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Review of the Influence of Axle Misalignment on Rolling Resistance and Wheel Wear

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Summary

The total speed-independent component of rolling resistance of a typical North American freight car has been estimated at 1.4 lb/ton/mrad of axle misalignment. The average axle misalignment in service may be 1 mrad. Consequently, on average, the component of tangent rolling resistance attributable to axle misalignment may be as much as 40 percent of the total rolling resistance. Of this 40 percent, half may be reduced through adequate tangent rail lubrication.[1]

This data is presented in support of a cost benefit analysis for laser-based wayside wheelset angle of attack (AOA) measurement devices located on tangent track. This equipment is used to detect poorly performing trucks where the indication of poor performance is excessive wheelset AOA.

The implementation of laser-based AOA measurement systems is an initiative of the Advanced Technology Safety Initiative of the Association of American Railroads (AAR).

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INTRODUCTION

North American railroads are purchasing laser-based wayside measurement equipment to determine the tracking inaccuracies of trucks on tangent track. Advanced Technology Safety Initiative has tasked TTCI to assist the implementation of this technology by:

- Arranging the introduction of data from these detectors to InteRRIS®
- Developing a cost benefit analysis to support the use of the detector and the consequent performance limits
- Assisting an industry technical advisory group in implementing performance limits and developing AAR Interchange Rules for presentation to the AAR's Equipment Engineering Committee

Part of the process of determining suitable performance metrics and associated maintenance limits is an analysis of the benefits of removing a poorly performing car from service and fixing it compared with the maintenance costs.

Data associated with car performance can often be difficult to obtain. Fortunately, in the case of wheelset AOA performance, much work was done during the fuel crisis in the mid-1980s to relate tracking errors to fuel consumption. This information is now of some assistance in developing a cost/benefit analysis.

The objective of this *Technology Digest* (TD) is to review the work done in the 1980s and to extract data considered useful to a cost/benefit analysis for this detector type. The cost/benefit analysis will be the subject of a future TD.

BASIC TRUCK TRACKING ERRORS

Truck tracking errors can be generically described in terms of radial and warp misalignments of the axle.[1]

Radial axle misalignment (Figure 1) is caused by the bearings of the two wheelsets being further apart on one side of the truck than the other.

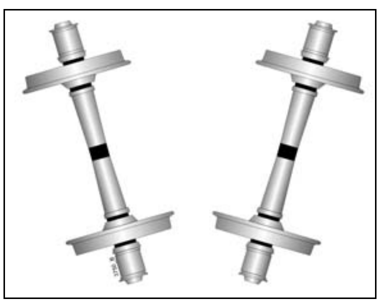

Figure 1. Radial Axle Misalignment

This can occur if the side frames of the truck have differing effective lengths, or (because of wear) incorrect fitment of the bearing adapters in the side frame.

Warp misalignment (Figure 2) is caused by misalignment of the side frames relative to the bolster as a consequence of, typically, one or a number of defects within the secondary suspension associated with the springs (broken, missing or misaligned), wedges, and / or wear plates.

The detector under consideration measures tracking errors of a truck when operating on tangent track. Consequently, this TD addresses those components of truck performance associated with tangent track performance measurement.

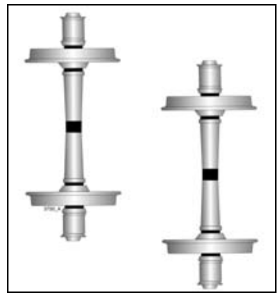

Figure 2. Warp Misalignment

Trucks in service generally exhibit a combination of both tracking errors. These errors are a consequence of:

- Inaccuracies in truck manufacture
- Wear (both truck component, as well as wheel wear – in particular, asymmetric wheel wear)
- Track topology; i.e., truck misalignment changing as a result of forces induced on curved versus tangent track
- History of track topology; i.e., a truck can "stick" in a warped position as a consequence of curving forces and take many miles of tangent running before "shaking down" to an improved alignment
- Asymmetric rail lubrication, where the wheels on one side of a truck become coated with lubricant and do not generate the required tracking forces for correctly aligned running

The tracking misalignments in Figures 1 and 2 are determined by measuring the AOA, α, of a wheelset and its lateral position, y, on tangent track (Figure 3).

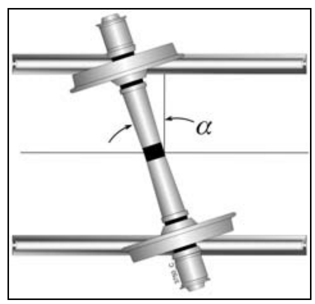

Figure 3. AOA of a Wheelset

These two metrics can be combined in a number of ways. They relate the tracking position of one wheelset to another in a truck. The tracking misalignments are the cause for increased lateral and longitudinal forces and creep between wheel and rail and, as a consequence of large tracking errors, in continual flange contact on tangent track, rail gage face wear and wheel flange wear. The consequences of these tracking errors on tangent track are, in particular:

- Increased rolling resistance and fuel consumption
- Wheel flange and tread wear (particularly flange wear)
- Rail gage face wear

Review of Relationship Between Tracking Errors and Fuel Consumption and Wheel Wear

Sing et al. reviewed the elements of the Davis equation:[2]

$$R = A + BV + CV^2 \quad \text{(1)}$$

Where: R = Train Resistance (lb), A = Speed Independent Train Resistance Component (lb) and B (lb/mph) and C (lb/mph^2) being coefficients of train resistance, dependent on V and V^2 respectively, where V is the speed of the train in mph.

They found that A and B were composed of elements that were strongly influenced by vehicle/track interactions. Except for the grade resistance component of A, A and B depend on vehicle weight, dimensions, truck type, wheel profile, bearing type, suspension stiffness and damping, track curvature, track class, track stiffness and speed.

They presented graphs relating resistance per truck to track curvature (degrees) and provided figures for fuel consumption for different train types on different routes (curvatures), having different classes of track, and calculated according to different methods, including the Davis formula. They conclude that:

- The Davis formula is not sufficiently accurate, or versatile enough, to determine fuel consumption when variations in track class, rail type, suspension design, and car dimensions are considered
- Wheel/rail lubrication can substantially reduce train energy needs
- To predict fuel consumption, a better understanding of car and track parameters is required

These conclusions led to many studies in the 1980s; e.g., the relationship between tracking errors, fuel consumption, and wheel wear.

When examining the benefits of improved suspension trucks, care must be taken in choosing the route, track quality and rail lubrication state when comparing performance.

Leary et al. conducted both laboratory tests on misaligned trucks as well as on-track tests at the Transportation Technology Center (TTC) located near Pueblo, Colorado.[3] They introduced controlled radial misalignments to trucks under test at TTC. In the on-track tests, there may have been elements of truck warp misalignment; this was not measured. Figure 4 shows their findings on wheel wear versus radial misalignment for carefully controlled tests at TTC. Figure 4 suggests that a limit for radial misalignment of approximately 3.5 mrad (*between* axles) might be used as a lower limit for reduced wheel wear.

There is no further reference to the relationship between wheelset radial misalignment and wheel wear other than the observations from test cars at TTC and general observations of cars in service that asymmetric wheel wear is a function of wheelset misalignment.

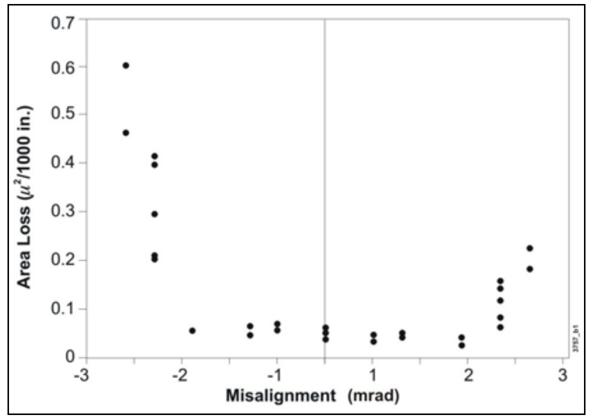

Figure 4. Wheel Wear Versus Radial Misalignment

Wilson et al., discuss these tests further.[4,5,6] They present comparisons of rolling resistance versus truck misalignment for laboratory and track models, as Figure 5 shows.

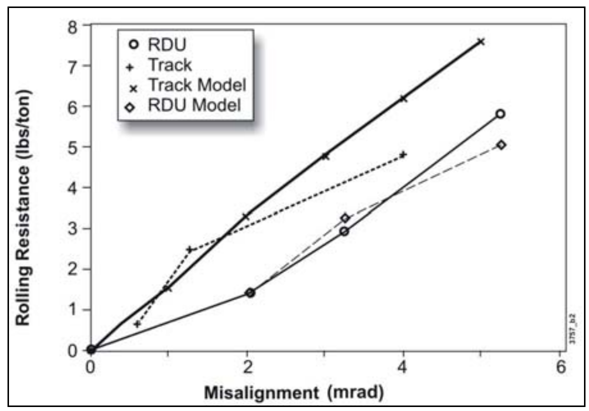

Figure 5. Laboratory and Track Model Truck Misalignment

They conclude from this graph that:

- Assuming a base figure for rolling resistance of 0.8 lb/ton to account for bearing and wheel/rail contact (wheelsets perfectly aligned). This figure is stated explicitly in Reference 6, but not in the other two references.
- The incremental rolling resistance as a result of wheelset misalignment is, on average, 0.62 lb/ton/mrad wheelset misalignment.

The difference between on-track (1.45 lb/ton/mrad) and laboratory tests (1.38 lb/ton/mrad) was attributed to differences in wheel/rail contact geometry and friction coefficient for each test.

Wilson then presents the population of truck *radial misalignments* (mrad) for a 111-car loaded coal train on CP Rail (Figure 6). He describes radial misalignments as "angle of attack differences between two axles in the same truck."[6] These figures are presented in the form of absolute AOAs with average values quoted between 2.04 mrad and 2.08 mrad.[4,5]

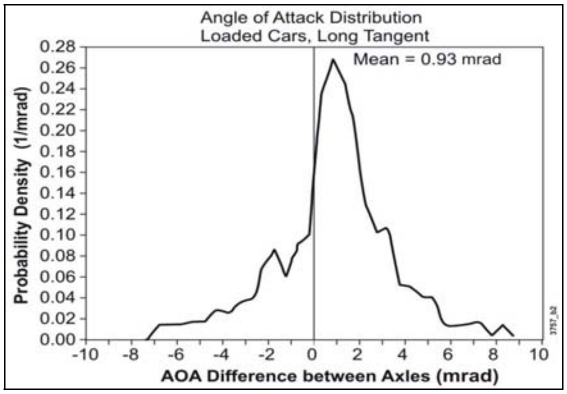

Figure 6. AOA Truck Radial Misalignments

Wilson further argues:[4]

- The average axle misalignment is 1 mrad
- That the total rolling resistance of a misaligned truck is, on average, 1.4 lb/ton/mrad (1.4 lb/ton for the 1 mrad misalignment mentioned above)
- Previous tests carried out on the AT&SF Railway indicate that the speed-independent value of rolling resistance was 3.15 lb/ton
- Therefore, the misalignment component of rolling resistance might be 1.4/3.5 = 40 percent of that portion of tangent track resistance that is independent of speed

Wilson goes further to transform Figure 6 above for 111 loaded coal cars to reflect the probability density for rolling resistance in the train, as Figure 7 shows.[6]

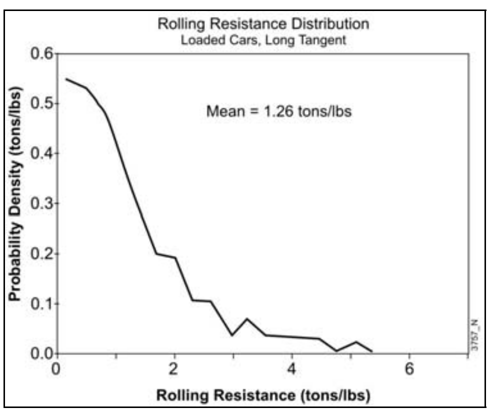

Figure 7. Probability Density for Rolling Resistance

Wilson suggests that experiments show that rail lubrication reduces tangent track rolling resistance by approximately 0.5 lb/ton to 1.0 lb/ton, and that rail lubrication reduces resistance due to axle misalignments by approximately 50 percent.[4] Based on these results, he suggests that rail lubrication may save 50 percent of 1.4 lb/ton or 0.7 lb/ton.

Finally, rolling resistance tests were conducted at TTC to establish the relationship between radial axle misalignment and curvature. Figure 8 shows the relationship between the sense of the curve, the sense of the misalignment and the resistance.

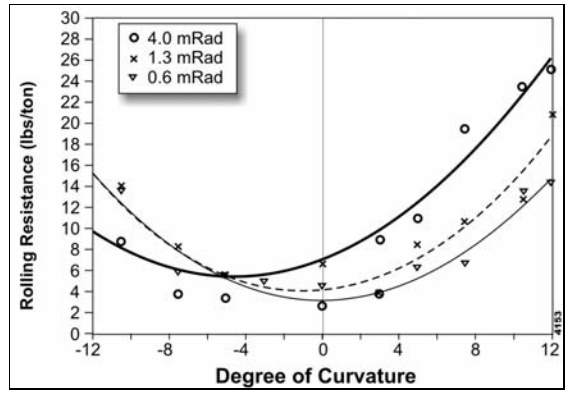

Figure 8. Rolling Resistance vs. Curvature with Three Levels of Axle Misalignment

CONCLUSIONS

A literature study of the relationship between wheelset AOA and wheel wear and rolling resistance reveals:

- Little evidence of the relationship to wheel wear other than the on-track tests at TTC suggest that radial misalignments above 3.5 mrad (*between* axles) leads to accelerated wheel wear.
- Total rolling resistance on tangent track is of the order of 1.4 lb/ton/mrad of individual axle misalignment.
- Limited data on rolling resistance of misaligned truck in curves is presented.

This information will assist in developing a cost/benefit analysis for AOA wayside detection systems.

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