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Bonded Insulated Joint Performance in Mainline Track

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Summary

Burlington Northern Santa Fe and Transportation Technology Center, Inc. teamed up on a Six-Sigma project to evaluate the performance of bonded insulated joints (IJ) in revenue-service freight main lines. Preliminary conclusions include:

- The average life of mainline insulated rail joints is 150-300 MGT. This service life is considerably shorter than any other track component, except high angle crossing diamond frogs.
- Variation in service life can be quite large with many early insulation fail-safe instances[**] and a few joints that survive a long time. In one study, the average life was 170 MGT with a standard deviation of 120 MGT. The early insulation fail-safe instances are not high cycle fatigue related and are cause for further investigation.
- IJ fail-safe occurrences are seasonal. Mechanical problems are more likely to occur in the fall, when cold periods put the rail in tension. Electrical (i.e., signal system) fail-safe occurrences are likely to occur in the warmest or wettest weather. Compressive rail forces cause flowed rail ends to touch and shunt the track. The IJ creates a fail-safe condition when it allows the rail ends to move relative to each other.
- A joint may cease to insulate electrically before it is removed from track. While two IJs are installed at the end of each track signal block, only one functioning joint is needed to operate the signal system. Thus, there are an unknown number of IJs that have ceased to insulate in track at any given time.
- A survey of removed joints showed that the majority of IJs had multiple defects. These include: glue debonding, insulator failures from component breakage or wear through, and mechanical joint component failures.
- Low levels of joint support are associated with IJ J problems. This includes fouled ballast, deteriorated ties, and ineffective fastening.
- Longitudinal stress plays a part in IJ performance. Railroads report that IJ service life is shortest in long segments of tangent track. No quantitative data on the effects of longitudinal stress is available.
- Recent inspections by TTCI revealed that distressed IJs were also more likely to be located near turnouts. This could be related to higher dynamic loads and/or higher longitudinal stresses at these locations

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[**] *A fail-safe instance is one in which the IJ has degraded to the point where it has lost electrical resistance or it allows longitudinal rail movement within the joint. In the case of an electrical resistance loss, the signal system will display a fail-safe aspect. In either case, the railroad will then replace the IJ.*

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INTRODUCTION

The performance of insulated joints (IJ) is important to railroads. Electrical failures disrupt service by impeding train operations until the IJ is repaired or replaced. They seldom result in accidents because the rail is still intact and the signal system stops trains. Mechanical problems, however, can disrupt service and may result in loss of integrity at the rail joint.

Burlington Northern Santa Fe (BNSF) and Transportation Technology Center, Inc. (TTCI) evaluated the performance of insulated joints in revenue service freight mainlines. The average life of insulated joints in mainline service in North America is about 200 MGT. This service life is lower than virtually all other running surface components, including turnout frogs and switch points. Only high angle crossing diamond frogs, with unsupported flangeway gaps, have similarly short service lives.

On high tonnage routes, IJs may be replaced in as little as 12 to 18 months, with direct costs of $10,000 per mile per year. Indirect costs (such as crew labor and fuel due to train delay) can be higher.

As part of a Six-Sigma project, performance data for insulated joints has been obtained and analyzed by BNSF and TTCI. A data collection system has been established to develop the data needed to direct further research and development efforts.

SERVICE LIFE DATA

Figure 1 shows service life data for a group of IJs that were installed during a signal-upgrading project. The joints are located in a main line that carries mostly higher speed intermodal traffic. Tonnage rates are 50-65 MGT/year/ track. The Weibull plot projects a median life of 172 MGT for the group of 150 joints. The industry committee on rail (AREMA 4) has surveyed its members about insulated joints. The average service life values returned in the survey are 280 MGT for tangent track and 230 MGT for curved track.

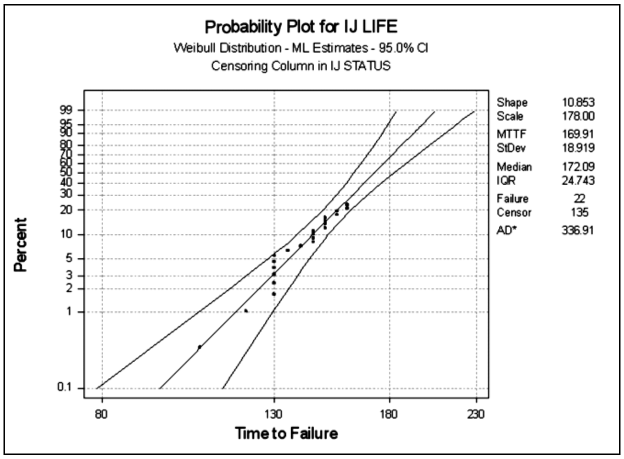

Figure 1. Mainline Insulated Joint Service Life Projection

Since most track circuits can operate with one insulated joint, there is redundancy in the typical two insulated joint installation. Thus, the service life reported for insulated joints (i.e., a track circuit life) is probably much higher than the actual life over which the insulation of the IJ is effective. Data from BNSF includes current joint condition (from inspections made by the local track inspector) and joints that were removed from track. Thus, it is closer to the actual usable life on an IJ. The data in Figure 1 confirms the long held belief that IJ life is relatively short. Improvements in other track components have left IJs as one of the weakest links in the track structure.

FAILURE MODE ANALYSIS

A sample of 20 insulated joints removed from revenue service was collected and examined by TTCI. The joints were from lines that carry coal traffic in mostly 286-kip cars. Results of the examination show that most joints have more than one defect. This finding is in keeping with the observation that many joints remain in track for some time after insulation fail-safe occurrences. Thus, the evidence of the initial cause may be obliterated by the subsequent damage from tonnage. Figure 2 shows a cross section view of one of the IJs examined by TTCI. The joints were destructively examined by cross-section cuts and disassembly.

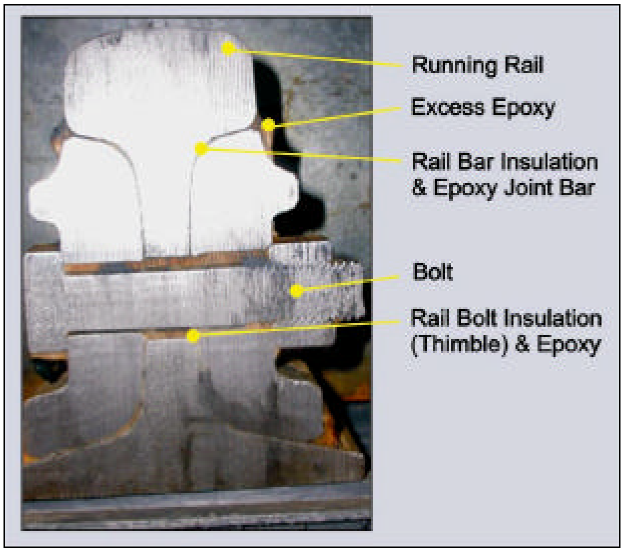

Figure 2. Bonded Insulated Joint Cross-Section View

SERVICE LIFE LIMITATION

There are several common modes that limit service life for IJs in HAL service. Some of these are related to quality control issues in components and assembly. Problems with batches of joints from a given supplier, batches of epoxy and batches of IJ kits have been reported by the railroads.

There are also service life-reducing aspects related to the design/capacity of the joint. These occur with structural aspects of the joint or components within the joint. These situations begin with the joint being a running surface discontinuity. Figure 3 shows small deformations in the running surface caused by the IJ gap. The discontinuity generates dynamic loads at the joint. The foundation is damaged and joint deflection becomes significantly larger than deflections typically found in surrounding track.

Figure 3. IJ with Running Surface Deformation due to Gap

Figure 4 shows a typical distressed IJ foundation in track that has generally good support. This causes cracking in the glue/epoxy at the top-center of the joint bar/rail interface. Figure 5 shows typical IJ glue cracking near the end post of the joint. The weakened epoxy bond allows moisture intrusion and larger deflections. Figure 6 shows a disassembled IJ with glue debonding and water intrusion. As the glue debonds, the joint becomes subject to “pull aparts” from longitudinal forces in the rails. This damages insulating components, such as thimbles and end posts, as well as mechanical joint components such as bars and bolts. Figure 7 shows an IJ that pulled apart in track. The joints can continue to function as insulators long after the initial deterioration begins. The design has much redundancy so that several defects can be present before safety is compromised. Failure of the IJ to insulate the track circuit brings an immediate replacement. Pull aparts, with broken bolts or beyond the hole drilling tolerance, are also replaced upon detection.

Figure 4. Distressed IJ Foundation in Good Mainline Track

Figure 5. IJ with Glue Bond Fail-Safe Occurrence Near End Post (Note: Rust near end post)

Figure 6. IJ that has Failed-Safe Electrically after Disassembly (Note: Wet areas near end post.)

Figure 7. Typical IJ Pull Apart In Track

Track Inspection of Insulated Joints

To learn more about track features that may affect insulated joint performance, TTCI and BNSF inspected insulated joints on mainline track. The inspections consisted of visual examination of the joints and surrounding track. A variety of lines was inspected in the Midwest and Southwestern parts of the U.S. Coal routes and intermodal routes were included. Fifty insulated joints were inspected.

Low track modulus conditions were associated with IJ problems. Figure 8 shows the distribution of foundation conditions for IJs in good and distressed condition. A poor foundation was one that had mud present, fastener problems, and low ties. Track deflection at the joint can be up to 2 inches at the center of the joint. A fair foundation condition was one that had low ties.

Longitudinal rail stress appears to play a role in IJ performance. It is difficult to define this role because measurements of longitudinal stress are not commonly available. However, fixed points in track are locations where longitudinal stress effects may be most evident. One such location associated with insulated joints is special track work. There is a correlation between IJ condition and proximity to turnouts. Figure 9 shows this relationship. It should be noted that the IJs on the diverging track (between switch and frog) in the turnout were not included in this analysis. These joints are in good condition. Their load environment is different from the rest of the track in that traffic is less (perhaps 10-20 percent of the straight route), train speeds are lower, and rail longitudinal stresses are generally lower.

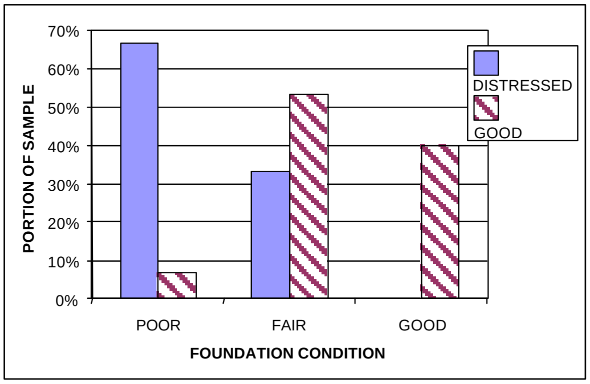

Figure 8. Foundation Condition at Insulated Joints

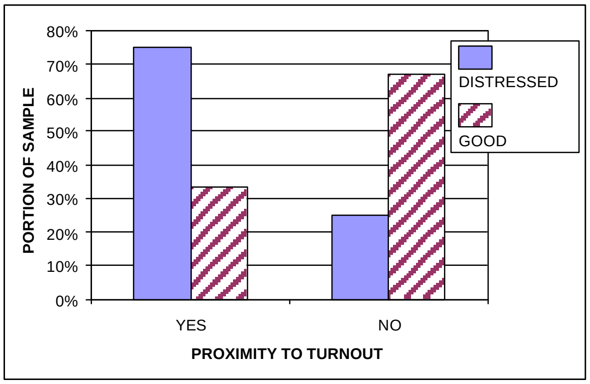

Figure 9. Effect of IJ Location on Condition

DESIGN ISSUES

More data is needed to draw conclusions about the effects of various design elements on IJ service life. However, one finding is that miter cut rail ends (full section or head only) have not been effective at increasing service life. The miter cut was intended to provide for a smoother running surface across the joint, allowing a wheel to span across the joint. Due to the cross sectional running surface profile of the rail, this benefit in reducing impacts was not derived. It also introduced additional stresses in the cantilevered railhead ends.

FUTURE WORK

These preliminary findings have provided the beginnings of an IJ performance database. This database will allow better root cause analysis for current-designed IJ failures. The next step will include establishing a baseline of current designs and assisting railroads and suppliers in developing improved design insulated bonded joints.

Measurements and modeling will be done for current-designed insulated joints to determine damaging internal and external input forces. Internal forces caused by longitudinal thermal stresses and external forces caused by the train's dynamic loads or the combination of both contribute to early failures. Finite Element Analysis modeling will be done to evaluate if the current IJ designs are capable of handling today's higher loads and higher speeds, or if a total IJ redesign is required. The findings will be incorporated into the IJ performance database.

Cooperative testing of improved designs with IJ suppliers, railroads, and TTCI have already been scheduled, and the results will drive the development of an improved bonded IJ for Class I railroads. These tests will examine the relevant design factors, such as tie spacing, and measure the HAL load environment. Longitudinal stress measurements are particularly needed. In other areas of research, railroads are investigating ways to eliminate the need for IJs. These include non-track circuit-based train control and alternative broken rail detection methods