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Proposed Method to Test and Calibrate Rolling Contact Fatigue Prediction Models

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Summary

A method is proposed to test and calibrate a rolling contact fatigue (RCF) prediction model based on the energy dissipated across the contact patch (the so-called T-gamma approach). This method utilizes a combination of observations, measurements, and simulations of contact on the low rail of a curve. The method is illustrated using observations, data, and simulations of contact on the low rail of a 10-degree curve.

It is recommended that a full analysis of the data currently available for this curvature be used to verify the proposed method and include an assessment of the effects of rail grinding, which is not included in this *Technology Digest*.

Transportation Technology Center, Inc. (TTCI) continues further investigations into the prediction of RCF due to longitudinal tractions as well as the prediction the rate of material flow (gage corner and field side “lipping”).

This work supports research to establish the root causes for RCF and was conducted by TTCI under the direction of the Association of American Railroads as part of the Strategic Research Initiatives Program.

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INTRODUCTION

TTCI has been tasked by the Association of American Railroads (AAR), as part of its Strategic Research Initiatives (SRI) program, to establish the root causes for RCF in wheels and rails. In the context of this SRI, RCF is considered as either on or a combination of: wear, cracking, or material flow.[1] Reference 1 lists details of further RCF failure modes and estimated annual costs to the North American railroad industry. A more precise classification of RCF failure modes and associated costs will be made in a future *Technology Digest* (TD).

Wheel RCF has been associated in particular with low rail contact conditions in curves, resulting in the formation of thermal mechanical shelling (TMS).[2] This association has been qualitative, and the effects of track curvature, tread wear, tread temperature, and friction coefficient on the cycles to failure have yet to be determined.

Low rail RCF in curves (in the form of head wear, material flow, and shelling of the running band on the head) is generally associated with lateral creep of the lead wheel. The effects of track curvature, operating speed, wheel/rail lubrication, and railhead profile would benefit from a more detailed understanding of the mechanisms causing these degradations. In addition, a quantification of degradation rates with respect to these variables would assist in the determination of optimal wheel/rail maintenance cycles.

High rail RCF (mainly in the form of head checks, but also in the form of shelling of the center of the head) is a more complex phenomenon. On the gage corner, RCF is associated with a combination of high contact stresses and longitudinal and lateral creep, and an improved understanding of the limits of contact stress for particular rail materials would be beneficial. The root cause for shelling on the center of the rail crown seems unknown. While it is not catastrophic, it can obscure ultrasonic test signals. Consequently it, in combination with head checks, results in high rail grinding.

Two RCF prediction models are available: the so-called shakedown theory model and the surface energy model (T-gamma).[1] Both require testing to determine their efficacy. The surface energy model, probably requires calibration for heavy haul conditions in North America. These models have been successfully used to predict RCF resulting from longitudinal tractions, but need to be tested under lateral traction conditions to simulate the effects of low rail contact on wheels and rails.

Traditionally, predictive models have been calibrated using twin disk rollers running at differential speeds to induce longitudinal tractions and creep. Mention is made in the literature of calibration under lateral creep;[3] results are not encouraging. The cost of building a rig to test under laboratory conditions is anticipated to be high and the relationship between laboratory and field conditions is unknown. Consequently, means to use field data to calibrate RCF models have been sought. This TD describes the proposed use of the observed RCF performance on low rails in conjunction with vehicle dynamic simulations to compare the two RCF prediction models currently available and to calibrate the surface energy model.

IN-SERVICE MONITORING REQUIREMENTS

The following factors were considered when choosing ways to observe the onset of RCF in service, the rate of RCF development, and to measure or evaluate the tractions and other contact conditions between wheel and rail:

- The creep condition should be relatively simple and easily defined.
- The effects of lateral creep are of particular interest for the study of both wheel and rail surface damage.
- RCF, wear, and material flow should be easily measured.
- Contact parameters (contact patch geometry) and contacting shapes should be consistent during the period of study.

CHOICE OF MONITORING SITE AND METHOD

Given the above requirements, it has been decided to monitor the performance of the low rail in curves:

- The main damaging mechanism is that of contact between the lead wheel and the low rail (Figure 1).

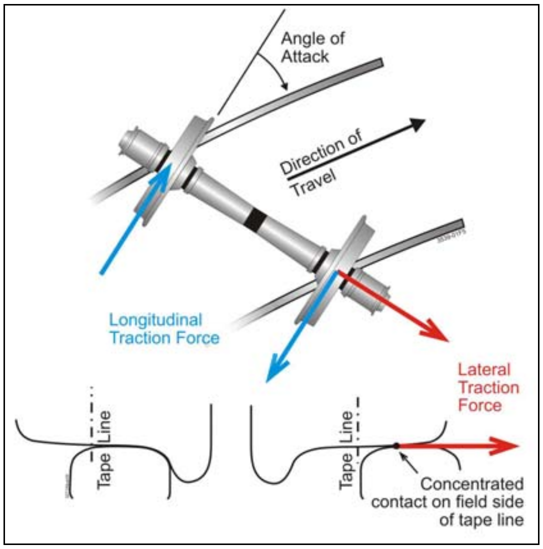

Figure 1. Forces on the Lead Wheelset in a Curve with Particular Reference to Low Rail Contact

- Trail wheel contact is relatively benign as the angle of attack (and lateral creep) of a trailing wheelset in a truck approaches zero, as does the radius differential (and longitudinal creep). Consequently, focus can be placed on the action of the lead wheel.
- Low rail contact results in large lateral creep in comparison with longitudinal creep. Consequently, focus can be placed on lateral creep; contact is similar to that which would be developed in a twin disk machine specifically designed to develop lateral creep forces (Figure 2).

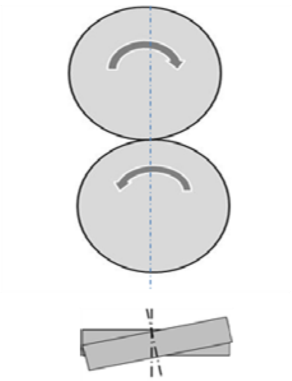

Figure 2. Typical Arrangement of a Twin Disk Machine with an Angle of Attack between the Disks to Develop Lateral Creep

- The effect of different lateral creepages can be observed by examining RCF performance in curves of different radius; the angle of attack of the lead wheelset of a typical truck in milliradians is approximately equal to the curvature in degrees.
- The effect of direction of travel is reduced as only the longitudinal creep force direction reverses between directions; the lateral creepage remains the same and equal with respect to direction for the same axle load.
- The most damaging creep and tractions on the wheel derive from the contact being observed with the rail; the behavior of the rail "reflects" that experienced by the wheel, and all that is required is to account for the differences in material properties and the thermal load of the wheel.
- The load cycles experienced by the low rail can be approximated if the total tonnage (MGT) passing the site is known as well as the typical axle load distribution in each traffic direction.

CRACK FORMATION ON THE LOW RAIL IN A 10-DEGREE CURVE

To investigate the practicability of in-service monitoring, the historic performance of the low rail in a 10-degree curve was investigated.

The low rail showed evidence of RCF during the period monitored (Figure 3).

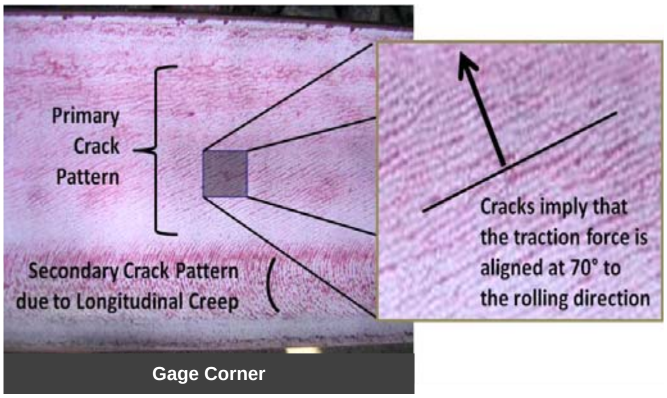

Figure 3. Crack Patterns on the Head of the Low Rail

The primary crack pattern on the center of the head comprises parallel, linear cracks aligned at 20 degrees to the rolling direction (the track longitudinal centerline); this suggests that the dominant traction is at an angle of 70 degrees to the track centerline, as Figure 3 shows.

Theoretically, since traffic tonnage patterns are approximately equal in each rolling direction, the cracks should be parallel to the longitudinal centerline of the track because they are attributed to the lateral creep force (Figure 1). This 10-degree curve lies, however, on a 2-percent downgrade and implies that brakes are applied on all cars in the downgrade direction while they are released in the opposite direction; this probably accounts for the longitudinal component of traction associated with a 20-degree crack direction.

This effect has been checked on curves of opposite sense, where the angularity of the cracks always remains in the sense of the downgrade. It has also been observed that low rail cracks are parallel to the longitudinal direction of the track on curves on river routes where the grade, and hence, the braking tractions are almost zero.

The secondary crack pattern takes the form of parallel, arced cracks on, or near to, the gage corner of the low rail. These cracks are probably associated with predominantly longitudinal tractions attributed to near-flange contact of trailing wheels with hollow worn profiles under dynamic conditions. This presumption needs verification.

In order to assess the role of the lateral tractions on crack formation on the center of the crown:

- The effect of braking should be removed; this is simple: if a constant train speed is assumed, there is a direct relation between grade, axle load, and braking traction.
- The proportion of trailing wheel contact on the gage corner of the rail, in relation to lead and trailing wheel contact in the region of the primary crack band, needs to be assessed. This assessment will always be approximate as the shape of all wheel profiles is not known. However, when considering the incidence of contact energy contributions from lead and trailing wheels, the effect of lead wheels dominates and an estimate of what? is probably sufficiently accurate at this stage?

LOW RAILHEAD WEAR IN A 10-DEGREE CURVE

Head wear on the low rail was monitored using Miniprof™ profiles. Figure 4 shows a typical example for the low rail in a curve, in this instance without top of rail (TOR) friction control. The vertical component of head wear loss is then plotted against MGT to obtain wear rates (Figure 5). Interestingly, the wear rate with TOR friction control is 60 percent of that without TOR friction control; this accords with common reports in this regard.[3,4,5]

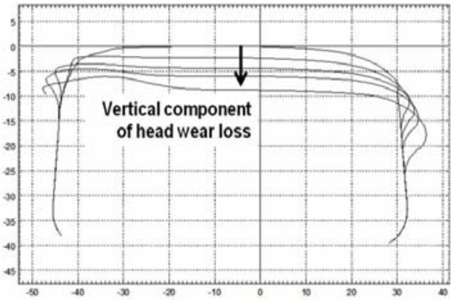

Figure 4. Low Railhead Wear

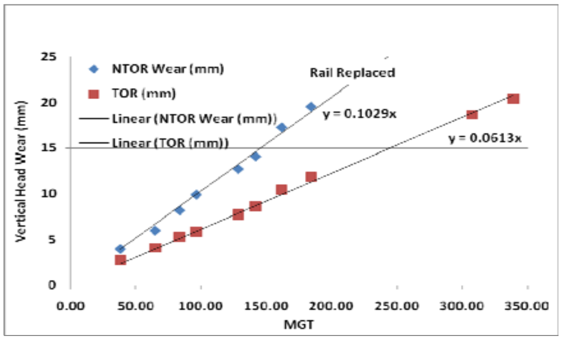

Figure 5. Low Railhead Wear versus MGT in a 10-degree Curve

VERTICAL LOADS IN A 10-DEGREE CURVE

A load station was placed in the vicinity of the curves being monitored. From the load station data, a histogram of typical wheel loads can be generated; Figure 6 shows an example.

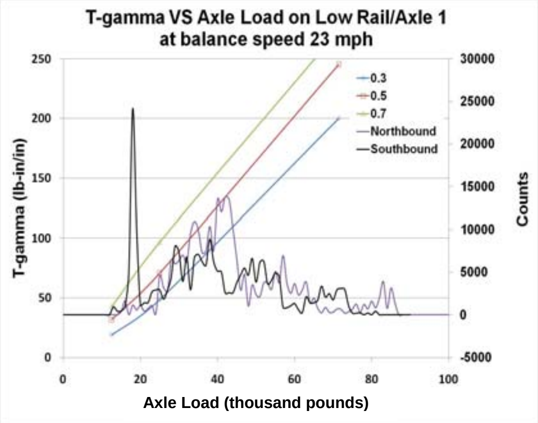

Figure 6. Histogram of Wheel Loads

TRACTION, CREEP, AND T-GAMMA ANALYSIS

Given the load spectrum and wheel and rail profiles, the tractions and creepages on the low rail can be calculated using NUCARS®* for differing car loads, contact conditions, friction coefficients, and speeds. Resulting values of T-gamma can be calculated (Figure 6) for each condition.

Given the MGT measured at each site and the spectrum of wheel loads, a count can be made of the number of cycles at differing surface energy (T-gamma) levels.

*NUCARS is a registered trademark of Transportation Technology Center, Inc., Pueblo, Colorado.

By observation (Figure 3), crack initiation takes place rapidly after each of two grinding cycles on the low rail, notwithstanding the current wear rate. Consequently, the total cycle count to failure must be greater than unity.[1]

Using these observations and those being made at sites with lower curvatures (2-, 4-, 6-, and 8-degrees), a T-gamma "map" can be drawn up for low rail RCF. This will include an assessment of the influence of wheel profile, cant versus speed and friction coefficient (including the effects of TOR friction control), as well as the effect of rail grinding.

It is intended that this analysis be further enhanced through a determination of wear numbers similar to those developed using twin disk machines.[6]

CONCLUSIONS AND FUTURE WORK

A method has been developed for establishing T-gamma relationships for lateral tractions under North American heavy haul conditions. These relationships should enable the determination of traction levels causing RCF. The relationships of RCF formation with load, TOR friction control, and speed will also be determined.

The full development of a T-gamma map will require the results from observations and measurements in different curvatures. It is, however, recommended that data currently available from a 10-degree curve be used to initiate and verify the process. Results of this analysis will be published in forthcoming TDs.

Investigations continue into the feasibility of introducing a similar process to establish T-gamma maps to predict the effect of longitudinal tractions as well as to predict material flow under heavy haul conditions. The effects of grinding need to be considered and accommodated in the analysis; this requires further study.

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