Improving Defects Imaging Resolution for Lamb Waves based on SAFT Algorithm

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Abstract. This paper developed an inspection and imaging system based on the theory of synthetic aperture focusing technique. Ultrasonic Lamb waves are applied in this system to detect the damage in the plate-like structures. Single mode Lamb wave was generated by electromagnetic acoustic transducers to reduce the influence of the multi-mode properties. This paper takes the advantage of the synthetic aperture focusing technique algorithm by performing the algorithm in the Fast Fourier domain to improve defects imaging resolution. This algorithm has been applied in an aluminum plate by detecting defects using A0 Lamb wave. 1 mm deep by 3 mm wide slot was machined into the plate to simulate defects. EMATs are carried by one guide rail with 0.05mm scanning accuracy to scan damage area to improve the defects imaging resolution. The best matched excitation frequency of A0 mode is confirmed as 132KHz through Lamb waves dispersion curves. The synthetic aperture focusing technique algorithm is developed in the Fourier domain to make the algorithm efficient and computation intensive and to benefit from Fast Fourier domain algorithm to reduce the processing time. The results show that the defects on the aluminum plate can be clearly detected and the improvement of the image resolution using the improved SAFT is about 20% compared with traditional SAFT algorithm.

1. Introduction

Ultrasonic guided Lamb waves are widely applied in the Non-Destructive Testing for the inspection of plate-like structures. Lamb waves can detect crack defects on the surface and inside the plate-like structures because of the energy of the Lamb waves exists in the thickness direction of the plate-like structures. Compared to the other ultrasonic guided waves, Lamb waves possess the advantages of fast propagation speed, less attenuation and sensitive to defects. However, there are still many difficulties to apply Lamb waves to the Non-Destructive Testing for the inspection of plate-like structures [1]. The multi-mode characteristics and dispersion characteristics of Lamb waves generated by the EMATs and the analysis of defect signals have been the focus of scholars [2,3]. Moreover, generating single Lamb mode in the plate-like structures is also quite difficult [4,5]. Therefore, Lamb waves inspection needs convenient imaging algorithm to improve defects imaging resolution.

Synthetic Aperture Focusing Technique (SAFT) is one of the suitable algorithms to improve defects imaging resolution [6]. The SAFT is very flexible to suit different detection materials [7]. Time-Domain topological energy imaging method of concrete cavity defect is proposed to address artifacts in the results of traditional ultrasound imaging methods [8]. A new SAFT of ultrasonic guided wave-based circumferential scanning of plates is proposed to suit the tanks [9], and it is superior to the traditional SAFT in both angular resolution and calculation efficiency.

This paper focusses on improving the defects imaging resolution based SAFT for the aluminum plate using EMATs generating Lamb waves. In contrast to the traditional SAFT, this paper performs the SAFT in the Fourier domain and therefore to benefit from the advantages of the fast Fourier transform (FFT).

2. SAFT Processing Algorithm

The principle of the SAFT algorithm is shown as Fig.1. The EMAT transducer scans the scanning area in the same step according to the scanning direction. EMAT transmits and receives Lamb waves at the same time. If a point-like defect P presents at the scan area, this defect will re-radiate the acoustic field. We assume that the echo signals received by the EMAT is $S(x, y, t)$, the peak arrives at the time $t = \frac{d_i}{v}$, where the d_i is the distance which the Lamb waves propagates and the v is the velocity of the Lamb waves in the plate-like structure.

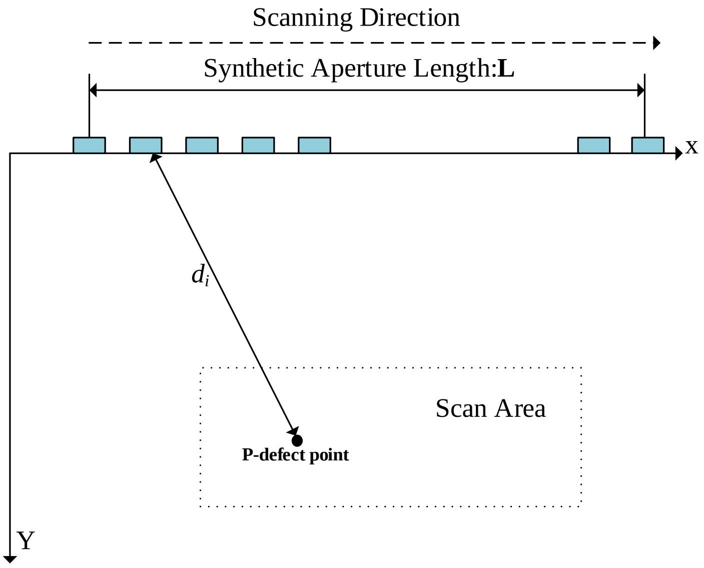

Figure 1. Principle of the SAFT algorithm

Then, the summation is shown as follow:

$$\sum(P) = \sum_n S(x, y, t = \frac{d_i}{v}) \tag{1}$$

Although this SAFT data processing is straightforward in its principle, it is not very efficient and computation intensive. However, this SAFT data processing can take advantage of the fast Fourier transform (FFT).

This improving SAFT algorithm is a backpropagation technique. According to the Fig.1, we assume that the received Lamb waves from the EMAT is $S(x, y, t)$, where the x is the position of the EMAT along the scanning direction, y is the distance from the scanning direction, t is the time. Then, we perform the Fourier transform on the $S(x, y, t)$ with respect to the (x, t), the expression is shown below:

$$FFT(S(x, y, t)) = \bar{S}(k, y, \omega) \tag{2}$$

Assuming that the defect is designed at the distance y, the transformed $\bar{S}(k, y, \omega)$ should multiply the $\exp(2\pi iky)$ to reduce the spatial phase shifting, the expression is shown below:

$$\bar{S}(k, y, f) = \bar{S}(k, 0, \omega)exp(2\pi iy\sqrt{\frac{f^2}{({}^{Vp}/_{2})^2} - k^2}) \tag{3}$$

Then, the processing signal is performed a summation over the frequency, the expression is shown below:

$$\check{S}(k, y) = \sum_f \bar{S}\,(k, y, f) \tag{4}$$

Performing the inverse spatial Fourier transform with respect to variable k , the final expression is shown below:

$$B(x, y) = IFT(\check{S}(k, y)) \tag{5}$$

3. Experimental Setup

The Fig. 2 shows the configuration of the experimental setup carried on a 1-mm-thick aluminum plate (1000mm*1000mm*1mm). The excitation toneburst signal is generated by the RIGOL DS2202A, and the signal is amplified by the US 2100L Power Amplifier. The received signal is also amplified and shown on a digital oscilloscope.

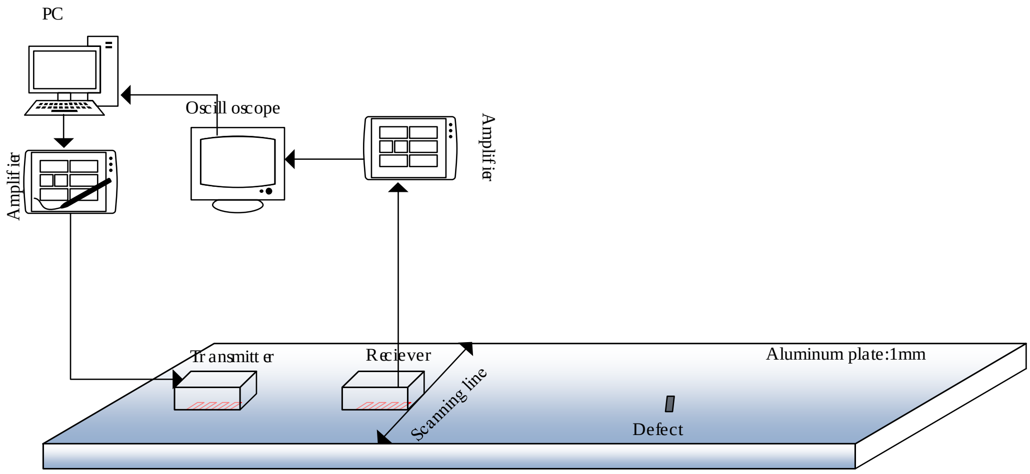

Figure 2. Experimental setup

The Fig. 3 shows the configuration of the defect. The defect is a 1mm deep by 3mm wide slot in the plate. The A0 Lamb wave mode is generated by the EMATs at the frequency 132KHz using meander coil. The scanning increment of the EMAT is 2mm, and the selected aperture length is 200mm. The waves were generated at proximately 40cm from the defect.

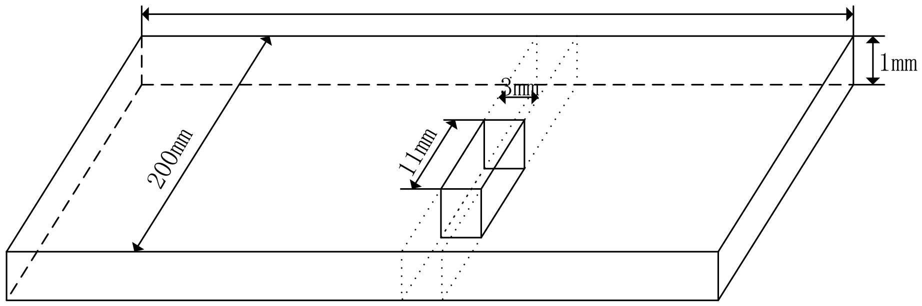

Figure 3. Defect configuration

The inspection parameters are given in table 1.

Table.1. The inspection parameters

Parameter	Value
Frequency	132KHz
Signal Numbers	100
Scanning Increment	2mm
Point Perl Signal	1400

4. Results and Discussion

The image resulting from improved SAFT processed image is presented in Fig.4. The image resulting from traditional SAFT processed image is presented in Fig.5. It can be seen from the Fig.5 that the defect is not clearly imaged and the defect is not presented at the expected distance. However, in the case of the improved SAFT method, the defect is clearly imaged and the defect is presented at the expected distance (about 41cm).

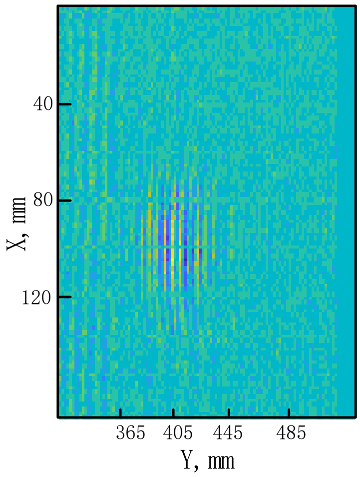

Figure 4. Improved SAFT processed image

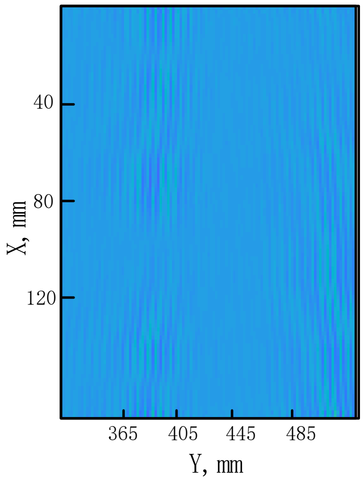

Figure 5. Traditional SAFT processed image

The dimensions of the defect are listed in table 2. These dimensions are measured on the figures using the MATLAB "ginput" function.

Table.2. The dimensions of the defect

Parameter	Value
Length	15mm
Depth	41cm
Shape	Slot

The length of the defect detected by the traditional SAFT is about 19mm. Therefore, compared with the traditional SAFT, the improvement of the image resolution is around 20%. The results show the ability of the improved SAFT to increase the image resolution using the meander coil EMAT equipment. This improved SAFT can also be applied to detect the defect in the plate-like structures.

Conclusion

This paper shows the improved SAFT to be used to improve defect resolution in the plate-like structures with the equipment of meander coil EMAT. The improved SAFT can clearly image the defect compared to the traditional SAFT, and the image resolution is 20% improved. Although this improved SAFT does not show the precision of the imaging, it is expected that this algorithm can work properly and this technique can be applied into the meander coil EMAT equipment, which can enhance the defect detection and evaluation potential.

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