TECHOLOGY DIGEST

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Frog Design Review and Failure Analysis

by David D. Davis, *Yi-Ren Chen,
*Frederick V. Lawrence, and **Christopher P.L. Barkan

Summary

A study sponsored by Transportation Technology Center, Inc. has identified impacts and the resulting running surface deformation, as well as metal flow, as the most significant problems with most frog designs. Findings also indicated that performance of the frog material, both austenitic manganese steel (AMS) and conventional rail steel, was also a significant cause of failure.

The study used a variety of sources to determine the performance, likely failure modes, and technical issues with mainline frogs. A literature review conducted by the University of Illinois identified more than 100 technical papers relating to service problems of frogs. Working with TTCI, an Illinois team of welding, metallurgy, and railroad engineering experts developed a Failure Modes Effects and Criticalities Analysis (FMECA) analysis of mainline frogs. The literature review was used to determine the common failure patterns of rail-bound manganese (RBM), spring, AMS insert, and all-rail frogs in mainline service. These were reviewed to determine the common failure modes and their effects. The most commonly cited frog design and maintenance problems were categorized into major problem groups

Once the common failure modes were established, a survey was developed using FMECA techniques. Separate sections of the survey covered RBM frogs, spring frogs, AMS insert crossing diamonds, and all rail crossing diamonds. The survey was sent to noted special track work experts from AAR member railroads and the supply industry. The following conclusions were developed from the survey results:

- RBM frogs exhibit a large number of low to moderate severity service problems.
- Spring frogs are not as widely used. They have fewer, but more severe, problems. These are related to moving parts failures.
- AMS insert crossing frogs, like RBM frogs, have few high severity problems. Casting cracking is the most prominent problem.
- High-angle (i.e., crossing diamond) frogs have a larger number of high severity problems. Three-rail-crossing frogs appear to have the most problems, which relate to crossing fit, alignment, and material toughness.

* University of Illinois at Urbana-Champaign
**AAR Affiliated Laboratory
University of Illinois at Urbana-Champaign

Suggested Distribution:
- ❑ Maintenance of Way
- ❑ Planning & Analysis
- ❑ Track Maintenance
- ❑ Safety

Note: In this document, "failure" means the point at which the component is no longer economically feasible to repair or maintain, and is not used to imply unsafe condtions. The terms "risk" and "high severity" are used under the same conditions.

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INTRODUCTION

While frogs are costly to operate and maintain, they are relatively safe. Analysis of data from the Federal Railroad Administration track safety data base suggests that frogs are relatively low on the list of causes for track-related accidents. Frog-related property damage losses were about $2 million of the approximately $11 million incurred for category T3 (Frogs, Switches and Track Appliances) in 1999, with no fatalities.

A study of frog performance and failure modes was conducted to help determine the areas in which research and development are most needed. The AAR special track work research program is intended to improve the performance of turnouts and crossing diamonds in mainline service. Frog performance has improved dramatically over the past 20 years as better designs and more premium materials have been used. However, frogs are still major consumers of maintenance resources and available track time. Railroads spend an estimated $300 million annually on special track work. Frogs are the highest cost components of turnouts and crossing diamonds. Approximately 7,000 frogs are replaced annually in the North American freight system at a cost of $120 million. Special track work is also a major source of over-the-road train delay, especially for frogs that have been slow ordered.

METHODOLOGY

Materials experts on the Civil Engineering staff of the University of Illinois conducted a literature review and failure modes analysis for TTCI.[1] The literature review was used to determine the common failure patterns of RBM, spring, AMS insert, and all-rail frogs in mainline service. Working with TTCI, the team of welding, metallurgy, and railroad engineering experts from Illinois developed an FMECA analysis of mainline frogs. The functions, failure modes and effects were developed from the literature review and discussions with TTCI staff.

The most commonly cited frog design and maintenance problems were categorized into the major problem groups listed below:

- Running surface and flangeway issues
- Materials issues
- Foundation issues
- Maintenance issues
- Standardization issues
- Fastener issues

A table listing the failure mode and effects for each frog type studied was prepared. Each table had blanks for the experts to rate the severity, occurrence and detection of each failure mode. These are each rated on a scale of 1 to 10, with 10 being the most serious. Additionally, there were blanks provided for the experts to add failure modes not included in the survey.

The severity, occurrence and detectability values are multiplied together to create a Risk Priority Number (RPN). This value can range from 1 to 1,000. The RPN value has greater sensitivity to the severe problems since a middle range score in each category will produce an RPN of 125 (5x5x5).

A panel of special track work experts was assembled from the AAR Engineering Research Committee's Technical Advisory Group for Special Track Work research and select members of the special track work supply industry. BNSF, CN-IC, CP, CSX, NS, and UP were member railroads represented. Supplier representatives included ABC-NACO, Cleveland Track Material, VAE-Nortrak, and Progress Rail Services.

RESULTS

The literature review identified six key areas that received most of the written attention of frog experts. While these may not be the only issues of concern, they do provide a good initial view of the problems that the railroad industry has addressed. Exhibit 1 shows the frequency with which these topics are addressed in the literature.

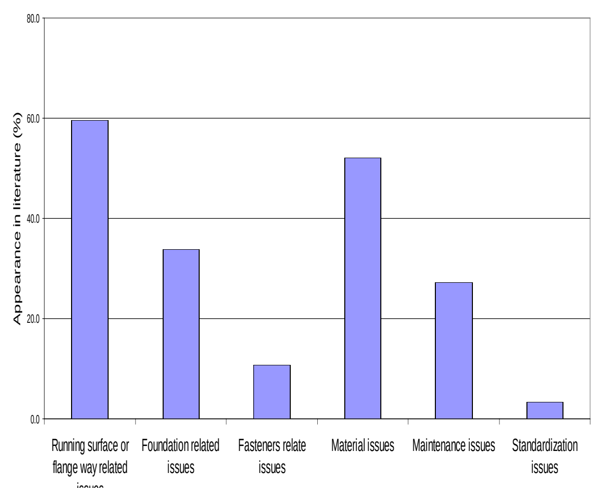

Exhibit 1. Frog Technical Issues in the Literature

FAILURE MODES, EFFECTS, AND CRITICALITIES ANALYSIS

For the RBM, spring, AMS insert, and all-rail frog surveys, a total of 11, 7, 11, and 7 responses were received, respectively.

The basic result of the FMECA can be seen in Exhibits 2 through 5 in which the RPN of all known problems associated with a certain type of frog are plotted in order of increasing risk.

RAIL-BOUND MANGANESE-STEEL FROGS

For the rail-bound manganese-steel frogs (Exhibit 2), eight problems have an RPN exceeding 125. Five of the eight problems with greater than average risk involve problems with the manganese-steel wing. Pumping, heel joint movement and frog point wear are also considered to be high-risk problems.

SPRING FROGS

For the spring frogs (Exhibit 3), only three problems have an RPN exceeding 125; but one of these three has by far the highest RPN value in the survey.

The most serious problem by far is retarder failure. Spring frog opening too wide is the second most serious risk. This failure mode can cause the wheel to drop between the wing hinge point and frog point. It can result in derailment. The contributing factors of this failure mode are (1) the hinge point being located farther from the frog point for larger frogs, (2) guard rails too short which begin opposite the frog hinge point, and (3) hollow tread wheel profile. Both the retarder failure and spring wing opening too far are the result of mechanical malfunctioning or failure maladjustment. The third above-average service problem involves the effects of dynamic loads and resultant plastic deformation and wear of the manganese-steel casting.

Location and Origin of Problem	RPN
Manganese wing cracking Failure of casting insert due to a casting defect	173
Pumping Increased dynamic loading on all frog components	156
Manganese wing chipping Acceleration of wear.	141
Manganese wing chipping Increased dynamic loads	139
Heel joint movement Increased dynamic loads	127
Manganese wing wear and plastic flow Loss of designed track profile; track maintenance required	127
Manganese wing wear and plastic flow Increased dynamic loading on the frog	127
Frog point wear and plastic flow Increased dynamic loads.	126

Exhibit 2. Railbound Manganese Frog Failure Modes and RPNs

MANGANESE-STEEL INSERT CROSSING DIAMONDS

For the cast manganese-steel insert crossing diamonds (Exhibit 4), only one problem has an RPN above 125.

There appear to be very few high-risk problems associated with the cast manganese-steel insert crossing diamonds.

ALL-RAIL CROSSING DIAMONDS

For bolted-rail crossing diamonds (Exhibit 5), eight problems have an RPN over 125 and five of these are quite high values.

CONCLUSIONS BASED ON RPN

- There is considerable variation in survey responses from the 11 experts. This indicates large differences of opinion about service problems. Variation was highest in the spring frog survey. There was also

Location and Origin of Problem	RPN
Retarder failure Significant increase in wing-rail return load cycles	291
Spring-wing opens too far Dropped wheel derailment.	188
Plastic flow and wear of manganese casting Increased dynamic loads	175

Exhibit 3. Manganese Spring Frog Failure Modes and RPNs

Location and Origin of Problem	RPN
Bolt hole cracking Loss of integrity of the crossing diamond	138

Exhibit 4. AMS Insert Crossing Frog Failure Modes and RPNs

Location and Origin of Problem	RPN
Improper alignment at installation Increased lateral loads and gage surface wear	**206**
Rail defects Fatigue crack growth.	**204**
Failure of stop welds Loose frog and rail alignment and gage	**199**
Improper design for service conditions Accelerated wear and component failure	**190**
Broken joint bars (internal and external) Loss of integrity, loosening of assembly	**178**
Vertical alignment problems Increased dynamic loads	**150**
Plate breakage Loss of integrity, loosening of assembly	**130**
Cracked or broken corner straps Loss of integrity, loosening of assembly	**127**

Exhibit 5. All-rail Crossing Frog Failure Modes and RPNs

more variation in rating detectability in all surveys.

- The rail-bound manganese-steel frogs are widely used and exhibit a large number of low to moderate severity service problems. Chief among the most severe problems are difficulties with the manganese-steel wing rail, all of which would seem to be aggravated by the apparently increasing incidence of hollow wheel treads. Foundation failure due to pumping and frog point wear are also important issues.
- In additional to the common service failure modes of rigid frogs, spring frogs seem to have a few more service problems related to the movable design of the spring wing. Two of these problems – retarder failure and opening too far, both mechanical problems – are quite severe.
- The manganese-steel insert crossing diamond apparently has few serious service problems. Bolthole cracking was the only really noteworthy problem according to the RPN. However, it should be noted that some of the other service problems, such as alignment failure and weld stopper failure, do exist in this type of crossing.
- All-rail crossing diamonds have more serious problems than the manganese steel diamonds, chief among which are improper alignment and fatigue-related problems.

FUTURE WORK

The intent of the AAR research program is to follow this survey with investigation of the highlighted research needs and appropriate research and development efforts needed to improve frog performance. Exhibit 6 lists the industry needs and the AAR research projects to address them.

Research Need	AAR Program
Reduced running surface damage	Wheel profile limits; Frog running surface profiles; frog steels
Reduce impacts at flangeways	Flange bearing frogs; Ramped frogs
Reduce impacts at structure changes	Foundations for Special Track Work
Improved performance joints & fasteners	FAST: Advanced Crossing Diamonds
Better maintenance of alignment	FAST: Advanced Crossing Diamonds

Exhibit 6. Industry Frog Design Research Needs

REFERENCES

1. Chen, Yi-Ren; F.V. Lawrence and C.P.L. Barkan; Frog Design Review and Failure Analysis; TTCI, February 2001.

Note: Please contact Dave Davis at (719) 584-0754 with questions or comments about this document.

E-mail: david_davis@ttci.aar.com

Web site: www.ttci.aar.comResearch Need

A MORE DETAILED REPORT, WHICH MAY CONTAIN REVISED INFORMATION, MAY BE AVAILABLE AT A LATER DATE THROUGH AAR/TTCI, PUBLICATIONS, P.O. Box 79780, BALTIMORE, MD, 21279-0780 <www.aar.org/pubs&serv.nsf>