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Effects of Track Gage Variation on Rail Performance: Results at 383 MGT

Ananyo Banerjee, David Davis, Joseph LoPresti, and Yuqing Zeng

Since 2016, Transportation Technology Center, Inc. (TTCI) has been studying the influence of track gage on rail performance in a 5-degree curve of the High Tonnage Loop at the Facility for Accelerated Service Testing (FAST) near Pueblo, CO. This *Technology Digest* reports the results of testing track gage variation on rail performance at 383 million gross tons (MGT). Intermediate strength (IS) rail from one manufacturer and with an approximate 350 Brinell hardness number (BHN), was used for this test. The nominal track gage for the railroad industry is 56.5 inches. Current Federal Railroad Administration (FRA) regulations for Class 3 and Class 4 tracks limit track gage to 56 inches minimum and 57.5 inches maximum. As such, the aim of this test was to analyze the effects of a narrow gage (56.25 in.) and a wide gage (57 in.) on rail wear and rolling contact fatigue (RCF) performance. Results of similar testing at 187 MGT were published in a previous *Technology Digest*.[1]

Preventive grinding was completed three times between 187 and 383 MGT. Grinding since 187 MGT was done at 202, 266, and 343 MGT. Pre-grind rail profiles, along with track gage measurements, were collected at 190, 262, and 273 MGT. Post-grind rail profiles and associated measurements were collected at 203, 273, and 344 MGT. The wide gage zone was found to have widened up to 57.4 inches in some locations, and was close to the FRA regulation limit cited above at 383 MGT. After testing concluded in the summer of 2019, the wide gage zone, and a part of the transitioning zone at FAST were re-gaged back to a nominal gage of 56.5 inches. Gage widening was observed in both narrow and wide gage zones. Figure 1 shows the change in gage over time.

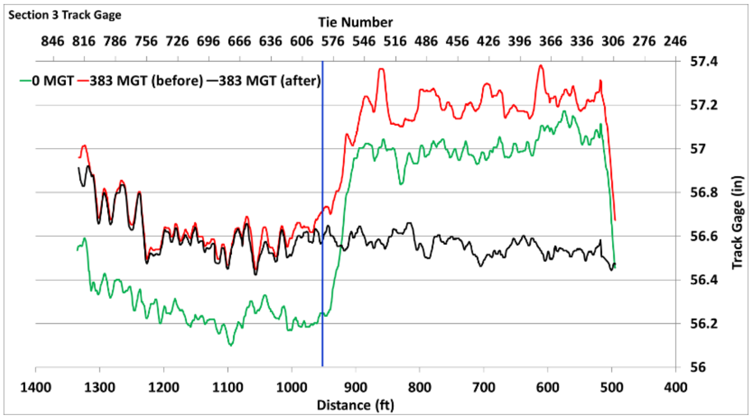


Figure 1. Measured track gage at start of test (0 MGT) and before and after re-gaging at 383 MGT

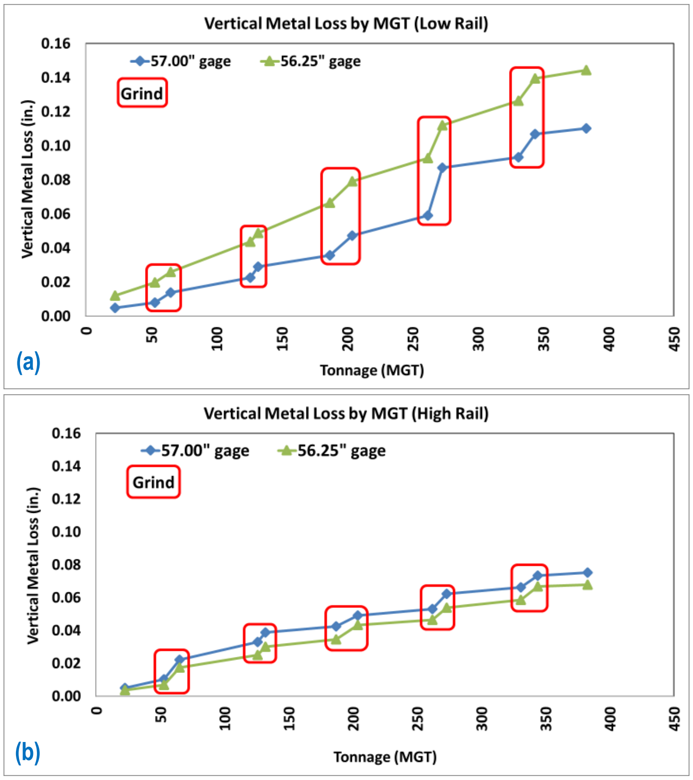
Key Findings:

- The narrow gage zone exhibited more vertical low rail wear and gage face high rail wear than the wider gage zone.
- Rolling contact fatigue (RCF) patterns on the low rail between the narrow and wide gage zones differed throughout testing. Sporadic spalls were observed on the low rail in the wide gage zone near the field corner.
- Eleven gage corner shells were observed on the high rail in the 376-foot gage zone, and one shell was observed in the 376-foot narrow gage zone.
- Computer analysis of wheel-rail contact stresses showed contact stress peaks on the gage corner of the high rail for both narrow and wide gage zones before grinding. Contact stresses were predicted to reduce after grinding. The wide gage zone exhibited higher contact stresses, possibly explaining the larger number of shells in the wide gage zone.

The green line indicates the initial gage when the rail was laid over the entire 792 feet of test zone. The red line shows gage measurements at 0.4- to 0.6-foot intervals across the entire test zone at 383 MGT. The black line represents the track gage of the entire original wide gage zone test zone after re-gaging was completed at 383 MGT. Measurements reported on the left of the vertical blue line are mostly for the original narrow gage zone, which was not re-gaged. Measurements to the right of the blue line were taken after the zone was re-gaged to nominal gage. The difference in median values of track gages at 0 and 383 MGT shows that the narrow gage zone widened by 0.386 inch and the wide gage zone widened by 0.202 inch. Thus, there was almost twice as much gage widening in the narrow gage than there was in the wide gage during the test and before re-gaging.

RAIL WEAR

Since preventive grinding was done with the same grinding patterns and number of passes in both narrow and wide gage zones, the total metal loss shown in Figure 2a indicates higher wear in the low rail of the narrow gage zone. High rail vertical metal loss was similar between narrow and wide gage zones, as shown in Figure 2b. Figure 2c shows gage face wear on the high rail. Preventive grinding at FAST is done from the field corner to the gage corner of the rails to reduce RCF and spalling. Thus, Figure 2c shows natural wear on the gage face of the high rail with higher wear observed in the narrow gage zone using a 0.05 level of statistical significance.



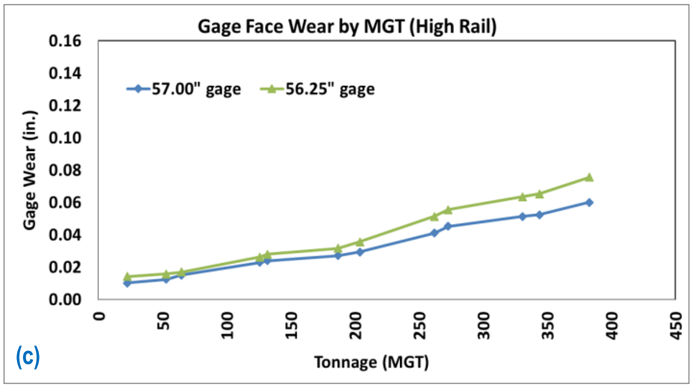


Figure 2. Vertical metal loss of (a) low rails and (b) high rails, and (c) gage wear of high rails

Gage face wear was a small contributing factor to the gage widening observed in both narrow and wide gage zones. Gage wear on the low rails was minimal in the 5-degree curve. The high rail in this 5-degree curve had gage face but no top-of-rail lubrication, while the low rail had top-of-rail but no gage face lubrication.

GAGE CORNER SHELLS

Fatigue-generated shells were observed in the gage corner of the high rails between 187 and 383 MGT. Eleven shells formed in the wide gage zone, while one shell formed in the narrow gage zone. Since the first four shells were formed on one 80 feet long piece of IS rail, the effects of rail metallurgy on shell formation were investigated. The rail manufacturer conducted a thorough metallurgical analysis of the rail steel surrounding the first three shells but no irregularities were detected. Consequently, analysis was focused on the intended variable of track gage.

Figures 3a and 3b show examples of two out of the seven shells that were removed for analysis. The morphology of the shells was similar in all cases, with the fatigue initiation point appearing inside the rail at 0.3 to 0.5 inch perpendicular to the gage corner. Fatigue rings formed as concentric circles surrounding the defect initiation point.

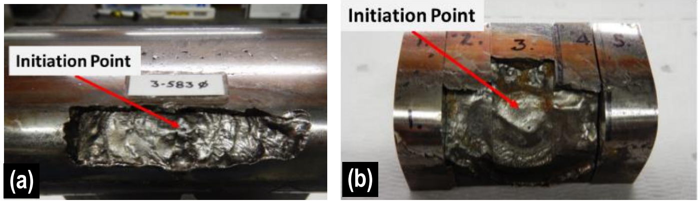


Figure 3. Shells in narrow gage zone (a) and in wide gage zone (b)

Wheel profiles were measured for three locomotives and 11 coal cars of the FAST consist, then analyzed for wheel-rail contact stresses using TTCI software NUCARS® and VTProfile™. Since wheel profiles of the FAST train are fairly uniform, the profiles for the three locomotives and 11 cars represent the entire train. Rail profiles were measured at 330 MGT before grinding and at 344 MGT after grinding for analysis.

Wheel-rail contact stresses were analyzed considering a 0.01-inch lateral displacement of all simulated wheelsets. Figure 4a shows a three-dimensional plot of wheel-rail contact stresses at 330 MGT for the wide gage zone.

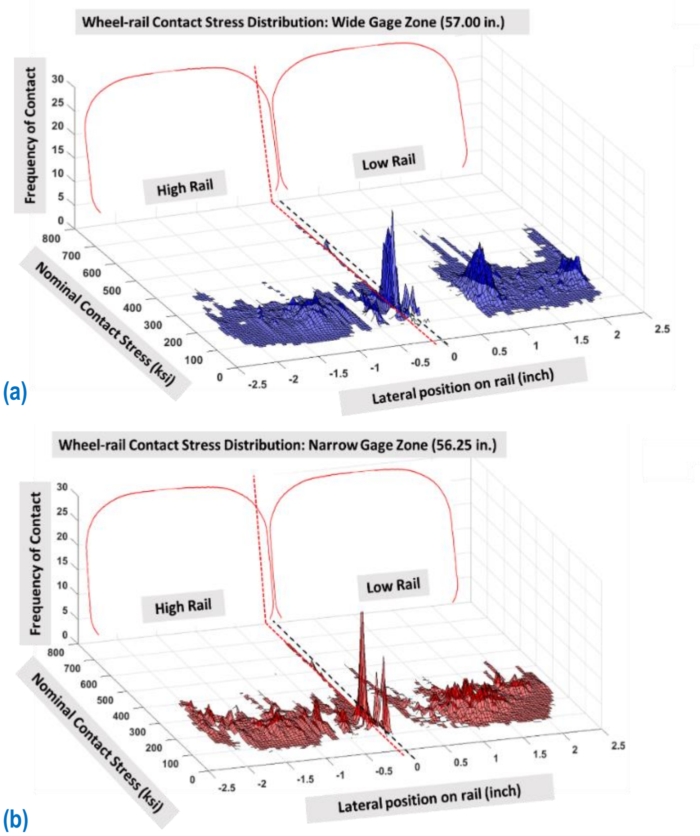


Figure 4. Wheel-rail contact stress distribution at 330 MGT for (a) wide gage zone (blue,) and (b) narrow gage zone (red)

The z-axis represents frequency of contact, the y-axis nominal contact stress, and the x-axis lateral position of the rail head where the wheel is possibly making contact. The dotted red line shows the approximate location of the gage corner, where the frequency of contact has multiple high peaks in the range of 100-300 ksi. Some wheel-rail contact was also observed in the range of 500-600 ksi. Similar observations can be seen in Figure 4b with the narrow gage zone, although here the frequency of contact is highest in the range of 100-200 ksi. The frequency of contact on the high rail diminishes significantly between the field corner and the gage corner for both narrow and wide gage zones.

The same wheel-rail contact stress analysis was also carried out with rail profiles at 344 MGT and measured after grinding. Previous FAST rail tests have shown delay in shell formation and longer rail life due to periodic preventive grinding at 60-70 MGT intervals.[2] Figure 5 shows that the frequency of contact at different nominal contact stresses on the gage corner changed before and after grinding for both narrow and wide gage zones.

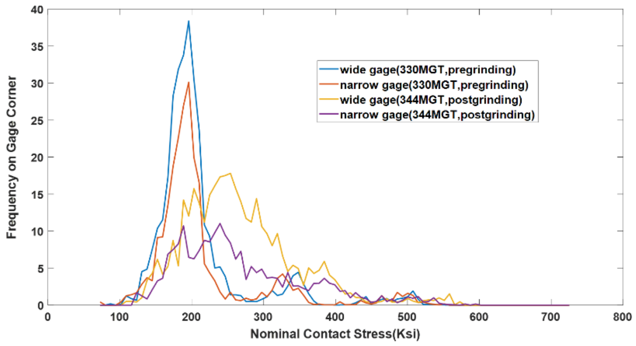


Figure 5. Frequency of contact distributions at (a) 330 MGT before grinding and at (b) 344 MGT after grinding

At 330 MGT, the wide gage (blue line) had a higher peak and broader distribution of frequency of contact than the narrow gage (red line) in the 150-220 ksi range. After grinding at 344 MGT, the peaks reduced significantly for both narrow gage (purple line) and wide gage (yellow line), but they shifted to higher stresses with frequency distributions spread over the wider range of 150-350 ksi.

It is important to note that Figure 5 shows conditions for one train pass with wheel-rail contact conditions averaged over three locomotives and 110 times the average distribution of wheel profiles measured from 11 different cars. The FAST train runs 100-130 laps with a consist of three to four locomotives and 100-120 coal cars four days a week; increasing the frequency of contact with each run. Consequently, a reduction in the number of peaks due to grinding is substantial when multiplied by the number of laps and days. Fatigue defects like shells originate due to repeated cycles of high contact stresses, making the frequency of contact an important factor in shell initiation. Nevertheless, as Figure 5 shows, the frequency distributions of wheel-rail contact at the gage corner shifted to higher stress ranges after grinding, with wider distribution and higher peaks observed in the wide gage zone than those observed in the narrow gage zone over a stress range of 100-400 ksi. It was expected to show the same trend until the next grinding. Thus, the difference observed indicates that the wide gage zone tended to show higher frequency of wheel-rail contacts at the gage corner than similar stress values at the narrow gage, even after grinding.

SPALLING ON TOP OF RAIL

Deep, sporadic spalls in the low rail of the wide gage zone and the narrow band of RCF on the low rail of the narrow gage zone were reported in TD20-001.[1] Analyses of wheel profiles have shown possible high contact stresses close to the field corner of the low rail when the wheel on the low rail is worn and the other wheel of the wheelset is flanging against the high rail; irrespective of its amount of wear. The same worn wheel moving on the low rail makes contact in the center of the top of the low rail in the narrow gage zone at a lower stress with a larger contact patch even when the other wheel continues to flange on the high rail. The difference is due to the track gage and the reduced distance between the contacting wheel and the low rail. Figure 6a shows spalls in the low rail of the wide gage zone, while Figure 6b shows a worn wheel profile making contact with a nearby area of the same low rail.

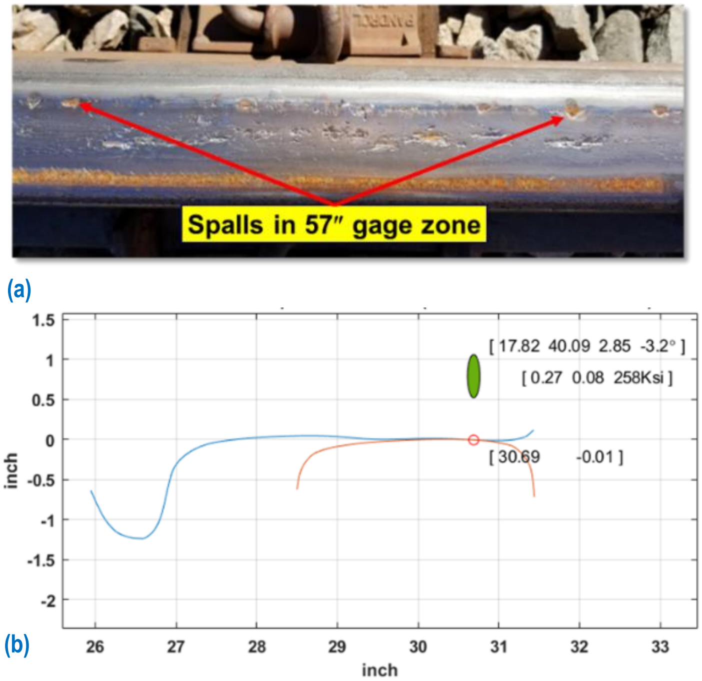


Figure 6. (a) Spalls on the low rail in wide gage zone, and (b) worn wheel profile making contact on same rail near field corner at 344 MGT

It should be noted that the stress values on the low rail are seldom as high as the maximum values indicated by simulations; however, repeated wheel-rail contact by multiple wheelsets over multiple laps can create fatigue cycles capable of creating RCF that can slowly transform to spalling.

CONCLUSIONS

A four-year study on the effects of track gage variation on rail performance was conducted with one IS rail type. Gage widening was observed in both narrow and wide gage zones. The wide gage zone and some of the transitioning gage was re-gaged back to nominal gage at 383 MGT. Although periodic preventive grinding to reduce RCF removed seemingly equal amounts of metal across the entire test zone, vertical wear on the low rail was greater in the narrow gage zone than the wide gage zone. Eleven shells formed in the wide gage zone, while only one formed in the narrow gage zone. The shells formed at the gage corner of the high rail. Computer analysis of wheel-rail contact stresses showed higher contact stresses on the gage corner of the high rails for both narrow and wide gage zones. After grinding, the contact stresses were predicted to reduce. Spalling on the top of the low rail in the wide gage zone seemed to correlate with analyses of wheel-rail contact near the field corner, indicated by worn wheel profiles and rail profiles measured near spalls.

References

1. Banerjee, A., Davis, D., Klopp, A., & Zeng, Y., April 2020, "Effects of Track Gage Variation on Rail Performance: Results at 187 MGT," *Technology Digest*, TD20-001, AAR/TTCI, Pueblo, CO.
2. Banerjee, A. and LoPresti, J., March 2017, "Intermediate Strength Rail Test: Wear and Defect Analysis," *Technology Digest,* TD17-005. AAR/TTCI, Pueblo, CO.

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