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Automated Cracked Axle Detection Using Resonance Testing

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SUMMARY

Transportation Technology Center, Inc. (TTCI) on behalf of the Association of American Railroads (AAR,) evaluated a cracked axle detection technology known as resonance testing, which has the potential to detect axle defects on a moving train. The evaluation showed good signal capability and repeatability of measurements in the laboratory environment. This *Technology Digest* reviews the findings, discusses the potential limitations, and makes suggestions for continued work.

Resonance testing detects shifts in the axle resonance frequencies induced by cracks in the axle. Measurements were taken using accelerometers attached to the axle on a free wheelset. The wheelset was rolled a short distance on a track panel in the laboratory. TTCI demonstrated that with appropriate excitation, the axle resonance exceeded rolling noise at high frequencies (above 20 kHz) and was measured repeatedly within 3 decibels (dB) for a single impact (tap testing) on a rolling wheelset. The measurements were shown to be repeatable for each axle tested. However, resonance differences between new axles of the same type were on the same order as differences between known good and artificially notched axles. The implications of this finding are that axle fatigue may be identifiable, but only if a baseline resonance test is stored for every axle in the sample population.

This research was funded by the AAR Strategic Research Initiatives Program. A goal of this work is to develop state-of-the-art of in-motion automated cracked axle detection systems by bringing forward promising technologies for eventual deployment by the railroads. The intent is to demonstrate nondestructive evaluation technologies at Transportation Technology Center to the level defined in the requirements document, as defined by the technology advisory group.

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INTRODUCTION

TTCI has performed feasibility research aimed at determining the potential for using resonance testing for detecting axle defects on moving trains. This *Technology Digest* (TD) describes the resonance method, which is based on the same physical principle of wheel tapping, but was applied in the non-audible ultrasonic spectrum. The question was whether the measurement can be made on a moving wheelset, and if so, can it be automated to work on a moving train. The objective of this work was to determine the range, sensitivity, and repeatability of the measurement that will be required and to assess whether the result is feasible for in-motion detection. In this first step, the range and repeatability of the measurement were determined using accelerometers mounted to the axle on a wheelset rolling in a laboratory rig. Later steps will be needed to determine whether this measurement can be duplicated with non-contacting methods such as using a laser doppler vibrometer (LDV).

A railway wheelset consists of two wheels press-fitted onto a solid axle. Nondestructive evaluation (NDE) technologies are often employed by the railroads to assure the integrity of the assembly. However, all existing current axle inspection NDE methods are performed when the train is stopped.[1] For example, in the method of wheel tapping, an inspector taps a wheel with a hammer and listens to its audible response, which is a function of its resonance. The wheelsets with cracks ring differently than those without cracks, because the defect affects the resonance of the body. NDE methods that can inspect axles on moving trains would increase productivity and enhance the safety of railroad axles.

BACKGROUND

All objects have resonance frequencies that are fundamental to their physical properties. Resonances in materials change with changes in shape, size, mass, rigidity, and other physical properties. These resonance frequencies have multiple modes that describe how an object will vibrate when excited by an impulse. These vibrations dissipate rapidly, but can be captured and converted from the time domain to the frequency domain, showing which resonance frequency or frequencies exist for that object.

Whole Life Rail Axle Assessment and Improvement (WOLAXIM) program under the European Commission conducted a project titled “Wheelset Integrated Design and Effective Maintenance” (WIDEM). This project aimed to improve inspection techniques on axles, as well as to expand the lifetime of axles in Europe.[2] In one WIDEM project experiment, a set of fully decommissioned axles known to be either good or cracked was tested in a suspended static test rig. The axles were excited by an impact source from a tap hammer, and the resonance frequencies were recorded and analyzed. The WIDEM data showed that resonance frequency shifts were significant on axles that were fatigued to the point of cracking.[2]

TTCI took the research farther to identify issues that may preclude implementation:

- Resonance response and measurement on a moving railroad car with varied sizes of wheels and axles.
- The changing boundary conditions of rolling contact—will they damp out the response to below a detectable threshold?
- Repeatability and sensitivity issues. Repeatable resonance frequency measurement on a moving wheel is essential to the viability of a wayside cracked axle detection system.
- How to make the non-contact measurements for different kinds of axle defects that meet the sensitivity requirements

TEST RIG

TTCI helped design a test rig consisting of a 12-foot track panel and a wheelset. The rig included a mechanism for safely rolling and stopping the instrumented wheelset, an automated impact mechanism to strike the wheelset with suitable amplitude to excite the resonance frequencies of the axle, and accelerometers and instrumentation to measure and record the resonance frequencies. Figure 1 shows the rolling wheel test rig in the laboratory.

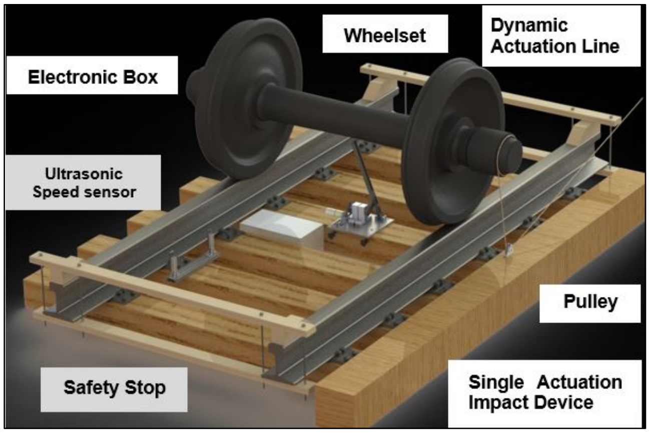

Figure 1. Rendering of rolling wheel test rig

There were three main parts to the system: the laboratory setup and movement system, the impact system, and the data acquisition system. The setup and movement system replicated normal railroad conditions. It included the wheelset, panelized track, rubber mats to insulate the system from the floor, and the motion control system. The impact system delivered a controlled impact transversely on the center to activate the bending mode on the axle with a metal hammer. The simple design of a crank wheel with a pin-in-slot on a swinging hammer created a self-resetting, quick repeating mechanism.

ACCELEROMETER PLACEMENT

Accelerometers were placed directly on the axle at four different locations. Multiple locations were selected so that resonance response as a function of location on the axle could be studied. Wires to the accelerometers were carefully placed to unwind from the axle as the wheelset moved. Figure 2 shows the accelerometer locations on the axle.

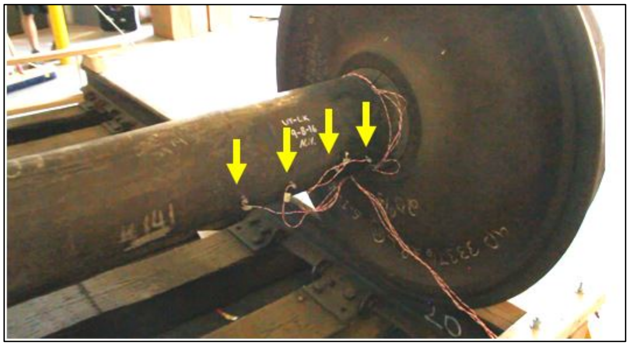

Figure 2. Accelerometer placement on the axle (shown by arrows) and wire handling mechanism

DATA ACQUISITION SYSTEM

The data acquisition (DAQ) system was configured to record the accelerometer measurement data in real time. The system consisted of an NI USB 6251 8 channel DAQ, PCB signal conditioner, and four accelerometers. The accelerometers were made by PCB Piezotronics, with 20-foot cables and BNC connections.

The accelerometers, rated to 10 kHz, were able to record data at frequencies much higher than the rated value. The rating corresponds to the range of linear correlation of the accelerometer response. Response up to ~100 kHz is reported by the manufacturer. Response up to 20 kHz was confirmed using online tone generators. As the sensors collected data outside of the rated range, the amplitude was amplified due to the resonance frequency of the accelerometer itself. This did not affect the frequency response of the readings since the research was not concerned with the magnitude response, but with the frequency content.

TESTING

For the wayside application, there is only a single impact opportunity in an axle as the train passes through the detector. Therefore, the response to a single impact must accurately and precisely characterize the axle. This was demonstrated by manually impacting the same axle four times using a non-instrumented hammer mechanism in the static test conditions. During this process, one full second was allowed to pass before impacting the axle again to assure ring down to zero before other measurements were taken. This was important to avoid missing any of the resonance frequencies that may have existed within the axle.

Next, it was important to determine if single impact response could be measured on a moving train. Also, for the concept to work, the impact response levels had to substantially exceed the vibration noise levels on the axle at the frequencies of interest (> 20 kHz). For this, a quick test was conducted at the TTC to measure train rolling noise, to determine acceleration transmission from track to axle, and to compare acceleration levels from impact with levels from transmission to axle.

Finally, tests were conducted multiple times on the same moving axle. Also, static testing was performed on a number of stationary axles with and without notches (cracks). This was done to make comparisons between stationary and moving axles and between good and bad axles.

RESULTS

Four peaks were chosen for a single accelerometer response. The effects of impact level variations were minimized by normalizing each response by the energy of the response signal. A Fast-Fourier Transform (FFT) of each response was then performed, and a peak picking algorithm was implemented. Figure 3 shows the resonance frequency peaks taken from the 30 to 40 kHz bandwidth range for entire static testing. It was observed that the entire response for the 10 kHz bandwidth range showed an average variance in the peak levels of 3 decibels (dB). From this test, it was determined that the spectral response of a single impact was enough to accurately characterize the axle.

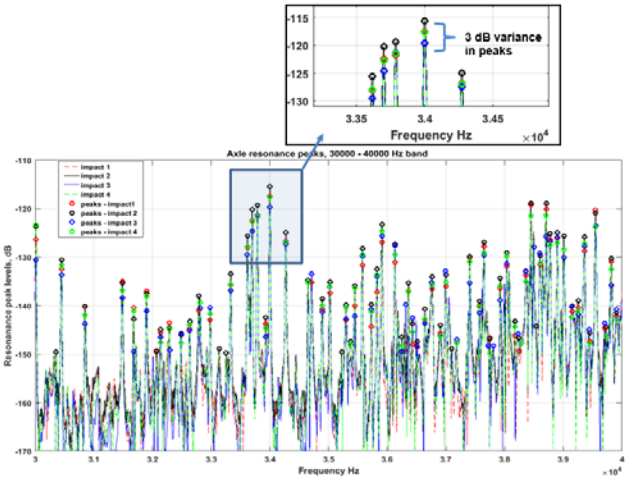

Figure 3. Spectral response for 10 kHz bandwidth peaks for entire static testing

Rolling noise measured for a 10-car train consist traveling at 5 mph and at 10 mph using high-frequency DAQ and accelerometers was also analyzed.

Figure 4 shows the results of the high-frequency train rolling noise compared to axle response in time and frequency domain. From this, it was evident that the axle resonance peaks exceeded track acceleration levels above ~15 kHz. As a result, there was no need to determine track to axle vibration transmissibility. Also, the results obtained validated that rolling noise levels were only significant up to 5 kHz.

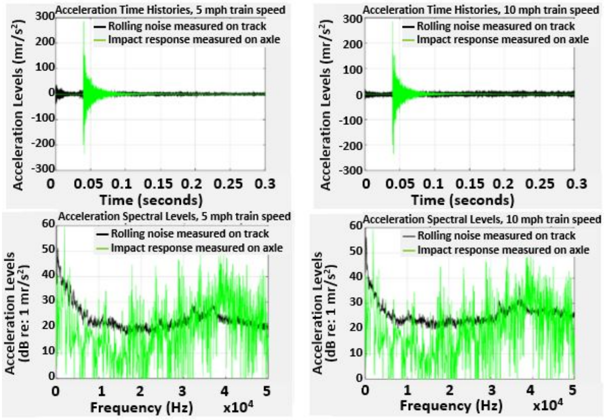

Figure 4. Comparison of impact response and rolling noise at 5 mph and at 10 mph

Similar results were obtained for the dynamic tests. The spectral response obtained from the 35 to 40 kHz bandwidth range indicated that the same frequencies appeared in several tests. Overall, 17 frequencies between the 17 kHz to 50 kHz range were identified from a histogram of all datasets, and all of them appeared in 95 percent of the tests that were conducted.

A comparison was also performed to compare frequencies obtained from the dynamic tests with those obtained from static tests. Significant static condition resonance frequencies were identified from 96 datasets. Frequencies observed during the static and dynamic testing were in good agreement, closely following the 45-degree line.

CRACKED AXLE RESPONSE

The final part of the project addressed the cracked axle response and how it compared to the good axle. For this, TTCI compared axles with notches (Axle E) (2-inch and 4-inch long and 0.5-inch and 0.65-inch deep) to new axles (axles H and I) under static conditions. Figure 5 shows the expected variations in resonance frequencies. But it also shows that frequencies for two new axles differed significantly, which was probably due to dimensional tolerances in manufacturing.

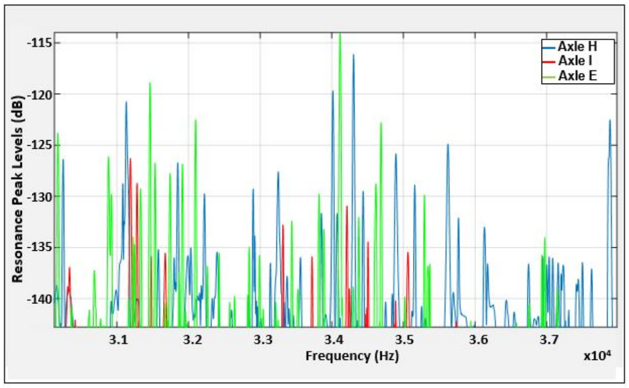

Figure 5. Comparison of resonance frequencies of new and used axles with notches

A study of damping characteristics of these axles did not reveal any differences. Axles with notches could not be differentiated from the new good axles. This is expected since surface notches only modify the stiffness of the axle, not the damping properties. The response from an actual cracked axle is not known and was not studied in this research.

The resonance response of a given axle/wheel assembly is more like a fingerprint than a characteristic; it is unique to each assembly. The resonance response differences between the good and the cracked axles were about the same as the resonance response differences between identical new axles. This implies that a baseline resonance response must be taken for every axle/wheelset that will be monitored by this method.

CONCLUSIONS

From the rolling wheelset testing, 10 repeatable frequencies occurred in 95 percent of the datasets. The majority of these frequencies were between 17 kHz and 50 kHz. Static and dynamic testing results agreed well, indicating that the WIDEM results should be applicable to a rolling wheelset. Unfortunately, the resonance differences between identical wheelsets were about the same as the differences between good and cracked axles. It is recommended that future work focus on the non-contacting approach for measuring the axle resonance responses.

REFERENCES

1. Poudel, A. and M. Witte. 2018. "Review of Railroad Axle NDE Inspection Technologies," *Technology Digest* TD-18-007. AAR/TTCI.
2. Verhelst, W. 2008. "Development of Compensated Resonance Inspection Prototype for Wheelsets." Project TST-CT-2005-516196, D6.1.