A Practical Continuous Operating Rail Break Detection System Using Guided Waves

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Abstract

This paper describes the implementation of a system using guided waves in train rails to continuously monitor the rail for breaks. The system transmits guided wave ultrasound between stations spaced at approximately 1km intervals along the line. The transmit stations transmit sequences of signals every few minutes and if these signals are not received at the receive station, an alarm is triggered. Various challenges were faced during the development of the system due to the changing nature of the environment it operates in. The system has proven its worth on South African freight rails, detecting a number of breaks at the iron ore line, potentially preventing extremely disrupting and costly derailments.

Keywords: ultrasonic broken rail detector (UBRD), guided waves

1. Introduction

Many methods are employed to improve the reliability and the timeliness of detecting rail breaks on railway lines throughout the world. Most of these methods are applied at scheduled times, resulting in extended periods during which rail breaks are not detected. These methods are manpower intensive, expensive to execute and sometimes interfere with train operations. With the advent of Communication Based Train Control (CBTC), making track circuits obsolete, operators now stand to lose the rail break detection capability offered by track circuits and an alternative method is required.

Rail breaks are a serious threat on South African freight rails especially during early winter when large day to night temperature swings are encountered and early morning temperatures may dip well below zero. Drastic and expensive measures are taken to prevent derailments of freight trains. With iron ore and coal trains from 2000 to 3700 meters long, and a freight mass of 37,000 ton, derailments are catastrophic and extremely costly.
The Institute for Maritime Technology (IMT) developed an Ultrasonic Broken Rail Detector (UBRD) to warn local freight rail operators when breaks occur. The Railsonic Ultrasonic Broken Rail Detector system continuously monitors rails using ultrasound waves, and reports breaks at time intervals down to a few minutes. It interrogates continuously welded rail in sections up to 1 kilometre long. The ultrasonic transducer used in this system was developed by the Council for Scientific and Industrial Research [1].

The principle of operation of the system is described in section 2 and various challenges encountered during the development of the system are presented in section 3. The current status and future development plans for the system are discussed in section 4.

2. Operating Principle and System Details

Guided waves propagate reasonably well in steel rail. The principle applied with the IMT Ultrasonic Broken Rail Detector is that the rail is excited with pulsed ultrasonic signals at one point, and monitored for the presence of these signals some distance away. Should the signals not arrive at the monitor point, an alarm is triggered. Transmit and Receive stations are interleaved along the length of the rail as shown in figure 2.
A specific Receiver receives signals from both rail directions (up and down). To enable Receivers to determine the direction from which acoustic energy originates, Transmitters insert a burst train consisting of 5 pulses at a pre-set Burst Repetition Interval (BRI) into the left rail, followed by a sequence at a different Burst Repetition Interval into the right rail. The BRI’s are set differently at adjacent transmitters. Burst Trains are repeated at a specific Interrogation Interval (II). See figure 3.

To ensure that received burst trains from the Up and Down directions do not overlap for extended periods at a specific Receiver, causing false alarms, adjacent Transmitters are factory set to different Interrogation Intervals (II).
Receivers measure the BRI’s to identify the direction of the specific Transmitter station. For this purpose, Receivers are also individually set to recognise specific BRI’s as arriving from either the Up, or Down direction, depending on the settings of adjacent Transmitters.

Receivers recognise valid signals using the following filtering criteria:

a) signal frequency
b) burst length
c) burst repetition interval

Severe continuous noise at a Receiver will jeopardize valid signal detection, regardless of detector efficiency. An approaching train will manifest as a typical case. Under such circumstances, the Receiver will indicate “Train in Section”, stop processing received signals, and remain dormant until the noise subsides, after which it will activate and resume normal functioning.

High voltage driving pulses generated by Transmitters are converted into acoustic energy by the ultrasonic transducers and propagates in both directions along the rail. The permanently installed transducer is kept firm in contact with the rail using a heavyweight rail clamp. Receiver transducers are similar to the transmitter transducer shown in figure 4.

![Figure 4: Rail Transducer with Mounting Clamp](image)

The system can be solar powered if power is not available as shown in figure 5 (left). The receiver station contains signal detection electronics for detecting the very small signals received by the transducers – see figure 5 (right).
3. Implementation Problems

The challenge here is to select the correct frequency and excitation configuration that will result in an effective propagation mode for signals to reach a reasonable distance, and to construct a low noise amplifier/filter enabling detection of minute signals at the Receiver (<1 uV). It is essential that the system does not produce false alarms. Although the principle is quite simple, the following issues make practical implementation and reliable operation (absence of false alarms) problematic:

(a) Big variance in signal propagation loss

(b) Large changes in received signal amplitude due to temperature effects

(c) Logic to prevent false alarms during periods of train movement induced noise

(d) Signal cross talk between rails

(e) Lay out design to ensure that equipment failures will not cause false alarms

(f) Hardening of electronics for very hostile EMI environment, both traction and lightning induced surges.

(g) Presence of Insulated/Bolted joints and turn-outs
Figures 6 and 7 below show the large variance in signal propagation loss due to different rail types, curves in tracks, and the presence of insulated joints.

**Figure 6:** Measured 60 kg Rail Propagation Loss at the UBRD Operating Frequency

**Figure 7:** Measured SAR 60 Rail Propagation Loss at the UBRD Operating Frequency

Temperature related received signal level changes also varies form position to position, and is different for different rail types and type of track civil construction. Figure 8 below shows temperature influences at a specific location. Note the drastic drop in signal level in the case of the second 06h00 period caused by a slight lower temperature (1.5 ºC).
4. Current Status and Planned Developments

After many years of fine tuning, the system is now able to detect breaks and is false alarm free at the freight rail installations. The currently installed system interrogates continuously welded rail in sections of 900 meters long on average (dependent on the condition of the rail). It has proven its worth on South African freight rails, detecting 3 breaks in a 34 kilometre section of the iron ore line (OREX) in 15 months, potentially preventing derailments which cause extensive damage and financial loss. Roll-out of the system over the entire 850 km OREX line is expected to commence within the next few months.

The SA Department of Science and Technology is generously sponsoring a program to upgrade and modernise the system. The aim is to achieve 1800 meter operating range, and to ensure compatibility with all rail types, and the metro environment (small time interval between trains). The current system, which was developed before the year 2000, will be upgraded to include newly developed ultrasonic transducer technology, and state of the art electronics and signal processing technology. The size of the much smaller but optimised (much more effective) transducer now makes it possible to position the transducer under the rail crown on the inside of the rails. This has a major advantage since the transducer can stay in place during rail tamping operations, whereas the current version transducer has to be removed.

With low power digital signal processor technology now available, the new receiver will use sophisticated transient analysis techniques, which should drastically improve performance and adaptability for different rail types (frequencies). It should be able to work reliably at low signal to noise ratios, where the current system requires up to 50 dB signal to noise ratio. Faster operation to cope with metro train intervals will also be possible.
5. References