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Research on total focusing method imaging method of pipeline defect detection based on phased array

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ABSTRACT. *This article describes the Total Focusing Method applied to pipeline defect imaging. Through the acquisition and processing of phased array time-domain signals, qualitative and quantitative imaging of pipeline defect parts is achieved. As a phased array ultrasonic post-processing method, this technology has high imaging resolution and can improve the imaging characteristics of pipeline defects. It is currently gradually developing and applied to the medical field and industrial non-destructive testing.*

KEYWORDS: *phased array; Total Focusing Method; pipeline defect imaging; non-destructive testing*

1. Introduction

Phased array ultrasound imaging technology has been developed in the industrial non-destructive field for more than 30 years. During the inspection process, phased array probes are used to transmit or receive ultrasonic waves. By controlling the delay of the pulses emitted by each array element, the focus position and deflection angle of the synthesized beam is controlled, so as to achieve ultrasonic imaging. because of its fast detection speed and strong flexibility, it is widely used. However, in complex environments, the detection effect of phased array technology is not good and the image resolution is low. With the development of ultrasound imaging technology towards high resolution, accurate positioning and access to more pipeline defect information, more advanced Total Focusing Method (TFM) performs post-imaging processing [1]. This article takes one-dimensional linear array as an example, writes program based on the principle of phased array-TFM and performs simulation to complete TFM imaging of pipeline defects.

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2. Principle of total focus imaging

2.1 Full Matrix Capture (FMC)

In order to maximize the flexibility of array signal processing, it is necessary to extract as much information as possible from the array [2]. For an array of N array elements, each array element is sequentially transmitted separately and all array elements are simultaneously received, then the complete data set from the N array element array has a limited size, that is the time domain signal of each possible transmit-receive array element N × N data combination, this N × N complete data set is called full matrix, and the process of obtaining it is called FMC.

Recording the amplitude of the echo signal transmitted by the ith element and received by the jth element as $g_{i,j}(t)$, saving the received data in sequence, the formed matrix $g(i, j, t)$ is shown in equation(1):

$$g(i,j,t) = \begin{bmatrix} g_{1,1}(t) & g_{1,2}(t) & \cdots & g_{1,N}(t) \\ g_{2,1}(t) & g_{2,2}(t) & & \\ \vdots & & \ddots & \\ g_{N,1}(t) & & \cdots & g_{N,N}(t) \end{bmatrix} \tag{1}$$

2.2 Total Focusing Method (TFM)

The TFM imaging technique is an imaging post-processing technique proposed by Holmes. It can only be actually implemented by FMC and post-processing, and fully utilizes the FMC data set. The fully collected data signals of the N array elements of the phased array are completely recovered. Using the linear superposition of the sound field [2], all the array elements are used to virtually focus each point in the image, thereby obtaining an image of the entire detected area. As shown in the TFM schematic shown in Figure 1, the array is located in the x-y plane, the axis direction is parallel to the z axis, and the x axis is the array scanning direction. A two-dimensional image is generated in the x-z plane (Imaging plane in the figure).

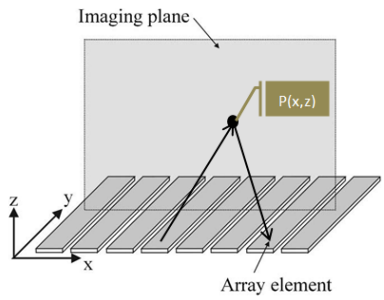

Figure 1 TFM schematic

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Any sound beam focusing point $P(x,z)$ in the plane, the image amplitude $I_0(P(x,z))$ at this point is the superposition of the amplitude of the full matrix data set focused on this point, ie

$$I_{\mathbf{0}}(P(x,z)) = \sum_{i=1}^{N}\sum_{j=1}^{N} g_{i,j}\,(t_{ij}(x,z)) \tag{2}$$

In the formula, $P(x,z)$ is the imaging position of the point in the plane; the subscripts i and j refer to the index of the position of the transmitting array element and the receiving array element respectively; $t_{ij}(x,z)$ represents the sum of the time when the sound wave emitted by the transmitting element i reaches the point $P(x,z)$ and the time when the sound wave reaches the receiving element j from that point, ie[3]

$$t_{ij}(x,z) = \frac{\sqrt{(x-x_i)^2+z^2}+\sqrt{(x-x_j)^2+z^2}}{c} \tag{3}$$

In the formula, c represents the longitudinal wave sound velocity of the structural steel used by the member; x_i and x_j represent the coordinates of the transmitting element i and the receiving element j on the x axis.

2.3 Total Focus imaging effect evaluation parameters

2.3.1 Array Performance Indicator (API)

In this paper, API [4] is used to quantitatively evaluate and analyze the effect of TFM imaging. API is a dimensionless number, the smaller the value of API, the narrower the beam width in ultrasonic testing and the better the imaging effect of pipeline defects; if the value of API is larger, the wider the beam width, the defect images of two adjacent pipelines is prone to mixing, and the imaging effect is worse [3]. The API value is defined as the area A_{-6dB} normalized to the square of the wavelength, its expression is:

$$API = \frac{A_{-6dB}}{\lambda^2} \tag{4}$$

In the formula, A_{-6dB} means the amplitude of the point reflector in this area decreases from the maximum value to -6dB.

2.3.2 Imaging time

In non-destructive testing, imaging time is a very important concept, and it also characterizes the performance of the instrument and the rationality of the imaging parameters. This article uses tic and toc to record the execution time of the total focus imaging command, which is used in combination.

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3. Simulation implementation of total focus imaging

3.1 Simulation model design

In this paper, the simulation is based on the Matlab + Field II simulation software platform. To obtain the TFM imaging of the pipeline defects, we need to establish a simulation model.

Set array center frequency $f_0 = 5\text{MHz}$, sampling frequency $f_s = 100\text{MHz}$, longitudinal wave sound velocity of structural steel $c_0 = 5900\text{m}/s$; the width of a single array element is 0.4 mm, the center distance between two adjacent array elements is 0.1 mm, the number of array elements is 16; the impulse response and excitation function are sine waves with hanning window; set three pipeline defects of different depths, and their center coordinates are (x_0,0,18)mm, (x_0,0,24)mm, (x_0,0,30)mm, x0 indicates the x-axis coordinate is the center of the imaging area.

3.2 Discussion and analysis of results

In order to see the change process of the imaging effect of the pipeline defect clearly, keeping the spacing of the array elements of the array unchanged, and change the number of array elements to 16,24,32,48 and 64. The 16-elements defect echo signal diagram is shown in Figure 2. TFM imaging of pipeline defects under different array elements is shown in Figure 3. The API value and imaging time under different array elements are calculated and recorded in Table 1.

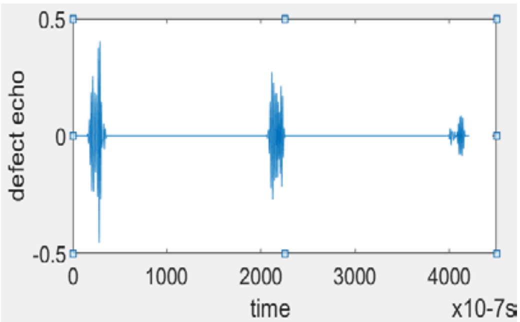

Figure 2 16-element pipeline defect echo signal diagram

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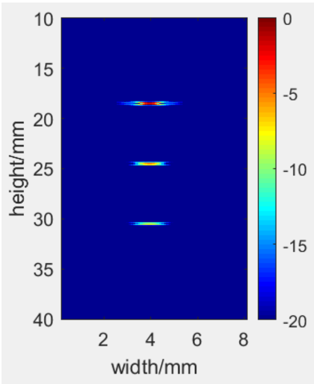
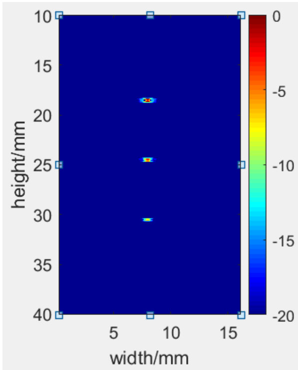
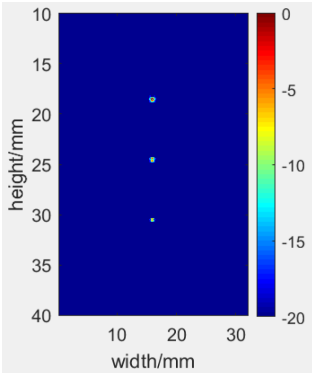


(a) 16-elements



(b) 32-elements



(c) 64-elements

Figure 3 TFM imaging of pipeline defects under different array elements

Table 1 API and imaging time values under different array elements

Number of array elements	*API*	*Imaging time (s)*
16	5.61	0.08s
24	4.46	0.25s
32	3.83	0.61s
48	3.32	2.00s
64	2.81	4.70s

It can be seen from Figure 3 that the TFM imaging of the pipeline defect changes as the number of array elements changes. When the number of array elements is 16, the defect's imaging effect is poor, the shape is long and the defect is not easy to identify; when the number of array elements increases to 64 array elements, the defect's imaging effect is great improvement. As can be seen from the API values in Table 1, as the number of array elements increases, the API value gradually decreases, the imaging time increases, and the imaging resolution of the defect

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improves. However, comparing the API of 48 and 64 array elements, the values are not much different, but the imaging time is greatly improved. As can be seen from Figure 2, as the depth of the defect continues to deepen, the echo signal of the defect gradually weakens. Figure 3 also shows that the imaging effect of the defect gradually deteriorates from top to bottom, and the image resolution is obviously reduced.

4. Conclusion

In this paper, TFM imaging technology based on phased array pipeline defect detection is proposed. The program is written and simulated on the Matlab + Field II simulation software platform. API and imaging time are used to evaluate the effect of the TFM imaging. During the simulation, three pipeline depth targets with different depths were set, and the imaging effect was observed by changing the number of array elements. From the simulation results, it can be seen that the effect of TFM imaging is related to the number of array elements. As the number of array elements increases, the imaging resolution increases; the effect of TFM imaging is related to the depth of pipeline defects. As the depth of the defect increases, the imaging resolution decreases; while improving the imaging effect, it is necessary to consider the time cost and choose the number of array elements reasonably.

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