A Review On Insulated Rail Joints (IRJ) Failure Analysis.

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Abstract: Insulated rail joints are a safety valve in railways that are used as part of the signaling system to determine the position of a train. Insulated rail joints are the weakest part of the railroad, where their life ranges between a third and half of the life of rails. Proper functioning of Insulated Rail Joints (IRJs) is essential for the safe operation of the railway signaling systems and broken rail identification circuitries. To gain substantial understanding of the current design of Insulated Rail Joints (IRJs) and their failure analysis are reviewed.

Keywords: Insulated rail joint, Rail joint bar, fatigue life, Failure Analysis, End post.

1. Introduction

Trains are the quickest, most comfortable and reliable transport choice compared with other land transport. They can carry huge numbers of individuals or extensive cargo loads at high speed in one unit, where the same number or burden would take numerous buses and considerably more lorries or cars. The train is far faster and more reliable than cars, buses and lorries [1]. Rail transport started in Greece during the 6 th century. The railway was 6 km long in the beginning [2]. The railway reappeared in 1350 in Germany after the dark ages. After that the rail transport witnessed great development until the present day.

2. Rail Joint

Rail joints are used to connect two rails end to end, so as to prevent the movement of the rail horizontally and vertically. They act as a bridge between the adjacent rails, as well as allowing longitudinal movement of rails when expanding and contracting as a result of temperature changes. Rail joints are the weakest part of the track, where their life ranges between a third or a half of the life of the rails. Rail joints consist of two opposite bars called “fish plates” with four or six bolts and washers (Figure 1). The joint bars are put in place by the action of bolt connections through rails. There are three types of rail joints which are described in the following sections [3]:

i) Standard rail joints.
ii) Compromise rail joints.
iii) Insulated rail joints.

Figure 1: *4 Bolt Rail Joint “fish plates”*

2.1- Standard Rail Joints

Standard rail joints, as shown in Figure 2, are used to connect two rail ends of the same specification, such as weight section. Standard rail joints are divided into standard rail joints 24in in length with 4-bolt holes for small rail sections and 36in in length with 6-bolt holes for larger rail.

Figure 2: *Standard Joint Bar*

2.2 Compromise Rail Joints

Compromise rail joints are used to connect two rails of different specifications, such as weight and section (Figure 3). There are two types of compromise rail joints, directional compromise rail joints and non-directional compromise rail joints. The directional compromise rail joints (right and left hand) are employed where a difference in the width of the head between two sections means offsetting of the rails is required to align the gauge side of the rails.

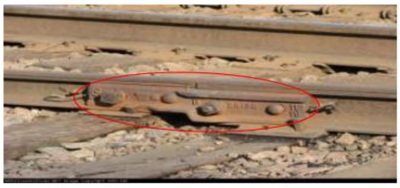

Figure 3: *Compromise Joint Bar*

2.3 Insulated Rail Joint (IRJs)

Insulated Rail Joints (IRJs) are used in track as part of the signaling system. Track signaling is employed to ensure that the movement of trains is safe and smooth so as not to pause the trains. For the purpose of train detection the track is split into blocks, each of which forms a circuit. A low-voltage electric current is fed from a battery to the rails at one end of the track section. At the other end of the track, a relay is attached to the rails. In an unoccupied circuit, as seen in Figure 4, the current is allowed to run through the relay keeping it switched to a position that allows a track signal to show that the track section is clear [8].

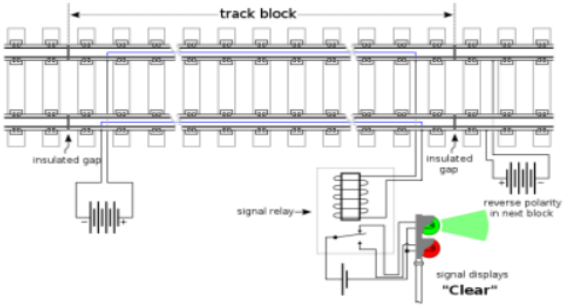

Figure 4: *Clear Track Circuit [8].*

When a train enters the insulated track section, the wheels and axles short the circuit as shown in Figure 5.

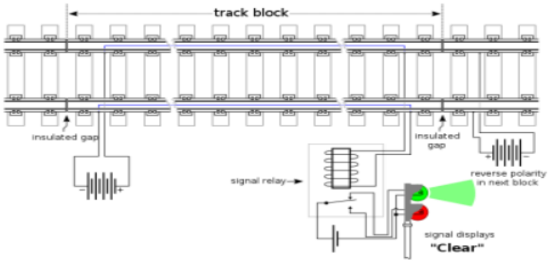

Figure 5: *Occupied Track Circuit*

The current is therefore diverted from the relay, causing the relay to switch to its other position which causes a track signal to show that a train is present in the block. IRJs are used to connect adjoining rails and provide a smooth surface for passage of train wheels on the railways as well as make the rail network electrically isolated. They preclude electrical current transfer between adjoining rails, thereby dividing a track circuit into circuit sections. IRJs employ insulating material between the rail ends (end posts). Insulated joints completely isolate the rails by insulating material placed between the fishplate and the rails and around the bolts. IRJs consist of the following components, as shown in Figure 6 [9, 10].

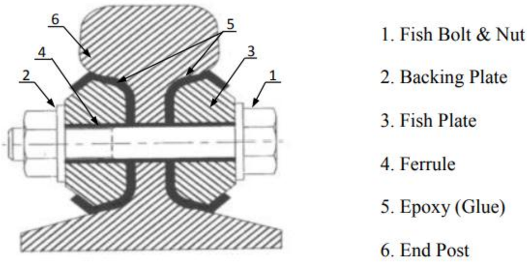

Figure 6: *Cross-Section of an Insulated Joint*

There are two designs of IRJs:
i) Non-glued (loose) IRJs
ii) Glued IRJs

In non-glued IRJs, the end post is put in the gap between rails then fishplates are installed on the rails by the action of bolts, while in glued IRJs the end post is put firmly in place by the action of high strength glue between joint bars and rails and bolts connections through rails and joint bars to ensure that they are coherent as one piece to bear the excessive loads and frequent vibration. The focus in this work will be on Insulated Rail Joints (IRJs).

3. Insulated Rail Joint Design

IRJs consist of insulating material (end post) placed in the gap between adjoining rails, and two joint bars held by bolts or by adhesive and bolts which connect the rails. There are several types of design depending on the form of rail and its support system.

Two types of IRJ supporting systems are used [3, 12]:
i) Supported IRJs 158 mm 20 mm 140 mm 10
ii) Suspended IRJs

Figure 7 shows the presence of the sleepers in a symmetrical position to the end post for suspended IRJs. For the suspended IRJs, there is no support under the end post.

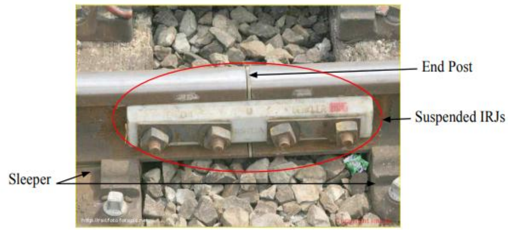

Figure 7: *Suspended IRJs [13].*

In supported IRJs, the end post is fixed on the sleepers. There are two types of supported IRJs:

1- Continuous IRJs (Figure 8) They are called continuous because they continuously support base of the rail. No metal-to-metal contact occurs between the joint steel bars and the rails.

Figure 8: *Continuous Insulated Rail Joints [14].*

2- Non-continuous IRJs

In the non-continuous supported IRJs the end post is fixed immediately above a sleeper, as shown in Figure 9, which reduces the dipping of the rails, and thus relieves compression on the end post and prevents its cracking and fragmentation [15].

Figure 9: *- Non-Continuous Supported IRJs [16]*

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4. Importance of IRJs

IRJs are used to electrically isolate the rails and split the circuit into sections to achieve signal control. IRJs failure is a serious safety case and railways operators are very focused on the issue of their maintenance and conservation. IRJs are considered to be a weak spot in the rail track. The service life of IRJs is 1/3 to 1/2 of rail life [15]. Improvement of the present IRJs is therefore needed to solve this growing issue. Recently there have been some studies looking at the mechanism of failures of IRJs in order to develop and improve their performance.

5: Insulated Rail Joints Failures

Many industries face the problem of wear, especially in the moving parts. Practically the moving parts are subject to wear in contact region with other parts. Wearing parts need replacement and this process leads to an increase in costs and down time. The engineers working in this area need to find and design certain materials to resist this wear occurring to the moving parts to increase the part's life and reduce the replacement of the part. Failures in rail joints are driven largely by the wheel/rail contact [17].

6: Insulated Rail Joints Failures Types

The first type is mechanical failure; this type of failure affects steel parts, such as the rails, joint bars and bolts. All the steel parts in the track are subjected to static and dynamic loads and fatigue. The first type of mechanical failure is broken joint bar failure due to excessive load and high impact forces at the IRJs as shown in Figure 10. The second type of mechanical failure is "battered" rail end. The influence of running wheels causes the rail end to be flow downwards and become flattened. These flattened rail ends are called ″battered″ or ″crippled″ rail ends. This happens when the gap between adjoining rails is excessive and fish plates do not fit snugly because of the lack of strong support at the ends of the rails (Figure 10). It is measured by comparing the height of the rail at the rail end and at a point 300 mm away from the rail end. Rail end battering up to 2 mm is accepted and 3 mm is critical.

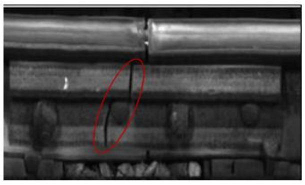


Figure10: *Cracked Joint* ***Figure 11:*** *Rail End Battering*

High loads can also cause failures in the epoxy that is used to hold the joints together. The epoxy can crack or peel away from the joint bars and rail that it is attached to, which can significantly weaken the insulated joint. Once the epoxy is weakened, it can cause the insulated joint to fail. The second type is electrical failure, which is a destruction of the insulated joints so that loss of the ability to isolate the electrical current in the rail network occurs. This leads to the transmission of electrical current between the adjacent rails. There are a few ways in which an electrical failure can occur in bonded insulated rail joints. The first reason that leads to electrical failure in IRJs is "Lipping", which is flow of rail head material due to high wheel loads and traction. When the train wheels pass over the rail head near the gap between adjoining rails at an IRJ, the steel of the rail can deform over time. After a period of time, the gap between rails will close and the adjoining rail comes into contact and an electrical occurs.

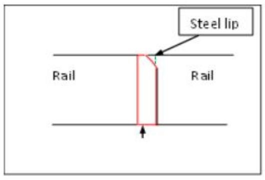
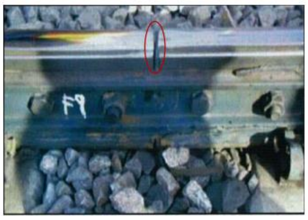


Figure12: Rail End Metal Flow **Figure13:** Schematic Diagram of Rail End Metal Flow. It can lead to the development of further damage such as spalling as shown in Figure 14. Key factors associated with this type of failure are rolling contact fatigue and the associated loading rate dependent metal plasticity as the wheel load exceeds the material yield point at the point of contact.

Figure 14: *Rail Head Metal Spalling in the Gap between Adjoining Rail at IRJs*

Electrical failure can also occur when bolts used to hold the joint bars together are permitted to touch the joint bars and the rail at the same time. This may happen when the insulation ferrules around the bolts fail due to high loads. Another method of electrical failure is a failure of the insulating end post of the joint. The end post may crack and come out of the space between the rails in the joint which may allow the rails to touch when they are extended or when the joint is loaded this is due to thermal effects and higher impact forces at IRJs (Figures 15 and 16). Damage or loss of the end post can allow water in the joint and thus allow the passage of electrical current.



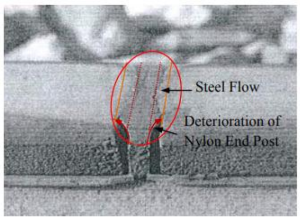


Figure15: *IRJ with End Post Crushed* ***Figure 16:*** *Plastic Deformation of Rail End*

7: Failure Analysis

Mandal and Peach [22] carried out an engineering analysis of different designs and failure modes of the IRJ and 3D finite element modelling for analysing the stresses experienced by three different joint bar size. They used the ABAQUS/ CAE product in their study. The longitudinal stress at the bottom and top of the joint bar is determined considering bending moment caused by train wheel load on the insulated rail joint. Rathod et. al. [24] investigated microstructural changes in the vicinity of the end post of insulated rail joints manufactured from uncoated and coated rail using scanning and optical electron microscopy techniques. Deteriorated insulated rail joints made from pearlitic head hardened rail steel was compared with head hardened rail steel laser coated with martensitic stainless steel. Service life of the laser coated steel was longer than the service life of the untreated rail. The problems related to the surface were identified and ways for developing IRJ's resistance to rolling contact fatigue proposed. Sandstrom et al. [23] monitored several insulated rail joints in the track over three years to show degradation. The material was damaged in early stage after installation, even though the applied loads were low. The damage of all joints was the same pattern with 19 deformation on the same side. Several joints exhibited cavity-like damage on the offstation side.

Conclusion:

Unfortunately, IRJ is regarded as a weak section of the track structure as they exhibit short service life. Due to the lower stiffness at the joint gap and the complexity of the assembly of various structural components, IRJs are susceptible to accelerated mechanical failure under various failure modes. To improve and develop IRJs, understanding of their failure mechanisms is firstly required.

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