The future of rail inspection technology and the INTERAIL FP7 project

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Rail infrastructure managers are showing strong interest in the development of novel techniques for the reliable and accurate evaluation of rails which will lead to the improvement of the efficiency of preventive maintenance and reduce the need for reactive maintenance to the lowest possible level. Commonly employed rail inspection methodologies do not achieve the highest level of reliability and cost-effectiveness objectives required by the industry. Inspection systems based on conventional ultrasonics probes will remain the main rail evaluation method in the foreseeable future. However, an integrated high-speed system which will combine automated visual inspection, with electromagnetic sensors and conventional ultrasonics could offer a more efficient and reliable method for inspecting rails in the short to medium-term. This would also allow sufficient time for novel non-destructive evaluation technologies under development to mature adequately before being successfully implemented. This paper will discuss in detail the novel rail inspection technologies currently being researched as well as the technical developments within the INTERAIL FP7 project which started in October 2009. Furthermore, the short and long-term outlook of rail inspection technology and standards will be thoroughly presented. Finally, the steps that need to be taken to ensure the successful application of new technologies in the field will also be analysed.

1. Introduction

Defects in rails can develop in the head, web or foot of the rail. The majority of rail defects are detected on the rail head although a significant number of defects are also found on the web as well as the foot of the rail. Rail head defects include kidney-shaped fatigue cracks, horizontal cracking with or without transverse cracking of the rail head, horizontal cracking beneath the gauge corner, longitudinal-vertical cracking, Rolling Contact Fatigue defects (such as gauge corner cracking, head checks, squats, shelling, and corrugation), wheelburns, and indentures. Rail web and rail foot defects include longitudinal and vertical cracking, cracking occurring at fishbolt holes or other holes found in the web (star-cracking), transverse fatigue cracking, and rail foot corrosion [1-3]. Defects in rail welds such as shrinkage cavities, porosity, inclusion and coarse dendrite microstructure that may develop during the solidification process adversely influence the structural integrity and fatigue performance of a weld by acting as crack initiation points [4]. Rail tracks are commonly inspected either visually, or using ultrasonic testing, eddy current testing, magnetic flux leakage testing or magnetic particle inspection carried out by appropriately trained personnel walking along the tracks and noting down any defects or missing components. Automated vision is also employed for profile and corrugation measurements. Radiography has found limited use in weld inspection [5-6].

UT of rails is carried out manually using walking sticks and portable instruments or at speed with hi-rail vehicles and special test trains [5-6]. High-speed ultrasonics systems have limited ability in detecting RCF type defects due to limitations in resolution as well as other issues associated with the inspection parameters as well as the deployment methodology. Although some commercial UT systems are capable of operating at speeds up to 100km/h, UT inspection is commonly carried out at lower speeds which sometimes may not exceed 15km/h. Hi-rail vehicles in particular operate at 15km/h [5-6]. UT measurements can be complemented by MFL or eddy current sensors to increase the probability of detection of surface and near-surface defects [5-10]. Nonetheless, MFL and eddy current sensors are also employed on their own either using manual carriers or at speed by installing the sensors on hi-rail vehicles or test trains. MFL and eddy current sensors in particular require good lift-off control. Automated vision is used as an important tool for the measurement of the rail head profile, percentage of wear, rail gauge, corrugation, failed sleepers, missing components and depending on the speed of inspection for RCF detection [11]. Certain vision systems are portable, whilst others are deployed at high speed by test trains. Recently, automated vision systems have been integrated with UT sensors to allow inspection of internal defects at the same time with the visual assessment of the rails [12-13].

Rail welds due to their large grain microstructure cannot be reliably inspected manually or at speed with conventional UT systems due to significant attenuation of the ultrasonic beam [14]. Nonetheless ultrasonic phased arrays have generated some promising results [15]. The use of radiography is possible but so far has found limited use within the rail industry [14].

2. Rail inspection research

Several alternative inspection techniques capabilities in the field are currently under development. Such techniques include ultrasonic phased arrays, Alternating Current Field Measurement (ACFM) sensors, guided wave systems, laser ultrasonics, Electromagnetic Acoustic Transducers (EMATs) and acoustic emission [5, 15-40]. The aforementioned techniques are currently under different stages of development with some having reached the stage of commercialisation already.

Ultrasonic phased arrays have been used in pilot studies for the assessment of rail welds [15-19]. They have also been used for the assessment of RCF cracks [19]. Ultrasonic phased array systems have been widely used in other industrial sectors but so far their application in the rail industry has been limited. Under manual inspection conditions, it is not the characteristics of the ultrasonic phased array systems themselves but the inspection procedure and relevant standards which require further development for widespread application of ultrasonic phased arrays within the rail industry.

Portable Alternating Current Field Measurement (ACFM) inspection systems have been used for the evaluation of RCF defects during trials in the UK and Portugal. ACFM walking sticks incorporate an array of probes which is shaped to conform to the shape of the head of the rail. The inspection across the rail head is carried out by sequentially scanning across the group of sensors enabling the uninterrupted inspection of the rail. The ACFM array can detect and size gauge corner cracks and head checks smaller than 2mm in depth at inspection speeds 2-3km/h [20-22]. A high speed ACFM array system is under construction by the consortium of the INTERAIL

FP7 project for inspection of the rail head surface at speeds up to 80km/h [13, 23-25]. The system is intended to undergo field trials in Portugal at the end of 2012.

Guided wave systems have been tried out in the UK and North America for the evaluation of long welded rail sections, including level crossings [26-30]. Such systems are sensitive to transverse defects and need to be big enough to reflect back a sufficient proportion of the transmitted energy otherwise they cannot be detected.

A hi-rail vehicle-based non-contact laser ultrasonics system has been tested by Tecnogamma S.p.A. (now part of the MER MEC Group of companies in Italy) in collaboration with the Transportation Technology Centre Inc. (TTCI) in North America [31]. The developed system has not been made available commercially but its further development is under consideration once further funding becomes available.

The applicability of EMATs for rail inspection was tested using a hi-rail vehicle for deployment purposes by Tektrend (now part of NDT Olympus) between 2000 and 2001 [32]. Since then a high speed EMAT guided wave system based on a pitch-catch concept (shown in figure 4) has been under development by UK researchers from the Universities of Warwick and Birmingham, and the I-RAIL consortium which is funded by the European Commission under Framework 7 [33-37]. The prototype I-RAIL EMAT system is expected to undergo demonstration trials in Portugal before the end of 2012.

Acoustic emission (AE) techniques have been tested in the laboratory and in the field regarding their suitability for the detection of surface rail defects at speed by researchers at AEA Technology Rail (now DeltaRail) and Cranfield University [38-39]. AE has also been under investigation by researchers in Birmingham University and elsewhere to evaluate the applicability of the technique for structural health condition monitoring of rail sections where structural defects have already been identified by other means and where their further growth requires attention [40].

A portable high-frequency vibration analysis system has been under development by APT Rail in Belgium in order to identify rail foot corrosion in grooved rails. The system has been undergoing test trials at STIB's network in Brussels as part of the INTERAIL FP7 project [13]. The system uses a small impact mechanism which is used to excite the rail section under evaluation. A dynamic sensor records the response and then compares it with the response obtained for a calibration rail section which is known to be in good condition.

3. The future of rail inspection

The rail inspection procedures currently in use, with the exception of automated vision and UT, provide qualitative information regarding the actual condition of the rails inspected. Several infrastructure managers carry out visual inspections separately from UT or other types of inspection. This is mainly due to the different schedules that are used for visual inspection and also the higher inspection speeds that can be achieved from automated vision systems. In certain cases UT hi-rail vehicles and test trains carry apart from the UT probes, MFL or EC sensors to increase the POD of surface and near-surface breaking defects of the system. More recently the integration of automated vision systems together with UT, EC, MFL or ACFM sensors has been put forward based on a modular operation concept. The combination of inspection systems with grinding test trains has also been developed in order to carry out the inspection simultaneously with the rail head grinding whilst evaluating the quality of the grinding itself [10]. Integration of conventional inspection techniques between them as well as with other maintenance processes offers significant advantages as it minimises the need for multiple possessions and requires less human effort, hence more limited availability of expert personnel. Moreover integration contributes to the improvement of cost-efficiency of the inspection process.

The integration of conventional techniques is an intermediate technological step forward in comparison to current common practice with short to medium term positive implications in terms of reliability and cost efficiency. The type of inspection systems and techniques being combined and the nature of integration itself have significant impact on the efficiency of the final integrated system. Automated vision systems and conventional UT probes will remain irreplaceable in the foreseeable future although inspection standards (particularly for rail UT) may become stricter as the use of high speed lines becomes more extensive around the world.

The addition of EC sensors offers distinct advantages to an integrated inspection system since surface and near-surface defects are more likely to be detected by EC testing rather than UT. However, EC sensors require excellent lift-off control in order to function properly adding to the complexity of the deployment mechanism. ACFM probes are an alternative to EC sensors but also require good lift-off control. Improved resolution during inspection may be achieved with ACFM arrays currently being tested within the INTERAIL project.

EMAT guided wave systems based on a pitch-catch concept such as the one developed within the I-RAIL project can be used for the evaluation of RCF defects in the place of EC or ACFM sensors at high-speeds. The EMAT system is practically not concerned about the speed of the test train since it will always be significantly lower (a few tens of metres per second) than the speed of the interrogating ultrasonic waves. Although, EMAT guided wave systems require excellent lift-off control like EC sensors they can be very accurate in quantifying the depth of RCF defects using amplitude and frequency analysis of the measured data [33-37]. EMAT inspection involves high sampling rates, generating a significant amount of data that is currently difficult to analyse in real time. Therefore, post processing is required. The EMAT technique does have a dead zone of 2mm deep from the surface of the rail head and thus any RCF shallower than 2mm remains undetected. On the other hand RCF cracks that are less than 2mm deep are not considered to be severe enough to be of concern to train safety based on existing standards.

Each of the above techniques has its own advantages and disadvantages and is designed to detect certain types of rail track damage and wear. Integration of automated vision with UT and EC or ACFM or EMAT sensors permits the full assessment of the structural condition of the rail track in a single run, resulting in a noteworthy reduction of inspection times while POD for certain defects is improved. Furthermore, data convolution during post-processing can increase the amount of useful information gained from the individual systems minimising the likelihood of false defect indications and increasing qualitative and quantitative accuracy for certain defects.

It is important to remember that each inspection technique has each own physical limitations with respect to the maximum speed it can be performed at. Test trains incorporating several inspection systems should be able to carry out modular operations when and if required since the maximum inspection velocity of an integrated system will always be determined by the UT module's limits which will remain an irreplaceable component of rail inspection.

The use of alternative techniques for manual inspection is more straightforward to implement and can provide increased accuracy. Ultrasonic phased arrays offer distinct advantages over existing conventional UT equipment used in manual inspection. Although ultrasonic phased arrays are more expensive they have better POD for most types of defects and can be used for the accurate quantification of the defects detected. They also perform better in rail weld inspection although their performance is not as good as desired due to attenuation caused by the large grain microstructure. Portable EC equipment, ACFM arrays and pitch-catch EMATs can provide better quantification results for RCF defects detected in comparison to MPI while the manual inspection process is speeded up. Digital X-ray radiography offers new possibilities and advantages in rail weld evaluation over traditional film radiography based on gamma rays. Rail welds have been traditionally a weak link in the rail network which has always been very difficult to evaluate accurately. Portable digital X-ray equipment can give very accurate information regarding the actual state of suspect rail welds. High-frequency vibration analysis equipment under development within the INTERAIL project can assist in the detection of damage in grooved rails, switches and crossings. Guided wave systems can also be used for the evaluation of level crossings in one off measurement.

It is important that the performance of high-speed rail inspection systems is complemented with advanced defect verification and evaluation techniques based on ACFM, ultrasonic phased arrays, high-frequency vibration analysis, pitch-catch EMAT testing, guided waves and digital radiography as they offer distinct benefits over existing state-of-the-art manual inspection procedures. The simplified schematic in figure 1 showing the overall INTERAIL inspection platform concept is a useful example of what improvements are possible if an integrated inspection strategy is adopted by infrastructure manager. In the INTERAIL approach each of the techniques complements the other and therefore increases the versatility of the overall inspection process.

4. The INTERAIL FP7 Project

INTERAIL is a European collaborative research project which is led jointly by ISQ (Portugal) and the University of Birmingham. The project is financially supported by the European Commission. The project launched officially in October 2009 and is expected to be completed by March 2013. The project will deliver a novel integrated high-speed inspection platform which will be demonstrated on REFER's network in Portugal in the next few months.

The INTERAIL consortium partners are currently involved in the development and implementation of an integrated high speed inspection system based on a modular design, which will enable the fast and reliable inspection of rail tracks at speeds up to

320 km/h depending on the system's mode of operation. The INTERAIL system combines the use of automated visual inspection with ACFM and UT probes into a single high-speed inspection vehicle.

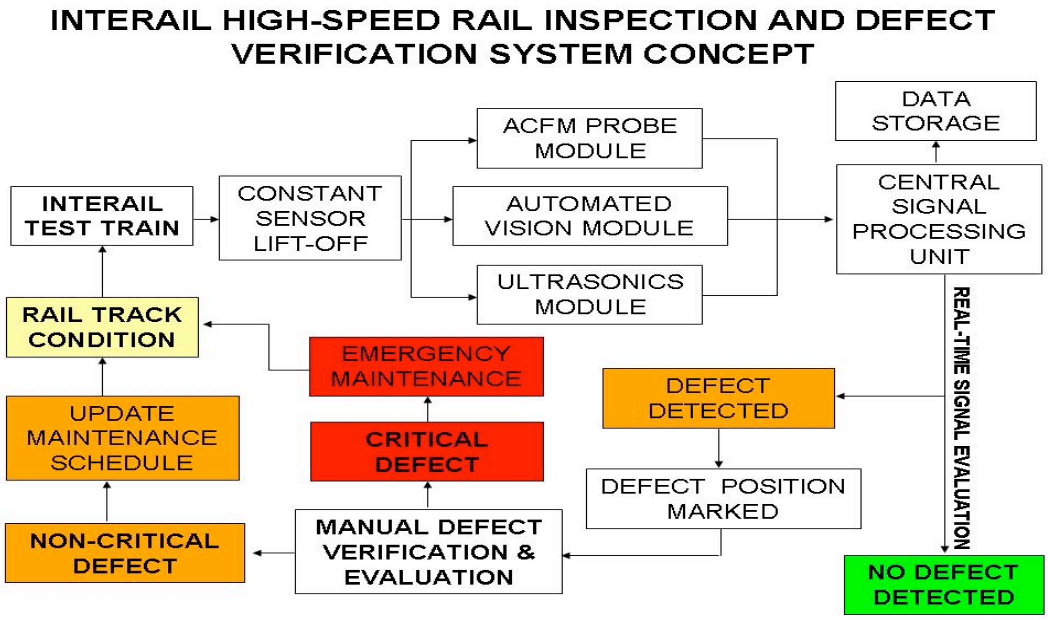

Figure 1: Simplified schematic showing the overall concept of the INTERAIL high-speed rail inspection and defect verification platform [after M. Papaelias].

Each module provides information for different aspects of the condition of the rail track. The automated visual inspection module provides information on levels of corrugation, rail head profile irregularities, missing parts, and defective slippers.

The ACFM module detects and evaluates the severity of RCF damage including head checks, gauge corner cracking and squats, whilst the ultrasonics module detects and evaluate any internal defects that may be present in the rail. Integration of the three aforementioned modules will allow the reliable assessment of the condition of the rail track in a single run, resulting in a noteworthy reduction of inspection times when compared with conventional inspection procedures.

5. Conclusions

Increasing traffic density, rolling stock speeds and axle loads are resulting in more complicated inspection schedules while the cost-efficiency of the non-destructive evaluation process itself is gradually decreasing and the desirable level of operational reliability is growing more difficult to maintain. Integrated inspection strategies coupled with measurable innovation in inspection technology can lead to significant improvements in operational cost efficiency and reliability without the requirement for a fundamental shift in the existing understanding of the inspection process and standards. The rail industry has already acknowledged this and is moving steadily towards the adoption of integrated inspection procedures based on existing commercial systems available in the market. INTERAIL, a European FP7 collaborative research project which is currently underway is looking into demonstrating the value of integrated inspection, coupled with the application of novel non-destructive evaluation techniques for both manual and automated inspection of the rail track under actual conditions. Several other projects which are currently on-going, such as RAILECT, I-RAIL and MONITORAIL also supported by the European Commission through FP7, are looking into demonstrating alternative inspection technologies in the field. Substantial improvements in rail non-destructive evaluation can be achieved when appropriate techniques are integrated together in a way so as to complement the capabilities of each other. Current developments in the rail industry already point to this direction, with conventional ultrasonic probes being integrated with other types of inspection systems.

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