TECHNOLOGY DIGEST

Timely Technology Transfer — 99-035

THE EFFECT OF WHEEL/RAIL PROFILES ON WHEEL PERFORMANCE AT FAST

by N. Wilson, D. Maal, D. Davis, J. LoPresti and S. Kalay

Summary

The unusually high rate of wheel flange shelling experienced by trains during unlubricated conditions of Phase IV of the Heavy Axle Load program has been found to be unique to the environment at the Facility for Accelerated Service Testing (FAST). These shells, which occur on the tread side corner of the flange tip, are not seen in revenue service and were investigated with NUCARS modeling, measurements, and testing at FAST.

The investigation has indicated that an adverse wheel/rail profile match, aggravated by the closed-loop operation, is the primary cause. The wheel/rail profile match occurring in the curves that are part of the rail grinding experiment is unusual. FAST train wheels, with a flat flange tip from the Flange Bearing Frog diamond, are running on a "shelf" created by the gage wear and profile grinding in the high rails of curves. This is creating an adverse contact condition on the flange tip corner of the wheel. The wheels are essentially flange bearing while providing steering forces in the curves. The forces that occur where the flange tip corner contacts the rail, in combination with several other factors, cause the shells.

This situation is unlikely to occur in revenue service and is unique to the operating environment of the FAST High Tonnage Loop, where a single train repeatedly travels over a short loop of mostly curved track.

Suggested Distribution:
- ☐ Maintenance of Way
- ☐ Planning & Analysis
- ☐ Track Maintenance
- ☐ Safety

Work performed by TTCI Transportation Technology Center, Inc.
a subsidiary of the Association of American Railroads
December 1999©

INTRODUCTION AND CONCLUSIONS

Wheel flange tip shelling has occurred at FAST throughout the HAL experiment and during the previous 33-kip wheel load experiments.[1] A conclusion from Gray's 1981 report on early FAST wheel experiments is that train operation on dry rail caused excessive plastic deformation resulting in fatigue cracking of the flanges.

Exhibit 1 shows more recent flange shells from HAL Phase III (lubricated rail) and Phase IV (dry rail). The shells occur on the side of the flange facing the rail. They range in size from 0.25 to 1.50 inch in length and do not span the width of the flange tip. The shells that were inspected using electron microscopy are fatigue defects originating at aluminum-oxide inclusions in the wheels.

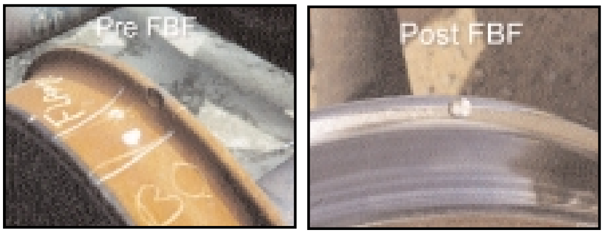

Exhibit 1. Typical FAST Wheel Flange Shells from HAL Phase III and IV

EFFECT OF DRY OPERATION

The rate of shelling increased dramatically in 1999 as several experiments were changed. The biggest change was the dry-rail operation of the FAST train. In 1998, under lubricated operations, six shells were found in 120 million gross tons (MGT) of operation. In 1999, 40 shells have been found in about 50 MGT of dry-rail operation.

FAST RAIL GRINDING EXPERIMENTS

Since 1994, significant portions of the two longest curves on the HTL have been part of a rail profile grinding experiment. The purpose of this experiment was to measure the effects of the profile grinding on rail defect and wear performance. All grinding profiles used in this experiment provided gage corner relief and promoted two-point contact between the wheel and rail. Two-point contact is designed to relieve the gage corner from high-contact stresses. Findings from the experiment include:

- Rails ground to two-point contact profiles had much higher gage face wear rates than non-ground rails.
- Two-point contact conditions on the high rail increase lateral curving forces that lead to increased rail wear and increased rolling resistance.

The grinding experiment, combined with the limited range of flange heights in the FAST train fleet, has created a rail profile with a significant lip or shelf. The profile was very conformal to a wheel shape seen prior to installation of a flange bearing frog (FBF) crossing diamond at FAST. Exhibit 2 compares measurements of the following three high-rail profiles from Section 25 at FAST:

- Control zone where no rail grinding is performed.
- Grind zone, after 490 MGT (before FBF diamond was introduced).
- Grind zone, after 563 MGT (and 7,800 train laps after installation of the FBF diamond).

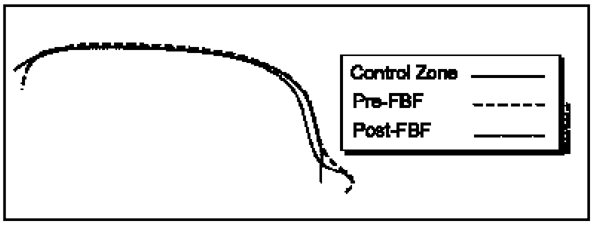

Exhibit 2. Comparison of Section 25 High-Rail Profiles, in Control and Gage Corner Grind Zones

Note that heavy gage face wear is evident in the grind zone, with a resultant prominent lip well down the gage face. This lip is largely the rail metal in its original location. Metal removal on the gage face and a small amount of metal flow forms the lip. In the plot, the three profiles are aligned at the rail centerline track. This view shows the relative gage face wear in each section.

Note that the gage face angle on all three profiles is essentially the same, indicating that the FBF flange profile is not affecting the shape of the flange above the tip. After dry test runs using wheels with flattened flange tips, the lip is still present; but the corner radius between the lip and the gage face has become much smaller.

Exhibit 3 shows how a wheel with a flattened flange tip and a normal FAST wheel contact the high rail in both the grind zone and the control no-grind zone. Note that wheels with flattened flange tips contact the grind zone rail in the sharp corner of the lip, leading to the potential for stresses significantly higher than normal due to the small radius of contact. When the rails were lubricated, this contact condition apparently did not adversely affect flange shelling. However, when flange lubrication was eliminated, the flange shelling increased dramatically. It was hypothesized that when running dry, the large rolling radius of the flange tip contact point generated large longitudinal steering forces that contributed to the shelling.

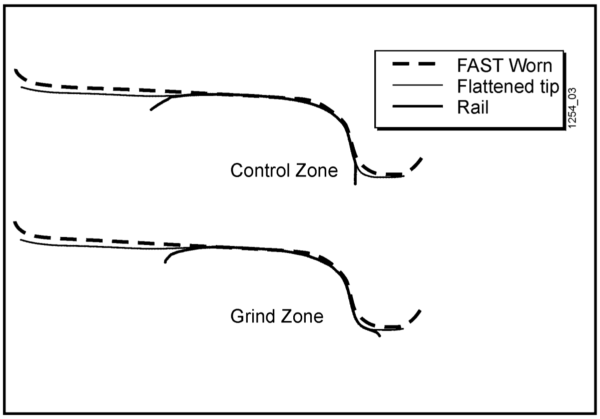

Exhibit 3. Contact Geometry of FAST Worn and Flattened Flange Tip Wheel Profiles on Control and Grind Zone Rails

NUCARS MODELING OF FAST HTL OPERATING CONDITIONS

NUCARS computer model simulations were conducted to evaluate the curving performance differences between wheels exposed to the FBF and ordinary FAST worn wheels under both dry and typical lubrication conditions. Normal FAST lubrication practice provides gage face lubrication of the high rail of curves and a small amount of lubrication on the head of the low rail to control gage spreading forces. The distribution of forces between the gage face and top-of-rail contact points were examined to help identify mechanisms that might lead to the flange shelling. Model predictions were corroborated by a series of tests conducted at FAST.

Simulations were made for a FAST 125-ton car equipped with Buckeye passive steering trucks, and with the Barber passive-steering trucks equipped with a FRAME BRACE™. The rail profiles and wheel profiles shown in Exhibit 3 were simulated to represent pre and post flattened-flange-tip conditions in both the no-grind zone and the grind zone. Wheel/rail contact geometries for input to NUCARS were calculated using the rail rotation angles measured during the tests at FAST. These showed that the high rail in the grind zone had a tendency to roll outward 0.5 degree, thereby increasing the contact between the flange tip and the sharp radius in the flow lip of the rail.

MODEL AND TEST RESULTS: EFFECTS OF WHEEL AND RAIL PROFILES

NUCARS predictions indicate that the highest contact stresses are generated with the flange tip wheel in the grind zone. The shear forces shown in Exhibit 4 are the combination of longitudinal and lateral forces in the contact plane. The dry condition is predicted to generate higher flange tip shear stress than the lubricated condition. Under dry conditions the large (wheel) rolling radius of the flange tip can generate large longitudinal steering forces.

These predicted stresses are well above the tensile yield stress of heat-treated wheel and rail steels and would be expected to lead to flow in the presence of large shear forces in the contact patch. Since the model does not account for plastic deformation, the predicted contact stresses are approximate. However, they do give an indication of the relative effects of wheel and rail profile. These large shear forces in combination with the very high contact stress could lead to the generation of flange shells.

NUCARS simulations are corroborated by test results shown in Exhibit 5, demonstrating that the increased longitudinal steering forces caused by dry running result in lower angles of attack (AOA) for all four combinations of wheel and rail profiles. Much lower AOA occurs in the gage corner grind zone for the flattened flange tip wheels running dry, due to the very large longitudinal steering forces.

REFERENCES

1. Gray, Donald E., "Major Variables That Affect Wheel Wear," FAST Engineering Conference, November 4-5, 1981, Denver, Colorado.

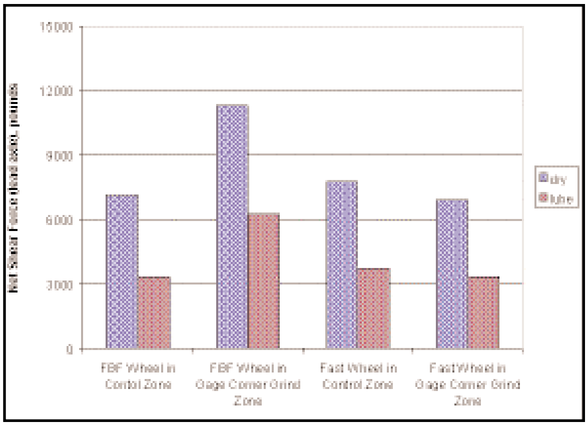

Exhibit 4. Effects of Wheel and Rail Profile on High-Rail Contact-Patch Shear Forces

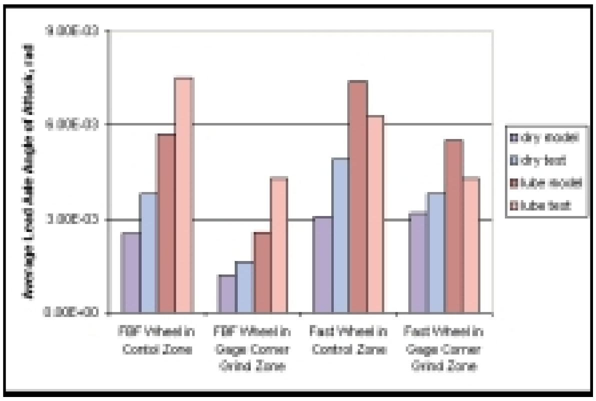

Exhibit 5. Effects of Wheel and Rail Profile on Lead Axle Angles of Attack

Note: Please contact Dave Davis at (719) 584-0754 with questions or comments about this document.

E-mail: davis_davis@ttci.aar.com

Web site: www.ttci.aar.com

A MORE DETAILED REPORT, WHICH MAY CONTAIN REVISED INFORMATION, MAY BE AVAILABLE AT A LATER DATE THROUGH AAR/TTCI, PUBLICATIONS, P.O. Box 79780, BALTIMORE, MD, 21279-0780.