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Using Proximity Sensors to Detect Broken Rims

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Summary

Transportation Technology Center, Inc. (TTCI) tested a broken rim detector designed by Diesel Intellect International (DII) of Hackensack, New Jersey. The detector uses proximity sensors to directly detect rim material. This device would have utility for detecting wheels with advanced levels of broken rim defects where material has already broken off of the rim. It is not meant to detect internal wheel defects. Its simplicity and ease of deployment would make it desirable for severe environments where wheel defects can develop rapidly. A network of these devices could frequently inspect every wheel at line speed.

The broken rim detector concept was originally validated using ultrasonic sensors. When these sensors were deemed not practical for the railroad environment, DII proposed substituting a reliable magnetic sensor already used by the railroads. While the magnetic sensors are proven suitable for the railroad environment, they did require changes to the approach. These differences were accounted for in the design of a new broken rim detector prototype. This prototype was built and tested on the Facility for Accelerated Service Testing (FAST) High Tonnage Loop (HTL) at Transportation Technology Center (TTC). After testing, the magnetic sensors were shown to be more sensitive to rim position than to tread voids. Wheel rim position influenced by hunting and tread wear caused greater deviation in the signal than a calibrated notch in the rim. The approach as presented with magnetic sensors is not practical for broken rim detection. From the development and testing performed at TTC, TTCI has determined that the system as designed is not sensitive enough to reliably differentiate a 4-inch long by 0.75-inch deep groove on the rim. The magnetic sensors measure over a broad area of the rim and are more sensitive to tread wear related displacement than to material voids.

The development and testing was performed by TTCI as part of a research effort funded by Federal Railroad Administration and the Association of American Railroads' Strategic Research Initiatives Program.

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INTRODUCTION

The broken rim detector is a track-mounted device for detecting broken railroad wheel rims on moving trains. The device relies on a direct measurement of material presence to determine rim integrity. If a portion of the rim material is missing, the proximity sensor should sense the void. Such a system does not sense internal defects. Figure 1 shows the prototype broken rim detector system installed at Facility for Accelerated Service Testing (FAST) at TTC.

Figure 1. Broken rim detector system installed at TTC

The broken rim detector system is a straightforward approach to broken wheel detection. It does not require any special trackwork and has no moving parts. It uses a direct physical measurement of the wheels to detect defects, and it operates at line speeds. The device could function as a stand-alone detector, or as a pre-inspection for cracked wheel detectors using tread bearing track work. Such track work cannot safely accept wheels with severe vertical split rim, so some means of detecting and diverting broken wheels prior to entry is desirable.

CONCEPT

The broken rim detector system is an alternative technology for directly identifying wheels with a shattered rim. It uses proximity sensors to assure wheel rim continuity. An array of proximity sensors is mounted just beyond the field side of the railhead. As a healthy wheel passes, it will trigger every sensor equally in succession. If a damaged wheel passes, the signal will be different on one or more of the sensors. Analysis of the signals directly identifies rim defects. The result is direct detection of a discontinuity in the rim.

HISTORY – ULTRASONIC SENSORS

TTCI and DII originally performed proof of concept testing using ultrasonic sensors. Although this concept showed promise, test results at FAST showed the ultrasonic approach is not suitable for use in the railroad environment. The ultrasonic sensors are not hardened for the environment and are a challenge relative to clearance requirements. Their preferred location violates clearances required for maintenance of way machines. They are also sensitive to blowing debris. Debris kicked up by the train causes noise in the signals. Any airborne material, rain, snow, dust, or even tumbleweeds cause noise that could be misconstrued as a wheel defect. Sensitivity to rain and snow precludes use of these sensors in the preferred outdoor location.

MAGNETIC SENSORS

To be commercially viable, the technology requires a robust sensor with a compact design. Magnetic wheel sensors provide this robustness. Figure 2 shows the proven robust magnetic wheel sensor used for the broken rim detector system.

Figure 2. Magnetic wheel sensor and wheel segment

The magnetic sensor is not limited by speed and does not react to airborne dirt and debris. When placed up along the field side of the railhead, it will sense the portion of the wheel tread overhanging the railhead.

A missing part of the rim will change the signal form. The signal response of the magnetic sensor is fundamentally different than the response from the ultrasonic sensors. The following investigation explores the nature of the signal from the magnetic sensors and an analysis technique to utilize it.

MAGENTIC SENSOR SYSTEM CONFIGURATION

Each magnetic sensor covers 2 inches of the rim surface, and 64 sensors per rail are required to inspect a complete wheel circumference. The magnetic sensors cannot be placed close enough together to sense the wheel in only one revolution. Therefore, their position must be staggered so that each sensor will sense a different segment of the rim over two full revolutions. Figure 3 shows a conceptual diagram of the sensor configuration.

Sensors are mounted in pairs across the track. The pairs are precisely positioned. Lateral and vertical positioning affect the magnitude of the signal, and longitudinal alignment across the track affects the timing of the peak at each location.

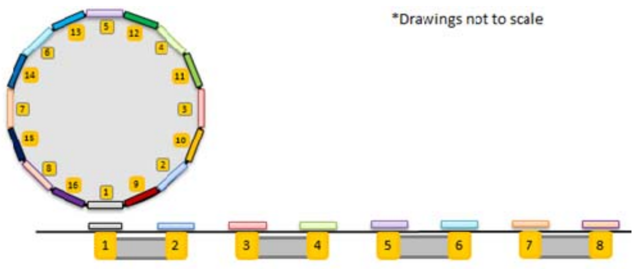

Figure 3. Sensors are staggered to inspect the rim over two revolutions

SENSOR RELIABILITY

TTCI placed the broken rim detector on the High Tonnage Loop (HTL) at TTC. The HTL is the nightly service track for the train at FAST. The FAST train loops the 2.7-mile HTL every 4 minutes. This captive train provides an opportunity to sense the same population of wheels repeatedly. With this test, statistically significant measures can be drawn.

DII monitored wheels on the FAST train during normal FAST operations. These tests were used to determine signal reliability and variability on known good wheels. Test results showed the magnetic sensors are reliable. They sensed 100 percent of the FAST train wheels over the entire test period. This provides confidence in their ability to assure reliable measurement.

VARIABILITY

From the same measurements, statistics were generated for signal length (amplitude). DII determined that there is considerable variability in the average reading. Figure 4 shows the distribution histogram of average readings for known good wheels on the FAST train.

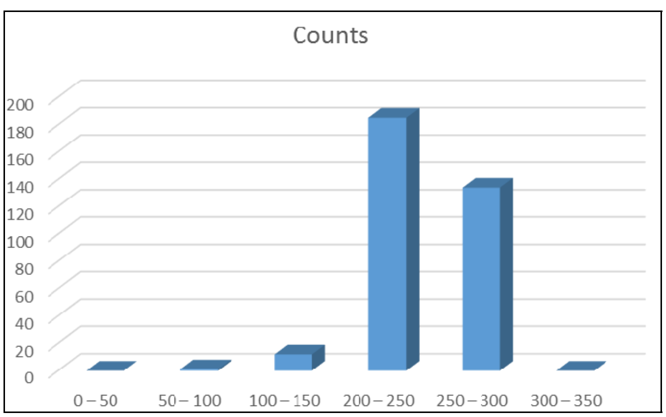

Figure 4. Histogram showing the distribution of magnetic sensor readings on known good wheels of the FAST train

The readings must be normalized so that the average event per wheel is consistent for known good wheels. An adaptive routine to normalize the signals is described next.

CALIBRATION

The magnitude of the signal depends on the distance between the sensor and the wheel. The amount of wheel tread overhanging the railhead is one of several factors that influence this distance. Lateral position of the wheelset on the rail and width of the wheel will affect the distance to the sensor and thus the magnitude of the signal. Also, the position of each sensor relative to the railhead will influence the measurement. Both the side to side distance from the railhead and up and down position from top of rail will affect the straight-line distance to the rim. Tread wear will also affect the result. Wheels with a hollow tread place the rim closer to the sensor than a freshly profiled wheel. This difference can be as much as 0.5 inch. Figure 2 shows a worn wheel profile relative to the sensor. The calibration procedure must distinguish the sensor position variations from the wheel geometry measurement in an objective way.

Figure 5 shows the signal from each of 12 sensors as a single wheel passes them.

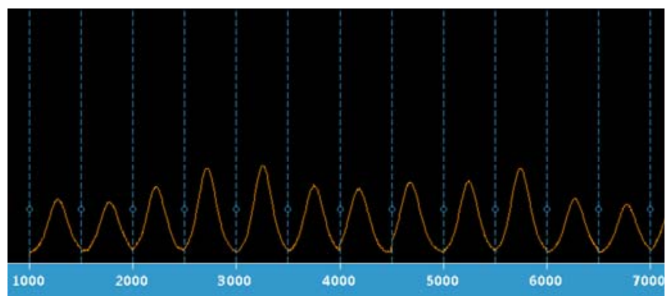

Figure 5. Amplitude readings from a single wheel passing the magnetic sensors on one rail

The relative magnitudes of the 12 signal amplitudes are similar for every wheel that passes. Sensors 1, 2, 7, 11, and 12 are consistently smaller. This means the sensors at these locations are installed lower or further away than the others.

Since the signal deviation from wheel to wheel is consistent, we can use this deviation from mean as the calibration coefficient to eliminate the differences in sensor position. Applying this coefficient to the data makes the wheel to wheel variation apparent, as Figure 6 shows.

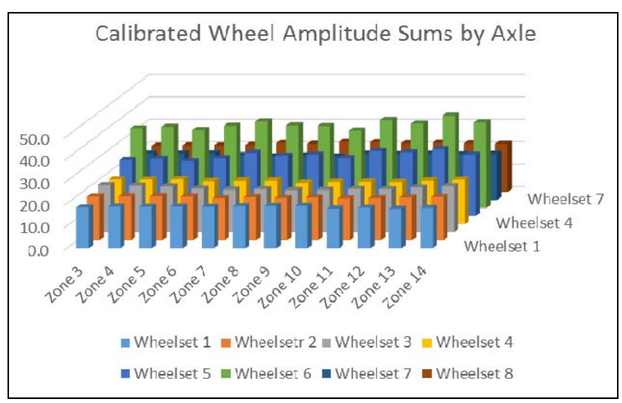

Figure 6. Amplitude readings normalized using average wheel deviation per axle

One would expect the normalized amplitudes to be consistent from sensor to sensor. This is the case for the first four wheelsets, which are the locomotive wheels. But the case is not as clear for the following four wheelsets, which are from the test car. They show greater deviation. Figure 6 shows for axles 5 (blue) and 6 (green), the deviation is about 4 times higher than on the other wheels. The following section explains the significance of these two wheels.

TEST WHEEL

TTCI produced a test wheel with three notches around the rim. Each notch has a different depth. One is 0.25-inch deep; one is 0.50-inch deep; and one is 0.75-inch deep. All notches were 2 inches wide originally. Figure 7 shows the 0.75-inch deep by 2-inch wide notch. The mating wheel on the axle has no notches.

Figure 7. Rim notch on the test wheel (0.75-inch deep by 2-inch wide)

RESULTS

The test wheel was on axle 5 of the test train. While this wheel does show variability from sensor to sensor, it is not as significantly different as wheelset 6. Wheelset 6 is a worn wheel with a continuous rim, and it should show lower deviation than wheelset 5. Unfortunately, the deviation for wheel 6 is greater than the deviation for wheel 5. The hollow tread causes a nonlinearity in the rim elevation as the axle moves laterally. The deviation due to wheel profile is more significant than the deviation caused by the notch on wheel 5. This factor complicates detection of the notch using magnetic sensors, because no amount of normalization can overcome the variability due to tread wear. It is more significant than variation caused by the notch. Adding a guardrail to hold the axle in position during sensing could presumably help this condition, but there is another limitation as described next.

TTCI increased the wheel notches to 4 inches long and repeated the testing. Similar results were found. The broken rim detector could not reliably find the 4-inch long notches. A fundamental characteristic of magnetic sensors is that they sense material presence over an area.

Unless the notch is directly centered over the sensor, the sensor will detect the closest corner of rim material within its field. It is sensitive to material presence around the void if that material falls within its sensing area. The area of the magnetic field must be much smaller than the size of the flaw to be detected.

The mechanical design of the system also showed shortcomings. Precise sensor location is critical for accuracy and the sensors did not stay in position. After only a few nights of operation at FAST, some of the clamp brackets came loose and the sensors shifted, as Figure 8 shows. A much more robust mounting system is required to maintain sensor position.

Figure 8. Unstable sensor brackets during testing at FAST

CONCLUSIONS

Test results for the DII broken rim detector showed neither the ultrasonic sensors nor the magnetic sensors are suitable for detecting rim continuity in the railroad environment. The ultrasonic sensors are not robust and are susceptible to airborne debris. The magnetic sensors are robust, but they proved to be more sensitive to bulk position of the target than to missing material. The size of their sensing area is much too broad to detect a reasonable sized broken rim defect. The broken rim detector based on proximity sensors is not practical for commercial application with these magnetic sensors

ACKNOWLEDGMENTS

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