Rail inspection by Flexible Electromagnetic Acoustic Transducer Reporting

Project Information

RIFLEX

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Closed project

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Coordinated by
TWI LIMITED

United Kingdom

Final Report Summary - RIFLEX (Rail inspection by Flexible Electromagnetic Acoustic Transducer)

Executive Summary:
Railway maintenance is a costly activity that can be improved by faster inspection of assets. If the speed of inspection of the rail head can be increased the potential cost savings are significant. At project launch some rail NDT processes still implemented hand held devices that effectively scan at walking pace. EMAT devices have been utilised to demonstrate that a vehicle mounted, non-contact solution operating at line speed is feasible. Technical development is therefore required to increase the scanning area and increase the speed of processing to inspect the entire rail head. Under the European commission’s “Research for SME” funding mechanism, a number of Small to Medium Enterprises (SME) and Research and Technology Organisations (RTOs) have come together to exploit an opportunity to develop a novel approach to rail head inspection. The system concept is defined by a transmitter/receiver transducer pair that consists of a number of flexible, active, non-contact EMAT devices. The transmitting unit sends an acoustic wave across the surface of the rail which is detected at the receiving unit. Any flaws in the surface or subsurface of the rail are detected as changes in signal shape and amplitude. RIFLEX has developed a system that inspects the entire rail head using multiple, flexible EMATs. Two or more devices will be used
in a complimentary configuration; the first generating an acoustic wave across a short distance on the rail head and the second collecting the resulting signal. An optical focussing system will ensure that a minimum gap between the rail and transducer is maintained to ensure that the transducer remains coupled to the rail head. The project has adopted a bottom up approach developing first a bespoke, integrated pulser/receiver and digitiser unit. This unit was integrated with a bespoke, active positioning mechanism and electronic control system. This system was then coupled and integrated with a high speed processing chain that records signal responses and interprets defects using a combination of FPGA processor and micro-controller units. The resulting RIFLEX system is a fully functional and integrated prototype solution that is ready for further development and exploitation.

Project Context and Objectives:
During routine vehicle operation, rails are subjected to intense bending and shear stresses, plastic deformation, and wear leading to the degradation of their structural integrity over time. Defects form in the rail head, web or foot, but are most prevalent in the rail head including: Defects that originate from the body of the rail such as progressive transverse cracking and kidney shaped fatigue cracks; Defects that originate from the surface resulting from wheelslips and rolling contact fatigue.

Railway inspection is concerned with ensuring the structural integrity of the track by detecting defects before they lead to failure. Whilst numerous techniques are employed for crack detection, they are not entirely reliable. At the time of the project concept development, in the EU more than 100 rail breaks were reported annually, with rail maintenance costs estimated in the hundreds of millions (€). A variety of defect types appear in rail with an array of causes including corrosion, rolling contact fatigue (RCF) as well as, creep and wear. RCF and wear constitute the two most prominent problems identified. RCF is a term used to describe the result of wear caused by shear and tearing forces in the contact area between the wheel and rail. Gauge corner cracking, a specific case of RCF, results from the impact between the flange of the front pair of wheels and the inner corner of the rails as the vehicle enters a bend in the track. This type of crack starts along the rail and grows at a downward angle of approximately 10 to 30 degrees to the rail surface. If the cracks are undetected and untreated, they can propagate along the rail head. If left unchecked this can result in catastrophic failures, evidenced by widely publicised events that have occurred in Europe. Rail defect detection has a vital role in ensuring the safety of the world’s railways. Maximum reliability of the railway network can be achieved through sufficient and reliable inspection and maintenance of the rail network. For that reason, the rail industry provided significant investment in the research and development of alternative NDT methodologies. The current international practice is to combine non-destructive evaluation of the rail network with preventative maintenance procedures, such as rail head grinding, in order to optimise the trade-off between maintenance cost and reliability.

The SMEs assembled for this project identified an opportunity to provide the European railway industry with a faster more reliable inspection system. However, larger industry leaders are also currently carrying out research and development work to generate alternative solutions to existing inspection problems. Therefore, one high level objective was for SMEs to gain a competitive advantage by contributing to the rapid development of an innovative solution utilising the European Commissions’ Research for SMEs instrument to engage with RTDs and advance technology in developing a novel approach to inspections. This was intended to not only benefit the SMEs through exploitation opportunities but also the rail companies by providing them with a solution to the identified need for change to their inspection
companies by providing them with a solution to the identified need for change to their inspection processes. The SMEs and RTDs in the consortium are ideally placed to develop new technologies that provide economical and reliable inspection solutions to the EU rail industry. In particular, the target development will not only provide a direct return on investment within the project, but will also enable access to wider European markets for the SMEs involved.

The RIFLEX project concept aimed at providing a major advancement in the non-destructive inspection of rail heads within the European railway infrastructure. Achieved through the development of a novel, self-contained, non-contact rail head inspection system that can be integrated with existing inspection trains or attached to an inspection carriage system. This project aimed to overcome the main limiting factors of inspection of the head of the rail for cracks which are: the speed of inspection due to the requirement to be in contact with the rail head, and the inherent limitations of the capability of non-contact techniques such as those based on electromagnetic inspection. The technical development supports a dry coupled, non-contact inspection technique that will enable a significant increase in the speed of travel during inspection. A system concept design includes bespoke and novel designs, including the application of a dry coupled, non-contact ElectroMagnetic Acoustic Transducer (EMAT) inspection system. The system concept is defined by a transmitter/receiver transducer pair that consists of a number of active, non-contact EMAT devices. The transmitting unit sends an acoustic wave across the surface of the rail, which is detected at the receiving unit. Any flaws in the surface or subsurface of the rail are detected as changes in these signals. The dual transducer mechanism is mounted on a rail running vehicle, so these signals are transmitted and received during transit. For this reason, rapid signal processing is required to capture the signals during motion. The proximity of the coils is controlled by a number of electro-mechanical actuators which move independently to control the position of the coils relative to the surface of the rail. The coils are backed by permanent magnets which can be applied in various configurations to meet the inspection requirements. The project consortium was brought together based on their unique capabilities and common interest in delivering a project of this type: collaboration to build a first prototype/demonstrator system.

The first key objective of the project was to develop and demonstrate the fundamental capability of a polyimide film based EMAT device to generate ultrasound by designing and developing a flexible transducer that can conform to the shape of the rail head, thereby providing coverage of the top surface profile as required.

The second objective was to demonstrate that a closed loop actuator assembly is able to independently control and maintain the proximity of the transducers to the rail head.

The third objective aimed to utilise an FPGA data logger to enable rapid signal processing of measured signals using FPGAs or similar devices to increase processing speed 1000x. This solution was subsequently used to demonstrate the functionality of a prototype system showing the ability to detect rail head defects at speeds > 112KPH.

The final objective was to design and manufacture a fully functional RIFLEX prototype system with a manufacturing cost of less than €20,000.

Project Results:
Project Results:
The main S & T results/foreground are:

The first result was the development of flexible electromagnetic acoustic transducers (EMATS) formed with electromagnetic coils embedded in a polyimide film and backed with permanent magnets. In order to ascertain the appropriate design characteristics, a simulation package was used to perform electrical/ultrasonic modelling and simulation. The optimum design of an EMAT requires a detailed understanding of the coupling mechanism of energy transfer between the electromagnetic and elastic fields. During the first stage of the analysis, the transfer function between the signal generator, the EMAT matching network and the EMAT coil was simulated in MatLab simulation package. The results showed that, through the action of conjugate impedance matching, the matching network optimised power transfer to the EMAT for a narrow frequency band around the resonant frequency.

The second stage of the analysis required an appreciation of excitation effects in the material. Previous work in this field demonstrated that the material excitation is introduced by two effects, the first being the Lorentz-force and the second being the magnetostrictive effect. The Lorentz-force effect appears in all conducting materials, whereas the second effect is only generated in ferromagnetic materials. Magnetic finite element modelling was carried out to determine the force on the EMAT due to magnetic attraction in various arrangements. A finite element model (FEM) package was subsequently used to generate a 3D model of a meander line coil surface wave EMAT for various magnet strengths.

The principle EMAT design was based on an industry standard which depicts the typical requirement for EMAT coils capable of generating Rayleigh waves. The design used a single permanent magnet and dual layer meander coil. A physical device was subsequently designed using PCB CAD application, and the film/coils were manufactured by a specialist fabricator. The fundamental capability and performance of a polyimide film based device to generate ultrasound was tested. Various designs were subsequently reviewed and tested and resulted in a candidate design promoted for the final evaluation. It was demonstrated that the conformance of the flexible transducer provides suitable coverage of the rail head.

EMAT devices were appended by an ultrasound pulser-receiver and digitiser unit. The prototype system was based upon an enhanced acoustic pulser-receiver design capable of delivering higher levels of power into EMAT coils as well as signal conditioning, digitising and data storage for up to four receiver EMATs. The received signal was made available in the appropriate format to feed into the upstream processing chain. This provided a standalone receiver-digitiser unit, capable of energising the transmitting EMAT, interfacing with the receiving EMAT and converting and processing the received signal. A digitisation circuit was developed on a first in–first out (FIFO) memory architecture capable of achieving upwards of 150Msample/sec, and therefore capable of supporting multiple receiver EMATs. The rapid rate of execution of a sample cycle supported two key objectives: 1) the application of an external processor such as a FPGA to process and log large amounts of data in quick succession, without adversely affecting the processing/translation speed, which supports 2) the high level objective of line speed inspection and accurate defect location. One of the main aims of the inspection system was to enable defects of the type typically searched for in running rail of the European railways. Therefore, in concurrence with the continued technical system development, the capability and performance of the transducers were enhanced through various trials and subtle design revisions.
The second project objective was to build a mechanism to control the position of the transducers relative to the head of the rail. This was delivered through an electro-mechanical design using an active PID controlled actuator capable of counteracting the lift-off force of the EMATs and maintaining the minimum required lift-off distance of the EMAT from the rail. The system consists of a voice coil actuator (VCA) and laser/optical positioning system working in a closed loop function to minimise the variation from the ideal lift-off position. The magnetic attraction force between the EMATs and the rail, which is a non-linear function of distance, was counterbalanced by a novel, integrated multi-spring system. The probe mount system provided position feedback to the inspection system, which allowed the processor to correct for variations in lift-off distance. The intention was to integrate the inspection data with position data to provide speed, location and distance information. This design went through a number of iterations to balance the cost of the system design against the strength of magnets applied. The resulting module controlled the transmit and receive coils in tandem, but equally could have been applied in isolation, though the system costs would have increased.

The third project objective was to enable a high speed of translation to be achieved. In recognising that embedded systems are capable of performing near real time signal processing, the project went about developing an appropriate signal chain. An FPGA module, based on Xilinx Vertex-5 chipset with a 200MHz frequency processor was employed. This device was selected for its ability to cater for multiple channels of data at a high processing rate. The first prototype supported the signal transfer from FIFO memory and the testing of the high speed synchronisation. A transfer rate of 50MSPS/Channel was achieved and tested reliably in the first instance. This arrangement and technical configuration supported the inspection of rail at speeds in excess of 110 KPH. The probe and processor arrangement was used to perform validation testing, using reference rail samples with artificial defects inserted, to differentiate between defective and defect free sections of rail. The rails were mounted onto a rotating rail rig capable of spinning the rail beneath the transducers at up to 80KPH. A pitch-catch transducer arrangement was configured with the transmitter mounted on a rig and positioned 200mm from the receiver. This arrangement transmitted a Rayleigh wave across the rail to a detector EMAT while the rail was spun beneath the carriage.

The results achieved by FPGA processing demonstrated that simple defect detection was achieved reliably. The FPGA post processing implemented a synchronised activation time to be used as the point when threshold interpretation was performed repeatedly during motion. This working function formed the foundation for further development of more complex arrangements of probes and associated signal interpretation.

The final objective was to build an overlying control system that supports the rapid interpretation of received signals into diagnosed defects. This solution effectively represents the integration of all subsystems, culminating in the ability to perform complex multi-probe inspection of the rail head. This aligns with standards to perform multi-probe attenuation inspection enabling sensitivity to flaws in all directions. The overall technical result is increased information recorded about the orientation and size of any discontinuity so that automated defect detection and interpretation can be implemented. The final assessment of costs demonstrated that the entire system could be delivered for well under the original targets cost of €20,000.
Potential Impact:
It is expected that the output from the project will create significant impact and economic value for the consortium SMEs through the development of an innovative and integrated prototype. The owners and operators of railway installations are either large, privately owned companies or government agencies. Recent business trends have seen many of these companies outsourcing their entire condition monitoring and inspection requirements to SME companies. A large percentage of monitoring equipment manufacturers in Europe are SMEs. Thus SMEs survey, inspect, repair and maintain railway components and structures on behalf of the owner and operators. The project will give the consortium SMEs a competitive edge in the European rail industry inspection business, and will enable significant technological progress towards a new market opportunity. A successful outcome of the project will open up market opportunities for the SME partners in their respective technical areas by enabling faster and more cost effective inspection capability.

RIFLEX is a system that utilises innovative techniques to revamp the inspection of rail heads for surface and subsurface defects, increasing the speed of inspection from the current maximum speed of 38KPH to over 112KPH. The RIFLEX system will support the inspection of the entire contour of the rail head using a flexible EMATs that conform to its shape, allowing 50% or more of the rail head to be inspected than current methods. The development of the RIFLEX inspection system will:

• Reduce cost of inspection by up to 25%
• Ensure the integrity of European railway networks estimated at over 212,000 km in length
• Open up new markets for railway maintenance companies and consolidate their gains in existing markets
• Promote the use of an environmentally friendly mode of transport (railway) since this inspection method will reduce the risks of accidents due to railway line failure.
• Provide efficient and effective inspection of railway networks

Infrastructure managers agree that controlling costs is essential to the viability of the rail industry. This has to be done without compromising on safety. Efficiencies can be achieved through managing rail infrastructure and railway assets in a way that reduces their whole-life cost whilst also continuing to improve their condition, helping to free up resources so as to further improve the railway. In a nutshell, rising demand for mobility has led to an increase in demand for rail traffic worldwide which has led to a growing demand for railway technology products and services. Innovations in the industry, such as in infrastructure maintenance, will improve performance of rail operators and infrastructure managers, and make rail solutions more attractive to end customers as opposed to other modes of transport. Therefore, a more efficient way of inspecting railways will lead to a major reduction in cost. One way of doing this is through the use of non-destructive methods of inspecting railways.

Therefore, the project impact will lead to:

• Increased availability - accomplished by supporting reducing possession times or removing the requirement completely, which is achievable by automating and optimising maintenance planning and scheduling, and also by speeding-up maintenance activities;
• Increased maintainability - accomplished by reducing the time taken to maintain infrastructure, which is
Increased maintainability - accomplished by reducing the time taken to maintain infrastructure, which is achievable by identifying tasks that lend themselves to automation and then developing and introducing appropriate technology.

During the period of the project concept development the industry was experiencing growth, with Frost & Sullivan estimating that the total services market is worth over €2 billion and an NDT equipment market worth €830 million. The Railway Inspection is approximately 8% of the total worldwide NDT inspection market valued at €160 million per year. European SMEs are however facing increased competition from NDT suppliers from the BRIC (Brazil, Russia, India and China) region. One of the main drivers of growth in this region is the application of NDT in transportation. The RIFLEX system will therefore offer the SMEs an opportunity to gain a decisive share of this market, offering a faster and more thorough inspection method. The financial position of the SMEs participating in this project will be enhanced due to participation in this project. The RIFLEX system will allow the SMEs to consolidate their positions in their current markets and also open up new and greater markets.

RIFLEX will serve to improve reliability and availability of rail systems thereby increasing consumer confidence in rail transport. The railway industry is a labour intensive sector that provides environmentally sound jobs. It contributes significantly to employment. According to EC statistics, the rail sector represents 11% of employment in European transportation. Investment in rail generates employment during the whole life cycle of the infrastructure. The RIFLEX system offers improved worker safety since the system is automated; the need for track workers to spend significant periods of time on or near the track is greatly reduced.

The RIFLEX project will help ensure that railways conform to the railway Safety Directive 2004/49/EC (RSD), which requires railways to be maintained to high and improving levels. Safety at the level of infrastructure and operations is one of the main issues addressed in the legislation. This legislation is continuously amended as the dynamics of the railway industry change so as to remain relevant. The adaptability of the RIFLEX project will thus ensure that Europe’s railways remain among the safest in the world.

List of Websites:
A project website was set up to act as a communication port between the partners and to disseminate the project: http://www.riflexproject.eu/

A project website was set up at the start of the project by the consortium partner TWI, with the domain name http://www.riflexproject.eu/ TWI maintained the website on behalf of the consortium. The purpose of the website is to facilitate dissemination and act as a communication tool for the consortium. It consists of two main areas: one accessible to the public and one only accessible by the members of the consortium. It includes a “contacts” page, when information is requested via this page the enquiry is sent to TWI who hosts the website. The homepage of the website hosts the blog page which summarises all the news related to the project and allows for comments from the public. In addition to the public part of the website, there is a secure members’ area to act as a repository for project related information and to allow easy transfer of electronic information between the consortium partners.