Wheelset Integrated Design and Effective Maintenance

WIDEM’s Strategic Objectives:

- Creation and validation of an innovative and rigorous methodology to design wheelsets
- Endurance strength design approach for wheels and axles which will lead to an optimisation of wheelset geometry, a reduction of un-sprung masses and an extension of maintenance intervals while meeting increasing safety and service requirements
- A new wheelset maintenance strategy based on more accurately defined inspection periods through the use of new NDT devices for railway (Compensated Resonance System)
- Optimise the design and maintenance of wheelsets, to reduce Life Cycle Cost. Wheelset loads will be measured and used to develop design guides for new axles and optimise testing regimes for existing axles
- The ultimate goal is to increase the competitiveness, capacity and availability of European railway products in the wheelsets area

General project information:

- WIDEM is a partly EU funded research project (Specific Targeted Research Project - STREP), the other half being funded by the consortium partners
- The project started in January 2005 and will end in December 2007 for a total duration of 36 months. WIDEM is coordinated by Lucchini with the assistance of UNIFE. There are 10 consortium partners
The economic efficiency and competitiveness of the rail transportation mode depends on safety, availability and maintenance of its individual highly loaded components such as railway wheelsets. The WIDEM research project, partially funded by European Community in the 6th Framework Program, aims to improve efficiency and competitiveness through a fundamental re-examination of wheelset design, which in turn will facilitate improved maintenance practices.

Combining inputs from reliable service measurement of wheel-rail forces carried out by means of an innovative instrumented wheelset and extensive assessment of actual material properties, an original endurance strength design concept is developed and validated through a comprehensive testing programme on full scale wheelset prototypes.

A flexible multi-body numerical tool is also proposed to address high dynamic loading conditions in presence of wheel/rail discontinuities like wheel flats or switches. In this way possible exceptional loads linked to possible geometrical irregularities ere considered in the evaluation of the life load spectra.

Additionally, the project addresses NDT (non-destructive testing) techniques applying methods to evaluate the crack size probability of detection (POD).

Such information together with results from full-scale crack propagation tests and measured load spectra will be the basis for setting up a schedule for NDT periodicity inspection.

The research work will lead to the definition of wheelset design and testing procedures and maintenance methods to be implemented into existing standards.

This newsletter gives an overview of the progress since the project start at the beginning of 2005.
Background information

The WIDEM project is in principle a re-examination of the basic information necessary to design and validate a railway wheelset and to manage the maintenance parameters that in some way are related its design criteria. The idea of starting this project was stimulated by the application of the new European design Standards. As the verification of full scale fatigue limits of wheels and axles become mandatory, testing methods and interpretation methods of the results were not defined or in general were not homogeneous throughout the European Laboratories.

The technical information that can be found in the new European Standards comes from the previous UIC norms; for example, in the case of axles, is based on the so called A1N steel grade extensively tested in the past 70’s by SNCF laboratories.

Over the past years these norms were surely proven to be safe when using this kind of steel grade. In the last 20 years many new vehicles were put into service with higher and higher speeds. Vehicle weight reduction, become a must for the majority of the European train manufacturers. Already in the 80’s in Italy, the former Fiat Ferroviaria (now part of Alstom Transport) started together with Lucchini to use an alloy steel grade (30NiCrMoV12) for the new axle of the first Italian Tilting Train. In this case design methods based on the manufacturers’ internal experience were used to handle this material. Also in this case the applied design was proven to be safe by years of service.

The new European Standards enable the use of materials different from E1N, but not so much of the latest experience and knowledge in using new material and in designing new advanced vehicles was considered when writing these norms.

For the above mentioned reasons, today, from a formal point of view, it becomes difficult for the designer to define more precise load spectra and material characteristics that can be accepted by an authority responsible to approve the qualification of a new component.

WP1     The accuracy in measuring wheel-rail dynamic loads

Main task

Measuring wheel-rail dynamic loads is today a very approximate exercise because of:

• inadequate technology of the instrumented wheelset (telemetry, data processing and self powering)
• static calibration of the measuring system which does not reflect the actual service conditions

The WIDEM project has developed an innovative measuring wheelset made of up to date wireless data processing and transmission technology. A dynamic calibration is performed by using a unique roller rig on which running conditions near to reality can be simulated. A mathematical calibration approach enables to turn the measured strains into vertical, lateral and longitudinal force components by optimising a transfer matrix. The final result is the possibility of improving and verifying the actual accuracy of the measuring system, together with a robust telemetry data transmission system.
Main achievements

At this stage POLIMI and Lucchini, have developed a new real-time measurement methodology of wheel – rail contact forces based on the acquisition of axle deformations having a bandwidth of about 70Hz. Alstom installed on an instrumented wheelset with wheel webs a measuring system devoted to the evaluation of lateral forces acting on each wheel. The measuring system consists in a particular application of the existing measuring system (already used by Alstom for several years) that should improve the accuracy of the measurement. All together there are 30 strain gauges channels acquired by a telemetry system. Together with a traditional analogue-multichannel telemetry, an innovative one based on digital transmission is developed to improve data transmission robustness.

Future work

In the end, the development of a standard procedure for processing load (or stress) measurements will allow the computation of a wheelset design mission profile, intended as a reliable load spectra, statistically representative of the total life loading time history.

Main achievements

The innovative instrumented wheelset developed in WP1 has been mounted on a Czech Pendolino vehicle and load measurements together with accelerations, speed and GPS coordinates have been recorded on various Czech railway routes across the country. Additionally, specific tests have been performed on the VUZ railway circuit based in Velim. Here, loads were measured in presence of switches, rail defects and artificial wheel flats made on the instrumented wheelset.

WP2 Wheel-Rail load test campaigns

Main Tasks

The main task is to collect load data for two different vehicles to be used as a basis for the definition of load spectra. Different load processing methods will be applied and confirmed. In the end, a common standard method should be suggested for the definition of wheelsets load spectra to be used in the design and in service-NDT periodicity evaluation.

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VUZ is involved in the organization of the in service tests with the Czech Pendolino Trainset along the Czech railway track and their unique railway testing circuit. Together with GPS recordings, correlation will be made between the position of the high force levels and the presence of rail defects and/or switches. Artificial defects on wheels will be caused on the wheels to evaluate the corresponding load increase.

Future work

The second test campaign will be performed in Sweden on the MTAB heavy haul vehicles from Kiruna to Narwik. With its current fleet of locomotives and cars, MTAB has a mine-to-harbour freight capacity of more than 23 million tonnes per year. This corresponds to about 7,000 fully loaded ore trains per year. Advancements in rolling-stock technology mean that the chain of ore logistics can be utilised with greater efficiency, with locomotives that can haul longer, heavier trains. The objective of reducing transport costs is achieved by investing in new locomotives and cars with a 30-tonne axle load. On one of these vehicles an instrumented wheelset will be mounted to measure load spectra in these rather quite extreme conditions.
WP3  Improving Flexible Multibody Models to understand the vehicle track interaction

Main tasks

In this workpackage, POLIMI is further developing their Flexible Multibody Vehicle model which is able take into account the deformability of both the wheelsets and the bogies as well as the carbody and the track. While the deformability of wheelsets, bogies and carbody is taken into account through a modal superposition approach, the deformability of the track is accounted for through a FEA model of the railroad. Together with concentrated defects, the passage of switches represents the most challenging service condition for the wheelset, in terms of peak values of wheel-rail contact forces. Therefore, the correct simulation of these running conditions assumes critical importance in order to reproduce correctly the extreme values of the load spectra.

Also, these are the loading conditions that show the highest sensibility to track flexibility. From a more general point of view, this modelling work aims to establish the effect of wheel and rail defects on wheel-rail contact forces, in terms of dynamic amplification factors expressed as function of a specific geometrical parameter describing the defect and as a function of speed.

Tests performed on the Alstom tilting train will be the basis for the validation of this kind of modelling. Finally, validated Flexible Multibody Vehicle models should become a tool to evaluate corrections to be applied to nominal load spectra to be used in the design of a wheelset which includes possible high loads that can be found during the life time of this component.

Main achievements

The Flexible Multibody Vehicle model is now able to simulate both straight/curved track running and the transit over concentrated defects and/or switches thus allowing to determine load spectra of the contact forces in any working condition.

Future work

As soon as experimental data form WP2 will be processed, a thorough validation of the model will be carried out. Then, load spectra of the contact forces will be determined even in working conditions that were not considered during the experimental campaign. Moreover, once validated, the Flexible Multibody Vehicle model can be used to assess the load spectra at the design stage.
WP4   The assessment of material properties

Main tasks

The final aim will be to define a precise procedure to perform full scale fatigue tests on wheel and axles. The reason for this is that different laboratories throughout Europe perform tests in different ways and results are not always comparable.

Testing experience from the past years plus a benchmark with other laboratories has enabled the definition of all the relevant parameters referred to the component geometry, the measurement of the load, and the statistical evaluation method of the test results.

From a research point of view much work is ongoing to describe better the fretting fatigue phenomena which depends on many parameters that are not carefully considered in the norms: hub thickness (h), interference (i), contact pressure (P), slip (s), axle seat length (L), axle diameter ratio (D/d), axle bending moment (M), nominal longitudinal stress (\(\sigma_n\)), real longitudinal stress due to bending moment (\(\sigma_r\)).

The following scheme shows how these parameters are related.
Main achievements

The possibility of combining full scale experimental fatigue tests results together with FEM models representing the actual longitudinal stresses and micro-slips between hub and seat can enable the definition of a design criteria against fretting fatigue.

Main innovation

By changing the main geometrical configuration \((D/d)\), different configuration limits of \((\sigma_r \text{ and } s)\) can be found and from there a theoretical area of permissible \((\sigma_r, s)\) couples could be defined. This work is presently under progress for A1N and A4T and 30NiCrMoV12 steel grades. Full scale tests are brought over on the Lucchini test rigs to find the fatigue limit at \(10^7\) cycles for different diameter ratios with the aim of validating the above described fretting fatigue model and of defining the “D/d border”: below this value cracks will appear on the axle seat, above this value cracks will appear on the body fillet. Such value will increase with the fatigue resistance of the steel grade so that it will be appropriate to define the optimal D/d for each kind of material.

Future work

A complete characterization of the material to enable a more advanced design requires the Wöhler curve. The missing information at low and very high number of cycle is found by fatigue tests on specimens performed by LBF laboratories. The knowledge of the Wöhler curve and of realistic load spectra will enable the application of typical endurance design methods based on Miner counting methods.

WP5  Development and validation of a new design method for wheelset

Main tasks

With the aim of optimising wheelset geometry, a new design procedure will be defined. Taking advantage of new inputs such as life-representative load spectra and actual material fatigue data, first stresses will be calculated according to standard principles and then fatigue cycles accumulation theories will be added according to Endurance Design Concepts.

Main achievements

These concepts, which are regularly adopted in other industrial sectors, e.g. in the automotive and aeronautical sector, will be based on the testing activity performed in the previous WPs where loads are measured and materials are tested.

Future work

The entire design procedure will then be validated by a full scale component fatigue tests on the LBF test rig.
WP6 The probability of detecting cracks in wheelsets

Introduction

Metallographic analysis made on fatigue cracks from tested axles, show that the initiation is generally from internal defects with a dimension of 20 – 100 µm.

Kitagawa-Takahashi diagrams experimentally determined by means of fatigue tests on artificially micro-notched specimens, show that the fatigue limit are strictly dependent on the dimension of defects.

On the other hand, NDT inspections made during the manufacturing process or in service are not able to identify defects or cracks smaller then 1mm. For this reason NDT inspections are required with a certain periodicity throughout the life service of a wheelset.

The possibility to define the reliability of different tests (Ultrasonic, Magnetic or Eddy currents) is the first information that is needed in a procedure to define the optimal inspection interval for an in service vehicle.

Two very different questions can be raised at this point:

- What is the largest crack that the NDT equipment will not be able to see; on the basis of this dimension, crack propagation criteria are applied to determine the remaining life.

- What is the probability of not detecting an existing crack and how this probability can be compared with the cost limits put on railway accidents. This probability will decrease by increasing the inspection periodicity or by improving the inspection method.

Main Task

The main task is to establish the POD for different inspection methods. This activity is carried out by TWI produces POD curves by performing inspection tests on both fatigue tested axles and real in-service cracked axles. Collection of the latter is very difficult, fortunately because it’s a very rare event However, axles from service have been collected in the UK and in Germany. Other axles with flaws have been produced in the Lucchini fatigue test rig.

Main Achievements

First trials were performed in LBF Darmstadt on the axles obtained there. This included the use of AC Potential Drop, Phased Array Ultrasonics and Time of flight ultrasonics to size the cracks and then the use of representative on site inspections to establish the probability of detection.

An example of the MPI indication of the crack and a POD curves are given in following figures.

Typical Crack in Darmstadt axle

POD Curves produced
Main Innovation

The data produced by LBF’s test are believed to be the first experimental POD type data for far end axle inspection.

Future work

The main trials for the solid axles and the trials on the Lucchini axles are planned for autumn 2006. WIDEM is also putting some effort in innovative NDT methods based upon vibration analysis. These methods are implemented by D2S, and through a simple vibration test setup with artificial excitation and a complex analysis of the collected data in the high frequency range (10-150 kHz) are able to detect changes in the vibratory response of the structure and to correlate these changes to the presence of cracks.

D2S has integrated the ARTEMIS%100 instrument within the scope of the project. It includes the artificial excitation, the measurement tool and the analysis methods based upon vibrational behaviour. The ARTEMIS%100 has been used to successfully identify cracked wheelset axles. The instrument has large capabilities for defective parts detection in following sectors: aerospace, oil, energy and transportation.

WP7 The periodicity for in service NDT inspection

Main Task

The determination of the optimal inspection periodicity is quite a new subject for the railway components. This is the final work package in the project and requires data from all the other work packages. The WIDEM project aims to put together all the information that are necessary to perform this evaluation. These include a knowledge of the actual load spectra that the wheelset experiences and the material crack propagation properties.

The original idea for determination of the periodicity is to use a crack growth curve together with the probability of detection of defects/cracks. The hypothesis made, is that when NDT inspections are made in service, in some critical place a small crack exists; but the dimension is such that it can’t be seen by the NDT equipment.

From this hypothetical undetected largest dimension, the crack propagation model is applied as a function of the load spectra and the number of cycles at which the crack will become critical is calculated. The Crack Propagation Software would be the well known NASGROW.
This value would be used to set the first inspection time, and other points set so that there would be multiple opportunities to detect the crack before failure.

The work performed in WIDEM is basically the experimental determination of all the material parameters necessary for using the NASGROW software plus the adaptation of the crack propagation model to take into account the rotating bending that increases the propagation speed and modifies the crack shape. Finally the full scale rotating bending test rigs will be used also to validate the model by applying variable amplitude loading. Fracture mechanics experimental tests have been carried out and used to define a stochastic propagation model able to take into account the scatter band of experimental results in the estimation of propagation lives. A set of FEM analyses were then made in order to define the differences, in terms of the constraint at the crack tip, between axles and traditional fracture mechanics specimens. A different set of FEM analyses were carried out in order to characterise the SIF (stress intensity factor) solutions for typical axles notches subjected to rotating bending. The future steps concern the introduction in the SIF solutions of the influence of press-fittings and the incorporation of all the obtained results in a crack propagation software.

The main material information needed for the periodicity model are the Paris curve with its constants (C, n, \(\Delta K_{th}\)), and the crack shape development. These are evaluated experimentally through constant loading – rotating bending full scale tests; the cracks are initiated by micro-notches.

With the same test rig it will be possible then to validate the propagation through variable load spectra measured in service.

An alternative point of view, which is currently under discussion, is that an acceptable level of axle failures is to be set, and work backwards from this to the necessary inspection periodicity.

It is possible to implement this idea using reliability methods and setting a given probability of failure. The proposed reliability software is STRUREL, a well recognised software used for structural reliability estimation. The following graphs show how the two models can be displayed.
Main Achievements

Significant work has been completed in deriving crack growth rate parameters under both plane and rotating bending conditions. Finite element analysis have been conducted to aid selection of appropriate stress intensity factors and crack shape development including complex effects such as the presence of the seats in the axle.

Main Innovation

The use of a reliability approach to establish periodicity for a given probability of failure is a new development for axle design.

Future work

Work is continuing on developing the final crack growth model and implementation within the two alternative methods. Data on loading spectra from other work packages will be processed into a format appropriate for the probabilistic model. Some consideration of the acceptable target reliability based on historical axle failure data is also ongoing and the potential impact of human error is to be examined.

WIDEM Structure & Contact

European Commission

Cooperator (Lucchini) -> Management Support (UNIFE)

Chair

Steering Committee (Lucchini, UNIFE, Microstystems, D2S, POLIMI, LBF, TWI, Alstom, MTAB, VUZ)

WP10 Project Management - WP Leader: Lucchini

WP1 Leader: Microstystems
WP2 Leader: D2S
WP3 Leader: POLIMI
WP4 Leader: LBF
WP5 Leader: Lucchini
WP6 Leader: D2S
WP7 Leader: TWI
WP8 Leader: Alstom

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