Broken Rail Detection On Lines Without Track Circuits

This presentation introduces a new method of detecting broken rails, which depends on electrically detecting the continuity of the rails using wayside equipment. It is primarily intended for lines where train detection is provided by some means other than track circuits. The method is believed to be novel and is the subject of UK patent application GB 00 08480.6. International patent protection is being sought. The method forms the basis of a broken rail detection system being developed by AEA Technology plc.

Operating Principle

The basic circuit of the broken rail detector is shown in Fig. 1.

![Fig.1: Basic circuit diagram](image)

The extremities of the detection zone are defined by two low impedance connections between the rails, and these behave as electrical short-circuits. A source of electric current is applied between these connections, so that electric currents flow in both rails. The rail currents are monitored, typically by a pair of current sensors attached to the low impedance connection at one end of the detection zone. A detection device compares the signals from the current sensors.

If both rails are unbroken, the current divides equally between the two rails: that is, the rail currents are balanced. It follows that the signals from the current sensors are also balanced, and the detector interprets this condition as an indication that the rails are unbroken.

If either rail is broken, the current in that rail is reduced, and most of the current flows in the other (unbroken) rail. In this case, the signals from the current sensors are unequal, and the detector interprets this unbalanced condition as an indication that one of the rails is broken.
Leakage

The current in the broken rail is zero at the location of the break, but is not necessarily zero elsewhere. This occurs because the rail break is bypassed by the electrical leakage paths that exist between the rails and ground. If there is a significant distance between the current sensors and the break, then these leakage paths allow current to transfer from the unbroken rail to the broken rail, reducing the imbalance measured by the current sensors.

There are two fundamentally different mechanisms for leakage:

- **near-surface conduction**: in which current flows directly from one rail to the other rail, via paths at or near the earth’s surface;
- **deep-earth conduction**: in which current flows from one rail to the other rail, or from one part of a rail to another part of the same rail, via a low impedance region deep inside the earth.

The imbalance of the measured rail currents varies with the position of the rail break. Consequently, it is necessary to limit the maximum length of the detection zone so that the smallest imbalance due to a rail break can be distinguished from random imbalances that may occur when there is no rail break.

Modelling

The relationship between the imbalance and the various controlling parameters is extremely complicated. It is affected by the electrical characteristics of the rails at the chosen operating frequency and the leakage paths; it may also be affected by the presence electrification and earth connections to one or both of the rails.

This relationship has been investigated using theoretical models based on an extension of classical transmission line theory. Second-order differential equations were developed describing the incremental changes in rail voltage and rail current over the length of an elemental section of track. General solutions for the distributions of the rail currents throughout the detection zone were determined by integrating these equations. Particular solutions were determined by applying the boundary conditions for the rail break and for the extremities of the detection zone. The theoretical results have been confirmed using circuit simulation software, and have been compared with practical results obtained from measurements on a test track.

Results

For simplicity, the results discussed here relate to excitation at zero frequency (DC) only, and assume that the circuit has no electrification and earth connections.
The results are expressed in terms of a parameter $U$, which describes the magnitude of the imbalance between the rail currents as measured by the current sensors. When the rail currents are exactly balanced, $U = 0$. When the currents are unbalanced, $U > 0$, having a maximum value of $U = 1$ if all the current flows in one rail.

The graph of Fig. 2 shows examples of the variation of $U$ with $X$, the distance between the current sensors and the break. For convenience, this distance is normalised: $X = 0$ represents a break adjacent to the current sensors; $X = 1$ represents a break at the far end of the detection zone. All these examples relate to a detection zone of length 4.2 km, and assume continuous welded rail with a leakage of 0.5 mho/km.

![Fig. 2: Variation of imbalance with position of break](image)

The upper (dashed) curve shows the theoretical variation of $U$ with $X$, assuming that all leakage is by near-surface conduction. The lower (dotted) curve shows the theoretical variation of $U$ with $X$, assuming that all leakage is by deep-earth conduction; this curve displays a minimum at $X = 0.75$ (i.e. with a rail break exactly three-quarters of the way along the detection zone). The centre (continuous) curve shows the practical results, which suggest that deep-earth conduction is the dominant leakage mechanism. Curves like these can be used to determine suitable constraints on the maximum length of the detection zone.

**Development Issues**

Practical tests have shown that AC operation is preferred; DC operation is susceptible to electrochemical effects in which the rails act as the electrodes of a battery. AC operation offers further advantages. Firstly, by operating adjacent detection zones at different signal frequencies, unwanted interactions between detection zones can be avoided. Secondly, by
choosing suitable signal frequencies, interference from electric traction systems can be
minimised. However, as the signal frequency increases, so do the series impedance of the rails
and the deleterious effects of leakage. Thus, to avoid unduly restricting the maximum length of
the detection zone, it is important to use very low signal frequencies. Signals in the frequency
range 4 Hz – 15 Hz are proposed for the system being developed by AEA Technology plc.

The use of such low frequency signals introduces special challenges for the system designer,
which add to the normal problems arising from the hostile environment of a railway. The
system under development will use noise-like signals that lend themselves to digital signal
processing. The preferred form of signal is a pseudo-random binary sequence that is frequency
translated into the desired frequency band using double side-band suppressed carrier
amplitude modulation. Such signals are easy to recover using synchronous demodulators, and
they have auto correlation properties can be exploited during signal detection and signal
estimation.

Conclusions

This presentation has described a new track-based method of broken rail detection for use on
lines without track circuits. The technique is limited by electrical leakage, deep-earth
conduction being the more significant of the two leakage mechanisms. Theoretical models and
practical measurements indicate that detection is possible over useful distances. AC operation
is preferred; but to maximise the length of the detection zone it is important to operate at a
very low frequency. A practical system is now being developed, and is expected to make
extensive use of advanced digital signal processing techniques.