A THREE-DIMENSIONAL PHASED ARRAY ULTRASONIC TESTING TECHNIQUE

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Introduction

Phased array techniques are becoming widespread in various industrial fields as well as the medical field, because they have major advantages over conventional ultrasonic techniques: *i.e.*, beam can be swept and focused without moving probes[1][2][3]. In various areas of industry, they are becoming core technologies to inspect component parts consisting of metal, FRP (fiber reinforced plastic), or other composite materials. Uses of the phased array techniques can be expected to expand to even wider ranges of markets and applications.

In phased arrays, ultrasonic beams are transmitted from an array probe, and swept two-dimensionally along an array of elements. The most commonly used scanning patterns are probably the “linear scan” and the “sectorial scan”. These electrically controlled scannings have brought about a significant increase in inspection speed. In this paper, we call these conventional phased arrays two-dimensional (2D) phased arrays to distinguish them from the three-dimensional (3D) phased arrays which we propose in this report.

Three-dimensional phased arrays

The 3D phased arrays[4] have the promise of improving scanning speed and efficiency of evaluation of scanned data. A schematic image of a 3D phased array scanning is shown in Figure 1. With a matrix array probe, target objects can be scanned volumetrically at one time or at least in less time than the 2D phased arrays. The typical scanning patterns of the 3D phased arrays are “rotational scan” and “fan scan” as illustrated in Figure 2. The

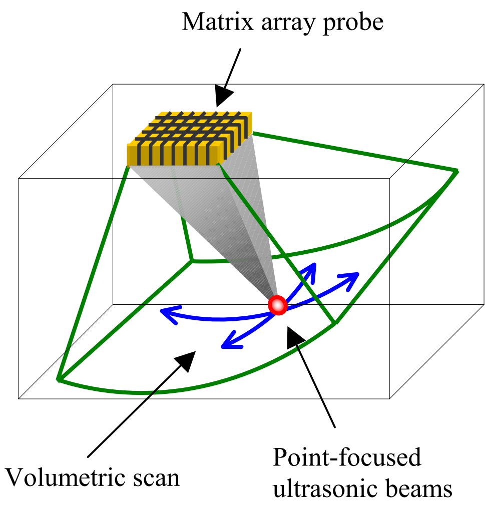


Figure 1. Schematic image of 3D phased arrays.

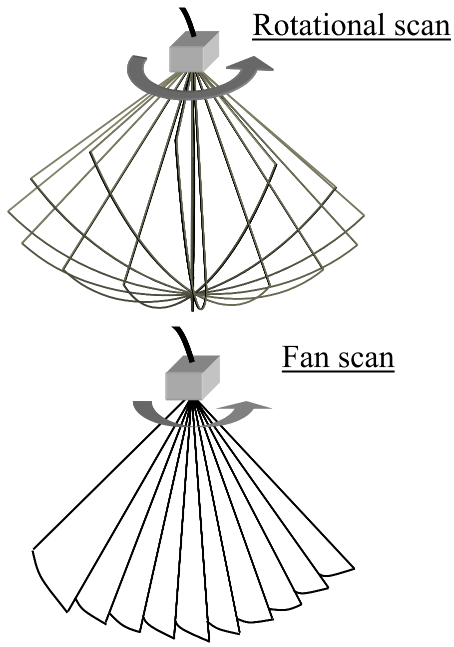


Figure 2. Typical scanning patterns of the 3D phased arrays.

rotational scan is composed of some sectors revolved around the axial direction as illustrated in Figure 2 above. In case of the fan scan, sectors are arranged like a fanning motion with respect to a fixed incident point as illustrated in Figure 2 below. Besides these, any 3D scanning is possible as long as the corresponding focal law can be calculated.
After the 3D scanning, the scanned data can be efficiently evaluated in a 3D space, while operators have to check sector images one by one for the conventional 2D phased arrays. Thus, the total inspection time of the 3D phased arrays is much shorter than that of the 2D phased arrays. In addition, detectability of the 3D phased arrays becomes higher because ultrasonic beams created by the matrix array probe are narrower and more focused than those created by an equivalent element linear array probe. The advantages of the 3D phased arrays compared to the 2D phased arrays are summarized below.

- ❑ Inspection speed is increased by 3D scanning.
- ❑ Spatial resolution is higher than that of the 2D phased arrays due to point-focused ultrasonic beams created by the matrix array probe.
- ❑ 3D rendered imaging provides easy-to-understand inspection results and facilitates evaluations.

The 3D phased arrays mainly use the following two techniques: 3D scanning of objects and 3D visualization of the scanned data. With recent developments in hardware technologies for array controllers and array probes, the 3D scanning itself is becoming easy, although highly specific hardware and sophisticated software to accommodate focal laws for 3D scannings are required.

Scanning system

A 3D phased array system called 3D Focus-UT has recently been developed. The system is comprised of three main parts including pulser/receiver equipment, a matrix array probe, and PC with software for data acquisition and 3D visualization. The data acquisition can be performed in conjunction with scanners as well as freehand. The pulser/receiver equipment was made by Hitachi Engineering and Services Co., Ltd. The hardware specifications and a photo is shown in Table 1 and Figure 3, respectively.
In 3D scanning, a larger amount of data have to be handled in a short period of time than in the 2D phased arrays. Thus, the capability for fast data processing is required of the equipment. The 3D Focus-UT mounts multi-channel high-speed circuit boards, which have the ability to transmit or receive ultrasound signals from each of the 256 elements in a matrix array probe simultaneously. Additionally, real time 3D data acquisitions are possible as well as conventional 2D scanning.

Table 1 Specifications of hardware equipment

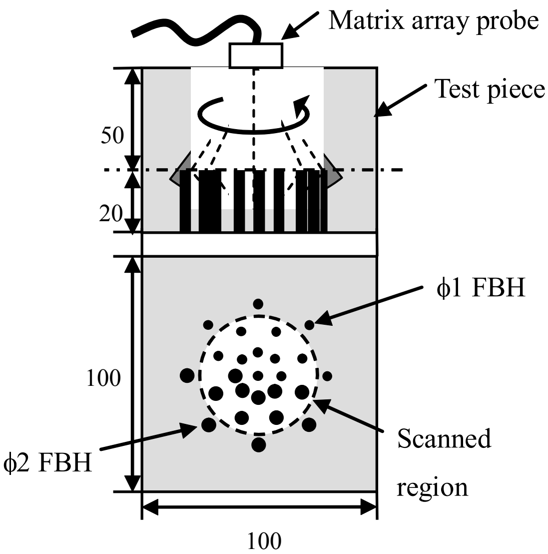
Simultaneously Active Channels	256 / 256 (Transmit / Receive)
Max. Pulser Voltage	125 V
Receiver	
Band Width	from 0.5 to 20 MHz
Gain	90 dB per channel
Sampling Frequency	200 MHz

Figure 3.
Photo of 3D Focus-UT.

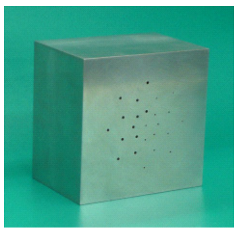
Application

FBHs in a stainless steel test piece

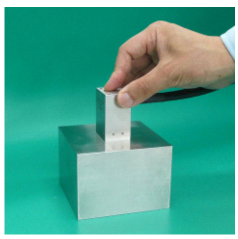
FBHs (flat bottom holes) in a stainless steel test piece have been scanned by the 3D Focus-UT, shown in Figure 4. The test piece has a depth of 70 mm and is given 25 FBHs of 20 mm height. The FBH diameters are 1 or 2 mm. The probe used in this case is designed for longitudinal wave to operate at 2 MHz. The probe has 256 (16×16) elements. The focal law is designed to focus the sound field at 50 mm deep in the test piece. The pattern of the 3D scanning in this case is the rotational scan, which is composed of 24 sectors revolved around the center line of the sectors in increments of 7.5 deg as illustrated in Figure 4 (a). The insonification angle in each sector is swept from -30 to 30 deg in increments of 1.5 deg. Thus, the total number of the focal points is 984. The 3D scanning is performed electrically in real time as the probe is kept at one position without moving. One of the revolved sectors and the reconstructed 3D image from the sectors are shown in Figures 5 (a) and (b), respectively. In the 3D image, the CAD images of the FBHs and inside wall are superimposed on the echoes. This technique reduces the evaluation time of 3D inspection results, because specific features on 3D-CAD data can be easily related to 3D echoes reflected from them. The CAD data can be provided as polygons in STL (stereolithography or standard triangulated language) format which is compatible with most commercial CAD software. The huge disk-like echo is the bottom echo, and the large and small cloud-like echoes above it correspond to FBHs of diameters of 2 and 1 mm, respectively. Each FBH echo is positioned at a correspondent chimney-like CAD image of FBH. Thus, the correspondence of echoes and their reflection sources can be easily determined. If echoes are shown at positions where no reflection sources are supposed to exist, the echoes indicate the existence of some defects. The evaluation can be performed in the following two steps. First, the relative position of echoes in space is comprehended in a 3D image; this is often done with the help of superimposed CAD



(a)



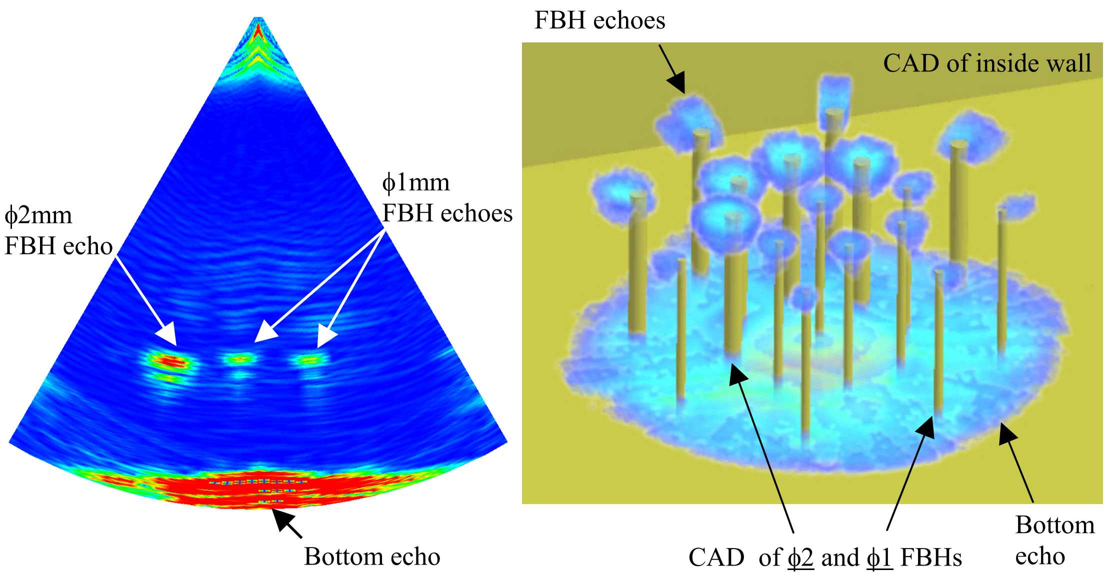
(b)



(c)

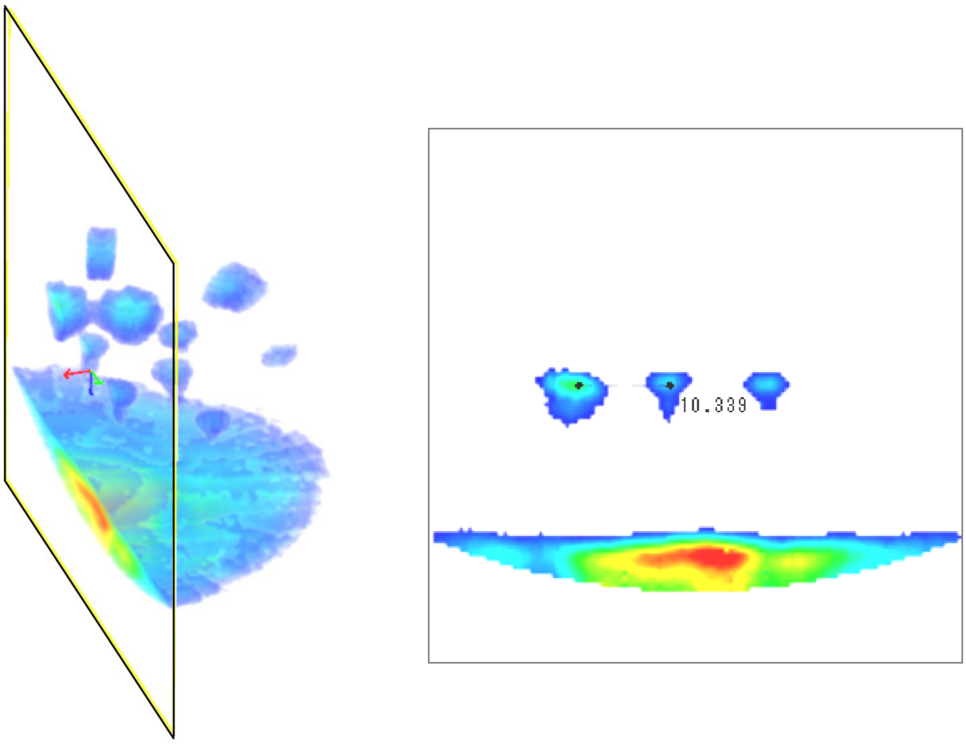
Figure 4. A stainless steel test piece with FBHs. (a) Dimensions of the test piece and the rotational sector scan described in the text. The scanned region is inside the broken line circle. (b) A photo of the bottom side of the test piece. (c) A photo of the test piece being scanned with a matrix array probe.

images. Next, defect sizing and detailed analysis are performed on some cross sections of the 3D image as designated by users.



(a) (b)

Figure 5. Ultrasonic images of the FBH test piece: (a) a conventional sectorial scan image and (b) 3D scan image with CAD of the test piece.



(a) (b)

Figure 6. (a) Cross section of the 3D image. (b) The same cross section displayed in another window with a distance measurement result.

In order to evaluate the 3D images in detail, the software has graphical functions to rotate, zoom, pan, and slice the 3D image. An example cross section is shown in Figure 6. The distance measurement can be performed in the cross section by just clicking two points on the image using the mouse as shown in Figure 6 (b).

Conclusions

This report presented the 3D phased array technique which has significant advantages over 2D phased arrays especially in terms of inspection speed brought about by 3D scanning and 3D visualization and evaluation. Although the basic techniques of 3D phased arrays have been developed, there are still some challenges to meet to ensure widespread use for inspections in the field: portability of hardware, image processing speed, image quality, and user-friendly evaluation functions. The system is planed to be used in nuclear power plants in Japan for maintenance in the near future. We do not think that all steps in the evaluating processes should be performed by 3D phased arrays. It is important to select 2D or 3D methods properly for individual cases, because both methods have their own advantages for specific uses.

References

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