1P2-17

Proceedings of Symposium on Ultrasonic Electronics, Vol. 34 (2013) pp. 69-70
20-22 November, 2013

Research of Non-Contact Air Coupled Lamb Wave for thin plate testing and application
空中励起したラム波による薄板の測定技術及びその応用に関する研究

Junjie chang[1,2†], Katsumi Ohira[1], Yukio Ogura[1] and Chao Lu[2]
([1]Japan Probe co., Ltd; [2]Nanchang Key Laboratory of Nondestructive Testing (Ministry of Education), Nanchang Hangkong University)
常俊杰 [1,2†], 大平克己 [1], 小倉幸夫 [1], 卢超 [2]
([1] ジャパンプローブ株式会社, [2] 南昌航空大学無損検測技術教育部重点試験室)

1. Introduction

Presently, with the rapid development of aviation, aerospace, defense and automotive technologies, the demand of steel and aluminum sheet is growing in the industry areas. As the metal sheet is manufactured by several rolling process with large deformation, some silver defects or layered defects may be generated from the interaction of cavity or inclusion with the base material. Such these defects may not only reduce the mechanical property of the structures, but also induce serious accidents and cause a great loss to people`s life and property.　In order to ensure the quality of the projet, the non-destructive testing is used to measure these plates for quality control. It is difficult to detect the thin palates punched by dies with Conventional ultrasonic (longitudinal and transverse waves). However Lamb (plate wave) is an effective for detecting such kind of thin plates. For the small diffusion along the horizontal direction of long-distance communication, some foreign large steel companies have measured the plates by automatic testing using Lamb wave. However, current ultrasonic inspection method is using the contact transducer with coupling. Therefore, it is difficult to be used for automatic detection(1-2).

Air-coupled ultrasonic nondestructive testing, with non-contact, non-intrusive, and rapid online scanning characteristics, becomes a very promising method in the detection and location of the thin plates. This paper describes the principle of Lamb waves excited in air, its dispersion curve and detection methods, and the solution to calculate the reflectance and transmittances ratios of leaked Lamb wave from plate to air. A simulation analysis and actual measurement have also been carried out. Finally, the air-coupled ultrasonic inspection system developed by us is applied in the plate detection.

2. Lamb wave excitation and Detection methods in air

Lamb wave's excitation in air and propagation in plate is shown in Fig.1. Lamb wave is guide waves which can be generated in a plate with obliquely incident longitudinal wave. Presently, Lamb wave is generally excited in the plate surface. When the ultrasonic wave propagates to the between air and plate, the Lamb wave can be generated in the plate. It can be deduced as:

$$\sin\theta = \frac{c_a}{c_p} \tag{1}$$

where θ is the incidence angle of longitudinal waves, c_a is the wave velocity in air, c_p is the phase velocity of Lamb wave in solid plate. Lamb wave can be divided into two mode, symmetric Lamb mode (S-mode) and asymmetric mode (A-mode), and their propagation speed is related to the nature of the solid plate and the product *fd* of the ultrasonic frequency *f* with the thickness of the solid plate d. Lamb wave propagation simulation by SWAN21 is shown in Fig.2.

Chimenti and Rokklin studied the calculation methods for Lamb wave's reflectance ratio when the ultrasonic wave propagation from liquid into steel plate. These theories can also be applied to air-coupled ultrasonic testing technology. When the ultrasonic wave propagates from the air into the solid plate, the reflectance ratio can be obtained by the following equation.

$$R = \frac{AS - Y^2}{(S + iY)(S - iY)} \tag{2}$$

where A is symmetrical method A0 mode and S is symmetry mode S0, which can be obtained by the following equations:

$$\text{S-mode:}\quad S = \frac{(q^2-1)^2}{q}\cot(kp\frac{d}{2}) + 4p\cot(kq\frac{d}{2}) \tag{3}$$

$$\text{A-mode:}\quad A = \frac{(q^2-1)^2}{q}\tan(kp\frac{d}{2}) + 4p\tan(kq\frac{d}{2}) \tag{4}$$

where, $p^2 = (c/c_l)^2 - 1$, $q^2 = (c/c_t)^2 - 1$, $k = \omega / c$, $\omega = 2\pi f$, *k*, *c* and d are wave number, phase velocity and thickness, respectively; the influence of air is determined by Y.

$$Y = \frac{\rho_a}{\rho}\left(\frac{c}{c_t}\right)^4 \frac{p}{qm} \tag{5}$$

where $m = (c/c_a)^2 - 1$, the subscript a is related to air, such as air density ρ_a and bulk wave velocity c_a in air. ρ is the density of steel.

----
chang@jp-probe.com

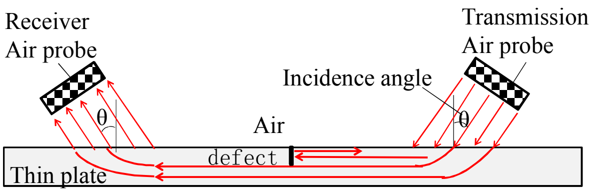

Fig.1 Lamb wave's excitation in air and propagation

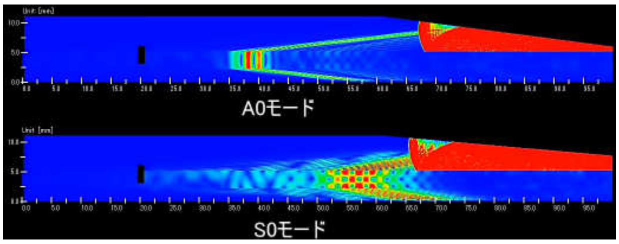

Fig.2 Lamb wave propagation simulation by SWAN21

3. Development of Image Equipment for NAUT

Fig.2 shows the non-contact air coupled ultrasonic detecting system for Lamb wave method. It is composed by computer, high-power ultrasonic pulser and receiver, high-speed encode and ultra-wideband air coupled probes and automatic scanner, control motor and memory module. The system can also realize the pulse compression and multi-path routing average. The transmission probe is fixed and the receiving probe can be moved along X-axis. The acoustic wave velocity in the plate can be averaged by changing the propagating distance.

Fig.3 System of non contact air coupled ultrasonic inspection (Lamb wave method)

4. Example and results

4.1 The transmittance curves of Lamb wave

As shown in Figure 4, 370 kHz ultrasonic wave is generated by the probe at the right. The Lamb wave is excited when the ultrasonic wave propagates from the air into the steel plate. Two receiving probes are placed symmetrically at the center line of the up and bottom sides of the steel plate with a distance of 10mm from the specimen surface, and 15 mm from the transmitter. By scanning the receiving probes along X direction with a step of 15 mm from the start position. Fig. 5 shows the normalized amplitudes of the received ultrasonic signals at different scanning positions. The solid line is the amplitude distribution of the sound field at the up side of the plate. The dotted line is the amplitude distribution of the sound field on the bottom of the plate. In Figure 5, it can be observed that the ultrasonic amplitudes between 15 mm and 30 mm at the top side of plate appear non-regular extrema, induced by interaction of incident wave with reflection wave at the top surface. However, the amplitudes of the sound field at the bottom side appear in a regular curve. It is interesting that the sound fields appear in different distributions at the same position from the plate surface. After 45mm the sound fields at the top side and bottom side become the same, and decrease with the increase of the propagation distance.

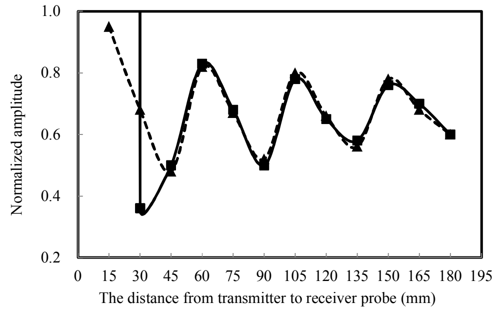

Fig.4 The transmittance curves of Lamb wave

4.1 Experiment result of Lamb wave

The experiment result is shown in Fig.5, the distance between the center of Air-coupled probe and the steel surface is 5mm. The distance between the transmitter and receiver is 30mm. The transmitter and receiver are arranged oppositely. The incidence angle is 7 degrees, and the receiver is also inclined in an opposite direction in angle of 7 degrees. Test specimen is 5mm thick steel plate with/without φ10 flat bottom holes in it.

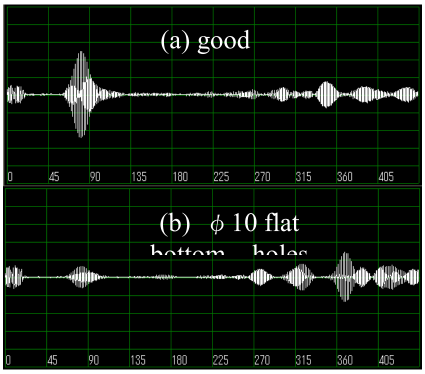

Fig.5 Experiment result with the Lamb wave

5. Conclusion

We have developed the Lamb wave inspection system using for online scanning, insitu-defects testing and automatic detection. The system consists of ultra-high power ultrasonic air coupled probes with the function of damping, pre-amplifier with large S/N. It obtains the pulse compression and multi-path routing average and enhance the S/N to a maximum value.

References

1. J. Chang:USE2012, Vol.30 (2012)427.
2. M. Takahashi: USE2011, Vol. 32 (2011) 69.