The Reconstructive Method for The Enhancement of Depth Resolution for Acoustic Image using the Spatial Frequency Response in NPPs' Material

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ABSTRACT

In this paper, we have studied the images which have been reconstructed by using combination of images acquired by the variation of operating frequency. When inner images have been reconstructed, they have been superposed by the surface state effect. In this case, the images of the phase object can be enhanced by the contrast of inner images. In this experiment, there are two kinds of specimens, one is a reference block having 1/4T, 1/2T, 3/4T side drilled holes as main run piping material of the steam generator in NPP(Neuclear Power Plant)s and the another is a part of a hemisphere type specimen having about 1-2㎜ distance gap. It has been shown that the two results of defect shapes have better than before in this processing and phase contrast grow about twice. And we have constructed the acoustic microscope by using a quadrature detector that enables to acquire the amplitude and phase of the reflected signal simultaneously. Further more we have studied the reconstruction method of the amplitude and phase images and the enhancement method of the defect images contrast.

NPP 매질내에서 공간주파수 응답을 이용한 초음파 영상의 깊이 분해능 개선을 위한 복원 방법

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요 약

본 연구에서는 초음파현미경의 동작주파수 변화에 따라서 획득한 영상의 조합을 통하여 얻어진 영상들에 관하여 연구하였다. 고체내부의 영상을 복원하는 경우, 얻어진 영상들은 표면이 상태가 중첩되어 나타나게 된다. 이 경우 위상체 영상들은 내부 영상의 콘트라스트 개선에 활용되어 질 수 있다. 실험에서는 두가지 종류의 시편이 사용되었다. 첫째는 NPP내부에서 스팀 발생장치의 주 파이프의 매질측면에 1/4T, 1/2T, 3/4T의 홀 결함을 갖는 기준 블록이고 다른 시편은 직경이 1-2mm인 반구형태의 시편이다.실험결과 기본의 영상처리 방법에 비하여 결함 형태에 대한 콘트라스트가 2배 정도의 향상을 보였다. 실험을 위하여 반사신호의 진폭과 위상을 동시에 획득할 수 있는 쿼드러춰 검출기를 사용한 초음파현미경 시스템을 구성하였다. 앞으로는 진폭과 위상영상의 재구성 방법과 결함영상의 콘트라스트를 개선시키기 위한 방법이 계속 연구되어져야 겠다.

Key words: 영상복원, 콘트라스트개선, 쿼드러춰 검출기, 초음파현미경 시스템

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SYMBOL

C1, C2, C3 ; Velocity of the lens, liquid, inspection material
A ; Diameter of the aperture
D ; Distance from the transducer to the test material
F ; Focusing distance of the acoustic lens
h ; PSF of the SAM
θ_i ; Incidence angle
θ_r ; Reflect angle
R ; Curvature radius
PSF ; Point spread function
Kn ; n number of the transducer
Ws ; Minimum bandwidth
Wm ; Maximum bandwidth
V(z) ; Output voltage of SAM

1. Introduction

Because the ultrasonic wave is a close relationship for the mechanical property of sample(density, viscous rate, the coefficient of elasticity), acoustic microscope has been used to detect the defects on surface or inner solid. The conventional acoustic microscioe has been used envelope detector to detect the amplitude of reflected signal, but the changes in amplitude is not sensitve enough for specimen with micro structure that in phase. It has been primarily used in non-destructive(NDE) of machined parts, composite materials, etc for the presence of cracks. Most SAMs measure amplitude only using envelope detector. By measuring phase as well, we can carry out quantitative NDE and image processing that can be done with amplitude or phase alone. In 1984, it has been constructed acoustic microscope to detect relative phase of SAW(Surface Acoustic Wave) to logitude wave with large aperture acoustic lens by Liang.[12] But that system has been able to detect the cracks which are under 1 wavelengh depth. in the sample.

In this paper, we have built a scanning acoustic microscope(SAM) operating in the 3 to 5㎒ range using quadrature detector that measures both amplitude and phase. We have demonstrated image processing applications that use amplitude and phase measurement; such as transducer characterization, material reflectance function measurements using V(z) inversion. We have been studied the reconstructive method for the enhancement of depth resolution for acoustic image using variation of the frequency. In this experiment, we have constructed the SAM system by 5㎒ central frequency and 35% fractional bandwidth. There are two kinds of specimens, one sample is a reference block to have 1/4T, 1/2T, 3/4T side drilled hole as main run piping material of the steam generator and another one is a part hemisphere to have about 1-2㎜ distance gap. The side drill holed sample 2, reference block which is made in stainless steel as a material of the nuclear power plants. The enhanced depth resolution has been applied to measure the profile of trench. We operated in the 4.4㎒ to 5.6㎒ range that measures both amplitude and phase reliably and accurately. In this experimental result, we have been found that image using variation of the operating frequency was better than image using single operating frequency. Even better depth resolution can be obtained by numerically combining images taken at several different frequencies. The resulting images have a greater range of coverage in the spatial frequency domain in the depth direction than does a single frequency image. Increased depth resolution can be obtained by taking three-dimensional images at more that one frequency and numerically combining the results.

In order to enhance depth resolution, we have reconstructed the image using the image acquired with multi operating frequency for acoustic microscope. This method has been able to increase the variation of the image intensity of amplitude image by comparison that with single frequency. And this method has been complement that the phase image has the limitation whose the operating range has been . It is also possible to improve the depth resolution of a low aperture microscope. So it is as good as with a wide aperture system. This could be very useful for imaging objects with high relief, where the use of a wide aperture lens could degrade the images of deep features. And the results of the enhance images could be used the optimum parameters from our first stage experiment of standard reference specimens [1], as a second, we can apply the material of the nuclear power plants.

2. ENHANCEMENT OF DEPTH RESOLUTION FOR ACOUSTIC IMAGE USING THE SPATIAL FREQUENCY RESPONSE

Generally, the resolution of the SAM has been decided by the performance of the ultrasonic transducer[1~4]. Therefore, the quality of image to be acquired from the SAM system was determined according to the operational frequency and the acoustic lens. Conventional SAM was operated at center frequency of an acoustic transducers fractional bandwidth to reconstruct acoustic image. Figure 1 shows a geometrical schematic of acoustic lens for the defocusing scan mode that is used to inspect insight of sample.

Not only does a SAM have good lateral resolution, it also good depth resolution. The fact that the V(z)curve falls off so rapidly as the transducer is defocused is evidence of good depth resolution. When the transducer is on focus, the wave fronts of the acoustic waves reflected from the surface coincide with the transducer face and give a large return signal. As the transducer is defocused the wavefronts are not aligned with the transducer face and cancellation occurs. And the percentage increase in depth resolution actually is much better than for the transverse resolution. To look at smaller objects, the wavelength must be reduced by using a high frequency acoustic microscope or a confocal scanning optical micro-scope(CSOM) that measures amplitude and phase[5,6].

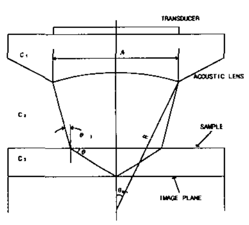

Fig 1. Geometrical structure of acoustic lens for defocusing mode

3. THEORY

The resolution enhancement technique is most easily visualized in the spatial frequency domain. The maximum depth resolution that can be obtained is determined by the range of special frequencies that are covered by the microscope spatial frequency response (SFR). Recall that this range is called the base of support of the SFR. The outside spectrum range of object is not measured by the microscope. This range of spatial frequencies limits the resolution that can be obtained. The top edge of the SFR corresponds to the circle separating propagating and evanescent waves [6]. The bottom edge is determined by the f-number of the transducer. If the transducer is operated at a different frequency, the base of support is shifted in the $k_z$direction. Figure 2 shows the based of support for a microscope

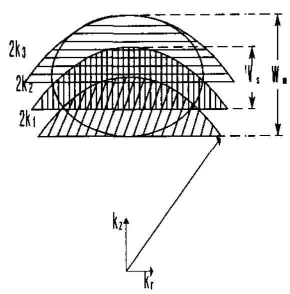

Fig. 2. Bases of support for the microscope's spatial frequency response at 3 different frequencies superimposed

operating at two different frequencies superimposed. The images formed by operating the microscope at different frequencies can be combined to cover a broader range of spatial frequencies along the k_z dimension. When the acoustic transducer is shaped like a cylinder and symmetric, the SAM has a region, where figure 2 shows, because transducer is used both transmitter and receiver, where the spatial frequency is equation (1).

$$|k| = \sqrt{k_x^2 + k_y^2 + k_z^2} \tag{1}$$

Transverse frequency is defined like equation (2) in direction of transverse.

$$|k_r| = \sqrt{k_x + k_y} \tag{2}$$

If the resolution of transverse is defined, the depth resolution is decided as equation (3).

$$k_z = \sqrt{k^2 - k_r^2} \tag{3}$$

The method that was used for enhancing image can be got by combining images taken operating at different frequencies within bandwidth of acoustic transducer in SAM. Image spectrum that was obtained at any single operating frequency is equation (4).

$$G(w_i;\vec{k}) = H(w_i;\vec{k})F(\vec{k}) \tag{4}$$

For each spatial frequency k, equation (4) can be viewed as a matrix equation relating the object to the measured images and spatial frequency of objects like equation (5) where equation (5) is indexed by w_i.

$$\begin{bmatrix} G(w_1;\vec{k}) \\ . \\ G(w_N;\vec{k}) \end{bmatrix} = \begin{bmatrix} H(w_1;\vec{k}) \\ . \\ H(w_N;\vec{k}) \end{bmatrix} \left[F(\vec{k})\right] \tag{5}$$

In matrix notation, equation (5) is equation (6).

$$G_{\vec{k}} = H_{\vec{k}} F \tag{6}$$

Equation (6) can be solved using the method of least square to get equation (7). F is the result, which is a best approximation to the objects as computed from the method combining images taken at multi-frequencies.

$$F = \frac{H_{\vec{k}}^{u} G_{\vec{k}}}{H_{\vec{k}}^{u} H_{\vec{k}}} \tag{7}$$

Where $H\frac{a}{b}$ means inverse matrix of original transducer spatial frequency response matrix.

4. EXPERIMENTS AND CONSIDERATIONS

In nuclear power plants, it is important that we can detect a defect like a presence of cracks, voids, and delaminations in the NPPs materials. So, we prepare to two kinds of materials as the same material. And we have built a scanning acoustic microscope operating in the 0.5㎒~4㎒ range. Figure 3 shows a block diagram of the scanning acoustic microscope. As a result, we can get good signal noise ratio for the 2 types samples. And lower frequency was used to obtain the depths penetration.

4.1 SAMPLE PREPARATION

One sample, reference block to have 1/4T, 1/2T, 3/4T, has side drilled defects with 4.6㎜ inner diameter and T = 67.5㎛ thickness and another one is a part hemisphere type specimen to have about 1-2㎜ distance gap. In the result of line scanning for the sample 2 with each side-drilled defects, it has been shown that the variation rate of amplitude image intensity and the variation rate of phase image intensity.

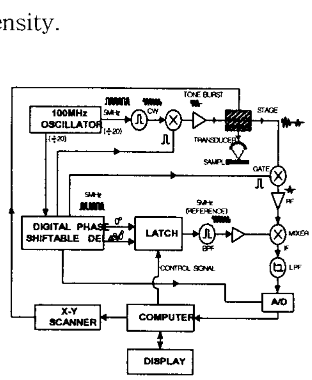

Fig. 3. A block diagram of the scanning acoustic microscope using quadrature detector

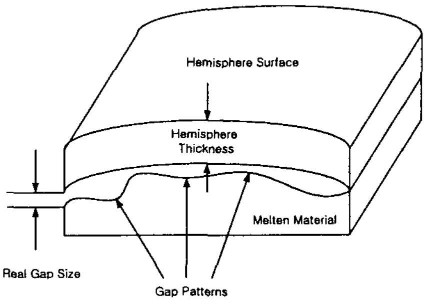

Fig. 4. A schematic of a sample 1.

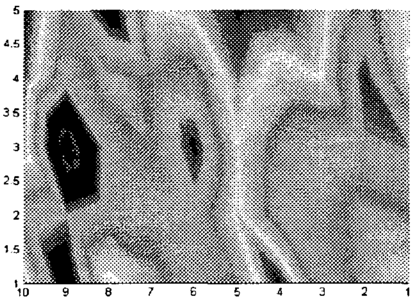

Fig. 5. Internal image reconstructed with a single frequency

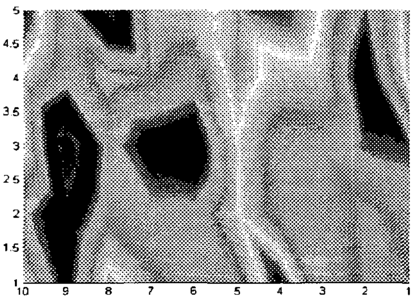

Fig. 6. Internal image reconstructed with multi-frequencies

4.2 SAMPLE 1(a part hemisphere type specimen)

Two classes put together like Figure 4. Following figure 5 and 6 are results. They are very similar because we scanned very rough. But we found a little enhanced resolution(color contrast) at gap distance distribution in data using multi-frequencies figure 6 than a single frequency figure 5. As results, the color contour was scaled up the gap distance distribution of the figure 6 than the figure 5

4.3 SAMPLE 2 (Reference block)

Sample 2, reference block, has three holes at different depth in each sectional plans of the sample like figure 7. Figure 7 shows a schematic of a sample 2 as a reference block. Each inner diameters of holes are 4.5mm in each sectional plans. We can detect two side drilled holes of three at one plan. We go through the same process as sample 1 do. Following figure 8 and 9 are sectional images

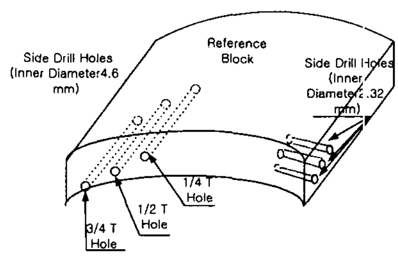

Fig. 7. A schematic of a sample 2 (Reference Block).

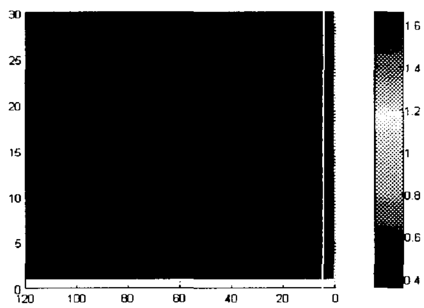

Fig. 8. Sectional image reconstructed with a single frequency

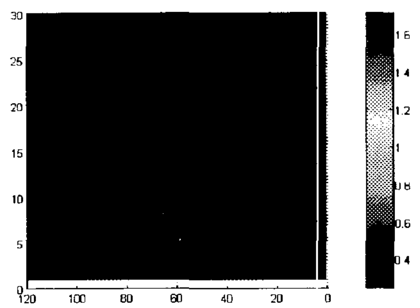

Fig. 9. Sectional image reconstructed with multi-frequencies

reconstructed with a single frequency and multi-frequencies.

We can get a little reducing noise that is generated by scattering at edge of hole. And we can found a hole-position accurately. Next two figures are mesh images for figure 6 and 7. So, they represent reducing noise and getting better depth resolution when sectional image is reconstructed by operating SAM with multi-frequencies. Better depth resolution can be obtained by numerically combining images taken at several different frequencies in fractional bandwidth of transducer. The resulting images have a greater range of coverage in the spatial frequency domain in the depth direction than does a single frequency image. Improved depth resolution can be obtained by taking three-dimensional images at more that one frequency and numerically combining the results.

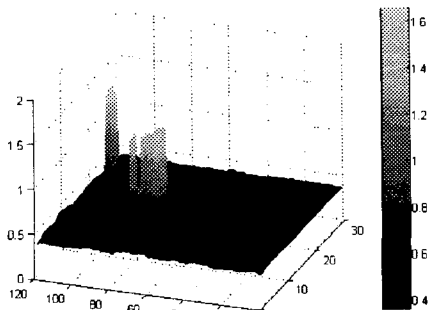

Fig. 10. Sectional image reconstructed with a single frequency

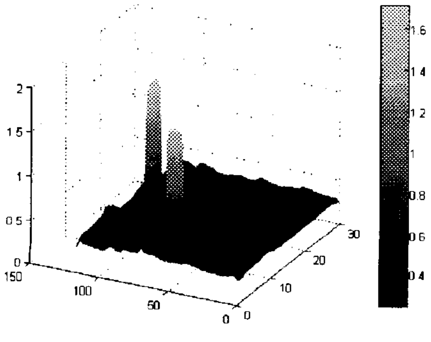

Fig. 11. Sectional image reconstructed with multi-frequencies

5. RESULTS

In this paper, we have studied the method for enhanced depth resolution of acoustic image. Up to now, SAM was operated at single frequency. But when SAM is operated at multi-frequencies, spatial frequency response region of SAM is widened, because bases of support for the microscope spatial frequency response operating at each frequency are delayed in spatial frequency domain. So enhanced depth resolution can be obtained by combining images taken at more than one frequency.

In sample 1, we can find the gap distribution from a part of a hemisphere type specimen, which is in the sample, using enhancing method. When imaging at an internal plane, we have moved the transducer closer to the sample in order to concentrate more acoustic energy on the below of the surface of sample. In this case, the internal image has the superposition of surface image characterization. With both amplitude and phase information, it is possible to remove the surface effect by taking an image with the transducer focused on the surface. From the result of this technique, we have obtained enhanced internal images which has better contrast than the image acquired by the conventional method.

In sample 2, we can reduce noises that are generated by scattering at edge of side drilled holes, and we can find a hole position accurately. They represent reducing noises and getting better depth resolution when sectional image is reconstructed by SAM operated with multi- frequencies.

From this experimental result, a better depth resolution can be obtained by numerically combining images taken at several different frequencies in fractional bandwidth of transducer. The resulting images have a greater range of coverage in the spatial frequency domain in the depth direction than does a single frequency image. A improved depth resolution can be obtained by taking three-dimensional images than by one frequency and numerically combining the results.

It is also possible to improve the depth resolution of a low aperture microscope. So it is as good as with high relief, where the use of a wide aperture lens could degrade the images of deep features.

And the results of the enhance images could be used the optimum parameters from our first stage experiment of standard reference specimens, as a second, we can apply the material of the nuclear power plants.

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