International Gas Union Research Conference 2011

A STUDY ON DEVELOPMENT OF EMAT SIGNAL ANALYSIS AND EVALUATION METHOD FOR CRACK AND COATING DISBONDMENT IN GAS PIPELINE

Sung-Ho Cho[1], Dong-Kyu Kim[1], Sung-Ja Koo[1], Hui-Ryong Yoo[1], Yong-Woo Rho[1], Hak-Joon Kim[2], Dae-Kwang Kim[2], Sung-Jin Song[2]

[1]R&D Division, Korea Gas Corporation, Incheon, Korea
[2]School of Mechanical Engineering, Sungkyunkwan University, Suwon, Korea

TABLE OF CONTENTS

ABSTRACT

1. INTRODUCTION

2. DESIGN AND FABRICATION OF SH EMAT SENSOR

   2.1 EMAT SYSTEM

   2.2 DESIGN OF SH EMAT SENSOR

3. EXPERIMENTS

4. EVALUATION RESULTS

   4.1 SIGNAL ANALYSIS AND EVALUATION METHOD FOR AXIAL CRACKS

   4.2 SIGNAL ANALYSIS AND EVALUATION METHOD FOR AXIAL GROOVES

   4.3 DETECTION OF COATING DISBONDMENT

5. CONCLUSION

REFERENCES

ABSTRACT

The more the operating time of gas pipelines has increased, the more the possibility of generating defects has also increased significantly due to the wear, erosion, material degradation, and fatigue of the pipelines. For the reasons, assuring integrity of gas pipelines has become one of the major issues in gas industry. Therefore, it is necessary that development of nondestructive evaluation methods inspect vast area efficiently since the length of gas pipelines is ranging from hundreds of meter to hundreds of kilometer. In general, in order to inspect gas pipeline, ILI(In-Line Inspection) systems have been utilized. Many advanced countries have been trying to inspect defects in the gas pipeline with ILI systems based on various types of nondestructive evaluation techniques. Typically, ILI system based on axial MFL(Magnetic Flux Leakage) technique is used. But axial MFL technique has very low POD(Probability Of Detection) of the axial defects, that is, which means that the POD of axial cracks and the axial groove defects are very low, compared to pitting, general corrosion and circumferential defects. Thus, ILI system based on EMAT(Electro-Magnetic Acoustic Transducer) technique are required for detecting axial defects such as axial cracks, axial grooves, coating disbondment in gas pipeline. To apply the EMAT technique for ILI system, design and fabrication of EMAT sensor, EMAT signal analysis and evaluation methods for defects are needed.

In this study, design and fabrication of the shear horizontal EMAT sensor were optimized based on phase and group dispersion curves in gas pipelines. Design parameters were chosen which were incident angle, center frequency and space of meander coil. And, the development of EMAT signal analysis and flaw evaluation methods were thoroughly performed in case of detecting and evaluating axial defects and coating disbondment in gas pipe specimens by using fabricated SH(Shear Horizontal) EMAT sensors. Finally, it was found that the signal analysis methods were valid for characterization of the axial cracks, axial grooves and coating disbondment in gas pipe specimens.

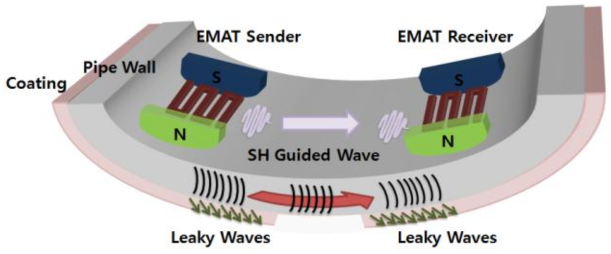
1. INTRODUCTION

In-Line Inspection(ILI) system based on various nondestructive evaluation methods has been developed and applied for inspecting defects in gas pipelines in some developed countries.

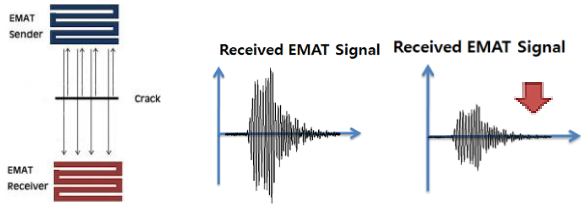
Generally, Magnetic Flux Leakage(MFL) tool and ultrasonic tool widely have been used for inspecting pipeline. But gas operation companies mostly have chosen MFL tool because ultrasonic tool requires couplant for the inspection of the gas pipeline. And for protecting the buried gas pipeline from the corrosion, it needs a protective coating and has to be protected by Cathodic Protection(CP). Because the coating could be damaged by environmental factors and external forces, there also could be lots of defects on this damaged coating area, like metal loss of wall thickness. Normally, Direct Current Voltage Gradient (DCVG) or Close Interval Potential Survey (CIPS) method has been used to detect these damaged coating. But these methods need so much time to inspect and there are many non-inspected area like an asphalt road. Therefore, it is very important for the gas operators to detect damaged coating as well as defects because damaged coating finally results in various defects due to the very excessive inflow or outflow of cathodic current. But, until recently it has been known as separate things to detect corrosion defects and damaged coating. So gas operators has been absorbed in utilizing Electro-Magnetic Acoustic Transducer (EMAT) technology for ILI of gas pipeline up to now because the EMAT technology can detect axial defects which have low Probability Of Detection (POD) in the inspection using axial MFL tool and damaged coating simultaneously. In order to apply EMAT technology for ILI of gas pipeline, it is essential that EMAT sensor consists of coil and magnets be designed and fabricated. EMAT sensor should be designed by considering as follows : what shape of coil, the dimension of coil and space between coil and coil.

Therefore, in this study, EMAT sensor was designed and fabricated to detect the axial defects and the coating disbondment. And, the experiments were performed with specimens containing axial cracks, axial grooves and coating disbondment in order to validate the performance of the developed EMAT sensor. Finally, the evaluation method for axial defects could be obtained.

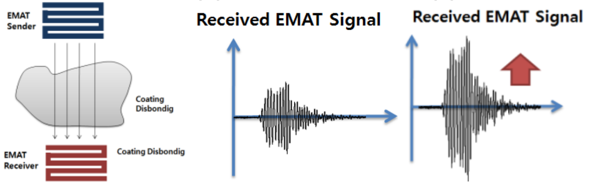
Generated Shear Horizontal (SH) guided wave propagates from the EMAT sender towards the EMAT receiver along pipe wall and the coated area in the circumferential direction as shown in Fig. 1(a). On zero-defect condition, this SH guided wave reaches the receiver and it is recorded as a transmission signal. If there are some defects like cracks between the EMAT sender and the EMAT receiver, the part of SH guided wave is reflected in the direction of the EMAT sender. In addition, the transmission signal amplitude decreases as shown in Fig.1(c). While SH guided wave propagates through pipe wall, the wave leaks into the coating. That is, the coating damps the wave. Hence, if the damping disappears, there would be a significant increase in transmission signal amplitude as shown in Fig.1(e)[1-2].



(a) SH guided wave propagation



(b) without crack (c) with crack



(d) without coating disbondment (e) with coating dis-bondment

Fig.1. Principle of detecting axial defect(crack) and coating disbondment using EMAT.

2. DESIGN AND FABRICATION OF SH EMAT SENSOR

2.1 EMAT SYSTEM

As shown in Fig. 2, EMAT system consists of a function generator to generate tone-burst sine wave, system controllers to control a function generator, RF gated amplifier to amplify the generated wave, an amplifier to amplify the received signal, digital oscilloscope to save the signals, impedance matching network to improve the efficiency of sending and receiving and finally EMAT sensors to generate and receive the guided wave. In this study, for a good impedance matching, EMAT sensors were coupled to the RF gated amplifier and preamplifier through LC impedance matching network [3].

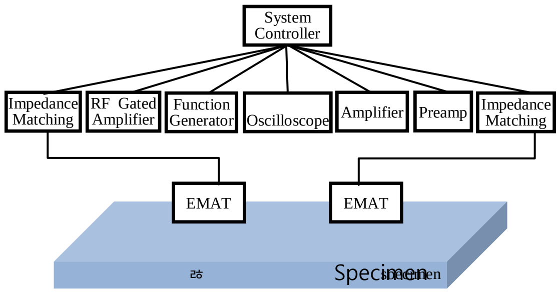


Fig. 2. A schematic diagram of an EMAT system.

2.2 DESIGN OF SH EMAT SENSOR

An EMAT sensor was designed and fabricated for inspecting gas pipe specimen with artificial axial defects and coating disbondment. Normally, there are two basic types of structure of EMAT sensors [4]. One is a lorentz force EMAT using meander coil, and the other is a magnetostrictive force EMAT which is using meander coil. In this study, the structure of a magnetostrictive force EMAT using bias magnets to apply magnetic field to magnetic conductor and meander coil to interact with a static magnetic bias (See Fig. 3) was chosen. Because the latter is more robust than former. And the latter is more effective when considering ILI system.

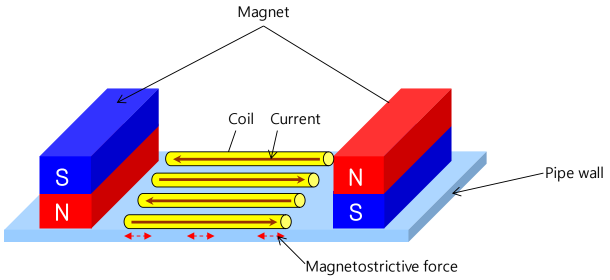
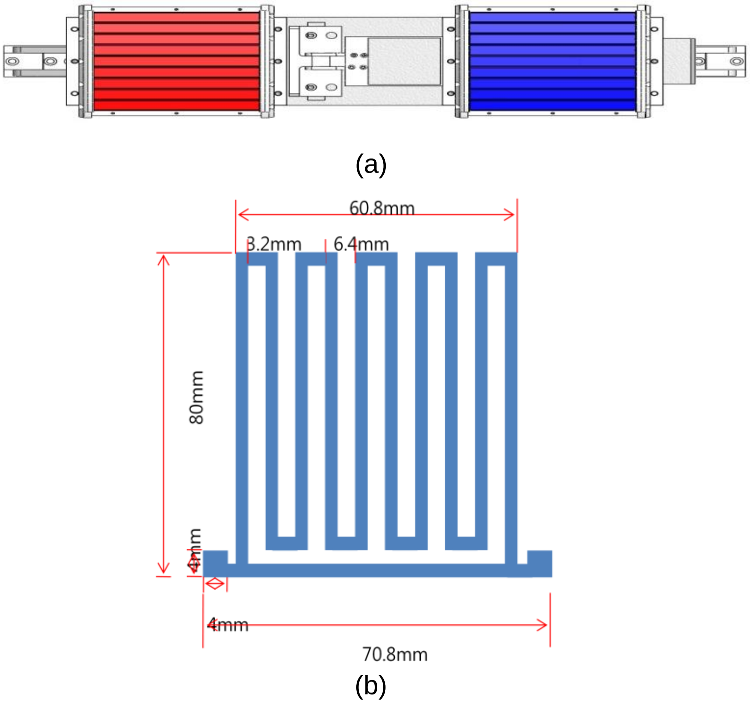


Fig. 3. Structure of a magnetostrictive force EMAT using meander coil.

In order to fabricate an EMAT sensor generating SH guided wave, an EMAT sensor which is able to generate non-dispersive SH0 mode, having a constant velocity regardless of generating frequency, was designed. Schematic diagrams of the designed EMAT magnetization system to magnetize pipe and the designed meander coil are shown in Fig. 4.

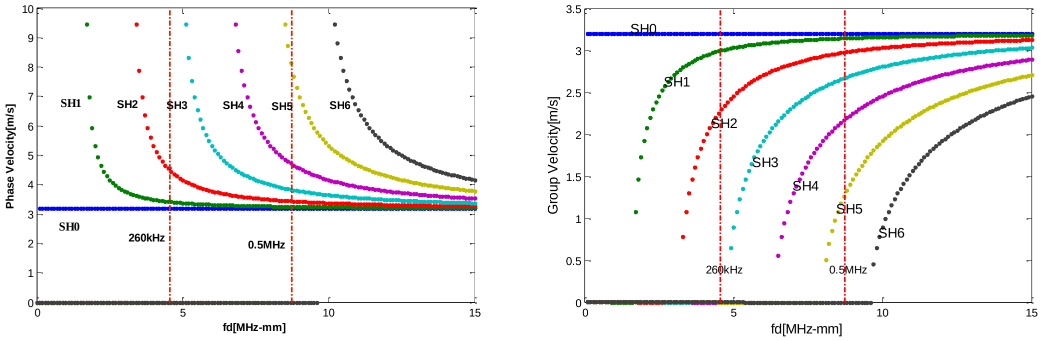


(a)

(b)

Fig. 4. Schematic diagrams of (a) the designed EMAT magnetization system and (b) the designed meander coil.

Fig. 5 shows phase velocity dispersion curves and group velocity dispersion curves of SH waves on a gas pipe specimen. As shown in Fig. 5, SH0 mode can be generated throughout all the frequencies. As the generating frequency becomes higher, lots of dispersive modes are developed as well as SH0 mode [5]. Therefore low center frequency is better than high frequency to avoid the dispersive modes. But at low frequency, energy consumption of ILI system is higher than at high frequency. Also, POD of coating disbondment is more effective at high frequency. Therefore center frequency should be determined by considering dispersive modes, energy consumption and material to inspect. In this study, since the high-pass filter of the EMAT receiver system used is not adjustable below to 0.26 MHz, the EMAT sensor with center frequency of below 0.26 MHz can't be applied. Among over 0.26MHz, at center frequency of 0.5MHz, most effective signals could be acquired through experiment. Therefore the meander coil with center frequency of 0.5MH is applied foe the EMAT sensor.



(a) (b)

Fig. 5. The (a) phase velocity (b) group velocity dispersion curve of SH wave for a gas pipe specimen.

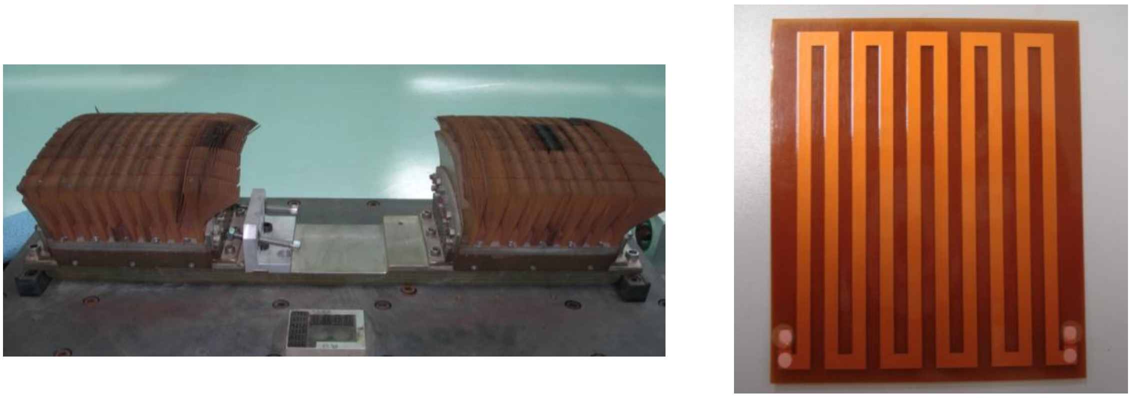
To improve the efficiency of sending and receiving of guided wave, an EMAT sensor with two layered meander coil was designed. A permanent magnet is used as Nd-Fe-B magnet with 8 mm in length, 4 mm in width and 25 mm in height. Design parameters *d* and *l* in Fig. 4 (b) are determined by Eq. (1) and Eq. (2). And a meander coil was made in flexible plate by printing method.

Acquired shear wave velocity was 3,202 m/s. A reflection signal from the bottom surface of a gas pipe specimen by pulse-echo method with shear piezoelectric transducer was used to measure the shear wave velocity.

$$l = \frac{C_s}{2f} = \frac{3.202\ \boldsymbol{mm / \mu s}}{2 \times 0.5\ \boldsymbol{MHz}} = 3.2\ \boldsymbol{mm} \qquad (1)$$

$$d = \frac{l}{2} = 1.6\ \boldsymbol{mm} \qquad (2)$$

where *l* is Interval between meander coil and meander coil, *d* is width of meander coil, C_s is the shear wave velocity and *f* is the center frequency. Fig. 6 shows the fabricated SH EMAT magnetization system and meander coil.



(a) (b)

Fig. 6. Photos of the fabricated SH-EMAT sensor : (a) Magnetization system, (b) Meander coil.

3. EXPERIMENTS

Experiments were performed to verify the performances of the developed SH EMAT sensor. Three specimens with artificial defects were fabricated. The first specimen has axial cracks with depth of 5 %, 10 %, 30 %, 50 %, 70 % and 90% of wall thickness(17.5 mm), 50 mm in length and 0.2 mm in width. The second specimen has axial grooves with depth of 10 %, 20 %, 30 % and 50 % of wall thickness(17.5 mm), 35 mm in length and 17.5 mm in width. The third specimen has coating disbondment with 50 mm in length and 100 mm in width. Fig. 7 shows photos of the fabricated gas pipe specimens with defects.

(a) (b) (c)

Fig. 7. Photos of the fabricated gas pipe specimens with (a) axial crack (depth : 30 %), (b) axial groove(depth : 30 %) and (c) a coating disbondment

As shown in Fig. 8, an EMAT system was built to evaluate the performance of the developed SH-EMAT sensor. As mentioned before, EMAT system consists of a high power pulser/receiver to generate tone-burst signal, control PC, impedance matching network, SH-EMAT sensors with the center frequency of 0.5 MHz and DSO(Digital Storage Oscilloscope).

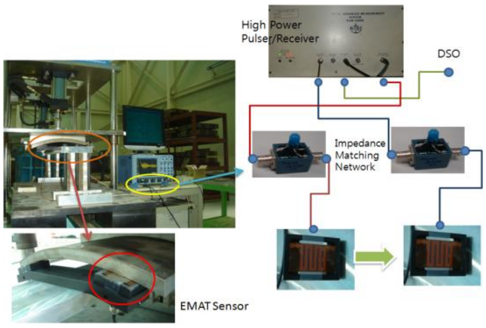
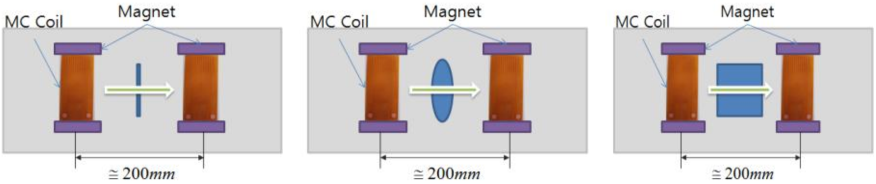


Fig. 8. An experimental setup for evaluating the developed EMAT sensor

4. EVALUATION RESULTS

As shown in Fig. 9, defects are located between an EMAT sender and an EMAT receiver. Transmission signals were investigated with respect to defects.



(a) (b) (c)

Fig. 9. Schematic diagrams of the position of (a) an axial crack, (b) an axial groove, (c) a coating disbondment (MC : Meander Coil).

4.1 SIGNAL ANALYSIS AND EVALUATION METHOD FOR AXIAL CRACKS

Fig. 10 shows comparison of transmission signal without axial crack to with axial crack with depth of 10% of wall thickness(17.5 mm) . As shown in Fig. 10, transmission signal amplitude decreases in the case of specimen with axial cracks. As the depth of defects becomes deeper, the energy of transmission signal decreases and normalized energy can be obtained by Eq. (3) as shown in Fig. 11.

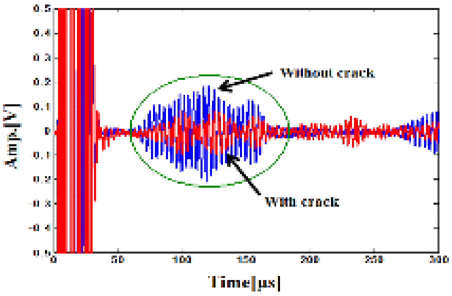


Fig. 10. Comparison of acquired transmission signal without axial crack to with axial crack

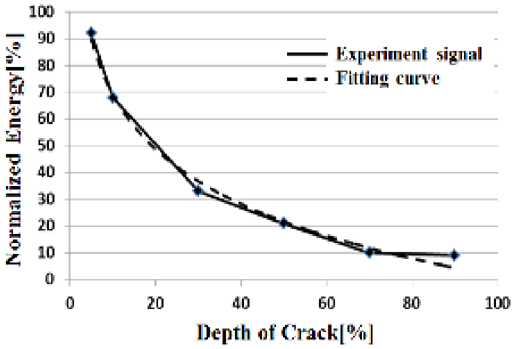


Fig. 11. Normalized energy of transmission signal with cracks of varying depth; solid line is experiment signal data and dotted line is exponential fitting data

$$Normalized\ energy = 222.14 \cdot \exp(-0.047 \cdot depth) \qquad (3)$$

4.2 SIGNAL ANALYSIS AND EVALUATION METHOD FOR AXIAL GROOVES

Fig. 12 shows comparison of transmission signals without axial groove to with axial groove with depth of 50 % wall thickness(17.5 mm). As shown in Fig. 12, transmission signal amplitude decreases in the case of specimens with axial groove. As the depth of defects becomes deeper, the energy of transmission signal decreases and normalized energy can be obtained by Eq. (4) as shown in Fig. 13.

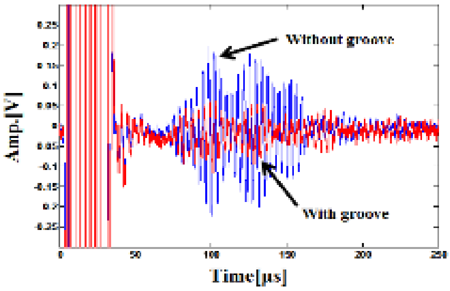


Fig. 12. Comparison of acquired transmission signals without axial groove to with axial groove

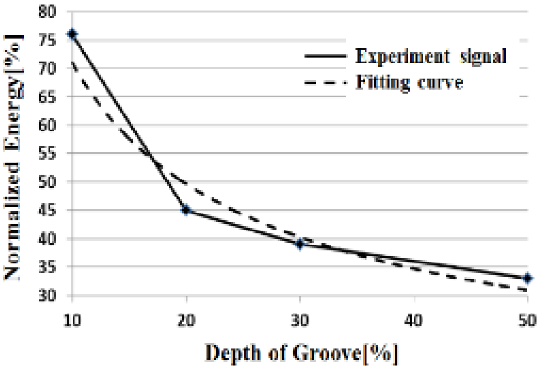


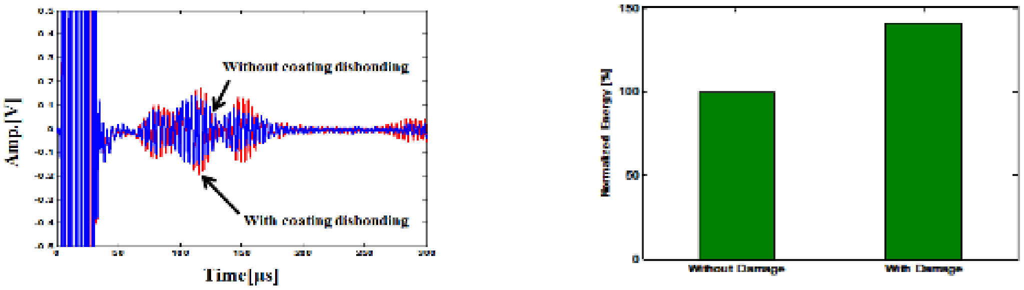
Fig. 13. Normalized energy of transmission signal with grooves of varying depth; solid line is experiment signal data and dotted line is power fitting data

.

$$Normalized\ energy = 231.41 \cdot depth^{-0.51} \quad (4)$$

4.3 DETECTION OF COATING DISBONDMENT

Fig. 14 shows the comparison of transmission signals without coating disbondment to with coating disbondment. As shown in Fig. 14, the transmission signal amplitude increases in the case of specimen with coating disbondment.



(a) (b)

Fig. 14. (a) Comparison of acquired transmission signal without coating disbondment to with coating disbondment and (b) comparison of normalized energy without coating disbondment to with coating disbondment.

5. CONCLUSION

In this study, EMAT sensors were designed and fabricated to detect axial defects and coating disbondment in gas pipeline. Major design parameters were determined on the dispersion characteristics of the guided waves in the gas pipeline. And using the determined parameters, EMAT sensors that can generate and receive SH wave were fabricated. Also, the experiments were performed with specimens in axial cracks, axial grooves and coating disbondment to validate the performances of the developed EMAT sensor. The EMAT sensor developed in this study can detect not only axial groove (depth of 10 % of wall thickness) and axial cracks (depth of 5 % of wall thickness) but also coating disbondment. Also, evaluation methods were developed by using normalized energy of acquired transmission signal.

REFERENCES

[1] J. Aron, J. Gore and etc, Development of an EMAT In-Line Inspection System for Detection, Discrimination, and Grading of Stress Corrosion Cracking in Pipelines, *Annual Technical Progress Report*, Tuboscope Pipeline Services(2001) pp. 11~12.

[2] Thomas Beuker and Dr.Joerg Damaschke, In-line Inspection with High Resolution EMAT Technology Crack Detection and Coating Disbondment, Rosen Technology & Research Center, 20th international Pipeline Pigging, Integrity Assessment & Repair Conference, (2008).

[3] M. Hirao, H. Ogi, EMATs for Science and Industry - Nondestructive Ultrasonic Measurements, *Kluwer Academic Publishers*, Boston (2003) pp. 73~75.

[4] R. B. Thompson, Measurements with EMAT Transducer, *Physical Acoustics Vol.XIX,* Academic Press INC., (1990) pp. 192~196 .

[5] J. L. Rose, Ultrasonic Waves in Solid Media, Cambridge University Press, (2000) pp. 101~113.