

# **Rail Track Monitoring in SA using Guided Wave Ultrasound**

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## **Abstract.**

A system, which uses guided wave ultrasound, for monitoring rail track has been developed in South Africa for use on the heavy haul lines operated by Transnet Freight Rail. While conventional ultrasonic inspections are performed periodically and repairs are made when cracks are detected, rail breaks still occur and can lead to train derailments. The broken rail detection system currently deployed on the ORELINE operates by transmitting ultrasonic guided waves along the rail between permanently installed transmit and receive transducers spaced approximately 1 km apart and inspects the entire line every 15 minutes. Numerical modelling and measurement techniques were developed and used to develop a smaller but more powerful piezoelectric transducer. This transducer and powerful digital signal processing techniques have enabled the distance between the transmit and receive stations to be doubled in a new version of the system undergoing field testing. Research into the detection of cracks prior to complete breakage of the rail has demonstrated the possibility of a future system that could detect certain types of cracks before they cause broken rails.

## **Introduction**

Regular non-destructive testing, using conventional ultrasound and magnetic induction inspection techniques, is performed on most railway tracks. Nevertheless rail breaks still occur at a rate of one broken rail for every 10 to 20 defects that are detected [1]. Fortunately only a small fraction of broken rails lead to train derailments. Continuously welded rails used on heavy haul lines are subjected to very high loads which can result in rolling contact fatigue and ultimately broken rails. In South Africa the dedicated iron ore export line known as ORELINE and operated by Transnet Freight Rail is an example of such a heavy haul line. This 861 km long single line is continuously welded and does not use track circuits for signaling. Trains on this line are 4 km long and have a 30 tonne axle load. Derailments due to broken rails were experienced on this line and Transnet performed a study of techniques to detect broken rails that could be used to continuously monitor the rail and raise an alarm when a break occurs [2]. After considering various techniques the ‘acoustic detection technique’ was selected for development of a system. This paper describes the system that was developed and further research and development that has been conducted over the past two decades.

## **Ultrasonic Broken Rail Detection System Development**

Development of the Ultrasonic Broken Rail Detector (UBRD) system started in 1996. The operating concept is shown in figure 1. The system uses permanently installed ultrasonic transducers attached to the rail track to transmit low frequency ultrasound along the rail to a neighbouring transducer which receives the ultrasound. Electronics at the transmit and receive stations is solar powered and operated autonomously. The transmit stations are programmed to transmit a sequence of signals every 15 minutes and if the signals are not received at a receive

station an alarm is sent to a control centre either by radio or GSM where the network is available. The Institute of Maritime Technology were contracted to develop the system and the CSIR was subcontracted to develop the ultrasonic transducers.

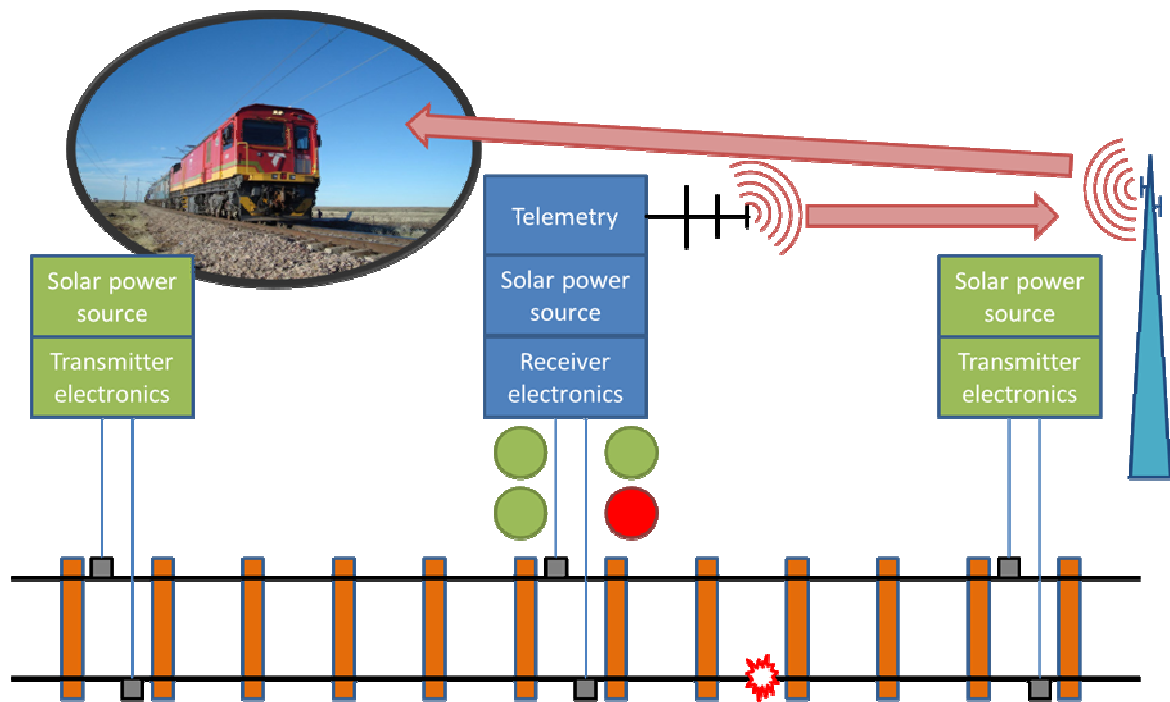


Fig. 1. Ultrasonic Broken Rail Detection System Concept.

While the concept is simple, obtaining reliable operation proved to be a great challenge. At the start of the development no knowledge of guided wave ultrasound was available in the team so there was no understanding of the various modes of propagation available in rail track or how best to excite and sense these modes. The original transducers were developed empirically by trying a few configurations on a rail track and selecting the one with the best performance [3]. Issues such as large variations in signal propagation loss, train and other noise sources, hostile EMI environment with traction and lightning induced surges, electronics and transducer reliability, poor availability of communications infrastructure and theft of equipment had to be overcome. Eventually, a reliable system without false alarms was demonstrated in a 15 month test covering 34 km of poor condition rail [4]. During this test, three complete breaks and six large defects were detected. Due to the success of this test the system was installed on 841 km of the ORELINE requiring a total of 931 transmit and receive stations. As a transducer is attached to both rails at each station a total of 2000 transducers were manufactured for this installation. This installation was completed in June 2014 and has been in operation since then and has detected at least 12 rail breaks [5]. Figure 2 shows some of the equipment installed at a typical station.



Fig. 2. Typical UBRD V4 Station Installed on ORELINE.

### **Guided Wave Ultrasound Research to Improve System**

The original system was developed without any theoretical knowledge of guided wave ultrasound. Research into the excitation and propagation of guided waves in rails began at the CSIR in 2002 when the semi-analytical finite element (SAFE) method [5] was implemented and used to compute the propagating modes in rail. In 2006 the CSIR began to encourage research and funding was allocated to research this topic. A method to model the excitation of guided waves was developed, which coupled a SAFE model of the rail with a three - dimensional finite element model of the piezoelectric transducer [6][7]. Computed dispersion curves and a model of a rail and a transducer are illustrated in figure 3. Later, a scanning laser vibrometer was acquired and a technique for measuring the modes of propagation was developed [8]. Figure 4 shows a scan performed on an operational rail line at a distance of 400 m from the excitation transducer. These measurements helped to identify the modes of propagation that propagate with relatively low attenuation.

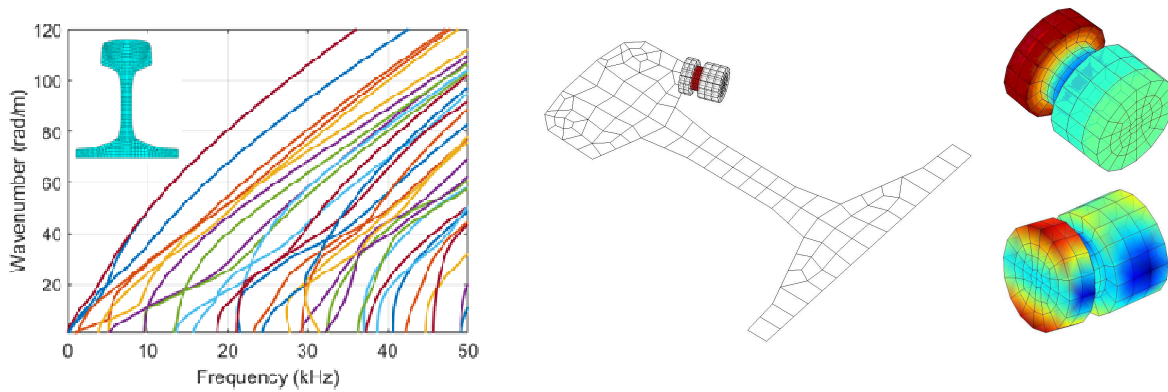


Fig. 3. Modelling of Propagation and Excitation using SAFE and 3-D FE Models.

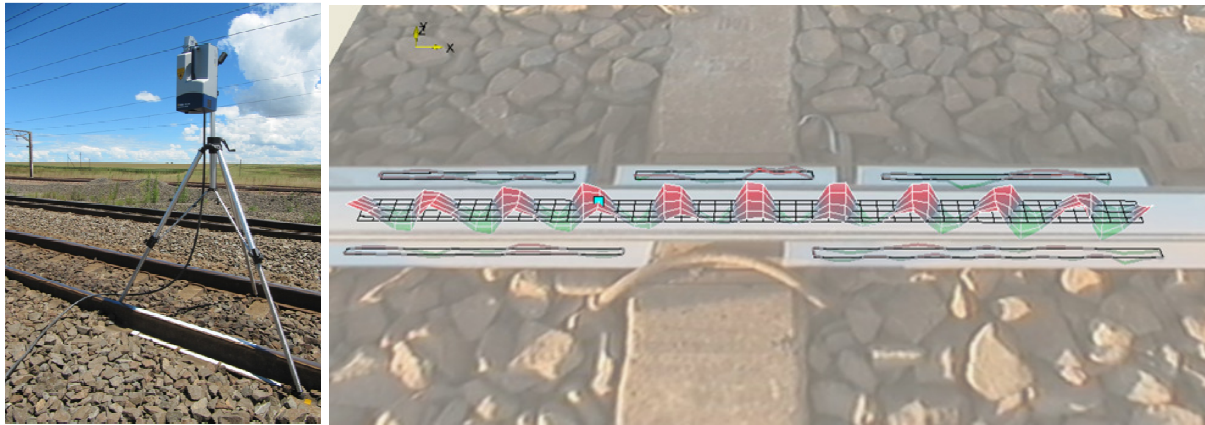


Fig. 4. Field Measurements using Scanning Laser Vibrometer.

The modelling and measurement tools were used to design the second generation rail transducer. This transducer is an order of magnitude smaller than the original transducers but excites the particular mode of propagation much more effectively. This transducer will be used in the UBRD Version 5 system. This system also includes modern digital signal processing, faster interrogation time and radio communication between stations. These improvements allow the distance between transmit and receive stations to be doubled and therefore fewer stations are required along the length of the rail. Final testing of the Version 5 system is currently underway at selected sites on the ORELINE. Figure 5 shows some of the equipment.



Fig. 5. UBRD Version 5 Transducers and Test Installation.

These systems are primarily broken rail detectors. When a broken rail is detected train operation is halted, the break has to be located within the 1 or 2 km section and repaired before train operation can resume. It would be advantageous if rail breaks could be avoided by detecting and locating a crack before the rail breaks. This is the aim of conventional ultrasonic inspections but the difference is that with a permanently installed monitoring system the entire rail can be inspected every few minutes. Because of the frequency of the inspections it is not necessary to be able to detect the small cracks that conventional ultrasound detects. Research into defect detection at long ranges using guided wave ultrasound has begun. This requires the addition of a pulse – echo mode of operation to the system. Instead of a single transducer an array of transducers would be required to preferentially excite and sense selected modes of propagation for testing different parts of the rail cross section and for controlling the direction of excitation and sensing. There are numerous different defect types that occur and information on the growth rates and critical sizes is limited as these appear to depend on a range of parameters. Some rail breaks occur without any sign of a crack and in this case triggering an alarm immediately is the best that can be hoped for. The defects we hope to detect are not available in operational rail track because if a defect has been detected and it is above a relatively small size the rail is repaired. We therefore can only simulate cracks or add artificial reflectors. The presence of aluminothermic welds, which have weld caps as shown in figure 6 are very useful for developing detection techniques. Figure 6 shows the results of field measurements to detect the aluminothermic welds. It was found that these can be detected at distances of over 1 km.

A numerical modelling technique for predicting the reflection of guided wave modes by a defect [9] has been implemented and used to compare the reflections expected from cracks to those expected from aluminothermic welds [10]. Figure 7 shows the results of one such comparison which indicates that even a relatively small transverse defect in the rail head would provide a reflection comparable to that of a weld and would therefore also be detectable at large distances.

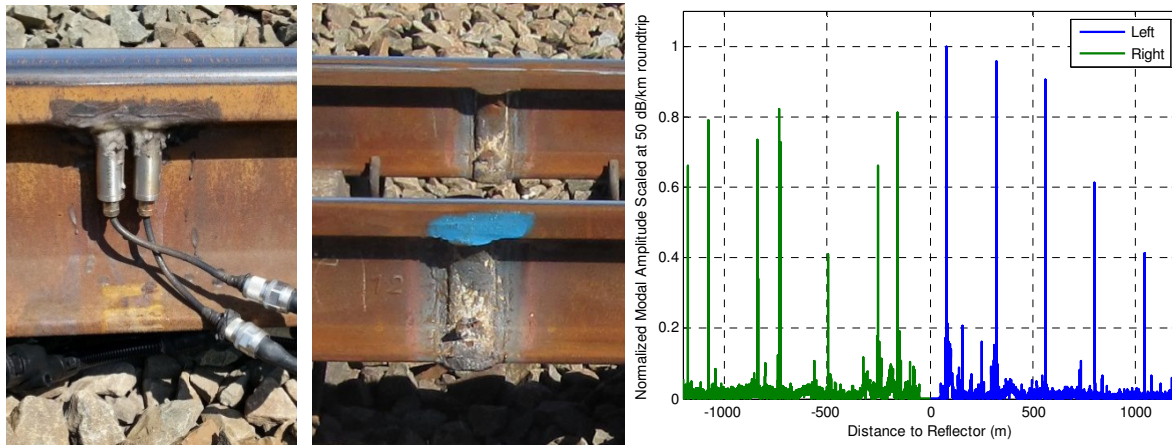


Fig. 6. Experiments Performed to Detect Reflections from Welds.

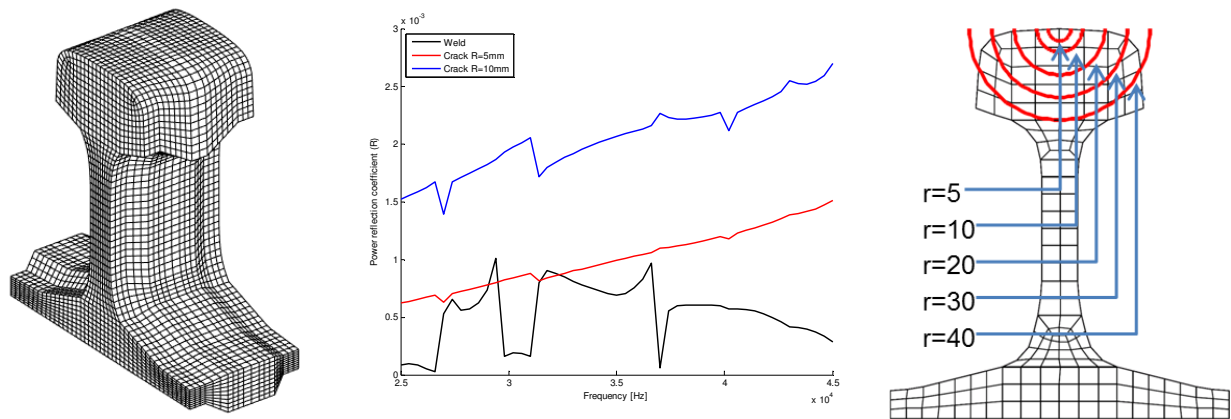


Fig. 7. Numerical Modelling to Predict and Compare Scattering by Different Defects.

One of the advantages of continuous monitoring over periodic inspection is believed to be that a great deal of data is captured and can be analyzed to detect the presence of a growing defect signature. Ideally one could subtract the signal obtained from subsequent signals and look at the difference. This baseline subtraction method does not perform well when the signals change due to changing environmental conditions. An experiment was performed in which measurements were performed regularly over a two week period and an artificial defect was glued to the rail. Principal component analysis and independent component analysis were applied to distinguish the defect signature for other features and to track the reflection while the glue joint deteriorated.

A technique which combines measured data, from a defect free pipeline including the influences of environmental operating conditions, with simulated corrosion defect signatures is being developed in the UK [11]. This offers the potential to quantify the probability of detection and probability of false alarms without requiring access to real defects. We intend to follow a similar approach where data measured on an operational rail line can be combined with a variety of defect signatures obtained from numerical modelling and the probabilities quantified.

It is hoped that defect detection will be included in a future Version 6 of the UBRD system which will be broken rail prevention system.

## Conclusions

A robust broken rail monitoring system has been developed and implemented on a large scale. This is the first monitoring system of its kind in the world.

Research undertaken in the area of guided wave ultrasound produced an improved transducer which, along with digital signal processing improvements, will double the spacing between stations

in the next version of the system. Further research has been performed to investigate the feasibility of detecting cracks in rails at long ranges. It appears that transverse cracks in the rail head will be detectable at long ranges and broken rails stemming from these defects should be avoidable. Other guided wave modes are required to monitor the web and the foot of the rail. Achieving reasonable propagation distances and sensitivity to defects in the foot of the rail is a current research topic that is proving to be extremely difficult.

Data processing techniques are being developed. The technique to quantify the probability of detection of specific defects is being developed. This technique will combine measured data from the rail track with simulated defect signatures.

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