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A Parametric Analysis of Lateral Forces on a Single Wheelset Curving with an Angle of Attack

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SUMMARY

In a project to develop a conceptual freight car truck design to address truck performance problems identified through the Association of American Railroads' Strategic Research Initiatives Program, Transportation Technology Center, Inc. (TTCI) analyzed the parametric relationship between wheelset angle of attack (AOA) and lateral forces on the wheel contacting the low rail of a curve modeling the action of a single wheelset operating with an AOA on tangent track using NUCARS®.*

The analysis suggests that to avoid shakedown and surface cracking of the wheel tread:

- Under controlled wheel/rail friction conditions (friction coefficients between 0.3 and 0.4) and while negotiating curves greater than 6 degrees, lead axle AOAs of between 6 and 8 milliradians (mrad) should not be exceeded.
- If wheel/rail friction coefficients are not controlled, (friction coefficients greater than 0.4), lead axle AOAs below 5 mrad are suggested. This can be achieved using steering trucks.

This analysis further suggests that lateral traction forces are a possible root cause of wheel tread surface cracking leading to the formations of high impact wheels (HIW).

As related in a recent *Technology Digest* (TD), the formation of two crack bands on HIWs has been linked to measured lateral forces acting on the wheels, resulting in the conclusion that lateral forces may be a root cause for crack band formation.¹

In that TD, TTCI presents a hypothesis for the progression of these crack bands to the break-out of material from the wheel tread to form HIWs, suggesting that lateral forces are, in turn, a root cause of HIWs. A way forward to the verification of this hypothesis and a solution to HIWs is proposed.¹

*NUCARS® is a registered trademark of the Transportation Technology Center, Inc.



INTRODUCTION

TTCI is tasked to develop a conceptual freight car truck design to address truck performance problems identified through the Association of American Railroads’ Strategic Research Initiatives Program.

A major problem is that approximately 50 percent of HIWs have been attributed to thermal mechanical shelling,² which is considered a consequence of both overheated wheels and rolling contact fatigue. Instrumented wheelset data suggests a strong correlation between the location of measured traction forces on the tread of the lead wheel contacting the low rail in tight curves and observed cracks on the wheel tread of HIWs³(Figure 1).

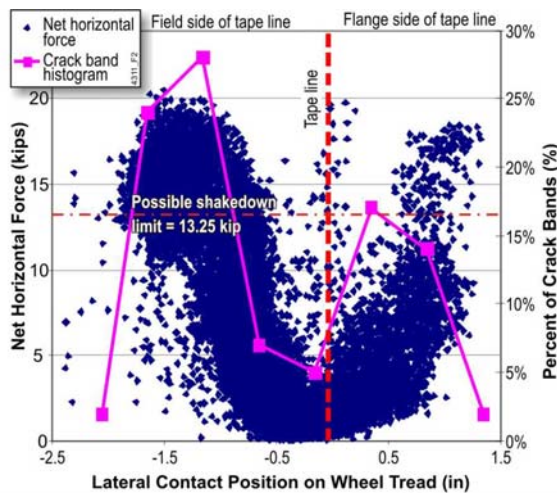


Figure 1. Relation between Measured Surface Traction and observed Crack Bands on the Wheel

A hypothesis has been presented to suggest the progression from the formation of these cracks to the break-out of material from the wheel tread.¹

A further analysis of the measured traction forces on the tread of the lead wheel contacting the low rail of a curve reveals that these high traction forces and the crack band to the field side of the tape line on the wheel are associated with high lateral traction forces (Figure 2).³

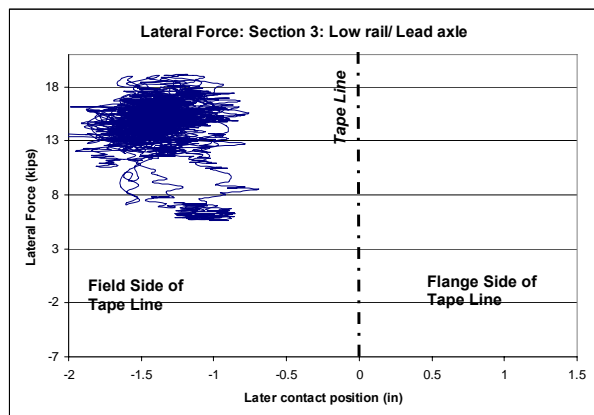


Figure 2. Lateral forces: Lead Wheel Contacting the Low Rail of a Curve

In this digest, NUCARS modeling shows:

- The relationship between lateral traction forces on the wheel contacting the low rail of a curve and the AOA of the wheelset
- The role of the wheel/rail coefficient of friction in determining the magnitude of these traction forces

NUCARS MODEL OF A SINGLE WHEELSET

The NUCARS model simulated the action of a lead wheelset in a 286,000-pound car negotiating curved track by:

- Applying a vertical load of 17,875 pounds to each journal
- Constraining the wheelset to roll with an AOA, α , and flange contact (Figure 3) on tangent track. The AOA was altered to simulate different curvatures.

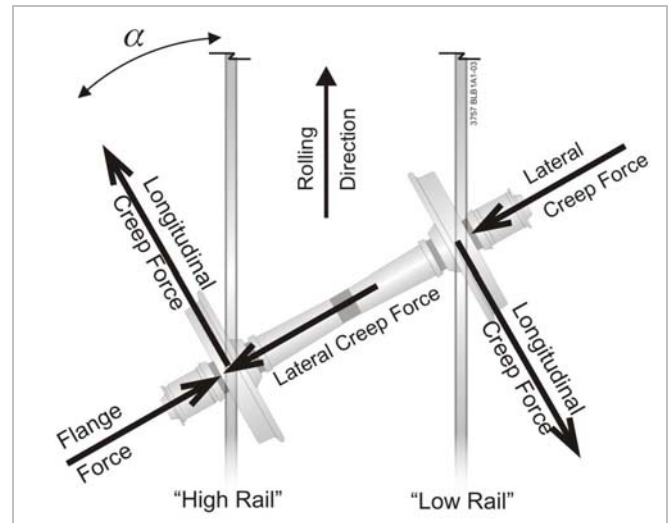


Figure 3. Model of NUCARS Simulation

The model comprised:

- A single wheelset with AAR-1B wheel profiles
- Tangent track to nominal (4 ft 8 1/2 inch) gage with new 136 lb/yard rail

This combination produced two-point contact between the wheel and rail on the flanging wheel (Figure 4). Two-point wheel/rail contact was chosen to reduce the dynamic action of the wheelset, simulating quasi-static conditions. Consequently, the longitudinal creep forces predicted in the results presented are lower than would generally be anticipated in service. The lateral creep forces due to the AOA, which are the subject of this study, are considered representative of in-service conditions and considered correctly modeled.

On initiating the forward rolling motion, the wheelset moves laterally under the AOA until flange contact is made with the high rail of the curve; forces then build up until steady-state conditions prevail.

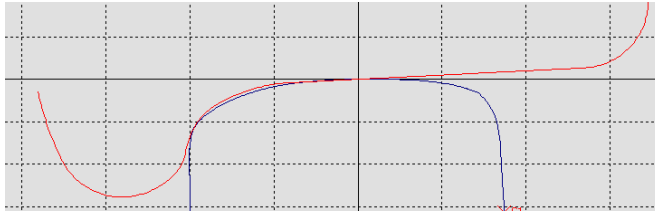


Figure 4. Flange Contact Conditions

The wheel/rail friction coefficient was varied within values encountered in service.

The resulting forces on the wheelset were computed.

RESULTS

The lateral traction force on the wheel contacting the low rail of the curve was computed as a function of:

- The AOA of the lead wheelset
- The wheel/rail friction coefficient

As anticipated, the lateral force on the wheel contacting the low rail of the curve increases with both AOA and friction coefficient, as Figure 5 shows.

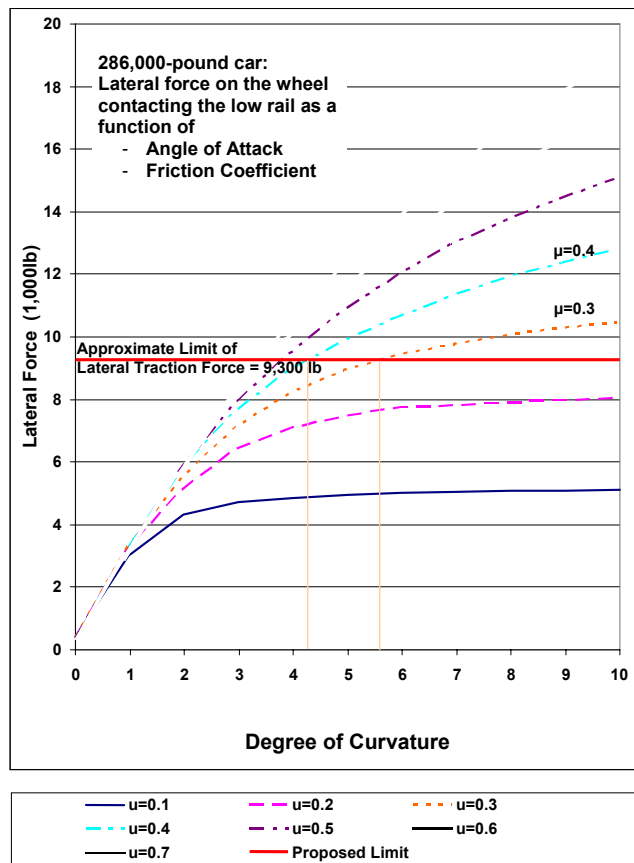


Figure 5. Lateral Traction Force on the Low Rail of a Curve

Estimation of the maximum allowable lead axle AOA to avoid the formation of cracks on the field side of the wheel tread

A limit of 13,250 pounds has been suggested for the net traction force acting on the low rail of a curve to avoid shakedown and the formation of surface cracks² on the field side of the wheel contacting the low rail. This suggests, as a first approximation, that this limit should not be exceeded under any dynamic conditions. A Strategic Research Initiative planned for 2010 will more accurately quantify this limit in relation to prevailing wear rates on the wheel tread and in relation to the number of cycles and magnitude of lateral loads. For the purposes of this TD, the 13,250-pound load limit is used.

The maximum net lateral traction force on the lead wheel contacting the low rail of a curve (Figure 3, Reference 3) is approximately 20,000 pounds. The average lateral force is approximately 13,970 pounds (Table 1, Reference 3). This suggests a ratio between the dynamic and quasi-static forces in a sharp curve of approximately $14/20 = 0.7$; consequently, we suggest that a quasi-static limit to the lateral forces in a curve should not exceed approximately $0.7 \times 13,250$ pounds = 9,275 or approximately 9,300 pounds (Figure 5).

Friction coefficients encountered in service are known to range from below 0.3 to as high as 0.7. Under controlled conditions (TOR friction control) friction coefficients between 0.3 and 0.4 are targeted.⁴ A lower limit of 0.3 enables locomotive adhesion, and 0.4 is considered a target upper limit for effective TOR friction control. Consequently, friction coefficients between 0.3 and 0.4 can be considered as optimal.

Figure 5 indicates that, under TOR friction control conditions, in order to remain below a quasi-static lateral force limit of 9,300 pounds for a 286,000-pound car, the lead axle AOA must be limited to between 4.2 and 5.7 mrad.

Conditions where TOR friction is not controlled (friction coefficients in excess of 0.4), require lead axle AOAs to be limited to below 4.2 mrad.

The Relationship between Angle of Attack to Truck Curving Alignment

Typically, the lead axles of North American trucks with a 5-foot 10-inch wheelbase will curve with an AOA of the lead wheelset, measured in mrad, which is numerically equal to the curvature; e.g., 4 mrad in a 4-degree curve.

A limit to an AOA of between, typically, 4 and 6 mrad suggests that for a truck under a 286,000-pound car, curving in an unwarped condition at balance speed, the minimum track curvature to avoid wheel tread surface cracking under ideal TOR friction conditions is between approximately 4 and 6 degrees.

Factors that will further influence this relationship are:

- Truck Warp: A truck can warp so that the lead axle has an AOA approximately double that of the relationship described above. This would result in a minimum allowable curvature to avoid wheel tread

surface cracking of between approximately 3 and 4 degrees.

- Excess Cant: A truck curves with an increased AOA under excess cant conditions in order to generate lateral forces to counter those associated with the excess cant. Typically for a 286,000-pound car, a 1 inch of excess cant results in a lateral force, L, on the axle of:

$$L = (1/2l) \times A \text{ where:}$$

2l = distance between wheel/rail contact points across an axle = 59.5 inch

A = axle load (pounds) = 286,000/4 = 71,500 pounds

L = 1,200 pounds

Consequently, for every inch of excess cant, the proposed limit to quasi-static forces may have to be reduced by at least 500 pounds, which is the likely minimum contribution from the wheel on the low rail. The angle of the contact patch on the high rail and high rail lubrication issues may result in this contribution being as high as 1,000 pounds.

Consequently, excess cant of 2 inches may result in the allowable minimum curvatures to avoid wheel tread surface cracking being reduced to between 3 and 5 degrees from the abovementioned 4- to 6-degree limit. This does not take into account the excess vertical load on the low rail contact patch because of the excess cant.

CONCLUSIONS

A parametric relationship between wheelset AOA and lateral forces on the wheel contacting the low rail of a curve have been developed by modeling the action of a single wheelset operating with an AOA on tangent track using NUCARS. The role of wheel/rail friction coefficient is also modeled for coefficients within practical service conditions.

The analysis suggests that to avoid shakedown and surface cracking of the wheel tread:

- Under controlled wheel/rail friction conditions (friction coefficients between 0.3 and 0.4), lead axle AOAs of between 6 and 8 mrad should not be exceeded.
- If wheel/rail friction coefficients are not controlled, (friction coefficients greater than 0.4), lead axle AOAs below 5 mrad are suggested.

The direct relationship between lead axle AOA and track curvature for unwarped North American trucks having a 5-foot 10-inch wheelbase and curving at balancing speed have been described. The influence of truck warp and excess cant has been presented. Analysis suggests that track curvatures tighter than:

- Between 4 and 6 degrees could likely result in wheel tread surface cracking, even if the friction coefficient is controlled between 0.3 and 0.4, when trucks do not warp, and when the car curves at or above balancing speed. Where the wheel/rail friction coefficient is not controlled, wheel tread surface cracking may occur when negotiating curves tighter than 5 degrees.
- Truck warp may result in wheel tread surface crack formation in curves tighter than between 3 or 4 degrees under controlled wheel/rail friction (between 0.3 or 0.4) conditions and when curving at balance speed; this is further reduced when friction coefficients exceed 0.4.
- Curving with excess cant will further increase the wheelset's AOA, resulting in wheel tread surface crack formation in shallower curves.

This analysis further suggests that lateral traction forces are a possible root cause of wheel tread surface cracking leading to the formation of HIWs.

RECOMMENDATIONS

To avoid or reduce the incidence of HIWs, car owners consider truck designs that reduce the AOA of the wheelsets in the curve as well as features that further reduce wheel traction forces. HIWs would be further reduced through improved brake rigging design, reducing elevated wheel temperatures resulting from stuck rigging and consequently the temperature limits beyond which TMS will occur.

REFERENCES

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