A$_0$ Mode Excitation and Defect Detection in Aluminum Beam Structure

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Abstract. As a method to realize the defect detection in beam structure, this paper constructs an EMAT-laser detection system to detect the notch defect in an aluminum beam. EMAT is designed as a transmitter to generate single Lamb wave mode. A high precision laser detector is used as a receiver to obtain the received signals. The defect is localized and quantified with the help of space-frequency-wavenumber analysis. The evaluated depth of the defect is 2.006 mm, while the actual size is 2 mm. It shows good agreement between the evaluated result and actual size, the error is only 0.3%. This method also can be used in the evaluation of defect in other materials.

Keywords: EMAT; Lamb wave; Beam; Defect; Space-frequency-wavenumber.

1. Introduction
Ultrasonic guided wave has been widely used in the field of nondestructive testing and structure health monitoring due to the advantages of high speed, long distance, wide range and relatively low cost, especially for some typical industrial structures, such as plate, beam, pipe, bar and so on. Among kinds of guided wave excitation method, Electromagnetic Acoustic Transducer (EMAT) and laser have the advantages of noncontact, no need of couplant and flexible designability [1-3]. Li et al. [4,5] designed an EMAT based on Lorentz force mechanism according to the guided wave dispersion curve by changing the finger space of the coil, which is respectively used for excitation and reception of a single Lamb wave mode in plate and pipe. Laser detector also has the characteristics of non-contact. The optical performance of laser also determines the high brightness and high precision characteristics. For this reason, many researchers do study on EMAT-laser system to detect defects [6,7]. Gliha et al. [8] studied the behaviour of cracks upon the residual-stress field. However, these studies are all about defect detection in plate structure, and they all take laser detector as transmitter, EMAT as a receiver. Seldom researchers use EMAT-laser system focusing on defect detection in beam structure. Therefore, this paper constructs an EMAT-laser system on notch type defect detection in aluminum beam structure. In this system, the self-designed EMAT is a transmitter to generate single Lamb wave mode, and the high precision laser detector performs one-dimensional scanning on the notch defect area in the aluminum beam structure. The received signal is analyzed by using short-space Fourier transform, so as to realize the notch defect detection in the aluminum beam structure.

2. Theory of Generation of Single Lamb Waves
EMAT is consist of magnet, coil, and test specimen. The magnet is used to provide a bias static magnetic field, the coil is powered by high frequency alternating current, and the test specimen is used
as a waveguide to propagate guided wave. Spiral coil, meandered line coil, and runway coil are the most common coils.

According to reference [4], this paper uses an EMAT based on the Lorenz mechanism. For this type EMAT, the finger space $D$ determines the wavelength $\lambda$ of generated Lamb wave mode.

$$\lambda = 2D$$

To a single Lamb wave mode, the relationship between wavelength $\lambda$, phase velocity $c_p$, and frequency $f$ is

$$\lambda = \frac{c_p}{f}$$

By dividing the thickness $d$ of the beam, equation (2) can be changed into

$$\frac{\lambda}{d} = \frac{c_p}{(fd)}$$

Figure 1 shows the dispersion curve of phase velocity in a 3 mm beam. A straight line with slope $\lambda/d$ is also depicted in this figure. According to these crossover points and equations (1)-(3), a single Lamb wave mode can be excited.

**Figure 1.** Dispersion curve of phase velocity of a 3 mm aluminum beam.

The test specimen in this study is a 3mm aluminum beam. A0 mode and excitation frequency 410kHz are chosen to have a detection on this specimen. Based on the principle of generation of single Lamb wave mode, the finger space of the meandered coil should be 3mm, as shown in figure 2.

**Figure 2.** Photo of the meandered coil.

3. **Experiment Setup and Sample**

The experiment setup is shown in figure 3(a). The test specimen is shown in figure 3(b), its dimension is 1000mm×30mm×3mm. It has a through-width notch of 10mm length, 2mm depth, which is located in the middle. EMAT is placed on the opposite side to the defect, and 250mm away from the end of the beam. The bias static magnetic field is generated by the Neodymium magnet (NdFeB), which size is 30mm×25mm×15mm. The laser detector starts to receive signal from 450mm, end in 550mm, with a 1mm step size, as shown in figure 3(c).
4. Results and Discussion

4.1. Generation of Single $A_0$ Mode

Figure 4 shows the time history waveform at $x=450\text{mm}$. The first wave packet is a crosstalk signal, the second wave packet is the incident wave. A Hilbert transform is performed to get the experimental arrival time of the incident wave, which is $74.24\mu\text{s}$. The theoretical arrival time of $A_0$ mode calculated from Disperse software is $69.268\mu\text{s}$. Thus, it can be verified that a single $A_0$ mode is generated.

![Figure 4. Time history waveform at $x=450\text{mm}$.]
4.2. Quantified Detection of the Notch

The space-frequency-wavenumber analysis is employed to perform a data processing with these received time domain signals. Figure 5(a) shows the time-space wavefield of received signals. It can be seen that an incident wave is propagating $x=450\text{mm}$ to $x=550\text{mm}$. Besides this, it is difficult to get other useful information. Figure 5(b) plots the resulting space-wavenumber spectrum after performing space-frequency-wavenumber analysis on the time-space wavefield. From the space-wavenumber spectrum, a symmetric distribution of wavenumber is found between $x=450$ to $x=510\text{mm}$, the positive wavenumber represents incident wave, while negative wavenumber represents reflected wave. A sudden increase tendency is happened at $x=500\text{mm}$, and it means the existence of defect. In the area of $x=510\text{mm}$ to $x=550\text{mm}$, only positive wavenumber exists, it means there only has transmitted wave. According to the wavenumber of reflected wave, it can be concluded that the notch defect appears approximately from 500mm to 510mm.

![Space-wavenumber spectrum](image)

**Figure 5.** The received signals (a) Time-space wavefield (b) Space-wavenumber spectrum.

By extracting the max wavenumber at each distance of the space-wavenumber spectrum, as shown in figure 6. The max wavenumber ($k=1.466\text{rad/mm}$) is chosen as a reference to calculate the thickness of defect area, and the corresponding phase velocity is $1757\text{m/s}$. According to figure 1, the frequency-thickness product should be $407.4\text{kHz}\cdot\text{mm}$ of $A_0$ mode. Then the thickness is evaluated as $0.994\text{mm}$, i.e. the depth of the notch is $2.006\text{mm}$. It matches with the actual machined size very well. The error is only $0.3\%$.

![Space-wavenumber curve](image)

**Figure 6.** Space-wavenumber curve extracted from space-wavenumber spectrum.

5. Conclusions

In this work, an EMAT-laser detection system is constructed to detect the notch defect in aluminum beam structure. The $A_0$ mode is generated, and space-frequency-wavenumber analysis is employed to quantify the notch. The evaluated depth only has an error of $0.3\%$ with the machined size. This
method has a high sensitivity on quantifying the depth of notch defect. Since the wavenumber only related to the thickness of the plate, the width of the crack will not affect the sensitivity.

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