Analysis of Bolts' Axial Corrosion Using Guided Waves Based on FEM

P Ding[1,2,*] C Lu[3], G F Ma[1], T Li[1], G F Yue[1] and X L Huang[1]

[1]Standard & Quality Control Research Institute Ministry of Water Resources. P.R.C, Hangzhou, China
[2]Key Laboratory of Research on Hydraulic and Hydro-Power Equipment Surface Engineering Technology of Zhejiang Province, Hangzhou, China
[3]Key Lab of Nondestructive Testing, Ministry of Education, Nanchang Hangkong University, Nanchang, China

Corresponding author and e-mail: P Ding, qddp2008@126.com

Abstract. Bolts are widely used in water conservancy and hydropower engineering. There are no good methods to test the corrosion defect of the bolts. Guided wave was used in this paper to test the simulation axial defect in bolt based on FEM. The trend of the axial corrosion coefficient and reflection coefficient of the guided wave was revelled. It shows that the change trend of the defect reflection and wave type conversion of L (0, 1) mode and F (1, 1) mode is consistent. The defect reflection of F (1, 1) is higher than the defect reflection of L (0, 1), both the defect reflection of F (1, 1) and L (0, 1) are no higher than 25%. And also it verified the capability of low-frequency guided wave in detecting the small and medium defects of bolts' corrosion.

1. Introduction

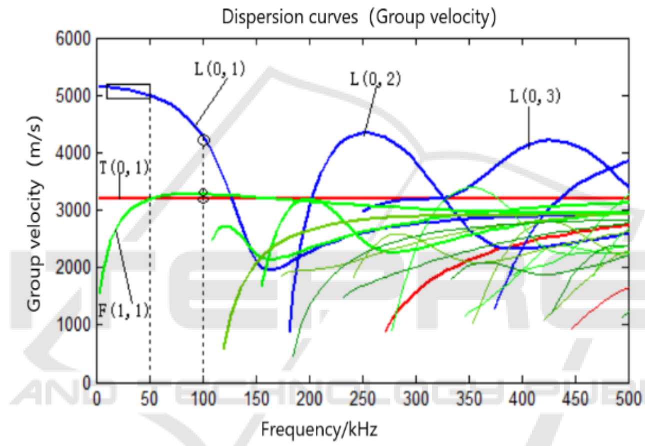
Hydropower project transmission tower is an important facility to erect high-voltage transmission lines. It is important to keep the tower fastness and reliable. The bolt is significant structure of transmission tower, the safety and stability of bolt is in a very great degree affect the safety, stability and service life of the transmission tower. Since the 1950s, China started using anchor in the coal mine. And as support structure the anchor is widely used in the rock. With the development of hydropower industry and the demand of the long-distance transmission, a large number of bolts have been used in the cable of power transmission tower. These bolts are main load-bearing members, which bear a large force and are used in bad environment. During the long term use, the effects of cutting, fatigue and rainwater corrosion and the potential defects in the construction process easily cause the failure, resulting in the occurrence of the accident. Not only does it cause enormous economic losses, but it also results in casualties. Therefore, it is very important to use nondestructive testing method to evaluate the operation condition and corrosion state of transmission tower. Guided wave is a kind of ultrasonic wave which can be propagated in plates, rods and tubes, with the advantages of small attenuation and long propagation distance. It has natural advantages for the detection of transmission tower bolts defects such as rust.

Ding, P., Lu, C., Ma, G., Li, T., Yue, G. and Huang, X.
Analysis of Bolts' Axial Corrosion Using Guided Waves Based on FEM.
In *Proceedings of the International Workshop on Materials, Chemistry and Engineering (IWMCE 2018)*, pages 616-620
ISBN: 978-989-758-346-9
Copyright © 2018 by SCITEPRESS – Science and Technology Publications, Lda. All rights reserved

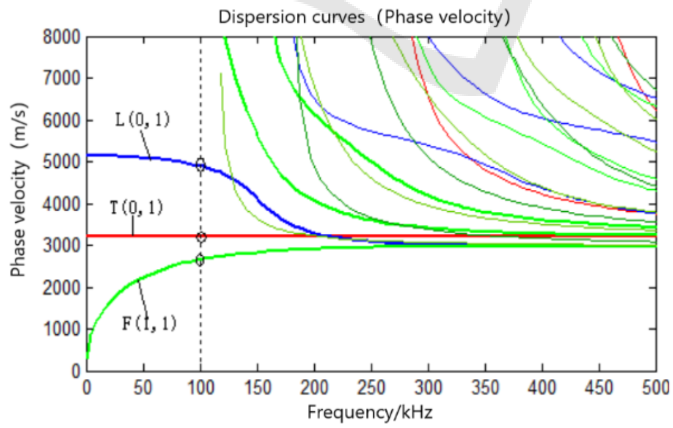
2. Guided waves in bolt

The ultrasonic guided wave is caused by wave interference and dispersion due to multiple reflection and scattering in the boundary of the propagation medium. The phase velocity is the rate at which the phase of the wave propagates in space. This is the velocity at which the phase of any one frequency component of the wave travels. The group velocity of a wave is the velocity with which the overall shape of the wave's amplitudes-known as the modulation or envelope of the wave—propagates through space. Guided waves are propagated by group velocity, and it have two characteristics: dispersion characteristics and multimodal characteristics [1-7].

There are three modes of the ultrasonic wave propagating along the axial direction in the bolts, the longitudinal axisymmetric mode L (0, m), the torsional mode T (0, m) and bending mode F (n,m). The same frequency corresponds to several wave Numbers, that is, there are several different modes at a certain frequency, and as the frequency increases, the number of modes becomes more and more. Theoretically, in the low frequency range (< 100kHz) only exist L (0, 1) and F (1, 1) mode, and the velocities of this two modes are quite different. The dispersion curve in theoretical draw by matlab of a solid cylinder with a diameter of 20mm and a length of 2m is shown in Figure 1.



(a) Dispersion curve of group velocity



(b) Dispersion curve of phase velocity

Figure 1. Dispersion curve of the solid cylinder with a diameter of 20mm and a length of 2m.

SCITEPRESS SCIENCE AND TECHNOLOGY PUBLICATIONS

From the dispersion curve, it approves that when the frequency < 100kHz, there are only two modes: the longitudinal mode L (0, 1) and the bending mode F (1, 1). So L (0, 1) mode and F (1, 1) mode are selected to detect the corrosion of the bolts in order to avoid the other modes mask the defect echo.

3. Simulation Model

According to the bolts' size, the model is shown in Figure 2. In this model D=20mm, L=2m. The length of the defect axis is indicated by a, and the axial corrosion coefficient (A) is defined as the percentage of defect length(a) and wavelength. Reflection coefficient of ultrasonic guided wave R is defined as $R=B(\omega)/A(\omega)$, In this paper, $B(\omega)$ is the amplitude spectrum of the waveguide wave echo at the end surface or the defect, $A(\omega)$ is the amplitude spectrum of the excitation signal wave. The greater R is and the greater of the energy of reflected echo signal will be.

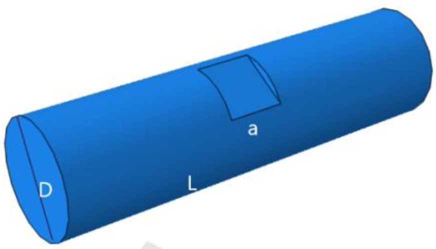


Figure 2. Bolt's Model.

The material properties of the bolt are: Young's Modulus E=206000Mpa; Poisson's Ratio σ=0.30; Mass Density ρ=7580kg/m3. ABAQUS/Explicit dynamic module was adopted in the simulation, and the grid cell type was selected as C3D4, the length of the elements was set as 1/20 of the wavelength. According to theory and simulation, guided wave excitation and acceptance point are set at the end surface, and the waveguide frequency is 50kHz.

4. Result and Discussion

The defect depth is 1mm and distribution along the circumference, the axial length corrosion coefficient(A) is 10%, 20%, 30%...90 percent to simulate. The results were shown from Figure 3 to Figure 11.

From Figure 3 - Figure 11, it shows that the change of axial length coefficient is related to the defect reflection coefficient. When axial length greater than or equal to 50%, the last time become longer both the defect reflection L (0, 1) and wave type conversion F (1, 1). The transformation wave pattern increases with the increase of axial length coefficient because that as the axial length increases, the front and rear surfaces of the defect position are all reflected. Figure 12 shows the relationship between the axial corrosion coefficient (A) and reflection coefficient (R). The change trend of the defect reflection and wave type conversion of L (0, 1) mode and F (1, 1) mode is consistent. The defect reflection of F (1, 1) is higher than the defect reflection of L (0, 1) mode, both the defection of F (1, 1) and L (0, 1) are no higher than 25%.

SCITEPRESS SCIENCE AND TECHNOLOGY PUBLICATIONS

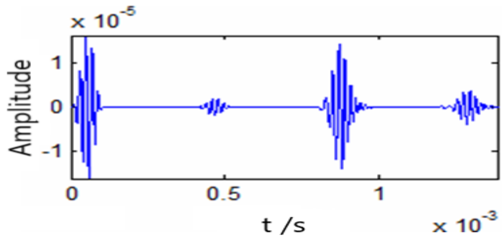


Figure 3. Waveform of A=10%.

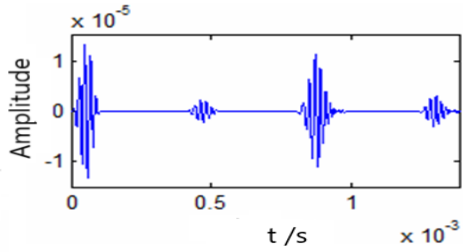


Figure 4. Waveform of A=20%.

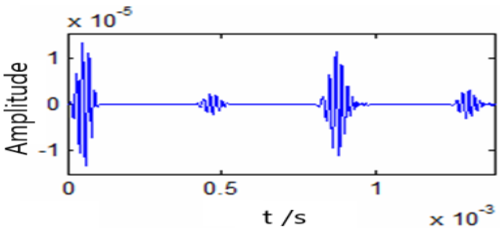


Figure 5. Waveform of A=30%.

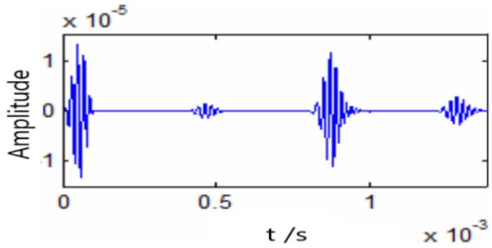


Figure 6. Waveform of A=40%.

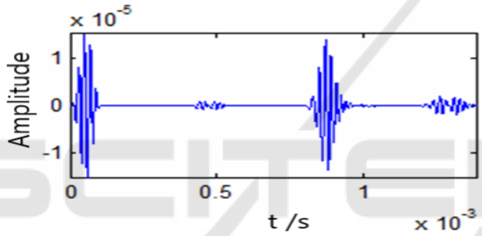


Figure 7. Waveform of A=50%.

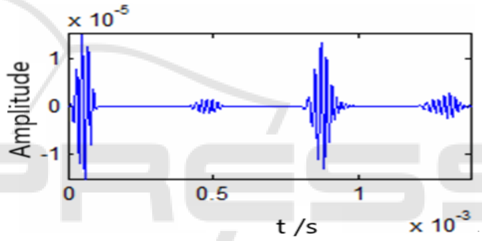


Figure 8. Waveform of A=60%.

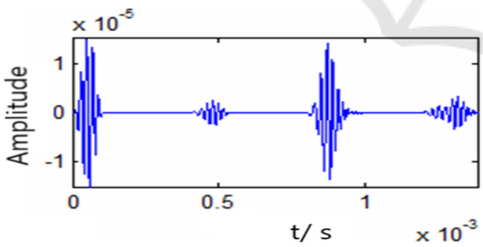


Figure 9. Waveform of A=70%.

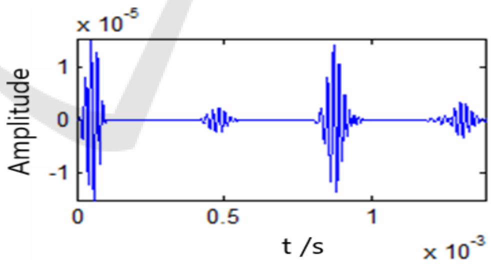


Figure 10. Waveform of A=80%.

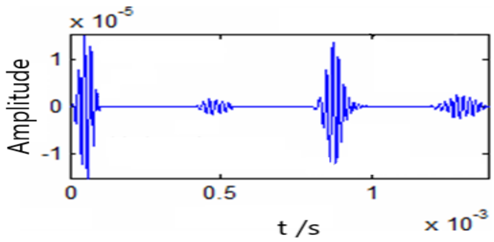


Figure 11. Waveform of A=90%.

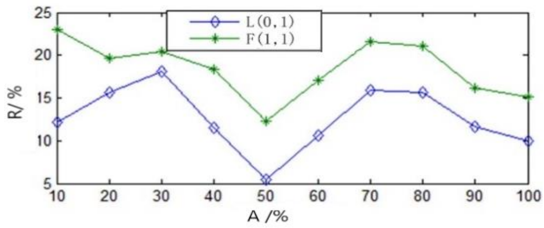


Figure 12. Trend of the Axial corrosion coefficient and Reflection coefficient.

5. Summary

Through numerical simulation, the capability of low - frequency guided wave in detecting the small - and - medium defects is verified. The reflection coefficient changes with the change of axial defect, and it has good correspondence which provides a good reference for the guide wave detection of bolt and other long straight bars, which are used in water conservancy and hydropower engineering. Through further research and experiment, it is beneficial to the development of water conservancy and hydropower engineering guided wave detection.

Acknowledgement
Thanks to the support of Science and Technology Project of Zhejiang Province (Nos. 2017C37062).

References

[1] Zeng G P 2017 *Study on propagation characteristics of ultrasonic guided waves in arch bridge suspender* Zhejiang University.
[2] Rose J L 1999 *Ultrasonic waves in solid Media* Cambridge University Press
[3] Gazis D C 1959 Three dimensional investigation of the propagation of waves in hollow circular cylinders Analytical Foundation *J. of the Acoustics Society of America* 31 pp568-573
[4] Menachem Z and Tapuchi S 2013 Analyzing wave propagation in helical waveguides using laplace, fourier, and their inverse transforms, and applications *Intech: Wave Propagation Theories and Applications*
[5] Ahmed S R and Saka M 2000 A new ultrasonic angle-beam technique for sensitive evaluation of closed cracks *NDT&E International* 33(4) pp 261-271
[6] Yang H 2013 *Research on using ultrasonic guided wave NDT technique to detect the quality of metal buffer rod cofferdam system* North University of China
[7] Ivanovic A, Neilson R D and Rodger A A 2001 Numerical Modeling of single tendon ground anchorage systems *Geotech. Eng.* 142(2) pp 103-113