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New Wheel Profile Design and Preliminary Service Test Results

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Summary

Transportation Technology Center, Inc. has designed a new wheel profile, named TTCI-1A,∗ with the intention of improving vehicle curving performance and reducing the wear-in period. Compared to the AAR-1B wheel profile, which produces a severe two-point contact pattern, the new wheel profile produces relatively conformal contact with the commonly worn high rail profiles in curves.

Simulations demonstrated that when contacting with the commonly worn rails, wheels with the TTCI-1A profile produced lower lateral forces and considerably lower rolling resistance on curves than the wheels with the AAR-1B profile, for both regular three-piece trucks and improved suspension trucks.

A small-scale service test of the new profile is being conducted using a five-unit articulated car. The wheels on three of the six trucks were trued to the TTCI-1A profile, and the remaining wheels were trued to the AAR-1B profile. Preliminary test results from the first 30,000 loaded miles of operation show that:

- The wheels with the TTCI-1A profile generally produced lower lateral forces on curves based on data from truck performance detectors.
- Neither the TTCI-1A nor the AAR-1B profiles showed indication of lateral instability based on the onboard acceleration data and the wheel impact load and hunting detector data.
- The wheels with the TTCI-1A profile generally produced lower wheel L/V ratios. In 31 cases where the L/V ratio exceeded 0.5, 26 cases occurred on the wheels with the AAR-1B wheel profile.
- The AAR-1B wheels show the trend of concentrated wear at the wheel flange face and asymmetrical wear between right and left wheels; whereas, the TTCI-1A wheels show even and symmetric wear at the wheel flange root.
- The total cross sectional area loss of material from the wheels with the TTCI-1A profile was 35 percent less than the wheels with the AAR-1B profile.
- There is no strong indication to relate tread surface defects to wheel profiles at this time. Wheel slide and brake wear-in may have contributed to some of the surface defects.

The five-unit test car will be continually monitored for an additional 20,000 to 30,000 miles of operation to see if the performance and shape of the two wheel profile designs eventually converge. A larger scaled service test is being conducted using coal cars.

∗Will be designated AAR profile, if adopted in the future.

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BACKGROUND AND INTRODUCTION

Changes in operating practices over the past decade, mainly from the implementation of improved rail grinding practices, improved truck suspensions, improved rail lubrication practices, and increased rail hardness, have raised concerns about the compatibility of the AAR-1B wheel profile with current North American freight tracks.

The AAR-1B wheel profile, developed in 1988, was designed to match measured worn wheel shapes.[1] It replaced the AAR-1:20 wheel profile as the North American freight service wheel standard profile. Compared to the AAR-1:20 profile, the AAR-1B profile increased the flange climb L/V (lateral force over vertical force) ratio limit by increasing the flange angle from 70 degrees to 75 degrees and lowered rolling resistance, wheel/rail wear, and tread surface damage through changes in the flange root shape.

An analysis of the AAR-1B wheel profile contacting with the commonly worn rail profiles from curves indicated a severe two-point contact pattern, which degrades truck steering, leading to higher wear and rolling resistance due to a large rolling radius difference (up to 0.5 inch) between the two contact points (see Figure 1).

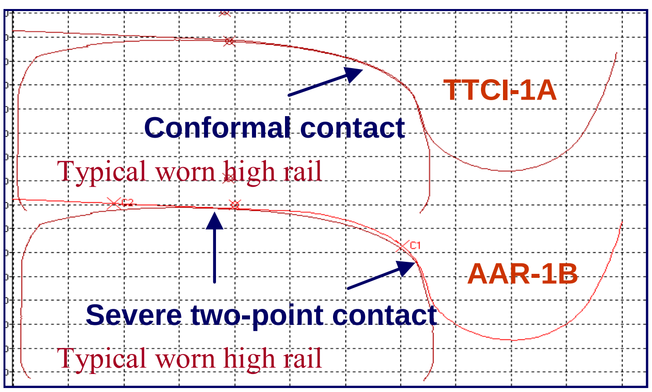

Figure 1. Contact Features of the TTCI-1A and the AAR-1B Wheel Profiles

AN IMPROVED WHEEL PROFILE FOR CURVING

Based on recently measured worn wheel and rail shapes, a modified wheel profile, named TTCI-1A, has been designed with the intention of improving vehicle curving performance and reducing the wear-in period. The new wheel profile produces relatively conformal contact with the commonly worn high rail profiles from curves (see Figure 1). The TTCI-1A wheel profile maintains the same tread shape as the AAR-1B profile, while modifying the flange root shape of the profile. The flange angle of the TTCI-1A profile remains at 75 degrees.

Estimation of the Potential Problem Size

Based on an examination of the wheel replacement and truing database for the North American freight railways, about 7 percent of the revenue service wheels are replaced or re-profiled annually to the AAR-1B profile (some railways stated higher annual replacement/re-profiling rates of up to 12 percent). Similarly, the estimated replacement rate of new rail is about 3 percent annually. Hence, it is estimated that about 97 percent of rails in North America have a worn or ground shape. In practice, rails are usually not ground back to the design shapes. The incompatible wheel and rail profile problem occurs for about 7 percent (or higher) of the wheel population with the AAR-1B profile contacting worn rails (97 percent of rail population).

Wheel Profile Evaluation Using NUCARS® Simulation

Vehicle curving simulations, using NUCARS®, were performed for two types of freight trucks — the standard three-piece truck and an improved suspension truck. The improved suspension trucks had higher warp stiffness and damping than the standard three-piece trucks. The simulated vehicle had a wheel load of 36 kips and was simulated negotiating a 7.5-degree curve under a dry wheel/rail interface condition (μ=0.5). Two wheel and rail profile combinations were assessed — the AAR-1B and the TTCI-1A wheel profiles contacting with a pair of measured worn rail profiles.

Figure 2 shows the simulation results for wheel lateral forces and rolling resistance. The rolling resistance, also called Wear Index, is defined in the equation below. The rolling resistance is the sum of tangential forces (T_x, T_y and M_z) and creepages (γ_x, γ_y and ω_z) at the contact patches of all eight wheels in a vehicle. Higher rolling resistance can induce either rolling contact fatigue or a higher rate of wear. It is also an indicator of the energy consumption at the wheel/rail interface.

$$Wear\ Index = \sum_n T_x\gamma_x + T_y\gamma_y + M_z\omega_z$$

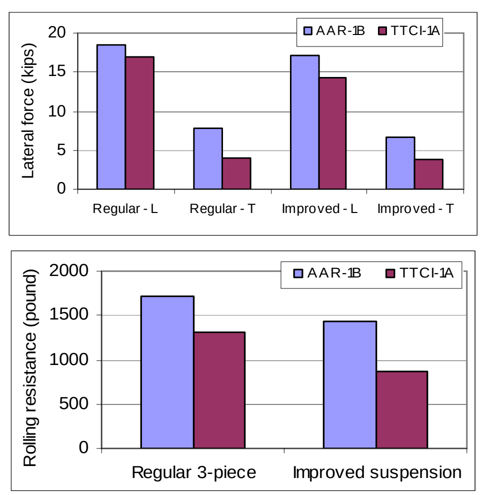

Figure 2. Wheel Lateral Force and Rolling Resistance (L – Leading wheels, T – Trailing wheels)

Simulation results indicated that when contacting with the measured worn rails, the wheels with TTCI-1A profile produced lower lateral forces and considerably lower rolling resistance than the wheels with AAR-1B profile for both truck types. Note that under the severe two-point contact condition produced by the AAR-1B wheel profile, the benefits provided by the improved suspension truck were less than those obtained when using the TTCI-1A profile. This analysis illustrates the importance of the wheel/rail profile match in vehicle curving performance.

WHEEL PROFILE EVALUATION BY REVENUE SERVICE TEST

After an extensive series of analytical and experimental studies at the Transportation Technology Center, the first revenue service test of the TTCI-1A wheel profile began in January 2006. The test is being conducted on a five-unit articulated car, provided by TTX Company. As Figure 3 shows, the wheels on three of the six trucks were trued to the TTCI-1A profile, and the remaining wheels were trued to the AAR-1B profile. Accelerometers and a data collection system were installed on the test car to monitor vehicle lateral stability during the revenue service test.

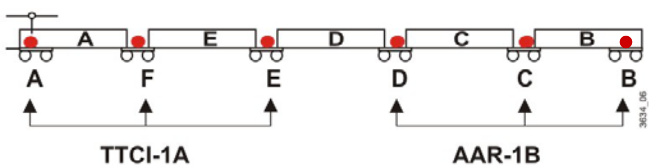

Figure 3. Five-Unit Test Car Configuration (the dots indicate the accelerometer locations on the test car)

By the end of June 2006, the test car had traveled about 30,000 miles in the loaded condition and 4,300 miles in the empty condition. Figure 7 shows the travel routes. The test car has passed truck performance detectors (TPD) 17 times and wheel impact load/hunting detector (WILD/HD) sites 29 times. TPDs measure vehicle curving performance and WILDs/HDs measure vehicle lateral stability.

Figure 4. Travel Route of the Test Car, Blue = Loaded Route, Red = Unloaded Route

In general, the wheels with the TTCI-1A wheel profile produced lower lateral forces, especially under heavily loaded conditions. Figure 5 shows an example of average lateral forces measured at one of the TPD sites.

Figure 6 displays the distribution of all wheel lateral force data received from the TPDs. Agreeing with the trend of the simulation results and the individual TPD site data, the TTCI-1A profile moderately reduced the lateral force on the leading wheels and considerably reduced the lateral force on trailing wheels on curves. It also reduced the lateral force on tangent sections.

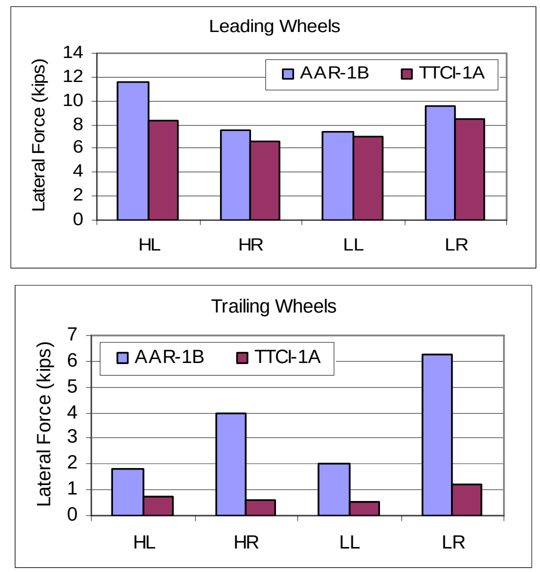

Figure 5. Average Lateral Forces Measured at one of TPD Sites (HL, HR – High Rail, left- and right-hand curves; LL, LR – Low Rail, left- and right-hand curves)

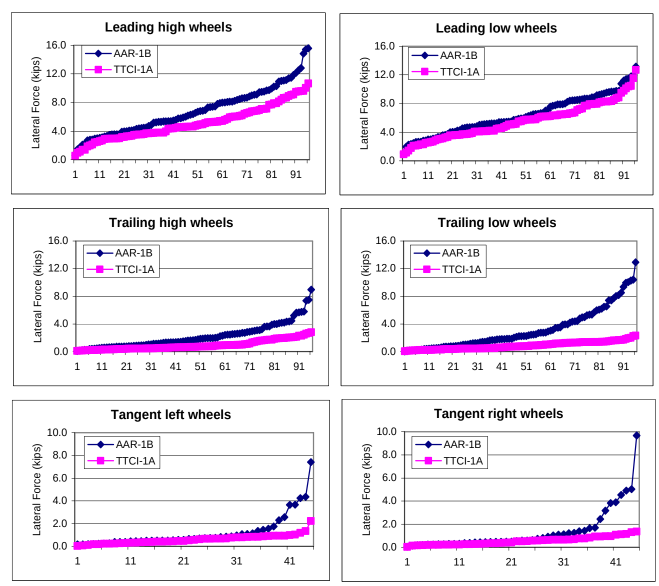

Figure 6. Distribution of Wheel Lateral Force (x-axis – the number of data)

Figure 7 displays all 940 values of wheel L/V ratio received from the TPDs, which includes the values from both curved and tangent tracks. The wheels with the TTCI-1A profile generally produced lower wheel L/V ratios. In 31 cases where the L/V ratio was greater than 0.5, 26 occurred on the wheels with AAR-1B wheel profile.

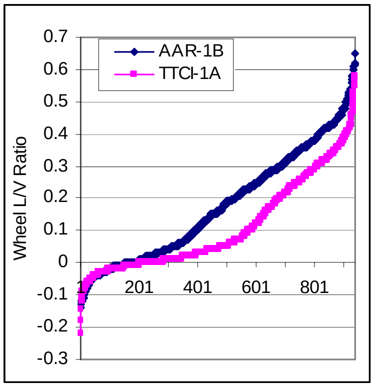

Figure 7. Distribution of Wheel L/V Ratio

Based on the onboard acceleration data and the WILD/HD data obtained to date, neither the TTCI-1A nor the AAR-1B profiles showed indication of lateral instability. Figure 8 shows the distribution of all hunting index data received to date. All values were below 0.2. A hunting index above 0.2 is considered as the level that requires attention.

Note that due to the different commodities this test car has carried, the loading conditions ranged from empty and light to heavy. Figure 8 shows the hunting index under all loading conditions this car has experienced. The highest speed detected by the WILD/HD for the test car was 68 mph with 9 percent of the load.

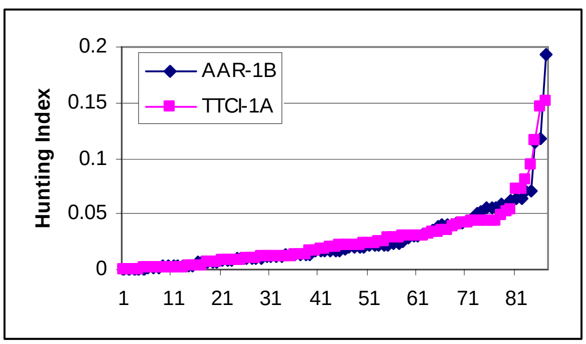

Figure 8. Distribution of Hunting Index Data

The wheel profiles were measured after 30,000 miles of loaded operation. Overlaying with the profiles measured just after the wheels were trued, the AAR-1B wheels show concentrated wear at the wheel flange face; whereas the TTCI-1A wheels show even wear at the wheel flange root. Four of six axles that have the AAR-1B wheel profile showed asymmetric wear while all six axles that have the TTCI-1A wheel profile showed symmetrical wear (Figure 9). Figure 10 separates the average cross sectional area loss on right and left wheels. The total cross sectional area loss of the wheels with the TTCI-1A profile was 35 percent less than the wheels with the AAR-1B profile.

Wheel surface conditions were also examined at 16,000 and 30,000 miles of operation. At 16,000 miles, both profile groups had some wheels with good surface conditions and some wheels with surface defects. At 30,000 miles, both profile groups showed better surface conditions than that at 16,000 miles. There was no strong indication to relate the surface defects to wheel profiles. Wheel slide and the brake wear-in may have contributed to some of the surface defects.

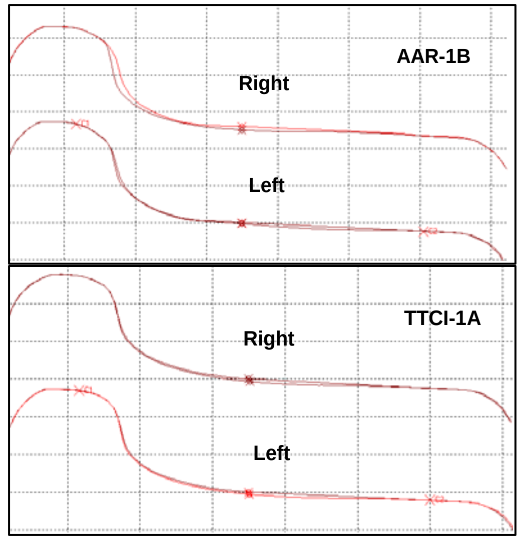

Figure 9. Wheel Profile Wear Patterns (at 30,000 miles)

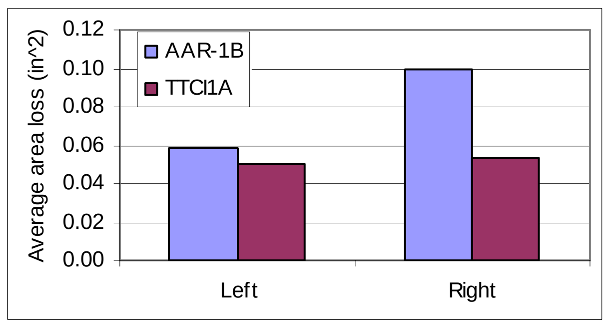

Figure 10. Cross Area Loss on Left and Right Wheels

CONCLUSIONS AND FUTURE WORK

The TTCI-1A wheel profile produced lower lateral force, lower cross sectional area loss, and better wear patterns than the AAR-1B wheel profile due to a relatively conformal contact pattern with the common worn rail profiles from curves.

The five-unit test car will be continually monitored for an additional 20,000 to 30,000 miles of revenue service operation to see if the performance and shape of the two profiles eventually converge.

A larger scale revenue service test is being conducted using 20 coal cars. Each profile group includes 20 axles.

REFERENCE

1. Leary, John F. December 1988. "Final Report on the Development of an Alternative AAR Interchange Wheel Profile," Report No. R-706, AAR, TTCI, Pueblo, CO.