TOFD-Scan Imaging Based on Synthetic Aperture Focusing Technique

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Abstract

In the field of ultrasonic nondestructive evaluation of the welds of pressured vessel or pipe, determination of location, shape, size and orientation of defects plays more and more important roles. Ultrasonic imaging has been more important than conventional testing technique based on pulse echo amplitude. Time of fly diffraction technology (TOFD) has been proved be more accurate to measure the location of defect end points. But no matter using the pulse echo (PE) method or TOFD method, the image obtained first is a fuzzy result because of the law of ultrasound propagation. In this paper signal model of TOFD scanning and the B scanning of PE method has been discussed. The synthetic aperture focusing algorithms of time domain(TD-SAFT) and frequency domain (FD-SAFT) are used to enhance the quality of scan image. Based on general algorithms, the affection of the weighted factor and propagation function have been discussed. A sparse array method serves to raise the calculation speed. After all, a relatively clear image can be obtained with a simple scanning associate with SAFT algorithms.

Keywords: ultrasonic imaging, SAFT, TOFD, B-scan

Introduction

In the field of ultrasonic nondestructive evaluation of the welds of pressured vessel or pipe, determination of location, shape, size and orientation of defects plays more and more important roles. Ultrasonic imaging has been more important than conventional testing technique based on pulse echo amplitude. Time of fly diffraction technology[3] (TOFD) has been proved be more accurate to measure the location of defect end points. But no matter using the pulse echo (PE) method or TOFD method, the image obtained first is a fuzzy result because of the discipline of ultrasound propagation. The synthetic aperture focusing technology (SAFT)[1],[2] has been used to enhance the quality of ultrasonic images.

The synthetic aperture focusing technology (SAFT) seems two meanings. First, take ultrasonic inspections of many smaller pies-electric elements at ordered position

as one single inspection of a larger ultrasonic transducer. On the second, take the actual testing facts that each transducer element transmits and receives the echo signal one by one as if they work synchronously. It is simple to obtain the testing signal, using a wide oriented transducer element scan alone the line, record the testing signal of every position. Take a group of signals of scan position as a phased array, dynamically focused on the point you care. In other words to add the signal of each element at the time of pulse arriving the receivers. The presentation is as follows:

$$I(x, y) = \sum_{x_s=x-\beta(y)}^{x_s=x+\alpha(y)} S(x_s, t(x, y, x_s)). \quad \text{---(1)}$$

I(x,y) is the scatter insensitivity pulse response at point (x,y), which relevant to the varies of acoustic damping. $S(x_s,t)$ presents the testing signal as a function of time of flying(from transmitting transducer at scan position x_s to point (x,y) and from the point to the receiving transducer of scan position x_s.

Time of fly diffraction (TOFD) technology uses a wide oriented transducer to transmit an ultrasonic wave to the area which is being tested, and uses another transducer locate with a pitch to the transmit one to catch scattering signal from the cared area. The reflection wave from crack face has a concentrated orientation, but the diffraction wave is widely oriented. This method can prevent to receive the strength reflection signal, and receive the weak diffraction signal from the tips of defects or cracks. From the time of flying of the ultrasonic propagation, the depth of the crack tips can be estimated. High accuracy of crack tip depth measurement have made TOFD technique widely used in nondestructive testing. TOFD technology requires the testing system record the raw data with scan position, and can illustrate the testing data in a B-scan image. But because of the wide overlay of depth dimension with one transducer, the diameter of the transducer must be small, so the lateral overlay of the same transducer element is rather wide. As a result, the image of TOFD is more fuzzy in lateral direction. And SAFT technique is appropriate to process the imaging data of TOFD testing.

Scan mode and algorithm

From the equation (1), it is obviously that the time of fly(TOF) is the key of SAFT algorithm. When we test workpiece with a one dimension scan, we get an imaging data record which is called B-scan. Following we discuss several model of scanning.

If the ultrasonic wave propagating direction is perpendicular to the scanning line. The presentation of the time of fly is just as follows:

$$t(x, y, x_s) = \sqrt{\left(\frac{2(x_s-x)}{c}\right)^2 + y^2}. \quad \text{---(2)}$$

x_s is the probe scan position; (x,y) is the coordinate value on the image. C is the propagation speed of ultrasonic wave.

The straight probe B-scan(SB-scan), angle probe non-parallel B-scan(D-scan),

non-parallel TOFD(NP-TOFD) scan and so on, many particular scanning method fit this equation(2).

When the ultrasonic direction and the scan in a same plane. Pulse echo testing has another time of fly presentation:

$$t(x,\ y,\ x_s) = \left(\sqrt{\left(\frac{2(x_s-x)}{c}\right)^2 + y^2} - \frac{4(x_s-x)y\sin(\theta)}{c}\right)。 \quad \text{---(3)}$$

θ is the refraction angle of ultrasonic wave.

It is useful to test the weld area with this parallel B-scan(PB-scan) method. The image presents the weld saw cross section which is helpful in characterizing of defects.

With the situation of parallel TOFD scan(P-TOFD), time of fly presentation is as follows:

$$t(x,\ y,\ x_s) =$$

$$\left(\sqrt{(a+x_s-x)^2 + \left(\frac{yc}{2}\right)^2 - a^2} + \sqrt{(a-x_s+x)^2 + \left(\frac{yc}{2}\right)^2 - a^2}\right)/c \quad \text{---(4)}$$

a is half of the probe center space(PCS).

Parallel TOFD scan presents the crack tip imaging within weld saw cross section.

SAFT algorithms enhances the lateral resolution of B-scan image. Besides this some other methods can be take to enhance the performance of imaging or speed up the calculation.

Lateral resolution of the SAFT process result is determined by effective aperture size and wavelength of ultrasound. If at a scan position, transducer element cannot reach the destination point, it will give no contribution to the focusing. To enhance the affect of effective aperture element, a weighted SAFT algorithm (WSAFT) is presented as follows:

$$I(x,\ y) = \sum_{x_s=x-\beta(y)}^{x_s=x+\alpha(y)} S(x_s,\ t(x,\ y,\ x_s)) \times W(x,\ x_s)。 \quad \text{---(6)}$$

The weighted factor:

$$W(x,\ x_s) = e^{-\frac{(x-x_s)^2}{r^2}} \quad \text{---(7)}$$

r is the aperture size.

With large aperture , calculation will be slow. Skipping the transducer elements in the aperture can reduce calculation amount and speed up the processing with a slightly influence to the lateral resolution .

Experience result

To evaluate the affection of SAFT processing on TOFD testing, we prepare three

test blocks to scan with different mode.

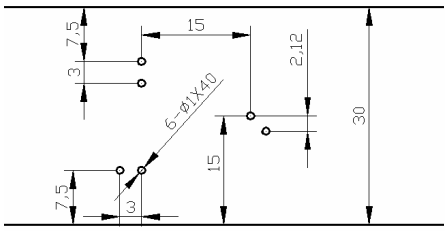
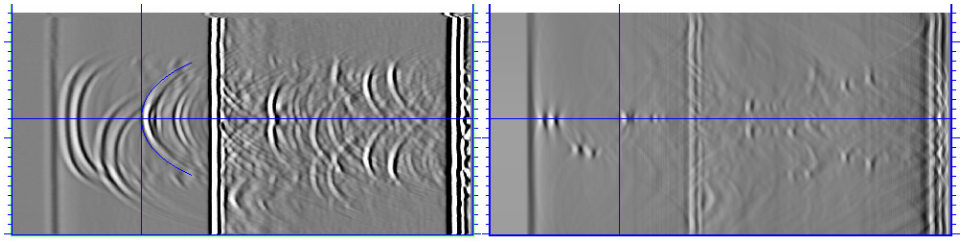
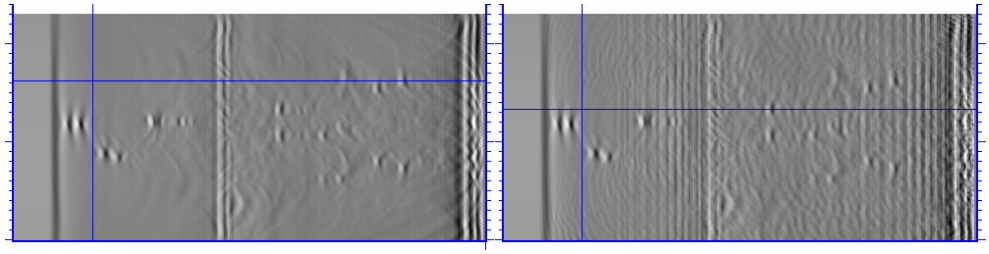


Fig.1

Block 1# is as fig.1, the thickness is 30mm; Three pairs of side hole of 1mm diameter were drilled. The distance between the paired hole is 4mm. SB-scan , PB-scan , P-TOFD has been taken . Test data and processing results are illustrated in fig.2. the scale of probe scan direction is 5mm/div.



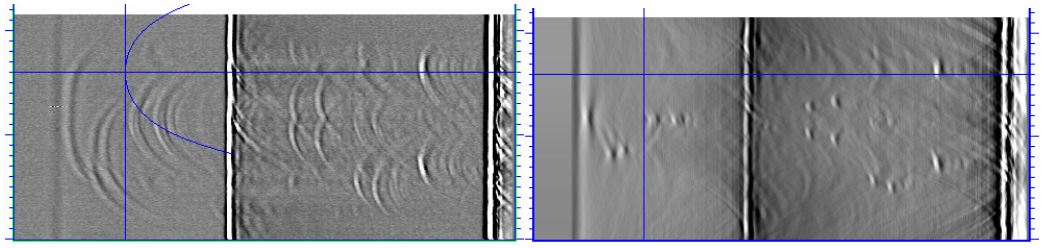
(a) P-TOFD of block 1# (b)after SAFT of (a)



(c) after W-SAFT of (a) (d)after S-SAFT of (a)

Fig.2

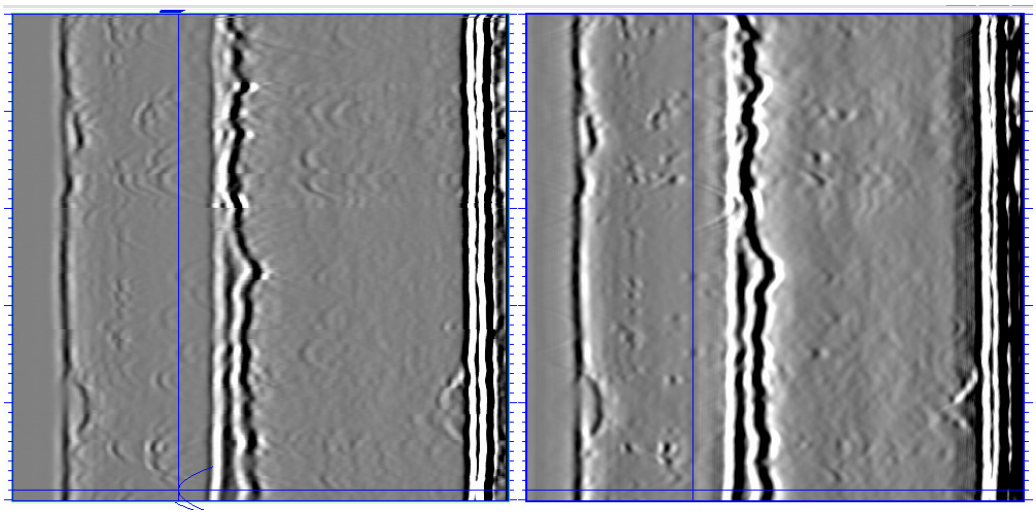
Fig.3 shows the situation when data was recorded with a low signal to noise ratio(S/N) on block 1#. The image is still clear after SAFT processing. one of the advantage of SAFT is the enhancement of signal to noise ratio(S/N).



(a) (b)

Fig.3 P-TOFD of block 1# with low S/N; (b) after SAFT of (a)

Fig.4 shows image of TOFD scan and SAFT process result of weld saw block 2#, which is 25mm thick and with two surface crack. There are many small bores in the weld. The image after SAFT processing is more easy to read.

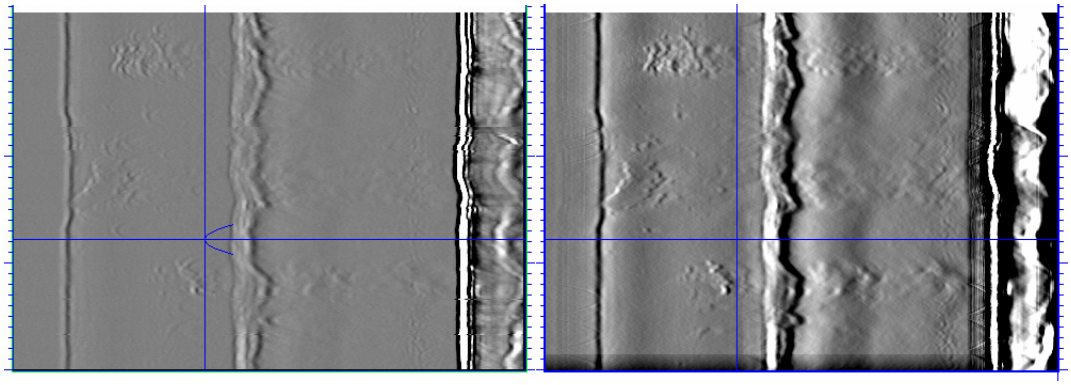


(a)

(b)

Fig.4 (a)NP-TOFD of block 2#; (b) after SAFT of (a)

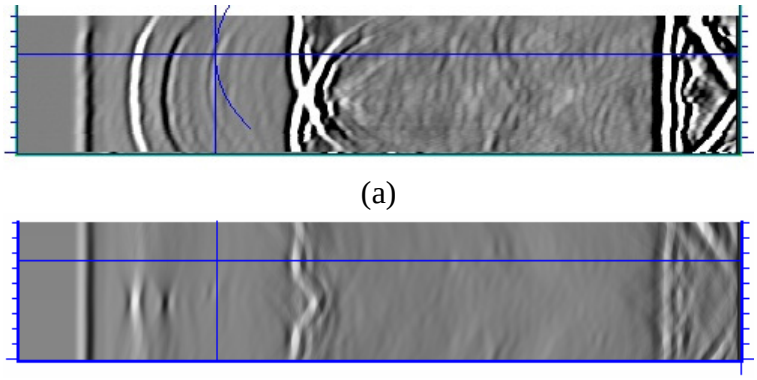
Block 3# is also a weld saw block with defects. The thickness is 30mm. D-TOFD and P-TOFD has been taken . Testing data and processing results are illustrated in fig.5 .and fig.6



(a)

(b)

Fig.5 (a)NP-TOFD of block 3#; (b) after SAFT of (a)



(a)

(b)

Fig.6 P-TOFD of block 3#; (b) after SAFT of (a)

From Fig.2, we compare the result of different processing, the influence of weight factor to the lateral resolution is ignorable. But it will take a lot of processing time. Sparse array element can speed up the processing and slightly influence the lateral resolution. But S/N of the image will fall down.

Conclusion

TOFD scanning can take out the image of defect end tips. But the fuzzy affection of complex situation makes it difficult to read the image. And the very small defects will be indicated as same as the large defects. The problem of TOFD is too sensitive. SAFT processing enhance the lateral resolution of TOFD image. It is helpful in ultrasonic testing to diminish the indication of small defects in the record of ultrasonic testing. The application of SAFT in P-TOFD scan has more potential .

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