Phase Reversed Image Reconstruction Method of Industrial Ultrasonic CT

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Abstract

Based on various ultrasonic CT technology that have been developed, a new type ultrasonic CT is proposed. One array transducer is used, detected at only one or two position on a specimen, and then created the received signal list array. With the received signal list array, the authors obtained a new algorithm, named virtual scan, which reconstructed the image of the specimen from both the amplitude and the phase of a received signal. Dealing the entire signal array with this method, the authors got a pretty image of the specimen, so the new method is effective in the situation of the experiments.

Key words: phase reversed, ultrasonic CT, image reconstruction, virtual scan

1. Introduction

Generally, there are two basic types of the ultrasonic CT, i.e. transmit CT and reflection CT. As shown in figure 1, the transmit ultrasonic CT is, the emitter and receiver are face to face, the specimen is between them, and the received signal is assumed to be the ultrasonic wave transmitted along the line L_{ab} in the specimen; and the reflection ultrasonic CT (figure 2) is, the emitter and receiver is at the same side of the specimen, the received signal is assumed to be the echo wave along the line L_{ab} in the specimen. Different to the B-scan, while the CT working, both the transmit type and the reflection type, are need to circumrotate around the specimen, in order to get different signal from every direction [1] [2] [3] [4].

About transmit ultrasonic CT and reflection ultrasonic CT, the common assumption is the ultrasonic wave transmitted in the medium along a straight line, the same with X-ray. Then using the flight time or amplitude attenuation, the image is reconstructed, which is the distribution of the ultrasonic velocity or the absorption property in the specimen. So the calculating models are the same to the X-ray, the algorithm of the X-ray CT could also be used in these two types of ultrasonic CT, e.g. the algorithm based on fourier slice theorem, and the filtered back projection method etc. The calculate speed is fast enough for real-time imaging, but the quality of the images are not so well, because of that in most of the material, the ultrasonic doesn't transmit in a straight way.

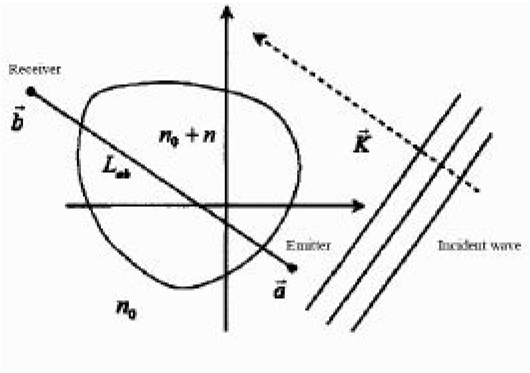


Figure1. transmit ultrasonic CT

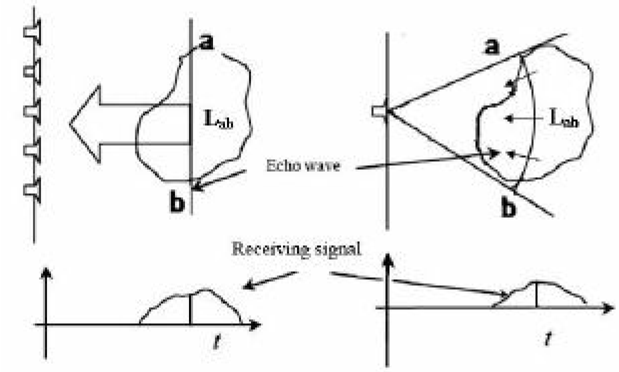


Figure2. reflection ultrasonic CT

To describe the transmit path of ultrasonic accurately, the refraction and diffraction (collectively as scattering) of the ultrasonic must be taken into account. The diffraction tomography is a technology of this kind, that is based on the fourier diffracting projection theorem, shown in figure 3. This theorem is similar to the fourier slice theorem of the X-ray CT, but the difference is, the projection data of the fourier slice theorem is transformed to a straight line belong to the fourier translation of the object in the frequency domain; or the other is transformed to a half circle belong to the object in the frequency domain.

So far, almost all the ultrasonic CT are based on the principle described before, the algorithm of them are only processing with the amplitude of the receiving signal, but not considering the phase message of the signal. And all the method need to rotate the transducer or the detecting objects, or set the transducer in a circle around the detecting objects, in order to get enough data to reconstruct the image.

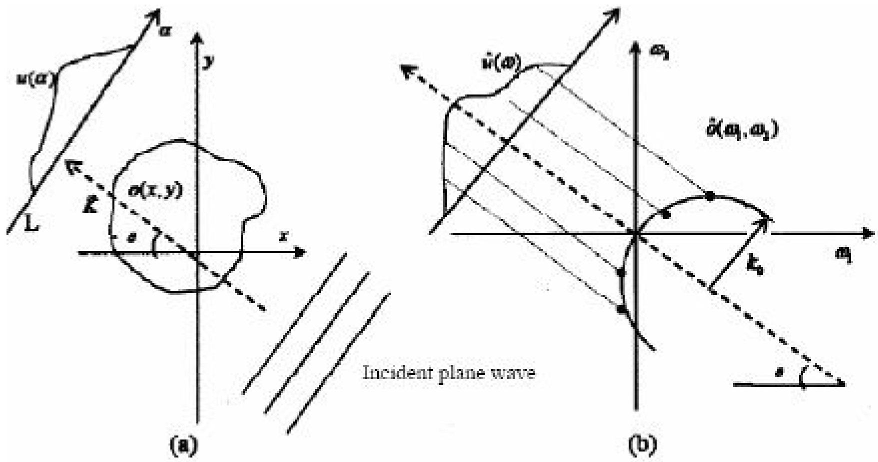


Figure 3. the fourier diffracting projection theorem

2. Phase Reversed Image Reconstruction Method of Industrial Ultrasonic CT

2.1 Principle

While the border situation, acoustic property of the medium, and the emitting position on the border are fixed, the acoustic field in the medium caused by an ultrasonic transducer is also fixed. As shown in figure 4, that's the transformation at different time of the acoustic field caused by an element belong to a phase transducer. We can obtained that if the elements of the array transducer are triggered one by one, and while an element is triggered, all the elements (including the emitting one) is receiving; when the all the elements have been triggered, a receiving signal list array is formed, the signal list array included all the information that the array transducer could get at this position. Using the signal list array we can make a virtual scan of the detecting scope of the array transducer.

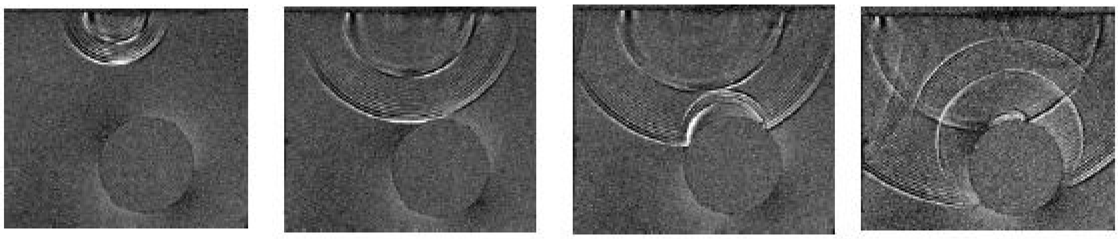


Figure 4. dynamic photoelastic photos of the acoustic field caused by an

As the acoustic field signal at a spatial point caused by all the elements with appropriate delay to each one, is the same as the signal received by all the elements with the same delays while there is a point source at that point [5]. The spatial points or scattering points in the detecting scope could be treated as point sources, according to the positions contrast to the array transducer; we can delay the signal from the signal list array with corresponding time, that's determined by the flight time, and sum up all the delayed signal, so the acoustic field signal of the scattering point is obtained (phase reversed). While the acoustic field signal of every point in the detecting scope is calculated, the ultrasonic CT imaging is finished. Because that while calculating the image, we can choose the spatial resolution, and scan the whole detecting scope, so we called this method virtual scan. The principle of the virtual scan is shown in figure5.

2.2 Virtual scan and phase reversed image reconstruction

As in figure 5, assumed the target point P is any virtual scanned point (scattering point) in the detecting scope, using an array transducer whose elements amount is N , while the element i is emitting, and all the elements is receiving, the amount of signal list can be got is N , and the signal list could be record as:

Fehler! Es ist nicht möglich, durch die Bearbeitung von Feldfunktionen Objekte zu erstellen. (1)

W_i is the signal lists when the element i is emitting, the figure6(a) is W_{18}, i.e. the element 18 emitted, and all the elements received, the x axis is sample points, and the y axis is the receiving element index.

In formula (1) $w_{ij}(n), i, j = 0,1,,2,\Lambda\ N-1; n = 0,1,2,\Lambda\ , M-1$, represent for the signal received by element j when the element i is emitting. M is the sample points' amount of time signal. If i=j, it is the signal emitted from element i and received by itself.

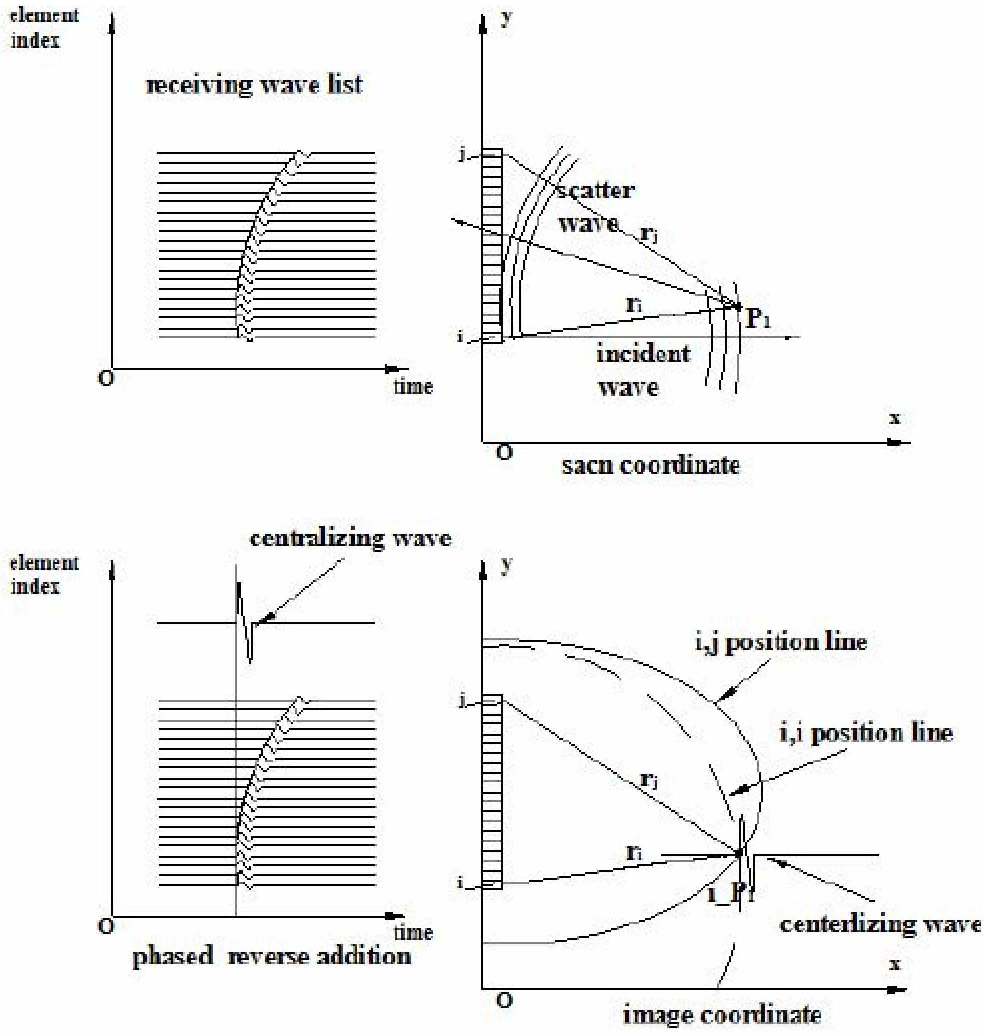


Figure 5. Phase Reversed Image Reconstruction Method of Industrial Ultrasonic CT(virtual scan)

The acoustic field signal of spatial point $P(x, y)$ could be extracted from signal unit $w_{ij}(n)$ as:

$$p_{ij}(x, y, n) = w_{ij}(n) win_{ij}(n) \qquad (2)$$

$win_{ij}(n)$ is a time window function whose center is l_{ij}, length is $2l$, l_{ij} is determined as:

$$l_{ij} = \text{INT}(t_{ij} / \Delta t) \qquad t_{ij} = \frac{r_i + r_j}{C} \qquad (3)$$

Where, C is the velocity of the ultrasonic in the medium, r_i and r_j are shown in figure 5, those are the distance between element i and the virtual scan point $P(x, y)$, and the distance between element j and $P(x, y)$, Δt is the sampling interval.

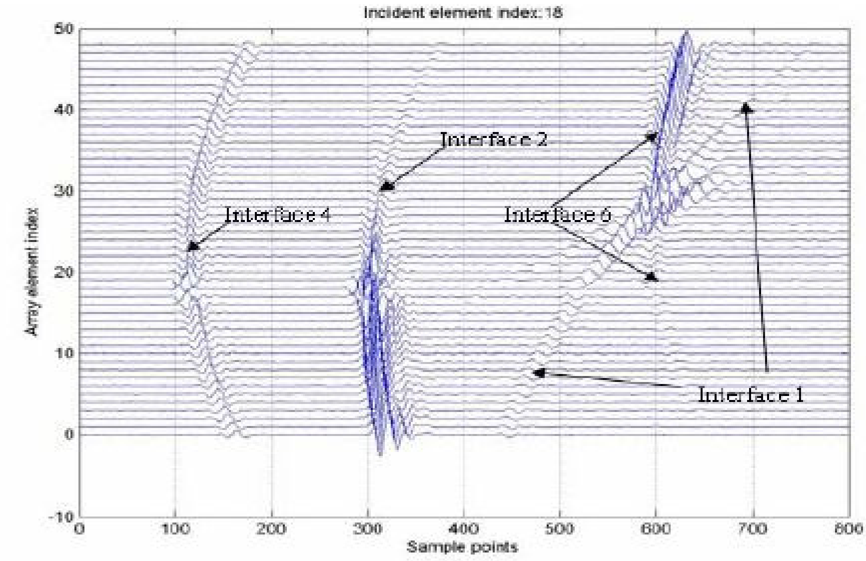
l can be calculated as:

$$l = \text{INT}(\lambda / (C \Delta t)) \qquad (4)$$

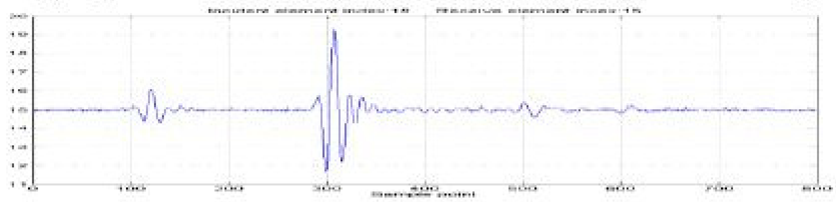
INT (.) is the rounded function, λ is wavelength in the medium.

According to the actual situation, different window function could be changed. In this paper, the follow window function is used:

$$win_{ij}(n) = \begin{cases} 1 & l_{ij} - l \le n \le l_{ij} + l) \\ 0 & others \end{cases} \qquad (5)$$



(a) signal that element 18 emitting ,all the elements receiving



(b) from(a), the amplified signal $w_{1815}(n)$

Figure 6. $W_{18} = (w_{181}, w_{182}, \ldots, w_{18N})$ from the array transducer A in figure 8

As the acoustic field signal at a spatial point caused by all the elements with appropriate delay to each one, is the same as the signal received by all the elements with the same delays while there is a point source at that point [5]. The acoustic field of any virtual scanning point $P(x, y)$ in the detecting scope could be calculated approximately as follow:

Fehler! Es ist nicht möglich, durch die Bearbeitung von Feldfunktionen Objekte zu erstellen. (6)

Where, $0 \le n \le 2l$.

Figure 7 shows the comparison of the signal from a real scattering point (indicated as 1) and the signal from a fictive scattering point (indicated as2), in the figure 3 is the origin signal received by a single element, i.e. $w_{ij}(n)$.

Select the imaging parameter from the signal calculated by formula (6), the parameter can be the maximum amplitude, the wave front amplitude, the mean amplitude, etc. The parameter is the gray value of $P(x, y)$ in the reconstructed image. Processed every point in the detecting scope like this, the rough image reconstruction of the detecting scope could be built up. That’s the phase reversed image reconstruction.

This method summed up many groups of signal, so the statistics effect filtered the noise. If the target point is not a real scattering point, the gray value of it is very near to zero (figure 7). Experiments showed that this method is effective for rough imaging of the specimen.

But if the scatterer is in some special shape, e.g. a cylinder cavity, the rough imaging does not go well, so the amendment is needed. The amending method included correlation analysis, wave front analysis, signal lists comparison, etc. And optimized formula (2) and formula (6), then a image with well quality would be there. For the space is limited and the amendments and optimization is complex, those will be discussed in another article.

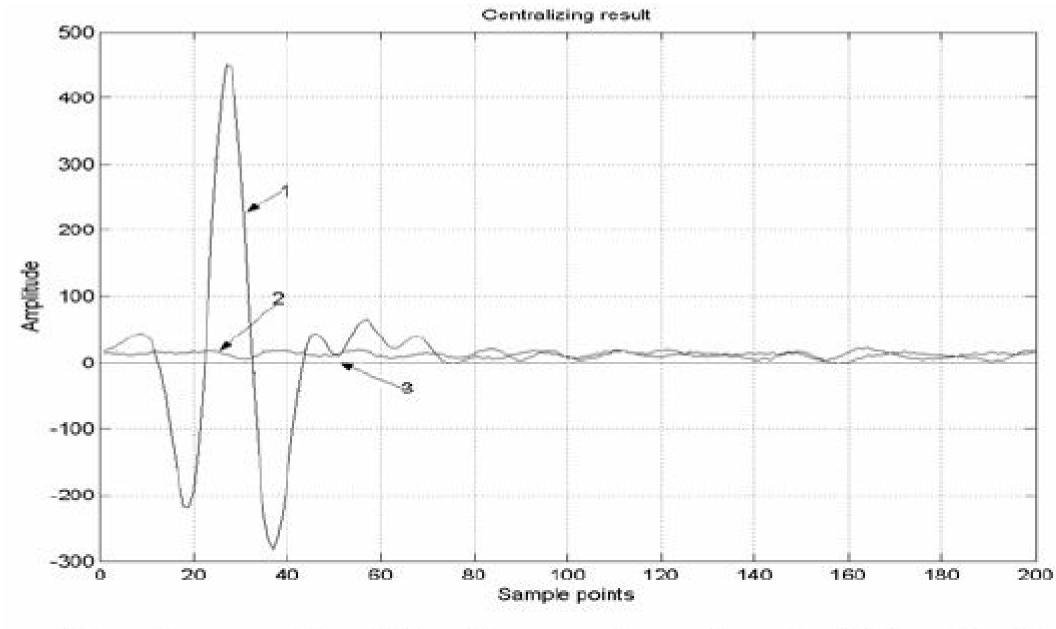


Figure 7. comparison of signal from a real scattering point (indicated as 1) and signal from a fictive scattering point (indicated as2), 3 indicated to the signal $w_{ij}(n)$

3. Experiments

The specimen tested is a titanium alloy CSK-IA specimen that is showed in figure 8, two linear array transducers named as A and B are set as shown in the figure, the area surrounded by dotted line is the detecting scope for rough imaging, image section I_1 is for array transducer A, image section I_2 is for array transducer B. In the figure, the scattering interface is indexed as interface1, interface2, etc.

The array transducer A has 48 elements, and the elements area is $1mm \times 20mm$, frequency is 6.25MHz; the array transducer B has 25 elements, elements parameter is the same with A. The thickness of the specimen is 20mm.

Using the linear array transducer A, performed virtual scan and phase reversed image reconstruction (rough imaging) in the detecting scope “Image Section I_1”(showed in figure 8), figure 9 showed the imaging result(the spatial resolution of virtual scan is $1mm \times 1mm$). The gray value in the image is determined by the maximum amplitude that calculated by formula (6). In figure 9, the scattering interface is imaged clearly, and the positions of the scattering interface are accurate enough at the spatial resolution of $1mm \times 1mm$. And about the interface is not imaged, while the rough imaging is extended, those interface would come out.

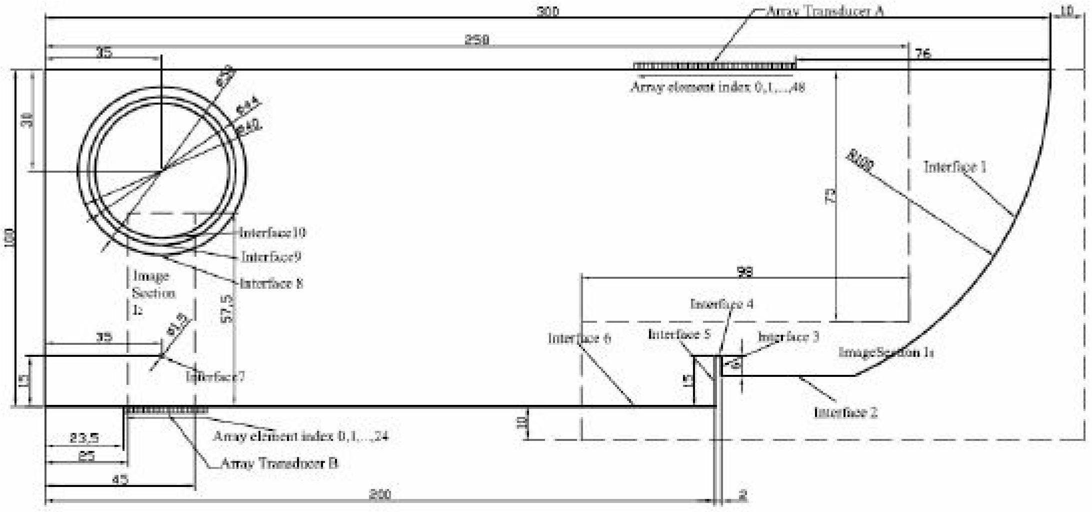


Figure 8. titanium alloy CSK-IA specimen and imaging parameter layout

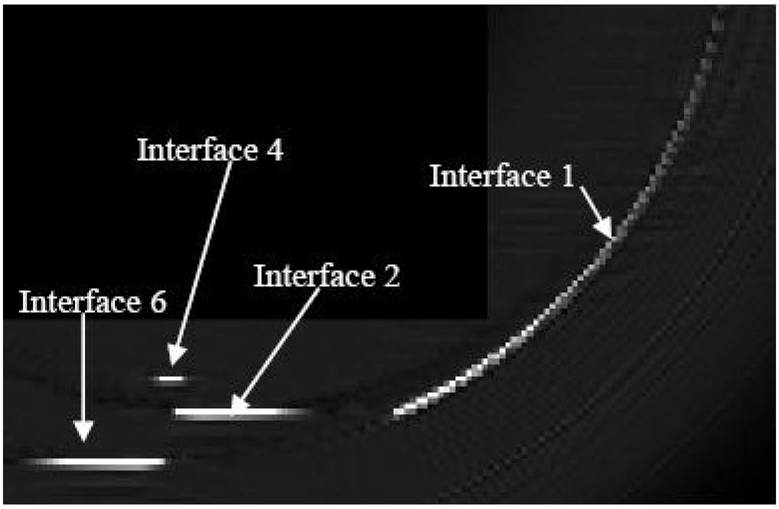


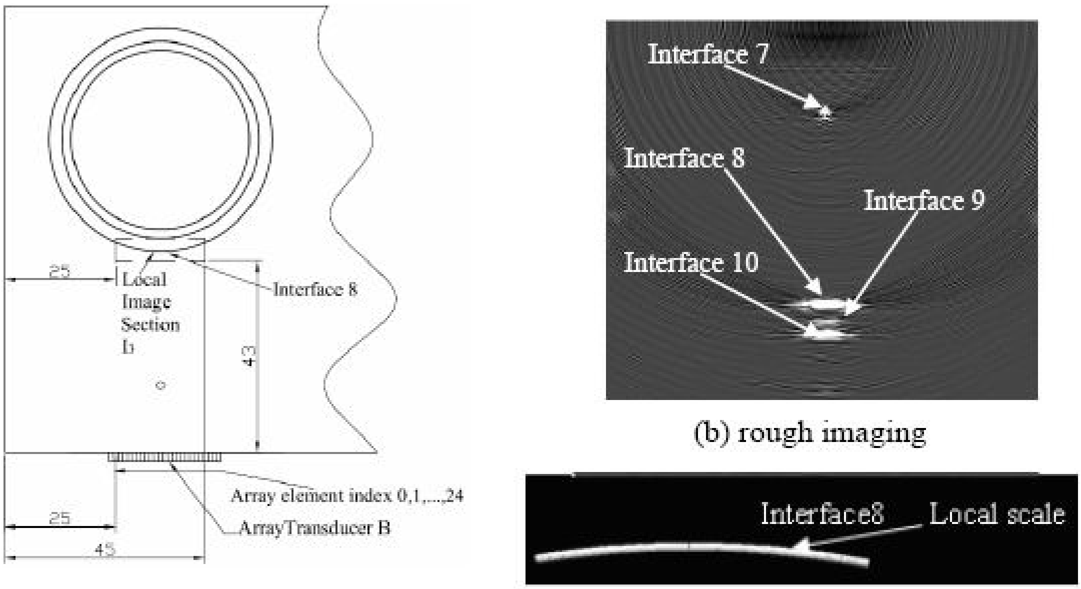
Figure 9. using array transducer A, in the detecting scope: Image Section I_1, the rough imaging result (the spatial resolution of virtual scan is $1mm \times 1mm$)

Using the linear array transducer B, performed virtual scan and phase reversed image reconstruction (rough imaging) in the detecting scope “Image Section I_2”(showed in figure8), figure 10 (b) showed the imaging result(the spatial resolution of virtual scan is $1mm \times 1mm$). The gray value in the image is determined by the maximum amplitude that calculated by formula (6). In figure 10 (b), all scattering interface is imaged at the right position, but the shape of the scattering interface is not very accurate. Then the amendment method (wave front analysis etc) is used, imaging in the detecting scope “Local Image Section I_3” (showed in figure10 (a)), and the result is shown in figure10 (c), the shape of the scattering interface is more clearly and accurate.

4. Conclusions

The virtual scan and phase inversed image reconstruction technology is proposed in this paper. Using this technology, with a linear array transducer that’s set at only one position, some well quality images were reconstructed about the titanium alloy CSK-IA specimen.

For this technology is still in developing, different from other Ultrasonic CT which is base on the linear assumption or weak scattering assumption, about it there are still lots of theorem and technology questions needing to be studied.



(a) detecting scope

(b) rough imaging

(c) amendment result

Figure 10. rough imaging and amendment result

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