TECHNOLOGY DIGEST
TD-11-041
©OCTOBER 2011
TIMELY TECHNOLOGY TRANSFER

The work described in this document was performed by Transportation Technology Center, Inc., a wholly owned subsidiary of the Association of American Railroads.

A Methodology to Evaluate the Curving Performance of a Freight Car Truck

Harry Tournay

Summary

Transportation Technology Center, Inc. (TTCI) has developed a conceptual freight car truck design to address current problems with the performance of current truck designs identified through the Association of American Railroads' (AAR) Strategic Research Initiatives Program.

TTCI proposes a methodology to assess the curving performance of freight car trucks and assess their propensity to develop thermal mechanical shelling resulting in high impact wheels (HIW). This methodology can use both calculated results (e.g., NUCARS®) or results from instrumented wheelset measurements.

TTCI based the methodology on the analysis or measurement of the traction forces developed by the lead wheelset on low rail contact, the determination of tangential/normal traction ratios and contact stresses, and the use of the shakedown map to determine the number of contact encounters above shakedown for given wheel temperatures.

TTCI based the determination on the probability of contact of a particular element of the wheel tread under particular traction ratios developed as a function of curvature, superelevation and car speed, curve sense, vehicle dynamics, direction of travel, and wheel diameter.

HIWs are a major cost factor in car operation as well as a contributor to increased track costs and derailments and are identified as a major problem in the railway industry. AAR car repair billing data shows that more than 400,000 wheels were removed in 2008 for HIWs in the North American industry, resulting in an estimated cost of more than $500 million in 2008.

The methodology has been used to assess the relative performance of four truck types with different steering characteristics. The results of these tests and the performance comparison will be reported in future *Technology Digests*.

Please contact **Harry Tournay (719) 584-0704** with questions or concerns regarding this *Technology Digest.* E-mail: harry_tournay@ttci.aar.com.

INTRODUCTION

TTCI was tasked to develop a conceptual freight car truck design to improve performance problems identified through the AAR's Strategic Research Initiatives Program.

HIWs are a major cost factor in car operation as well as a contributor to increased track costs and derailments. AAR car repair billing data shows that more than 400,000 wheels were removed in 2008 for HIWs in the North American industry resulting in an estimated cost of more than $500 million.

HIWs result from a combination of wheel shells (thermal mechanical shelling or TMS) and skids resulting from unreleased hand brakes. This *Technology Digest* (TD) focuses on the causes for TMS.

TMS has been associated with high tractions developed as the wheel of the lead axle contacts the low rail in curves with an angle of attack.[1,2,3] These tractions and angle of attack have been associated, in turn, with the steering ability of trucks, particularly the yaw constraint of the wheelset.[4,5]

Tractions can be quantified analytically using TTCI's simulation modeling program NUCARS® or by using an instrumented wheelset (IWS). Analytical tools, such as NUCARS, are used typically in a design phase; whereas, IWS might be used for vehicle qualification.

This TD suggests a method for evaluating truck performance. It can be useful for both an analytical as well as experimental approach. If proven successful, it will replace the curve resistance approach currently quoted in the M-976 specification.

TEST METHOD

An IWS was placed in the lead axle position of the lead truck of a loaded car to measure lateral and longitudinal steering tractions, vertical wheel load, and lateral position of the contact patch on the wheel tread.

Lead truck rotation was monitored using displacement transducers and trackside beacons to identify the position of the truck with respect to the tangent and curves. Vehicle speed was also monitored.

The car was dragged in both a clockwise and counterclockwise sense through the Wheel/Rail Mechanism Loop and on tangent track and through switches at Transportation Technology Center, Pueblo, Colo. Curve speeds were 12, 24, and 32 mph, which relates, generally, to under- and overbalance speeds, respectively.

ANALYSIS

Normal and Tangential

(Traction Loads across the Contact Patch)

Measured vertical and lateral tractions, ($F_{lateral(IWS)}$ and $F_{vertical(IWS)}$), in low rail contact are associated with the lateral position of the contact patch measured by the IWS (Figure 1). These measured tractions are normal and parallel to the longitudinal centerline of the axle.

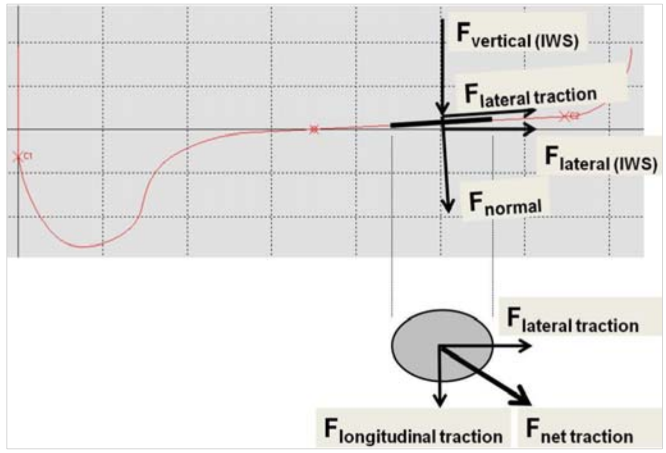

Figure 1. Forces on the IWS in Relation to Normal and Lateral Tractions

The measured tractions and vertical wheel loads are then related to the wheel profile and resolved into components normal and tangential to the plane of the contact patch (F_{normal} and $F_{lateral\ traction}$).

The longitudinal traction, $F_{longitudinal\ traction}$, are then added vectorially to $F_{lateral\ traction}$. This resultant is then the net traction across the contact patch associated with F_{normal}.

Contact Loads in Relation to the Shakedown Limit

Wheels and rail materials in rolling contact under sufficiently high traction loads will deform plastically. This deformation can result in material hardening and the generation of residual stresses (a condition known as shakedown). Higher tractions may be sufficient to prevent further accumulation of plastic strains, and cracks will form. This is termed "ratcheting." The transition between shakedown and ratcheting is known as the limit of shakedown. The objective of this analysis is to relate the contact loads and stresses with respect to the limit of shakedown, the stress level at which surface cracks will initiate on the wheel and rail.

Shakedown is not well defined. It is a function of the shape of the contact patch and material properties which are, in turn, a function of wheel temperature. It also does not define cycles to failure. Shakedown is, however, a possible means for comparison between two contact conditions lacking more defined limits. The analysis described here is focused on quantifying the number of load cycles above shakedown for which an element of wheel material is subject per 100,000 miles and comparing these cycles for different truck designs and operating speeds over typical eastern and western routes.

Figure 2 shows the shakedown map. The vertical axis of this map is a measure of the maximum normal stress across the contact patch, P_0, normalized with the maximum shear yield stress, K, of the wheel material. P_0 is a function of the vertical load over the contact patch, F_{normal}, and the shape of the wheel and rail profiles. K is a function of the wheel material and temperature.

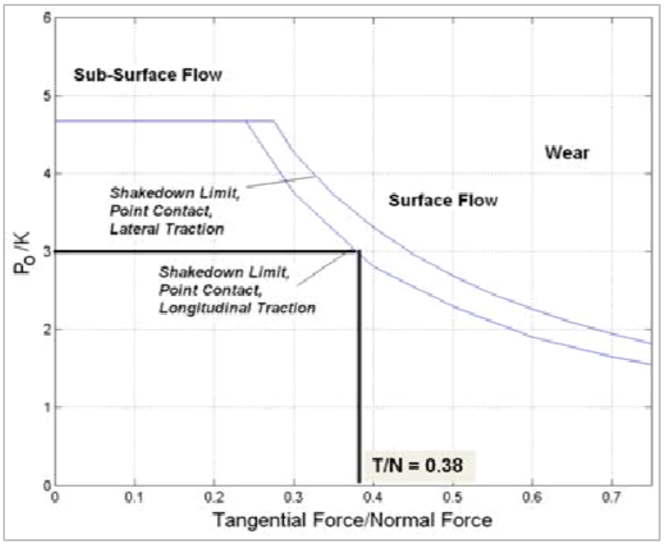

Figure 2. Shakedown Map indicating a Limit for T/N of 0.38 for P_0/K of 3 to avoid Surface Flow

A typical value for P_0/K for the field side of the wheel contacting the low rail at normal temperature (20°F) is 3 (Figure 2). This suggests that a maximum tangential/normal (T/N) force ratio of 0.38 can be sustained over the contact patch without surface flow.

Figure 3 shows the relationship between yield strength for different wheel steels versus wheel temperature.[6] The shear yield strength is proportional to the yield strength; consequently, values for P_0/K and limits for T/N to avoid surface flow for different wheel temperatures can be derived as Table 1 shows.

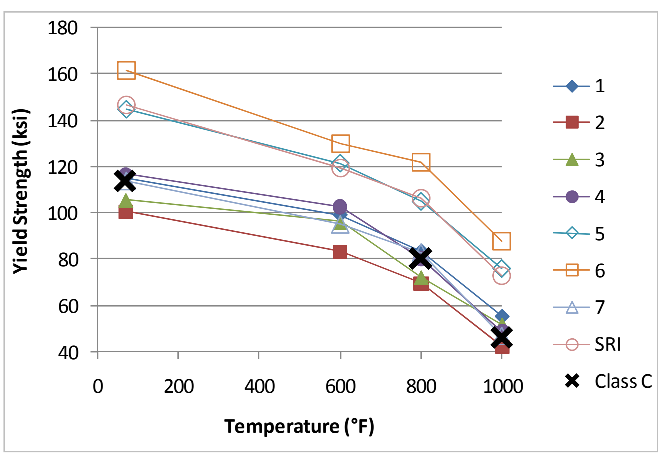

Figure 3. Yield Strength versus Temperature

Table 1. Relationship between P0/K and Limiting T/N for Different Wheel Temperatures

Temperature (°F)	P_0/K	Limiting T/N Class C Wheels
20	3.00	0.38
500	3.38	0.34
700	3.70	0.30
800	4.32	0.26

Prediction of the Number of Cycles above the Shakedown Limit Experienced by an Element of Wheel Material

The number of stress cycles and levels experienced by an element of the wheel tread is a function of the combined probability of contact of that element with the rail and the level of traction experienced by the wheelset during that contact. This combined probability is a function of:

Truck/wheelset dynamics: Test or analysis results can be expressed in terms of the percent of contact occurrences between the wheel and rail for different ratios of T/N derived above. Figure 4 shows typical test results expressed as a percentage of contact occurrences in a curve.

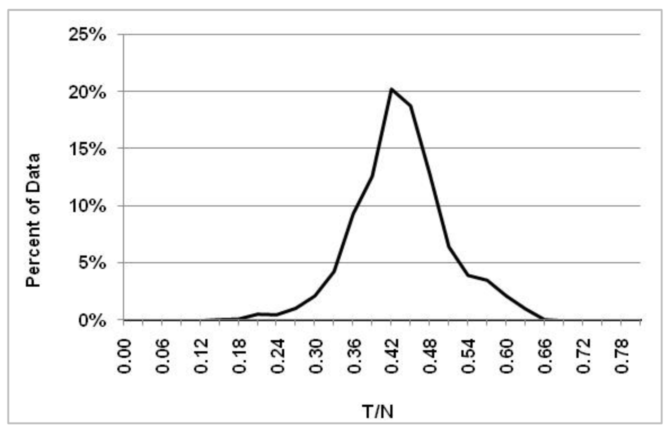

Figure 4. Probability of Contact under Different Values of T/N Ratios (This is a consequence of wheelset/truck dynamics.)

Curvature: The curvature on a route is expressed in percentage of the route as Figure 5 shows. The analysis has assumed that there is an equal number of left- and right-hand curves, and the probabilities reflected in Figure 5 for all curves has been halved because the probability of low rail contact by one wheel of a wheelset is half that of the wheelset itself.

Direction of travel: The lead wheelsets of the trucks experience the highest T/N traction ratios with low T/N ratios being experienced by the trail wheelsets. The lead wheelset of the trail truck generally experiences lower T/N ratios than the lead truck. This analysis assumes that the lead wheelsets of both trucks experience equal T/N traction ratios and that the trail wheelsets experience negligible T/N ratios. It also assumes that the car has an equal probability of running A-end lead as B-end lead; consequently, the probability of a contact encounter with a given T/N ratio is again halved.

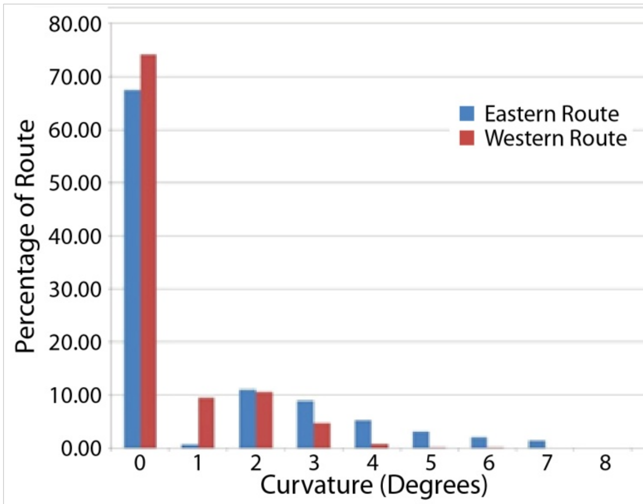

Figure 5. Probability of Encountering Track of Different Curvature (typical eastern & western routes)

Ratio of the circumference of the wheel to the size of the contact patch: The rotation of the wheel further reduces the probability of a contact encounter with a given traction ratio (Figure 6). This analysis assumes 36-inch diameter wheels (having a circumference of 113 inches) and a 1/2-inch-long contact patch (1/2 inch in the direction of travel); consequently, the probability of a contact encounter with a given T/N ratio is 0.5/113, or 0.00442.

Figure 6. Diagrammatic indication of the probability effect attributable to wheel rotation

The net probability of a contact encounter at a particular traction (T/N) ratio is thus the product of the above probabilities; consequently, these net probabilities can be used to predict the number of T/N cycles likely to be experienced by an element of the wheel tread, and thus the number of cycles above the shakedown limit experienced by this element.

This approach is approximate given the assumptions described above. It should be noted that no account is made of the lateral migration of the contact patch on the wheel tread resulting from variations in effective gage in curves; this is because of its complexity and varies with track maintenance condition.

CONCLUSIONS

A methodology is presented to quantify the stress cycles encountered by an element on a wheel tread as a consequence of T/N traction ratios developed through steering dynamics. This methodology is approximate; however, it is considered that it will provide a useful indication of the relative merits of the performance of different truck designs and a means to evaluate their propensity to develop TMS and, in turn, HIW.

The method described will be compared with (and calibrated to) the performance of wheelsets in revenue service and to results from rolling load machines. Service data is being sought from railroads and operators. Plans are in process to develop test data using rolling load machines.

WAY FORWARD

This methodology has been used to evaluate the relative steering performance of four truck types:

1. A standard 3-piece truck with low warp stiffness.
2. An M-976 truck with improved warp stiffness and fitted with adapter pads.
3. An M-976 truck with improved warp stiffness, but fitted with steel-on-steel adapters (no pads).
4. A modified M-976 truck with increased pedestal clearance and fitted with low stiffness adapter pads.

The results of these tests and subsequent analysis and performance comparison will be provided in forthcoming TDs. In addition, recommendations will be made to the M-976 Task Force to use the approach described as an improved means to assess the curving performance of M-976 trucks.

REFERENCES

1. Tournay, H., S. Anankitpaiboon, and S. Cummings. September 2009. “A Mechanism for the Formation of Shells on Freight Car Wheels.” *Technology Digest* TD-09-027. AAR, TTCI, Pueblo, CO.
2. Tournay, H. and C. Duran. December 2009. “A Parametric Analysis of Lateral Forces on a Single Wheelset Curving with an Angle of Attack.” *Technology Digest* TD-09-038, AAR. TTCI, Pueblo, CO.
3. Tournay, H. M. December 2009. “A Review of the Mechanism for the Formation of Thermal Mechanical Shells.” *Technology Digest* TD-09-041, AAR, TTCI, Pueblo, CO.
4. Tournay, H., C. Duran, and S. Anankitpaiboon. December 2009. “A Wheelset Suspension to Prevent Shells on Freight Car Wheels.” TD-09-039. AAR, TTCI, Pueblo, CO.
5. Tournay, H. and S. Anankitpaiboon. December 2009. “Wheel/Rail Forces Associated with the Formation of High Impact Wheels.” *Technology Digest* TD-09-040. AAR, TTCI, Pueblo, CO.
6. Cummings, S. September 2009. “High Temperature Tensile Properties of High Performance Wheel Steels.” *Technology Digest* TD-09-026. AAR, TTCI, Pueblo, CO.