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Whole Life Rail Axle Assessment and Improvement Using Ultrasonic Phased array and Corrosion Inspection Systems

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Content

Summary

The European rail network is targeting a considerable expansion of passenger and freight traffic by 2020; this is supported by a significant mandate given to the European rail sector in 2011 by the European Commission to shape the future of transport in Europe. The Transport White Paper presented by Commission Vice-President Siim Kallas outlined a step change for passenger and freight transport in Europe to be operated largely by rail by 2050. In order to achieve this, increased reliability and availability of rolling stock is necessary whilst maintaining the same or a better level of safety.

The overall objective of the RAAI project is to develop novel NDT solutions for the corrosion assessment and crack detection as well as reliability software for high cycle variable amplitude corrosion fatigue of rail axles. Currently, the most sensitive non-destructive testing methods for inspection of rail axles are surface inspection methods designed for crack detection (such as MPI, eddy current and ACFM) and these do not typically attempt to measure corrosion. Besides current trend is that axles are withdrawn from service long before their design life because of suspected corrosion developed on the axle surface. The decision to withdraw from service is taken without the full knowledge of the way in which the failure will result from corrosion as this requires a crack to initiate and the mechanism for this is unknown.

RAAI aims to develop two novel methods:

1. Corrosion assessment,
2. Phased array ultrasonic.

The first method assesses the effect of corrosion on high-cycle fatigued component such as the axle and evaluates its remnant life thereby improving the sentencing of corroded axles. The second method is specifically for hollow axles of high speed trains and aims to improve the speed of the inspection (by 75%) and improve crack detection reliability (almost 100% with a crack of 2-3 mm depth) without dismantling the wheel set and with minimum time of inspection. The primary impact of the project is to improve the competitiveness of the SMEs in the project by enabling them to provide NDT solutions to reducing the cost of and improving the safety margins of rolling stock operation.

The RAAI system will have twofold impacts on the European rail industries. Firstly, it will make inspection and assessment reliable and cost-effective and secondly it will improve the operation of the European rail industries. We will endeavour to enhance the two novel methods (phased array system for detecting cracks in hollow axles and corrosion inspection system for measuring corrosion assessment in rail axles) developed in the WOLAXIM project, to reduce the inspection cost and time, to increase the reliability of corrosion assessment thereby decreasing the sentencing of the axles, etc.

The results of the RAAI project will be used in the rail industry which will offer higher probability of detection (POD) of corrosion and cracks, improved and sustainable inspection of rail axles and savings of inspection cost through 75% reduction of inspection time and at least 20% of savings of rail axles and thus more economical for rail operators.

1 Introduction

In 2011, the European Commission gave the European rail sector a significant mandate to shape the future of transport in Europe. The Transport White Paper presented by Commission Vice-President Siim Kallas outlined a step change for passenger and freight transport in Europe to be operated largely by rail by 2050 [1]. The European Commission acknowledged rail as the greenest of transport modes. The impact of this on the development of the rail infrastructure is considerable and expansion of fleets and pressure on rolling stock availability can be expected, while levels of safety are expected to be maintained and any additional environmental impact minimised.

The rolling stock count at present in Europe is approximately 250 thousands passenger carriages and 1.25 million freight wagons. Assuming 4 axles per passenger carriage and 2 per freight wagon this gives a total of around 3.5 million axles.

The role of inspection in determining the safe life of an axle is crucial. Inspection of the axles for cracking takes place at intervals set by knowledge of expected loading, known crack growth rates and inspection sensitivities. Usually, the inspection interval is such that an inspection is required between major overhauls, so inspection of axles while the train is in service is still required and this is currently inconvenient and costly for the train operators. Current inspection methods designed for crack detection typically do not attempt to identify or measure the corrosion and lifetime.

Axles can be inspected either in the depot (while still on a train) with limited access, or at overhaul when worn wheels are removed and there is good access to the surface. At overhaul, there is no additional disruption of the train service for inspection and generally this time for inspection is preferred by the train operating companies. However, currently it is not usually possible to extend the inspection period to overhaul times and depot inspection is necessary.

Production inspection of axles is carried out by surface inspection methods (dye penetrant and MPI) and ultrasonics for solid axles. Inspection of hollow axles is by automated ultrasonics with a group of rotating probes in a similar way to the service inspection.

Methods of inspection at depot and overhaul and degrees of automation vary from country to country. In Germany highly automated phased array ultrasonic methods are used at overhaul, whereas in the UK surface methods such as MPI are used most commonly at this time.

In service, axles often tend to crack either in mid-span or under or close to the wheel seats. Various inspection methods have been tried or developed for this particular inspection. In the UK, surface inspection methods (particularly MPI and electromagnetic) have been introduced since the Rickerscote accident in 1996 [2] for accessible areas. However, where the crack initiates from an inaccessible surface (e.g. fretting cracks under a wheel) the inspection is by ultrasonics. The methods adopted are generically known as the high angle scan (applied from the axle body), the near end scan and the far end scan (applied from the axle end).

Hollow axles are also used, particularly for high speed passenger trains, where the loss of weight has advantages, and the ultrasonics used in this case is an angled beam scan from a rotating probe in the bore. This inspection is mechanised and requires incrementing and rotating the probe, a very slow process. Portable devices for use in depots have been manufactured but these tend to be unreliable due to the long reach and sensor rotation required.

The Rickerscote accident report also concluded that the cracks had initiated as a result of corrosion, although all previous analysis had focussed on fatigue and very little work on the process of corrosion fatigue had been carried out.

The analysis of fatigue properties of railway axles had been investigated earlier (Snell [3], Beretta et al. [4]) and the crack growth in railway axles had also been studied (Zerbst et al. [5]) in order to better define fatigue design and the scheduling of inspection for these components. However, until recently the diffused corrosion that can appear on some areas of the axles and the possibility that the pits caused by corrosion can promote the nucleation and the subsequent propagation of fatigue cracks had not been considered to date when defining axles fatigue properties.

Some bibliographic notes report cases of axle failures due to crack propagation from corrosion pits. Hoddinott [6] reports that about five mid-span failures of in-service axles occurred in the UK from 1996 to 2003, four of which have been connected to the presence of diffused axle surface corrosion and corrosion pits. On the other side of the Atlantic, the Transportation Safety Board of Canada [7] reported one axle failure to have been caused by corrosion pits under the journal bearing. It also mentions another seven failures with similar features occurring between 1998 and 2000.

The overall objective of the RAAI project is to develop novel NDT solutions for the assessment of railway axles, as well as reliability software for high cycle variable amplitude fatigue of railway axles. We have developed the technology for rapid and cost effective inspection of rail axles through an EC funded project WOLAXIM (FP7-SME-2010), which started in 2010 and ended in 2012. In WOLAXIM, three novel methods of crack detection and corrosion assessment for railway axle inspection were developed and tested. Of these three, two methods, the corrosion inspection system for measuring and analysing corrosion assessment in rail axles and phased array ultrasonic hollow axle inspection for detecting cracks in hollow axles, met expectations and were considered to be feasible for commercialisation.

2 Overall concept of the RAAI system

The concept of the RAAI project is to improve the inspection technologies and efficiency in the use of train axles by increased safety and extending their life. Improved inspection technologies, with knowledge of the conditions causing crack initiation and growth under corrosion conditions associated with reliability theory can achieve this objective. The application of the RAAI concept is to determine the remaining life of rail axles. This will be carried out in four steps:

1. The train arrives for inspection.
2. All axles are inspected with the RAAI techniques.
3. The data collected during the inspection is analyzed to determine the remaining lifetime of those components.
4. The train is returned to service without dismantling of the wheel sets and with minimum disruption of the service.

The RAAI system has two NDT monitoring techniques:

1. Corrosion Inspection system for corrosion analysis; which will enable the characterisation and sentencing of degradation by corrosion. This will give robust and accurate 3D reconstructions to allow measurement of profiles, roughness, etc.
2. Phased array ultrasonic hollow axle inspection; which will be pushed inside the hollow axle for the detection of cracks. This device will make the inspection of such components faster as one scan along the axle will give full coverage.

3 Corrosion Inspection System

Following the WOLAXIM project, a USB microscope was used in the order to observe and assess rail axles with a degree of corrosion [8]. The microscope had revealed the presence of pitting and also some cracking. The microscope allowed a visual record of the different indications and also measurement of the length of cracking.

The process developed for the microscope corrosion assessment, would be of use where at wheel set overhaul the light corrosion found cannot be machined out, because of dimensional constraint's, particularly in the transitional radii areas. The axles in this case would be fully prepared and speed is not so important, if small areas are being looked at. If the axle that has been quarantined for corrosion passes microscope and stress corrosion cracking is not identified, then the axle may be released into service for another cycle of operation. Also the light corrosion (up to 0.25 mm deep) would have to be proven to be in a dormant state and all rust oxides removed by chemical / polishing prior to painting, before release can be accepted. Heavy corrosion (in excess of 0.25 mm deep) is not suited for the microscopic examination and axles with such corrosion would have to be either machined if allowed, or put to scrap.

The Rail Industry would as a first priority prefer to machine out the corrosion, but a significant number of axles cannot be machined and to apply the above combinations of inspection would save customers a lot of money replacing axles. The overhaul sites may not want the responsibility / liability of releasing axles with minor corrosion pits and in any case to avoid internal abuse of vested interest this process would have to be carried out by an independent NDT organisation approved by the customer / owner / operator of the wheel set. Passenger axles are more likely to benefit from the above recommendation, because machining is restricted and most freight axles can be machined. However there are many freight axle types that cannot be rectified in radii areas and this is where the current scrappage rate is high where the vehicles carry corrosive substances or run near coastlines. However, where the overhaul site is also an axle manufacturer they tend to replace the axle rather than polish or machine.

Scanning will have to be speeded up in order for the process to be practical, if large areas are tested, however the speed is not required when testing rejected axles for acceptance with small areas of corrosion. Experience has shown that light corrosion does not cause cracking in most cases and this is the area where the most benefit can be made by using both MPI and the microscope. Stress corrosion cracking can be very tight on moderate to severe corrosion and certainly unless an enhanced MPI process is used significant defects can be missed and some are even difficult to pick up with the microscope, therefore a combination of the processes is required and only light corrosion should be tested regarding the release to service policy. The system will also need to be portable as it will be used on site. It should be deployable on a number of axles during the testing.

The microscope system can be of great value following the requirements mentioned above. It will give a faster acquisition, will have crack detection capabilities, and will be portable and usable on site. However it is important to highlight a slower system can be used for scrapped axles as the timeline is different for axles in service.

4 Phased Array Ultrasonic System

The ultrasonic inspection system will combine the classical approach for inspection with phased array technologies. The probe will be maneuvered through the inside of the hollow axle for the detection of axial-tangential orientated flaws. This device will make the inspection of such components faster and easier. The concept of the system is to detect cracks open to the surface of train axles without demounting the wheel set. The ultrasonic testing will be performed when the train is stopped for in-service inspection.

The idea of the phased array bore inspection device is to replace the rotating probe methods used to inspect hollow axles by a phased array probe that rotates the ultrasonic field electronically. This enables a much faster inspection and could reduce the inspection time of a hollow axle from around 20 minutes to 5 minutes. The system allows ultrasonic testing of transverse cracks in the axle surface with full coverage and is capable to detect 2 mm deep cracks. The concept of the ultrasonic inspection system is to scan a complete hollow axle with a fixed beam angle in the axial direction of approximately 45° and an electronic rotation of the sound field by sweeping the active element groups around the circumference [9].

The equipment will consists of the phased array device with the rotation scanner probe, a motor driven linear axis for moving the probe inside the bore and a PC for system control. The axial scanning will be realised by a commercial motor driven linear axis. The pumping system for the coupling liquid is realised with a commercial hose pump for silicon hoses. The COMPAS phased array device, made by BTD, is applicable without changes.

In traditional hollow shaft testing a probe is rotated mechanically in the shaft. The new approach with a conical rotation scanner phased array probe offers the following benefits:

- extremely short testing time;
- the probe design can be adapted easily to different bore diameters;
- no complex and trouble-prone mechanical parts will be used;
- above all no transmission of RF-signals via a commutator ring is necessary.

5 Corrosion-fatigue model

The corrosion-fatigue process can be essentially seen as the propagation of tiny cracks, under the electrochemical action of corrosion, at stress levels much lower than the ones for fatigue in air. The idea, developed within the WOLAXIM project, has been to measure the onset and development of corrosion-fatigue in terms of the detection of the population of microcracks that grow from the initial pits.

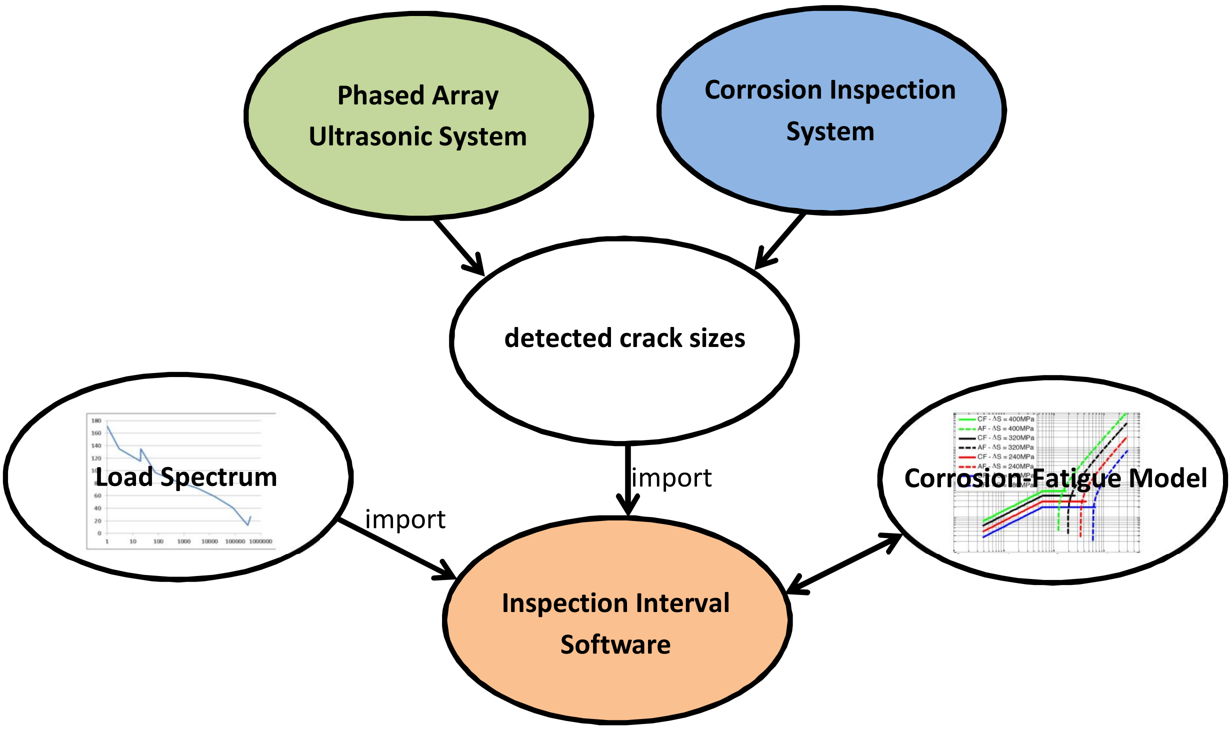
In order to have an idea of the effect of the minimum detectable crack upon the life prediction for specimens, a series of simulations have been carried out for the two materials by calculating the number of cycles needed to reach a crack length that can be measured with an optical device. These calculations have been expressed in terms of percentage of the mean life at the different stress levels. For the sake of clarity, the percentage of remaining life has then been also calculated. This gives a rough idea about the percentage of life that could be expected after the detection.

A detectable crack between 100 µm and 200 µm is able to give a significant measure of corrosion fatigue damage, that corresponds to approximately 40-50% of life spent for EA1N and 40- 50% of life spent for EA4T. As a reference from the WOLAXIM project [10], a series of comparison with plastic replicas of the full scale axles and SEM images, allowed us to compare the crack length measured with the on-axle microscope. The conclusion was that the deoxidizing procedure and the on-site observations allow the user to accurately detect and measure cracks with a length of the order of 200 µm. This is, in first instance, the minimum requirement for the motorised detection and image analysis system.

6 Inspection Interval Software

The inspection interval software will provide the reliability of the axle under HCVA (High Cycle Variable Amplitude) fatigue and corrosion conditions. The best use of this will be in combination with the corrosion Inspection system for corrosion analysis, for example for illustrations of the lifetimes available when the cracking is above or below certain stages.

The inspection interval software can predict the minimum inspection interval, in order to obtain a target failure rate. The user interface will be simple operable for the operator of the RAAI system. It will also be enhanced so that more informed decision can be taken depending on the trend analysis of the faults in the axles testing and the distribution of crack length. The software includes the algorithm for importing a high cycle load spectra, which would be typically be provided by a vehicle operator and the crack growth equations. A standalone program for calculating crack growth during corrosion fatigue and including the modifications to the Paris equations was produced and checked. It will be also incorporated into the software suite. The other input required is the initial crack length. A number of values were chosen for this, the lowest value 35 µm corresponds to the pit to crack transition or where no crack could have been detected by an instrument. Higher values are for example those which may be detected by the microscope on inspection.



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