FIELD EVALUATION OF IMPROVED PERFORMANCE
FROG PROFILE DESIGNS FOR HEAVY AXLE LOAD SERVICE

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Abstract

Transportation Technology Center, Inc. (TTCI), under sponsorship of the Association of
American Railroads (AAR), has developed improved-performance turnout frog running surface
profiles. The designs were developed to reduce maintenance required by metal flow and to
reduce impacts from hollow tread profile wheels. Prototypes were evaluated in a proof-of-
concept test at the Federal Railroad Administration’s (FRA) Facility for Accelerated Service
Testing (FAST), Pueblo, Colorado, under 39-kip wheel load traffic. The prototype frogs were
then installed in revenue service locations on two western U.S. heavy haul routes.

The paper will describe the prototype designs and field performance of the four prototype frogs.
The two revenue service frogs had approximately 120 million gross tons (MGT) and 200 MGT,
respectively, as of December 2003.

Results to date include:

• Reduced grinding maintenance by 50 percent compared to conventional designs.
• Reduced running surface height loss compared to conventional designs.
• Improved dynamic performance as measured by vertical dynamic loads.

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INTRODUCTION

Transportation Technology Center, Inc. (TTCI), a subsidiary of the Association of American Railroads (AAR), has developed improved performance running surface designs for Number 20 rail-bound manganese (RBM) frogs. The improved running surfaces are intended to minimize impacts at transition points, minimize contact stresses, and minimize elevation changes for a wheel traversing a frog. TTCI has developed five prototype Number 20 frogs that were tested under heavy axle load (HAL) traffic both in revenue service and at the Federal Railroad Administration (FRA)’s Facility for Accelerated Service Testing (FAST), Pueblo, Colorado.

Review of current Number 20 mainline frog running surface designs in the wing-point transfer area reveals several shortcomings with respect to dynamic performance. The existing designs do not accommodate a smooth transition from frog wing to point for either new or severely hollow worn wheels. The typical 3/16-inch point depression on Number 20 frogs is not sufficient to prevent 1:20 taper wheels from striking the point on facing point moves. The provision to have the point and wing at the same elevation beyond the end of the point slope results in hollow tread wheels striking the wing in trailing point moves. This situation is analogous to a “riserless” switch point where the hollow tread wheel strikes the stock rail on trailing point moves.

The currently used standard frog design, with a depressed point and no wheel risers, allows the wheel to fall into a depressed area at the point. The design conicity of the wheel changes the elevation of the axle as the contact point changes. Thus, as the flangeway becomes wider in the toe of the frog, the wheel elevation decreases.

Contact is not conformal between the wheel and frog. The running surfaces of the frog are not primarily designed to minimize contact stresses — they are designed with ease of manufacture in
mind, with mostly flat surfaces. Different parts of the frog bear different parts of the wheel and can be customized for their duty. For example, each wing of the frog carries traffic on only one track. Toward the heel of the frog, the wing will only see the field side portion of wheels. This portion of the wheel is largely linear with a 1:20 taper.

DEVELOPMENT OF A DESIGN/ANALYSIS MODEL

TTCI developed a frog design wheel/rail contact evaluation model to evaluate frog designs. The frog analysis model allows TTCI to evaluate the effects of various frog design elements and wheel profiles. Among the features that can be varied are:

- Flangeway width
- Point elevation
- Wing elevation
- Point corner radii
- Wing corner radii
- Point side slope
- Wing side slope
- Wing top surface slope

ANALYSIS OF CURRENT DESIGNS

The current designs are derived from studies of cone-shaped wheel profiles and modified by field experience. However, the designs lack optimum clearance for new wheels at the 1/2-inch point of the frog. Wheelsets at the maximum back-to-back spacing will strike the point with an impact. The designs also lack optimum clearance for hollow tread profile wheels at the point-wing transition. The elevation difference between point and wing is not sufficient to raise the false
flange above the wing (as is done on the switch point with a riser). The result is interference between the wheel and wing on trailing point moves. In facing point moves, the wheel contact leaves the wing and goes onto the point as the flangeway widens.

Additionally, the wheel and car lowers in elevation going through the frog. The change in elevation is a function of wheel profile and flangeway width in the toe end of the frog. With a typical flat wing, cone-shaped wheels drop in elevation at the rate of $1: (20 \times \text{frog number})$ from the theoretical frog point until the actual frog point supports the wheel. For a Number 20 frog, this rate is 1:400.

From a track designer’s point of view, all frog running surface problems are attributable to wheel profile problems, or the range of wheel profiles allowed in service. Early designs were developed for the nominal new wheel profile and largely ignored worn wheel shapes. Examples are designs with wing risers and no point depression. Recent designs have made more allowances for worn wheel shapes. Examples include the heavy point designs with no wing risers and 3/16-inch point depression.

**DESIGN CRITERIA**

Design criteria for the prototype frog are based on an AAR-1B wheel and a 1-B wheel that has worn to a 5-mm hollow tread wheel. Based on these design wheels, the following criteria were used to develop the frog running surface design:

- Minimize impacts (i.e., elevation changes) at transition points.
- Minimize the occurrence of high contact stresses due to edge loads and contacts with small radius frog surfaces.
- Minimize elevation changes for wheels traversing the frog.
The design dimensions selected are dependent on the design wheel profile and frog number chosen. For an AAR-1B wheel and a Number 20 frog, the point depression (wing elevation minus point elevation) must be at least 0.29 inch at the frog’s 1/2-inch point. For a 5.5-mm hollow tread wheel and a Number 20 frog, the point riser, or wing depression (point elevation minus wing elevation), must be at least 0.05 inch at a location that is 10-15 inches from the 1/2-inch point.

PROTOTYPE DESIGN

Cross-Section Profiles

Minimizing the occurrence of high contact stresses was achieved by altering the cross section profile of the frog. The “conventional” Frog (Number 1) has a larger gage corner radius and a conventional flat running surface. The larger gage corner radius moves the wheel/rail contact from the gage corner, preventing some of the expected metal flow. Frog Number 2, the “conformal” frog, has the larger gage corner radius as well as a 1:20 tapered wing. As shown in Figure 1, the tapered wing allows for a larger contact area on the running surface cross section.

Longitudinal Profiles

To address the first concern, minimizing impacts at transition points, two design options were developed into prototypes. The first prototype addresses the three design criteria listed earlier. The second follows existing design practice in allowing wheel elevations to lower in the wing-to-point transfer zone. Option 2 is closer to existing designs, and perhaps easier to maintain in the field.
Option 1

Figures 2 and 3 show the first prototype design selected by TTCI. Figure 2 is a profile view of the wing and point elevations. Note the wing riser designed to keep wheel elevations level up to the transition to the point. The point depression is the typical 3/16 inch. The point slope is very steep to incorporate the point riser. This point riser ensures that all wheels will transition to the point before contact leaves the wing. The wing elevation decreases 6 inches past the beginning of the frog point to allow for clearance of hollow tread wheels.

Figure 3 is a cross-section view of the frog at the 1/2-inch point. Features to note include the sloped wing top surface and the wing riser at full height, and the large point depression. The sloped wing top surface is conformal to the outer half of the wheel tread profile. This should spread the contact over a larger area and prevent wing corner breakdown.

A comparison of the wheel elevation for new and worn wheels through the AAR and AREMA Number 20 frog designs is shown in Figures 4 and 5. In the AREMA design, new wheels decrease in elevation as the flangeway widens. Worn wheels do not change elevation since they are already riding on the outer portion of the wheel tread. New wheels strike the point immediately and rise back to nominal elevation with the point slope. Hollow tread wheels contact the point at about 14 inches and rise with the rest of the point slope. The peaks in the curves show where impacts are likely to occur as the wheel makes a sudden jump in elevation. These can be found at the 1/2-inch point for new wheels and at about 14 inches for worn wheels.

With the new design, both wheels remain at near constant elevation through the toe of the frog. At about 4 inches past the 1/2-inch point of the frog, the new wheels make contact with the point. They are elevated with the point slope and rise up to 12 inches beyond the 1/2-inch point.
Beyond 12 inches, they are lowered with the point riser. Hollow tread wheels remain on the wing until about 10 inches from the 1/2-inch point. They begin to lose elevation after the wing riser peaks at 6 inches. They encounter the point riser at about 12 inches, near its peak. They continue to lose elevation with the downward slope of the point riser. The hollow tread wheels then gain elevation as the frog heel widens enough to bear the false flange again.

Option 2

A second design has been developed for higher speed applications. This design has features similar to the existing frog with minor modifications to account for a wider range of wheel profiles. Impacts from new wheels in facing point moves are avoided with a larger point depression (5/16 inch). The elevation difference needed for wing-to-point transfer is provided by lowering the wing from the 1/2-inch point toward the heel end of the frog. This will accomplish the same objective as the point riser in the previous design, assuring that the wheel is bearing on the point and raising hollow tread wheels above the wing in the transfer area.

Figure 6 is a profile view of this design. The wing slopes downward from the 1/2-inch point for 12 1/2 inches from an elevation of 1 7/8 inches to an elevation of 1 3/4 inches on a slope of 1:100. A further refinement of this design is to make the 15-inch point slope into two slopes. The first is steeper at 1:32 for 6 inches followed by a 1:72 slope for 9 inches. This will make a smoother transition for moderately worn wheels.
FIELD TEST RESULTS

Cross Section Profile Frogs

Five prototype frogs were built for testing under heavy axle load (HAL) traffic in the High Tonnage Loop at the Federal Railroad Administration’s (FRA) Facility for Accelerated Service Testing (FAST). The first two prototypes have changes to their cross-sectional profile only. They were built to evaluate the effects of changes to contact conditions without the compounding effects of longitudinal profile changes. Frog Number 1 (conventional) has a larger gage corner radius and a conventional flat running surface. The larger gage corner radius moves the wheel/rail contact from the gage corner, preventing some of the expected metal flow. Frog Number 2 (conformal) has the larger gage corner radius as well as a 1:20 tapered wing. As shown in Figure 7, the tapered wing allowed for a larger contact area on the running surface cross section. The conformal frog has a wide wear band across the entire wing; whereas, the conventional frog has contact in a narrow band near the gage corner.

The conventional frog and the conformal frog have accumulated over 230 MGT. The frogs were installed in turnouts at FAST for the first 130 MGT and have been installed in conventional track for the remainder of the test.

The conformal frog not only had larger gage corner radii but a 1:20 taper on the wings. The tapered wings are effective at spreading wheel contact over a wide running band. This wider running surface area should result in a longer service life and longer period between weld repairs.

Both prototypes have been successful in reducing metal flow and the need for maintenance grinding. Typical Number 20 fixed point frogs in FAST require significant maintenance in the
first 20 MGT. Grinding at 1, 5, and 20 MGT is usually required in this 39-kip wheel load service. Remarkably, these two frogs did not require any grinding for 65 MGT.

Also, the larger gage corner radii on the conventional frog successfully moved the wheel contact away from the gage corner. This alone reduced maintenance grinding on the frog by approximately 50 percent in the first 100 MGT compared with a typical RBM frog at FAST.

**Longitudinal Profile Frogs**

Frog Number 3 (LP1) and Frog Number 4 (LP2) have changes to their longitudinal profiles (Figure 2). These changes helped to reduce the impacts due to running surface discontinuities. These features include:

- Sufficient point clearance to accommodate cone shaped wheels.
- Sufficient wing clearance to accommodate hollow worn wheels. At the typical point-to-wing transfer area, the elevation of the point is above the wings to avoid impacts and assure that all wheels are running on the point in facing point moves.

Figure 8 shows how these design changes shortened the wheel transfer zone to about 18 inches from the typical 30-36 inches.

Frog Number 3 (LP1) and Frog Number 4 (LP2) were tested at FAST in conventional track for the first 80 MGT. They were removed and installed in revenue service turnouts. Frog LP1 was installed at Laramie, Wyoming on the Union Pacific (UP) railroad in October 2002. This line accumulates approximately 140 MGT annually, with tonnage split evenly between mainline and diverging routes. The traffic consists mainly of mixed freight.
Frog LP2 was installed at Bragdon, Colorado, on the Burlington Northern Santa Fe (BNSF) railroad in August 2002. This line accumulates approximately 60 MGT per year, with coal trains making up roughly two-thirds of the traffic. The loads are facing point mainline moves.

Figure 9 shows the cumulative running surface height loss for the longitudinal profile frogs. Both frogs had similar wear rates at FAST. After installation in revenue service, the wear rates increased despite static wheel loads that were lower than those found at FAST (33,000 and 36,000 pounds versus 39,000 pounds). This increase in wear and deformation may be due the variety of wheel profiles in revenue service.

The changes to the longitudinal profile are intended to minimize impacts at transition zones by controlling the wheel path in these areas. Instrumented wheelset (IWS) runs performed at FAST indicated that Frog LP2 has shown the most improvement in dynamic performance (maximum vertical load of 52,000 pounds versus 62,000 pounds for Frog LP1). Figure 10 shows IWS data from measurements taken when the four prototype frogs had approximately 45 MGT of FAST traffic. The load measuring wheelsets have a FAST worn profile with little wheel tread hollowing. For largely cone-shaped wheel profiles like these, Frog LP2 is expected to provide a smoother ride than Frog LP1 as it applies less change to the elevation of cone-shaped wheels. For comparison purposes, conventional Number 20 frogs at FAST see maximum dynamic vertical loads of 60,000-80,000 kips (1.5-2.0 times static load).

Of course, a more severely hollow tread profile wheelset is needed to measure the full performance benefits of the prototype designs.

In the revenue service trials, the local track supervisors noted that the frog points have had less deformation and have required less maintenance grinding than conventional design frogs.
installed at those locations. Frog LP2 developed a crack in the point requiring weld repair at 127 MGT. Similar to the crack on the conformal frog, the crack occurred approximately 2 feet back from the 5/8 inch point of the frog. This area is beyond the wheel transfer zone, indicating the failure was not related to the impacts from the wheel transferring from the wing to point.

Frog Number 5 (Gen II) was designed from a combination of the best “new” features from the first four prototype frogs. It was installed in a turnout at FAST in March 2003. To date, it has accumulated approximately 77 MGT and is still in service.

**ASSESSMENT OF DESIGN**

The current flat running surface profile and shallow point depression frog design is used because it is easy to manufacture and it minimizes dynamic loads for typical worn wheels. It is practical, with advances in manufacturing, to design new running surface profiles to accommodate a wider range of wheel profiles while reducing impacts and improving dynamic performance. The profile changes in the five prototype frogs are relatively easy and inexpensive to make. These changes have reduced maintenance requirements and have improved dynamic performance.

Maintenance requirements have been greatly reduced by the new profile designs. The larger gage corner radius alone has reduced required grinding maintenance. In revenue service trials, local track maintenance supervisors noted that the frog points have had less deformation than conventional design frogs in these locations. Two frogs required weld repairs due to small casting defects. The cracks occurred 2 feet back from the 5/8 inch point, beyond the wheel transfer zone. This indicates the designs are working as intended; and that the failures were not due to running surface profile related impacts.
The service life of a frog is dictated by its ability to withstand impacts at its transition zones. Average running surface height loss is a secondary issue. The changes in the longitudinal frog profiles have focused on improving dynamic performance by minimizing impacts at the transition zones. The changes to LP1 and LP2 have been successful in reducing these impacts and impacts from hollow tread profile wheels. The IWS runs performed at FAST indicate that Frog LP2 had the best dynamic performance overall.

**SUMMARY**

TTCI has developed improved performance running surface designs for Number 20 RBM frogs. The improved running surfaces are intended to minimize impacts at transition points, minimize contact stresses, and minimize elevation changes for a wheel traversing a frog. TTCI has developed five prototype Number 20 frogs that were tested under HAL traffic both in revenue service and at FAST.

The running surface of each prototype was modified and monitored to determine which “new” features contributed to improving the dynamic performance of the frog. Profile frogs Number 1 (conventional) and Number 2 (conformal) had modifications to their cross-sectional profiles. These changes are intended to minimize contact stresses and minimize grinding maintenance. Profile frogs Number 3 (Longitudinal Profile-1 or LP1) and Number 4 (Longitudinal Profile-2 or LP2) had changes to their longitudinal profiles. These changes are intended to minimize impacts at transition points. Frog Number 5 (Generation II or Gen II) is a combination of the best features.

Findings include:

- The cross-section profiles were effective at moving wheel contact off the gage corners.
− The larger (9/16 inch) radius corner alone was effective at reducing required grinding maintenance.

− The 1:20 sloped wing was also effective at spreading wheel contact over a wide running band.

− During 230 MGT of 39-ton axle load traffic at FAST, grinding maintenance was reduced by about 50 percent on the two frogs.

• The cross-section and longitudinal profile frogs (LP1 and LP2) have been tested at FAST and in revenue service.

− LP1 and LP2 have been effective at controlling the wheel path in the wing-to-point transfer area. This should reduce impacts from hollow tread profile wheels. In revenue service trials, the local track maintenance supervisors noted that the frog points have had less deformation than typical.

− Two frogs have required weld repairs due to fatigue cracks in the points. Both resulted from relatively small casting defects. Both occurred back about 2 feet from the frog’s 5/8-inch point, beyond the wheel transfer area. This indicated that the designs were working as intended. The failures were not related to running surface profile related impacts.

− On the same frogs, height loss rates (wear and deformation) were higher in revenue service than at FAST. This is despite the higher static wheel loads at FAST (39,000 pounds versus mostly 33,000 and 36,000 pounds in revenue service). Operational factors such as higher train speeds, a wider range of wheel conditions, and more
frequent train route changes produce a more severe dynamic load environment for frogs.

- The profile changes in these designs were relatively easy and inexpensive to accomplish. They should not significantly add to the price of a frog.

The cross section profile frogs have been tested at FAST since April 2001. They have accumulated over 230 MGT. The longitudinal profile frogs were tested at FAST from September 2001 to May 2002. They accumulated 80 MGT at FAST and then were installed in revenue service on the UP and BNSF railroads. Frog LP1 has accumulated 200 MGT and Frog LP2 has accumulated 150 MGT.

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Figure 1. Wheel Contact on Frog Wing
Figure 2. Profile View of AAR Design 1 Frog Wing and Point
Figure 3. Cross Section View of AAR Frog at 1/2-Inch Point
Figure 4. AREMA Frog Profile Design
Figure 5. AAR Frog Design Profile
Figure 6. Profile View of AAR Design 2 Frog Wing and Point
Figure 7. Wear Pattern on Frog 1 and Frog 2.
Figure 8. Wear Pattern on Frog 3 (LP1) and Frog 4 (LP2)
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Figure 10. IWS runs vertical loads at FAST
Figure 11. Transition Zone of Gen II Frog