A Pedestrian and Vehicle-Mounted System for Detecting RCF in Rail using Eddy Currents

Scott SAUNDERS 1, Robert CROCKER 1
1 Sperry Rail, Derwent House RTC Business Park, Derby, UK
Contact e-mail: 
ssaunders@sperryrail.com, bcrocker@sperryrail.com

Abstract. Rolling Contact Fatigue is an expensive problem for railway companies predominantly due to increases in freight tonnage, vehicle speeds and cant deficiency. In order to maximise rail lifetime it is necessary to optimise grinding regimes so that exactly the right amount of the surface of the rail is removed. This requires accurate knowledge of not just the locations of surface cracking regions but also the depth to which it permeates below the surface of the rail. This paper outlines a system developed by Sperry Rail which has been successfully assisting railways across the globe in this endeavour for the last two years. The data generated by the system has resulted in a number of interesting discoveries that have motivated significant changes in attitude to how rail infrastructure should be managed. Some of these discoveries will be presented along with the actions that they have motivated.

1. Introduction

The Hatfield high speed rail disaster which occurred just north of London in October 2000 sent a ripple through railways around the world that can still be felt today. Along with the devastation that accompanies all derailments, Hatfield was different in that the rail appeared to have shattered into many fragments that were spread throughout the site. The subsequent enquiry [1] found that the cause of the accident was a distributed surface defect known as Gauge Corner Cracking (GCC) which belongs to a broader category of rail defects known as Rolling Contact Fatigue (RCF).

Fig. 1. Fragments of rail scattered during the Hatfield rail disaster
In the time since the accident, much work has been done to try to determine the causes and the most effective way of dealing with RCF. Because of the large number of variables that contribute to its formation, modelling the phenomena is extremely difficult [2, 3], however it is generally accepted that it occurs when the rail repeatedly experiences a stress regime that exceeds the limits that it was designed to tolerate. The reason that RCF has only become a widespread problem in the last few decades is because the higher speeds and higher axle loads of the modern era, coupled with non-ideal track geometry, often exceed these limits. As population increases, both speeds and axle loads will increase and so RCF is likely to remain a problem for the foreseeable future. Most railways around the world are focusing their efforts on trying to minimise it, and on managing it through suitable maintenance practices.

2. Rolling Contact Fatigue

As rail steel endures millions of axle loads, the shear forces exerted can cause the metal to slowly deform and harden. If the stress is large enough, the deformation can be sufficient for the structural integrity of the steel to be compromised resulting in the formation of tiny cracks on the running surface. If the axle loads continue without maintenance, the plastic deformation increases and the cracks grow to the point where they could threaten to cause a rail break.

![Fig. 2. Surface damaged rail: heavy RCF (left) and severely damaged rail (right)](image)

The stresses experienced by the rail are generally greater in curves in the track as the train’s position moves up and down the rail as dictated by the centripetal force and the cant of the track (see Figure 3). The problem is exacerbated if the curve is traversed at a number of different line speeds as the cant of the track cannot satisfy every speed and so invariably there will be a “cant-deficiency”. The higher shear forces that this situation causes result in a higher probability of RCF formation.
Like any material that experiences repetitive stress and abrasion, over time rail steel also wears away through everyday use. This natural wear rate is often insufficient to remove enough steel to avoid the formation of cracks hence additional maintenance is required. This additional maintenance usually takes the form of a grinding (see Figure 4) or a milling machine to remove material from the surface of the rail. Assuming that the maintenance has removed the cracks entirely, fresh steel is revealed which will then resist further cracking. Obviously if more steel is removed than necessary then the rail life is reduced and so balancing these conflicting requirements results in what has been termed a “magic wear rate” where rail is removed (through grinding, milling and/or natural wear) at a rate that maximises the life of the rail [4]. Figure 5 illustrates how the life of rail can be extended through an appropriate maintenance schedule.
Although RCF generally develops in fairly localized regions of anything from a few metres to a few hundred metres in length, these regions are spread relatively thinly and locating them is far from trivial. In the UK, Network Rail maintains approximately 32,000 km of track and until relatively recently, the majority of the RCF inspection had been done manually by employees who walked the track, often at night, trying to find RCF regions with a flashlight. Not only is this an expensive and inefficient method, it is also ineffective in detecting the cracks when they are very small which most agree is the optimum time to do something about them. Sperry Rail Limited has developed a Surface Crack Detection (SCD) system which has been successfully locating and classifying RCF in a number of European rail networks for the last three years. The rest of this paper will give an overview of the system and report on the impact that it is having on train scheduling and the way that maintenance is carried out on the network.

3. The Surface Crack Detection Roller Search Unit

Sperry has been testing railway tracks for defects using a number of different NDT techniques since 1928. In the 1960s their ultrasonic Roller Search Unit (RSU) system was introduced and it is still used to this day. This system encloses the ultrasonic transducers in a polyurethane tyre allowing testing through switches and crossings without needing to lift the RSU. Introduced in 2013, the SCD system employs the same fundamental concept. The new eddy current RSU consists of ten absolute eddy current sensors interleaved in two rows giving full head coverage of the rail. The coils are individually spring loaded so that they press lightly against the surrounding membrane which is in turn pressed down to conform to the curvature of the rail head. By getting the down-pressure and the spring constants just right the wheel is able to turn and the lift-off of the probes is dictated by the thickness of the tyre.
The SCD RSU can be considered a smart sensor in that the drive electronics, analogue signal conditioning, digitisation circuitry and digital signal processing are all housed within the RSU itself. The system is capable of driving its coils with up to four different frequencies simultaneously allowing advanced defect detection techniques to be used. Power over Ethernet (PoE) is used to power and communicate with the sensors which simplifies wiring requirements. Every millimetre, the RSU sends a data packet back to the host application for storage. This data packet contains the current state of the probes and consists of an In-phase and a Quadrature component.

Eddy current probes are notoriously sensitive to lift-off and in the often unpredictable railway environment, this can cause a significant problem for any eddy current testing system. As well as protecting the probes and dictating a precise lift-off, the tyre that surrounds the RSU uses this sensitivity to its advantage. A patented tyre fabrication process allows the metallic properties of the rail as well as the operating angle in the impedance plane to be measured throughout the testing period.

The system is capable of measuring cracks that permeate deeper than the skin depth of steel. This result can be explained using a thin-skin approximation which has been verified though electromagnetic simulations using the Maxwell FEA package from Ansys Inc. The current system routinely reports cracks that reach up to 5 mm below the rail surface and although the response to deeper cracks falls off asymptotically, the maximum reported crack depth is likely to increase in the future. On numerous occasions the accuracy of the results have been verified by extracting rail from the network and destructively testing it by milling layers of steel until the cracks have disappeared.

4. The Train Based System

When mounted on a train, an individual system routinely tests hundreds of kilometres of track per shift. The normal testing speed is currently 50 km/h however trials have indicated that this will be able to be increased to at least 80 km/h. The system can test in all weather conditions and is relatively easy to set up and operate.

After a test is complete, the raw data is passed through a suite of processing algorithms which extract not only the location of any distributed surface damage but also calculate the depth and width of the deepest and widest cracks on a per metre basis. This information is
used to allocate a severity to the damage in that metre of rail before it is tagged with location information including railway mileage, GPS, track ID, region, etc.

Future development will allow the system to be able to recognise numerous track features such as rail ends, welds, and switches. This information will feed back into the route maps to help keep them up to date. The system is not sensitive to grinding marks however defects that are visible in the raw data include squats, wheel burns and Belgrospi. In the future these will also be included in the final report issued by the system.

![Fig. 7. A squat defect (left) and Belgrospi (right)](image)

The train-based system is currently actively testing in the UK, Ireland, Switzerland, Belgium and the USA with numerous other countries showing interest. Each client generally has slightly different reporting requirements so the deliverable has been tailored in each individual case to simplify the integration into their respective infrastructure monitoring systems.

5. The Pedestrian “Walking Stick” System

The train based surface crack detection system is also accompanied by a pedestrian “Walking Stick” device. This instrument mounts an eddy current RSU that is identical to the ones used in the train based system in a frame that can be pushed along the rail. It is often used to record data in sidings or other hard to access sections of the network as well as to verify measurements recorded by the train based systems. Because the RSU is identical, the data can be directly compared between the two systems.

![Fig. 8. The surface crack detection walking stick](image)
The walking stick offers numerous different viewing modes including a C-Scan mode that gives a colour coded plan view of the rail. It also has the ability to tag locations of interest which then appear on the report so that they can be easily located in the future.

![Fig. 9. An unusual surface defect](image)

**Fig. 9.** An unusual surface defect

![Fig. 10. A C-Scan representation of the defect shown in Figure 9 captured by the SCD walking stick](image)

**Fig. 10.** A C-Scan representation of the defect shown in Figure 9 captured by the SCD walking stick

The SCD walking stick has been used in the United Kingdom for some time and more recently in Ireland, The Netherlands, Sweden, Germany, Switzerland and the United States. Interest in other regions, most notably in Asia and Australia is rapidly developing.

### 6. Interesting Discoveries

On multiple occasions the system has indicated surface damaged rail in unexpected areas. When this has been investigated with representatives of the railway, they are often initially adamant that there is no way that there could be any RCF in the locations that have been reported until almost invariably, a careful investigation has indicated that indeed the rail is
damaged just as the system indicated. Often the damage is localized and sometimes even found on straight track. This suggests a formation mechanism other than the traditionally accepted one that RCF should be found on the high rail of curves. In almost all cases, the cause of the localized surface damage is not difficult to determine. An example could be when ballast subsidence leads to insufficient rail support which intensifies the stresses on the rail leading to surface cracking. This is not unlike the softening of a metallic wire by bending it back and forth repeatedly. If the damage is on a curve leading into a station, the different speeds of trains that pass through the station compared to trains that stop at the station lead to a cant deficiency in the curve that again exerts non-ideal stresses on the rail. In a number of Network Rail sites where this has been found to be the cause of the surface damage, the speeds of the trains have been standardized so that all traffic goes through that track section at the same speed.

Another behaviour that can lead to RCF formation is the hunting of a train as it leaves a curve. Patches of RCF can often be found first on one side of the rail, then a little further down on the other side as trains repeatedly “hunt” back and forth until they find an equilibrium.

The system is helping evaluate new high performance rails that are starting to be used to resist the formation of RCF. Because the main lines are tested regularly it is possible to apply data mining techniques to find trends over long periods of time. New visualization techniques are being created in order visualize these and trends and to make sense of the data.

Fig. 11. Visualization of how cracking varies around corners. The top curve shows curvature while the blue dots show crack depths on the left and right rails

In the United Kingdom, the SCD system allows Network Rail to upgrade the severity classification of ultrasonic defects if they are located within an area of RCF. If a rail breaks in an area that is free from other defects, it is unlikely to cause a derailment as the support structure of the rail is designed to be able to hold the two sections of the rail together allowing trains to safely pass. If the rail break occurs in an RCF region there is a high possibility that the surface cracks could compromise the structural integrity of the rail around the break and cause the rail to fracture into many pieces as it did in the Hatfield disaster.

The railways of the USA are used predominantly for freight and as such there is significantly less pressure on the railways to maintain their rail. The result is excessive
surface damage that often renders ultrasonic inspection impossible. It has recently been proposed that the surface crack detection system could be used to identify when the surface damage has reached a point where the track is untestable and so should be re-railed.

Almost ironically, the system seems to have initially had an apparently negative financial impact on the railways because many of them have been required to put speed restrictions in regions that contain RCF beyond a certain threshold. This is of course preferable to not knowing that the damage is there at all as it reduces the chances of a catastrophic accident. As the railways slowly start to get control of the problem through directed grinding and other track maintenance, these speed restrictions will become less frequent and rail operators will start to see a significant positive financial impact. By adhering to the magic wear rate, rail life should be maximized while passengers will enjoy a much safer travelling experience.

7. Conclusion

This paper has introduced a new surface defect detection system that is has been testing the railway networks of many European countries for a number of years. An overview of the both the train based and pedestrian systems has been given along with a brief discussion of some of the discoveries that it is allowing the railways to make. The system is already a powerful tool which is increasing the safety of rail networks while simultaneously reducing the cost of maintaining them.

8. References


