LASER GENERATION OF FOCUSED ULTRASONIC WAVE

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ABSTRACT. An arc-shaped line array slit is used for the laser generation of focused laser-ultrasonic wave. The spatially expanded Nd: YAG pulse laser is illuminated through the arc-shaped line array slit on the surface of a sample to generate the ultrasonic wave of the same pattern as the slit. Then the generated ultrasonic wave is focused at the focal point of which distance from the slit position is dependent on the curvature of slit arc. The relationship between the characteristics of the generated ultrasonic wave including the focusing performance and several design parameters such like as slit width and slit interval are investigated. By using the focused wave we can upgrade the inspection ability for the small size defect with the improvement of spatial resolution. Also this method can be combined with the scanning mechanism to get image just like we can get by the scanning acoustic microscope (SAM)

INTRODUCTION

Lamb waves are guided elastic waves propagating in plate structures parallel to the boundary surfaces[1]. The propagation of these wave modes allows for the inspection of plates and strip materials along the length of the sample thus providing for the possibility of a considerable saving in time over a C-scan of the sample[2]. Recent years have seen considerable application of Lamb wave testing applied, for example, to defect detection in metal[3], composite plates[4,5], sheet thickness measurement[6], elastic constant evaluation[7] and bonded metal joint inspection[8]. The usual method of launching Lamb waves is to utilize a compression transducer coupled to sample plate with a matching wedge such that effective spatial matching into the desired Lamb wave mode is obtained[1]. An additional technique is to employ laser generation[9]. Attractive features of a laser-ultrasound source include its non-contact nature, reproducibility, broad bandwidth and capability to launch a variety of acoustic modes. Preliminary work on laser-acoustic sources was conducted by White[10] using a pulsed ruby laser. But, in these methods, laser generated Lamb waves had wide bandwidth frequency, low directivity, and low sensitivity. Several techniques have been investigated to increase the amplitude and narrow the bandwidth of laser generated signal. One approach is temporal modulation of the laser source[11]. Another method is controlling the shape and phase of the laser source to generate Lamb waves with narrow band and high directivity. Line array slit was used to generate narrow-band, high-directivity wave[12]. In his paper, arc-shaped line array slit was used to generate focused Lamb wave. This technique can upgrade the inspection ability of conventional line array slit for the small size defect with the improvement of...
spatial resolution and be combined with the scanning mechanism to get image just like we can get by scanning acoustic microscope (SAM).

EXPERIMENTAL ARRANGEMENT

FIGURE 1 shows the experimental arrangement for the laser generation of focused Lamb waves in the sample plate. The source laser was a Q-switched Nd:YAG laser system. The diameter of the laser beam was extended to about 20 mm by a beam expander. Extended laser beam transmitted through an arc-shaped line array slit and generated ultrasonic source as same shape of the slit on the sample plate. The sample was an aluminum plate with 2 mm thickness. The ultrasonic waves generated by the laser source was detected by a pinducer, and the wave signal was monitored by oscilloscope. A standard GPIB data interface allowed signals to be transferred from the oscilloscope to a personal computer for subsequent data processing and storage.

DESIGN OF ARC-SHAPED SLITS

Three parameters of arc-shaped slits were determined. The parameters are slit space, slit number, and focusing length of arc. In first step, we determined slit space. In this step, taking the sensitivity of detector into consideration, we determined the frequency of ultrasonic wave generated by slit. From the frequency, we determined the wave length with dispersion curve (FIGURE 2). Generally, A0 mode is generated dominantly so that we have tried to generate A0 mode, and its wavelength was determined from the relationship between the frequency and wavelength which is given by

\[ V = \left( \frac{\lambda}{d} \right) \times (f \times d) \]  \hspace{1cm} (1)
FIGURE 2. Lamb wave phase velocities in an aluminum plate.

Where, $V$ is phase velocity of the wave, $\lambda$ is wavelength, $d$ is thickness of the plate, $f$ is frequency of the wave. As frequency is selected and the thickness of the plate is determined when we select the plate, from the dispersion curve at FIGURE 1, we can find the velocity of the wave. In here, the thickness of the plate is 2mm, frequency is 1.75MHz. At the dispersion curve, phase velocity of the A0 mode Lamb wave is about 2.8km/s. By substitute velocity, and frequency in equation (1), the wavelength was determined as 1.5mm and this become space between slits.

In the next step, number of slits was determined. Many slits make frequency-bandwidth narrow, but laser spot diameter was limited as 10~20mm. So, too many slits were not needed. Generally, the number of slits $N$ is

$$N = \frac{D_s}{\lambda} + 2,$$

where $D_s$ is laser spot size on the slit array. because the wavelength was determined in the former step, we can determine the number of slits by the equation (2).

Lastly, The focal length of the slits was determined from radius of arc.

**LAMB WAVE SIGNAL GENERATED BY ARC-SHAPED SLIT**

Typical signals recorded at the focusing point are shown in FIGURE 3 with STFT contour plot. Peak frequency of signal generated by slit space 1.5mm was about 1.75MHz, and it was about 600kHz when the slit space was 4mm. It shows that frequency of the Lamb wave generated by the arc-shaped slit array was determined by slit space as we designed. From the contour plot of STFT, we can find that A0 mode Lamb waves were dominantly generated. More intensive ultrasound was generated from the slit array which have 4mm slit-space than 1.5mm slit-space.

To verify that the arc-shaped line array slits were generating focused wave in a satisfactory manner, experiments were performed on an aluminum test plates of 2mm thickness. A 1.75MHz pinducer was moved from point to point as seen in FIGURE 4 to detect the Lamb wave signals and peak to peak value of the signal was measured at each points. Simulation using simple scalar diffraction theory was performed to compare with this experiment. FIGURE 5 shows the result. The experimental result and simulation
FIGURE 3. Lamb wave signal and its contour plot of Short Time Fourier transform. The focusing length of the arc was 35mm, the thickness of aluminum sample plate was 2mm.

FIGURE 4. Lamb wave detection points to verify generating focused wave. The pinducer located on these points and amplitudes of the Lamb wave signals were measured. The spaces between the points were 5mm.

FIGURE 5. Wave intensity distribution measured at 5 points along three lines. (dashed : front, solid : center, dashdot : back)
FIGURE 6. Variation of frequency bandwidth as slit numbers.

result are similar in crossing points between the intensity distribution lines and side lobes. It shows that focused waves could be generated by the arc-shaped line array slits effectively.

FIGURE 6 illustrates Lamb wave signal which was generated by arc-shaped single slit to compare with waves generated by arc-shaped slit array. The wave generated by slit array have relatively narrow bandwidth and low frequency area was eliminated which represented in wave signals generated by single slit.

CONCLUSION

Arc-shaped slits were designed for generating the focused ultrasound. Intensity of ultrasound increases around the designed focusing point and it shows that the focused Lamb wave can be generated by arc-shaped array slits. It is expected that the focused Lamb wave generated by arc-shaped slit will be more effective to detect small size defect than conventional linear line array slit.

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REFERENCES