Application of Logarithmic Amplifier to Ultrasonic Imaging

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Abstract

This paper describes development of an ultrasonic image enhancement method using a logarithmic amplifier. At the present time, ultrasonic imaging instruments equipped with linear amplifiers are popular for use in the industrial market. Such instruments can display the target echo with a good signal to noise ratio because their dynamic range on a screen is around 26dB. On the other hand, ultrasonic imaging instruments equipped with logarithmic amplifiers can display signals with a wider dynamic range (e.g. 80dB) on a screen. The wider dynamic range of a logarithmic amplifier allows the imaging instrument to collect broader information than a liner amplifier. Suitable information for flaw analysis can be extracted from the collected data by combining the signal gain level filtering and sectional image display of the data. The effectiveness of the ultrasonic image enhancement using a logarithmic amplifier is experimentally verified through the examination of intergranular stress corrosion cracking (IGSCC) in the weld joint of austenitic stainless steel piping. With this method, the IGSCC echo and geometry echoes from the inner surface, weld root, and base metal to weld interface are successfully displayed as an extracted sectional image.

Key words: Ultrasonic Testing, Logarithmic Amplifier, IGSCC, Image Enhancement

1. Introduction

The ultrasonic examination instrument with a logarithmic amplifier can collect and display a wide range of echo height without resetting the data collecting gain. This capability, with an automated data recording system, is useful when it is required to record all the echoes including geometry echoes that may contain faint, but significant echoes from small flaws. On the other hand, the ultrasonic examination using a linear amplifier observes the echo signals around 26dB range (from 5% to 100% of the screen height) displayed on a screen. When the examination gain setting of a linear amplifier is suitably adjusted using reference reflectors, the linear amplifier can display significant flaw echoes with a good signal-to-noise ratio (SNR).

Since the first report of inter-granular stress corrosion cracking (IGSCC) in primary loop recirculation piping of boiling water reactor (BWR) in the 1970s, the nuclear power industry has made much effort to develop the methods for IGSCC detection and sizing using the ultrasonic examination. Figure 1 shows a schematic sectional view of a weld joint in stainless steel piping with IGSCC. By the manual ultrasonic examination, the examination personnel identify IGSCC and the neighboring geometry echoes by observing waveforms, dynamic signal characteristics and its location [1]. For the depth sizing of IGSCC, the crack tip diffraction technique is demonstrated to be reliable [2]. The most difficult part of IGSCC depth sizing by the tip diffraction technique is to discriminate the faint tip echo from the other noise echoes originated in the weld metal.

With these reasons, the ultrasonic examination instruments with a linear amplifier, that displays good SNR echoes on a screen, were selected for the field application and the logarithmic amplifiers were expelled from the market.

From the middle of 1980s, considerable effort has been made to improve the ultrasonic examination techniques, and new methods for flaw detection and sizing based on ultrasonic flaw images, such as phased array techniques, were developed and gradually accepted in the nuclear industry. The flaw detection and sizing by ultrasonic flaw images suggests application of the logarithmic amplifier to the industrial examination instrument again, like medical ultrasonics where logarithmic amplifiers are widely used to overcome attenuation in the human body [3].

This paper discusses the advantage of the logarithmic amplifier combined with sectional view presentation.

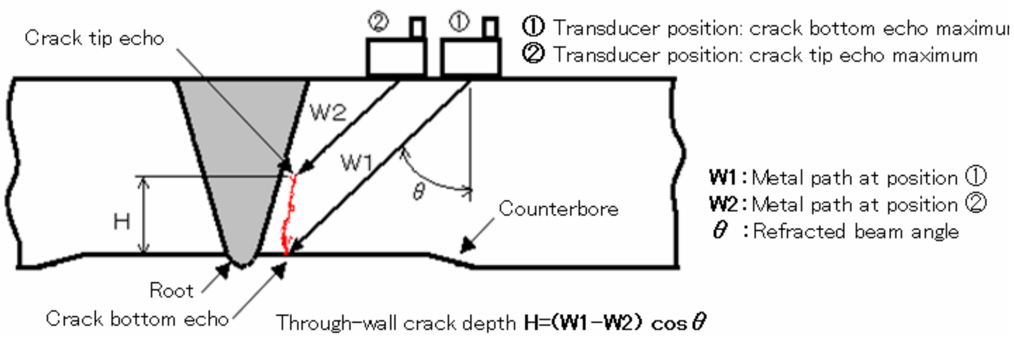


Figure 1. Sectional view of pipe wed

2. Test Equipment

2.1 Test Specimen

A stainless steel test specimen with IGSCCs was prepared for ultrasonic examination. The test specimen was sectioned from 350mm nominal diameter and 25mm nominal wall thickness stainless steel piping with laboratory induced circumferential IGSCCs along the weld line of the inside surface. Two IGSCCs were used in the experiment. One is located at the base metal and the other is located at the heat affected zone. The cross section of the test specimen with IGSCC is shown in figure 2.

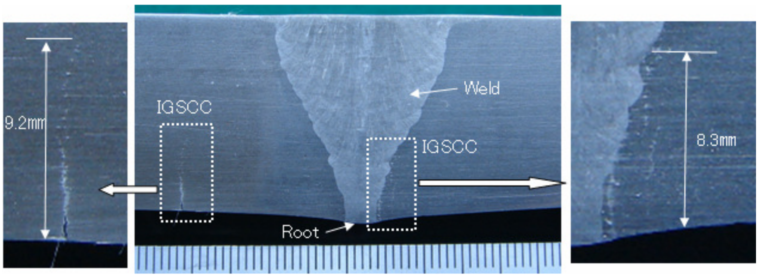


Figure 2. Cross sectional view of the test specimen

2.2 Ultrasonic Examination Equipment

To compare the imaging capabilities of a linear amplifier and a logarithmic amplifier, two types of ultrasonic examination equipment were selected. One is Ryouden Shonan Electronics Inc., UI-25, the equipment with a linear amplifier, and the other is IRT Ltd., Scan Master upi-50, the equipment with a logarithmic amplifier.

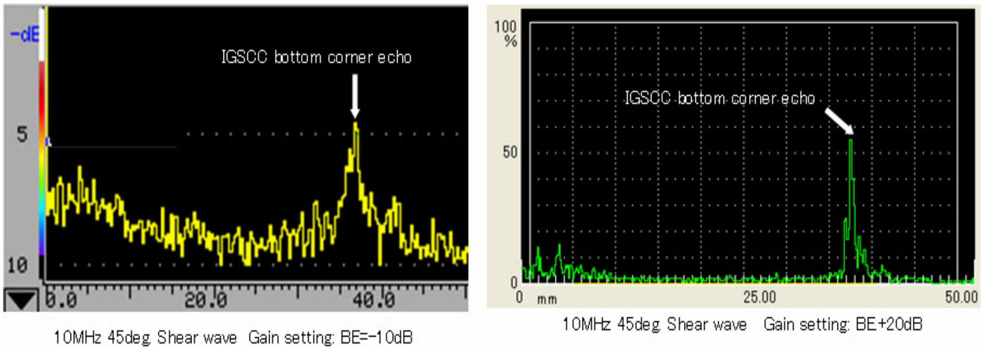
A broadband 5MHz transducer for normal examination, Panametrics V109, 12.5mm in diameter and a broadband 10MHz transducer, Panametrics V538, 12.5mm in diameter with 45 degree shear wave shoe were used for both the equipment.

3. Data Analysis by A-scope

Figure 3 and figure 4 compare waveforms (A-scope) of IGSCC bottom corner and tip echoes obtained by (a) the logarithmic amplifier and (b) the liner amplifier. The same IGSCC, located in the heat affected zone shown in figure 2, was examined by the equipment with the different amplifiers using the same transducer. It is clearly found that A-scopes of IGSCC bottom corner and tip echoes obtained by the linear amplifier show a better SNR than the logarithmic amplifier. This good SNR and quick dynamic movement of echoes on the screen make it easier to analyze the echo characteristics.

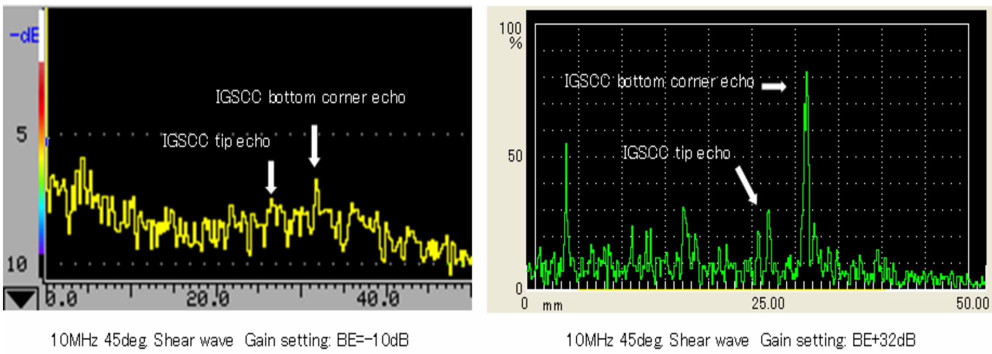
It should be noted that the linear amplifier has to use different gains for each of the crack bottom corner echo and the crack tip echo on the screen. On the other hand, the logarithmic amplifier does not need to use different gains for both the echoes.

The wider range of echo height display on the screen for the logarithmic amplifier makes it possible to collect the ultrasonic data at the high gain setting without losing amplitude information of strong echoes such as the IGSCC bottom corner echo. This wide gain to collect echo height allows recording faint echoes granted as noise and ignored. These faint echoes may have information of geometry that will help the examination personnel to understand geometry configuration for flaw identification.



(a) Logarithmic amplifier (Scan Master upi-50) (b) Linear amplifier (UI-25)

Figure 3. A-scope of IGSCC bottom corner echo



(a) Logarithmic amplifier (Scan Master upi-50) (b) Linear amplifier (UI-25)

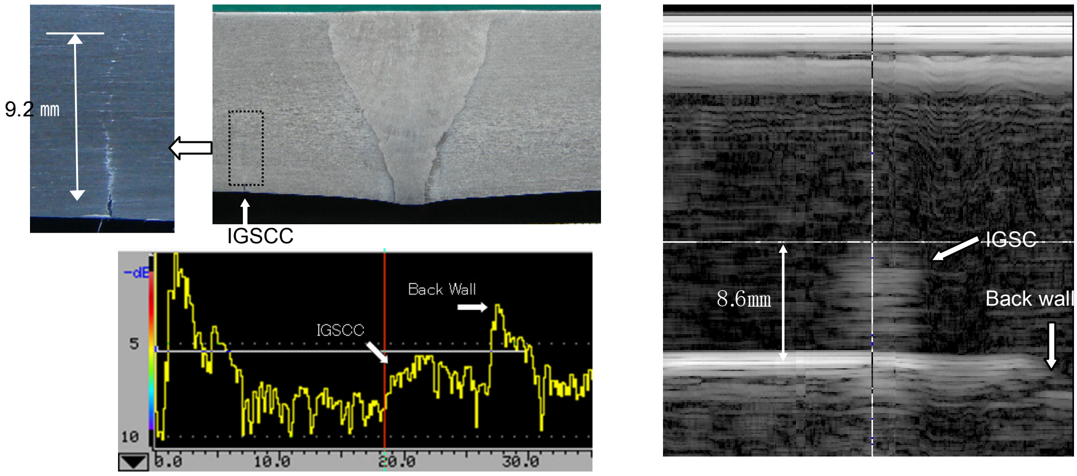
Figure 4. A-scope of IGSCC tip echo

4. Flaw Evaluation by Cross Sectional Image

4.1 Normal Examination

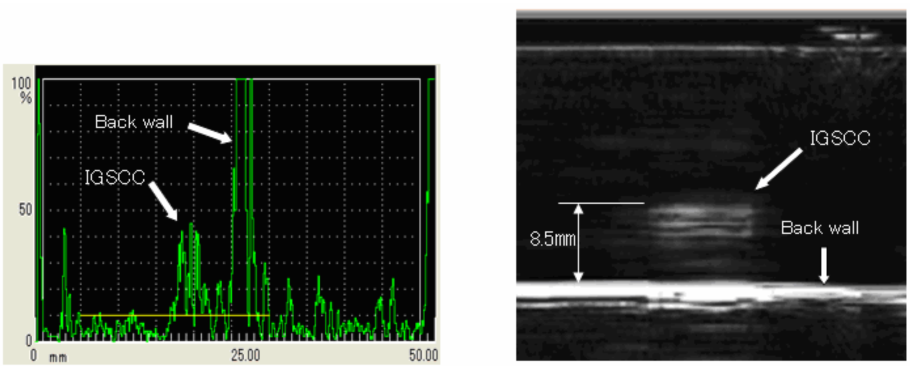
The normal examination is generally applied for detecting volumetric flaws like blowholes, slag inclusions, and the planner flaws that are extending parallel to the scanning surface. It is not considered to detect the planner flaws stretching vertical to the scanning surface by the examination. However, in some cases, when the method is applied with an extremely high gain setting, cracks extending through wall direction can be detected.

Figure 5 shows the waveform (A-scope) and cross sectional view (B-scope) of the IGSCC in a weld joint of stainless steel piping. The IGSCC located in the base metal could be detected by the normal examination using a 5MHz normal transducer with high gain. As the echo height difference between back wall echo and the crack tip echo is 42 dB, the echo from IGSCC could be easily missed by the conventional normal examination using linear amplifier. Figure 6 shows the A-scope and B-scope of IGSCC taken by a linear amplifier using the same transducer as the logarithmic amplifier. The gain setting was 80% of the back wall echo, + 32dB. Although both the data were taken by 0.2mm increment and crack tip location was same, the B-scope obtained by the logarithmic amplifier seems more precise and vivid.



(a) A-scope (b) B-scope

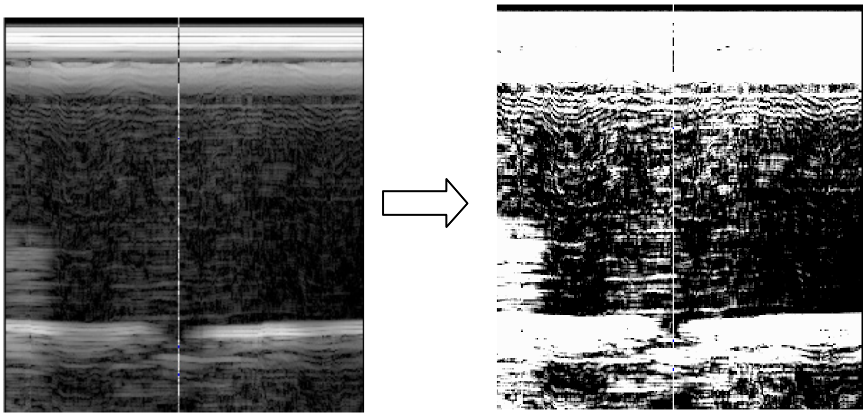
Figure 5. A-scope and B-scope of IGSCC collected by logarithmic amplifier



(a) A-scope (b) B-scope

Figure 6. A scope and B-scope of IGSCC collected by liner amplifier

Figure 7 shows the result from the normal examination over the weld region of the same specimen as the former one with the same scanning condition. The analysis gain window was modified to enhance the weld joint configuration. This function is the advantage of the logarithmic amplifier. By reducing the analysis gain window width, small echo height changes of interested reason was emphasized, although the quality of the picture is also reduced at the same time.



Analysis gain window width: 68dB   Analysis gain window width: 8.5dB

Figure 7. Modification of gain setting to enhance weld geometry

4.2 Angled Beam Examination

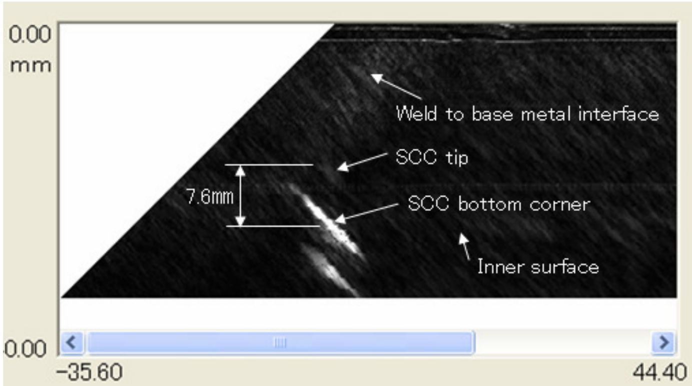
To compare the imaging capability of the linear and the logarithmic amplifier, the IGSCC shown in figure 2, initiated in the heat affected zone next to the weld fusion line was examined by UI-25 and Scan Master upi-50.

A broadband 10MHz transducer, Panametrics V538, with 45 degree shear wave shoe was used with UI-25 and Scan Master upi-50.

The scanning direction is coincident with axial direction of the specimen (perpendicular to IGSCC), and the data were collected at 0.2mm inclement.

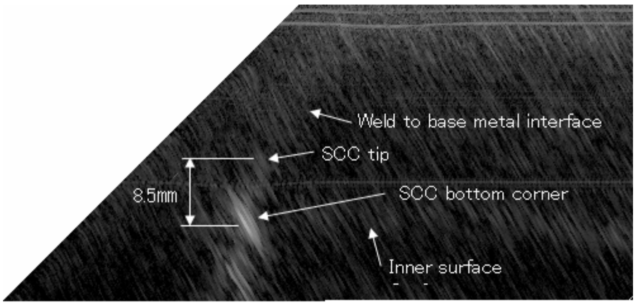
Figure 8 shows the B-scope of the test specimen taken by UI-25. In this case gain is set to the noise level, equals to 10% of the full screen height. The crack bottom corner echo and crack tip echo are seen together with the echoes from the inner surface and the interface of weld to base metal.

Figure 9 (a) shows the B-scope of the test specimen taken by Scan Master upi-50. In this case the corner echo of 25mm thick reference block was set at -10 dB and the echo height data from 0 dB to -80 dB was collected. The B-scope of Figure 9 (a) was obtained with the analysis gain window width of 60 dB. The crack bottom corner echo, crack tip echo, and the echoes from the inner surface and the interface of weld to base metal are more precisely displayed than the case using the linear amplifier. Figure 9 (b) shows the B-scope obtained by narrowing the analysis gain window width to 26dB. The B-scope of figure 9 (b) seems to show the geometrical echo and the crack tip echo with higher contrast than figure 9 (a), but it resulted in coarse-textured image. Figure 9 (b) is similar to the B-scope displayed by the linear amplifier shown in Figure 8. The similarity will be caused by the fact both the methods display the B-scan with a similar analysis gain window of 26dB which is 5% to 100% of screen height of the liner amplifier.

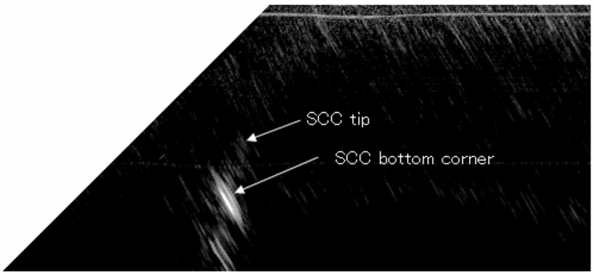


UT Instrument: UI-25
Transducer:
Panametrics V538
10MHz, 12.5mm dia.
Shoe: 45deg. Shear wave
Scan direction: Axial
Data sampling inclement: 0.2mm

Figure 8. B-scope of 45degree shear wave examination using linear amplifier



(a) Analysis gain window width: 60dB

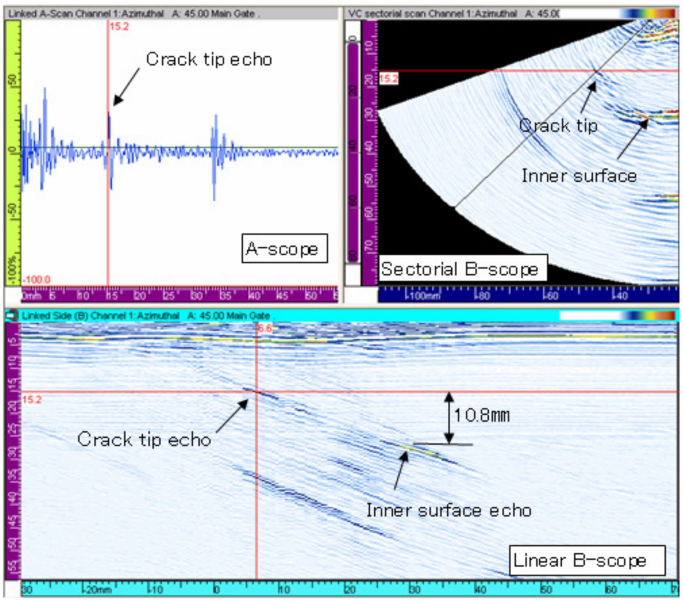


(b) Analysis gain window width: 26dB

UT Instrument: can Master upi-50
Transducer:
Panametrics V538
10MHz, 12.5mm dia.
Shoe: 45deg. Shear wave
Scan direction: Axial
Data sampling inclement: 0.2 mm

Figure 9. B-scope of 45degree shear wave examination using logarithmic amplifier

The A-Scope and the B-scope of the test sample obtained by a phased array system are shown in figure 10 as an example. Though the phased array system allows various kinds of data collection and analysis using the beam steering function, the texture of the image is similar to the B-scope obtained by the linear amplifier. Phased array systems are successful in detection and sizing of IGSCC in piping. However, the price of the phased array system is much expensive than the conventional ultrasonic equipments with B-scope display because of the versatile abilities of data collection and analysis. In addition, the phased array system requires highly trained personnel for operation.



UT Instrument:
R/D tech Tomoscan
Transducer:
Imasonic 5MHz, 64elements

Figure 10. A-, sectorial B-, and linear B-scope of test specimen

5. Conclusion

In this paper, the usefulness of the logarithmic amplifier with B-scope presentation is discussed and experimentally verified using the weld joint of austenitic stainless steel piping with IGSCC. By using the logarithmic amplifier, IGSCC and geometry echoes such as inner surface, weld root, and base metal to weld interface can be obtained more clearly than the conventional image shown by the liner amplifier.

The B-scope gives good images of signal location, pipe geometry that is useful for identifying signal sources and they are very helpful to interpolate reflectors. The usefulness of B-scope presentation is confirmed through Japanese performance demonstration for IGSCC sizing [4].

The ultrasonic examination system equipped with the logarithmic amplifier giving B-scope imaging capability assists the examination personnel by providing the precise information of surrounding geometries and offers cost effective examination with reliable examination quality.

If image based flaw detection and sizing are accepted by the inspection code or standard, ultrasonic examination equipment with the logarithmic amplifier giving B-scope capability could offer simplified and lower cost inspection.

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