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Revenue Service Evaluation of Steels for Flange Bearing Frog Crossing Diamonds

David D. Davis, Rafael Jimenez and Jim Beyerl (CSX)

Summary

This *Technology Digest* reviews the performance of steels used in revenue service flange bearing frog (FBF) applications as well as the candidate materials evaluated in simulated frogs. Flange bearing places significant demands on the steel used in frogs. The material must be wear resistant, plastic flow resistant and tough enough to handle dynamic loads from typical freight car wheels and bearings.

To date, the running surface vertical height loss rates of FBFs in revenue service are too high for railways to derive most of the potential economic benefits that flange bearing may provide. Austenitic manganese steel and a higher initial hardness die steel have had height loss rates of 0.3 inch per 100 MGT or higher. However, one of the tool steels tested in revenue service by Transportation Technology Center, Inc. and CSX Transportation has proven to be the likely candidate for the next generation of flange bearing frog crossing diamonds.

The goal of the next iteration is to extend the running surface service life by an order of magnitude. This will be accomplished by using the more durable tool steel, which has shown 15 to 20 percent lower height loss rates, and by making some frog design changes. The design changes include:

- A larger wear allowance before the frogs revert to tread bearing. The first frogs had 0.25-inch clearance for new wheels above the tread rail. The next iteration of frogs will have 1.0-inch clearance
- A more conformal running surface. An initial concave running surface will lower contact stresses and initial deformation as compared to the flat surfaces used on the first frogs.

As FBF technology is implemented, more wheel flanges will become conformal to FBF running surfaces. Ultimately, this will lower wear rates on both frogs and wheels, with the limiting case being the fully conformal conditions tested in the closed loop operation at the Facility for Accelerated Service Testing.

Flange bearing has been proven technically feasible for heavy haul freight operations.[1] The benefits of flange bearing include lower dynamic forces on vehicles and track, fewer condition related speed restrictions on crossing diamonds, and less track surface maintenance at crossing diamond. Flange bearing may also allow higher operating speeds at crossing diamonds.

INTRODUCTION

FBFs offer the potential to reduce railway operating costs and improve safety for heavy haul applications. The FBF concept has been proven technically feasible for North American mainline crossing diamond applications.[1] However, a more durable flange bearing material would allow the FBF frogs to provide a significant economic payback to railway operations.

This *Technology Digest* describes the performance of frog steels evaluated in flange bearing heavy haul revenue service tests on CSX and BNSF Railway.

Candidate Materials

Previous analysis suggested that a stronger material than currently used frog materials was required.[2] This analysis suggested a material with a tensile ultimate strength of 200 ksi or higher was needed to provide an economic service life for frogs with a 0.25-inch wear limit.

Subsequent testing of candidate materials in controlled conditions at the Transportation Technology Center showed that currently used materials, such as austenitic manganese steel (AMS) with much lower strengths, were performing adequately in the heavy axle load tests at the Facility for Accelerated Service Testing (FAST).[2] Table 1 lists the materials evaluated.

Based on the results at FAST, the first revenue service diamond was built using AMS castings. Flange bearing running surface wear lives of 1,000 MGT (0.25-inch height loss) were expected.

Table 1. Candidate FB Frog Steels and Lab Performance[3]

Steel Name	Steel Type	Initial Hardness (BHN)	Relative Performance versus AMS
AMS (hardened)	Austenitic Manganese Steel	380	100
AMS (unhardened)	AMS	250	27
J7 Rail	Bainitic	430	161
J9 Frog	Bainitic	410	52
NS-450	Martensitic	450	27
4340	Martensitic	500	79
12-S	Martensitic	450	37
Aeromet 100	Ni - Maraging	500	47

Revenue Service Experience on CSX

The first full FBF crossing diamond installed in track with operating speeds above 10 mph was installed by CSX at Shelby, Ohio, in July 2006. Figure 1 shows the diamond. The performance of the diamond was very good in terms of operations, dynamic loading, and required maintenance. The diamond was operated at 40 mph on the CSX mainline side for about 4 years without any speed restrictions. No operating issues were noted by either CSX or the Ashland Railroad, which operated across the other track of the diamond at 10 to 20 mph. Routine maintenance, such as track surfacing, was significantly reduced on the FBF diamond, as compared to maintenance required on the previous conventional tread bearing diamonds. The flange bearing design did reduce dynamic loading on the frogs as evidenced by the reduction in track settlement and reductions in noise when trains are on the diamond. The use of a hydraulic wrench to keep all bolts in the diamond properly tight also contributed to the good performance seen.

Figure 1. CSX FBF Diamond, Shelby, OH

The flange bearing running surfaces made of Hadfield's steel or AMS (typically 1.2% carbon, 14% manganese) did not perform as well as expected, based on laboratory tests and tests at FAST. The running surface height loss (i.e., deformation) rates in the earlier tests decreased rapidly after the first few passes. In revenue service, however, the deformation rates remained nearly constant. Figure 2 shows running surface height loss versus tonnage for AMS frogs in test at FAST and in revenue service. AMS flange bearing surfaces on the CSX diamond had a wear life of about 80 MGT (0.25-inch height loss) before reverting to tread bearing. The actual diamond was in service for over 200 MGT. During some of that time, the tread running surfaces carried a significant portion of the wheels. Also the tread running surfaces were ground to provide more clearance for flange bearing after about 105 MGT of traffic.

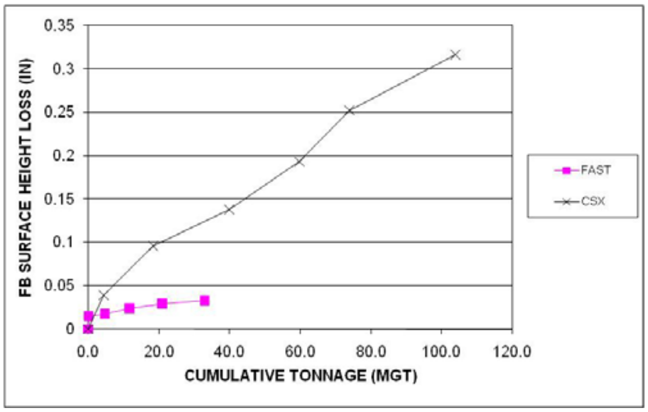

Figure 2. Flange Bearing Surface Height Loss versus Tonnage

In looking at the surface hardness data from the two tests (see Figure 3), the frog materials showed the same work hardening rates. The primary variable that changed between the two tests was the wheels. At FAST, the same train accumulated all of the tonnage over the diamond. In revenue service, the CSX diamond saw a much larger population of wheels. In the tests at FAST, the wheel flanges and frog running surfaces quickly became conformal to each other. This lowered the contact stresses and the deformation rate over time. In revenue service, the frogs had nonconformal wheels running across them throughout the test.

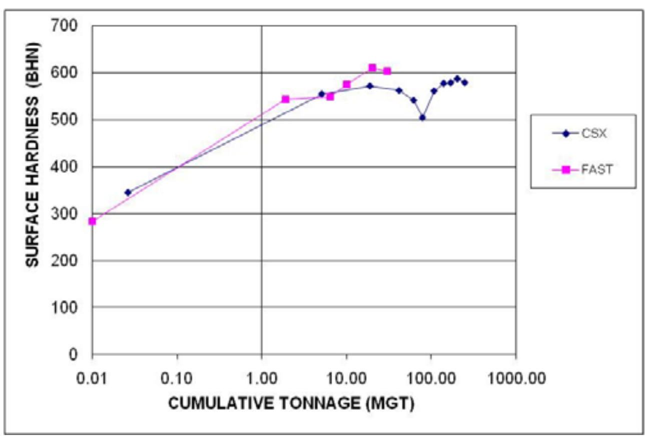

Figure 3. Flange Bearing Surface Hardness versus Tonnage

Revenue Service Experience on BNSF

Based on the deformation results and the desire to simplify construction by avoiding customized casting patterns, the next revenue service diamonds were built with die steel flange bearing running surfaces. The frogs were built from rail and rectangular bar sections. The die steel has a higher initial hardness, but lacks the work hardening capability of AMS. It was selected to reduce the initial deformation seen in the AMS castings.

The die steel material diamonds were installed in BNSF track at Moorhead Junction, Minnesota, in September 2008. Figure 4 shows the two diamonds in track.

Figure 4. BNSF FBF Diamonds at Moorhead Junction, MN

The performance of the diamonds was very good in terms of operations, dynamic loading, and required maintenance. The diamonds were operated at 35 mph on the double track mainline and at 25 mph on the single track crossing line. Speed restrictions are in place because of adjacent curves and bridges on the two routes. No crossing diamond condition related speed restrictions have been issued in the nearly three years of operation. No operating issues were noted by BNSF on either of their two routes that cross at the diamonds. Routine maintenance, such as track surfacing, was significantly reduced on the FBF diamonds, as compared to maintenance required on the previous conventional tread bearing diamonds. The flange bearing design did reduce dynamic loading on the frogs as evidenced by the reduction in track settlement and reductions in noise when trains are on the diamonds.

The performance of the die steel was also disappointing. The initial height loss rates were higher than those seen on the AMS frogs. Figure 5 shows the height loss versus tonnage relationship for the die steel diamonds. The rates quickly dropped after sufficient height loss caused many wheels to revert to tread bearing across the diamond. Ultimately, the vertical height loss rate of the rail controlled the wear rates of the flange bearing surfaces. With this dual sharing of load, the reductions seen in dynamic loading and noise were largely eliminated. The diamonds began to look and sound more like tread bearing diamonds. The usual impact sounds and frog flangeway corner fatigue are now evident. The AMS frogs underwent rapid work hardening, as compared to the die steel, as Figure 6 shows.

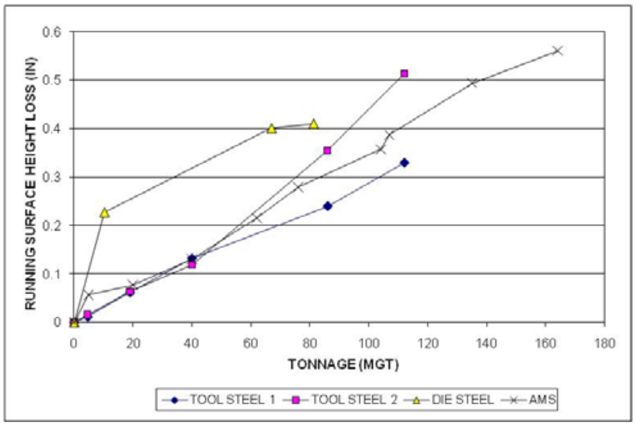

Figure 5. Candidate FBF Materials Height Loss versus Tonnage at Moorhead Junction, MN

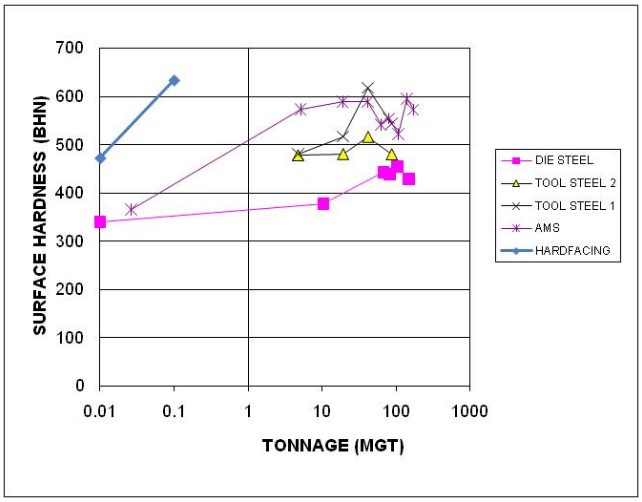

Figure 6. Candidate FBF Materials Surface Hardness versus Tonnage at Moorhead Junction, MN

A flange bearing test panel was built and installed near the Moorhead Junction diamonds to provide a lower cost proof test of additional candidate materials. The test panel was built to the same flange bearing ramp design as the diamonds. The frogs are replaced in the test panel with a flat section approximately 12 feet long. This allows a flange bearing length of more than one complete wheel revolution for all wheel sizes. Two candidate flange bearing materials were evaluated in the panel. Figure 7 shows the test panel in June 2009, shortly after installation. The candidate materials in the test panel were Tool Steel 2 and Tool Steel 1. Both are high strength tool steels, with surface hardness values of 450 and 500 BHN. Figure 5 also shows their performance in comparison to the other flange bearing materials tested in revenue service. Tool Steel 1 has a projected wear rate that is 15-20 percent lower than AMS. As Figure 6 shows, Tool Steel 1 also has relatively good ability to work harden with deformation. From this test, it appears that Tool Steel 1 is the likely candidate for the next FBF diamonds. The material performed better than AMS in a test panel that better simulated revenue service conditions.

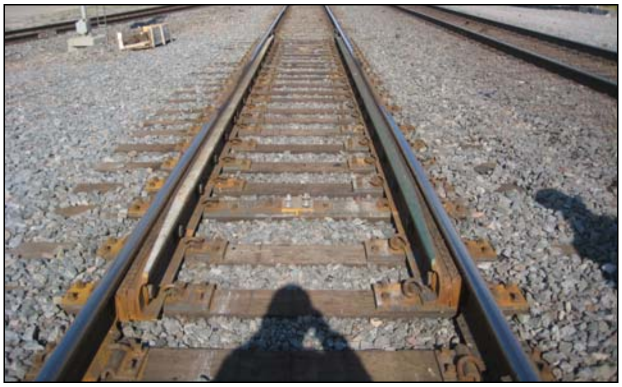

Figure 7. BNSF Flange Bearing Test Panel at Moorhead Junction, MN

The material labeled as "HARDFACING" in Figure 6 was a second iteration test panel material: Tool Steel 2 with a weld deposited surface layer of high strength steel. The running surface rapidly deteriorated as the weld deposits cracked and broke away from the Tool Steel 2 substrate within 1 MGT of service. This material was too brittle and/or incompatible with the substrate.

FUTURE WORK

Some frog design changes and, eventually, wheel flange conditioning will improve the economic performance of FBF crossing diamonds. The design changes include:

- A larger wear allowance before the frogs revert to tread bearing. The first frogs had 0.25-inch clearance for new wheels above the tread rail. The next iteration of frogs will have 1.0-inch clearance
- A more conformal running surface. An initial concave running surface will lower contact stresses and initial deformation as compared to the flat surfaces used on the first frogs.

As FBF technology is implemented, more wheel flanges will become conformal to FBF running surfaces. Ultimately, this will lower wear rates on both frogs and wheels, with the limiting case being the closed loop operation at FAST.

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