Surviving RCF: Emerging Frontiers

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Abstract

Rolling Contact Fatigue (RCF) defects are hallmark of most of the railroads carrying heavy axle loads and intensive passenger traffic. RCF defects of nearly vertical orientation are one of the most lethal types of rail defects on account of their low chances of detection in rail testing regimes prevailing on rail networks. Detection of defects with favorable orientation under adverse rail surface condition is also a challenging task. The paper highlights Indian Railways' experience in dealing with these defects and R&D efforts made to develop potential technology for their detection.

1.0 Introduction

1.1 One of the most significant fallout of sub optimal rail-wheel interaction on today's rail steels is development of Rolling Contact Fatigue (RCF) defects in rail head. As a consequence, transverse defects of various orientations in rail head are common on rail networks carrying heavy axle loads. Many of the rail networks are proactively choosing effective management of rail-wheel interface as preventive strategy to address the problem. However, detection of rail defects in non destructive manner is invariably employed in parallel as equally important and useful tool on most of the railroads to keep the risk of rail breaks to minimum levels.

1.2 Generally railroads adopt detection strategies based on their past experience of service failures on account of transverse defects in railhead. On Indian Railways (IR) the most commonly found orientation of transverse defects is approximately 20 degree from vertical. This led to deployment of 70 degree probes for detection of these defects. Presently an array of 70 degree forward and backward looking probes forms the mainstay of ultrasonic testing on IR. However, IR is not able to get complete freedom from service failures on account of undetected transverse defects with its present ultrasonic testing regime.

2.0 Key Challenges

2.1 The increase in traffic density on account of introduction of additional passenger/freight trains and heavier freight trains on one hand and use of harder rail steel on other coupled with non management of rail wheel interface has led to a rapid spread of RCF defects in rails on IR. Ultrasonic testing of rails in vogue is effective in timely detecting large population of the RCF defects. However, the instances of service failure and/or mishaps on account of undetected RCF defects are being increasingly encountered. The analysis of all service failures leading to derailments is undertaken at RDSO. One of the key issues examined during investigation is whether the defect was detectable by prescribed ultrasonic testing protocols. Deciding this conclusively is often tricky if not impossible.

2.2 There are three distinct issues related with the non detection of transverse defects in rail head.

2.3 Compromised rail surface condition (scabs, wheel burns) inhibiting proper coupling

2.3.1 Heavier trains especially those operating without right powering are causing rail scabbing/wheel burns at several locations which inhibits unhindered passage of ultrasonic energy to/from defects. Such surface conditions are less than ideal for coupling and transmission of ultrasonic energy using conventional piezoelectric probes. These conditions can result in compromised quality of rail defect detection even for those defects which are easily detectable otherwise.

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2.4 Presence of head checks masking transverse defect beneath

2.4.1 Rail profile grinding is not being practiced on IR. Thus most of the 880 grade rail on IR network is commonly exhibiting cyclic head checks. In certain circumstances the head checks can seriously impair the capability of detection of defects sitting beneath them even though they might be progressing at favorable orientation.

2.5 Adverse orientation of defects leading to very poor reflection of ultrasonic energy

2.5.1 RCF defects of orientation flatter than 20 degree from vertical are also being encountered increasingly. These types of defects can also pose serious problems in their detection. Earlier, it was generally believed that RCF defects of nearly vertical orientation are a typical feature of rails carrying bi directional traffic. However, recent cases suggest that this hypothesis is not entirely correct. One of the recent cases of this type is the one which led to derailment at New Faridabad (Please see Plates 1,2 &3below). Although it is customary to believe that all defects have facets which reflect certain ultrasonic energy, in a real life testing situation detection of feeble signal is easier said than done.

Plate1, 2: Transverse Defect in UIC 60, 880 Grade Rail covering 30% of railhead area leading to derailment at New Faridabad Station in April 09. Nucleus of fracture initiation corresponds to landing of shear crack present on gauge side of rail table. Adjoining Plate shows extant of Head Checks at the location. Question: Did head checks mask defect?

Plate 3: Rail pieces in juxtaposition exhibiting angle of inclination (Approximately 6 degree from vertical) of Transverse Defect. Ultrasonic test report of the rail less than 15 days prior to failure did not indicate any defect. Question: Did orientation play a role in non detection?

2.6 From the foregoing it can be seen that in the prevailing scenario, present ultrasonic testing protocols are not capable of detecting all types of RCF defects. Considering that such undetected defects can potentially be dangerous for a safety sensitive network like IR, it is imperative that efforts are made to address the problem.

3.0 Handling Strategies

There can be three distinct approaches to tackle the problem.

3.1 Preventive Approach

3.1.1 This involves effective management of rail profile to optimum level to achieve:

- Prevention of initiation of RCF defects by limiting contact forces at rail wheel interface.
- Prevention of further growth of defects which have already initiated by limiting contact forces at rail wheel interface and/or shifting point of contact away from the affected location
- Removal of rail surface irregularities such as scab, wheel burns and corrugation etc.

3.1.2 However, the process of implementation of rail profile management on IR on most of its routes is likely to take time. Further, identification and evolution of optimum rail profile for various sections is also a gradual process involving close monitoring. Experience of railroads abroad provides ample evidence of this fact. It is also not known that whether and to what extant rail profile grinding will be able to control onset and spread of such defects on IR. Therefore, it is considered that IR should also pursue advancements in detection strategies in parallel.

3.2 Conventional Detection Approach

3.2.1 This approach can provide relief to certain extant in case of defects of adverse orientation only. This may typically involve testing of rails with enhanced gain to capture signal from facets of defects with nearly vertical orientation. IR has adopted this approach on single line sections and for 'D' marked rails on double/multiple line sections. Another option could be side scanning of railhead. This, however, would have issues like difficulty in holding the probe at proper orientation on rails having wear and rails on curves and proper coupling between rail and probe on a nearly vertical surface.

3.3 Advanced Detection Strategies

3.3.1 The detection of transverse defects of all orientations and under adverse surface conditions in railhead reliably is one of the focus areas of research globally, especially on railroads carrying heavy haul traffic. A brief overview of the same is provided in the following paragraphs.

3.3.2 Transportation Technology Center Inc. (TTCI) in association with Tecnogamma SPA has developed laser based rail flaw detection system for detection of transverse defects in railhead and vertical split head (VSH). The system can apply mechanical energy to the rail at any location accessible to the laser beam as against conventional inspection systems which are currently limited to applying ultrasonic energy into the rail from the top. The system is not available commercially at present and is undergoing testing/ trial.

3.3.3 In year 2000, Tektrend International, a Canadian company undertook development of a mobile inspection system for rail integrity assessment for Transportation Development Center of Transport Canada. The RailPro system developed for real time testing of rails using electromagnetic acoustic transducers (EMAT) technology could detect and locate rail defects. The detection capabilities were assessed over an evaluation track in Taschereau Yard in Montreal on Canadian National (CN) Railway. It was concluded that system along with procedures developed is an efficient and reliable inspection approach.

3.3.4 In year 2004, researchers in the University of Warwick developed a non-contact method of using ultrasound to detect and measure cracks and flaws in rail track – particularly gauge corner cracking. The technique makes use of low frequency Rayleigh waves generated using EMATs to interrogate top 15mm depth of rail.

3.3.5 Chong Myoung Lee of Pennsylvania State University produced an extensive research on capability of EMAT system in detecting railhead defects under shelling in year 2006.

3.3.6 Study of international literature on the subject by RDSO in year 2005 indicated that Electro Magnetic Acoustic Transducer (EMAT) is one of the most promising potential technologies for reliable detection of railhead defects. Following paragraphs deal with EMAT technology in detail.

4.0 Ultrasonic Inspection Using EMAT

4.1 The working principle of EMAT is shown in Plate 4 below. In case of conventional piezoelectric transducers (PZTs), the ultrasonic waves are generated in the transducers and transmitted to the specimen via a coupling medium e.g. water, oil etc. However in case of EMATs, the ultrasonic waves are produced in the specimen itself. This provides a unique advantage of contact less inspection. EMATs are thus finding attractive applications in many areas of ultrasonic non destructive testing (NDT), especially because of their non-contact nature as compared to the conventional PZTs.

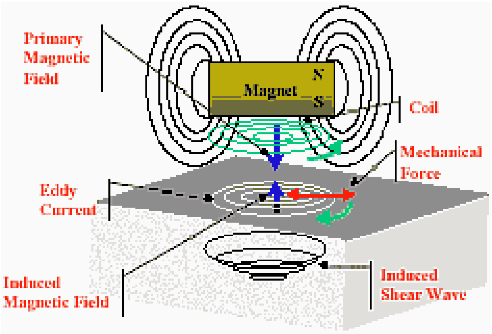
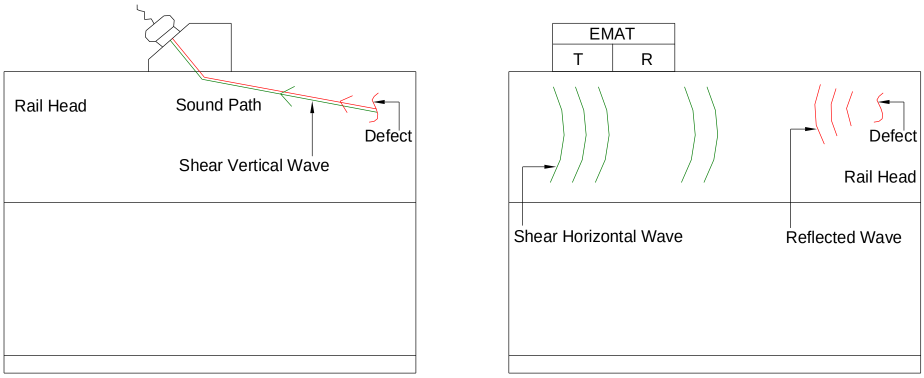


Plate 4: Working Principle of EMAT

4.2 An additional specialty of EMAT is generation of Shear Horizontal (SH) wave mode. This unique wave mode has provided solution to many ultrasonic NDT problems. This is possible in case of EMAT essentially due to the absence of mode conversion, beam skewing and distortion. SH waves can not be efficiently generated using PZTs. SH waves generated by EMATs are commonly being used to detect and characterize defects in stainless steel plates and welds.

4.3 A comparison of defect detection using conventional probe and EMAT guided wave probe is shown in Plate 5 below.



Conventional UT Probe

EMAT Probe

Plate 5: Wave Propagation and Defect Detection in Conventional and EMAT Probes

4.4 As mentioned in the preceding paragraphs, EMATs are also being used to find defects in rail and welds. Besides Transport Canada's initiatives, A Canadian firm TISEC Inc. developed long range ultrasonic technology (LRUT) for rail inspection The LRUT technology is stated to detect rail head defects axially in the rail at distances ranging from a few feet to a few hundred feet. The system was put on extensively trial at Transportation Technology Center Incorporated (TTCI)'s Pueblo test track facility. The test system exhibited remarkable detection levels for transverse defects in rail head under adverse surface conditions.

4.5 However, EMAT rail testing systems are not readily available commercially and the technology is being guarded.

5.0 RDSO-IITK Joint Initiatives

5.1 In view of advantages of EMAT technology and non availability of rail testing systems commercially, it was decided to explore the technology indigenously. This paved way for initiation of a joint research on the subject with Indian Institute of Technology (IIT), Kanpur under Technology Mission on Railway Safety (TMRS) in year 2005.

5.2 Initially generic EMAT equipment along with normal and angle probes was procured from Innerspec Technologies Inc, USA in order to obtain first hand experience with EMATs.

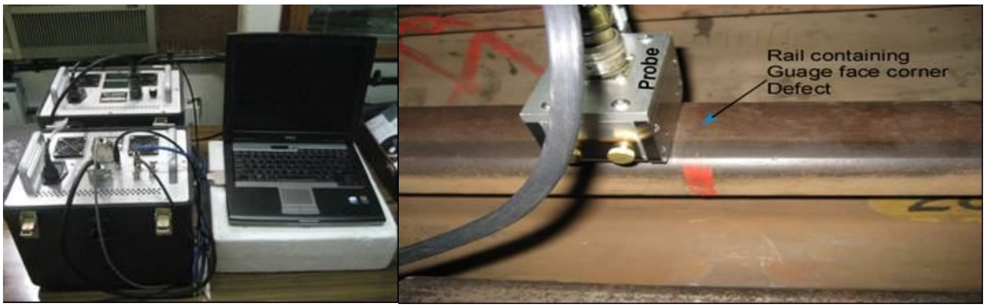
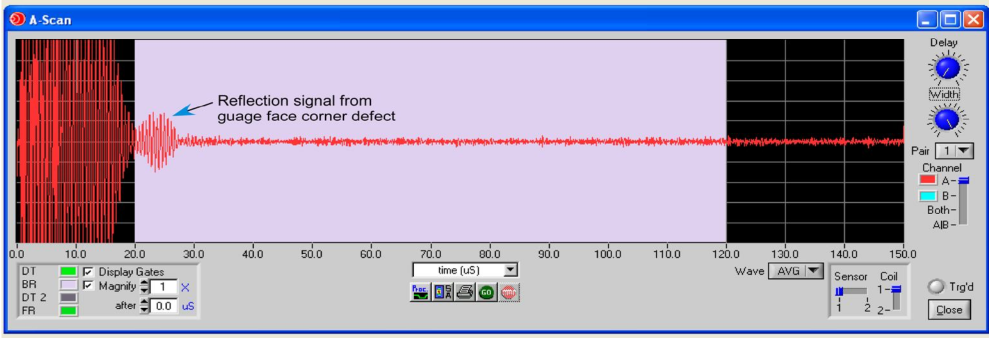


Plate 6: Power Box Set up from Innerspec and Testing of Rail Containing Natural GFC defect



Reflection signal from guage face corner defect

☑ Display Gates

☑ Magnify 1 x

after 0.0 uS

time (uS)

Wave AVG

Pair 1

Plate 7: Screenshot Indicating Signal Obtained form GFC Defect in Rail Using Angle Probe

5.3 Initial experiments with rails containing natural and artificial defects led to following conclusions:

- The EMAT technology is able to pick up transverse defects in rail head.
- The weight of the system and requirement for the power source for electromagnets dictated that the rail testing system be essentially vehicle based.
- In order to make it suitable for rail testing considerable customization of user interface and probe parameters was considered necessary.

5.4 Initial experiments provided ample evidence that in order to reap full benefit of the technology, guided wave probes customized for rail testing application and ‘trained’ to pick up IR target defects would be essential. This required that rail containing natural and artificial defects be sent to the manufacturer of probes. The guided wave probes manufactured for the purpose were put to tests in laboratory at IIT K and RDSO.

5.5 The focus of studies with guided wave EMAT probes were detection of vertical defects of various sizes in rail head from distance. Another area of interest was detection through alumino thermic welds in rails.

5.6 Excellent detection levels were exhibited by the guided wave probes for gauge corner defects of area 4 mm^2 and higher from a distance of 36cm to 94cm (Please see Plate 8).

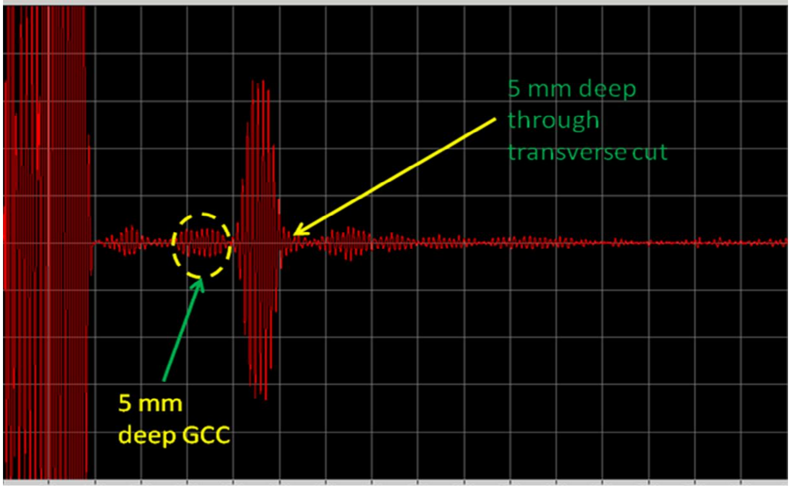


Plate 8: Defect Signals from 5mm deep Gauge Corner Defect and 5mm Deep Through Cut in the Railhead

5.7 These experiments provided insight into the capabilities of EMAT guided wave technology for detection of transverse defect under adverse surface condition. These included reasonable accuracy in detection of target defects of very small size from a distance. It was also noted that guided waves are able to penetrate through defect free welds, thus proving useful for detection of defects in welds and see through the welds for inspection of rail section behind welds.

5.8 The tests also helped in identifying the challenges required to be addressed for deployment of the technology. These included following:

- Timely availability of equipment and accessories
- Need for in house development of software and hardware
- Customization of test system
- Identification of key parameters and their values for railhead inspection
- Development of data acquisition system for continuous rail testing
- Evolution of calibration procedure

6.0 Conclusions and Recommendations

6.1 EMAT based rail testing system can provide highly effective detection of RCF defects of adverse orientation commonly being noticed on IR.

6.2 Risk of rail breaks on account of non detected RCF defects masked by adverse surface condition can be mitigated with use of guided wave technology.

6.3 EMAT systems can prove to be very effective in ensuring overall safety against rail breaks together with conventional rail testing system.

6.4 R&D efforts in the field should be pursued further with Indian / international partners having capability to design and manufacture key hardware and software.

6.5 Development of indigenized capability to manufacture and customize EMAT systems is the key to success.

7.0 References

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8.0 Acknowledgements

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