Project Periodic Report
M42

Grant Agreement No 265706

EURAXLES
Minimizing the risk of fatigue failure of railway axles
Theme SST.2010.4.1-2
Collaborative Project

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Periodic report: □ 1st □ 2nd □ 3rd
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Declaration by the scientific representative of the project coordinator

I, as scientific representative of the coordinator of this project and in line with the obligations as stated in Article II.2.3 of the Grant Agreement declare that:

- The attached periodic report represents an accurate description of the work carried out in this project for this reporting period;

- The project (tick as appropriate)¹:
  - [ ] has fully achieved its objectives and technical goals for the period;
  - [ ] has achieved most of its objectives and technical goals for the period with relatively minor deviations.
  - [ ] has failed to achieve critical objectives and/or is not at all on schedule.

- The public website, if applicable:
  - [ ] is up to date
  - [ ] is not up to date

- To my best knowledge, the financial statements which are being submitted as part of this report are in line with the actual work carried out and are consistent with the report on the resources used for the project (section 3.4) and if applicable with the certificate on financial statement.

- All beneficiaries, in particular non-profit public bodies, secondary and higher education establishments, research organisations and SMEs, have declared to have verified their legal status. Any changes have been reported under section 2.3 Project management during the period in accordance with Article II.3.f of the Grant Agreement.

Name of scientific representative of the Coordinator: Léa Paties

Date: 31.01.2014

For most of the projects, the signature of this declaration could be done directly via the IT reporting tool through an adapted IT mechanism.

¹ If either of these boxes below is ticked, the report should reflect these and any remedial actions taken.
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1. Publishable summary

1.1 Project context and objectives
EURAXLES aims to bring the risk of failure of railway axles to such a minimum level that it will no longer be considered as a significant threat to the safe operation of the European interoperable railway system; at the same time, it shall keep the cost of maintenance to a reasonable level and minimise the risk of service disruption.

The global concept approach for axle design, production and maintenance includes:

- A design approach development, including a risk analysis method which could offer a simple design route by combining loads with difference occurrences including loading specificity of vehicles and service conditions together with the axles resistances, including new materials and methods in order to predict the ‘failure probability’.
- New developments also include:
  - Improved axle protection against corrosion, including protection of already corroded axles
  - Improved adhesion of coatings with a study of the roughness influence (adhesion and fatigue behaviour)
  - New, innovative coating solutions. The new solutions also aim to fulfil environmental requirements to avoid or limit VOC emissions.
- New/improved NDT inspection methods will allow the in-service inspection of axles in order to guarantee safe service conditions with a low impact on the vehicle availability.
- A RAMS/LCC analysis of the solutions was also carried out. The railway transportation system requires a risk analysis of the safety components. Activities improve design validation and inspection technologies of axles which will optimise costs, safety and environmental compliance to be shown with RAMS/LCC analyses.

The EURAXLES global concept will not only guarantee the current level of safety, but improve it in an interoperable network at optimized cost.

1.2 Work performed since the beginning of the project and main results achieved so far

a) Summary of WP1- Project Management

The summary of WP1 can be found under section 2.3 – Project Management during the period.

b) Summary of WP2- New axle fatigue design method

The main tasks that were addressed in WP2 during the period are:

- Validation of the Finite Element Models (FEM) developed during the project by comparison with experimental tests carried out in WP3 and finally proposal of a commonly accepted process for the evaluation of the stresses in the axles in general.
The numerical results were compared to the tests carried out in WP3 and enabled to validate the simulation process. It was observed again that the concentration factors defined in EN13103/13104 for transitions and grooves were different from those obtained with FEM. In the meantime, experimental results from WP3 also showed that the fatigue limits were underestimated in the standards, so that the current design process remains safe (as it can be stated from return of experience from the field). Simulations of whole wheelsets were also performed. Finally, recommendations on how to use FEM in the validation process of axles and how to generate relevant FEM models were given. Deliverable D2.3 describes all the numerical activities within WP2 and deliverable D2.4 describes the general recommendations for the axles modelling when using FEM.

- **Development of a method to estimate the real in-service reliability (probability of failure) of axles, taking into account the variability of the loads and the fatigue strength of the steel grades (A1N and A4T) and applying it to a real operating axle.**

First, a semi-probabilistic approach, based on the FKM guidelines and the Eurocode standard, was proposed by Polimi as an approach to validate an axle design, taking account of the scatter of the fatigue limits of the material and the uncertainties on the loads. This method uses a representative load spectrum coming from measurements and enables to propose minimum safety coefficients to be defined in the validation process, depending on the target probability of failure and the coefficient of variation of the load. A second method, fully-probabilistic, based on the Stress and Strength Interference Analysis, was also proposed by SNCF in order to estimate the probability of failure of an axle, considering the fatigue limit scatter but also the distribution of the load severity, as defined in the first tasks of WP2. The axle tested by SNCF in the load analysis was taken as an application and the probability of failure of this passenger coach was estimated. The results showed that, when using the final material characteristics identified in WP3, this probability of failure of this trailer axle, is quite small, but its order of magnitude seems rather realistic.

**c) Summary of WP3- New testing methods of railway axle fatigue limit assessment**

The WP3 scope was to experimentally estimate fatigue limits of axles; such information is a main input in the design. The WP considered axles made in standard material (A1N and A4T) and defined a standard method for testing and analyzing the obtained data from a statistical point of view in order to be able in the future to apply the same method in the characterization of new materials or new surface treatments.

Axles conditions considered for the actual testing were axles in standard surface finishing for which axle body (free surface) was evaluated separately from axles seats where wheel, brake disc or bearing press fits take place; in this later case the coupling of the components can generate, when high bending is applied to the axle, relative micro sliding and derived friction forces that end up in local wear and possible micro cracks of the seat side surface; the phenomena is known as fretting corrosion and the result is that the fatigue limit is substantially lower than on the body. The severity of this phenomenon is depending more on the geometry of the axle (Seat-body diameter ratio) rather than on the material itself; for this reason different axle geometries were defined and tested. This part of the testing activity was complemented by task 3.3 dedicated to the theoretical modeling of fretting fatigue providing criteria’s for evaluating both the possibility for crack initiation and assessment of the crack propagation. The aim was to provide tools for optimizing the design.
An important subject that was treated in WP4 concerns the study of possible solutions that can improve the axles surface protection from corrosion and for this some surface treatments techniques were proposed (shot pinning, increase roughness ecc); as similar solutions can have an effect on the surface fatigue limit; some solutions were verified in WP3 trough simple 1/3 scale axles and then in full scale conditions.

WP3 also tested corroded axles to verify the actual reduction of the fatigue limit.

A common testing procedure was defined in order that similar tests performed in different laboratories could produce comparable results.

A list of small scale and full scale tests and the relative drawings were defined and the wheelset manufacturing partners prepared the materials for the tests. All tests were performed by 7 partners of the Project in their laboratories.

d) Summary of WP4 - Tools, technologies and surface protection systems minimizing the negative influence of corrosion

The work in WP4 was completed by end of April 2014. The major objectives were achieved.

In the beginning of the project the relevant state of the art was determined. This included especially experience from service, currently used painting process technology, analysis of quality test methods in current standards and service conditions. Therefore a survey was performed among axle manufacturers, operators, paint suppliers and research institutes. The analysis of the survey showed potential fields of improvement, as e.g. expectations of the performance of axle coatings and possible improvement for the quality test methods of axle paintings. These results were base for the further work in WP4.

Test series were performed with different surface preparation methods to find a method for better paint adhesion with respect to other important requirements like fatigue behavior and non-destructive testing (NDT). About 183 samples were produced under industrial conditions and tested with different methods. Finally, grit blasting shows improved adhesion behavior, also for water-based (VOC reduced) painting systems.

Different alternative and innovative coatings were investigated. Three environmental friendly coatings are recommended for further investigations. Especially service behavior, maintenance aspects and inspection methods should be further examined.

Unpainted axles from service were analyzed regarding their surface aspect and chemical composition of the corrosion layer. The possibility to produce the corrosion layer artificially was examined, but the artificial reproduction of corrosion was rejected. Therefore 10 axles from service without painting were gathered from SNCB for fatigue tests in WP3.

The quality test methods for painting systems in standard EN 13261 were reviewed. Alternative test methods, especially from automotive industries were examined. Finally, a proposal for revision of EN 13261, clause 3.9 for quality test methods of painting systems was prepared in WP4 and will be given to working group CEN/TC256/SC2/WG 11. Further recommendations were worked out for cleanliness check and for fire protection of railway axle coatings.

The results and the potential impact of WP4 are in general new surface preparations and procedures for the design method of wheel-set axles, including corresponding fatigue limits tested in WP3 which are acceptable by the operators, system suppliers, wheel-set manufacturers and the technical approval authorities. The recommended alternative and innovative coating systems are environmental friendly and have potential to reduce costs.
The proposal for changes of the quality test methods for the painting or protection systems in EN 13261 shall improve the quality standard of painting. In the proposal, methods which are realistic for all the partners with regard to operating conditions and reasonable costs are considered. For unpainted axles new fatigue limits (WP3) were determined.

Generally the new surface preparation method and the improved test methods should support the change from solvent-based painting systems to VOC reduced or VOC free painting systems.

e) Summary of WP5 - Non-destructive testing (NDT) and verification of the reliability of axles in service

A summary of key WP5 activities is provided below.

- Completion of a questionnaire by railway operators and companies carrying out maintenance for the Non-destructive Testing (NDT) of Wheel-set Axles. This questionnaire included the request to describe the testing procedures applied in their maintenance facilities, including probe characteristics, calibration procedures, evaluation and experiences from the application in service. Results are given in Deliverable D5.1: Questionnaire on Current European Practices on NDT

- Participation in a Testing Week in Kirchmöser. During this meeting, some members contributed with hollow/solid axles with artificial cracks, to inspect these with their inspection systems applied during fabrication or in service. Results given in Deliverable D5.1: Report on current European practices in NDT of wheel set axles Subtask 5.1.2: Testing benchmark.

- A GAP analysis of present inspection methods was carried out, focusing mainly on the greatest threats to the safety of the rolling stocks and their passengers. The results are shown in Deliverable D5.3: GAP analysis document identifying weaknesses and proposing methods of present methods and technologies.


- A study of a new inspection method using the analysis of new classification techniques and analytical models has been done. The results obtained from the simulation of the model have been used to test a specific designed algorithm. The data from a 1/8 scaled benchbank has been obtained from different axle speeds and levels of crack. The data obtained has been used to provide good results of the algorithm presented in Deliverable D5.4: Inspection method proposal. The first conclusion of the different trainings carried out is that the ANNs have a better behaviour as the number of axles measured increases. Having a higher number of specimens helps the system to avoid noise and other significant differences between measurements, which can hide the crack effects. Classification algorithm used is a Radial Basis Function Neural Network and success rates achieved are around 95%.

- Tests performed with a real axle and simulating the operational conditions applied in the tests performed at 1/8 scale. To roll the axle, we have used two different lathes with different speeds and axles with artificial cracks (different size and depth) to show the behaviour they cause on the axle. Very promising results have been obtained and are given in the documents Milestone MS25: Delivery of analysis methods and Deliverable D5.7: Simulation Report of New Method Proposal.

- Regarding to the verification of influence of surface damage and corrosion in service axles, a Benchmark study of electrochemical and NDT techniques has been done. A review on different techniques has been performed. After this, two preliminary feasibility studies were performed:
considering the feasibility of respectively EIS and lamb wave testing for assessment of the surface condition in interference areas. These results are given in Deliverable D5.6: Report on the set of electrochemical and NDT techniques [...]

- It has been developed a concept based on the change of the elastoresistive behaviour of an adhesive plug using electrochemical techniques. The response of the adhesive plug material will change when mechanically loaded. Therefore, its elastoresistive behaviour will be measured to deduce the strain field applied to it which gives an indication of the load applied to the plug. This can be a static load, or a dynamic one, as it is the case of an axle of a train moving at a certain speed. The goal of this measurement is to track cracks, which will have an influence on the vibration pattern of the axle, consequently on the dynamic loading of the adhesive deformation plug which influences its elastoresistive behaviour. The results of these studies were presented in Deliverable D5.8: Report on proof of concept of deformation sensitive adhesive plugs for crack detection [...]

- Different NDT techniques have been presented in Deliverable D5.5: Report on the inspection of “in-service” axles, which will be focused in the improvements of the actual inspection techniques and new proposals to assure that all potential defects endangering axle integrity have been considered and to give a comprehensive view of today’s axle safety problematic.

- A cross-reference table has been distributed and filled to get a clue of the POD attainable with the inspection methods applied by the WP5 partners. The partners were asked to separately evaluate the POD in the different sections of hollow and solid axles according to the assessment criteria shown in the table. The detailed analysis obtained is included in Deliverable D5.5.

f) Summary of WP6- RAMS and LCC taking into account market update

As a first task within the WP6, a survey to analyze the state of the art of the RAMS/LCC techniques with particular emphasis in the railway sector has been performed. The results of this survey have allowed to identify the most relevant standards that are applicable to the different steps of a RAMS/LCC analysis and to define a common tool that will be used to compare the different innovative solutions. The tool takes into account the most relevant stages of the axle’s lifecycle which, according to the partners of the Euraxles project, correspond to the acquisition and operation phases.

Several questionnaires have been prepared and distributed amongst the partners to collect data based on the common tool in order to define the parameters for the reference cases which will be used for the comparative analysis of the different solutions investigated in the project. The reference cases chosen include wheelsets from Freight, High speed, Passengers/EMU/DMU and Loco.

It has been found that the available data coming from the return of experience is limited, specially referring to reliability data of axles. As an alternative, public available data coming from databases have been analyzed and, according to this data, the risk to have axle failures in actual railway traffic is very low so the safety is very high. In addition, experts in maintenance of partners contributing to WP6 have been contacted so, through their expertise, the reference data for the selected application may be established.

The collected data features a significant scatter of maintenance rules both among the contributors and applications considered. This result shows a lack of harmonization of maintenance rules in Europe. Collaboration between different companies involved in the supply and maintenance of axles is needed for further optimization of safety and LCC of these components.
The collected data has been analysed by all WP6 partners and reference cases for each application in terms of maintenance operations, intervals and associated costs have been defined. Afterwards, and applying the LCC calculation tool developed in this work package, life cycle costs (LCC) analyses of these reference cases have been performed. The axle related operations can represent the 15% of the total LCC costs.

Costs of different alternative and innovative coatings have been investigated. There is a lack of expertise of the application of innovative coatings to railway axles both specially in maintenance so further investigations are needed.

A parametric LCC analysis has been performed to determine the trends which can be used to assess the optimization for different applications. The results obtained can be used to estimate the cost savings when modifications on the maintenance practices are considered.

The investigations carried out in the project have been combined to assess, in a first attempt, the maintenance practices in order to achieve the target reliability of the axles in service. A method for risk analysis linked to cost calculations for determining the optimal inspection intervals has been derived and applied to a high speed application. The resulting intervals depend on the maximum stress of the load spectrum.

The common approach to RAMS/LCC analysis defined in EURAXLES can serve as a starting point for unified safety and cost evaluation of railway systems in general and wheelsets in particular within the European railway industry.

g) Summary of WP7- Dissemination, Training and Exploitation (UNIFE)

The objectives of the WP7 throughout the duration of the project period were:

- To set up dissemination strategy and tools to facilitate wide-spread information transfer among and beyond the members of the consortium;
- To ensure the project outputs reach the relevant rail stakeholders who will implement them;
- To ensure the project output reaches targeted decision makers at EU and National level for input in the standardisation and regulation work;
- To guarantee the delivery of high-quality results and sound technical solutions with the help of advisory groups.

During this final period of 6 months, UNIFE continued and finalised to support the administration of the work of the Paint Suppliers Group and oversaw the organisation of Transport Research Arena 2014 as well as the organisation of the final conference.

The main focus was in addition the coordination of the uptake of the final results of the project to standardisation. UNIFE and UIC have liaised with CEN working groups until the end of the project in order to ensure a successful integration to the current standard revision.

1.3 Expected final results and their potential impact and use

For WP2:
• The main limitations on the numerical determination of the stresses in the axles of the current design standards EN 1310X have been identified. A complementary approach, using the Finite Element Method (FEM), in order to provide designers with an additional method to avoid misunderstandings has been defined. This approach will be integrated in the Technical Report to be published by CEN. The definition of this complementary approach requires the determination of the fatigue limits for the different materials. In general, fatigue limits for EA4T obtained in WP3 are consistent with the current standards. However, EA1N material would require further investigations to get more accurate fatigue limits.

• General recommendations on how to model an axle with FEM techniques are provided. Methods to make fatigue reliability analyses of axles are proposed. The first one is based on the FKM guidelines and suggests the use of a semi-probabilistic approach to define minimum safety factors to be used in the design process when applying a representative load spectrum and probabilistic data on the fatigue limits of the material. The second one is a fully-probabilistic approach that makes calculations of probability of failure based on the scatter of the fatigue limits but also on the variability of the load spectra, taking account of the variability of axle’s usages.

The WP3 results give an estimation of fatigue limits of axles; such information is a main input in the design. The WP considered axles made in standard material (A1N and A4T) and defined a standard method for testing and analyzing the obtained data from a statistical point of view in order to be able in the future to apply the same method in the characterization of new materials or new surface treatments. Axle conditions considered for the actual testing were axles in standard surface finishing for which axle body (free surface) was evaluated separately from axles seats where wheel, brake disc or bearing press fits take place; in this later case the coupling of the components can generate, when high bending is applied to the axle, relative micro sliding and derived friction forces that end up in local wear and possible micro cracks of the seat side surface; the phenomenon is known as fretting corrosion and the result is that the fatigue limit is substantially lower than on the body. The severity of this phenomenon depends more on the geometry of the axle (Seat-body diameter ratio) than on the material itself; for this reason, different axle geometries were defined and tested. This part of the testing activity was complemented by task 3.3 dedicated to the theoretical modeling of fretting fatigue providing criteria for evaluating both the possibility for crack initiation and assessment of the crack propagation. The aim was to provide tools for optimizing the design.

WP3 also tested corroded axles to verify the actual reduction of the fatigue limit. A common testing procedure was defined in order that similar tests performed in different laboratories could produce comparable results. A list of small scale and full scale tests and the relative drawings were defined and the wheelset manufacturing partners prepared the materials for the tests. All tests were performed by 7 partners of the Project in their laboratories.

The results of WP4 and their potential impact and use mainly affect alternative protection systems and improvement of protection systems for wheelsets. Increasing the surface roughness by an alternative surface preparation method based on blasting is recommended based on results from the project, leading to a better adhesion of the paint systems. The surface preparation procedure for the design method of wheel-set axles includes corresponding fatigue limits tested in WP3 which are acceptable by the operators, system suppliers, wheel-set manufacturers and the technical approval authorities. An important potential impact is to increase the use of water-based paint systems, as these systems generally have lower adhesion than solvent-based paint systems. But also for the commonly used solvent-based paint systems a
better corrosion protection was shown in the project for blasted surfaces. For the blasting process a recommendation as guideline for use was prepared.

For unpainted axles a result was achieved together with WP3. Based on the performed fatigue tests it is expected that the decrease of fatigue limit as currently stated in the standards can be reduced thus making unpainted axles more attractive.

The results of WP5 are outlined below. The development of an innovative testing methodology was achieved through the delivery of the following improved Non Destructive Test (NDT) techniques, predictive techniques and methodologies (WP5):

- Improvement of ultrasonic based non-destructive testing techniques and optimized inspection periodicity → in the Project context, possible improvements, the actual NDT techniques as well as new alternative ones were proposed. These new techniques could be the key for the NDT inspection techniques applied to railway axles. By means of these inspection techniques, and the improvements proposed, it could be possible to optimize the periodicity of the axle inspection intervals, depending on their application and conditions of use. However, this process is expected to be quite complex due to the different maintenance companies and railway operators existing and the differences between the procedures applied by each of them.

- Identification of the most suitable NDT techniques for in-service axle damage detection; → After studying of the different existing techniques used currently in railway axles by the different maintenance companies and railway operators and the performing of a POD study based on the crack detection in different zones of the axle with different depths, it has been possible to check the detectability of each inspection technique currently in use. These data are very valuable to show which methods are the most optimal to check each type of axle in the most reliable way possible.

- Development of on-board diagnosis system enabling effective condition monitoring and fault diagnostics by distinguishing different kinds of faults occurring in railway axles to provide significant improvements in maintenance; → It has been developed an on-board detection system, based on the on-board analysis of vibration signals and the following signal processing by means of an specific algorithm developed. Some lab tests have been performed in a scaled benchbank with scaled axles, obtaining very promising results. The verification of these results has been done testing them in a lathe with real axle (with artificial cracks) and it came that this method could be very useful in the future. It is necessary to continue working with this inspection method (tests on axles in trains real service) to check the behavior of the axle in real service conditions. The development of this inspection system could be very useful in the future, since it could detect cracks in axle just at the moment of its appearance.

- Benchmarking and identification of the most suitable non-destructive and electrochemical techniques for corrosion detection of in-service axles or a combination of the existing methods; namely Electrochemical Impedance Spectroscopy (EIS), Electrochemical Noise Analysis (ENA), advanced ultrasound Lamb or Rayleigh wave (Lamb wave), acoustic resonance (AR) and acoustic emission (AE). → The benchmark study of electrochemical and NDT techniques performed, can determine that the most optimal techniques for the corrosion detection are the Electrochemical Impedance Spectroscopy (EIS) and the advanced ultrasound Lamb or Rayleigh wave (Lamb wave). It has been also analyzed the crack detection availability in hollow axles based in a new inspection technique by means of adhesive deformation plugs and its elastoresistive change occurred in this process. Very promising results have been obtained, but it’s necessary to continue investigating to obtain best results comparing the response with and without defects, for various
crack depths and sizes and to improve the manufacturing processes regarding the elastoresistives materials.

WP6 results:

- A common RAMS/LCC tool for the evaluation of the different solutions was investigated in the project which can be used for future assessment of wheelset components.
- Analysis of the RAMS related activities and associated LCC collected from the participants and definition of reference cases for selected applications to be used as the starting basis for the evaluation of new solutions.
- RAMS/LCC analysis of the innovative solutions investigated in the project and comparison with current solutions.
- Definition of recommendations for the revision of the existing European standards related to the design and maintenance of axles.