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Study on the Technology of Ultrasonic Imaging Detection based on Phase Array

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Abstract

Ultrasonic testing is an important flaw detection technology in nondestructive testing field. With its unique electronic scanning, dynamic deflection focusing (DDF), sectorial scanning characters and ultrasonic phased array (UPA) technology can be used for defecting detection of objects with curved face or complex structure. Thus, UPA technology has become a focus of ultrasonic testing research. In order to solve a kind of problem of the internal inspection, this paper analyze methods of phasing array imaging and make a simulation scheme. The simulation result shows that the fan imaging method proposed by this article is right, establishing basis for the real-time imaging test analysis of ultrasonic flaw detection.

Keywords: *phased array imaging; Steer and focus; directivity function; matlab*

1. Introduction

Because the ultrasonic beam is accomplished by summing multiple ultrasonic impulse signals at all array elements with proper delay compensations corresponding to the propagation time delays, the focusing and deflection can be achieved flexibly according to the requirements. As a result, there can be kinds of scanning modes and the sensitivity of ultrasonic testing systems can be greatly improved. Ultrasonic Phased array technology has remarkable advantages in inspection speed, quantitative analysis of disfigurement, reducing working intensity, and so on. It has been the trend of development.

The data of reflection pulse can be obtained by directly analysis in the ultrasonic phased array technology. But this method just judges the deficiency of tested parts based on the state of reflection wave, making it difficult to archive quantitative result. Therefore, applying ultrasonic imaging technique to ultrasonic phased array testing can show the test results accurately in the form of image. Testing personnel can also easily qualitative quantitative conclusions according to the graphical features. This will greatly reduce the burden of testing personnel and improve the reliability and validity of the detection results [1-3, 9].

2. The Performance Analysis of Phased Array

Using ultrasonic phased array for flaw detection, we mainly make use of its excellent point adjustment and deflection focusing control; there are a series of evaluation indicators to archive these properties including side lobe level, grating lobe, beam angle and so on. Factors affecting these indicators include the geometric parameters of phased array itself (quantity, size and spacing of array element), the deflection angle and so on [4-6].

2.1. Main Lobe

As ultrasonic phased array is used for detecting flaw, the width of the main beam should be narrowed as much as possible so that excellent directivity can be archived, improving

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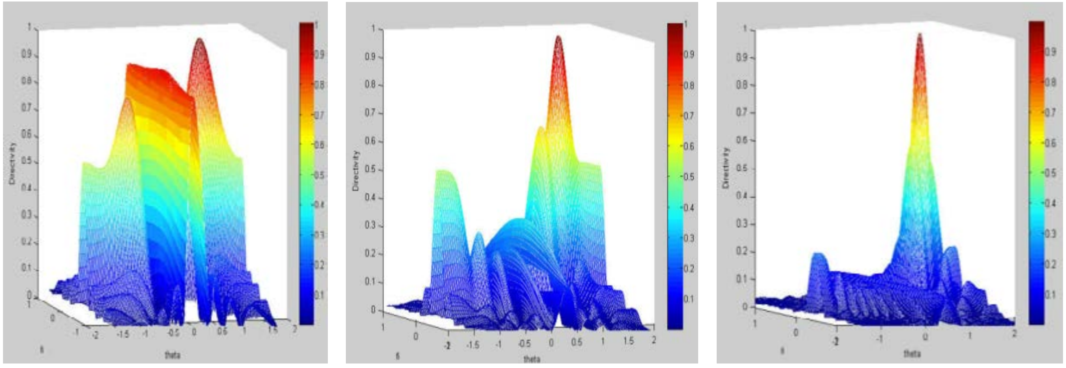
the resolution of damage detection. Considering the ultrasonic phased array directivity function, normalization direction of different array element number is shown in Figure 2-1. It can be seen from the figure that when N=4, beam cannot focus at all with side lobe being great. As the number of array element increases, the main beam becomes acute, width becoming narrow and the beam angle becomes very small. But, as N increases, channel beam of system also increases, increasing the complexity and cost of system. Generally, make N≥16.



(A) N=4 （B）N=8 （C）N=16

Figure2-1. Different Number of Array Directivity Function

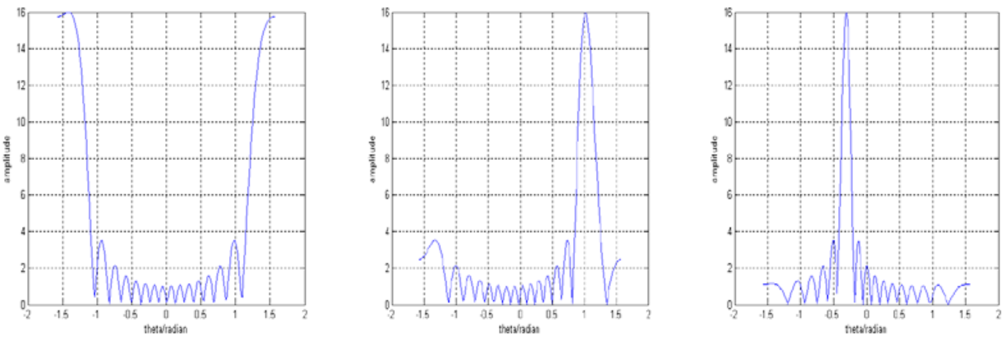
2.2. Grating Lobe

Except for causing the leakage of sound energy in beam and lowering the signal to noise ratio, the grating lobe is also likely to send a pseudo echo signal to the receiver, leading to false detection in the process of testing. According to the study of Shi – Chang Wooh etc, for uniform linear array, the condition to eliminate gate valve within the beam allowed deflection scope is:

$$k = \frac{d}{\lambda} \le \frac{1}{1+\sin\theta \max} \qquad (1)$$

Where d is the array element spacing, λ is the wave length, θmax is the maximum deflection angle. From the above formula can be found: the array element spacing of d determines the maximum deflection Angle θmax.

The direction of different deflection angle obtained when d/λ≤0.5 is shown in Figure 2-2.



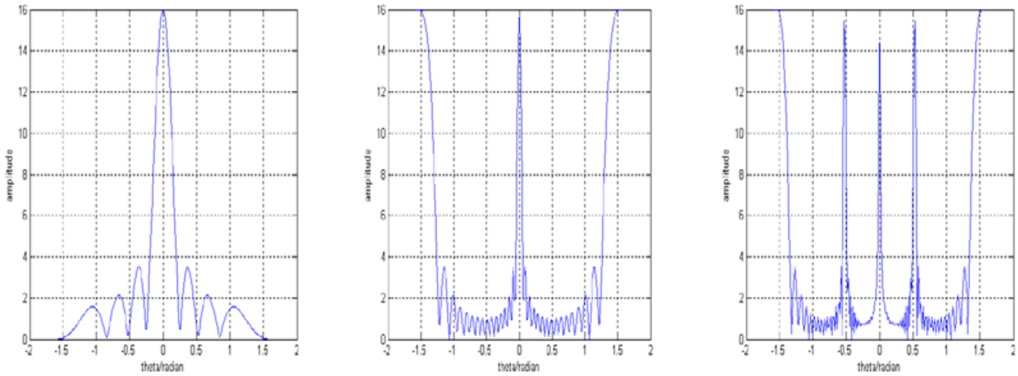
(A) deflection of 30° (B) deflection of 60° (C) deflection of 60°

Figure 2-2. Different Deflection Angle of the Directivity Function

From the above we can see, when array element spacing is less than the half wavelength, even though the beam deflects in any Angle in the detection plane, it will not have a gate valve. Under the condition of the zero deflection Angle, the directivity shows in Figure 2-3 (the array element spacing were taken: d=0.25λ, d=λ, d=2λ). The simulation results show that, the critical point is d=λ, and when d≥λ, even there is no deflection it will produce gate valve.

2.3. Side Lobe

The sound energy leakage can be reduced through effectively suppressing side lobe while completely eliminating side lobe is impossible, but maximizing the launched ultrasound in the control direction can be done by minimizing the side lobe amplitudes. The simulation result shows that the increase in the number of array element effectively suppresses side lobes; increase in the array element spacing suppresses side lobe to a certain extent, however, too much spacing wavelength ratio will cause a gate valve while deflection angle and array element width have little influence.



(A)d=0.25λ (B) d=λ (C) d=2λ

Figure 2-3. Different Array Element Spacing of the Directivity Function

3. Principle Analysis on Deflection Focusing of Phased Array

The biggest advantages of ultrasonic phased array are that it can realize the beam deflection and software-control focusing. One of key characteristics in transmitting and receiving the ultrasonic phased array is to accurately control delay time of various signals. When conducting phased array ultrasonic testing, there are three main ways to control acoustic beam: beam deflection, beam focusing and combination control of deflection and focus. Then we will describe time delay calculation method of the last beam control mode [7, 8].

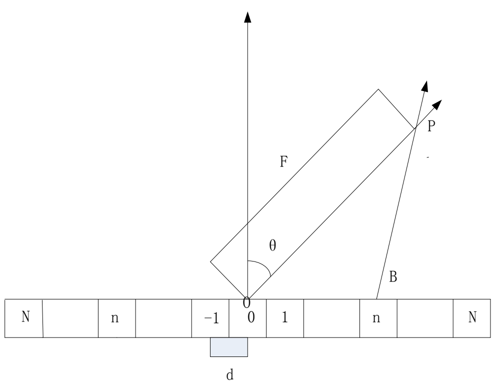


Figure3-1. Sound Beam Steering and Focusing of Ultrasonic Phased Array

There are 2N line array transducer array shown in Figure 3-1, considering a typical array element for NO. n which is in the triangle of OPB:

$$\mathrm{OB} = \mathrm{dn} \qquad (2)$$

According to the cosine theorem we get:

$$\mathrm{PB}^2 = \mathrm{F}^2 + (\mathrm{nd})^2 + 2\mathrm{nFd}\sin\theta \qquad (3)$$

Here: d—the distance between adjacent array center;

PB—the distance from the array of NO. n to focus point;

F—the distance from the center of linear array to focus point;

θ—deflection angle of the center of beam.

Then the acoustic path difference between array of NO. n and linear array center:

$$\Delta\mathrm{S} = \mathrm{F} - \mathrm{PB} \qquad (4)$$

Assuming the velocity is C, it can be concluded that the delay value of the array of NO. n:

$$t_n = \frac{\Delta S}{C} + t_0 \qquad (5)$$

According to Equation (3) and (5), to get:

$$t_n = \frac{F}{C}\left\{1 - \left[1 + \left(\frac{nd}{F}\right)^2 - \frac{2nd\sin\theta}{F}\right]^{\frac{1}{2}}\right\} + t_0 \qquad (6)$$

Here: t_0—a constant which avoids the negative delay;

C— speed of sound.

For an even number of array element for phased array, they only need to type in the n to (n+0.5).

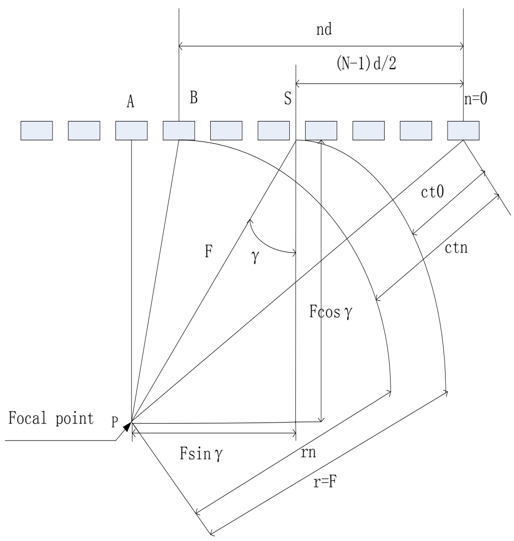


Figure 3-2. Geometric Sketch Map of Linear Ultrasonic Phased Array

The t_0 of Equation (6) is not accurate, from the following research which is shown in Figure 3-2, we can obtain:

$$(\mathrm{Fcos}\gamma)^2 + [\mathrm{Fsin}\gamma - \left(\mathrm{nd} - \frac{\mathrm{N}-1}{2}\mathrm{d}\right)]^2 = [\mathrm{F} - (\mathrm{ct}_{\mathrm{n}-}\mathrm{ct}_0)]^2 \quad (7)$$

Simplifying:

$$\mathrm{t_n} = \frac{\mathrm{F}}{\mathrm{C}}\left\{1 - \left[1 + \left(\frac{\mathrm{d}}{\mathrm{F}}\right)^2(\mathrm{n} - \frac{\mathrm{N}-1}{2})^2 - \frac{2\mathrm{d}}{\mathrm{F}}(\mathrm{n} - \frac{\mathrm{N}-1}{2})\mathrm{sin}\gamma\right]^{\frac{1}{2}}\right\} + \mathrm{t_0} \quad (8)$$

According to Taylor series, ignoring the above polynomials of order two, we get:

$$\left[1 + \left(\frac{\mathrm{d}}{\mathrm{F}}\right)^2(\mathrm{n} - \frac{\mathrm{N}-1}{2})^2 - \frac{2\mathrm{d}}{\mathrm{F}}(\mathrm{n} - \frac{\mathrm{N}-1}{2})\mathrm{sin}\gamma\right]^{\frac{1}{2}} \approx 1 - \frac{\mathrm{d}}{\mathrm{F}}\left(\mathrm{n} - \frac{\mathrm{N}-1}{2}\right)\mathrm{sin}\gamma + \frac{1}{2}[\mathrm{d}/\mathrm{F}(\mathrm{n} - (\mathrm{N}-1)/2)\mathrm{cos}\gamma]^2 \quad (9)$$

Combined (8) and (9) this paper got the beam focusing delay time of adjacent array elements:

$$\Delta\tau_{\mathrm{n}} = \mathrm{dsin}\gamma/\mathrm{c} + \mathrm{d}^2(\mathrm{N} - 2n)\mathrm{cos}^2\gamma/2\mathrm{cF} \quad (10)$$

4. Ultrasonic Phased Array Insperction Image Interpolation

The image spatial domain transformation operation can be considered as pixel-to-pixel transformation between the input image and the output image. However, the processed object in this paper is digital image whose important feature is the discrete horizontal and vertical coordinates, which induces that some pixels in output image cannot find their corresponding pixels in input image and that the original pixels may fall in invalid area of output image after the implementation of spatial domain transformation. Interpolation of image needs to be introduced to compensate for this display defects, estimating the value between pixels, effectively filling up the blank points possibly appearing in image.

The storage format of sampled data of the sectored scanning area, is shown as Figure 4-1, and it can be seen from the figure that: echo data is the date of 1267 sampled points on 61 scanning lines. Each time one scanning line sampling is completed, a data file with 1267 data inside comes into being; then sample next scanning line, another data file forming. So there will be 1267×61 sample data in total after all the 61 scanning lines are sampled.

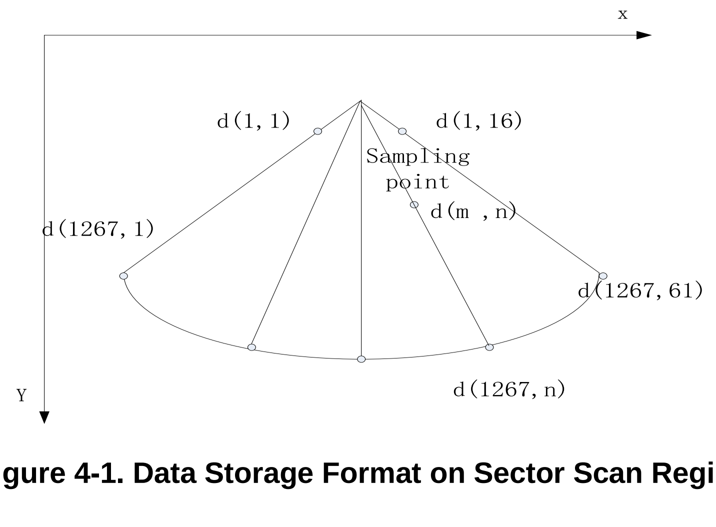


Figure 4-1. Data Storage Format on Sector Scan Region

In order to apply computer to manipulate image. Firstly, spatial and amplitude discretization must be introduced to process the continuous image function f (x, y).

As shown in Figure 4-2 and Figure 4-3, this paper conducts data interpolation research on defect image, adopting nearest neighbor interpolation and double thrice interpolation. It can be seen from the image magnified by the two interpolation methods mentioned above that blocky effect can be seen clearly in image magnified by nearest neighbor interpolation method, but it is still acceptable on condition that high quality is not required while the result of double thrice interpolation method is best without blocky effect. Therefore, double thrice interpolation is adopted in this paper to manipulate defect image.

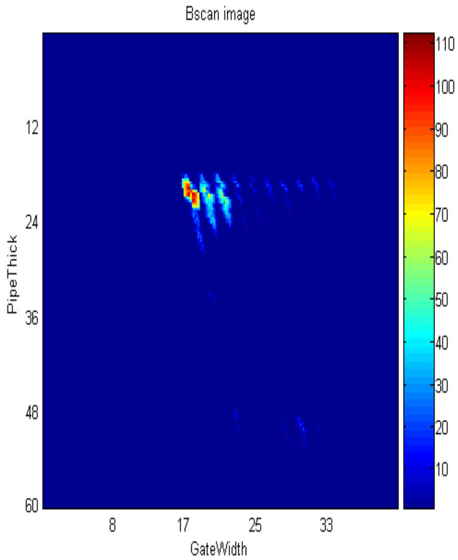


Figure 4-2. Impression of Contiguious Interpolation

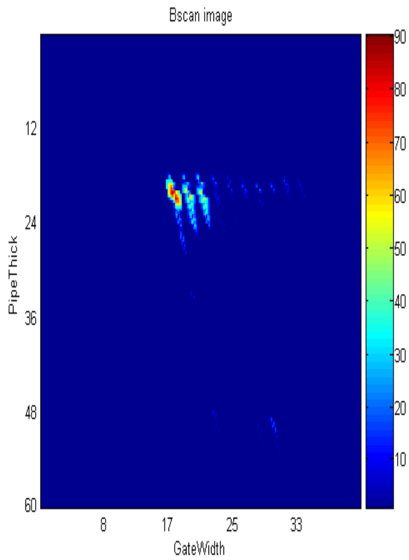
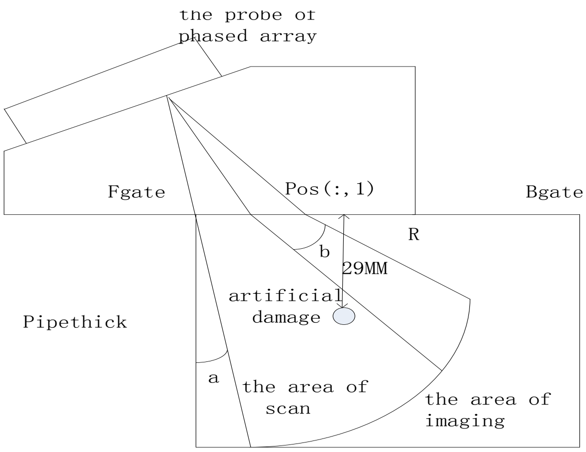


Figure 4-3. Impression of Double Thrice Interpolation

5. Sector Scan Imaging and Simulation based on Ultrasonic Phased Array

Sector scanning and B scanning are at the same side， and the imaging display area of ultrasonic phased array probe sector scanning detection is shown in Figure 5-1.Block size is 400mm × 60mm × 50mm, and a flat-bottom blind hole with depth of 29mm and diameter of 3.2mm is manufactured in its side. Specific location is shown in Figure 5-1.



Where: a= anglestart, b= angleend

Figure 5-1. Region of Ultrasonic Phased Array Sector Scan Imaging

The imaging algorithm of ultrasonic phased array sector scanning detection is as follows:

1. Define the index of sector scan imaging;

The total number of acoustic beam(songnum),the data collected by the system volume(num),the beam radius, sector scanning start angle(anglestart),image compression and resolution of Image resolution, total channels, speed, sampling frequency, the actual position of front sluice gate, the actual position of rear sluice gate(Bgate), the actual thickness of sluice gate(Pipethick), and radius of beam scanning as R, The actual position of each beam(denoted as pos(:,1)).

Where, indexes are not independent, where certain relationships are certain among each other[10], such as:

$$num = 2 \times R \times 16 \times 10^9/(V \times 10^3) \quad (11)$$

$$Bgate = pos(songNum{:}\,1) + R \times \sin(angleend) \quad (12)$$

$$Pipethick = R \times \cos(anglestart) \quad (13)$$

2. The data is collected using a text file into a matrix of num ×songnum, then the data were taken and intercepted;

3. Determine the incident position according to the indexes of wedge;

4. Conduct deflection and interpolation calculation for each column of the matrix imported from B according to the angle interval.

The paper adopts the thrice interpolation method to fill interpolation, making the image color change continuously. Each data column is turned into a new matrix after deflection; then it is placed into the new matrix again according to the incidence position of every sound bunch. The maximum value is chosen at the points whose position overlaps. In this way, sector scan imaging comes true.

5. Adjust the image coordinates and output the image according to the actual scan area and the proportion, the paper.

Conduct sector scan test for the flat bottom hole distance, and select ultrasonic phased array probe for 16 arrays, with the scanning range is 30 ° - 60 °, and the sound path is 34000μs, the width of the gate 1935, the focal depth is 24mm, the sector scan image as is shown in Figure 5-2 in MATLAB software, the figure clearly shows the imaging area of ultrasonic phased array sector scanning, scanned area, and the defect position and the shape.

Figure 5-2 shows results of sector scan from the flat bottom hole whose depth is 29 mm, making a the comparison of Figure 5-1 that: the position of the defect images is close to bottom hole in test block, and the defect diameter are calculated as 3.3mm, which is close to the actual size of flat bottom hole (3.2mm).

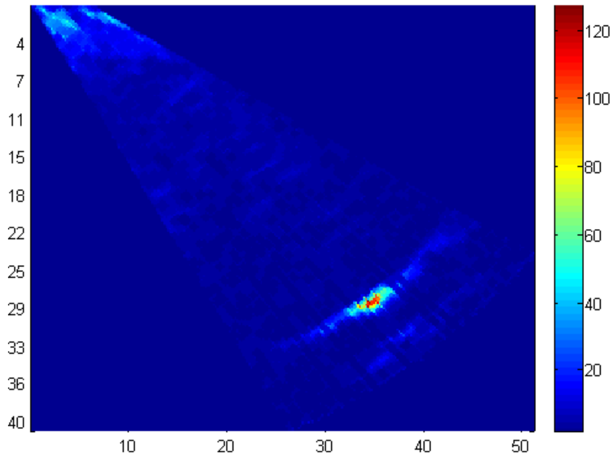


Figure 5-2. The Sector Scan of Flat-Bottomed Hole

6. Conclusion

This paper introduces the ultrasonic phased array inspection imaging technology, first summarizing how each parameter of phased array affects its performance through simulation analysis and analyze the focusing method at the same time, studying ultrasonic phased array fan stroke imaging algorithm, imaging the internal deficiency of work piece. The experimental results shows that: the ultrasonic phased array scanning detection technology proposed in this paper can reappear the manual manufacturing deficiency; the size of detected deficiency is very close to the results of manual ultrasonic flaw detection, rendering the whole developing trend of deficiency faithfully.

Ultrasonic phased array technology can control the space-time characteristics of the beam flexibly and effectively with the advantages like visual imaging test, complex-shaped geometry test, improving the SNR, sensitivity and resolution of ultrasonic detection and so on, providing strong support for work piece internal deficiency detection through the study in this paper.

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