig. 1 for a typical PEC signal.

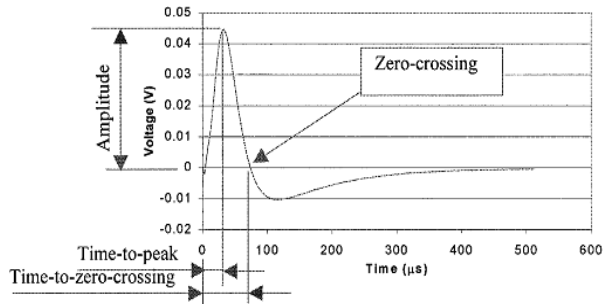


Fig. 1 Key features of a typical PEC signal [3]

A variety of NDT methods to detect corrosion in pipelines exists, the majority of these methods use magnetic principles. Below a number of important methods of corrosion detection will be presented. Magnetic Flux Leakage (MFL) is a suitable method for detection of corrosion and its location; however, it has limitation in determining size of corrosion, especially in undersides. Pulse Magnetic Flux Leakage (PMFL) is a new technique used for corrosion detection which is able to determine corrosions automatically. Recently Pulse Magnetic Resistance (PMR), which is a novel magnetic force, is used in NDT [4]. Some applications of Eddy current testing include: fault detection of ferromagnetic sections such as gas and oil pipes [5], railroad threads [6], bearing [7] and ferromagnetic elements [8]. Remote Field Eddy Current (RFEC) technique is one of the magnetic field principles based methods which is able to detect internal and/or external defects in pipes [9].

Pulsed Eddy Current (PEC) testing is a new method for measuring thickness of coating and/or material properties (conductance or penetrability) as shown in Fig. 2 [10].

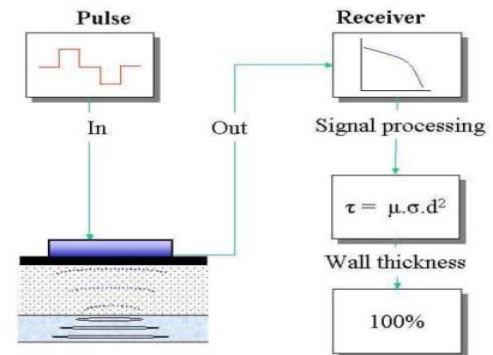


Fig. 2 Calculated wall thickness analysis of the voltage pulse return [13]

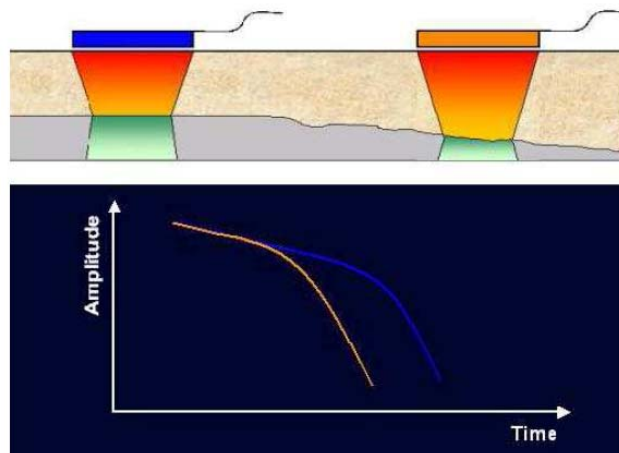


Fig. 3 RTD-INCO TEST method used to identify corrosion [13]

PEC testing is a suitable method for detecting cracks in thick conductive or ferromagnetic structures [11]. Insulated Component Test, (Incotest), is a technique based on PEC for detection of corrosion in pipes and hulks (Fig. 3). It is efficient in terms of time and cost since there is no need for removing coating and insulation [12].

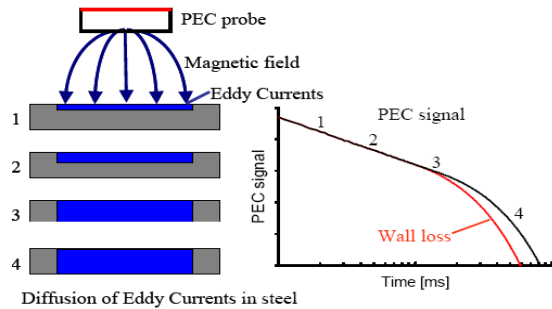


Fig. 4 Graph results PEC system [13]

In PEC signal there is superposition by two sources; insulated coating and the pipe wall. The signal range of the coating is longer than pipe’s wall since it is closer

to probe. Also, the decay of the coat signal is faster than the wall’s because of low thickness of the coating compared to pipe thickness (Fig. 4) [14]. Gap changes between probe and sample under test which result in change in induced magnetic capacity is called Lift-off. Lift-off might be due to insulator thickness changes, irregularity of sample surface or irregular movements of the operator during test. Investigators use Lift-off Intersection (LOI) in order to remove Lift-off disorders. LOI is the point where changes and effects of Lift-off are negligible [15]. In this paper, PEC testing has been applied to an isolated gas pipe with the objective of detecting and quantifying corrosion in gas pipes.

## 2 SIMULATION OF EDDY CURRENT TESTING

In practice, one important parameter in PEC testing is the exciting frequency of probe’s driving coil. This parameter shows the magnetic field penetration depth. In this study, by using Maxwell simulator software, we determined optimal parameters in PEC testing for corrosion detection in gas pipes. First geometry of the gas pipe and PEC probe were simulated.

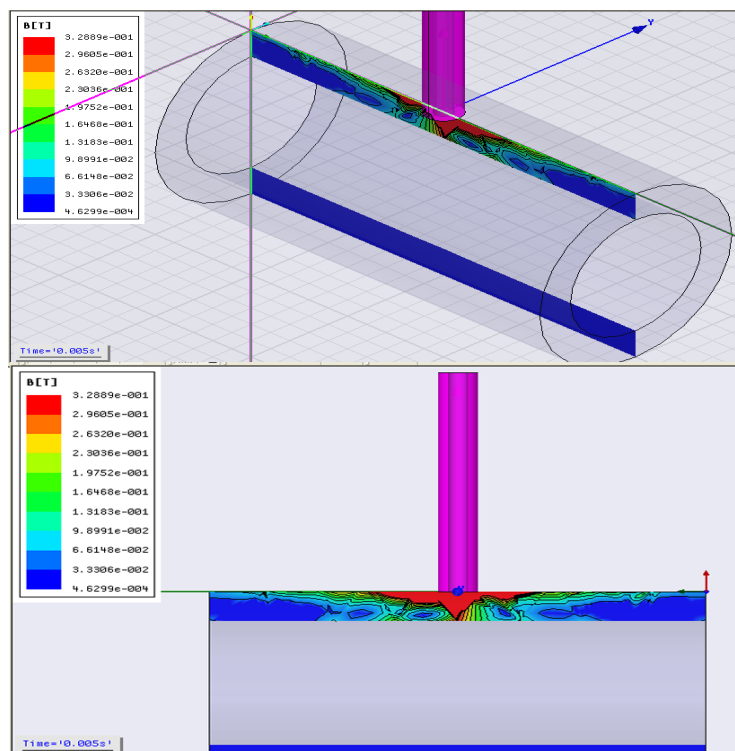


Fig. 5 Process simulation and analysis of the magnetic field Maxwell simulator software

Regarding field analysis shown in Fig. 5, the effect of induced field and penetration depth of the magnetic field can be determined, and make sure that penetrated magnetic field could reach to internal part of pipe so that it was possible to determine thickness decrease, which specifies rate of corrosion in gas pipe, by analysis of recursive field induction. According to simulation results illustrated in Fig. 5, the exciting frequency 500 HZ and input voltage 4 volt are suitable parameters to detect the corrosion of a gas pipe which is 6 inches in diameter and 5.2 millimetres in thickness.

### 3 PULSED EDDY CURRENT TEST SETUP

Pulsed Eddy Current testing system is consisted of a pulse generator, model 1003-SFG, a pulsed eddy current probe, a low noise preamplifier model SR 560, a digital oscilloscope card, SDS200A, and a computer controlled data acquisition system, as shown in Fig. 6. A schematic of this setup is shown in Fig. 7. The driver coil is excited through an input voltage of 4 volts. Stepwise pulse function is a pulse generator by pulse generator. The response signal measured by pick-up coil, is fed into a low noise amplifier. The output signal from the amplifier is send to the digital scope card to be displayed and saved on the computer.

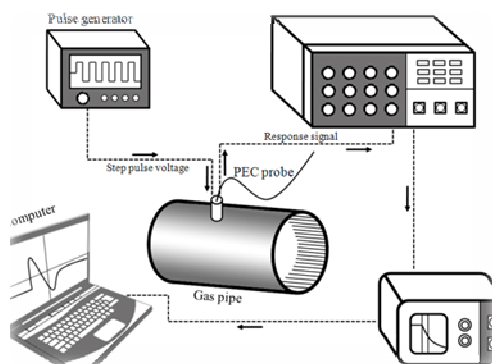


Fig. 6 Overview of pulse eddy current test system

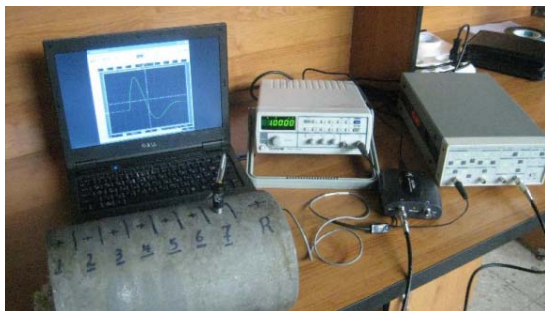


Fig. 7 System and pulse eddy current test equipment

In order to prepare sample specimens, some corrosion areas with 1.4, 1.98, 2.58, 3.16, 3.74, 4.26 and 4.98 mm thickness are simulated on a 6 inch gas pipe with 5.2mm thickness. These corrosions are simulated by milled area in the inner side of the pipe, as shown in Fig. 8.



Fig. 8 Simulated corrosion with different thickness on gas pipe

### 4 RESULT AND DISCUSSION

Prior to measuring signal on simulated corrosion areas, signals received from intact areas of the pipe having the initial pipe thickness is recorded as reference signals. Then, signals related to each simulated corrosion thicknesses were measured. Subsequently, the reference signal was subtracted from those of simulated corrosion, resulting in a set of reference subtracted signals. These represent the perturbations due to corrosion identified in Fig. 9. Henceforth, these signals will be referred to as simple PEC signals. At first, we analyze the time domain signals due to changes in the corrosion, without introducing the changing lift-off. Fig. 9 shows a set of PEC signals for 1.4, 2.58, 3.16, 3.74 and 4.98 mm thickness loss which were used to calibrate the system.

The two other thickness loss 1.98 and 4.26 mm are used to estimate the accuracy of the test system. The results indicate, increasing signal amplitude follows increasing thickness loss. A calibration curve for corrosion thickness loss based on the minimum amplitude of PEC signals was constructed, as shown in Fig. 10. Then, two thickness losses of 1.98 and 4.26 millimetres were used to obtain system accuracy estimation. PEC signals related to these two thickness losses were displayed in Fig. 11 and their minimum amplitudes were obtained. Finally, using the calibration curve and an interpolation the thickness losses were estimated and compared with the actual thickness losses in Table 1.

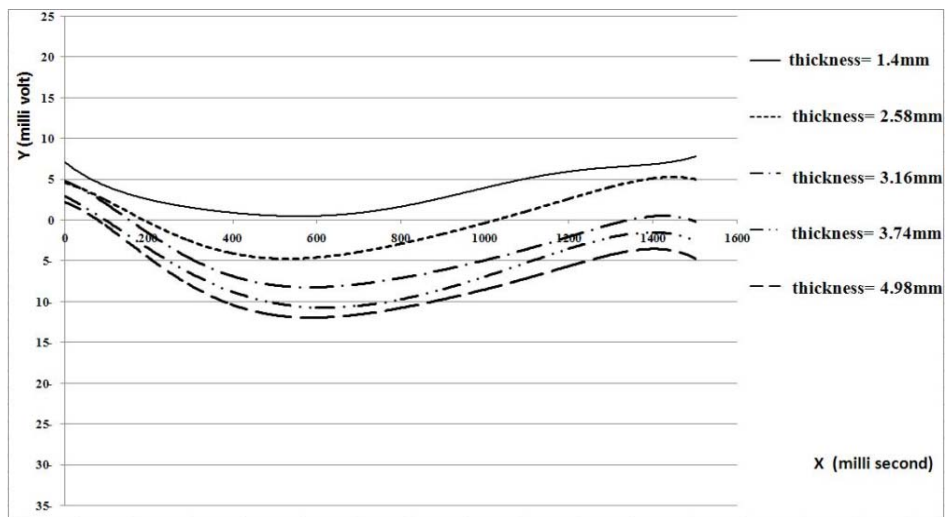


Fig. 9 PEC signals for different corrosion thickness loss on a gas pipe

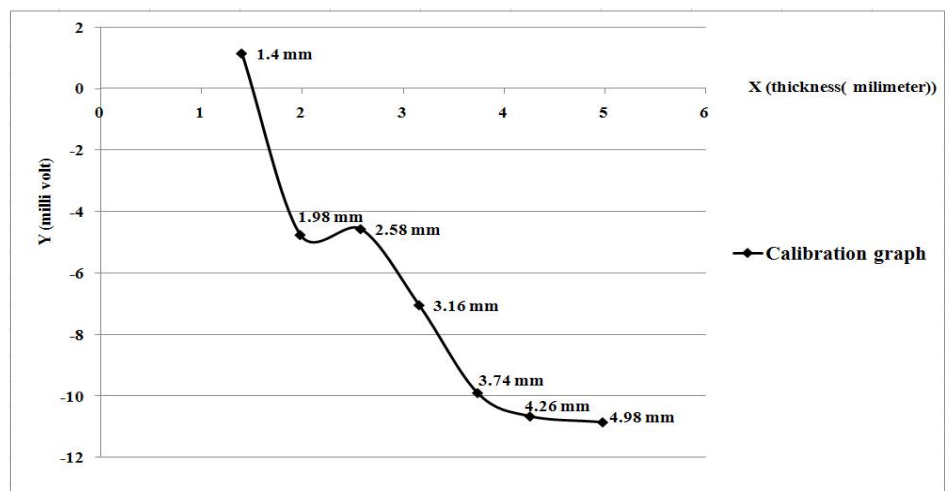


Fig. 10 Calibration curve for different corrosion thickness loss on a gas pipe

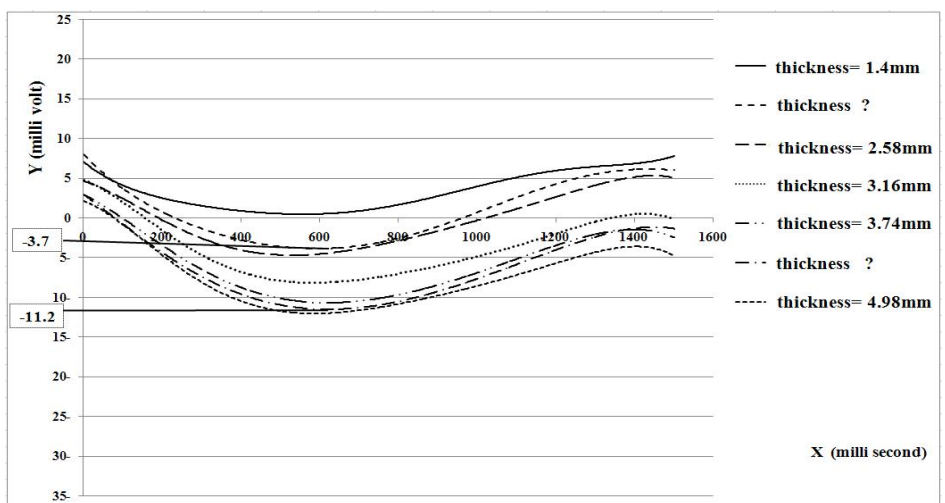


Fig. 11 PEC signals including testing signals

**Table 1** Comparing thickness losses measured by PEC and actual thickness loss

Error	Thickness loss estimated by PEC	Actual thickness loss
4.98	1.9302 mm	1.98 mm
3.4483	4.1131 mm	4.26 mm

By comparing thickness losses estimated by PEC and actual thickness losses the maximum error tends to 5% approximately. Although, this error is acceptable but by increasing the number of tests it can be reduced and thus the calibration curve can be drawn.

At this stage, the previous experiment is repeated with an isolated gas pipe in order to illustrate how the lift-off effect can be eliminated. The insulation which has been used here is a kind of cold insulation with 1mm thickness. These insulations have been applied to protect Non-buried gas pipes. Three insulation layers were applied to the specimen (gas pipe with simulated corrosion) during three stages and each time PEC signals were examined (Fig. 12).

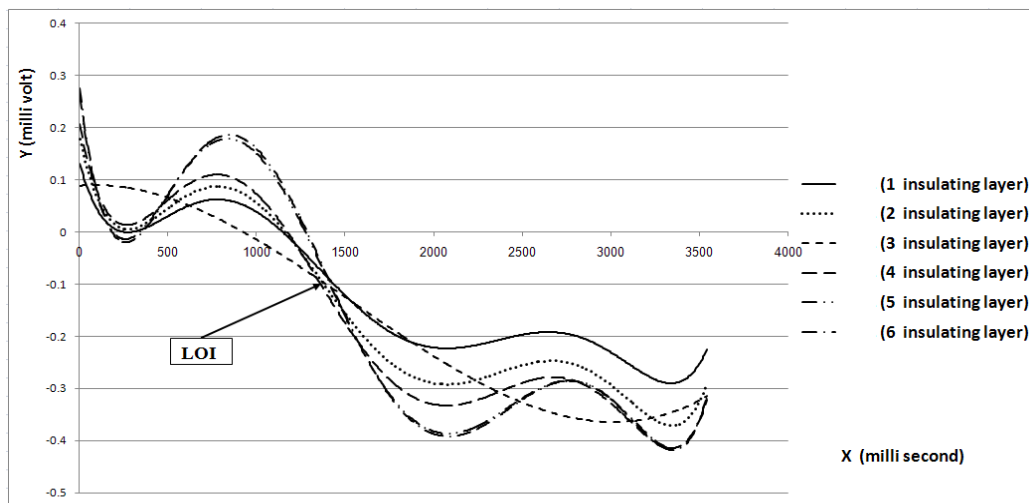
The results show the effects of changing corrosion thickness losses while the lift-off is varied. As shown in Fig. 13, the PEC signal parameters at peak amplitude are affected by the lift-off and it is impossible to make corrosion detection and sizing without compensation for this lift-off.

By examining test results, it is concluded that all PEC signals for a thickness loss with different lift-off values pass through one point or a very small region called the lift-off-off Intersection (LOI).



**Fig. 12** Corrosion tests on three layers insulation on a gas pipe

If the amplitude of PEC signals at this point (LOI) is used to estimate corrosion thickness loss, one can be sure that adding insulation layers has no effect on the results. We performed the similar experiment to those in the last stage. Fig. 14 shows the calibration curve obtained from the amplitude values in LOI of PEC signals. Estimation of corrosion thickness losses with one, two and three layers of isolation were compared with the actual thickness losses in Table 2 In this case, the corrosion thickness losses with one, two and even three layers of isolation were estimated with an average error of 11%. It is again an acceptable error and it should be taken into consideration that corrosion measurement was carried out over and over for three layers of isolation. However by increasing the number of tests the error can be reduced to draw the calibration curve.



**Fig. 13** PEC signals for a thickness loss with different lift-off values

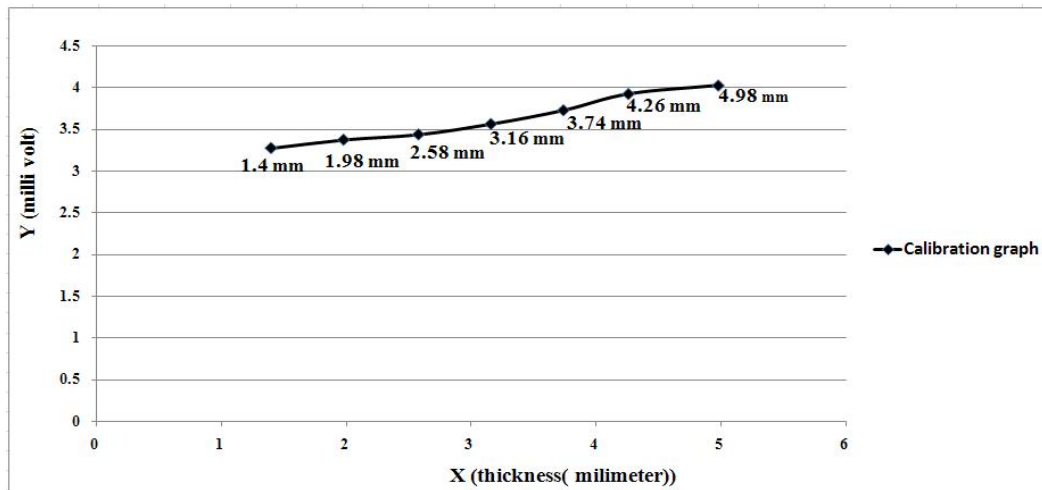


Fig. 14 Graph minimum signal amplitude difference in a state without insulation and pipe insulation

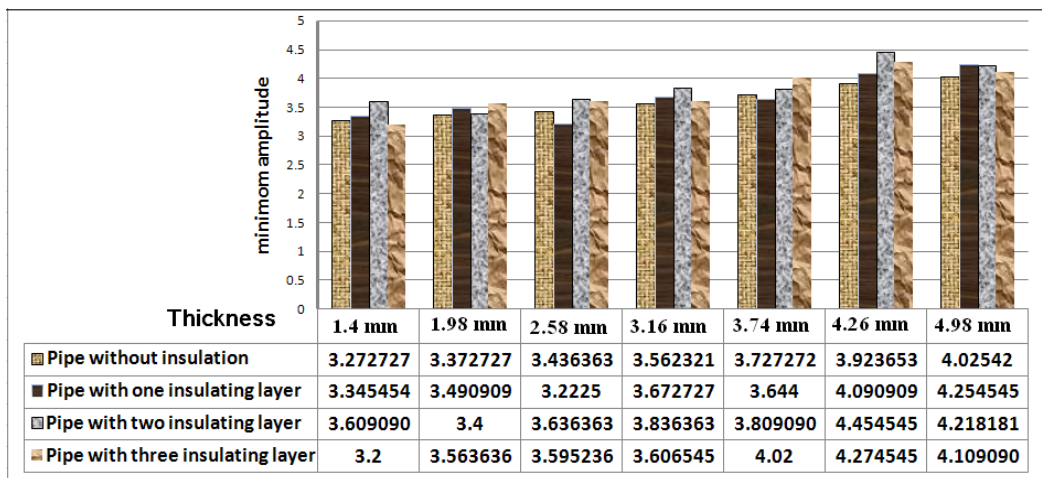


Fig. 15 Block diagram comparison of minimum amplitude against thickness layers of a pipe without insulation and pipes with different insulating layers

If the amplitude of PEC signals in this point (LOI) is used to estimate corrosion thickness loss, one can be sure that adding insulation layers has no effect on results. We performed the similar experiment to those in the last stage. Fig. 14 shows calibration curve obtained from the amplitude values in LOI of PEC signals and also Fig. 15 shows Block diagram comparison of minimum amplitude against thickness layers of a pipe without insulation and pipes with different insulating layers. The estimation of corrosion thickness losses with one, two and three layers of isolation were compared with the actual thickness losses in Table 2. In this case, the corrosion thickness losses with one, two and even three layers of isolation were estimated with an average error of 11%. It is again an acceptable error and it should be taken into

consideration that corrosion measurement was carried out over until three layers of isolation. However, the error can be reduced by increasing the tests for the construction of calibration curve.

## 5 CONCLUSION

In this research, the application of pulsed eddy current method (PEC) for detecting and estimating corrosion in gas pipe lines has been investigated. The proposed method can be applied to an unburied gas pipeline without any need to remove the insulation. The other advantages of The PEC method are easy application, identifying both surface and sub-surface defects and sub-surface defects and portable test equipment.

Results show that the PEC method is a promising approach, enabling the elimination of the lift-off effect and also enabling inspections to be performed remotely without pre-treatments such as cleaning or isolation removal.

**Table 2** Accuracy of thickness measurements for different layers of insulation by PEC

Error	Thickness estimated by pulse eddy current test	Actual thickness	
15	1.683	Applying one layer of insulation	1.98 mm
10	1.782	Applying two layer of insulation	
12	1.7424	Applying three layer of insulation	
9	2.875	Applying one layer of insulation	3.16 mm
12.5	2.765	Applying two layer of insulation	
10.5	2.828	Applying three layer of insulation	

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