Technical Report

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Non-destructive Inspection Technique for Assuring the High-end Quality of Our Pipe and Tube

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Abstract

Non-destructive inspection (NDI) is one of the important technologies, not only to assure the high-end quality of our pipe and tube but also to gain customer's great satisfaction. That is the main reason that we've developed new NDI technologies and applied them to our manufacturing process for more than several decades. This paper describes the NDI technologies, which have been developed in these 5 years, such as the ultrasonic phased array technique and the superimposed magnetic field rotation technique.

1. Introduction

Pipe and tube products made by Nippon Steel & Sumitomo Metal Corporation are used in diverse fields. Pipe and tubes for the energy field (oil wells, pipelines and power plants), and mechanical tubing for automotive and construction equipment purposes, are used in fields that demand quality assurance in the form of specification guarantees based on Japanese standards, foreign standards, and individual customer specifications, and as performance guarantees covering specific uses.

To ensure pipe and tube quality against flaws and dimensional inaccuracies, a total guarantee based on non-destructive inspections (NDI) plays an extremely important role, and has become indispensable to every pipe and tube supplier who wishes to maintain and raise customer satisfaction. NDI techniques, including ultrasonic testing (UT), eddy current testing (ET), and magnetic flux leakage testing (MFLT) were first applied to pipe and tube manufacturing lines in the 1950s. Due to the increased sophistication of sensing devices, and the conversion of electric/electronic circuits from analog to digital, the precision and guaranteed accuracy of UT, ET and the like have been enhanced. In addition, those testing techniques have been increasingly automated and generalized through the use of computers.

At the same time, because the environment in which NDI techniques are applied has become stricter than ever before, customer demand for NDI-based quality assurance has become so stringent that it can hardly be satisfied solely with the aid of general-purpose NDI technology. However, by proposing effective solutions to the demand for advanced testing and strict quality assurance, a company should be able to outperform the competition. Advanced NDI techniques are important as an aid to impart the required quality to products, in order to supply products of required quality on a stable, just-in-time basis and thereby secure customer satisfaction.

Guided by the basic concept that making the most effective use of NDI to maintain and raise customer satisfaction and outperform the competition is indispensable for the development of its pipe and tube business, Nippon Steel & Sumitomo Metal has been striving to develop and put into practical use advanced new NDI techniques that take advantage of its sophisticated R&D system.

In this report, the author presents several application examples of the NDI techniques the company has developed on its own in order to stand above the competition.

2. Phased Array Inspection Techniques for SAW Weld Zones [1-3)]

2.1 Background to technical development

With the recent increase in demand for higher quality line pipes, there are now calls for unusually strict inspections of UOE pipe weld zones. For example, to detect flaws in the weld line, inspections had been performed with two pairs of angle probes—one pair for the internal flaws and the other for the external flaws. In recent years, however, a growing number of customers are demanding higher strict flaw detection using a larger number of probes.

2.2 Newly developed phased array probe features

The company developed a phased array probe that consists of micro piezoelectric elements arranged in the form of an arc, as shown in **Fig. 1**. The probe has two salient features:

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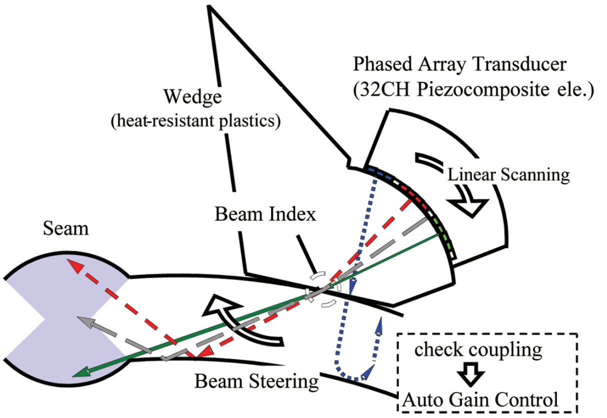

Fig. 1 Diagram of developed phased array probe

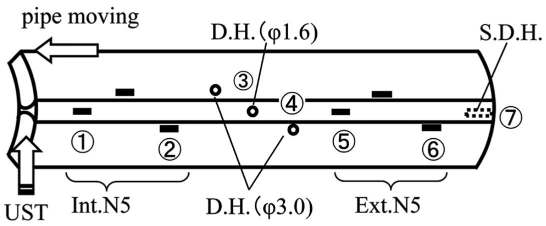

Fig. 2 EDM notches and drilled holes for in-line test

1) A small level of flaw echo intensity fluctuation caused by changes in the curvature of the surface being inspected (outer surface of the pipe).
2) A wide range of incident angle scanning (refraction angle: 0° to 80°).

In particular, inspection at the refraction angle of 0° (straight beam) allows for an acoustic coupling check. And a refraction angle between 70° and 80° is especially effective in direct inspection for flaws at the wall thickness center, which might occur in a double-V groove.

2.3 Performance evaluation results

A pipe given artificial flaws (**Fig. 2**) was inspected with the newly developed probe while the pipe was being moved at an ordinary speed. Test results are shown in **Fig. 3.** It was confirmed that all of the artificial flaws could be detected with a signal-to-noise ratio (SNR) greater than 3. In addition, it was found that an excellent SNR could be obtained by a direct inspection for flaws at the wall thickness center (**Fig. 4**). This newly developed technique was introduced to the UOE pipe manufacturing line of Kashima Works of Nippon Steel & Sumitomo Metal, and is now used also for rigorous inspections of the SAW weld zones of UOE pipe. It has already achieved great respect from many customers in Japan and other countries.

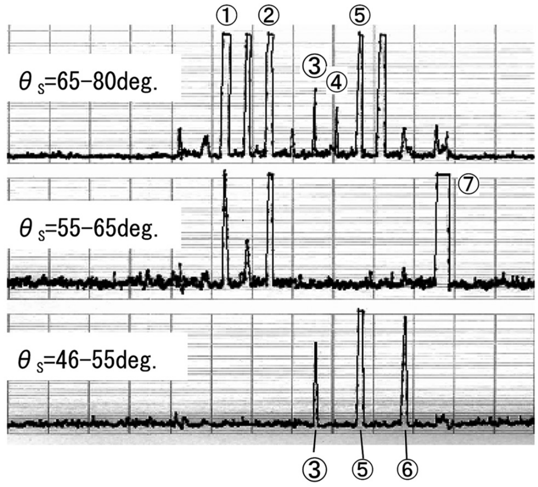

Fig. 3 Strip chart output of in-line test (32” OD × 38 mmWT)

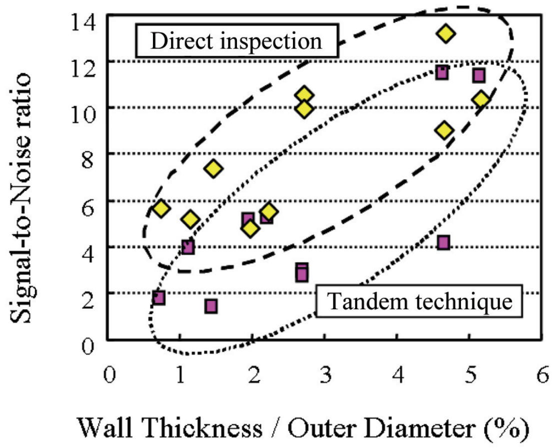

Fig. 4 Signal-to-noise ratio of imperfect penetration

3. Techniques for Quantitative Evaluations of Lamination Area [4]

3.1 Background to technical development

Criteria for flaw depths, areas and other factors applicable in pipe quality assurance are set out by relevant standards and the like. For example, tolerable areas are specified in API-5CT with regard to laminations (i.e., laminar flaws running in parallel on the inner and outer surfaces of pipe). Lamination areas are evaluated using such methods as the echo drop method. With conventional methods, however, flaw size smaller than the transducer size cannot be measured accurately.

3.2 Techniques for quantitative evaluation of flaws using synthetic aperture focusing

With the development of electronic devices and pre-/post- processing equipment in recent years, sophisticated techniques are being put into practical use to post-process flaw detection data that requires huge amounts of arithmetic operations. One of those techniques is the synthetic aperture focusing technique (SAFT), which has already been put into practical use in the field of radar.

Flaw-reflected locations, and reconstructs cross-section images of the flaw within the area being scanned are obtained by SAFT, using geometrical and sound velocity information supplied by the transmitter/receiver transducers and the material (see **Fig. 5**). By assuming a large-aperture multi-focus sensor through arithmetic operations, the technique makes it possible to obtain high-definition cross-section images of flaws, and to measure flaw dimensions accurately.

The author and collaborators applied SAFT for the identification of flaw widths, which is key to ensure the high accuracy of evaluations of lamination areas. By mechanically moving the array probe along the pipe axis, SAFT cross-section images at scanning positions can be produced continuously. A lamination area is evaluated using the sum of flaw widths along the pipe axis in the individual cross-section images. It is also possible to obtain plane images of individual flaws (**Fig. 6**).

3.3 Evaluation results

As illustrated in **Fig. 7**, the accuracy of flaw width evaluations by SAFT is much higher than by the conventional echo drop method. In addition, SAFT evaluations of flaw width do not depend on the flaw depth. Thus, it was confirmed that SAFT could be a powerful tool for quantitatively evaluating the area of laminations.

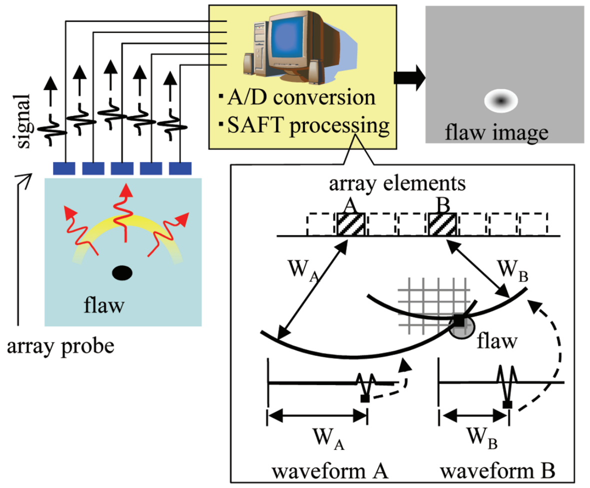

Fig. 5 SAFT processing

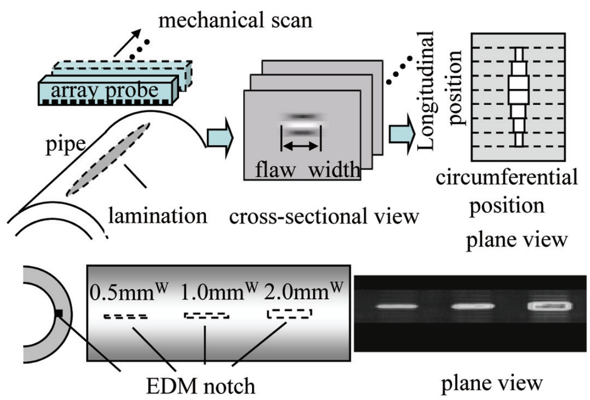

Fig. 6 Schematic diagram of lamination measurement

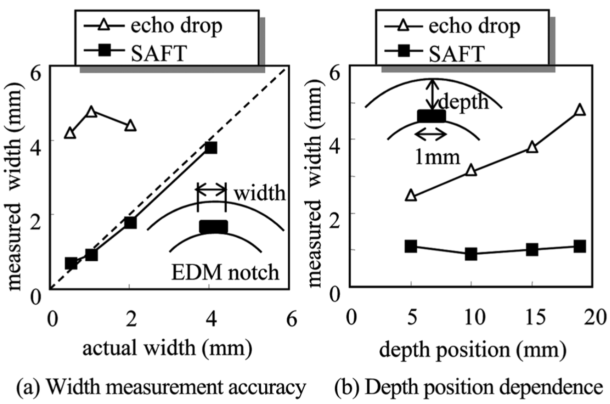

Fig. 7 Measurement accuracy comparison

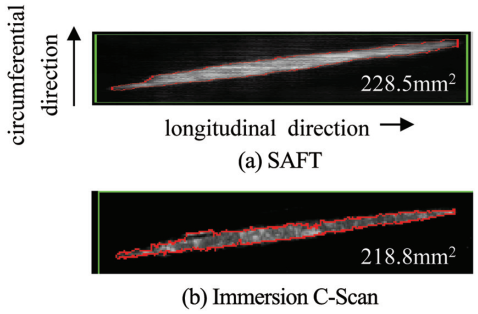

Fig. 8 Verification of area estimation of natural flaw measurement

For the purpose of comparison, after measurement of a natural flaw using SAFT, the flaw was measured by the C-scan immersion method using a point focusing probe. Both the plane images of the flaw and the results of quantitative evaluations of the flaw area agree very well (**Fig. 8**), indicating that SAFT can be applied effectively to natural flaws as well. Applying the technique to actual pipe manufacturing lines is now being studied.

4. Technology for Sealability Evaluation in Premium Connections [5)]

4.1 Background to technical development

Figure 9 shows the appearance of premium connection between oil-well pipes. Conventionally, sealability of premium connections has been evaluated by measuring the torque during the make-up (visual check on chart). However, because this is merely a macroscopic evaluation technique, local defects or damaages in the connections, etc. can hardly be detected. In addition, except for destructive examinations, no supplementary evaluation techniques used to be available. When it comes to excavating fossil fuels such as crude oil and natural gas, the quality of the contact between pipe connections is extremely important. Therefore, the company has been tackling the development of techniques that will make it possible to accurately evaluate the performance of metal seals, which significantly influence the quality of the premium connections.

4.2 Ultrasonic wave technology for evaluating contact

During make-up, high contact pressure is applied to the metal seal to maintain a high quality of contact. It is well known that ultrasonic echo intensity from the interface varies according to the con-

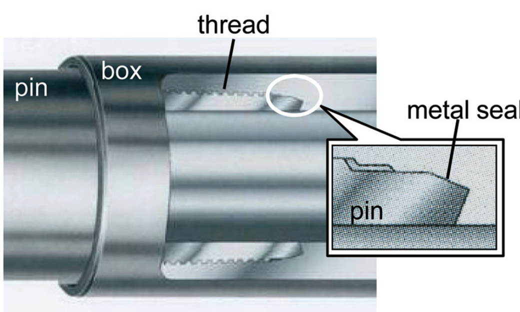

Fig. 9 Cross-sectional view of a premium connection

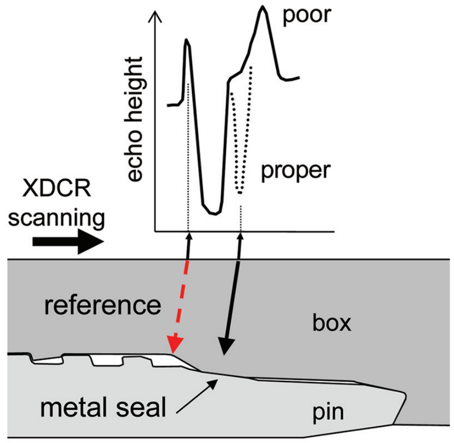

Fig. 10 Schematic diagram of the contact evaluation

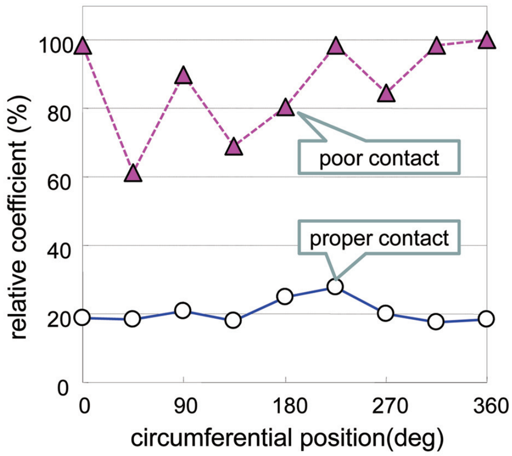

Fig. 12 Comparison results of the relative coefficient

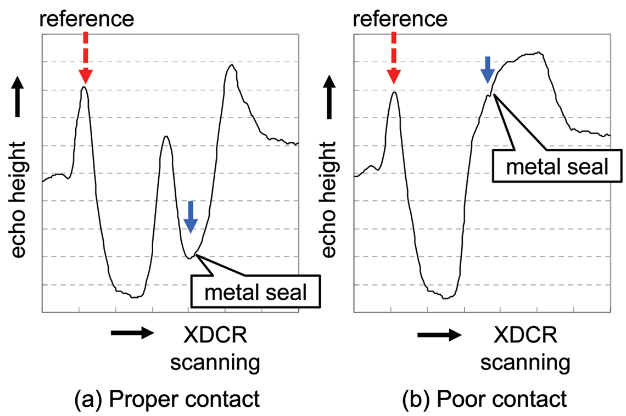

Fig. 11 Typical echo profiles along scanning direction

dition of contact at the interface. However, echo intensity at the interface also varies according to setting conditions, such as incident surface properties, incident angle, and probe position during scanning.

Figure 10 schematically shows the newly developed technique to evaluate metal seal contact. While the ultrasonic probe is being moved along the pipe length, (a), interface echo intensity from the seal surface is compared with the reference echo intensity in the neighborhood (b). **Figure 11** shows examples of interface echo profiles. By applying the relative coefficient defined by Equation (1), the author and collaborators obtained a good prospect for eliminating the error factors mentioned earlier and for implementing an accurate evaluation of contact.

Relative coefficient = Interface echo/Reference echo (1)

4.3 Laboratory evaluation results

Figure 12 shows the results of an evaluation of a connection whose contact was intentionally made defective. Compared with a sound connection, the defective connection shows a high relative coefficient over the entire circumference. This confirmed that the contact quality of premium connections can be evaluated using Equation (1). When this new technique is put into practical use, it should become possible to evaluate sealability between premium connections more accurately than ever before, and to ensure the sophisticated maintenance and management of the premium connections.

5. Techniques Utilizing Electromagnetism to Detect Omnidirectional Flaws

5.1 Background to technical development

Conventional electromagnetic testing (ET and MFLT) of steel pipe is performed to detect axial and circumferential flaws. At present, the company is developing new techniques for accurately detecting flaws extending in any direction.

5.2 Superimposed Magnetic field Rotation Technique (SMaRT)[6, 7]

AC magnetic testing is generally used to detect micro-flaws on pipe surfaces being inspected. **Figure 13** shows changes in flaw signal amplitude when the AC magnetic field direction given by the sensor (sensor directivity) and the flaw direction change. Signal amplitude tends to become the greatest when the magnetic field direction intersects at right angles with the flaw direction, whereas signal amplitude decreases as the two directions deviate from the perpendicular.

By making sensor directivity intersect with the flaw direction at right angles, and by giving a bias magnetic field in a direction parallel with the flaw direction, as shown in **Fig. 14**, it is possible to maximize the SN ratio of the flaw extending in a particular direction. This is because by giving a bias magnetic field parallel with the flaw direction, the noise caused by the uneven permeability (μ noise) of the pipe material can be minimized, with the noise suppression effect given uniformly over the areas other than the flaw.

The superimposed magnetic field rotation technique (SMaRT) shown in **Fig. 15** has been developed to allow for optimum flaw detection conditions (shown in Fig. 14) for flaws extending in any direction. A bias magnetic field is generated by passing an AC current having frequency fr and phase difference 90° around a couple of electromagnets, the magnetization directions of which intersect at right angles. In addition, air-core coils, the magnetization directions of which intersect at right angles, are arranged immediately above the detection coil. An electric current, whose high-frequency ft is 50 to 100 times that of the fr and which is amplitude-modulated by sine waves having a frequency fr and phase difference of 90°, is passed through the coils. This makes it possible to generate a rotating magnetic field while maintaining the optimum conditions shown in Fig. 14.

5.3 Laboratory test results

It was confirmed that, by using the magnetization and signal processing methods shown in Fig. 15, flaws extending in any direction were detected with the same degree of sensitivity (**Fig. 16**). It was also possible to determine the direction of any flaw with the precision of ±15 degrees. In addition, it was confirmed that, by giving a bias magnetic field, the μ noise of pipes of carbon steel (a strong magnetic material) could be reduced to 70% or less, and the SN ratio of flaw signals were improved (**Fig. 17**).

SMaRT is still being developed. The company plans to put it into practical use as early as possible in order to permit the detection of pipe flaws that extend in any direction, and to refine electromagnetic flaw detection techniques, thereby contributing to improvements in the quality of its pipe and tube products.

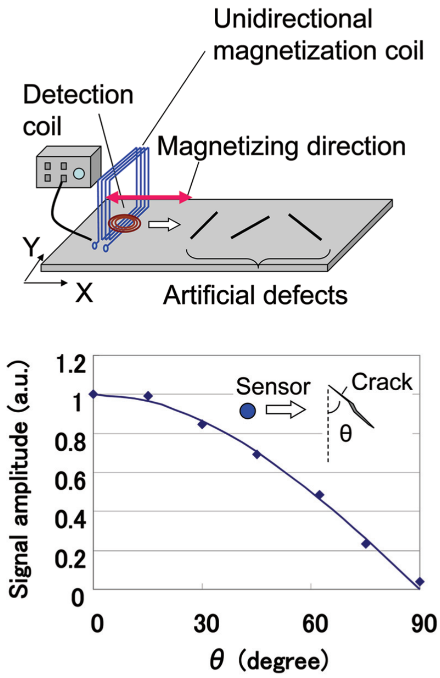

Fig. 13 Signal amplitude corresponded with the crack angles

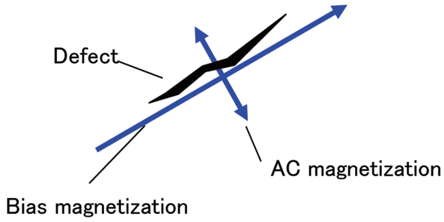

Fig. 14 Optimum AC magnetization and bias magnetization for defect detection

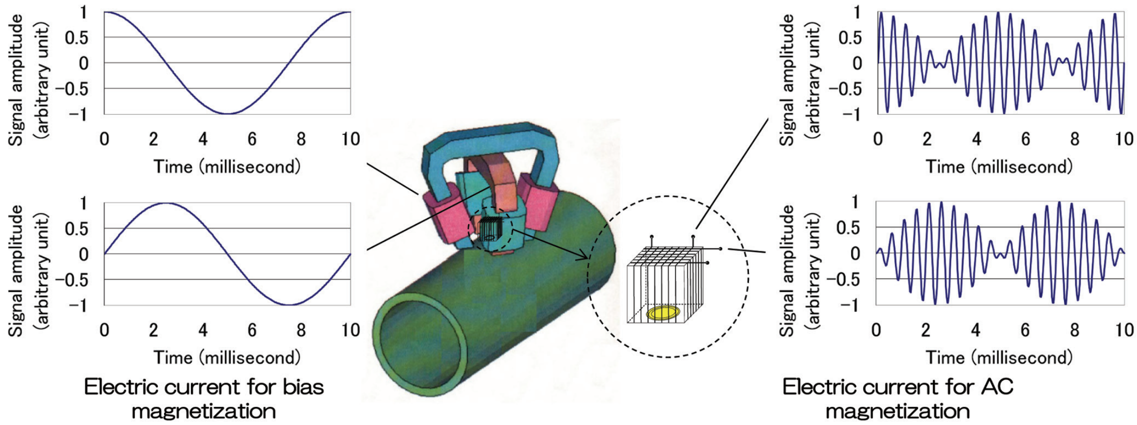

Fig. 15 Schematic design of SMaRT devices

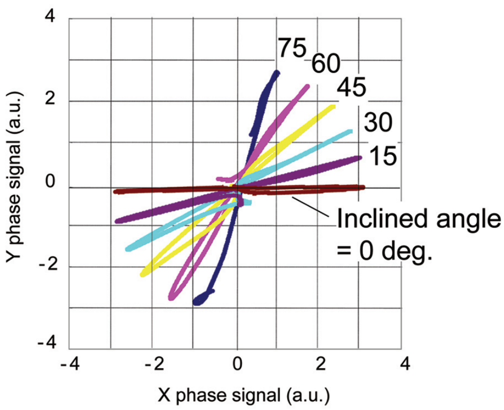

Fig. 16 Signal waveform corresponded with the crack angles on SMaRT method

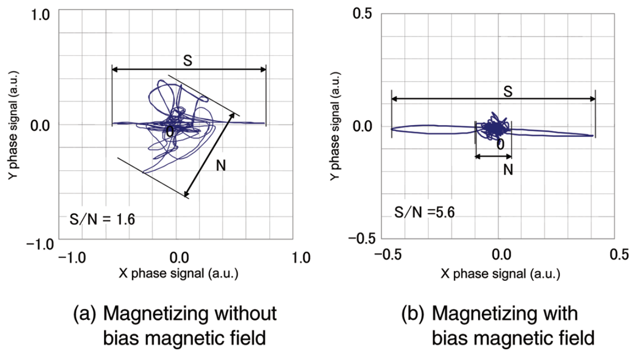

Fig. 17 Improvement of SNR on a 0.25% carbon steel pipe

6. Conclusion

In this report, the author presented several NDI techniques that Nippon Steel & Sumitomo Metal has developed on its own to lift the company above the competition. These techniques include: an ultrasonic phased array flaw detection technique for SAW weld zones; a technique to quantitatively evaluate lamination areas; a technique to evaluate the seal surface pressure of oil-well pipe premium connections; and a technique employing superimposed magnetic field rotation to detect flaws extending in any direction. The company intends to work harder than ever before to develop and put into practical use innovative NDI techniques that maintain and raise customer satisfaction, in order to promote the company's pipe and tube business and stand above the competition.

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