Non invasive rail track detection system using Microwave sensor

K. Vijayakumar, S.R. Wylie, J. D. Cullen, C.C. Wright, A.I. Al-Shamma’a.

General Engineering Research Institute (GERI), Liverpool John Moores University, Byrom Street, L3 3AF, United Kingdom

V.Karunamoothei@2006.ljmu.ac.uk

Abstract. As fuel costs continue to rise, efficient public transport, especially rail will play an increasingly important role in the UK and worldwide. For the safe operation of the rail system, it is necessary that the condition of the rails can be monitored on a continual basis. An important part of this monitoring process is crack detection. Much research effort has been spent in the development of reliable, repeatable crack detection methods for the use on the service rail. In this research a new crack detection method has been investigated which utilizes microwave sensors to inspect the rail surface. Initial data from experiment are presented.

1. Introduction

This research has investigated a new crack detection method for rail tracks which utilizes microwave sensor to inspect the rail surface during the passage of a train wheel. The main idea is to design a new sensor that can obtain a level of accuracy well above the industrial demands of 95% to detect defects in rail tracks. This research could be a vital progression for the railway industry. The railway was one of the key factors in the industrial revolution and the development of the modern industrial societies of the world. The need for good transportation for both freight and passengers is still just as important in modern society. It is even argued that the railways alone had the largest impact of all innovations in initiating economic growth providing the people in industrial societies with higher living standards [1]. Britain for instance has 16,116 route kilometres which need to be inspected and maintained if derailments are to be avoided. Since 1995, nineteen new sections of passenger line and 52 new stations have been added. Britain now has the fastest growing railway network in Europe with passenger kilometres rising by 43.1% during 2006/07 and journeys by 43.8% compared to ten years earlier. Freight tonne kilometres have increased by 49.6% during 2006/07 [2]. About 400 accidents occur every year easily one of the worst in world, of which 60% are caused by human error. Derailments account for 70% of all accidents, with level crossing accidents accounting for another 25%. These statistics speak for themselves, unless something is done immediately, accidents and the consequent loss of life will be inevitable [3]. In Britain, derailments occur about twice a week and although the vast majorities are minor, serious accidents such as the Hatfield rail crash which occurred on 17th October 2000, will happen. The train was travelling at over 115mph, four people were killed and a further seventy injured. The investigation found was that a rail had fragmented when the train passed over it, and that cause was "gauge corner cracking" which mean microscopic cracks in the rails. Such cracks are caused by the high loads under the wheels, where the wheels make contact with the rail surface [4]. Another fatal accident occurred on 23rd February 2007, when a train travelling at
about 145kph (90mph) from London to Glasgow derailed near the village of Grayrigg, one passenger
died and twenty-two were injured. The accident came five years after defective points caused Britain’s
last major rail disaster at Potters Bar in 2002[5]. In this paper we introduce a Microwave horn antenna,
which is being used to detect the crack in rail track.

2. Microwave Theory
Basiclly it is describes about the electromagnetic waves with wavelength ranging from 1mm to
1m. The frequency between 0.3 GHz and 300GHz, in free space [6]. An electric field is created by
electric charges and a magnetic field is created by moving electric charges. A time changing magnetic
field produces an electric field, and vice versa. These electric and magnetic fields are represented by
Maxwell’s equations. The solutions of Maxwell’s equations are electromagnetic waves in which
electric and magnetic fields travel together through space at the speed of light [7,8]. The features of
electromagnetic waves are frequency, wavelength, impedance, power density and phase. Microwave
systems transmit microwaves from their transmitter through space to a receiver [9]. But inside the
transmitter and the receiver, microwaves cannot be conducted efficient by wires, so they are
transmitted from one component to another inside microwave transmission lines [10].

3. Microwave Horn Antenna
Microwave horn antenna may be involved as a flared-out or opened out waveguide [11]. The horn will
produce a uniform phase front with larger aperture than the waveguide with greater directivity [12].
Microwave horn antenna with dimensions 42mm length and 30mm width has been used for the
experiment. With a frequency range between 8GHz to 12GHz. The simulation result using High
Frequency Simulation Structure software (HFSS) is shown in Fig.1.

4. Model simulation result by using HFSS
High Frequency Structure Simulator (HFSS) is an interactive software package which been used to
understand how the Microwave Horn Antenna and the rail interact. HFSS is the industry-standard
software for S-parameter and this software has been developed to allow for 2D and 3D visualization of
the radiation pattern for many different types of antennas including Microwaves Horn Sensor [13,14].
HFSS not only improves engineering productivity, reduces development time and better assures first
pass design success, but also make, it easy to design, simulate and validate complex high performance
RF, microwave, millimetres wave device and so on. An HFSS project is a folder that includes one or
more HFSS models, or designs [15]. Each design ultimately includes a geometric model, its boundary
condition and material assignments, and field solution and post-processing information.
Figure 2 shows the E-Field of the Microwave Sensor, the E-Field of the Microwave Horn Sensor. It is found when the crack is closed the minimum $S_{11}$ shifts to a lower frequency.

Figure 3 presents the XY pattern Graph of Microwave horn sensor. It shows that the simulation result occurs in the xz plane when there is no defect occur in rail track.

Figure 4 shows the E-Field of the Microwave Sensor, it is found that the electric field is in the outward direction from the defect rail.
Figure 5: $S_{11}$ Plot result for the crack surface

Figure 5 presents the $S_{11}$ for a range of frequencies at the crack. The cut-off frequencies are a 23mm×10mm TE$_{01}$ or TE$_{10}$ is 6.5GHz.

5. Experiment set up using Microwave sensor

The experiment setup is shown in Fig.6 a microwave test set used to drive the horn and measure the amount of power reflected from the track over a range of frequency as the horn is moving along the track shows the variation in signal at 9.5GHz as the horn passes over the crack which as shown in Fig 7 and Fig 8. The data presented here constitutes the first step in the development of a train based analysis system for defect detection in rails. All the results are analysed using a spectrum analyzer. This is used to primarily measures power and frequency. The spectrum analyzer is used to locate and measure the power/energy of the electromagnetic wave reflecting off the rail track frequencies between 8 GHz and 12 GHz. A sample of rail track which is 400mm long has been used for testing purposes. In this experiment an additional crack has been added. The reason is to identify in more detail how accurately the Microwave sensor can detect the crack, in order to get good output. Fig.6 also shown the output from the spectrum analyser at the same cracks, the reading was constant as shown in Fig.6, until the crack is reached. They have a width between 0.2 to 0.3 cm. The electrical field will usually effect back from the normal surface, but it will be radiated to free space when the gap occurs in the rail track and only, very limited amounting electrical field will reflect back. That can be seen clearly in the graph as well on the spectrum analyser.

Figure 6: Experiment set up testing using Microwave horn antenna
Figure 7: The output result obtain for second phase experiment

Figure 8: Experimental results obtained using microwave horn antenna

Figure 9: The minimum S11 value shift to a higher frequency when there is a defect

Figure 9 show the simulation result obtain with two different reading, that is reading obtain with rail track without defect and rail track with defect occur. Based on the result, it can be seen clearly the
different between the two output. So, it can be said that with using the Microwave sensor to detect a defect in rail track in future is a good idea because the result is more accurate compare with other current technology.

6. Conclusions
This paper discusses how a Microwave horn antenna has been used to detect the cracks in a rail track. Based on the simulation results obtained from the High Frequency Simulation Structure (HFSS), it has been shown that the current design of the Microwave sensor has the potential for detecting defects in the rail surface including minor cracks as well as more serious flaws. Further simulation tests have to been carried out to investigate maximum depth for which the sensor can detect these cracks and also the accuracy of the detection.

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