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Static Analysis of Rail Grinding Templates

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Key Findings:

- Class 1 railroads use low rail grinding templates with much variation in shape including crown radii between 6 and 14 inches and vertical field side reliefs between 0.037 and 0.103 inch.
- A vertical field side relief of at least 0.070 inch appears to be effective in avoiding extreme field side contact and associated low Functional base-to-height ratio (B/H) values for wheels with up to 3 mm hollow.
- The three rail profiles that were most tolerant of more heavily hollow worn wheels all had a crown radius of less than 10 inches and a field side relief of at least 0.073 inch.
- Nominal B/H is not an accurate predictor of the ability of a low rail to avoid contact between the false flange of a hollow worn wheel and the extreme field side of the rail head.

Transportation Technology Center, Inc. (TTCI) conducted an analysis of the grinding templates used on curved track by Class 1 railroads in North America. Particular emphasis was placed on the low rail templates because they tend to require the heaviest grinding effort and because a comparison of the templates used on low rails shows much variation. The static portion of the analysis is discussed here, while the dynamic portion of the analysis is described in a separate *Technology Digest.*[1] This was work performed under the Association of American Railroads (AAR) Strategic Research Initiatives program

BACKGROUND

Restoring a desired rail head crown radius on the low rail in curved track is an important goal of rail grinding. Natural wear and material flow on the low rail flattens the rail head, which can allow the false flanges of hollow worn wheels to contact the field side of the rail head. This creates two problems: it inhibits the desired steering effect produced by having a smaller rolling radius on the low rail wheel in comparison to the rolling radius of the high rail wheel; and it reduces the rail's geometric resistance to rolling outward toward the field side of the track.

One common metric used to evaluate the propensity for the latter is the base-to-height ratio (B/H). Traditionally, the B/H value for a rail is calculated without regard to cant, and is based on the highest vertical point on the rail. The greater the B/H, the farther the highest vertical point on the rail is located away from the field side.

In addition to this "Nominal B/H" metric, a "Functional B/H" has also been calculated for this analysis. The Functional B/H value analyzes the rail in a canted position and is calculated based on the actual location of the contact patch between a particular wheel and a particular rail. Figure 1 illustrates how the same rail profile can have different Functional B/H values depending on the wheel profile. The hollow (red) and non-hollow (blue) wheels in this image would produce different Functional B/H values due to their different contact points on the rail. The Functional B/H value is important because it relates to the actual overturning and restraining moments acting on the rail.

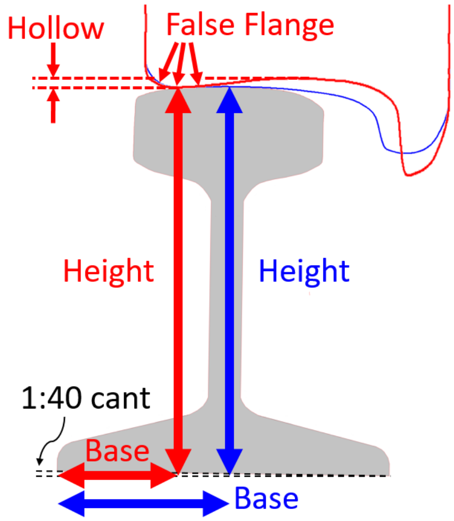

Figure 1. Calculating a Functional B/H value requires matching a wheel profile to a rail profile.

Hollow worn wheels can contribute to contact toward the field side of the rail, leading to low Functional B/H values and reduced resistance to rail rollover. Current limits for hollow wear are 4 or 5 mm, depending on whether the car is already at a repair facility.[2] Because the AAR uses metric units for hollow wear, that standard practice will be continued here (1 mm = 0.039 in.). For visual reference, the red wheel profile in Figure 1 has 4 mm of hollow wear.

Figure 2 shows typical evidence of hollow and non-hollow wheel contact on a low rail. The red arrow in the figure shows a smooth surface indicating contact with hollow worn wheels toward the field side. The blue arrow shows rolling contact fatigue (RCF) damage indicating frequent contact at center of rail head. The white arrow shows marks from previous grind treatment indicating infrequent contact toward gage side.

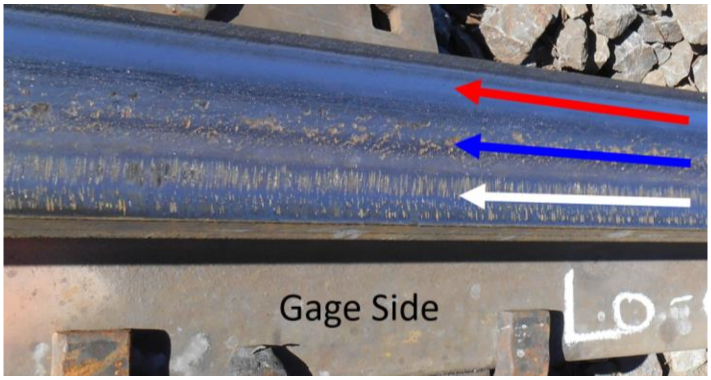

Figure 2. Curve low rail running bands

METHODOLOGY

Rail grinding templates for Class 1 railroads were obtained and overlaid on typically-worn low rail and high rail profiles. Applying the templates to actual rails was a necessary step in order to allow realistic comparisons of the resulting profile shapes while considering differences in track gage and rail field corner contact with hollow worn wheels. The templates were applied to worn rail profiles in a manner intended to replicate the most common alignment method used in the North American freight rail industry while simultaneously ensuring that the template shapes were fully represented between the gauge corner and field corner of the rail. This alignment method has been described in detail previously as "Method C (Range)."[3]

Figure 3 shows overlays of the resulting low rail and high rail profiles vertically aligned at the highest point. Compared to the low rail profiles, the high rail profiles show much less variation. Although the field side of any rail could potentially come into contact with the false flange of a hollow worn wheel, this scenario is expected to occur more regularly on the low rail of a curve as wheelsets shift laterally until the high rail wheel flange comes into contact with the gauge face of the high rail. Thus, low rail interactions with hollow worn wheels are the focus of this analysis.

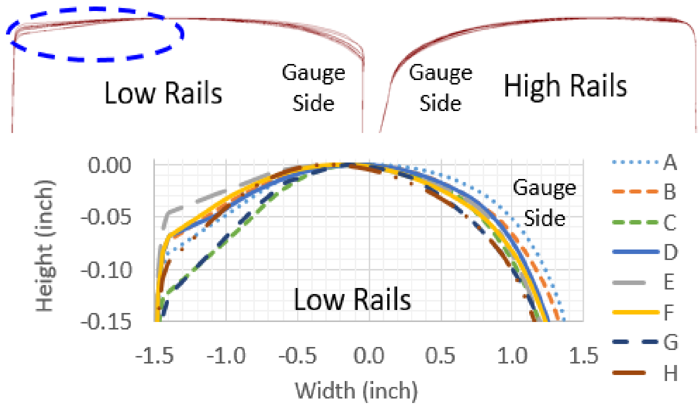

Figure 3. (top) Scaled profile overlays highlight variation of low rail grind templates, particularly on the field side of the rail where contact is expected with hollow worn wheels, (bottom) vertically zoomed view of the low rail profiles

Each of the eight low rail profiles analyzed was matched with its corresponding high rail profile(s) for analysis, ranked by Nominal B/H values (in descending order), and given an alphabetic designation based on this order (see Figure 4).

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STATIC ANALYSIS

Nominal B/H values were calculated for each low rail profile using a constant H-value of 7 5/16 inches representing the height of a new 136 lbs./yard rail. Any Nominal B/H value greater than 0.41 indicates that the highest vertical point occurs toward the gage side of the rail centerline. This is the case for profiles A, B, C, and D while the opposite is true of profiles F, G, and H.

Functional B/H values were calculated for each set of rail profiles using a library of 604 wheelsets from a variety of car types measured by a wayside wheel profile detector. Each of the wheelsets in the library had at least one wheel with a hollow reading between 1 and 4 mm.

All wheelsets were oriented so that the wheel with the most hollow wear was on the low rail. Starting at a centered position, each wheelset was moved toward the high rail in increments of approximately 0.02 inch until reaching hard flange contact. This allowed for the determination of the lowest possible Functional B/H value for each combination of wheelset and rail pair assuming 0-degree axle angle-of-attack.

Figure 4 shows both the Nominal B/H values and Functional B/H values for these rails and wheels. Nominal B/H values are shown at an x-value corresponding with zero hollow wear.

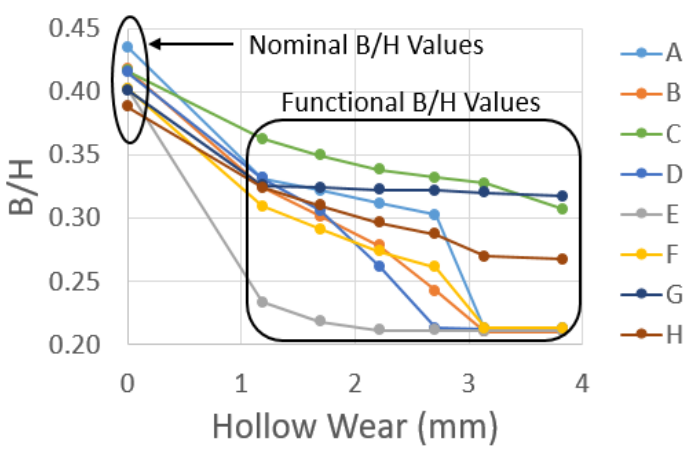

Figure 4. Static analysis of low rail Nominal B/H values and Functional B/H values generated by a library of hollow worn wheels

For plotting the Functional B/H values in this figure, the wheelsets were divided into 0.5 mm hollow groups and plotted values were based on the median hollow and the median B/H value for the group. For example, a wheelset with a 2.36-mm hollow wheel would be part of the 2.0 to 2.5 mm hollow group and would contribute it's lowest B/H value to that group. The median hollow for this group is 2.22 mm and is plotted at this x-value in Figure 4. Note that the minimum B/H value physically possible for the 136RE rail is 0.2.

Figure 5 plots the crown radius of each low rail and the vertical relief present on the field side of the rail. The crown radius was determined using a best fit circle over the central 1 inch of the running surface. Field side relief was evaluated as the difference in rail head height between the highest point to a point 0.25 inch from the field side edge of the rail. For comparison, a new 136RE rail profile set at a typical rail cant of 1:40 has an 8-inch crown radius and a field side relief of 0.164 inch. While the crown radii of low rail profiles produced by grinding span a range which includes that of new rail, the largest field side relief after grinding was only 63 percent of the new rail value.

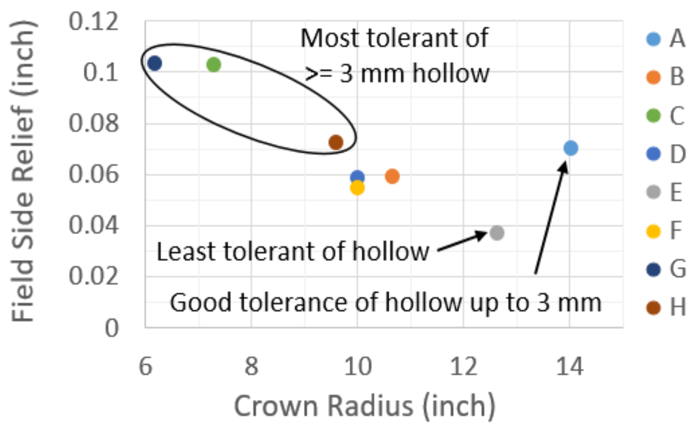

Figure 5. Low rail template crown radius and vertical field side relief

DISCUSSION

The Nominal B/H values were larger than the Functional B/H values calculated with 1- to 4-mm hollow wheels. In general, the Functional B/H values decreased as the hollow increased, though profile G was largely unaffected by increasing hollow. Profiles C, G, and (to a lesser degree) H had notably higher Functional B/H values than the other profiles for wheels with a minimum of 3 mm hollow. Profile

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E showed the lowest Functional B/H values for wheels with mild to moderate hollowing up to 2.5 mm.

Inspection of Figure 5 lends insight to the results from the static analysis. Profiles C, G, and H have the smallest crown radii (6.2 to 9.6 in.), the most field side relief (0.073 to 0.103 in.), and showed the best performance for wheels with heavy hollowing. Detriments of using a tight crown radius include potentially conducting more grinding than needed and potentially having a higher initial rate of rail wear, material flow, and RCF damage immediately after grinding. On the other end of the spectrum, Profile E has a large crown radius (12.6 in.) and the least field side relief (0.037 in.). This profile is generally the least tolerant of hollow worn wheels with regard to Functional B/H values. Profiles B, D, and F have similar moderate crown radii (10.0 to 10.6 in.) and moderate field side relief (0.055 to 0.059 in.) while producing similar moderate Functional B/H results.

Profile A is an anomaly in that it combines the largest crown radius (14.0 in.) with a relatively large field side relief (0.070 in.). These shape parameters appear to offset each other somewhat to produce Functional B/H values that are quite tolerant of hollow wear up to 3 mm, but produce low Functional B/H values for wheels with more than 3 mm hollow.

The static analysis simply calculates contact positions as a library of wheelsets translate across the track to a full flanging position. Though it provides good insight and involves hundreds of different wheel profiles, the static analysis cannot easily take into account some of the variables that will affect actual wheel/rail contact conditions, including degree of track curvature, axle angle-of-attack, and wheel/rail friction levels. To address this shortcoming, a dynamic analysis was also conducted as discussed in a separate publication.[1]

CONCLUSIONS

A static analysis of the rail profiles produced by the grinding templates used by Class 1 railroads shows relatively small differences in the high rail profiles but relatively large differences in the low rail profiles. Low rail Functional B/H values, distinct from Nominal B/H values, as traditionally calculated by track inspection vehicles, were calculated based on a library of 604 measured wheelsets with between 1 and 4 mm of hollow wear. Nominal B/H values are not a good predictor of Functional B/H values. A vertical field side relief of at least 0.070 inch appears to be effective in avoiding extreme field side contact and associated low Functional B/H values for wheels with up to 3 mm hollow. The three profiles that were most tolerant of more heavily hollow worn wheels had crown radius of less than 10 inches and field side relief of at least 0.073 inch.

References

1. Cummings, S. and S. Gurulé, September 2020, “Dynamic Analysis of Rail Grinding Templates,” *Technology Digest* TD20-022, TTCI/AAR. Pueblo, CO.
2. *Field Manual of the AAR Interchange Rules*, 2020, Rule 41 Wheels, Association of American Railroads, Washington, DC.
3. Keylin, A. and S. Cummings, November 2016, “Comparison of Rail Grinding Template Alignment Methods,” *Technology Digest* TD16-053, TTCI/AAR, Pueblo, CO.

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