TECHNOLOGY DIGEST

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WHEEL-FLANGE SHELLING UNDER UNLUBRICATED CONDITIONS AT FAST

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Summary

A high rate of wheel shelling has been observed with the introduction of unlubricated conditions in Phase IV of heavy axle load testing 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, where a much larger population of wheels traverses a much more diverse population of curves. They are believed to be unique to FAST and its particular operating conditions. The FAST train also spends considerably more time in curves than typical revenue service trains.

The causes of the flange shelling were investigated with measurements, modeling, and experiments. These studies suggest that the following are factors in the formation of wheel shells at FAST:

- Dry (unlubricated) operation: This increases the longitudinal steering forces on the wheel flange.
- Curve-worn profile of premium rails in curves: Profile grinding has created a pronounced gage-face lip on the high rails.
- Wrought wheels: The FAST train has a high proportion of wrought wheels compared to revenue service. These particular wheels have more aluminum oxide inclusions and are more likely to produce shells.
- Flange Bearing Frog (FBF) crossing diamond: The artificially high rate of FBF crossings has created a flat flange-tip profile with a sharp corner.
- Closed-loop FAST operation: The testing environment has created wheel and rail profiles unique to FAST.
- Limited range of flange heights in FAST train: Short average flange height allowed distinct high-rail lip to form.
- Time sequence of experiments: Introduction of FBF under lubed conditions followed by dry running and FBF removal produced the detrimental wheel/rail profiles. This allowed the wheelset steering forces to concentrate near the flange tip corner of the wheels.

Suggested Distribution:
☐ Car Department
☐ Maintenance of Way
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INTRODUCTION AND CONCLUSIONS

Since the beginning of Phase IV with its dry rail conditions, the train operating at the Facility for Accelerated Service Testing (FAST) Heavy Axle Load (HAL) experiment has experienced a high rate of wheel shelling. These shells, which occur on the tread-side corner of the flange tip, are believed to be unique to FAST and its particular operating conditions. They are not seen in revenue service, where a much larger population of wheels traverses a much larger population of curves.

An adverse wheel/rail profile match that occurred in the curves that are part of the rail-grinding experiment caused the flange shelling seen at FAST. FAST train wheels, with a flat flange tip from the FBF diamond, were running on a “shelf” created by the gage wear and profile grinding in the high rails of curves. This created an adverse contact condition on the flange-tip corner of the wheel. The wheels were essentially flange-bearing while also providing steering forces in the curves.

The causes of the flange shelling were investigated with measurements, modeling and experiments. Results of these studies suggest that the following were factors in the wheel-shelling formation at FAST:

- Dry (unlubricated) operation: Increased the steering forces on the wheel flange.

- Curve-worn profile of premium rails in curves: Profile grinding created a pronounced gage-face lip on the high rails.

- Flange Bearing Frog (FBF) crossing diamond: The artificially high rate of FBF crossings created a flat flange-tip profile with a sharp corner.

- Closed-loop FAST operation: This situation created wheel and rail profiles unique to FAST.

- Limited range of flange heights in FAST train: Short average flange height allowed distinct high-rail lip to form.

- Time sequence of experiments: Introduction of FBF under lubed conditions followed by dry running and FBF removal produced the detrimental wheel/rail profiles.

BACKGROUND

Wheel-flange tip shelling has occurred at FAST throughout the HAL experiment and during the previous 33-kip wheel load experiments.[1] Exhibit 1, taken from Gray’s 1981 report covering the initial FAST wheel experiments, shows the location of the typical flange shell as well as the typical wheel and rail profiles that produced them. A conclusion from this report is that unlubricated train operation caused excessive plastic deformation that resulted in fatigue-cracking of the flanges. Exhibit 2 shows a typical shell from HAL Phase III (lubricated rail and pre-FBF diamond) and a typical shell from Phase IV (dry rail and post FBF diamond). The

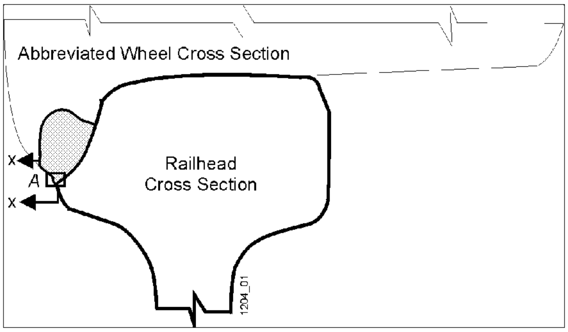

Exhibit 1. FAST Wheel Flange Crack from the 1970s

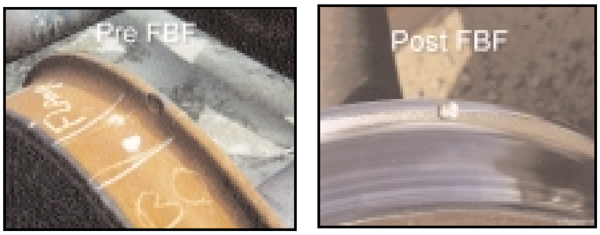

Exhibit 2. Typical FAST Wheel-Flange Shells from HAL Phase III and IV

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 running surface of the flattened flange tip. The shells are fatigue defects that originate at aluminum-oxide inclusions in wheels. Shells are found by normal train visual inspections after they "pop out." They are not considered to be an immediate safety hazard. A wheel with a shell, running on its flange tip, is not creating large impact forces.

Several flange shells were examined visually to determine the likely failure mechanisms. Additionally, a detailed examination of a typical shell removed during the dry operations was conducted. Visual examination of the defects gives the appearance of a small shattered rim defect. The fracture surfaces are ellipsoidal with fatigue bench marks originating at the center of the fracture.

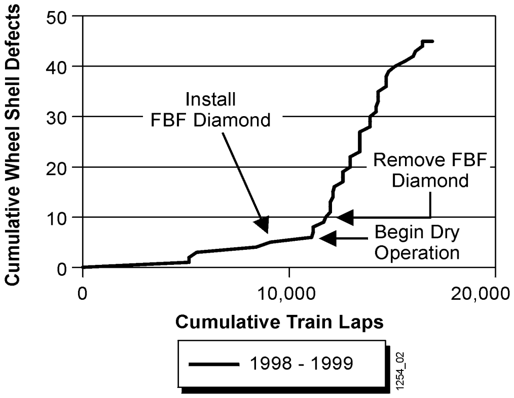

Exhibit 3. FAST Wheel-Flange Shelling Occurrence

Examination of the defects with a scanning electron microscope revealed the remains of a particle of aluminum oxide. As is the case with these flange defects, larger, shattered rim defects are initiated at alumina or silica inclusions. Aluminum oxide inclusions are either the remains of aluminum additions made at the end of the liquid phase of steel processing or exogenous inclusions that are the remains of eroded refractories that were part of the furnace or ladle linings.

A microhardness survey was conducted along a line perpendicular to the defect plane from the flange surface. The test plane was in the radial direction adjacent to one of the defects. At strains less than 0.6-percent, rail and wheel steels work softens. Strains greater than 0.6-percent cause work hardening. Shattered rims and their rail equivalent, horizontal-split-heads, form preferentially from large nonmetallic inclusions in the work softened zone. In normal wheel/rail contact conditions, the failure zone is 5/8 inch below the wheel tread or rail head surface. Notice that at 0.25 inch from the surface of the flange there is a dip in hardness that indicates the work softened zone. 0.25 inch is also the depth of the origin of the adjacent crack.

EFFECT OF DRY OPERATION

The rate of shelling changed dramatically in 1999 as several experiment changes were made. The biggest change was the "dry" (unlubricated) operation of the FAST train. Exhibit 3 shows the rate of wheel-shell defect occurrence in 1998 and 1999 to date. The sharp kink in the curve corresponds to the start of dry operation. Installation of the FBF diamond preceded the start of dry operation by about 31 million gross tons (MGT) or 2,700 laps. In 1998, under lubricated operations, six shells were found in 120 MGT of operation. The rate of shelling remained constant until near the end of operation, when it decreased somewhat. In 1999, 40 shells have been found in about 50 MGT of dry operation. Statistical analysis of the shelling data shows that the data does fit Weibull distributions. The data can be split into two groups: (1) the lubricated operating regime and (2) the dry operating regime (as seen in Exhibit 4). The slopes of the two distributions are quite different. The lubed regime slope is around 1, whereas, the dry regime slope is about 9. This corresponds to the differences in shell-occurrence rates seen during these periods (1 shell in 20 MGT lubed vs. 1 shell in 1 MGT dry).

Using Weibull analysis techniques the combined data set was analyzed for “mixed failure modes.” The results suggested that the data have two failure modes. The change from one to the other occurs at the start of the dry running. We interpret this result to suggest that dry running changed the operating environment for the wheel flanges, increasing the rate of shelling. The failure mode (a fatigue defect) is the same, but it occurs more rapidly under dry conditions.

COMMON CHARACTERISTICS OF FLANGE-SHELLED WHEELSETS

The shelled wheelsets have several characteristics in common. These include:

- Flange bearing: All shelled wheels have run over the FBF diamond. All have a flattened flange-tip shape.

- Wrought wheels: All shelled wheels are wrought (i.e., forged); not cast. About 75 to 80 percent of the FAST train wheels are wrought.

- Truck type: About 75 percent of the shelled wheels were in one of the three trucks being tested at FAST; approximately 50 percent of the train has this type of truck.

- Hollow-worn wheels: The wheel that shells tends to be the more hollowed of the two on the wheelset.

- Freshly worn flange tip at the time of shelling: Long after the removal of the FBF diamond, the shelled wheels are flange-bearing on curve worn rail.

REFERENCES

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

2. Mace, Stephen, et al., “Effects of Wheel-Rail Contact Geometry on Wheel Set Steering Forces,” Fourth International Conference on Contact Mechanics and Wear of Rail – Wheel Systems, Vancouver, Canada, 1994.

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