DEVELOPMENT OF ULTRASONIC WAVE NONDESTRUCTIVE INSPECTION ROBOT WITHOUT COUPLING MEDIUM USING EMAT

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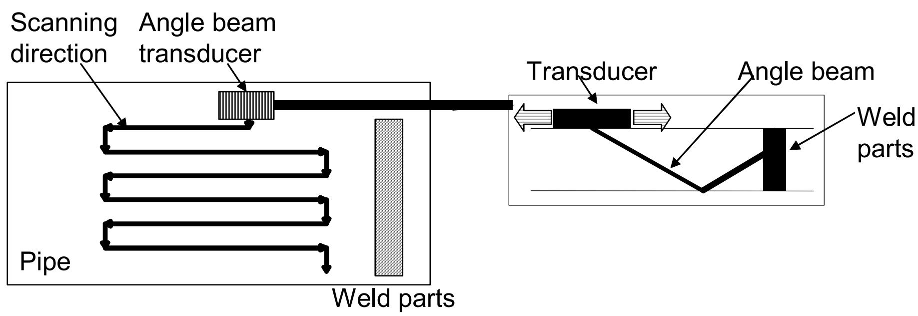
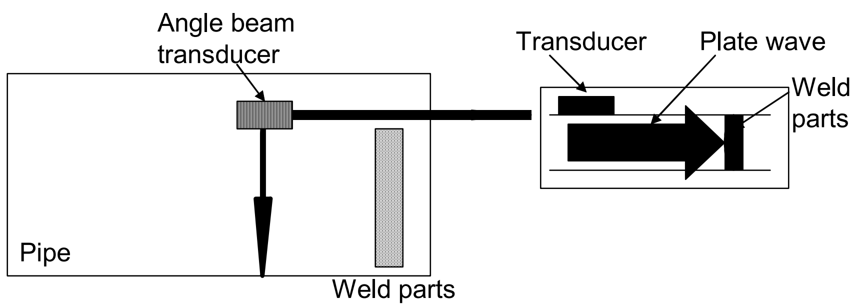
Abstract: The ultrasonic wave is applied as an inspection method for the gas-holder and the pipeline in service. In such an inspection, the application of an automatic inspection system is desirable, because a manual inspection is difficult to accomplish perfectly and exactly due to its enormity, a so-called nondestructive inspection robot is then preferable. However, an ultrasonic nondestructive inspection robot with a piezoelectric oscillator needs to directly touch the material surface to be inspected using the coupling medium. Therefore, a mechanism where the coupling medium is spread thoroughly between the sensor and the material surface and where the sensor is always held at a constant pressure in the same direction on the material side to be inspected, are performances requested for the inspection robot. Actually, it is difficult to overcome this problem and the ultrasonic inspection robot could not be applied widely. We then tried to develop an ultrasonic inspection robot with an electromagnetic acoustic transducer (EMAT) which did not require the coupling medium, which inspected the circumferential parts in the pipe. We especially developed the EMAT to transmit and receive a S_0-mode with high sensitivity and a SH_0-mode plate wave without the influence of the welding bead alternately as the sensor parts. The fixed method between the pipe and the inspection robot was not especially fabricated, because the magnetic force of the EMAT was very strong and was sufficient for attaching the inspection robot on the surface of the steel pipe. The method in which the inspection robot turned around in the direction of the steel pipe surroundings was executed by observing the tape pasted in the direction of the steel pipe surroundings with an installed CCD camera. In this study, the basic mechanisms of this inspection robot and the examination results are described.

Introduction: Generally, an angle beam method is used as the nondestructive inspection method of welded parts, but the precise depth and lateral scanning is absolutely required to cover the entire welded part as shown in Fig.1 (a). In addition we must control any ultrasonic transducers so that they touch with a constant pressure on the surface of the steel pipe. A resolution of these problems is important in order to put an inspection robot into practical use.

On the other hand, the inspection by a plate wave does not require depth scanning as shown in Fig.1 (b). In addition, we could supplement each method's good points and faults if we could simultaneously use a Lamb wave and a SH plate wave. However, it is difficult to use a SH-plate wave for auto-scanning inspection, as we must use a coupling medium with a high viscosity. We then wrestled with the development of an ultrasonic nondestructive inspection robot which carried an EMAT that could alternately drive a Lamb wave and a SH-plate wave, because an EMAT can theoretically transmit and receive ultrasonic waves without any coupling medium.



(a) Angle beam method



(b) Plate wave method

Fig.1 Fundamental concept of an ultrasonic nondestructive inspection robot

Basic characteristic of a plate wave (SH_0, S_0): The basic oscillation pattern of a fundamental plate wave (SH_0 and S_0) is shown in Fig.2 (1). The SH_0-mode plate wave as shown in Fig.2 (a) has a perpendicular oscillating direction in the advancing direction and is parallel to the material surface. Therefore, it is not influenced by the surface condition of the sample plate. Next, the oscillating components of the S_0-mode Lamb wave shown in Fig. 2 (b) mainly consists of the parallel direction to the advance direction. Therefore, we think that it is easily influenced by the surface condition of the sample plate and that the distance attenuation is large.

Drive principle: The EMAT consists of a magnet that produces a bias magnetic field and a sensor coil that produces a dynamic magnetic field. The driving force uses a high frequency vibration of magnetostriction generated in the direction of the compound's magnetic field by combining the dynamic magnetic field generated by a high frequency electric current in the sensor coil and the static field by the electromagnet. Although the direction of the magnetostrictive change occurs in the direction of the slant to the direction of a sensor coil as in the case of the SH_0 mode plate wave shown in Fig. 2 (a), the power ingredient, which causes the magnetostrictive change, occurs in the space frequency to the direction of a sensor coil and in a perpendicular direction and is considered to be changed into the SH_0-mode plate wave [(2)-(4)].

Next, in the case of the S_0-mode Lamb wave, the change in the magnetostriction occurred due to the

compound's generated magnetic field being in a parallel direction to the traveling direction as shown in Fig. 2 (b). This magnetostrictive change was converted into the S_0-mode Lamb wave.

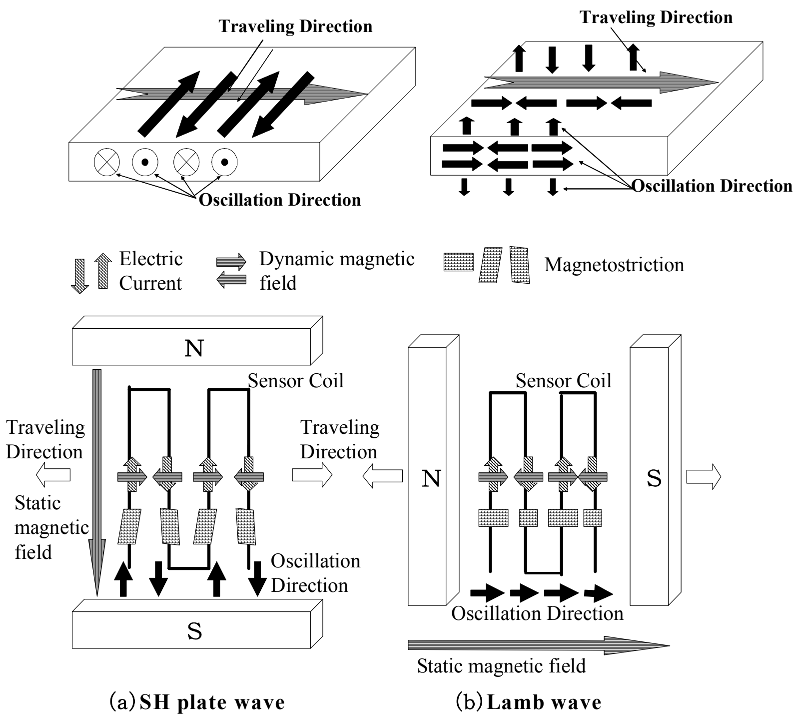
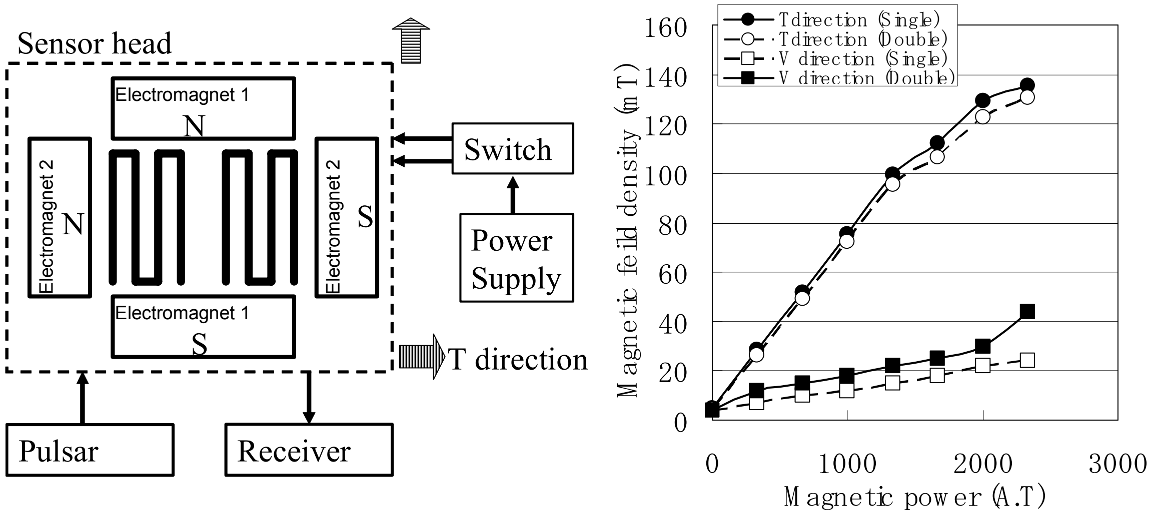


Fig.2 Drive mechanism by the EMAT

Experimental method: The sensor coil was incorporated into the structure as shown in Fig.2, so that the interval between the lead lines is 3mm; this sensor coil produced a plate wave of 6mm wavelength. Figure 3(a) shows the outline of the sensor system. There are two-sensor coils for the receiver and transmitter. These two sensor coils were placed parallel to the traveling direction of the plate wave having a 30mm distance between both magnetic poles. These sensor coils and two electromagnets are connected to the experimental system. When the SH_0-mode plate wave was generated, the electromagnet 1 in the Fig. 3(a) arrangement was driven and when the S_0-mode Lamb wave was generated, the electromagnet 2 in the Fig. 3(a) arrangement was driven. As a result, the magnetic field distribution in part of the sensor coil induced by one electromagnet might be influenced by the other electromagnet. Figure 3(b) shows the measured magnetic field density in the T-direction and V-direction by the driven electromagnet 1 when electromagnet 1 and electromagnet 2 were placed on the 1mm thick steel plate or only electromagnet 1 was placed on the 1mm thick steel plate. When electromagnets 1 and 2 were on the plate, the T-direction magnetic field density decreased by 2% and the V-direction magnetic field density increased by about 20% compared to the magnetic field density when only electromagnet 1 was used. We considered that this result does not significantly influence the measured received signal by the SH_0 and S_0-mode plate waves.

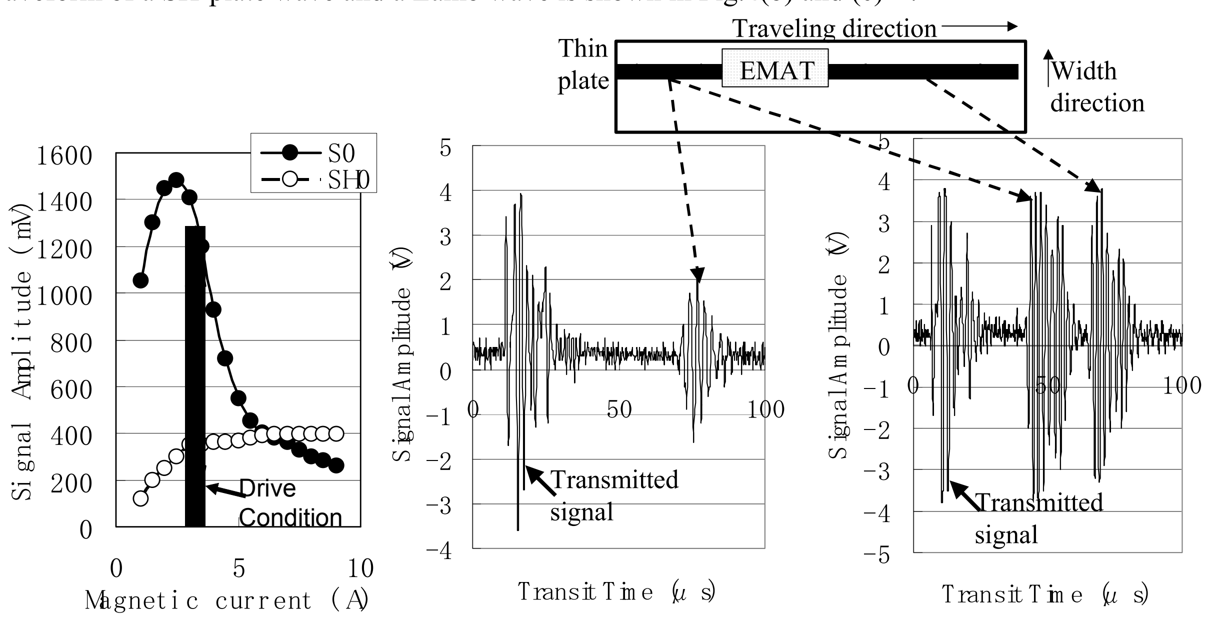


(a) **Sensing system**

(b) **Magnetic field density of parallel and vertical direction**

Fig.3 Basic EMAT driving system and the measured magnetic field between the magnetic poles

Basic performance of the EMAT: In order to check whether an alternating generation of the two plate wave modes could be realized by the same transducer, the following evaluation tests were then carried out using 0.6mm thick plates as shown in Fig. 4(a). Although the optimum magnetic current of the SH-plate wave is different from that of the Lamb wave, we could confirm that there is a drive condition that we could detect in both a Lamb wave and a SH-plate wave. The waveform of a SH-plate wave and a Lamb wave is shown in Fig.4(b) and (c)[5].



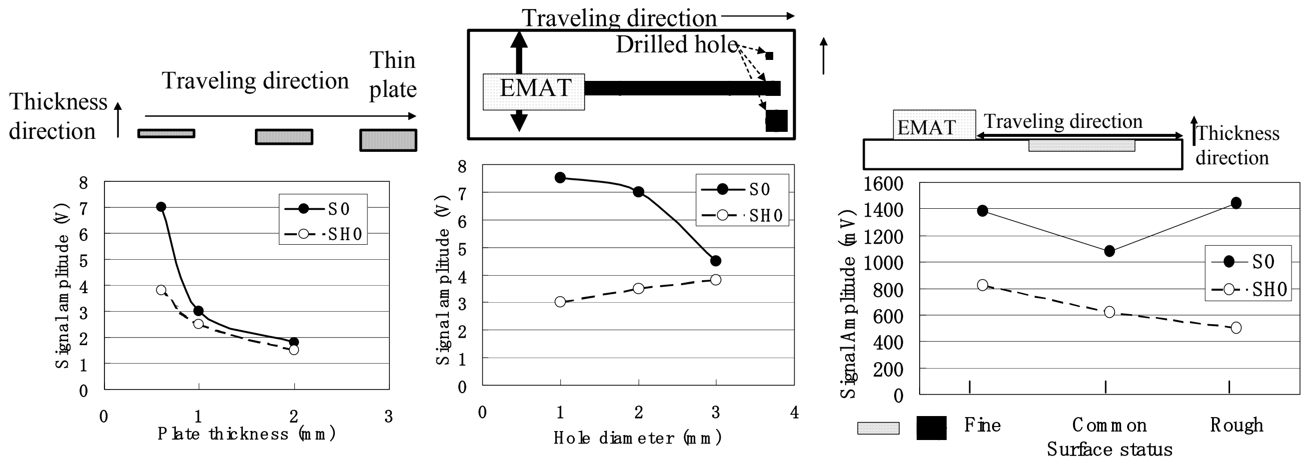
(a) Relationship between signal amplitude and magnetic current

(b) Waveform of SH_0-mode plate wave

(C) Waveform of Lamb wave

Fig.4 Basic experimental results

Basic characteristics of both plate wave modes: Figure 5 (a) shows that we confirmed the relationship between the reflected signal amplitude from the edge of the plate and the plate thickness. We confirmed that the signal amplitude of both modes decreased as the plate thickness increased, but its variation in the SH-plate wave was smaller than that of the Lamb wave. This feature is effective for inspection on a manufacturing line where the plate thickness is always variable. We then confirmed the relationship between the reflected signal amplitude from the drilled hole and the diameter as shown in Fig. 5 (b). With regard to the defect size, the signal amplitude of the SH_0-mode plate wave remained almost constant as compared to that of the S_0-mode Lamb wave. The influence of the surface condition of the plate was investigated using a 1mm thick test sample whose area ［20mm(width) x50mm (length)］ was machined to give a rough surface as shown in Fig.5(c). The signal amplitude decreased for the SH_0-plate wave as the surface condition became rougher. On the other hand, for the Lamb wave, the signal amplitude increased contrary to our expectation. By combining the information from the Lamb wave and the SH_0-plate wave, we believe that quality assurance can be attained.



(a) **The relationship between the signal amplitude and the plate thickness**

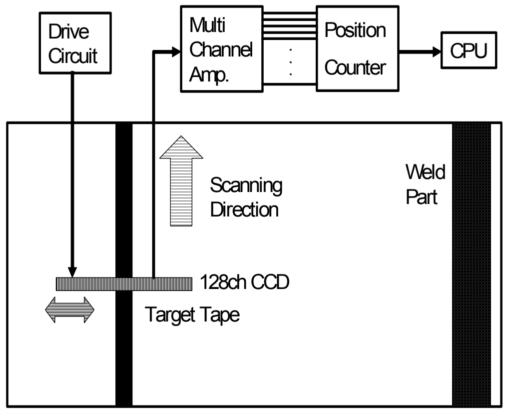
(b) **The relationship between the signal amplitude and the hole diameter**

(c) **The relationship between the signal amplitude and the surface roughness**

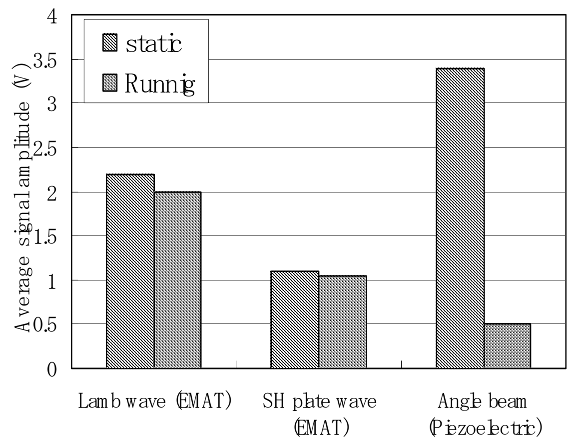
Fig.5 Evaluation of the sensitivity

Mechanical device and running test: Cylindrical rails are generally used in order for the inspection robot to stably move around a steel pipe. However, if that is the case, an enormous preparation time is required and the cylindrical rails must be changed according to the diameter of the pipes. Therefore, we attached white tapes with a high reflection ratio in the circumference direction of a steel pipe and devised a mechanism which followed the white tape top using a one dimensional charge-coupled device camera. The charge-coupled device camera has 128 channels, with a 0.2mm width for a single element. We then built an algorithm from which the output of an element from a central part of the charge-coupled device camera became the maximum in order for the inspection robot to turn by adjusting its position on the pipe as shown in Fig. 6(a).

We then executed a driving test on a steel pipe with a diameter of 750mm. The attractive force for the steel pipe used the magnetic force of the electromagnet in the EMAT. We were then able to confirm that the inspection robot could go around a steel pipe. The robot also carried a piezoelectric oscillator type ultrasonic transducer for reference evaluation. Figure 6(b) shows the results. The EMAT was superior in comparison to the ultrasonic transducer with a piezoelectric oscillator for signal stability. However, the robot meandered through more than 10mm in the axis direction. A possible cause is that the magnetic force could not be symmetrically set for a traveling car. Modification by the turnover rate of a tire did not work as a partial response to the problem.



(a) **Mechanical concept of the inspection robot**



(b) **Evaluation of the running test results**

Fig.6 Mechanical concept of the inspection robot and evaluation of the running test results

Conclusions: An ultrasonic inspection robot equipped with an EMAT that alternately excites the SH-plate wave and the Lamb wave for steel pipes was developed. We found that mutual excitation was fundamentally possible. However, the experimental results indicated that different drive conditions are required for the Lamb and SH-plate waves. We also confirmed that it is effective to combine the information of the received signal from both ultrasonic modes with respect to the detection of a defect. However, further improvement on the detecting ability of the system is required, because the ability decreases, as the sheet thickness increases.

The inspection robot could also follow a white tape wrapped around a steel pipe by experimentally controlling the one dimensional charge-coupled device camera, although the robot meandered away from the pipe welding line.

References:

(1) R.Murayama; Acoustic Science & Technology 23(1) pp.47-49 (2002)
(2) R.B.Thompson; Journal of Applied Physics 48(12) pp.4942-4950 (1979)
(3) E.P.Papadakis et al.; Proceedings of Ultrasonics Symposium pp.1007-1015 (1990)
(4) A.V.Clark et al.; Research in Nondestructive Evaluation 2(4) pp.239-257 (1990)
(5) R.Murayama; Ultrasonics 34 pp.729-736 (1996)