Damage detection for train axles based on quasi-surface waves

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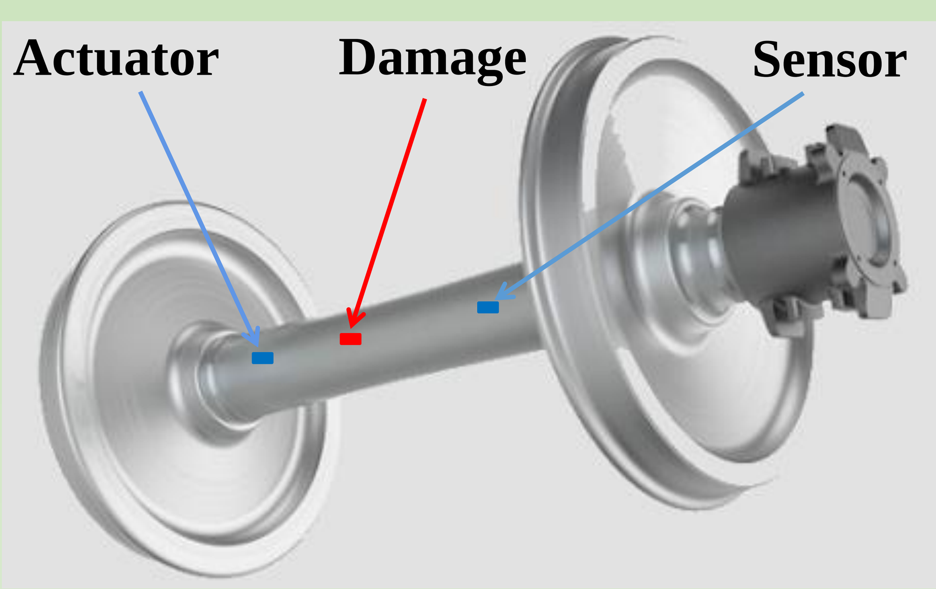
Motivations

In railway systems, train axles are deemed to be one of the most crucial components. Although they are designed assuming an infinite service life, their normal operation is typically limited due to possible damage caused by some unforeseen factors, e.g. stochastic loading conditions due to the irregularities of wheels or rails, corrosion, flying ballast impacts, non-metallic inclusions, etc. Therefore, it is highly required to frequently inspect the axles to ensure their safety. The structural health monitoring methods based on ultrasonic guided allows effective detection of structural defects by using the interaction between the propagating guided waves and damage. This method is sensitive to small and local damages in the structure, and can well realize the real-time, online and effective monitoring of large equipment and structures. In addition, a sparse transducer array ensures to cover a large monitoring area. Therefore, such methods show great promise for crack detection in train axles.



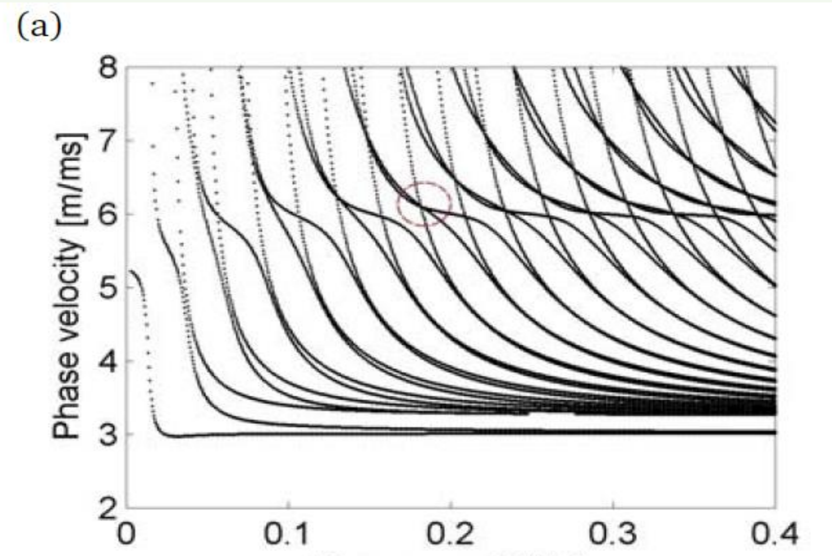
Guided-wave-based inspection scheme

Crack to be detected

Guided Wave theory in thick-walled hollow cylindrical structures

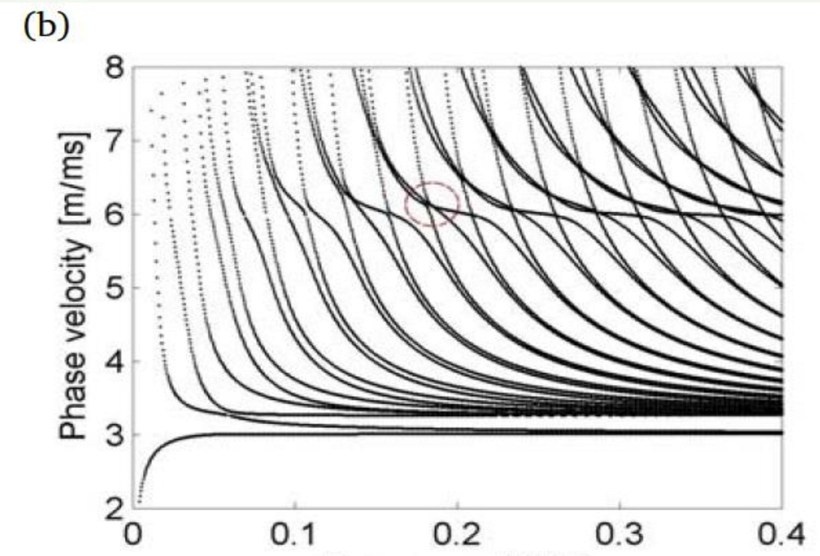
The key to using ultrasonic guided waves for damage detection is to understand the wave propagation characteristics in the structure to be tested. Due to the complex structure of the train axle, a hollow cylindrical structure is studied to simplify the analyses for theoretical analysis. Specifically, a typical steel thick-walled cylinder with an inner diameter of 50mm and an outer diameter of 150mm was selected for analysis. Through theoretical calculations, the dispersion curves are obtained to reveal the relationship between the phase velocity and frequency of different modes. Generally, there are three types of guided waves in such hollow cylindrical structures: longitudinal waves (L mode), torsional waves (T mode) and flexural waves (F mode). In addition, for a given frequency (larger than 20 kHz of particular SHM interest), various guided modes coexist in the structure with different propagating velocities. In principle, the single mode can be only excited when the load distribution across the thickness perfectly matches with the wave structure of the specific mode, which is hard to achieve in practical applications.

(a)



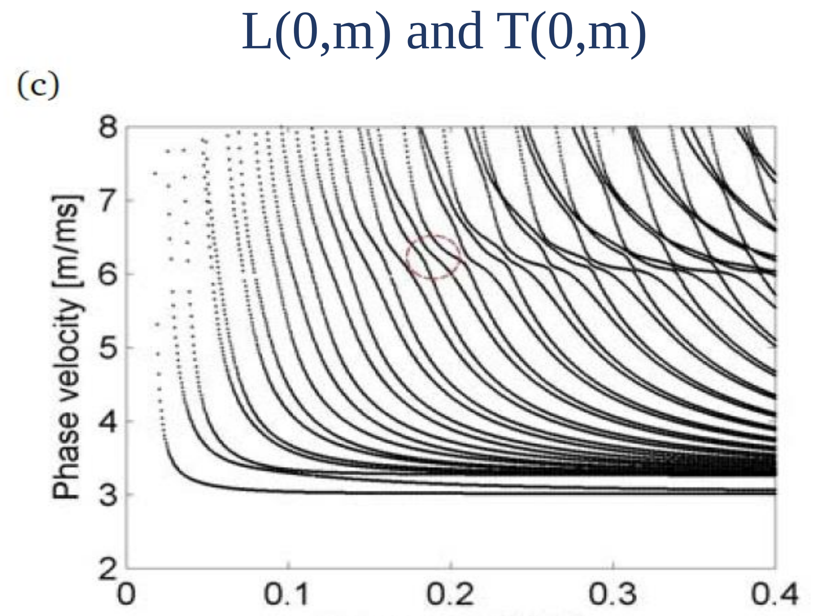
L(0,m) and T(0,m)

(b)



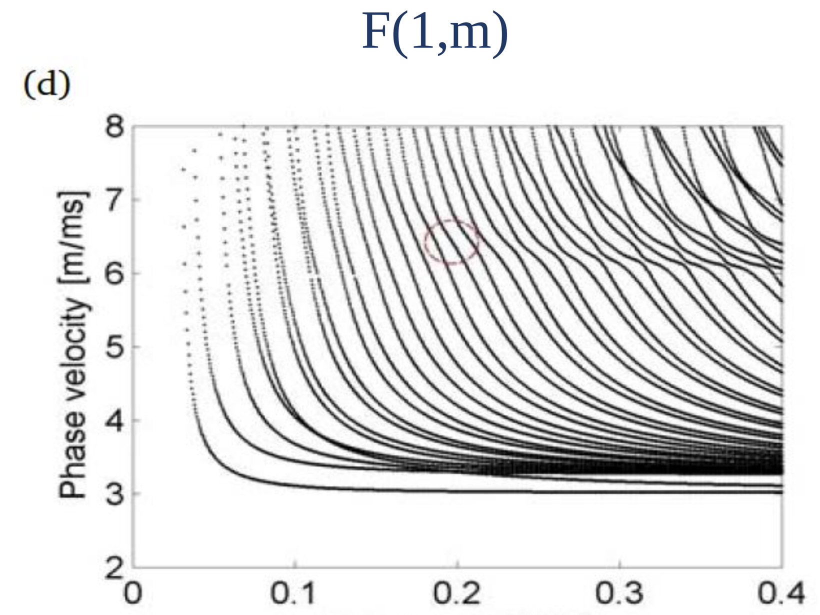
F(1,m)

(c)



F(2,m)

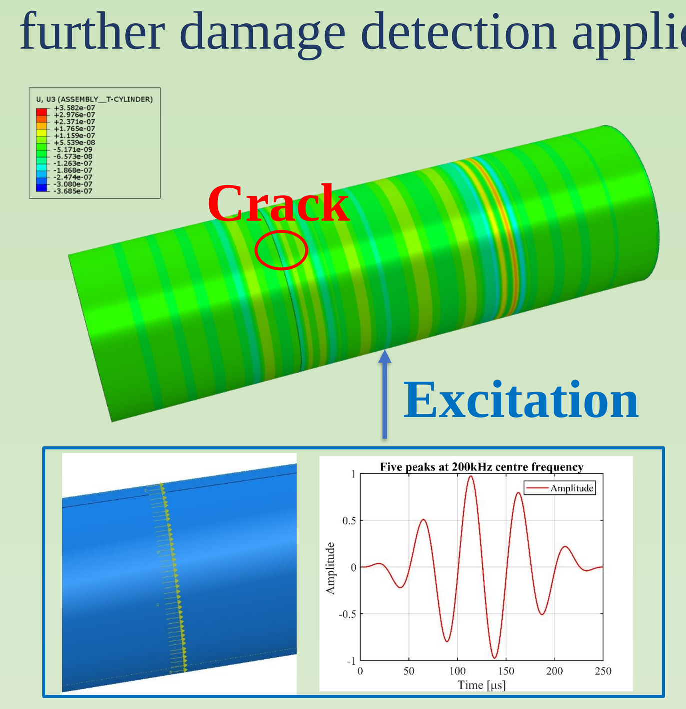
(d)



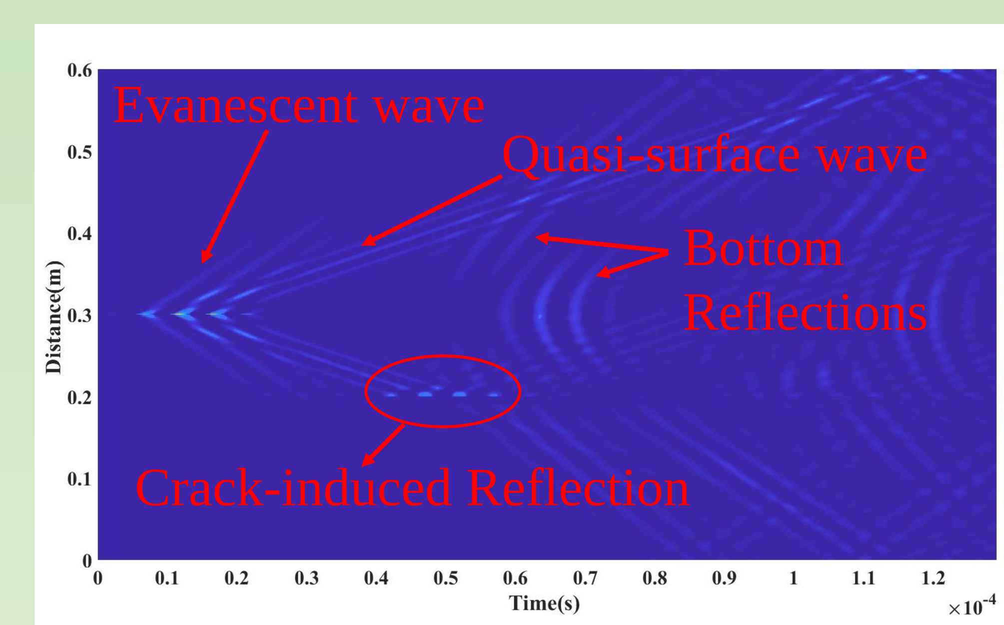
F(3,m)

Quasi-surface wave generation interaction with cracks

In practical applications, transducers are usually attached to the surface of the structure for the wave excitation. When the selected excitation frequency is high enough and the guided wave wavelength of various modes at this frequency is much smaller than the wall thickness, the guided wave energy will mainly propagate along the cylindrical surface. These are the propagation of quasi-surface waves. Finite element method is used to confirm this phenomenon and further apply the quasi-surface waves to detect cracks to testify its ability for damage detection. In the simulations, a surface traction excitation is applied on the outer surface of the cylinder at 200kHz. The wave propagation pattern on the outer surface is extracted by plotting the time-space diagram. It can be seen that apart from some reflections and evanescent wave, the generation and propagation of the quasi-surface wave is clear. Meanwhile, through the introduction of a crack, the quasi-surface waves are significantly reflected, which facilitates the further damage detection applications.



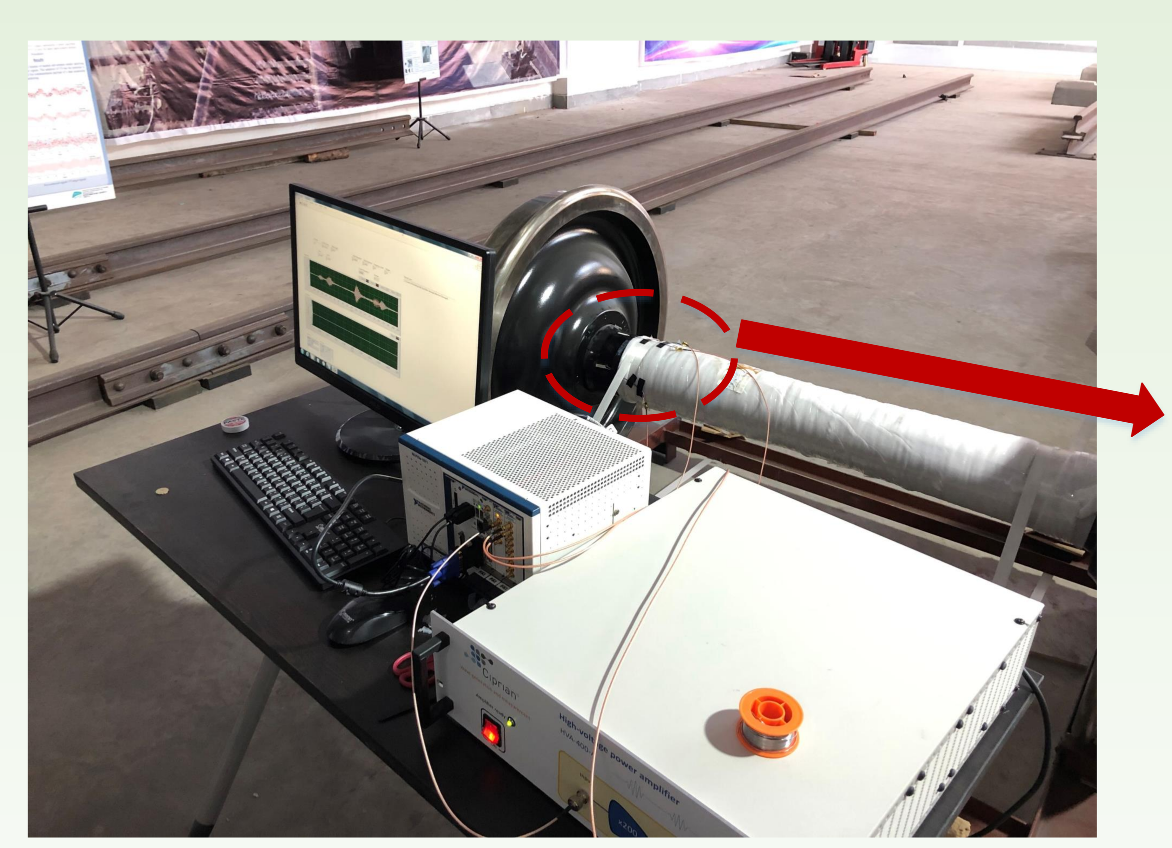
Finite element model

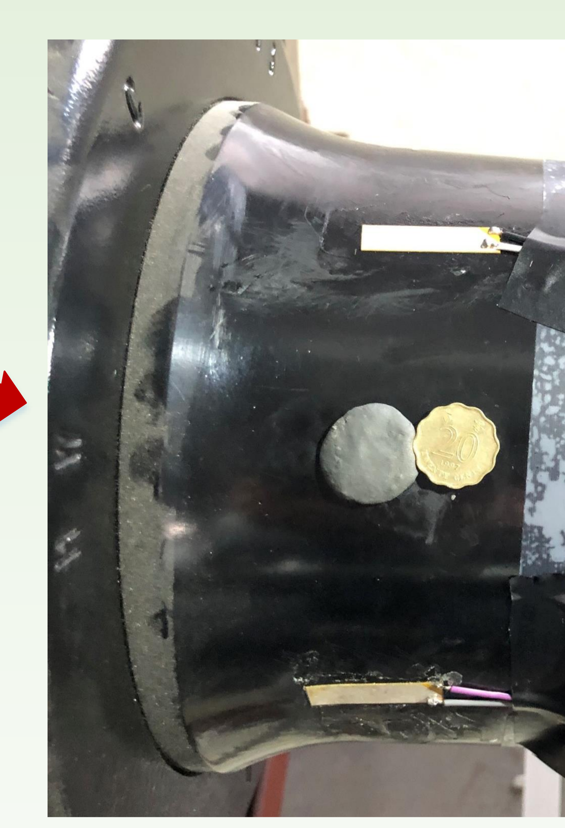


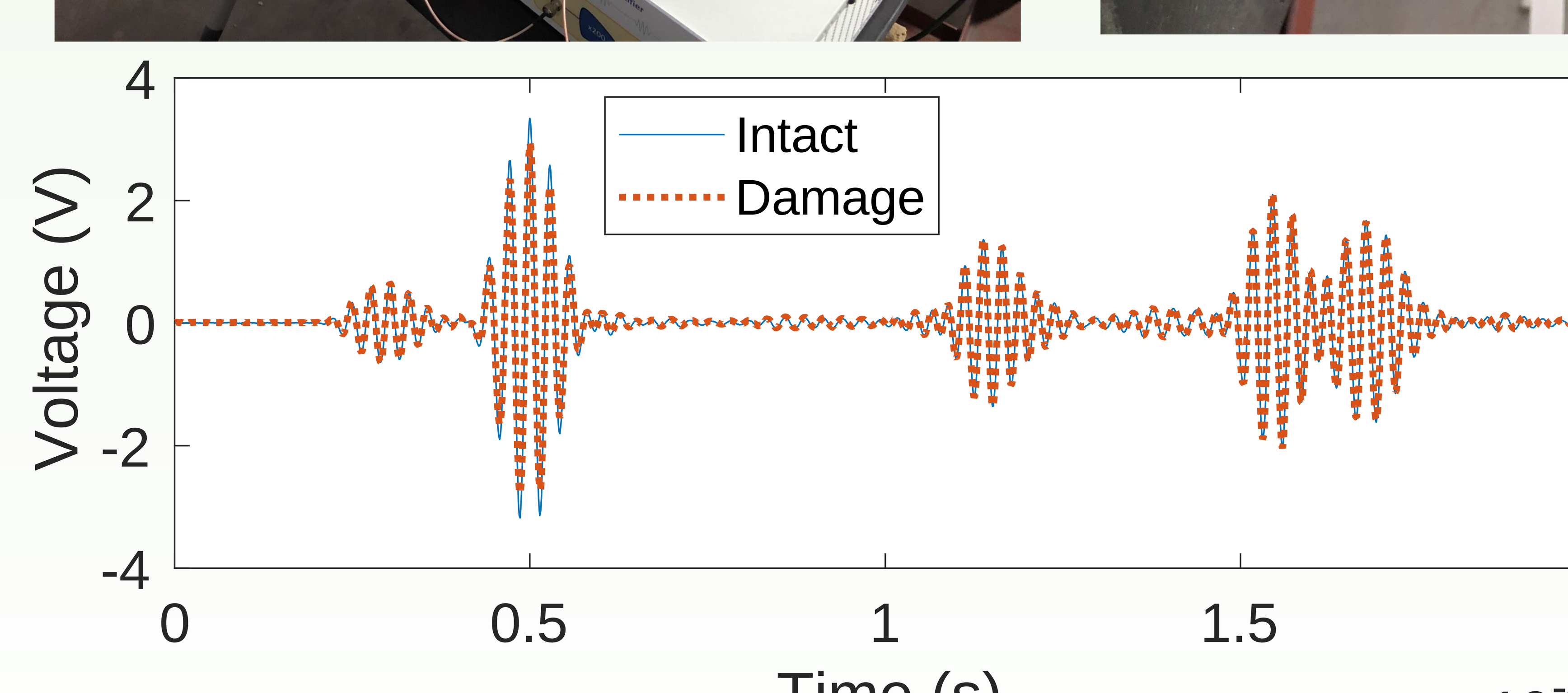
Wave propagation diagram

Case Study

Experiments are carried out on an offline train axle. PZT transducers are used to excite and capture the quasi-surface waves at 200 kHz. The damage is artificially introduced to the system by mounting a small damping material on the outer surface of the axle. Results show a significant decrease in quasi-surface wave amplitude thus clearly demonstrate the effectiveness of the developed system.







Experimental set-up and results

Reference

Ziaja-Sujdak, Aleksandra, et al. "Near-field wave enhancement and 'quasi-surface' longitudinal waves in a segmented thick-walled hollow cylindrical waveguide." Structural Health Monitoring 17.2 (2018): 346-362.

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