TECHNOLOGY DIGEST

Timely Technology Transfer — 98-004

Effect of Hollow-Worn Wheels on Wheel/Rail Rolling Resistance

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Summary

Recent research indicates that wheels worn to a hollow profile of 3mm (0.12 inch) or more greatly increase wheel/rail rolling resistance (w/r resistance). In the absence of severe two-point wheel/rail contact conditions, and for equal friction values on both rails, a study sponsored by the Association of American Railroads (AAR) has yielded the following conclusions:

- Model predictions show large increases in w/r resistance once hollow wheel wear reaches 3mm (0.12).
- In tests in curved and tangent tracks, cars with new (tapered) wheels give w/r resistance values and gage-spreading forces very similar to cars with 2mm (0.08) hollow-worn wheels.
- Similarly, model predictions give very similar w/r resistance values for a car with tapered, 1mm (0.04 inch) hollow-worn wheels and 2mm (0.08 inch) hollow-worn wheels.
- The predicted and measured w/r resistance values for cars with tapered wheels and 2mm (0.08 inch) hollow-worn wheels agree well, especially in curved track.

The study included coupler force measurements on cars with all new wheels (AAR-1B) and all hollow-worn wheels (2mm [0.08 inch]). Tests were backed up by predictions of w/r resistance using the NUCARS vehicle dynamics computer package for cars with all tapered wheels, and all hollow-worn wheels (1mm [0.04 inch], 2mm [0.08 inch], and 3mm [0.12 inch]).

The study, conducted by researchers from Transportation Technology Center, Inc., a subsidiary of the AAR, forms part of the AAR's Wheel/Rail Profile Optimization Project, and the results contribute to an economic model studying the extent to which railroad costs can be reduced by the early removal of hollow-worn wheels.

Suggested Distribution:

- ❑ Equipment/Rolling Stock
- ❑ Equipment Maintenance
- ❑ Planning and Analysis
- ❑ Track Maintenance

Work performed by TTCI Transportation Technology Center, Inc.

a subsidiary of the Association of American Railroads

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INTRODUCTION AND CONCLUSIONS

Association of American Railroads (AAR) studies of the effects of wheel profile shape show that wheels worn to a hollow profile of 3mm (0.12 inch) or more greatly increase wheel/rail rolling resistance (w/r resistance). Coupler force measurements were made on cars with all new wheels (AAR-1B) and all 2mm (0.08 inch) hollow-worn wheels. Predictions of w/r resistance were done with the NUCARS vehicle dynamics computer package, for a car with all tapered wheels, and all hollow-worn wheels (1mm [0,04 inch], 2mm [0.08 inch], and 3mm [0.12 inch]).

Results from the study include:

- NUCARS predicts large increases in w/r resistance once hollow wear reaches 3mm (0.12 inch).
- NUCARS also predicts large increases in w/r resistance in severe two-point contact conditions.
- In tests in curved and tangent tracks, cars with new wheels give w/r resistance values and gage-spreading forces very similar to cars with 2mm (0.08 inch) hollow-worn wheels.
- Similarly, NUCARS predictions give very similar w/r resistance values for a car with tapered, 1mm (0.04 inch) hollow-worn wheels and 2mm (0.08 inch) hollow-worn wheels.
- The predicted and measured w/r resistance values for cars with tapered wheels and 2mm (0.08 inch) hollow-worn wheels agree well, especially in curved track.

The study forms part of the AAR's Wheel/Rail Profile Optimization Project, and the results contribute to an economic model studying the extent to which railroad costs can be reduced by the removal of hollow-worn wheels.

ROLLING-RESISTANCE MEASUREMENTS

Tests were undertaken on the Wheel Rail Mechanisms (WRM) loop at the Federal Railroad Administration's Transportation Technology Center near Pueblo, Colorado, on tangent track and 3-, 4-, and 7.5-degree curved dry track. Two consists of five cars were tested. The first had all wheels machined to the new AAR-1B profile. The second had wheels machined to a measured 2mm (0.08 inch) hollow-worn profile. The 100-ton cars were equipped with American Steel Foundries Ride Control™ trucks. The test train consisted of a locomotive, a buffer car, and the test consist. A coupler instrumented to measure coupler force connected the buffer car and test consist. Wayside measurements were made of angle of attack and lateral gage-spreading forces.

Tests were done at 10, 15, and 20 mph, in both directions, but there was little consistent effect of speed or direction on coupler force or angle of attack and gage-spreading force measurements. Therefore, measurements were averaged over all tests for each wheel/track curvature condition. Bearing, grade, and aerodynamic resistances were subtracted from measured coupler forces to give w/r resistance in units of pounds per ton.

Exhibit 1 shows the effect of wheel condition and track curvature on w/r resistance. Also shown are the standard deviations, which are large. In all cases the resistances with the 2mm (0.08 inch) wheels are slightly larger than with the AAR-1B wheels, but, with the exception of the result at 4-degree curvature, the differences are not statistically significant. For both wheel types, the measured tangent track w/r resistances are larger than expected. This may be because the tangent track section was located near the exit of a 10-degree curve, causing the test cars to enter the tangent section with misaligned axles.

Wheels	Track curvature			
	0°	3°	4°	7.5°
AAR-1B				
Average	2.02	3.85	4.79	9.61
Std. Dev.	0.94	1.39	0.91	0.93
2mm hollow				
Average	2.26	4.27	5.73	9.70
Std. Dev.	0.84	1.07	0.82	1.31

Exhibit 1. Wheel/Rail Rolling Resistances in lb./ton for New and Hollow-Worn Wheels

The 2mm (0.08 inch) hollow wheels gave only small changes in high- and low-rail lateral forces. Consequently, they had a minor effect on gage-spreading force, as shown in Exhibit 2, which illustrates the maximum and average measured gage-spreading forces. Like the w/r resistance measurements, the only significant difference between the new and 2mm (0.08 inch) hollow wheels occurred in the 4-degree curve.

PREDICTIONS OF W/R RESISTANCE

The rail vehicle dynamics computer program NUCARS was used to predict the effects of track curvature and hollow-worn wheels on w/r resistance, angle of attack, and gage-spreading force. Exhibit 3 lists the parameters used in the analysis. The truck parameters are typical of revenue-service trucks.

Three different axle misalignment cases were examined, since revenue-service tests have shown that cars run misaligned, typically by 2 mrad. Two levels of wheel/rail friction were studied: 0.45 on both rails to simulate dry track, and 0.4 on the head and 0.2 on the gage face (both rails) to simulate lubricated track.

As expected, increasing misalignment caused w/r resistance to rise, especially in tangent track. Reducing wheel/rail friction caused the axles to run at higher values of angle of attack, but reduced w/r resistance by about 30 percent. To compare the NUCARS predictions with the results from the WRM loop tests, the predictions made using a 2 mrad misalignment and a wheel/rail friction of 0.45 will be presented here.

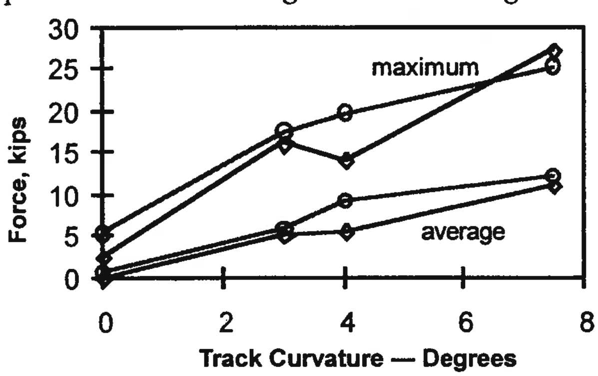

Exhibit 2. Measured Average and Maximum Gage-Spreading Forces (◊ = AAR-1B wheels; O = 2mm (0.08 inch) wheels)

Parameter	Value
Car weight	263 kips
Truck	Constant contact side bearing, 3000lb. pre load
Truck snubbing	Part worn
Truck warp stiffness	Normal
Center bowl friction	Normal
Axle misalignment	0, 1, 2 mrad
Wheel/rail friction	0.45; 0.4/0.2
Track curvature	Tangent, 2°, 4°, 6°
Speed	30 miles per hour
Wheel profile*	All tapered; all 1mm hollow; all 2mm hollow; all 3mm hollow

* The wheel profiles had simulated worn flanges

Exhibit 3. Parameters Used in NUCARS Predictions of W/R Resistance

Exhibit 4 shows the NUCARS predictions of w/r resistance for tapered, 1mm (0.04 inch), 2mm (0.08 inch), and 3mm (0.12 inch) hollow-worn wheels.

There are several points to note. First, for a given level of hollow wear, w/r resistance increases linearly with curvature. Second, for practical purposes, there is no effect of hollow wear on w/r resistance for wear up to 2mm (0.08 inch). Third, there appears to be a step change in w/r resistance at hollow wear greater than 2mm (0.08 inch). This may be associated with truck warp. However, it must be noted that these results are for the specific model conditions shown in Exhibit 3, and may vary with changes to these conditions.

Total rolling resistance can be predicted by adding estimated bearing and aerodynamic resistance to the predicted w/r resistance. For the tapered, 1mm (0.04 inch) and 2mm (0.08 inch), wheels this gives:

Total Resistance = 2.0 lb./ton + 0.98 lb./ton/degree

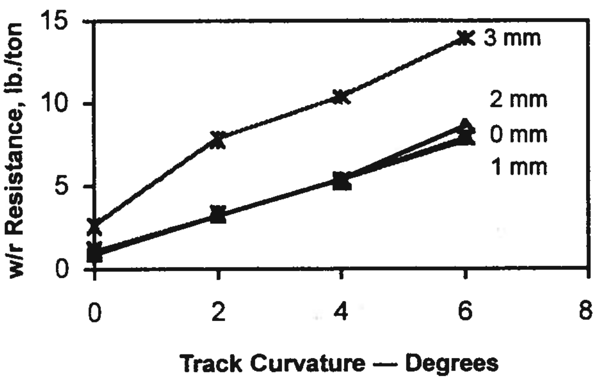

Exhibit 4. Predicted Effect of Track Curvature and Hollow-Worn Wheels on W/R Resistance

This is close to the commonly assumed formula of: 1.8 lb./ton + 0.8 lb./ton/degree. This agreement gives confidence that NUCARS is predicting w/r resistance reasonably well.

Exhibit 5 compares the NUCARS predictions of w/r resistance with tapered and 2mm (0.08 inch) hollow wheels with those found in the WRM loop tests. Reasonably good agreement is found, except in tangent track. As noted earlier, the test values from tangent track may have been influenced by the immediately preceding 10-degree curve.

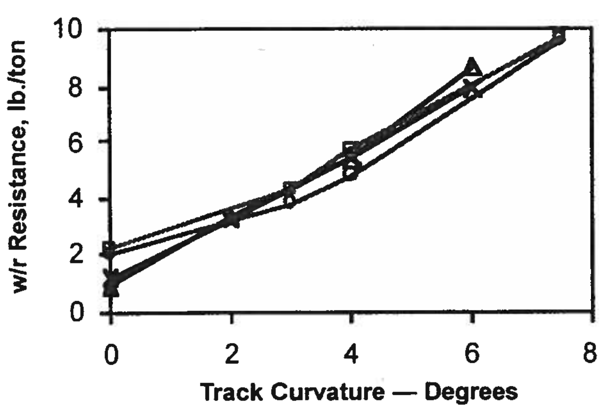

Exhibit 5. NUCARS Predictions (Solid Lines) and Test Results (Dashed Lines) for Tapered and 2mm (0.08 inch) Hollow Wheels

EXTREME TWO-POINT CONTACT CONDITIONS

Initial NUCARS work in this study used worn wheel and rail profiles which generated extreme two-point contact conditions on the high rail. These in turn led to much higher than expected w/r resistances when the vertical distance between the two contact points on the rail exceeded about 10mm (0.4 inch). These results suggest that excessive gage corner relief of the high rail (produced by grinding) may lead to high w/r resistance (and hence increased fuel costs), and higher lateral gage-spreading forces.

They may also explain earlier tests where coupler force measurements were made using a single car equipped with tapered and 2mm (0.08 inch) hollow wheels (TD-95-021). The tests apparently showed that 2mm (0.08 inch) hollow wheels greatly increased rolling resistance. However, testing was done with the rail ground to encourage two-point contact, and this may have contributed to the increased resistance.

FUTURE WORK

The work reported here has focused on the cases where all wheels on a car have the same profile. This is unlikely to occur in practice, but was chosen as a base case. Further work is planned to examine the effect that differentially worn wheels have on w/r resistance and gage-spreading forces.

Note: Contact Kevin Sawley at (719) 584-0636, with questions or comments about this document.

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A MORE DETAILED REPORT, WHICH MAY CONTAIN REVISED INFORMATION, MAY BE AVAILABLE AT A LATER DATE THROUGH THE AAR, PUBLICATION ORDER PROCESSING, 50 F STREET, NW, 5TH FLOOR, COG, WASHINGTON D.C., 20001