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Testing of an Air-Coupled Acoustic Device as an Energy Source for Acoustic Cracked Wheel Detection

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Summary

Acoustic cracked wheel detection relies on evaluating the vibration response of a train wheel after an energy input event. Recent testing with a rail joint impact energy source suggests that an alternative excitation energy source may improve the performance of acoustic cracked wheel detection. Transportation Technology Center, Inc. (TTCI) tested a high-powered air-coupled acoustic device for possible use as an energy source for acoustic cracked wheel detection. The Long Range Acoustic Device 1000XI was evaluated for its ability to impart energy to moving train wheels. This device is commonly used for long range communication and is one of the most powerful acoustic devices available. The 1000XI model, provided by LRAD Corporation, was tested to determine if it could impart sufficient energy into the wheel to reliably identify cracked wheels. Testing demonstrated that the device was capable of imparting energy into moving train wheels, but the signal was not substantially greater than the rolling noise produced by the train.

In efforts to optimize the energy transfer, several parameters were varied. Two different acoustic tones were evaluated — a steady tone near the resonance frequency of the wheel and a sonic impulse consisting of a recording of a hammer striking the wheel. The hammer strike tone produced the greatest response. TTCI also investigated the placement of the acoustic hammer relative to the train wheel. TTCI varied the point of incidence on the wheel and distance from the wheel to the acoustic source. The acoustic energy reached maximum intensity at a point about 20 feet in front of the device. Aiming the device at a point 4 inches above the rail provided the most reliable acoustic coupling to the wheels. In the best case, the signal generated by the acoustic hammer was less than 2 times the train rolling noise at 20 mph. A value at least 10 times this level is considered necessary for reliable crack detection.



BACKGROUND

Since the mid-2000s, ultrasonic automated cracked wheel detection has been available for the North American railroad network. This technology has seen very limited application in revenue service. Mechanical complexity with high maintenance, remote in-yard location, and the resulting low through-put capacity has limited the application of this technology, and thus has limited the availability of its benefit.

An alternative to ultrasonic inspection is acoustic cracked wheel detection. An acoustic cracked wheel detector monitors train wheels at line speed and determines whether or not wheels have a crack open to the surface. The detectors measure the vibration response of train wheels after an external energy source has imparted a shock. The fundamental idea is similar to a ringing bell — an intact bell will ring, but a cracked bell will not.

Acoustic cracked wheel detection is a developing technology proposed for finding train wheels with cracks that extend to the surface of the wheel. Unlike ultrasonic cracked wheel inspection that can find internal flaws, acoustic cracked wheel detection will only find serious defects that break the surface of the wheel. As such, high reliability is required to ensure that the diagnosis is made correctly every time.

TTCI has previously tested an acoustic cracked wheel detector that uses an impact with a rail joint to ring the wheels. Generating a consistent wheel impact over time has proven difficult at the rail joint. Seasonal variations and joint wear result in inconsistent energy input and unreliable diagnoses. An alternative excitation method is needed to regulate the energy imparted to the wheel. This testing evaluates an air-coupled acoustic device as an energy source to replace the rail joint for the cracked wheel detector. An air-coupled acoustic energy source must be able to provide a consistent energy impulse to every wheel every time. This device will have added advantages of being noncontacting and low maintenance.

INTRODUCTION

With BNSF Railway, TTCI tested a high-powered air-coupled acoustic device for possible use as an energy source for acoustic cracked wheel detection. Figure 1 shows the Long Range Acoustic Device (LRAD) 1000Xi model received from LRAD Corporation for evaluation. The LRAD 1000Xi model was designed for long range communication and is one of the most powerful acoustic devices available. In concept, with optimal coupling of the energy from the acoustic device to the wheel, strong vibrations will occur in the wheel near its natural frequency. TTCI evaluated the 1000Xi model to determine if it could impart sufficient energy into the wheel to reliably identify cracked wheels. Testing demonstrated that the device was capable of imparting energy into the wheel, but at a level not substantially greater than the rolling noise produced by the train.



Figure 1. Long Range Acoustic Device

Figure 2 shows the components of the acoustic cracked wheel detector used for this testing. This equipment is identical to the acoustic cracked wheel detector used in revenue service except without the rail impact joint. The smooth rail at the vibration sensor creates a test bed for evaluating different energy sources. The sensors in the rail are the heart of the system. These sensors take advantage of coupling between the wheel and rail to sense the vibrations within the wheel. The wheel presence detectors sense train arrival. The control box determines when to take measurements and processes the data. The power and communications box provides system power and a network link for sending alerts and data.

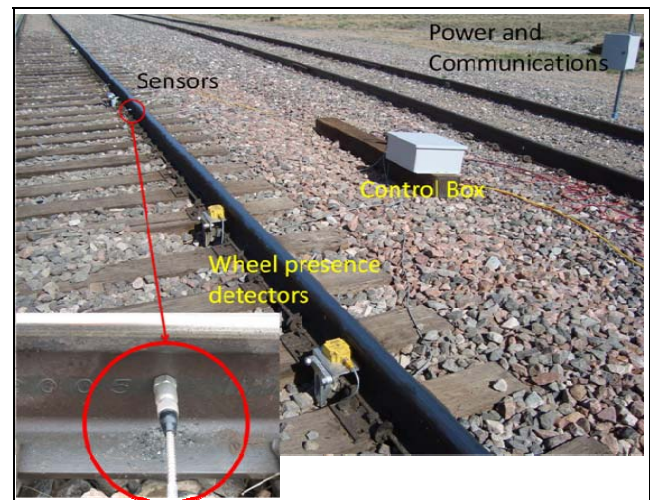


Figure 2. Acoustic Cracked Wheel Detector Components

METHODOLOGY

LRAD testing followed a progressive approach. First, static testing was conducted to determine the level of acoustic coupling between the hammer and the wheel. The static testing was used to find optimal energy transfer by looking at tonal variants and position of the device relative the wheel. Next, dynamic testing was performed to determine the acoustic energy level in the wheel relative to rolling noise. The goal was to achieve a level of acoustic energy at least 10 times greater than the rolling noise.

Static Testing

Static testing of the acoustic hammer was completed in two phases. During the first phase, an accelerometer directly on the wheel measured the vibration levels induced by the acoustic hammer. This method provides the most precise measurement of the total energy imparted to the wheel. During the second phase, the cracked wheel sensors in the rail were used to monitor wheel vibrations. This test provides a true indication of signal strength available for the cracked wheel detector.

Initial static testing was performed using a single wheelset on the track. This simple configuration made it easy to test the effect of positioning of the acoustic device. The acoustic intensity of the LRAD has a pattern of peaks and troughs. Per LRAD Corporation, the maximal intensity occurs at a focus point about 20 feet in front of the device. With a bare wheelset, it was possible to study the effects of incidence angle and position. TTCI varied the incidence point of the beam on the wheelset. Variants included aiming the device at the axle end cap and the wheel plate.

TTCI personnel varied the distance from the LRAD to the wheel to determine the distance for maximum energy transfer into the wheel. While the published data indicates that the maximal sound intensity is produced at 20 feet in front of the LRAD when the device is pointed toward an open space, the test team considered that putting a train wheel in front of the device might alter the intensity distribution. Since acoustic pressure drops off rapidly with distance, the closest placement to the wheel might produce the highest coupling. For practical purposes, the closest that a device was placed to the rail was about 4 feet. For this reason, the distance was varied from 4 feet to approximately 20 feet during static testing.

Dynamic Testing

Dynamic testing was performed to evaluate the performance of the acoustic hammer during an on-track test at Transportation Technology Center’s (TTC) Facility for Accelerated Service Testing (FAST). The test was performed between sections 28 and 30 on the High Tonnage Loop (HTL.) Figure 3 shows the acoustic hammer positioned for testing on the HTL.



Figure 3. Air Coupled Acoustic Device in Position for Testing

For the dynamic testing, TTCI used the full FAST test train (110 cars) plus three test cars equipped with cracked wheel defects. The test matrix for the dynamic test called for five trips past the acoustic hammer at speeds of 20, 25, 30, and 35 mph. Wheel vibrations were measured using the acoustic detection system hardware. Signal conditioning and data analysis were performed by personnel from the supplier of the acoustic detector.

Acoustic Intensity

The LRAD is an amplified speaker system that projects sounds from any mp3 audio file. Both the frequency and the tonal quality of the sound affect the acoustic intensity of the output signal. The maximal acoustic intensity of the LRAD 1000Xi is measured in decibels (dB) on an A-weighted scale. Figure 4 depicts the published data and shows a 155 dB peak that occurs near 3,000 hertz (Hz).

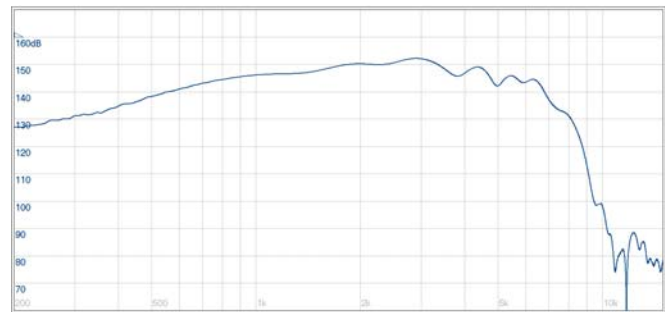


Figure 4. Frequency Response of the LRAD 1000Xi as published by the LRAD Corporation

Sonic Tone

The tone delivered by the LRAD strongly influences the vibration response of the wheel. As such, two different tones were selected for evaluation during the test. The first was a pure sinusoidal tone corresponding with the fundamental vibration frequency of the wheel nearest to the maximal output range of the LRAD. This pure tone was very near 3,100 Hz. The second tone was a recording of a hammer repeatedly striking a railroad wheel. It was hypothesized that the broad spectrum and the impulsive nature of the hammer impact tone might induce vibration in the wheel better than the pure tone.

RESULTS

Maximal Intensity

The acoustic intensity of the acoustic hammer was verified using handheld noise meters placed at various locations around the device. These tests confirmed that the device was capable of operating at full power in the test environment at TTC. The maximum sound intensity did occur as published at a convergence point approximately 19.8 feet in front of the LRAD.

Static Test

During testing, TTCI varied the incidence point of the LRAD device on the wheel from the axle to the rim. These variants were not significant. To hit the wheel at its most accessible location when on the car, the device was aimed about 4 inches above the rail for all subsequent testing.

TTCI made noise measurements with the acoustic hammer at distances ranging from 3.3 feet to 19.8 feet from the wheelset. Noise measurements were collected at each location for the two different tones. In all cases, the highest vibratory response from the wheel occurred with the acoustic hammer located 19.8 feet from the wheel. Further, the hammer impact tone always produced a greater vibration response from the wheel than the pure tone. The vibration energy absorbed by the wheel was a nominal 0.65 g (acceleration) root-mean-square (rms) with the pure tone and 1.8 g rms with the recorded hammer impact tone. As a reference, the vibration energy value, produced when a railroad wheel was struck with a hammer, was 30 g rms. In the best-case configuration, the LRAD imparted only about 6 percent of the energy to the wheel compared to that produced by a steel hammer impacting a wheel. While this is a substantial reduction in energy, TTCI continued with the dynamic test. The dynamic test would determine the wheel's response to the acoustic hammer compared to the rolling noise of the train.

Dynamic Test

The 20 mph measurement showed the rolling noise produced by the train to be about 2.5 g rms for a good wheel with values ranging from 1.2 to 3.0 g rms. This value, about 10 percent of that produced by a steel hammer striking a wheel, is the threshold that must be overcome by the acoustic hammer to achieve a minimally acceptable signal-to-noise ratio. Figure 5 shows a graph of the rms acceleration in response to the hammer impact tone for a train moving at 20 mph. The red, green, and white curves are from the three different sensors in the cracked wheel detector. The vertical red line indicates the time of tone arrival.

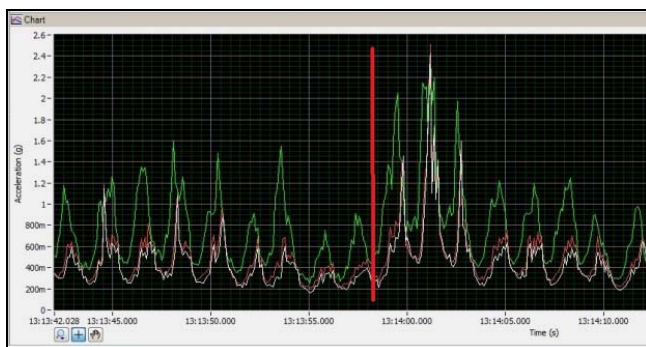


Figure 5. RMS Acceleration Response due to the Hammer Impact Tone
(The vertical red line indicates the time of tone arrival)

The peak value from the hammer impact tone is about 2.5 g rms. The hammer impact tone arrival signature is clearly visible on this trace, but the overall magnitude of it is relatively low. The hammer impact tone is of the same order of magnitude as the rolling noise produced by the train. The signal produced by the acoustic hammer used in the test was not strong enough to be differentiated from the rolling noise of the train. It is doubtful that the air-coupled acoustic hammer as tested would be a suitable excitation source for cracked wheel detection.

CONCLUSION

Testing demonstrated that the energy imparted to the wheels by the acoustic hammer was not sufficient to produce a vibratory response that was substantially greater than the noise produced by the wheel rolling on the rail at 20 mph. The air-coupled acoustic device tested is not a suitable excitation source for use with the acoustic cracked wheel detection system.

FUTURE WORK

Future work will include testing other energy sources for acoustic cracked wheel detection. Proposed devices include an electromechanical hammer and a mechanical hammer. Testing for the electromechanical hammer is underway.

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