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Improved Signal Reliability: Rail-To-Wire Bonding

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Summary

In an effort to minimize future train delays by reducing the frequency of failures related to rail/wire interfaces, the Association of American Railroads has sponsored research by the Transportation Technology Center, Inc. to learn more about the factors contributing to these failures, and to propose follow-on research that could ultimately lead to solutions to this problem. Five areas of independent investigation comprise this report. This research is intended to provide foundation material for further research into improved rail/wire interfaces and improvements in rail/wire interface reliability.

This digest relates information gathered from an investigation into the problem of track signal wire failures, and their potential significance in contributing to train service disruption. A number of track signal wire issues have been identified as a result of this investigation:

- Rail/wire interface failure is a significant source of service disruption today. When a rail/wire interface (i.e., bond) fails, train delays usually occur, which can be costly. On a busy railroad line, a single 1-hour train delay may create a series of train delays across several states.
- From data provided by two railroads participating in this investigation, 10,000 track wire and 12,500 bond wire connection issues over a 1-year period can be postulated. This implies a significant opportunity to reduce service disruptions if a reduction in rail/wire interface failures can be successfully achieved.
- Development of a standard set of trouble desk defect codes across North American railroads, which is not the case today, would permit easier pooling of data across the industry, and allow a more accurate picture of rail/wire bonding failure events.
  - Of the few track wire failure modes identified, track personnel work procedures and vandalism were the most common.
- Several alternative rail/wire bonding methods are being investigated, such as wedgepins with removable wire, welding, brazing or epoxy-type bonding. They all offer potential advantages over currently used methods.

Modern railroads utilize various types of electrical and electronic signaling equipment to operate trains efficiently and competitively. Railroad signaling systems are a vital part of the national railroad system, supporting industry productivity and profitability.

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INTRODUCTION

Under the Association of American Railroads' Strategic Research Initiatives Program, Transportation Technology Center, Inc. investigated the problem of track signal wire failures and their potential significance in contributing to train service disruption.

Methodology and Analysis

The following independent investigations were conducted:

- A historical investigation was completed.
- Interviews with track and signal personnel from four major North American Railroads were conducted.
- "Trouble desk" data was obtained from two of the participating railroads, to develop statistical characteristics of rail/wire interface failures.
- Analysis of current and past wire/rail interface methods and the identification of promising new technologies in use or under evaluation by North American railroads were performed. A clearer understanding of these methods and the difficulties with each approach was desired.
- The plug bonding methodology was evaluated in order to appraise the need for development of a Finite Element Analysis model of the rail stresses surrounding plug bonds.

Historical Review

Based on the closed circuit principle and fail-safe characteristics, signaling systems have expanded the founding principles incorporated in William Robinson's original 1872 patent for "Improvements in Electric Signaling Apparatus for Railroads" (U.S. Pat #130,661) into a wide variety of systems. By incorporating the track itself into the circuits used to detect the presence of trains, wayside signaling and grade crossing warning systems have effectively overcome one of the major drawbacks of many signaling systems proposed earlier; i.e. it is possible to detect failures in almost any single vital component of the system. But this came at a price. In order for the signal equipment to function reliably, each individual component now had to be extremely reliable. The reliability of the system as a whole was no better than the individual reliability of each component.[1, 2]

Interviews: Track and Signal personnel

Interviews began with a series of eight questions and several follow-up questions. The conclusions that can be drawn from the interviews conducted by TTCI with railroad signal and track personnel are as follows:

- The present methods of rail/wire attachment all have shortcomings that are creating signal and rail reliability problems for railroads. This translates rather directly into train delays, downtime, lost productivity, and lost profitability for the railroads.
- The newer methods have not provided ideal solutions.
- The problem of train delays resulting from rail/wire interfaces may not be immediate, but is a sufficiently significant problem to warrant further investigation and the development of better attachment methods and materials.

Trouble Desk Statistical Data

Of the railroads contacted, two major North American railroads were able to provide downloads from their trouble desk database dataset. The details recorded in each dataset were unique; therefore, datasets could not be merged. Analysis of their respective data, however, yielded two Pareto Charts, as Figures 1 and 2 show.

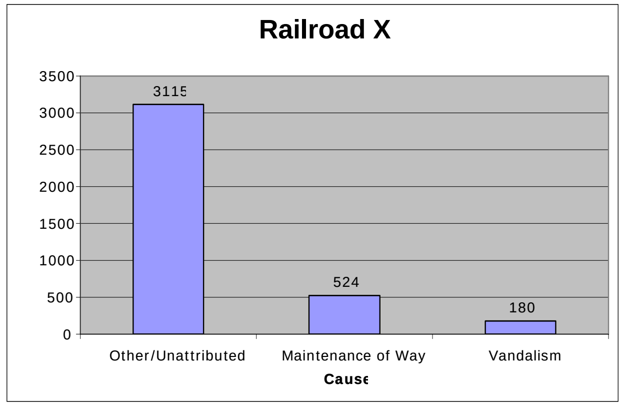

Figure 1. Road X: Chart of Track Wire Failure Causes

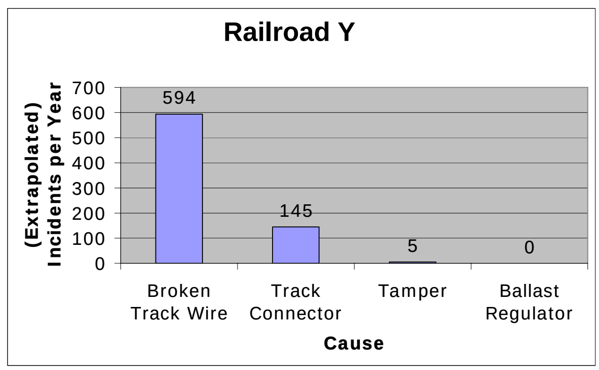

Figure 2. Railroad Y: Chart of Track Wire Failures

Neither of the two trouble-desk systems was originally designed or configured to capture the specific bits of data needed to answer many of the specific questions relating to rail/wire interfaces. To create a more comprehensive picture of the occurrence rates and causes of the various types of failures associated with rail/wire interfaces, trouble codes need to be defined to track the occurrence of broken rails that can be attributed to the application of a signal wire bond. The rate of rail failures being reported that can be attributed to a rail/wire interface is low enough to frequently escape being reported in the narrative columns of the trouble desk database, as they are currently used. With thousands of broken rail events between them, neither Railroad X nor Railroad Y had a single broken rail event in which a specific reference to rail/wire interfaces was classified as a root cause.

Of particular interest are the relative frequencies of the combined failure rates of Railroad X and Railroad Y (Table 1). Assuming that a broken rail has the same or greater ability to delay a train, as do broken track wires or broken bond wires, it would appear that broken rails constitute by far the greatest source of train delays.

Table 1. Comparison of Primary Failure Categories (Extrapolated for one year)

Equipment Failure Type	RR X	RR Y	Combined
Broken Track Wire or Connector	3,819	(1,708)	(5,527)
Broken Bond Wire	4,312	(2,302)	(6,614)
Broken Rail	6,274	(6,951)	(13,225)

Rail/Wire Interface Methods — Analysis

Seven current and three experimental methods of wire/rail interface bonding were explored:

- Hard or Soft Solder
- Amalgamated Contacts
- Stranpins and Channel Pins
- Interference-Fit Pins (Plug Bond) — See Figure 3
- Bolted Contacts
- Exothermic Welding — See Figure 4
- Pin Brazing — See Figure 5
- Conductive Epoxy Bonding (experimental)
- Stud Welding (experimental)
- Driven-In Threaded Stud (experimental)

As these investigations progressed, the following desired attributes for new bonding designs were identified:

- Low Contact Resistance: The contact resistance in the bond should be at least as low as a properly installed plug bond, and preferably lower.
- Bondstrand Retention: The mechanical strength of the bond should ideally be at least equal to the "pull-out" strength of a crimped-sleeve connection. Although this will not render the bond tamper-proof with respect to Maintenance of Way (MOW) equipment, it will at least provide protection against vandals that is equal to current technologies. An alternative standard would be to withstand the pulling force that can be applied by an average young male.
- Ease of Installation: While somewhat subjective, the weight of the equipment required to install the bond should be carefully considered as a significant portion of this parameter. The number of tools and consumables should also be considered.
- Application during Inclement Weather: An ideal bonding technology will not be prevented from installation during extremes of temperature, humidity, and precipitation.
- Temporary Disconnection of Track Wire from Track: This is a key feature that has kept plug bonds viable for many years. This is particularly important when arc-welding processes and arc-air gouging will be used to repair track work. Disconnecting the track wires from the rails serves to isolate expensive electronic signal equipment from potentially damaging voltages and currents on the rails. This is also standard practice by some railroad signal maintainers when a MOW/tamping crew is working in the area.
- No damage to Rails: Sectioning and etching of each new rail bonding method should be used to determine the impact of the bonding method on the steel of the rails.
- Cost: As always, the installed cost-per-bond, including amortized equipment cost and labor costs, should be considered.

Figure 3. Plug Bond or Chicken Head Track Wire Bond

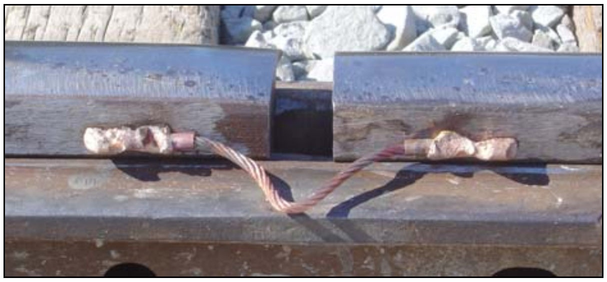

Figure 4. Thermite Welded Track Wire Bond

Figure 5. Pin Brazed Track Wire Bond

Plug Bonding

Professional text books from 1910 state that plug bonds have been in use for nearly a century.[1, 2] Welded bonds require heat to make a weld, and the effect of that heat on the crystalline structure of the underlying rail steel may cause the formation of martensite. Martensite is a hard and brittle crystal structure that occurs in modern rail steel as a result of very rapid cooling (quenching) of the heated steel (at a rate of about 1000ºC or 1832ºF per minute). The presence of untempered martensite in rails creates a hard spot in the steel that is likely to initiate cracks in the rail when placed under load. Mechanical rail connectors (i.e., a plug bond) would appear to have an advantage. Previous research by the Transit Cooperative Research Program has concluded that drilling holes in the neutral axis of rails (for the application of a plug bond) does not damage the steel in the rail; however, repeated installation and removal cycles may result in a loose-fitting plug bond, due to frictional wear.[3] This is commonly experienced in the field. Plug bonds were not intended to be used in this way, even though they sometimes are. The less than 0.001-inch interference fit, created by broaching a soft-steel pin into a sharp-edged hole in a much harder steel rail, does not leave much material that can be worn away before the plug bond will begin to fit loosely in its 3/8-inch hole in the rail web, leading to a plug bond failure.

CONCLUSIONS

- Presently there is no ideal solution to address rail/wire interface failure, but there are several contemporary methods being widely used and a few alternative methods that hold promise. These alternatives should be carefully evaluated against current methods. A comprehensive test program, based on the critical test parameters identified in the expanded final report,[4] is recommended.

  The failure rate of rail/wire interfaces suggest that the problem is not immediate, but merits effective attention and treatment. As there are sufficient signal equipment failures attributed to defects at the rail/wire interface that results in substantial train delays, additional research into new and improved rail/wire interfaces appears warranted.

- Plug bonds (aka chickenheads) do not appear to overstress the steel of the rails that they are installed into, even when driven much deeper into the rails than necessary.
- Interviewees during this research effort felt that there is room for improvement with respect to the drilling practices commonly employed when installing plug bonds in the field. Application of machine shop practices, such as hole deburring, should be applied to the field, where possible.
- Failures of the rail/wire interface without an identifiable root cause are overwhelmingly the most common type failure, with failures having an identifiable root cause such as damage by MOW equipment or vandalism being much less common. The following findings require answers through further research:
  - With damage by Maintenance-of-Way equipment often leading the list of identifiable causes of rail/wire interface failure, this particular topic may be the easiest to investigate.
  - Investigations into rail/wire interface failures, with no identifiable root cause, are seriously hindered by the lack of detailed information about each failure. There is an urgent need for additional details to be reported to every railroad's trouble desk database.
  - Future research into "no root cause identified" rail/wire interface failures could be significantly enhanced, if there were greater standardization of trouble desk defect codes across North American railroads. This would permit easier pooling of data, and a greater quantity, with greater validity of results.
  - Provided that significant changes in defect code uniformity are made, analysis of the type performed during this investigation should be repeated after at least six months of data have been collected. A data set encompassing one year would strongly be preferred, in order to accommodate seasonal fluctuations in the data.
- Exothermic welding of track wires should be improved to eliminate the process variations which now exist. Elimination of the potential for thermal damage to the rail is of prime importance.

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