TECHNOLOGY DIGEST

TD-17-028
©OCTOBER 2017

TIMELY TECHNOLOGY TRANSFER

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Wheel Impact Load Detector Crib Mapping Feasibility

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Summary

Transportation Technology Center, Inc. (TTCI) has investigated the capabilities and feasibility of using crib level data from wheel impact load detector (WILD) sites to map forces around the circumference of passing wheels. Mapping the crib level data to each wheel may allow WILDs to provide the amount of tread surface damage that is occurring around the circumference of the wheel and not just the highest peak vertical force. This information may help with prioritizing removal of wheelsets at risk of having cracked or broken wheels. Broken wheel risk analysis with mapped crib level data is planned, using data to be provided by the railroads.

The highest sources of variation in the WILD crib mapping process have been identified and quantified. This work illustrated the feasibility of mapping forces around the wheel circumference given knowledge of the following.

- The site crib layout – the tie spacing is unique for a specific layout design
- The wheel diameter – the tapeline (circumference) of the wheel is most affected by the wear condition and wheel rim type (1-wear, 2-wear, and multi-wear wheels) with a minimal effect from out-of-round due to differing rim thicknesses

It is possible that wheels with a higher percentage of worn high impact surface increase the stress state in the track compared to those with smaller percentages. Crib-based mapping may allow removal prioritization of these wheels.

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INTRODUCTION

Wheel impact load detectors (WILD) currently in service are wayside detectors that utilize a series of strain gages installed onto the rail web which measure vertical and lateral load forces of passing wheels.[1] The work described in this *Technology Digest* only considers vertical forces. The WILD systems measure forces when the wheel is in the space between ties also known as the crib. As the wheel moves from tie center to tie center, it traverses the crib's area of influence where the system is most sensitive to vertical loads. Figure 1 shows an example of a crib of a WILD site.

Figure 1. Typical WILD Site Strain Gage Installation

The instrumented cribs of a WILD site are typically laid out over 50 feet to provide the most coverage for a range of wheel diameters in order to have a high probability of reading the highest impact from a given wheel. The coverage for various wheel diameters is not uniform, and some wheel sizes will have a slightly greater chance of having their highest force reading detected than other wheel sizes, depending on the site layout. A 36-inch wheel rotates six times through the most common WILD site layout. WILD site software uses the strain gage signals from the crib to determine a single value of wheel load and maximum impact value.

The proposed WILD crib mapping method uses all cribs, typically 16, to map the measured forces along the circumference (or tapeline) of the wheel. In order to map crib force measurements to the wheel, the site layout and wheel circumference are needed. There are several site layouts being used by various vendors, and wheel circumferences for a given nominal diameter wheel (i.e., 36 inches) will vary due to wheel wear and/or wheel rim type (1, 2, or multi-wear wheels). WILD systems are primarily installed in tangent track and tend to read the vertical forces at the tapeline of the tread. Defects that occur away from the tapeline toward the flange or field side of the tread may be missed unless the truck is hunting or has excessive inter-axle misalignment.

The objective of this work is to provide evidence that the proposed WILD crib mapping method can be accomplished with acceptably small variation and the results can be used for a larger scale broken wheel risk analysis.

In order to investigate the proposed crib mapping method, WILD crib level data and site layout information was provided to TTCI from a single site over one week each in the summer of 2015 and winter of 2016. This data was used to provide examples of the crib mapping methodology as shown here.

CAPABILITIES

The main advantage of WILD crib mapping is that it provides a more comprehensive view of the wheel tread condition or health. With crib mapping, the percent of the wheel's circumference that is impacting at an elevated force level can be determined. This information can be used for risk analysis of potential cracked or broken wheels, as well as prioritization of wheelset removals.

Consider two wheels that both have a peak WILD measurement of 90 kips. If one has high measurements in a small location representing 10 percent of the wheel's circumference and the other has high readings for 80 percent of the circumference of the wheel, a risk analysis of broken wheels might show that wheels with a larger effected circumference to be more likely to experience crack growth or initiation. Even without a risk analysis, the wheel with a higher percent of impact around the circumference might be prioritized for removal, because it is impacting more of the rail.

WILD crib mapping may also permit categorization of wheel defects. Figure 2 shows crib mapping results from one 36-inch wheel. All 36-inch wheels in the available data were mapped to the site and assumed to be new 36-inch wheels in terms of circumference. The outside circle represents the circumference of the wheel (~113.1 inches). The dots are plotted at the point on the circumference of the wheel (in inches) where each crib center would land as the wheel rotates over the site and at the force level that was measured from that crib; dots farther away from the center of the circle indicate a higher force reading. The wheel has two high readings above 80 kips that are mapped onto the circumference of the wheel between 40 and 60 inches. The rest of the crib centers show lower kip measurements around the remainder of the circumference, which are consistent with a loaded wheel. The result is an indication of a single defect; possibly a flat spot or shelling.

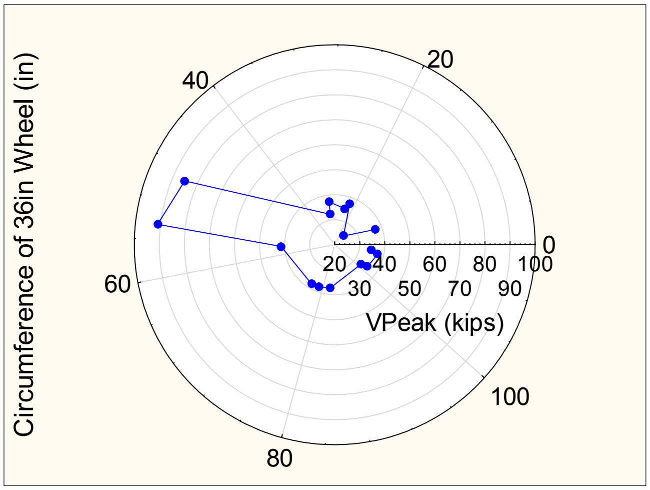

Figure 2. Example Results of Wheel Mapping for a 36-inch Wheel Showing a Single Defect

Figure 3 shows results from a different wheel with two areas on opposite sides of the wheel's circumference with high measurements of over 90 kips. This force pattern may indicate an out-of-round wheel.

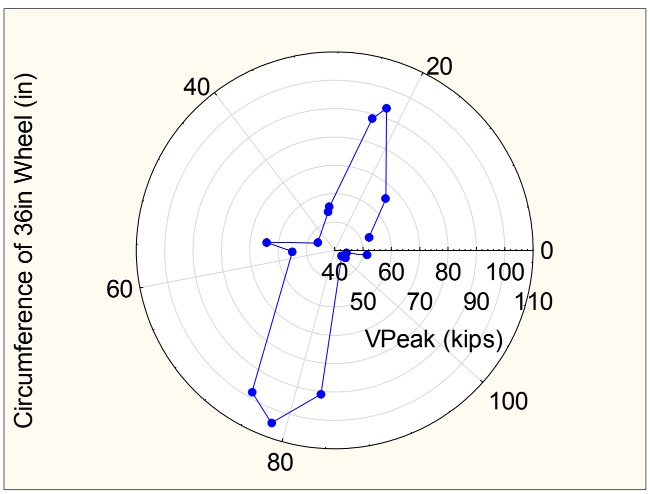

Figure 3. Example Results of Wheel Mapping for a 36-inch Wheel Possibly Showing the Wheel as Oval

SOURCES OF VARIATION

When performing WILD crib mapping, there is variation involved that could cause the crib force measurement to be mapped to incorrect parts of the wheel. The largest sources of variation are the following:

- Unknown wheel circumference due to an unknown diameter at the tape line
- Unknown site crib spacing/layout

Unknown wheel Tape Size/Circumference

The exact wheel tape size/circumference is continually changing as the wheel wears. Without a wayside detector that directly measures wheel tape size or circumference, the diameter can be calculated if the nominal wheel diameters, wheel rim types (1, 2, or multi-wear wheels), and rim thicknesses are known. Nominal wheel diameters are known from the Umler® registry. Wheel rim type and nominal wheel diameter can be collected from Comprehensive Equipment Performance Monitoring (CEPM) data, or from a vision system that can measure the wheel plate. Car repair billing data is incomplete and not considered due to cars repaired by the owners not being reported. Rim thickness measurements can be taken from a wheel profile monitoring system (WPMS) detector.

Table 1 shows the dimensions associated with different wheel rim types of 36-inch wheels.[2] The difference between the starting thickness and the minimum rim thickness allowed after turning of 1 inch is the maximum rim thickness difference. The rim thickness difference results in the circumference difference (2π* rim thickness dif.) shown. Each circumference difference is multiplied by six to represent the typical number of revolutions it takes a 36-inch wheel to pass a common WILD site layout; the result is the total variation. The total variation of 18.85, 37.70, and 56.55 inches for 1-W, 2-W, and M-W wheel rim types, respectively, might result in a high impacting area missing the crib and landing directly on the tie or even in the next crib. The maximum rim thickness difference for 28-, 33-, 36-, and 38-inch wheels is 1.5 inches.

Table 1. Maximum Possible Variation from Unknown Wheel Tape Size/Circumference for 36-inch wheels

	1-W	2-W	M-W
Starting Rim Thickness (in)	1.5	2	2.5
Min. Rim Thickness after Turning (in)	1	1	1
Max. Rim Thickness Difference (in)	0.5	1	1.5
Circumference Difference (in)	3.14	6.28	9.42
Total Variation (in)	18.85	37.70	56.55

Wheel shape due to uneven tread wear also affects the tape size/circumference of the wheel. The red dotted line in Figure 4 represents an exaggeration of an out-of-round oval shaped wheel. The blue and green circles represent resulting circles drawn based on the oval's diameter measured at its shortest and longest points. The circumference measured at the blue or green circles represents the variation from the actual shape (shown in red).

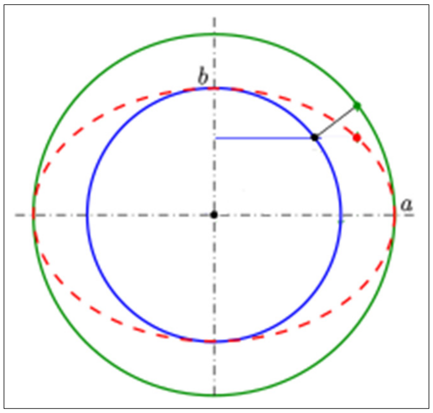

Figure 4. A Single Rim Thickness Measurement May Not Catch the Most Worn Part of an Out-of-Round Wheel

Using rim thickness data collected while investigating worn wheel profile variation and its implication on wayside measurement,[3] the resulting variation from out-of-round wheels was estimated. The largest difference in rim thickness measurements for any one wheel was 3/16 inch. When a measurement tolerance of 1/32 inch is included, then the difference in rim thickness on a wheel could be as high as 7/32 inch (0.21875 inch). The circumferences of the blue and green circles are 111.7 and 113.1-inches, respectively, for a 36-inch wheel. The perimeter of the red oval can be approximated as follows;[4]

$$p \approx 2\pi\sqrt{\frac{a^2+b^2}{2}} \quad \text{and} \quad p \approx 112.4 \approx 2\pi\sqrt{\frac{18^2+17.78^2}{2}}$$

This would result in a 0.70-inch difference in circumference length for new wheel diameter, and the total variation would be 4.2 inches assuming six rotations to pass a detector site. This total variation for variation of the rim might result in a high impacting area missing the crib and being directly on the tie.

Unknown Site Layout

There are several different crib layouts being used by vendors, including the number of cribs, location of cribs, and crib sizes/tie spacing. Each of these vary by site and vendor. The crib layout is known to the railroad and its vendor but can be modified, for example, if the site is modified to change the number of cribs.

Fifteen WILD site layouts were provided to TTCI by two vendors. The most commonly used 16-crib layout was compared to the other 16-crib layouts. The distances of each crib from crib 1 were measured and calculated for its position on a 36-inch wheel. In the most extreme case, 8 out of 16 cribs would misidentify a spot on the wheel 48 inches or more from its expected location, with the highest difference being 76.5 inches. The remaining 8 of 16 cribs would identify a spot 26 inches or less away on the wheel circumference. Figure 5 shows how the wheel in Figure 3 would be mapped if it were to be mapped using the wrong site's crib layout in the most extreme case.

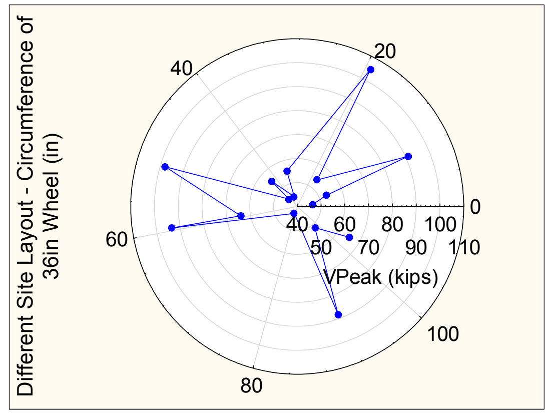

Figure 5. Example Results of Wheel Mapping for a 36in Wheel using Most Extreme Different Layout

CONCLUSION AND NEXT STEPS

Crib-based measurements can be used to map the damage around the circumference of a wheel given a knowledge of the crib topology at the site and the approximate diameter of the impacting wheel.

To reduce variation in the WILD load mapping to each wheel, the site layout and circumference of each wheel at the tapeline must be known. The circumference can be calculated using CEPM data with WPMS rim thickness measurements, or the circumference can be found using other wayside detector technology. Rim thickness variations in a given wheel could provide a small amount of variation to the process. Once the variation above has been accounted for, the method can be applied to a large number of wheelsets. TTCI will perform risk analyses of broken wheels to compare the risk of wheels measuring high impacts at certain percentages of their circumference.

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