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Conceptual Design of Ultrasonic Tomographic Instrumentation System for Monitoring Flaw in Pipeline Coating

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Abstract: This study describes the conceptual design of ultrasonic tomographic instrumentation system for monitoring flaw in pipeline coating. In oil and gas industry, an ultrasonic inspection is the common method used to inspect pipeline integrity due to flaw existence such as corrosion, pitting, holiday, pinhole and others. The ultrasonic tomography system is used in this project to monitor flaws circumferentially on pipeline coating with contactless measurement of distance from sensors which is based on thickness changing in coating. The design of the ultrasonic tomography system consists of ultrasonic sensing system, data acquisition and image reconstruction system. Experimental test for lab scale is performed by using 2 inch pipe. The transceiver sensors of 40 kHz are mounted around the pipe with a distance of 2 cm from sensors to the pipe surface. Reflection mode is used as the ultrasonic sensing mode for the ultrasonic signal as it propagated through air medium to the pipe coating. The data collected are based on ultrasonic signal amplitude and time of flight measured by ultrasonic transceiver sensor. Based on the time travelled by the ultrasonic signal from the sensor to the pipe coating, the distance can be determined using Time of Flight (ToF) method. The thickness changing in pipe coating indicates the existence of flaws (internal or external). From the acquired output data, a tomographic image of pipe coating thickness is reconstructed. In the image reconstruction system, the image coating will be reconstructed using MATLAB software based on suitable algorithm.

Key words: Ultrasonic, tomography, flaw, image reconstruction, MATLAB

INTRODUCTION

Oil and gas pipelines are prone to degradation with time due to corrosion or the appearance of defect or flaws such as holiday, corrosion, crack, notches and pinhole (Beller *et al*., 2001). Coating is one of protective layer for external corrosion and it may lead to rapid corrosion if failures existed in the protective coating. Pipelines need to be monitored earlier for these threats in order to prevent incidents and to maintain integrity (Teitsma, 2004). Most research conducted in ultrasonic testing is used for localized flaw detection and the result produced is on analysis of flaws characterization. In industry, the overall image of pipe being inspected is needed in order to view or predict the exact location of the problem encountered with the pipe. Tomography is the most beneficial technology that can be applied to solve the problem as this technique involved with the image reconstruction system. Ultrasonic testing is the best and known method applied by industries for pipeline inspection due to its effective measurement based on ease of operation, low cost and high sensitivity for small flaw (Li and Rose, 2002). Most of ultrasonic tomography techniques are applied for flow measurement such as investigated by Abdul Rahim *et al*. (2004), Rahiman *et al*. (2006), Brown *et al*. (1995), Yang *et al*. (1999), Chen and Sanderson (1996) and others. Pipe coating is a protective layer for external corrosion and it may lead to failure (rapid corrosion) if flaws encountered in the coating surface. A non-destructive ultrasonic tomographic instrumentation system is needed in order to monitor flaws in pipe coating as an early prevention method to avoid rapid corrosion occurred. The change in coating thickness can be seen through the detected flaws (internal and external flaw).

Through this study, a conceptual design of ultrasonic tomographic instrumentation system for monitoring flaw in pipeline coating is developed in order to successfully reconstruct the tomogram image of coating profile (flaws and coating thickness). These flaws affect coating thickness which accelerates corrosion to be

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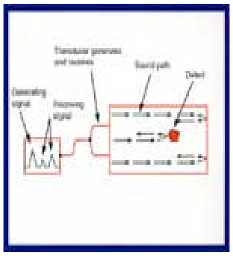
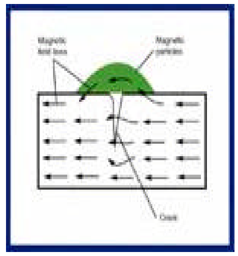
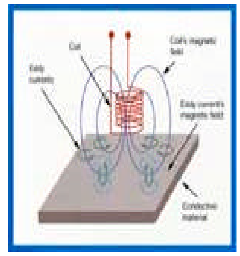
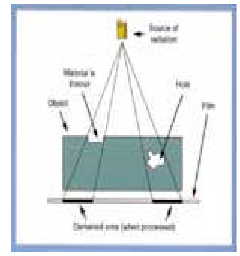
Table 1: Comparison of current NDT method applied in industry (Larson, 2012)

Methods	Ultrasonic	Magnetic particle	Eddy current	Radiography
Schematic diagram				
Main uses	• Locate surface and subsurface defects in many materials. • Measure the thickness and characterize properties of material based on sound velocity and attenuation measured.	• Inspect ferromagnetic materials for defect. • Detect surface and near surface defect	• Detect surface and near-surface flaws in conductive materials. • Measure thickness of thin sheets of metal and nonconductive coatings.	• Inspect any material for surface and subsurface defects. • Locate and measure internal features • Locate hidden parts of defects and measure thickness of materials.
Advantages	• Can penetrate thick materials and highly accurate • Provide distance information	• Moderate cost • Can rapidly inspect large surface areas • Produced directly on the surface and form an image of discontinuity	• Moderate cost • Readily automated • Test probe does not need to contact the part	• Can inspect wide range of material and thickness • Ability to inspect complex shapes
Limitation	• Need coupling material for contact surface • Skill and training required is more extensive	• Only for ferromagnetic material • Large currents are needed • Demagnetization and post cleaning is necessary	• Only inspect conductive materials • Depth of penetration is limited • Skill and training is more excessive	• Relatively expensive equipment investment • Radiationsafetyrequiredprecaution

occurred on the pipe surface (Beaver and Thompson, 2006). By monitoring coating thickness and flaw detection, corrosion can be avoided earlier. It is important to measure coating thickness and flaw detection in non-destructive way. Non Destructive Testing (NDT) is a reliable and cost effective testing as it does not affect or damage the inspection material (Zhoa *et al*., 2010). There are four common methods used in NDT such as radiography, eddy-current, magnetic particle and ultrasonic testing (Zhang *et al*., 2007). Table 1 shows the comparison on four current NDT methods carried out in industry based on their main usage, advantages and limitations.

The change in coating thickness can be seen through the detected flaws (internal and external flaw). Through this paper, a conceptual design of ultrasonic tomographic instrumentation system for monitoring flaw in pipeline coating is discussed in order to successfully reconstruct the tomogram image of coating profile (flaws and coating thickness).

MATERIALS AND METHODS

The overall process flow for the ultrasonic tomography system consists of designing ultrasonic sensing system, data acquisition and image reconstruction system (Fig. 1). The ultrasonic sensing system is modelled based on design configuration, number of sensors and its arrangement, ultrasonic signal behaviour and image grid estimation. The ultrasonic sensing system is designed to monitor the flaws circumferentially in pipeline coating based on reflection mode. The raw data collected from the ultrasonic sensing system is analyzed using Time of Flight (ToF) method to obtain distance from time of ultrasonic signal travelled. For image reconstruction system, the new image of pipe coating thickness with flaw detected is reconstructed based on data acquisition collected. The schematic diagram of overall ultrasonic tomographic instrumentation

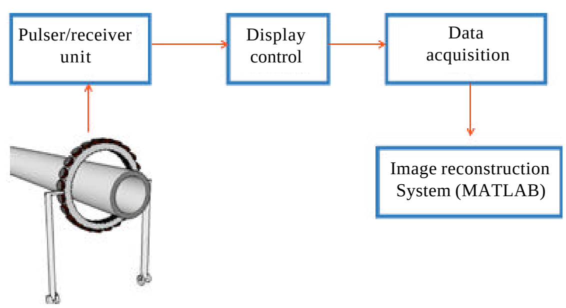


Fig. 1: Schematic diagram of ultrasonic tomography system

system consists of sensing system, pulser/receiver unit, data acquisition and image reconstruction system is shown in Fig 1.

The pulser/receiver unit is used to provide a short and high voltage pulse to the ultrasonic transducer in order to generate high frequency ultrasonic energy. The ultrasonic energy in a form of mechanical vibration is introduced and propagates to the test specimen (coating). The reflected energy from the test specimen will be received back by the transducer and the signal is converted into a voltage and being amplified into display control unit (Charles, 2003). The signal is displayed for amplitude of signal strength versus time of total signal travelled (transmitted and received). The time taken by the transducer for transmitting and receiving the signal is used to calculate the distance travelled by the signals. Two main parameters are analyzed from the experiment which are time and distance travelled by the signals. This measurement is called as Time of Flight method (ToF). The data collected from the data acquisition are then being analyzed by comparing the standard outer diameter of the pipe with the distance taken by the signals to receive back by the transducer. The data will be used to reconstruct the image of pipe thickness with flaws (2-Dimension) by using MATLAB software based on suitable algorithm. The overall image of pipe thickness and flaws can be displayed through the image reconstruction system.

ULTRASONIC SENSING SYSTEM

The ultrasonic sensing system is used to monitor flaws in pipe coating that affects the change in coating thickness. The ultrasonic sensing system is modelled with ultrasonic transducers mounting around the pipe with specific distance. The transducers configuration is the key factor in the efficiency of data acquisition (Al-Salaymeh and Durst, 2004). The ultrasonic transducer used is a type of transceiver sensor with 40 kHz in frequency which is functioning to transmit and receive the ultrasonic signal. There are 36 of transceiver sensors mounted around the pipe with 10 mm distance between each other and 45 mm distance from pipe surface. The ultrasonic transceivers are arranged based on beam angle specification which is 30° of each transceiver. Based on beam angle and its pattern for a distance of 45 mm from coating surface, the estimated image grid for each sensor is about 5.67 cm^2 (Fig. 2).

ULTRASONIC SIGNAL BEHAVIOUR

Ultrasonic signal is characterized in terms of wave propagation and sensing mode for this system. Ultrasonic sensing mode is used to determine the mode of energy incident onto pipe coating. Based on the modelling, reflection is selected as sensing mode for the ultrasonic incident energy onto pipe coating. The justification for

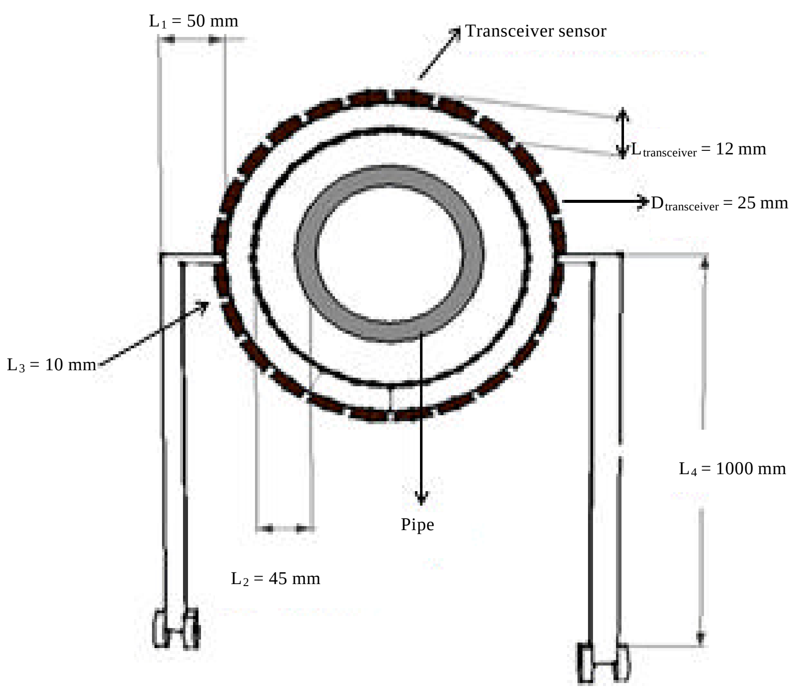


Fig. 2: Schematic diagram of ultrasonic sensing system configuration

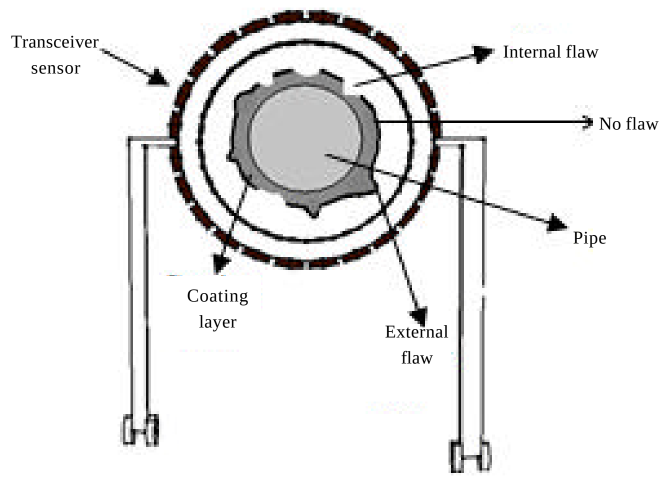


Fig. 3: Schematic diagram of external and internal flaws on pipe coating

the sensing mode is done through calculation of percentage of incident energy produced by each mode, by which the percentage of energy incident based on reflection mode is 99.94% due to high mismatch acoustic impedance. There are several possible cases classified to be investigated for the experiment in order to monitor flaws in pipeline coating There are two main cases which are, the defect and non- defect coating (no flaw) cases. In the defect coating case, there are two possible cases which are (a) External flaw that cause increasing in coating thickness and (b) Internal flaws that cause decreasing in coating thickness from the standard thickness (Fig. 3).

RESULT AND DISCUSSION

Data interpretation for data acquisition: Time of Flight (ToF) method is used for data interpretation. The ultrasonic signal obtained is displayed through display unit based on signal amplitude versus time of signal travelled. The formula used to calculate the distance from the time obtained through ToF method is shown as follow:

$$D = \frac{ct}{2} \tag{1}$$

where, D is distance travelled by ultrasonic signal, c is sound velocity and t is time of signal travelled. By comparing the standard outer diameter of the pipe with the distance taken by the signals to receive back to the sensor, the image of the pipe thickness can be constructed by the image reconstruction system.

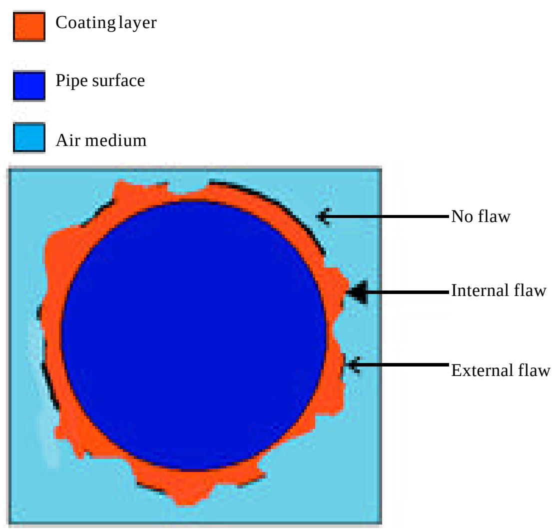


Fig. 4: Expected tomographic image of pipe coating profile (thickness) with flaws existence

Image reconstruction system for tomographic process: Image reconstruction system is the final part of the overall tomographic instrumentation system. In image reconstruction system, the data collected from the data acquisition is used to develop a cross sectional plane image of pipe coating thickness using MATLAB software based on suitable algorithms. Through this system, the change in coating thickness (increased or decreased) due to the flaws can be seen in 2-dimensional view through MATLAB software. Finally, based on data acquisition the expected tomographic image of pipe coating profile is determined (Fig. 4).

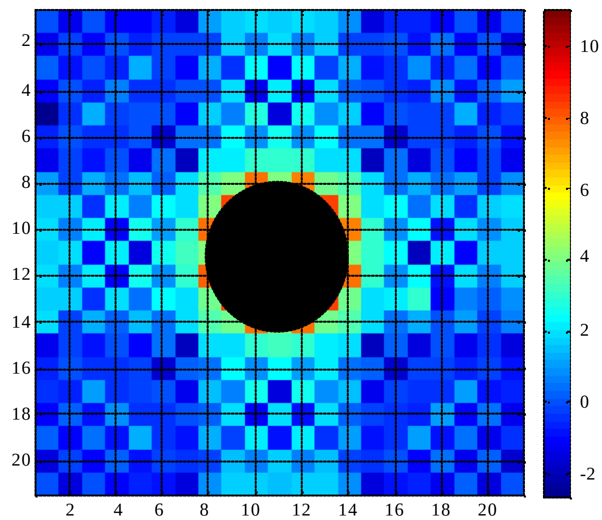


Fig. 5: Tomographic image of pipe coating profile based on simulation

Figure 5 shows the tomographic image of pipe coating profile based on simulation.

CONCLUSION

Ultrasonic tomographic instrumentation system is a reliable inspection technique to monitor flaw in pipeline coating as it can provide accurate data to reconstruct cross section image of pipe coating. It is expected to be successful in designing tomographic instrumentation system for flaw detection in pipe coating and to produce a clear cross sectional image of complete coating profile for future enhancement using MATLAB software and based on suitable algorithm in image reconstruction system. The used of transceiver sensor is able to detect the flaw in coating precisely and further reduced the cost.

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