Simulation and Practice of Guided Wave Test Method in Circular Rod

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Abstract. Guided wave mode and dispersion curve in the circular rod are analyzed, and the time domain waveform of Φ20mm*2m circular rod is analyzed. Though finite element simulation and experiment, the variation law of reflection coefficient of different guided wave modes is analyzed. The L(0,1) is consistent with the change trend of F(1,1) modes for axial and circumferential defects, and the simulation results of L(0,1) modes are consistent with the test results.

1. Introduction
As a common structure, rod members are widely used in all kinds of projects. The losses caused by corrosion of rod structures are common. Rod structures are also widely used in water conservancy and hydropower projects[1-4]. As a new nondestructive testing technology, guided wave detection is different from the traditional methods such as electromagnetic detection and x-ray detection. It has the advantages of wide detection range, long propagation distance, high efficiency, low cost and high accuracy. In the practical application of engineering, the propagation of guided wave in rod caused by corrosion is complex and difficult to identify[6-9]. Based on theoretical analysis, finite element simulation and test method, the guided wave detection method of circular rod corrosion is studied.

2. Theoretical analysis
Because the boundary repeatedly reflects the ultrasonic wave, the ultrasonic wave propagating in the solid material forms the guided wave[10-14]. The guided wave propagation modes can be solved by using the elastic mechanics formula:

\[ \sigma_{ij} + pf_i = \rho \ddot{u}_i \quad (i = 1,2,3) \]

Equation of motion:

\[ \varepsilon_{ij} = \frac{1}{2}(u_{i,j} + u_{j,i}) \quad (i,j = 1,2,3) \]

Variable displacement equations:
\[ \varepsilon_{ij} = \frac{1}{2} (u_{i,j} + u_{j,i}) \quad (i,j = 1,2,3) \]

For isotropic materials, the wave equation of isotropic elastic solid media can be obtained by eliminating the strain and stress terms of the formula:

\[ (\lambda + \mu) u_{,ij} + \mu u_{ij} + \rho \ddot{f}_i = \rho \ddot{u}_i \]

By solving the wave equation, the propagation mode of the wave in the medium, that is, the dispersion curve, can be obtained. Figure 1 shows the dispersion curve of a 20 mm, 2 m long round rod obtained by PCdisp software.

![Dispersion curves of Φ20mm circular rod](image)

We can see from Figure 1 that there are three modes in the circular rod, the longitudinal axisymmetric modes \( L(0, m) \), torsional modes (axisymmetric) \( T(0, m) \), bending modes (asymmetric) \( F(n, m) \). The number of modes increases with the increase of frequency. Too many modes will mask the effect of the defect reflected wave. At 0-100 kHz low frequency range, the modal dispersion is less.

By applying a surface load to the end of a non-defective circular rod, excitation \( L(0, 1) \), \( T(0, 1) \), \( F(1, 1) \) mode respectively, observe the amplitude of the bottom wave and calculate the propagation time, we can get it, the reflection amplitude of bottom wave of \( T(0, 1) \) modal is in a low level. The difference between the calculated value of wave velocity and the theoretical value is also large. It is
not suitable for actual testing. For L(0, 1) and T(0, 1) mode, the amplitude loss of the bottom wave reflection is less, and the calculation wave velocity is close to the theoretical wave velocity. 50kHz is a suitable frequency for detecting Φ20mm rod, because there are only L(0,1) and F(1,1) modes. When the incident frequency is 50 kHz, three modes’ domain waveforms in Φ20mm*2m rod were shown in figure 2.

3. Simulation and Test

3.1. Model parameters
Defects are set in the middle of the Φ20mm*2m rod, and simulation calculation and test were carried out. The defect size is shown in figure 3, where a denotes the axial length. The axial corrosion coefficient is defined as the percentage of the wavelength: A=a/λ×100%. The b denotes the circumferential length, and the circumferential corrosion coefficient defined as the percentage of the circumferential length of the circular rod: B=b/(2πr)×100%. The h denotes the defect depth[15].

3.2. Circumferential defects
The excitation signal with the central frequency is 50 kHz and the period number is 5, is used to simulate and verify. When the defect depth h=1mm, and the axial length a=0.5mm, circumferential corrosion coefficient B respectively set as 12.5%, 15%, 37.5%,…,87.5%, and 100%,to simulate. And 25%, 50%, 75% were tested. Guided wave reflection coefficient R, the ratio of the amplitude spectrum of the end echo or the defect echo B (ω) to the amplitude spectrum A (ω) the excitation signal wave, The trend is shown in figure 4.
It is easy to find from figure 4 that the reflection coefficient of the defect reflected L(0,1) wave becomes larger with the circumferential length, and the reflection coefficient of the wave mode F(1,1) also becomes larger, but the reflection coefficient varies in a very small range. Its value does not exceed 10%.

3.3. Axial defects
The excitation signal with the central frequency is 50 kHz and the period number is 5, is used to simulate and verify. When the circumferential corrosion defect coefficient B=100, defect depth h=1mm, and the axial corrosion coefficient A is set respectively to 10%, 20%, 30%,...,80%, 90%, and 100% for simulation, and 30%,60% and 90% for test. Guided wave reflection coefficient R, the ratio of the amplitude spectrum of the end echo or the defect echo B (ω) to the amplitude spectrum A (ω) the excitation signal wave, The trend is shown in figure 5.

When the axial length is greater than 50%, the duration of the defect reflection and wave type conversion wave becomes longer, and the conversion wave type increases with the increase of the axial length coefficient. That because, with the increase of the axial length, the front and rear ends of the defect position are reflected. It is easy to find from figure 5 that the overall trend of defect reflection and waveform conversion wave is the same, the reflection coefficient of wave type conversion wave is larger than that of defect reflection, and the reflection coefficient of both waves is not more than 25%.
4. Conclusion

The defects have an effect on the propagation characteristics of guided waves. For axial and circumferential defects, with the increase of circumferential coefficient, defect echo mode F(1,1) and converted wave mode L(0,1) changes. With the increase of axial length, defect echo mode F(1,1) and converted wave mode L(0,1) also changes. For the defects with the same size, the test results are in good agreement with the simulation results. Above all, it is appropriate to use L(0,1) mode to detect and quantitatively analyze the defect size in circular rod guided wave detection.

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