Thick Part Inspection using Volume Focusing Technique and Large Aperture Phased Array

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ABSTRACT

In the nuclear maintenance field, there are cases where accessing a location where flaws must be tracked can only be done through a long UT path. In such cases, not only the lateral resolution, but also the inspection scanning time becomes an issue.

This paper presents an original solution based on using large apertures and the Volume Focusing technique, which allows significant gain in inspection time by factors between 5 and 10 times in comparison to conventional phased array techniques. Also, this method provides solutions that can preserve a very high detection ability and lateral resolution, where small flaws can be detected and separated from each other, and eventually sized.

INTRODUCTION

Ultrasonic testing has been used widely throughout the electric industry for maintaining structural integrity and preventing structural failures. Recently, the electric industry has shown a need for more reliable and accurate inspection techniques for their in-service inspection period. Reliable inspections of nuclear power plant components play a significant role in public safety. From the above demands, phased array ultrasonic testing has emerged very rapidly and is used extensively in various industries, including the power industry.

Since the catastrophic failure of a low pressure turbine disk because of SCC in the keyway at the Hinckley Point nuclear power station in the United Kingdom in 1969, the power industry has significantly increased their attention to this problem. Very thick parts like turbine discs or bore inspections require a very long range of ultrasonic time of flight. Therefore, the inspection of thick parts is very difficult and small cracks can't be found, and it isn't possible to ensure resolution between indications of beam divergence and attenuation. Recently, phased array ultrasound has already been developed and commercialized for high-value, automated inspections such as turbines and BWR core shrouds, and is an emerging technology because of its various merits.

Phased array technology is highly computerized and can be operated without mechanical scanning and offers several advantages, such as speed flexibility data storage, imaging, reproducibility, beam steering and focusing. In this study, 300mm thick stainless steel 304 material was used for a feasibility study for detecting small defects and evaluating the resolution between flaws by phased array ultrasonic testing. The Volume Focusing technique is adapted to enhance inspection speed and detection capability.

DESCRIPTION OF THE METHOD AND TOOLS USED FOR THE EXPERIMENT

Phased Array technology is based on sampling the surface of the probe in small elements that act as punctual probes transmitting and receiving basically to and from any direction, and whose signals are phased so that the UT beam has the characteristic the operator wishes. Symmetrical electronic lenses allow focusing on the desired depth, taking in account the wedge and part refracting interface. Dissymmetrical lenses allow deflecting the beam along a different axis of propagation from the natural axis of the probe.

Phased array does have limitations. If elements are too large versus the wavelength, the ability to focus or deflect will be limited because the element will have sensitivity mainly only in front of the transducer. However, the focusing and deflection ability of phased array is usually very profitable to provide images without moving the probe, with very good accuracy and clearness. Besides, scanning with a phased array can capture overlaps between images with different positions, so that the immunity of the analysis to the speckle noise improves by a significant factor.

1D arrays, which are usually called “linear phased arrays”, generally have a linear sampling of their surface in small elements. They can adjust their beam only within the electronic plan (defined by the sampling axis and the depth axis). This type of array has been intensively used for about 10 years in various applications all around the world.

For the experiment, the following items where used:

Sample test pieces

The test piece based on SUS304 has 300mm thickness. All flaws inside this TP are 1mm diameter SDH (Side Drilled Holes). See figure 1.

There are 2 zones of interest. The first zone (A) has 5 SDHs with 5, 4, 3, and 2mm distance between their centers, located at 290mm depth on a line parallel to the backwall.

The second zone (B) is on the side of the block where SDHs are located every 10mm in the depth along a line perpendicular to the surface, which can be noted as the main line of SDHs. At some particular depth (50, 100, 150, 200 and 250mm) there is another SDH 3mm from the main line.

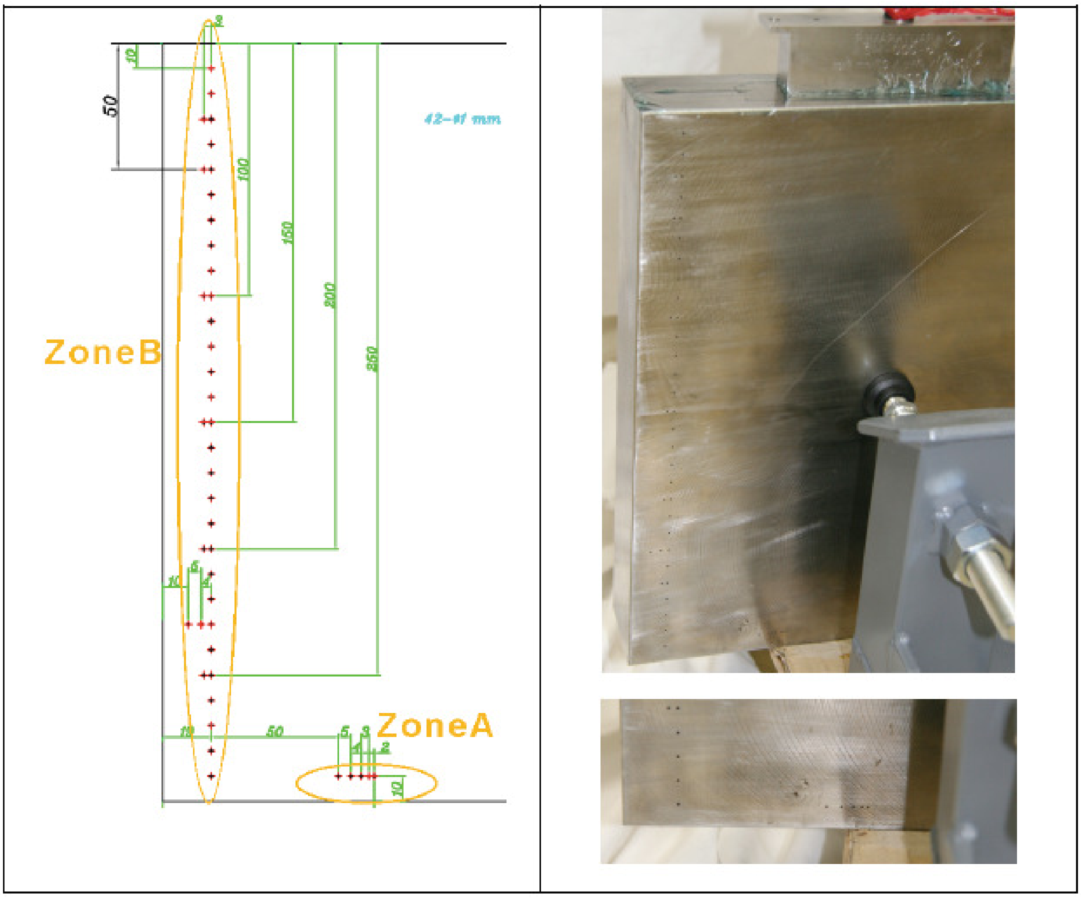


Figure 1 - Drawing and photo of the sample test piece used for experimentation

Probe

Several probes have been used for these experiments:

- 2MHz, 128 elements, 1.6mm pitch
- 4MHz, 128 elements, 0.7mm pitch
- 5MHz, 128 elements, 1.2mm pitch
- 10MHz, 128 elements, 0.7mm pitch
  All probes are piezo-composite made.

The electronic equipment: FlashFocus

The FlashFocus, from KJTD inc., shown in photo No. 2, is a massive parallel 128/128ch acquisition system, allowing both Conventional Focusing and Volume Focusing, with the ability to drive complex matrices in addition to linear phased arrays. In the case of matrix, it can combine deflection along tilt and skew angles at the same time.

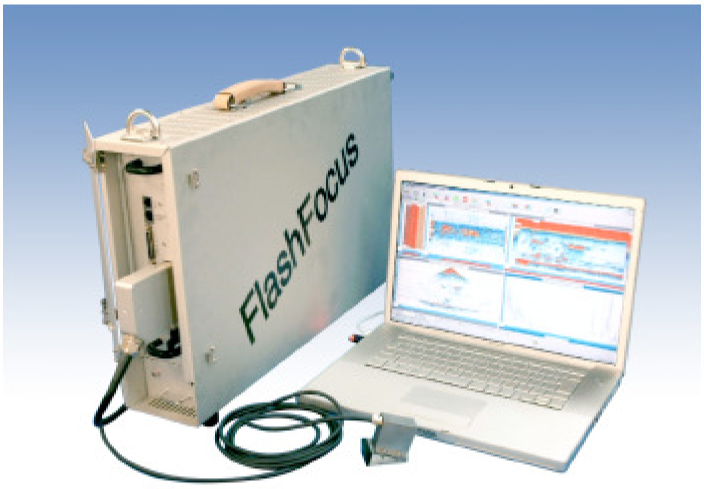


Figure 2 - FlashFocus from KJTD

EXPERIMENTATION RESULTS WITH CONVENTIONAL PHASED ARRAY TECHNIQUE

Using a 300 mm thick SUS304 block mainly presents 2 challenges: keeping a small lateral beam spot size and having a very long depth of field. At first, the experiment aims to show the advantage of working with large apertures.

Effect of the aperture

Here is the result on Zone A of the block, using a 64 then 128-element aperture and 5MHz probe.

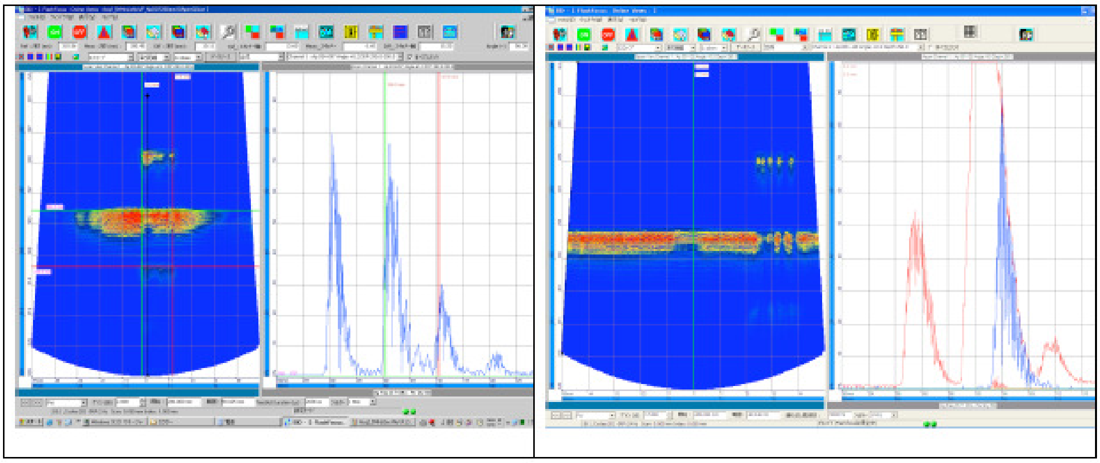


Figure 3 - Left: 64-element aperture. Right: 128-element aperture.

The difference between a 64 and 128-element aperture appears clearly in figure 3. In the case of a 128-element aperture, all 1mm SDHs have been successfully separated, confirming that the theory is correct. In addition, we can notice that this separation is done with the depth of the flaw at 290mm and their relative distance from 1 to 5 mm.

With 64 elements, the Fresnel distance is about 1.2m, but with 128 elements it becomes almost 5m. But the focusing depth is 290mm, so that the focusing factor with a 128-element aperture is 4 times stronger than with a 64-element aperture. The beam spot size is then roughly half its width using 128 elements versus 64 elements.

Comparison between frequencies

Figure 4 shows the result on zone A and the bottom of zone B of the block. Both probes have the same pitch, 0.7mm, but the first probe is 4MHz and the second probe is 10MHz. In both experiments, we use a 128-element aperture.

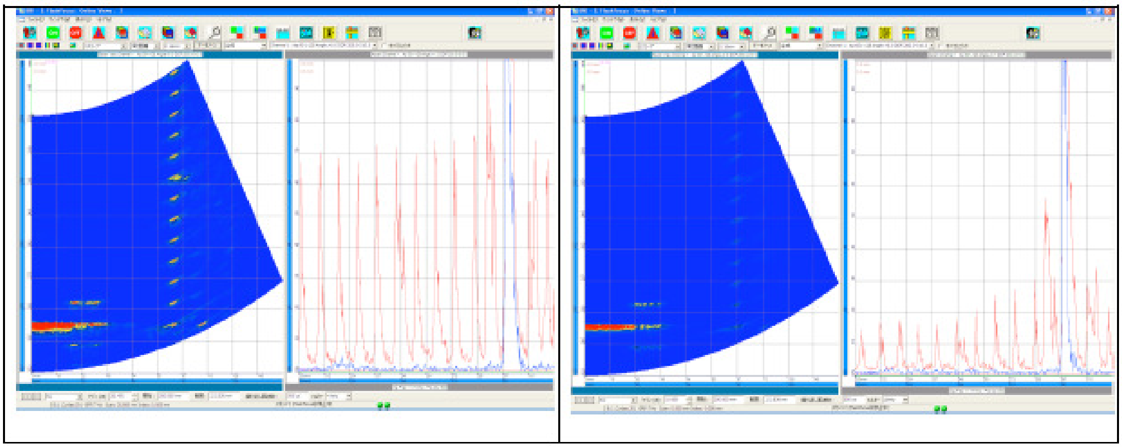


Figure 4 - 0.7mm Pitch, 4MHz in the left, 10MHz on the right.

We can notice 2 major effects:

- For the same reason as in the previous explanation (comparison between 64 and 128-element probes), the case of 4MHz does not allow us to separate very well all of the echo from the SDHs in zone A, though the resolution is excellent with 10MHz probe. Indeed, the previous explanation is valid, according to the ratio between the aperture and the wavelength. Then, as the theory tells us, 10MHz probes with the same aperture will provide a smaller beam spot size.
- On the contrary, the ability of a 4MHz probe to deflect is better. This is clearly shown in the last 150mm of zone B where SDHs are 12 dB stronger than in the case of the 10MHz probe. This is perfectly in line with the theory. The element directivity decreases as much as its size versus the increase of the wavelength.

With increasing the gain by 12 dB (see figure 5), the 1mm SDHs on the side (from zone B) appear clearly, though the 1mm SDHs of zone A are saturated, but are still mostly separated.

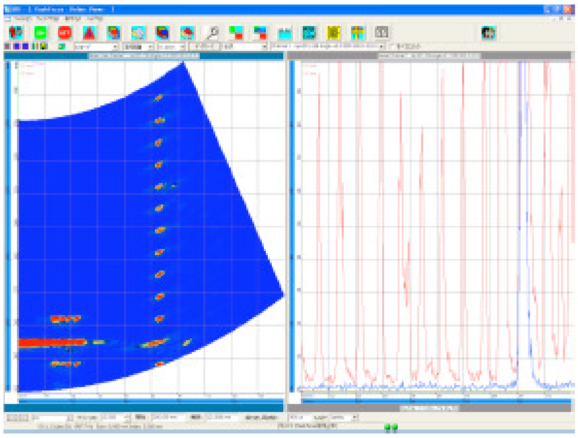


Figure 5 - 0.7mm Pitch, 10MHz with higher gain.

An experiment with a zoom on zone A is shown in figure 6. In both cases, the aperture is 128 elements. Thanks to the 1.6mm pitch of the 2MHz probe, although the wavelength is 3mm, all 1mm SDHs are separated, except for the 2 closest flaws (1mm gap). This is to mean that even with a depth of 290mm, 4, 3, and 2mm gap 1mm SDH can be clearly separated. Of course, the results are even better with 5MHz 1.2mm pitch probe.

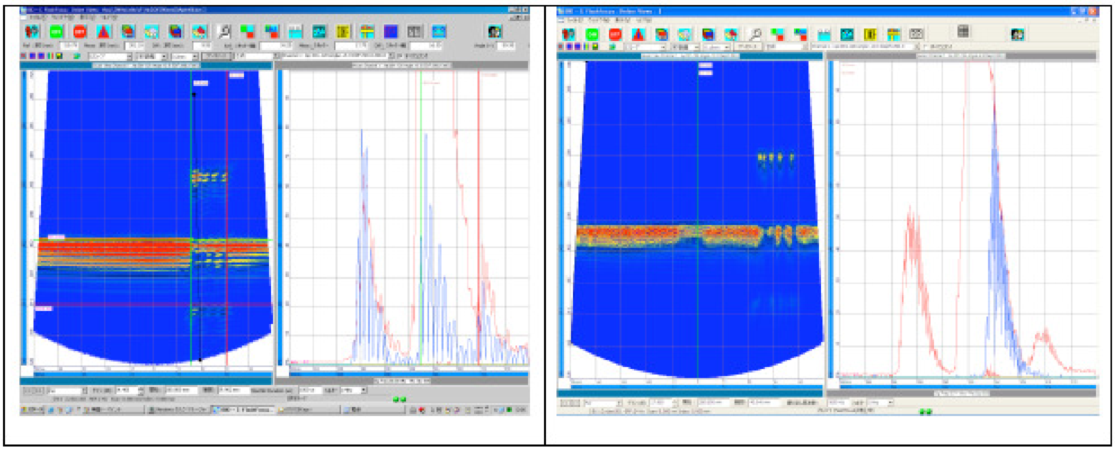


Figure 6 - 2MHz in the left, 5MHz in the right.

Comparison between pitches

The following experiment aims to compare probes with almost the same frequency, but very different pitch, on the same test piece. The aperture is always 128 elements in both cases. We actually used a 4MHz 0.7mm and a 5MHz 1.2mm pitch probe. When we normalize to the wavelength, there is a factor 2 in the aperture.

Looking at figure 7, we can do without surprise the same assessment as in the case of the "comparison between frequencies" paragraph; however, instead of the fact that the element size versus wavelength variation is done by changing the frequency, it is done by changing the element size itself.

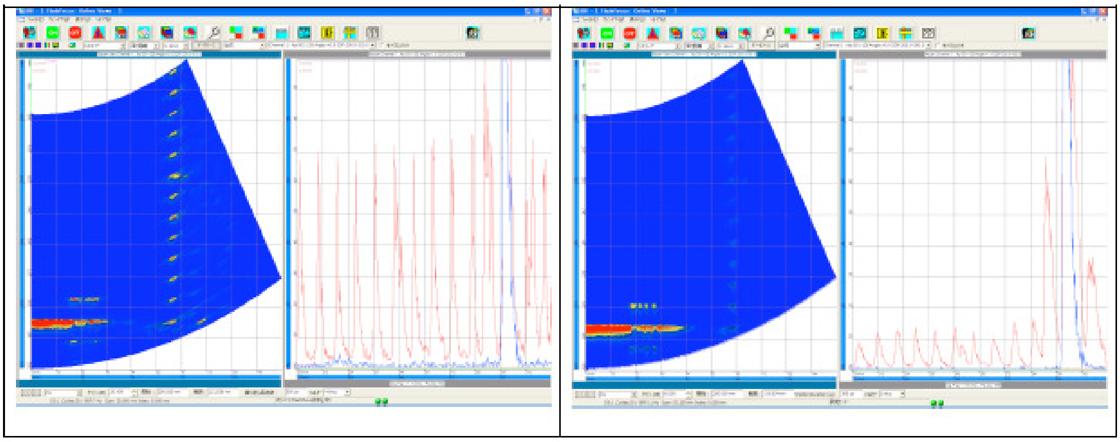


Figure 7 - 0.7mm pitch in the left, 1.2mm pitch on the right.

As a matter of fact, we can notice that the small element pitch probe does not permit a good discrimination of the flaw of zone A, but it provides a good sensitivity with any deflection angle. In the case of the biggest element pitch probe, all SDHs are separated well, but the angle range of a sector scan that has good sensitivity is limited. Figure 8 shows the result of a 1.2mm element pitch probe with 14 dB more gain, and then, all SDHs from the last 150mm of zone B appear clearly. We can even distinguish without any difficulties the 3 SDHs at the depth of 230mm, and the 2 SDHs at the depth of 250mm.

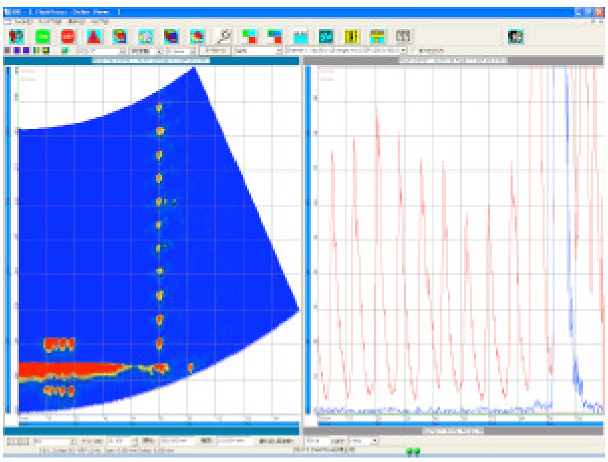


Figure 8 - 1.2mm pitch with a higher gain.

Intermediate conclusion concerning a large aperture inspection

The experiments presented previously in this document show a high ability to separate small flaws such as 1mm SDH very close to each other, at a deep location by using large aperture. However, there is a tradeoff to consider with the deflection angle that drops the sensitivity quickly when the size of the element increases versus the wavelength.

Ghost limitation

High PRF with conventional phased array inspection can cause ghost echoes (See figure 9). The only way to remove ghosts is then to reduce the PRF, but then the inspection speed reduces also. Ot the contrary, the Volume Focusing eliminates ghost echoes, but increases the inspection speed dramatically.

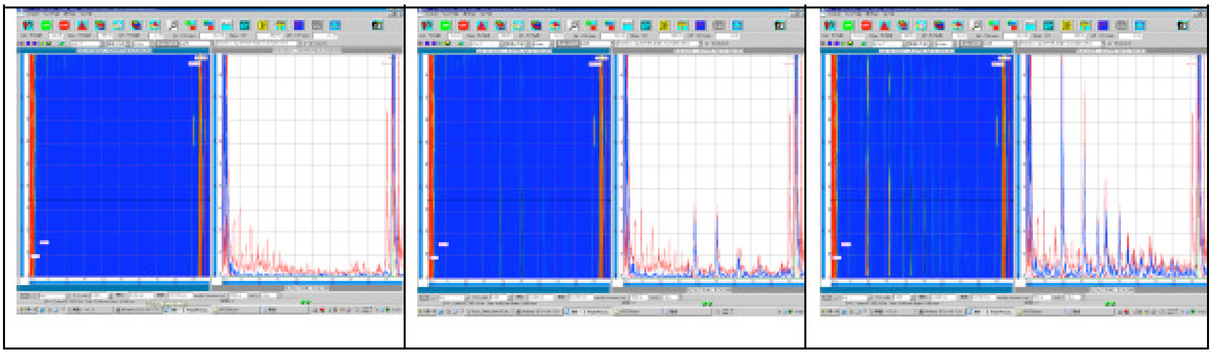


Figure 9 - Comparison of ghosts with different PRFs
(500Hz in the left, 1KHz in the middle, and 2KHz in the right)

Volume Focusing is based on the fact that the all the elements in the probe is fired at once, and the result is calculated inside the equipment with very high speed data processing.

Volume Focusing Experiments

As the beam is not focused during the transmitted pulse, the lateral resolution is of course not as good as in the case of large aperture focusing.

Figure 10 shows a non corrected view of SDHs in zone A (on the contrary from results displayed previously in the document. The depth axis is horizontal). Although it is possible to separate only 2 of them, the S/N retains its integrity.

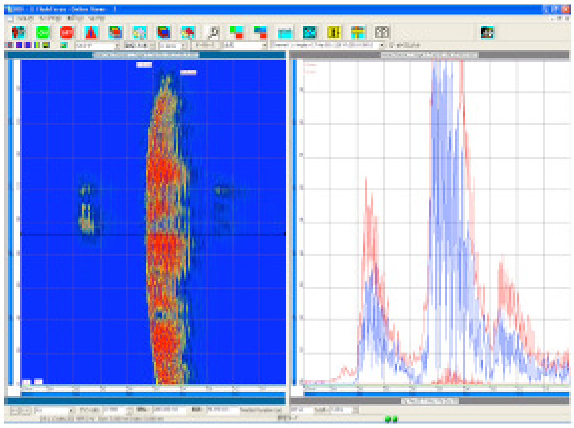


Figure 10 - Zone A in Volume Focusing mode, 5MHz probe

Figure 11 shows an acquisition done in Volume Focusing mode, with a 15 degree angled beam, using a 5MHz, 1.2mm pitch probe. This acquisition is operated along zone B and shows the depth of field very accurately which is provided by the Volume Focusing technique. The acquisition was done with 1 acquisition sequence, and 3 calculation sub-sequences. Although the acquired thickness is more than 300mm, the acquisition was done up to an SRF of more than 200Hz. This is to mean an equivalent PRF of 6KHz, which is absolutely impossible to get with conventional phased array techniques.

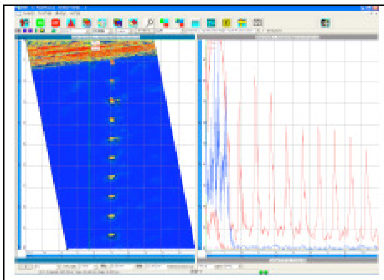
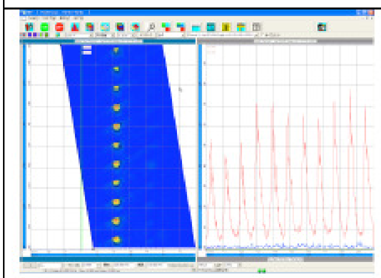
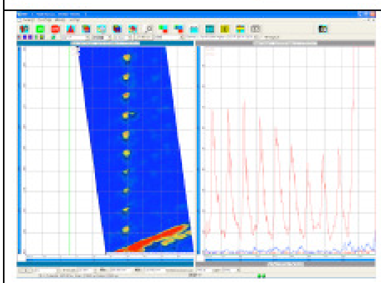
	Sub-sequence 1: Depth 0 to 100mm
	Sub-sequence 2: Depth 100 to 200mm
	Sub-sequence 3: Depth 200 to 300mm

Figure 11 - Depth of field with 5MHz probe in Volume Focusing mode.

Some of the SDHs beside the main line such as depths of 30, 50, 230mm are clearly visible. The angle probably should be varied in order to distinguish all of them.

Clearly, the S/N is excellent at any depth.

CONCLUSION

Phased Array using large apertures shows multiple advantages in the case of thick part inspections. Excellent detectability and beam spot size can be obtained. This paper proves that even 1mm SDHs can be separated from each other when there is a distance of only 2mm between their axis, at a depth of 290mm. Using a large sector scan also permits a detection of 1mm SDH along the same vertical axis, and can even separate some that are 3mm apart from each other at different depths.

The Volume Focusing technique using large apertures provides the same advantages, but of course, the lateral resolution increases so that the separation ability is a bit affected. However, the depth of field shows excellent results for SUS304 with 300mm thickness, and excellent detectability also. In addition, the speed increase of the Volume Focusing technique is incredibly high, as it is underlined in the application “BWRVIP Core Shroud Mockup Ultrasonic Investigation” realized with EPRI.

REFERENCES

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2. Junichiro Nishida, MITSUBISHI HEAVY INDUSTRIES LTD., Yoichi Iwahashi, Takanori Yamashita, E-TECHNO, Dominique Braconnier, KJTD, *Inspection of thick part with Phased Array Volume Focusing technique,* EPRI USA May 2006.
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