46th Annual Review of Progress
in Quantitative Nondestructive Evaluation
QNDE2019
July 14-19, 2019, Portland, OR, USA

QNDE2019-7023

ANALYSIS OF CRITICALLY REFRACTED LONGITUDINAL WAVES BASED ON FOCUSED TRANSDUCER

Zenghua Liu, Bin Zhao, Ning Pei, Xin Zhao, Cunfu He, Bin Wu
College of Mechanical Engineering and Applied Electronics Technology, Beijing University of Technology,
Beijing, China

ABSTRACT

Critically refracted longitudinal (LCR) waves can be applied to a variety of non-destructive tests (NDT) such as surface geometry characterization, subsurface defect detection, and primarily for residual stress measurements. Discussion the numerical and experimental characteristics of the LCR beam profile to optimize the incident angle selection to obtain sufficient energy. In the obtained results, all the components of the refracted sound field and the energy distribution of the LCR waves obtained with different incident angles were proved. However, since the parallel ultrasonic beam has a hole effect similar to that of the light, the energy is diverged during the propagation, and the loss is severe, so that the critically refracted longitudinal wave after the refraction is not strictly parallel to the interface of the medium. This paper aims to obtain LCR wave by using a focused transducer to refract propagation in different media. Modifying the relevant parameters to obtain better signal, that can be applied to various non-destructive engineering tests.

Keywords: ultrasonic stress detection, ultrasonic, LCR wave, focused transducer

1. INTRODUCTION

The LCR wave is generated by a longitudinal wave incident at a first critical angle, propagating only at the surface of the test piece against the interface of the medium, and characterizing the surface and subsurface features by the nature of the wave associated with the elasticity or defect characteristics of the material. The LCR wave is a body wave that propagates under the surface at the velocity of the longitudinal wave and is sensitive to a finite thickness stress field, usually used for stress detection [1].

In the theoretical study of LCR waves, the theoretical studies of Basatskaya and Ermolov are based on two-dimensional analytical calculations in the case of harmonics. The typical sound field of LCR was obtained by Langenberg in 1990 using numerical simulation of elastic finite integral technique [2]. The application of residual stress measurement using LCR waves is mainly carried out by Bray and Qozam [3]. S. Chaki et al. [4] characterized the ultrasonic sound beams in large volumes in the frequency domain, and the LCR waves did not propagate strictly along the surface.

In this paper, we study the characteristics of the LCR wave obtained by focusing the transducer's converged sound beam in different media, and optimize the relevant parameters to obtain the LCR wave actually propagating along the material surface as the theoretical situation.

2. MATERIALS AND METHODS

2.1 Ultrasonic stress detection theory

When ultrasound is transmitted from one medium to another, reflection and refraction will occur. For example, when a longitudinal wave is transmitted from water to steel, both longitudinal and transverse waves will be generated in the steel. The angles for the transmitted waves follow Snell's law:

$$\frac{C_{L1}}{\sin\alpha} = \frac{C_{L2}}{\sin\beta_L} = \frac{C_{S2}}{\sin\beta_S} \qquad (1)$$

where C_{L1} is the longitudinal velocity in the water, C_{L2} and C_{S2} are the longitudinal and transverse velocities respectively in the steel.

According to Snell's law, as the incident angle, α, increases the refraction angle will reach 90°. When β_L reaches 90°, it is called the first critical angle and a wave knows as the LCR or creeping wave forms, as shown in Fig. 1. In principal this LCR or creeping wave propagates parallel to the interface of water and steel, but in reality the wave is transmitted at an angle to the interface.

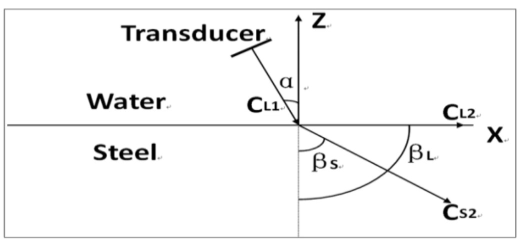

FIGURE 1. The generation of LCR waves.

2.2 Simulation Analysis of the Refraction Characteristics of Focused Acoustic Wave at Water-Iron Interface

A simulation model of the focal sound wave refraction at the water-iron interface was established using COMSOL software, as shown in Figure 2. The medium below is water and the medium above is iron. The parameters of iron are shown in Table 1. The sound speed in water is 1500m/s. The transducer diameter is 6.35mm. The excitation frequency of the signal is 2.25MHz. The time step of the simulation is 0.05μs.

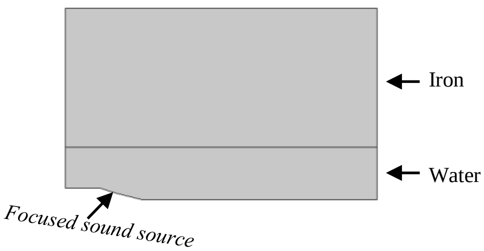

FIGURE 2. Sound field simulation model.

Table 1: Parameters of iron.

Density ρ (g/cm^3)	Young's modulus E (GPa)	Poisson ratio v	Wave velocity (m/s)	
			Longitudinal	Transversal
7.8	210	0.29	5940	3230

3. RESULTS AND DISCUSSION

According to the simulation results of COMSOL, the sound pressure data of the relevant points are extracted, and the longitudinal displacement amplitude distribution map of the refracted waves is plotted. The figure shows the distribution of the energy amplitude of the refracted waves after the sound waves pass through the water-iron interface. Figure 3 is a longitudinal displacement amplitude distribution diagram of a planar transducer. Figure 4 is a longitudinal displacement amplitude distribution diagram of a focus transducer.

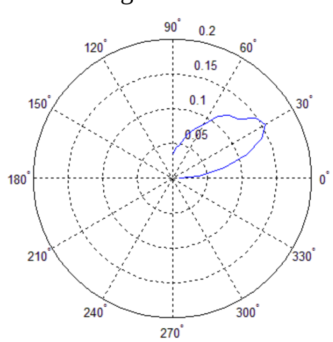

FIGURE 3. A longitudinal displacement amplitude distribution map of a planar transducer

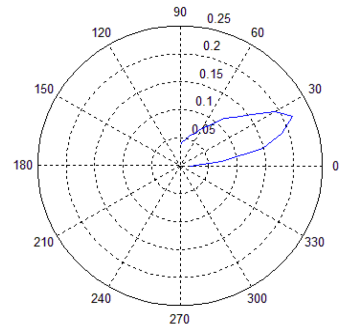

FIGURE 4. Focusing the longitudinal displacement amplitude profile of the transducer.

The longitudinal wave energy after the plane acoustic wave is refracted is concentrated in a region 30° from the interface. The longitudinal wave energy after the focus sound wave is refracted is concentrated in a region at 24° to the interface. The longitudinal waves refracted by the focused sound waves through the water-iron interface are more likely to propagate along the surface of the material.

4. CONCLUSIONS

The simulation model of the focused acoustic wave refraction at the water-iron interface simulates the process by which the focused acoustic wave from the focused transducer propagates through the water into the iron. A part of the sound waves are reflected back into the water, and a part of the longitudinal waves are refracted into the iron. The refracted longitudinal wave tends to propagate along the interface boundary, and its energy is more concentrated on the surface of the material.

Critical refracting longitudinal wave detection in ultrasonic testing is particularly suitable for stress detection of materials. Residual stress is more sensitive to critical refracting longitudinal waves. Acoustic waves excited by a planar transducer have sound wave divergence and energy loss during propagation due to the aperture effect. The use of a focusing transducer is easier to propagate along the surface of the material than the longitudinal wave excited by the planar transducer, making it easier to obtain critically refracted longitudinal waves. It is more convenient to detect stress with the critical refracting longitudinal wave generated by the focused sound field, and it has higher sensitivity.

ACKNOWLEDGEMENTS

The study was supported by the National Natural Science Foundation of China (Grant Nos. 11772014, 51475012, and 11527801).

REFERENCES

[1] Egle D M, Bray D E. *Measurement of acoustoelastic and third‐order elastic constants for rail steel* [J]. The journal of the Acoustical Society of America, 1976, 60(3): 741-744.
[2] Langenberg K J, Fellinger P, Marklein R. *On the nature of*

the so-called subsurface longitudinal wave and/or the surface longitudinal "creeping" wave [J]. Research in Nondestructive Evaluation, 1990, 2(2): 59-81.
[3] Bray D E, Stanley R K. *Nondestructive evaluation: a tool in design, manufacturing and service* [M]. CRC press, 2014.
[4] Chaki S, Ke W, Demouveau H. *Numerical and experimental analysis of the critically refracted longitudinal beam* [J]. Ultrasonics, 2013, 53(1): 65-69.