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Proceedings of Symposium on Ultrasonic Electronics, Vol. 32 (2011) pp. 331-332
8-10 November, 2011

Reflection and Transmission Behavior of Ultrasonic Wave at Micro gap Using Newton's Ring
ニュートンリング微小隙間における超音波の反射・透過挙動

Masaki Inoue[1], Tsuyoshi Mihara[2], Hatsuzou Tashiro[2], Takashi Furukawa[3] ([1]Graduate Student U-Toyama, [2]Graduate School of Eng. U-Toyama, [3]Japan Power Engineering and Inspection Corporation)
井上　将輝 [1],三原　毅 [2],田代　発造 [2],古川　敬 [3]（[1] 富山大(院), [2] 富山大大学院, [3] 財団法人　発電設備技術検査協会）

1. Introduction

Nondestructive guaranty for the strength of the aged structures have been applied using accurate ultrasonic flaw sizing techniques. Since the sizing accuracy is directly relate to the estimated strength, accurate behaviors of reflection and transmission at small gap become important. Up to now, basic behaviors of reflection and transmission at small gap using Newton's ring have been investigated [1, 2, 3]. From these investigations, reflection amplitude of the interface of air gap and glass plate began to decrease below the gap of 100 nm. Mechanisms of these behaviors are still uncertain and the experimental equipments of acoustic lens and convex glass for Newton's rings experiment might also be improved.

In this study, highly focused 20 MHz aspheric acoustic lens and the lager radius of convex glass for Newton's rings experiment are prepared for more accurate experiment. Addition to these, loading setup of the glass contact interface and air vent chamber also applied to investigate ultrasonic reflection and transmission behaviors of the interface of slight air gap.

2. Reflection coefficient at micro gap interface

The ultrasonic reflection coefficient of 3 layered interface of micro gap structure of normal incident is expressed by the equation (1) [4].

$$r=\frac{P_r}{P_i}=-\frac{\left(\frac{Z_1}{Z_3}-1\right)\cos k_2 d+j\left(\frac{Z_1}{Z_2}-\frac{Z_2}{Z_3}\right)\sin k_2 d}{\left(\frac{Z_1}{Z_3}+1\right)\cos k_2 d+j\left(\frac{Z_1}{Z_2}+\frac{Z_2}{Z_3}\right)\sin k_2 d} \qquad (1)$$

where $k_2=2\pi/\lambda_2$, λ_2 is wavelength of medium 2. As shown in Fig.1, acoustic impedance of the medium 1, 2 and 3 is Z_1, Z_2 and Z_3, gap of the medium 2 is d. In this experiment, medium 1 and 3 are glass and medium 2 is air. Fig.1 shows the relationship between the gap and reflection coefficient of glass/air gap interface using equation (1) for the frequency of 20 MHz. Although total reflection occurs when the gap is large enough, slight transmission could be obtained in case of micro gap interface. Since especially at the crack tip of a fatigue crack and SCC, crack opening recognize nm-order, this relation might be important for the understanding of an ultrasonic inspection.

3. Experimental set up and procedures

3.1 Experimental set up

Fig.2 shows the experimental set up. At the top of the water tank of the commercial acoustic imaging system, glass plate of 5 mm in thick fixed and contacted to the convex glass of 100 m in radius for Newton's ring experiment. Optical mirror was located below the contact interface and the interference fringe due to the micro gap of Newton's ring set up was observed. In addition, contact conditions of compression load were controlled quantitatively using the Z axis stage and the strain gage for loading calibration. New acoustic lens of highly focused aspheric type of 20 MHz in frequency and 29 mm in focal length in water was prepared. An acoustic image and an interference fringe at the same contact condition were compared.

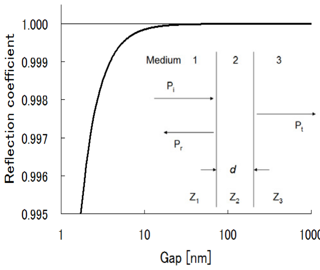


Fig.1 Relationship between gap and reflection coefficient

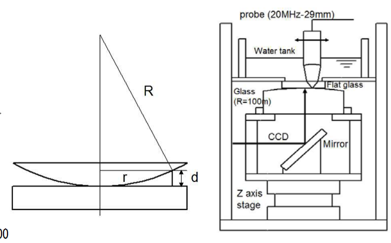


Fig.2 Experiment apparatus

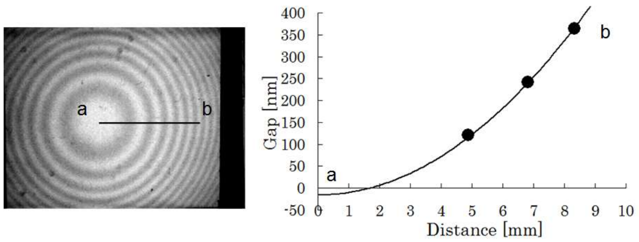
3.2 Experimental procedures

Fig.3 is a sample of the interference fringes pattern obtained by experimental set up in Fig.2. Dark and bright fringes can be expressed by equation (2),

$$2d=\frac{r^2}{R}=m\lambda$$
$$2d=\frac{r^2}{R}=\left(m+\frac{1}{2}\right)\lambda \qquad (2)$$

where d is a gap distance, λ is an optical wavelength, and m is a fringe number of 0,1,2...

Experiment fringe position measured by Fig. 3 along the positions of a and b was plotted in fig.3(b). Solid line in this figure was the estimated gap distance by equation (2). Keeping the contact condition to monitor the fringe pattern, we measured the acoustic image at same contact condition and compare the both experiment.



(a) Newton's Ring image (b) Extrapolation

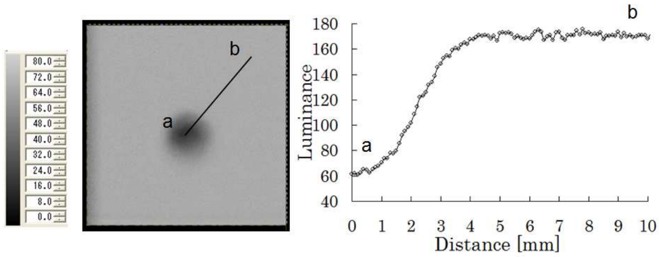
Fig.3 Newton's Ring data

3.3. Characteristics of prototype acoustic lens

Before experiment, following performances of new acoustic lens developed here were investigated. First one was the laser interferometer displacement measurement at the back surface of the bottom glass plate in Fig.2 to monitor the waveform at the focal position at interface. Obtained waveform was half-wave and the maximum peak displacement was 2 nm. Second one was the acoustic imaging experiment for the surface reflection echo for the drilled hole of φ 3 mm in diameter. According to the spatial resolution of the acoustic lens, the amplitude of the surface reflection echo changed from 2.7 mm (disappearance of echo) to 3.3 mm (full reflection of surface echo). From these experiments, we judged that the fabricated acoustic lens show highly focused ability at the interface as planed and the spatial resolution was within ±0.3mm.

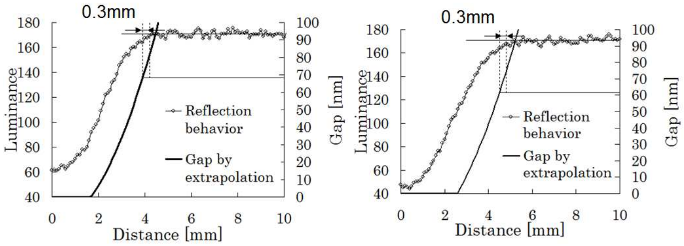
4. Experimental result

Fig.4 shows the sample of the C scope image of reflection echo at the contact interface at the same contact condition of Fig.3. At the center area of the contact, the amplitude of reflection showed decrease due to the transmission component. Distribution of the acoustic amplitude of echo along a and b was plotted in Fig.4(b). According to the gap distance and the contact conditions, amplitude distribution was changed. Samples of the two loading conditions of 2.86 kg and 4.93 kg in vertical directions were shown in Figs.5(a) and 5(b). Solid lines in these figures were the estimated gap distance as shown in right vertical axis by interference experiment for each contact conditions. Considering the spatial resolution of the acoustic lens as ±0.3mm, ultrasonic began to transmit through the gap at the position less than 0.3 mm at least from the decrease starting point of reflection amplitude as shown in Figs.5(a) and 5(b).



(a) C scope reflection behavior (b) Change of reflection behavior

Fig.4 Reflection behavior results



(a) Load 2.86kg (b) Load 4.93kg

Fig.5 Relationship between gap and reflection behavior

Corresponding points measured by the decrease of intensity of acoustic image were compared to the gap distance measurement by interference experiment as shown in Figs.5(a) and 5(b). Comparisons the directions for every 30 degree of acoustic images and the interference fringe patterns were applied and the corresponding gap distance for every comparison were 60-70 nm as a result. Though these relations supposed to relate equation (1) and Fig.1, quantitative investigation would be difficult. Furthermore, air vent chamber was also applied to estimate the relationships between the ultrasonic reflection and the slight air gap.

5. Conclusion

Combining the larger convex glass and accurate acoustic focusing lens, details of the ultrasonic reflection and transmission at the micro gap were investigated based on the Newton's ring experiment. Then, the ultrasonic transmission could occur through 60-70 nm air gaps. Further investigations must be required for quantitative understanding.

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