Development, testing and operation of an Ultrasonic Broken Rail Detector System

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1 Background

The Sishen-Saldanha iron ore export railway line suffers from unpredictable rail breaks causing a great loss annually to Spoornet. Rail-breaks are however a common phenomena in all railways over the world. This can cause very costly derailments if not detected before the passage of a train. Small amounts of impurities trapped in the metal structure of the rail are potential points of rail defect development. The development of these defects is associated with metal fatigue, which is a function of the loading applied to the rail. Many of the minute irregularities of metal structures in the rail are a given factor of rail manufacturing and will most probably never cause an actual rail break. These irregularities are practically undetectable when the rail is installed and therefore the only effective method to prevent breaks from occurring is to monitor the rail for growth of rail defects.

The most common defect is a crack that develops in the crown of the rail, at an angle of approximately 70° relative to the horizontal axis. It is known as a kidney defect, because of its distinctive shape. Various methods have been developed to detect the defects and the most commonly used is a mobile ultrasonic system, which transmits an acoustic signal into the rail and measures the reflection of the waves from the defect. This is a very effective method, but requires scanning of the complete line on a regular basis and is thus very labour intensive. The risk of breaks occurring between scans always exists with this type of detection. Motorised vehicles, equipped with sophisticated ultrasonic and

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Eddy Current measurement equipment, are therefore employed to increase the frequency and efficiency of defect detection.

Although the design of some signalling systems (i.e. track circuits) are such that it often detects clean rail breaks this is not a guaranteed meganism in the signalling configuration employed in South Africa and other parts of the world (single rail traction return). With the move, in the future, to transmission based signalling on lines in many parts of the world, this advantage will however also disappear.

Since the Orex iron ore export line traverses huge distances in desolate country with block sections of up to 90km in length, special measures had to be introduced to detect these breaks and include [1]:

- trolleys employed to manually scan the rails before a train enters the section,
- patrolmen which inspect the rail on a daily basis,
- manual ultrasonic scanning of the rail,
- scheduled ultrasonic and magnetic scanning of the rails for defects,
- reduced train speeds.

These measures are costly and only provide discontinuous protection. Because of these difficulties and the unavailability of a suitable solution in the world market, Spoornet initiated the development of an acoustic broken rail detector, which has the capability of detecting a broken rail almost continuously without human intervention.

2 Technology selection

With the absence of an industrialised system in the world market the development a number of technological concepts was possible. In order to reduce the cost of the selection of the most viable technology, a systematic approach was developed [6]. This was based on the well proven system engineering principles as widely applied in the military industry [2].

2.1 System specification

In order to establish technology trade-off criteria, the overall system requirements were developed from an initial User Requirement Statement [3]. The system requirements was developed through the normal functional and requirements analysis process and resulted in the following functional requirements:

- The installation in the existing infrastructure must be non intrusive
- Minimum additional infrastructure, such as power supplies.
- Existing power supplies of the installed dragging equipment detectors was available with a capacity of 12V @ 10mA continuous.

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- Five bits were available on the existing DED radio communication system (distance between DED installations is approximately 5 km).
- A broken rail with a clean gap of 3mm or more must be detectable.
- The complete line (820km) shall be scanned for broken rail with a maximum interval of 16 minutes.
- The alarms shall be integrated with the existing MMI of the current DED alarm system (MOSCAD)
- Harsh physical and electromagnetic (50kV AC) environment prevails
- Railway lines in South Africa can experience severe lightning storms with densities up to 1.2 strikes/sq-km/month.
- Development should be conducted according to system engineering principles and conform to the normal Railway RAMS requirements

2.2 Technology trade-off

A number of technologies were proposed for further development. These included:

- Traction return current distribution, *
- Acoustic propagation, *
- Track impedance monitoring, *
- Metallic time domain reflectometry, *
- Wire glued onto the rail,
- A train mounted mechanical detector,
- A remote-controlled trolley in front of the train,
- Track circuits,
- Optic fibre glued onto the rail.

A feasibility study was conducted to determine the viability of each concept, which resulted in the selection of the most viable concepts (see * above). The ideal would be to develop all these concepts and to make a selection based on each system's performance. This would however be too expensive and it was decided to use experimental verification of each concept, as well as a value system to trade the different concepts against each other [4]. Each concept owner was contracted to do the minimum experimental verification to enable them to propose a system for development and installation.

A value system was developed, based on the system specification and consisted of all the relevant parameters and their relative weights in terms of user preference. This together with the results of the experimental tests was used to perform a trade off study between the different concepts. The prepared proposals were presented to an experienced panel of railway engineers. Final analysis of the results indicated the ultrasonic broken rail detection concept as the preferred and most cost-effective concept. A contract for the development of "Ultrasonic Broken Rail Detector" (UBRD) system was awarded to the Institute of Maritime Technology (IMT).

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3 Ultrasonic Broken Rail Detector system

One of the major advantages of the acoustic concepts is its non-intrusive nature. Its introduction does not require any alteration to the existing infrastructure such as the traction return current bonding arrangement.

3.1 Basic operation

The system consists of a transmitter units wired to transducers mounted on the rails. These transducers introduce an ultrasonic signal into the rails at a given point (see Figure 1). The receiver transducer receives the ultrasonic signal present in the rail and feed the electrical receive-signal into the receiver unit. The receive unit decodes the information contained in the signal and validates the contents, before generating the output signals.

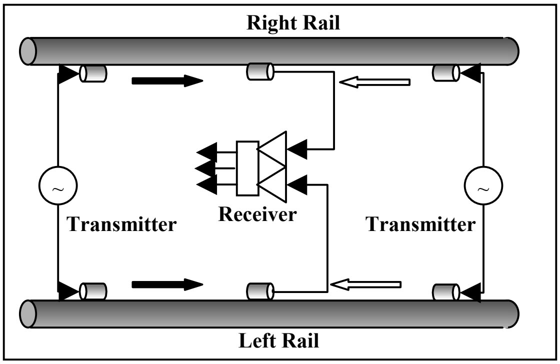

Figure 1: Block diagram of the UBRD.

In order to reduce the component count and improve overall system reliability the same transmitter unit is employed for both rails. The transmitter output signal is first switched to the one rail and on completion of transmission, it is switched to the other rail. The same information is thus transmitted into the rails from a particular transmitter, but separated in time. Alternate transmitters (i.e. the transmitters on the left and right of the receiver shown in figure 1) transmit different information content into the associated rail sections. This allows the application of algorithms in the system receiver to improve detection integrity.

Receivers are generally situated at a distance of approximately 1.8 km from the transmitters. At the receiver, the same ultrasonic transducer on each rail is employed to receive signal from the transmitters on either side. The receive unit have duplicate receiver electronics for each rail transducer and can therefore receive the signals arriving at the receiver location, spread in time.

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3.2 System characteristics

3.2.1 Pilot installation

Approximately 190km of the OREX iron export line was equipped with the UBRD system. This installation was used to investigate detection reliability and the false alarms, and other parameters which could influence the performance of the system. The following investigations were conducted and the results were used to arrive at the current system configuration.

- **Methods of rail coupling**. Determine the consistency of acoustical signal transfer and evaluate different methods of coupling to the rail.
- **Influence of rail temperature (tension) variation.** Study signal strength variation between night and daytime (±25 ºC) as the rail moved from tension to compression state.
- **Influence of section length.** Quantify the attenuation as a function section length.
- **Attenuation characteristics of geographically different sites**
- **Variation of equipment characteristics.** (transducers and transmitters)
- **Position of the receive transducer relative to the acoustic wavelength.**
- **Detection algorithm.** Investigate algorithms to determine the robustness in the presence of electrical corona (50kV AC traction), the effect of storms, and the presence of maintenance teams.
- **Influence of rail defects on the system.** Determine the effect of rail defects with varying size on signal attenuation.

3.2.2 Current system configuration

The results obtained from these extensive tests at the pilot installation, guided the enhancement of the system to its current configuration. Extensive features were built into the system to aid maintainability and improve reliability. Some of the major features of the current system are briefly presented below.

An ingenious clamping meganism ensures easy replacement of the transducer and ensure good acoustic transfer to the rail even under frequent remove and replace cycles.

Failure modes of the various components are incorporated into algorithms which will identify failed equipment rather than producing a false alarm. For example, if the signals from a specific transmitter are lost in both rails at two adjacent receivers at the same time, it is obvious that the transmitter unit has failed.

Parameters such as the pulse repeat rate, duration, receiver gain etc. are easily selected from the front panel of the receiver and transmitter units. LED indications on the front panel are provided to assist the maintainer during fault finding actions. Strategic test signals, such as the amplified receive signal, the analogue detector output, etc. are made available on an easily accessible connector.

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Extensive diagnostic features are present in the software. A complete log of the events is time stamped and kept in the receiver unit. These log files can be downloaded via a RS232 communication port.

A moving window detection algorithm is employed to improve the immunity against spurious noise sources such as corona, rain, and maintenance crews.

The receiver and transmitter units are designed such that a repeater unit is formed when these units are plugged into the same motherboard at a location. This configuration has the advantage of protection on long sections, but have the disadvantage of the whole section being in-active when a train enter the section. If the system configuration is not designed properly this can still lead to false alarms.

3.3 Components of the Ultrasonic Broken Rail Detector system

3.3.1 The ultrasonic transducer

The ultrasonic transducer is used to send and receive ultrasonic signals to and from the rail at an optimised frequency [5]. The head of the transducer is shaped to fit the rail profile and a suitable rail attachment method is incorporated. The head of the transducer is a cast of marine grade aluminium. A piezzo-ceramic stack and a back-mass are housed inside a Ni-Cd plated canister fixed to the head. The stack, the back-mass and the stainless steel electrical connector is hermetically sealed into the unit. The electrical isolation is in excess of 2.5kV. All of this result in a very robust unit with excellent reliability in the harsh railway environment. The operating frequency was fixed, based on the ultrasonic propagation characteristics of the rail. This was deter-mined with extensive tests performed on sections of rail in the laboratory and also on installed rails on an operational line.

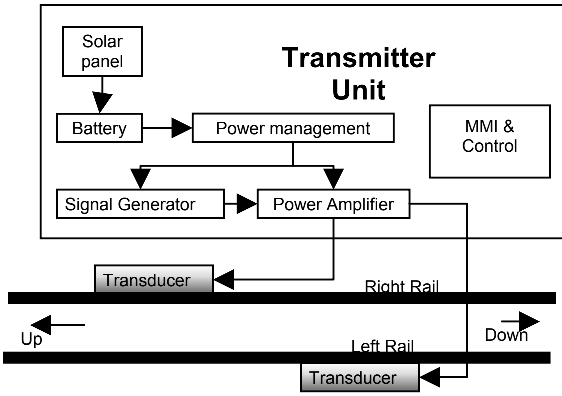

Figure 2: Ultrasonic transmitter unit.

3.3.2 The transmitter unit

The transmitter consists of a power supply, signal generator, a power amplifier and an impedance matching circuit as shown in the block diagram of Figure 2.

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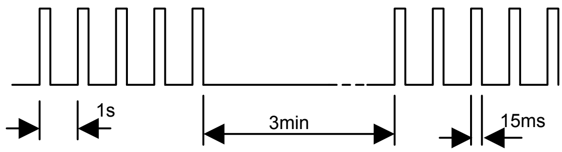

Figure 3: UBRD acoustic signal coding.

The signal generator generates a signal consisting of five pulses at the transmitter frequency. The time spacing between the pulses are settable to suite the application and the available power. The signals from the transmitters at both sides of a receiver are at the same frequency but coded differently. When operated from a solar supply, such as on the Orex line, the signal from one side is transmitted as a 5 pulse train, each pulse separated with a period of 1 second and the pulse duration of 15 ms (see Figure 3). The transmit signal from the other side of the same receiver consists of 5 pulses with a separation of 1.5 seconds and a duration of 15 ms.

3.3.3 The receiver unit

The receiver consists of an impedance matching circuit, an amplifier, decoding electronics and a power supply. A very small signal (approximately 5 uV) is received at the ultrasonic transducer terminals and is send to the preamplifier via the impedance matching circuit. The pre-amplifier amplifies the signal with a gain settable between 92 and 106 dB. The amplified signal is then send to the detector and decoding electronics to decode the signal and check its validity. If three consecutive pulses with the correct time discrimination are received system will indicate a no broken rail. If no valid signal were received within a given period (ten minutes for the Orex line) the system will indicate a broken rail. The status of the four pieces of rail monitored by the receiver will be indicated on the digital interface via opto-isolated bits. A fifth bit indicates the presence of a train within the section. No broken rail detection is available while a train is present in a monitored section.

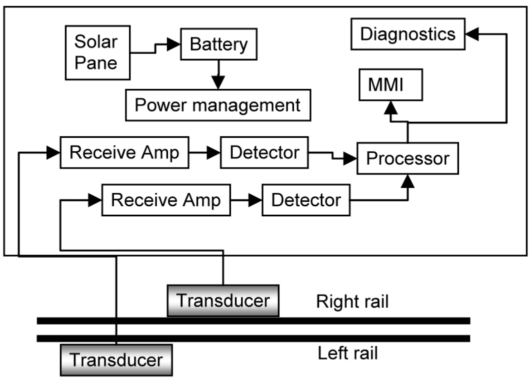

Figure 4: Ultrasonic receiver unit.

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4 System evaluation

This is the first successful development of its kind in the world and has been installed on a trail basis on the Orex line (SA), the CoalLink heavy haul line (SA) and the TTCI test centre in Pueblo, North America. Further trail installations are currently implemented on the lines of NYCT and CSX in the USA. The technical evaluation of the system on the Spoornet lines was completed in November 2002. The development was supported by the UIC and formed part of the Joint Research Project No. 2 [6].

Following the success of the development of the UBRD, Spoornet and IMT has entered into a joint venture with equal shareholding operating under the name RailSonic. The units will be manufactured in South Africa and further applications of the technology are currently under consideration.

5 Conclusion

This paper presented the development of a cost-effective Ultra Sonic Broken Rail Detector. It is the result of extensive research undertook in South Africa, and trail installations in the USA. It was found that the acoustic system is easily adapted to the differing rail profiles, operate in environments ranging from hot and dry South African climates to an extremely cold (snowy) ambient in USA. The acoustic signal propagation over distances in access of 3.5km gives enough detection margins to ensure reliable detection in the presence of various spurious noise sources. The acoustic system is totally non-intrusive and requires no of very minimal additional infrastructure.

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References

[1] Spoornet, Orex Broken rail detector business case, January 2002.
[2] Mil-Std-490, Spoornet, User Requirement Statement: Rail Break Detection System, CSE-1174-015 Cat E42.
[3] Spoornet, Value system for the Rail Break Detector on the Saldanha line, CSE-1174-015 Cat D96.
[4] Philip W. Loveday, Development of piezoelectric transducers for a railway integrity monitoring system, Feb 2000.
[5] J.F.W. Pretorius, “Broken rail detection concepts with a specific focus on the acoustic detection concept”, ERRI, Des 1998.
[6] UIC Report, Report on the Acoustic Rail Break Detector development by Spoornet and IMT, UIC JRP2, March 2002.

Computers in Railways IX, J. Allan, C. A. Brebbia, R. J. Hill, G. Sciutto & S. Sone (Editors)