Study on defect detection in cylindrical cavity by electromagnetic ultrasonic creeping wave

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Internal defect, especially the parts of the cavity structure defect, is a difficult task in the field of nondestructive testing and often to be false detection or undetected in the testing process. Creeping wave detection provides a possibility to recognize this type defect. In this article, the detection of cylindrical cavity defect by using the electromagnetic ultrasonic creeping wave was studied through the finite element method (FEM). The sensitivity of creeping wave detection was improved through the design of coil parameters, which concentrate the energy and reduce the oblique incidence beam width of the shear waves. Three common crack defects were analyzed in the structure of holes by FEM. The simulation results show that creeping wave detection can be used to recognize the defects which are more difficult to detect in the holes and the features of the defect is obvious, which provides a new method for the internal cavity defect detection.

Index Terms—**Cavity structure defect, electromagnetic ultrasonic creeping wave, FEM**

I. INTRODUCTION

Internal defect, especially the parts of the cavity structure defect, is a difficult task in the field of nondestructive testing (NDT) and often to be false detection or undetected in the testing process [1]. Creeping wave detection provides a possibility to recognize this type defect. Creeping wave is a type of compressional wave, which propagates below the curved surface and is sensitive to surface and near-surface defects [2]. The creeping wave that test near surface defects can be produced by creeping wave probe. And creeping wave can also be produced when an ultrasonic bulk wave encounters a free surface and the incident angle is not normal to the surface, it cannot only be reflected but also be partly converted into creeping waves on the concave and convex surface [3]. Currently, piezoelectric ultrasonic transducer is the most commonly to excite creeping wave in nondestructive testing. The electromagnetic ultrasonic transducer (EMAT) is a kind of non-contact transducer, which can produce and receive ultrasonic waves though electromagnetic coupling. Meanwhile, the EMAT can easily arouse various types of ultrasonic and the structure is simple. Therefore, in this article EMAT is selected to detect the crack defects in the cavity surface.

II. SIMULATION AND ANALYSES

When the ultrasonic wave incident on the cavity surface at a certain angle, the ultrasonic will produce reflection and scattering, and the scattering wave that is called creeping wave will spread along the cavity surface. As shown in Fig. 1, the EMAT adopts transceiver integrated structure, and the excitation frequency is 1 MHz.

The transducer produces ultrasonic wave in the form of sound beam. The width and incident angle of the sound beam on the surface will affect the excitation of creeping wave. Creeping wave has a better detectability if the incident angle is smaller and the energy is more concentrated. Fig. 2 shows the influence of different coil inner diameter to ultrasonic beam and incident angle. It can be seen that two beams are produced axisymmetric by the racetrack coil, and the beam is much narrower, the acoustic energy is more concentrated when the coil diameter is smaller.

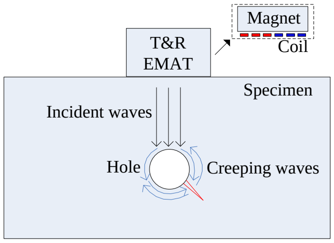
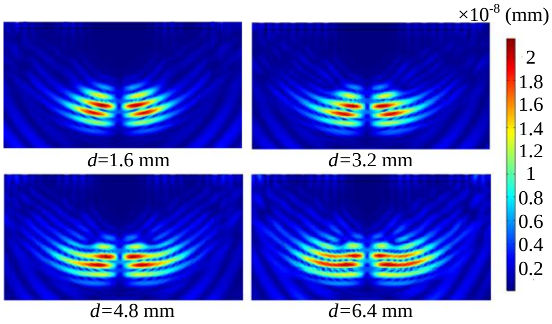


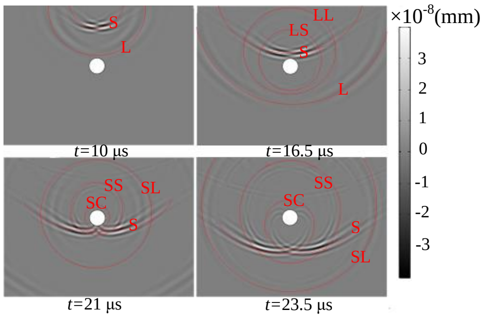
Fig. 1. The simulation diagram of creeping wave excitation.



d=1.6 mm
d=3.2 mm
d=4.8 mm
d=6.4 mm

Fig. 2. The distribution of energy under different distance *d*.

The propagation of ultrasonic in the specimen encountering with the hole at different time is shown in Fig. 3. It can be observed that longitudinal wave and shear wave all have occurred mode-conversion when the incident wavefront encounters the hole, where L denotes longitudinal wave, S denotes shear wave, C denotes creeping wave, LL denotes longitudinal to longitudinal mode-converted wave, LS denotes longitudinal to shear mode-converted wave and so on. Now, take shear wave as an illustration to describe how the process interaction between the ultrasonic and the hole. When the wavefronts of the shear wave encounters the hole, one part of the energy of the shear waves is reflected and some part of the energy is mode-converted into two creeping waves (SC). When the creeping waves propagate around the hole, most of the waves scatter into the material in the mode of shear waves in all directions around the hole.



t=10 μs t=16.5 μs

t=21 μs t=23.5 μs

Fig. 3. The propagation of ultrasonic wave with a hole at different time.

Fig. 4 is the received echo of the EMAT after the ultrasonic encounters the hole, and the four wave packets are the induced voltage of LS wave, SL wave, SS wave, SC wave in turn. There should be a wave packet (LL) between the first wave packet and the LS wave, but the value is very small. Using Δt denotes the receiving time lag of the SS and SC wave packet, which is decided by the circumference of the hole. It can be known that the time interval Δt is 9.1 μs from the Fig. 4, and we suppose that the creeping velocity is equal to the shear velocity 3.13 mm/μs. So, the computational acoustic path difference between SS wave and SC wave is 28.48 mm, and the circumference of the hole (radius r = 5 mm) is 31.42 mm. There is some error between the calculated result and the circumference of the hole. It is because that the creeping path is not completely round holes and it is influenced by the creeping wave incident angle and shear wave transmission angle.

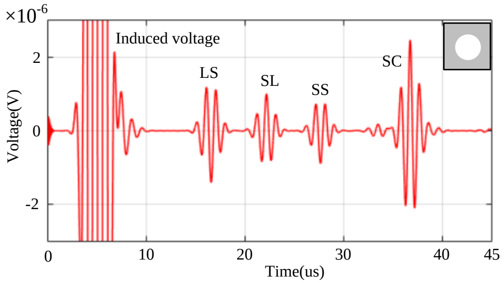
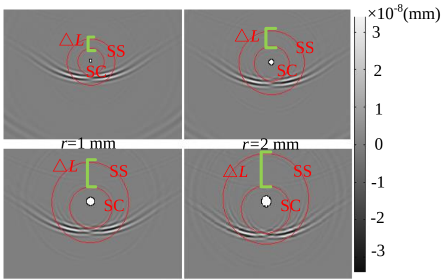


Fig. 4. The received echo with a hole.

In order to study the sensitivity of the ultrasonic at 1 MHz, the specimen with different size hole (radius from 1mm to 4 mm) is analyzed. The simulation results are shown in Fig. 5, where ΔL is the acoustic path difference between the SS wave and the SC wave. It can be observed that the acoustic path difference ΔL between the SS wave and the SC wave becomes larger as the hole becomes larger, so, the SS wave and the SC wave at 1 MHz can be identified from the ultrasonic field when the radius of the hole is greater than 2 mm in time domain.



r=1 mm r=2 mm

r=3 mm r=4 mm

Fig. 5. The simulation result with different size hole.

As shown in the above analysis, the creeping wave can propagate along the cylindrical cavity and reach the shadow zone that the traditional ultrasonic waves cannot reach directly. Therefore, the crack in such region can be detected by creeping wave. The simulation results are shown in Fig. 6. From the contrast between Fig. 6 and Fig. 4, it can be observed that the time of the SC wave appearing is earlier than in the case without crack when the crack is located in the direction of -45 degree. The reason is that reflection occurs when the SC wave encounters the crack, so that the acoustic path of SC wave is shorter.

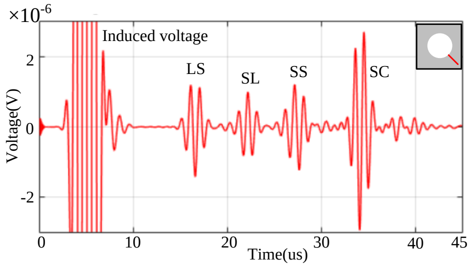


Fig. 6. The simulation result with crack.

III. CONCLUSION

A numerical model based on finite element method (FEM) was developed to simulate the interaction process of the EMAT-generated ultrasonic waves with the cavity crack. FME analysis shows that, the inclined incidence shear wave with narrower beam and energy concentration can be produced by optimizing the coil parameters. And the excitation efficiency and sensitivity of the creeping wave can be increased by selecting appropriate parameters. Creeping wave detecting has been used to detect cavity crack defect, and the simulation results show that creeping wave detection can well identify the crack which is difficulty to bulk waves. The size and location of crack can also be evaluated through analyzing the scattering creeping wave and reflection shear wave, which provides a novel way to detect the internal defect.

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