Reduction of the Impact of Coatings Thickness Variation on Pulsed Eddy Current Signal

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Abstract. Pulsed eddy current testing (PECT) is widely used in industrial pipe wall thinning inspection because it can measure through the wrapped coatings. But the inevitable variation of coatings thickness is commonly known to be one of the main obstacles for PECT as it can easily lead to an erroneous measurement. A method to reduce the variation is proposed, which indicates that the testing signals under different coatings thickness could be translated to the ones under same coatings thickness by multiplying different coefficient. Simulation and experimental testing on the proposed technique and results are presented in this paper. Results show that significant reduction in the impact has been achieved in pipe wall thinning inspection. The method is simple and suitable for engineering application.

Introduction

Pulsed eddy current testing (PECT) is widely used in industrial pipe wall thinning inspection because it can measure through the wrapped coatings. But the inevitable variation of coatings thickness is commonly known to be one of the main obstacles for PECT as it can easily lead to an erroneous measurement.

In order to solve the problem, many scholars directly treat the impact of coatings thickness variation on pulsed eddy current signal as lift-off effect, and proposed lots of methods to reduce the lift-off effect. Guiyun Tian proposed an approach using normalization and two reference signals to reduce the lift-off effect [1]. Catalin Mandache proposed a time domain method for lift-off compensation [2]. Yunze He proposed a method based on principal component analysis and support vector machine for PEC defect automated classification in aircraft multi-ply structures with interlayer gaps and lift-offs [3]. However, all of scholars above without exception acquiesce that the coatings is only made of the thermal insulation; they neglected the cladding wrapped on the thermal insulation and the methods they proposed are only applicable to the small lift-off variation, which are not suitable for industrial pipe wall thinning inspection. The impact of cladding thickness variation on pulsed eddy current signal could not be ignored. Xinjun Wu developed a saturation PEC testing system for wall thinning through insulation with ferromagnetic cladding. The system employs a magnetic apparatus to magnetize ferromagnetic cladding to saturation; therefore, the magnetic shielding effect of the cladding becomes weak [4]. But the magnetic apparatus is so lumpish that it is hard for engineering application. Zhiyuan Xu proposed a characteristic to test the wall thinning covered with cladding [5], but the characteristic requires the same coatings thickness in different position.

However, the anomaly structures such as overlap and rivet, the inevitable installation error and the growing eccentricity with the service life could lead the variation of coatings thickness in different position. It is especially seriously in horizontal pipelines as shown in Fig. 1. The existing methods become unfeasible in practice.
Our starting point is to find an efficient and easy-to-use method to reduce the impact of coatings thickness variation on pulsed eddy current signal. The rest of this paper is organized as follows. In Section 2, a method to reduce the variation is proposed, which indicates that the testing signals under different coatings thickness could be translated to the ones under same coatings thickness by multiplying different coefficient. In Section 3, it verifies the effectiveness of the method by simulating the situations of different cladding thickness and different thermal insulation thickness. In Section 4, a pulsed eddy current experimental platform is built to further verify the effectiveness of the method. Finally, a brief conclusion is given in Section 5.

The proposed method

The industrial pipe wrapped with coatings can be approximated by a three-layered structure as shown in Fig. 2(a).

From top to bottom the mediums are respectively the cladding, the thermal insulation and the pipe wall. The coatings thickness is the summation of cladding thickness and thermal insulation thickness. A PECT probe, which includes two coaxial cylindrical coils that are used as the driver and pickup coils, is placed on the cladding. During the measurement, the driver coil is driven by a square-wave current. At the edge of square-wave, the eddy currents are induced both in the cladding and in the pipe wall. As time goes on, the eddy currents fade away. The voltage in the pickup coil, which is the PEC signal, is induced due to the variation of magnetic field produced by the eddy currents that induced in the cladding and in the pipe wall. While the eddy currents in the cladding fade much faster than that in the pipe wall, its contribution can be negligible in the middle and late stage of PEC signal. Through analyzing the middle and late stage of PEC signal, which is under the same coatings thickness, the pipe wall thinning could be easily worked out.
The typical PEC testing signals under different cladding thickness and thermal insulation thickness are as shown in Fig. 2(b).

The middle stage of PEC signals are paralleled, which should coincide to each other well under the same coating thickness. In order to reduce the impact of coatings thickness variation on pulsed eddy current signal, a method is proposed, which indicates that the testing signals under different coatings thickness could be translated to the ones under same coatings thickness by multiplying different coefficient as shown in Eq. (1).

\[
S_r = S_o \times K = S_o \times \left( \frac{\sum S_r}{\sum S_o} \right)
\]  

(1)

Where \( S_o \) are the PEC signals under different coatings thicknesses, \( S_r \) is the corresponding signal translated to the same coatings thickness as \( S_r \). Simulation and experiment are used to verify the effectiveness of the method in the next sections.

**Simulation**

A matlab program which implements the analytical model that based on the TREE method [5] is used to simulate the situation of different cladding thickness and different thermal insulation thickness.

**Different cladding thicknesses:** The cladding thickness is always variation with the flaking, overlap and riveted structure as shown in Fig. 1. To the flaking, the worst situation is that there is no cladding on the thermal insulation. To the overlap and riveted structure, we consider that the thickest situation is no more than 3 times of cladding sheet thickness. Since the 0.5mm galvanized sheet is widely used in industry, it simulates the situation of different cladding thickness with 0mm, 0.5mm, 0.7 mm, 1.0 mm, 1.2 mm, 1.5mm, while the thermal insulation thickness is 20mm and the pipe wall thickness is 21.5mm. The corresponding simulation signals are as shown in Fig. 3(a).

Fig. 3(b) shows that with the thicker cladding, the amplitude of early signal is greater, and the decay time of eddy current induced in cladding is longer. As time goes on, the amplitude of signals decreases with coatings thickness increases because that the induced eddy current in coatings could be negligible. Therefore, we select the middle and late PEC signal, which as shown in Fig. 3(c), to verify the validity of the method in the rest text.

The most part of the cladding is simple (single sheet). But considering the curvature of the pipeline, the cladding thickness in Fig. 2(b) should be more than the thickness of single sheet. Here for 0.7 mm. Consequently, we translate other signals under different cladding thickness to the ones under the cladding thickness 0.7 mm by Eq. (1). Where the summation of \( S_r \) and \( S_o \) should base on the middle signal because the late signal is hypersensitive to the wall thinning. The results are as shown in Fig. 3(d).

In Fig. 3(d), the translated signals are coincide to the signal 0.7mm so closely that only one curve is visible. Being compared to the signals shown in Fig. 3(c), there is significant reduction in the difference among the signals with different cladding thicknesses.
Different thermal insulation thicknesses: Installation error and increasing service life lead to the eccentricity of thermal insulation. It is especially seriously for the horizontal pipeline, which is widely used in industry. With regard to the thermal insulation thickness mentioned above, we simulates the situation of different thermal insulation thickness with 10mm, 15mm, 20 mm, 25 mm,
30 mm, while the design thickness of thermal insulation is 20mm, the cladding thickness is 0mm and the pipe wall thickness is 21.5mm. The corresponding simulation signals are as shown in Fig. 4(a).

Since the design thickness of thermal insulation is 20mm, we translate other signals under different thermal insulation thickness to the ones under same thermal insulation thickness (20mm) by the method mentioned above. The results are shown as Fig. 4(b).

In Fig. 4(b), the translated signals are coincide to the signal 20mm so closely that only one curve is visible. Being compared to the signals shown in Fig. 4(a), there is significant reduction in the difference among the signals with different thermal insulation thicknesses.

Experimental setup and results

For testing purposes a pulsed eddy current experimental platform is built to obtain testing signals and the experimental set-up is illustrated in Fig. 5. A square-wave voltage signal with duty ratio 0.5 and repetition frequency 0.2Hz is generated by a function generator, then converted to a current signal with amplitude 4A by a power amplifier. The amplified square wave current is provided to the driver coil. The induced voltage of the pickup coil is amplified by a preamplifier, then digitized and sampled by a 16-bits data acquisition card, and finally interfaced to a computer to analyze and display. A 16Mn steel plate, a 0.5mm galvanized sheet and three 10mm plastic plates were prepared. The steel plate has steps with the thicknesses of 14.8 and 21.5 mm to simulate the pipe wall thinning 31.16% and 0% respectively. Different numbers of galvanized sheet and plastic plates to simulate different cladding and thermal insulation thickness. The testing signals are shown as Fig. 6(a). As can be seen on Fig. 6(a), the testing signals are variation with the coating thickness significantly, and it can easily lead to misinterpretation.

All of the signals are translated to the ones under same coatings thickness (0.5mm gladding thickness and 20mm thermal insulation). The results are shown as Fig. 6(b).

Obviously, the amplitude of later PEC signal is corresponding to the pipe wall thinning. Quantitative analysis by a non-linear fit algorithm [6], which is suitable for the signals under same coatings thickness, the reasonable results of wall thinning 29.82% and 22.38% can be easily worked out. It proves the effectiveness of the proposed method.
Conclusions

The inevitable variation of coatings thickness deforms PEC signals and it can easily lead to erroneous measurements. A method to reduce the variation is proposed and it has been shown to be greatly successful in reducing the impact of coatings thickness variation on pulsed eddy current signal by simulation and experiment. It is suitable to select the middle of signals to analyze, which is insensitive to both the cladding thickness and the pipe wall thickness. But the SNR of translated signals could be worse because there is a constant coefficient multiplication operation in the method, it will influence the precision of result. Further work will investigate the limitation of the method.

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