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Design, Manufacture and Maintenance of Wheelset at SNCF

F. Cocheteux[†] and T. Pouillart[*]

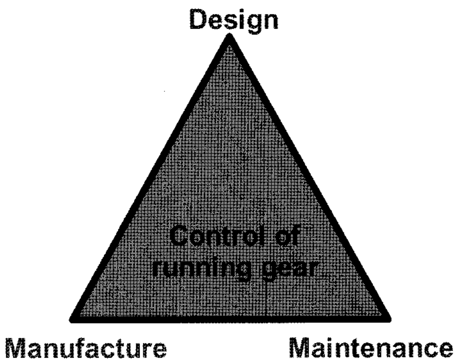
Abstract

The wheelset, by its functions and position under the train is the prime safety-critical component. Whether in design, qualification, manufacturing or maintenance, the wheels and axles have been the focus of special attention at SNCF for over 25 years and the French Railways are actively involved in various Research and Development work towards interoperability between the railways, railway reliability and running safety.

Keywords : *Running gear, Wheels, Axles, Fatigue criteria, Wheelsets*

1. Introduction

Reliability of railway running gear[1] is based on three fundamental factors: design, manufacture and maintenance.



Until now this has been achieved with some success by each of the long-established rail networks in accordance with their own policy and experience. Standardising rules (CEN, UIC, etc) and local regulations have often been put in place to convey these experiences.

The aim of the draft -which will take into consideration the stresses on running gear in their design, manufacture and maintenance – is to expose the French railways (SNCF) philosophies.

† wheelset exrert, SNCF
E-mail: francis.cocheteux@sncf.fr
*wheelset exrert, SNCF
E-mail: thierry.pouillart@sncf.fr

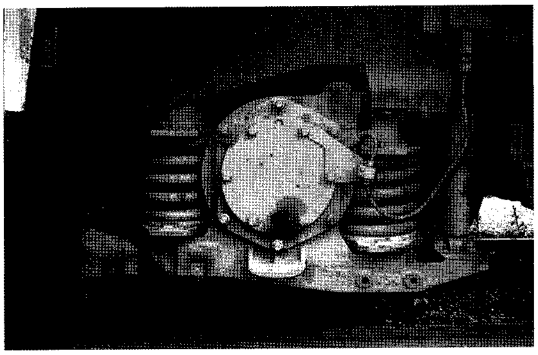
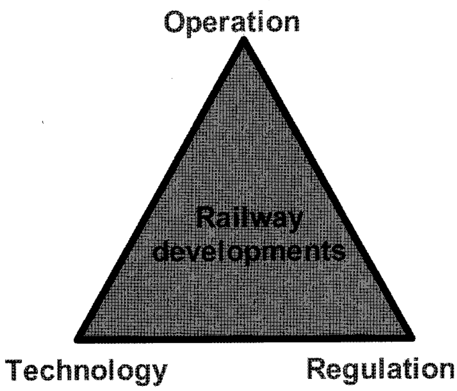


Photo 1 The running gear

2. Developments in the Railway Context

The global analysis of current Research and Development work in Europe and in the world, carried out on running gear, shows that development in this field, as with other railway components, is governed by three factors: operation, technology and regulation.



In the framework of railway operation, it can be noted:
- the nature and characteristics of the infrastructure: rail/sleeper/ties/ballast/...
- the nature and characteristics of the defects of the wheel running surfaces;
- the nature of future operation: higher axle-loads (25 t/axle for freight), higher running speeds (300 km/h for the HST, 120 km/h for freight), increase in intervals between maintenance operations;
- tilting of rolling stock

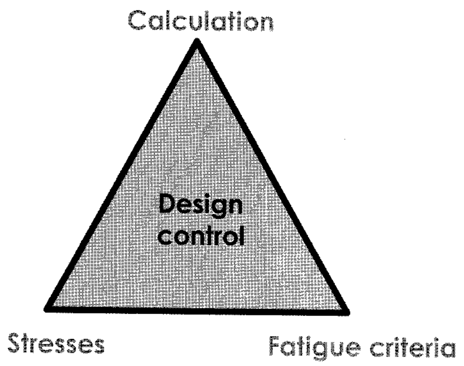
In the framework of railway technology, it can be noted:
- the nature and characteristics of new materials, for example for making axles lighter;
- the nature and characteristics of new vehicles, for example tilting coaches;
- the diameter of smaller wheels

In the framework of railway regulation, it can be noted:
- reduction in railway noise at the wheel/rail level including expert knowledge of the roughness of surfaces in contact and of the wheel/brake-block;
- formalisation of the evaluation of the conformity of products to need;
- a contribution of design and content for establishing a European maintenance programme.

3. Inventory of Fixtures

3.1 Design

Command of the design of running gear is based on three fundamental parameters according to the following scheme:



Up to now, command of design has been achieved using rules worked out in the 1970s and 80s by the historical railways. The European standardisation, underway since the 90s, is to set out a common rule derived from those different experiences.

European Standards (ENs) should replace and supersede the present documents, amending them or elaborating upon them, as follows:

- for wheels
  : UIC Leaflet 510-5, standard NF EN 13979
- for powered axles
  : UIC Leaflet 515-3, standard NF EN 13104
- for non-powered axles
  : UIC Leaflet 515-3, standard NF EN 13103
- for wheelsets
  : UIC Leaflet 510-1
- for journal bearings
  : UIC Leaflet 515-5, NF EN 12080 & NF EN 12082
- for axlebox grease
  : UIC Leaflet 814, NF EN 12081 & NF EN 12082
- for axleboxes
  : UIC Leaflet 515-5, NF EN 13749
- for bogie frames
  : UIC Leaflets 510-3, 515-4, 615-4, NF EN 13749

The conventional loads referred to in these standards are defined on the basis of the axleload (load per wheelset) on the track. They are fairly independent of the dynamic behaviour of the rolling stock, i.e. high-speed rolling stock, wagon, locomotive, electric multiple unit or other, and even more independent of the condition of the infrastructure.

3.2 Current calculation methods

3.2.1 Axles

For axles, the design calculations currently employed are based on the beam theory and nominal stress method.

The stress calculations are intended to determine the dimensions of the axle taking into account its geometry, its material, its utilisation, i.e. whether it is powered, non-powered or steering), its amount of service it sees and its method of manufacture. From the geometrical characteristics of the axle, the axle type (solid or hollow) and the forces applied to it (weight on the journals, weight of the fitted axle and braking forces), it is possible to calculate

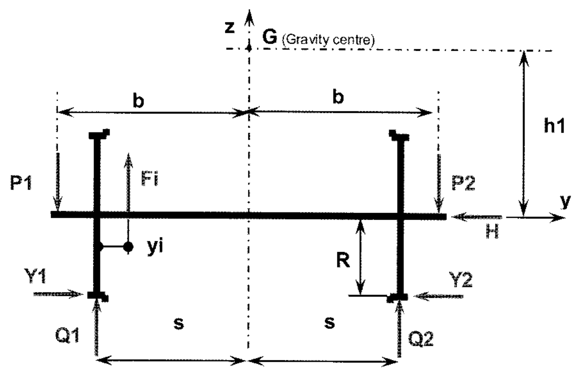


Fig. 1 Calculation parameters

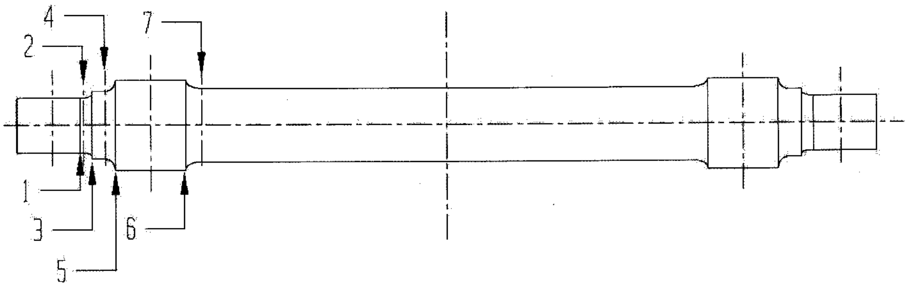


Fig. 2 Location of the calculated sections

the reactions at the bearings (at the wheel-rail contact). During this first phase of calculation, a distinction is made between powered axles and non powered axles in accordance with French and European standards NF EN 13103 and NF EN 13104.

Given steel grades are associated with specific permissible stresses at various locations on the axle. The stress thresholds, derived from mono-axial fatigue tests done in the laboratory on test pieces representative of the component and the material, are obviously set with a safety factor to take into account the statistical variations due to fatigue and to the manufacturing process.

The axle is divided into sections bounded by geometrical discontinuities (different diameters, stress relieving grooves, transition radius, etc.). At each end of those sections, the calculated stresses must remain below the permissible stresses. It should be noted that the fatigue stress concentration factors (K) are found from nomographs according to the two ratios, r/d and D/d.

3.2.2 Wheels

Axisymmetric wheel centres are calculated by the finite element method in order to determine the principal stresses under conventional loads following the procedure described in NF EN 13979 and UIC 510.5.

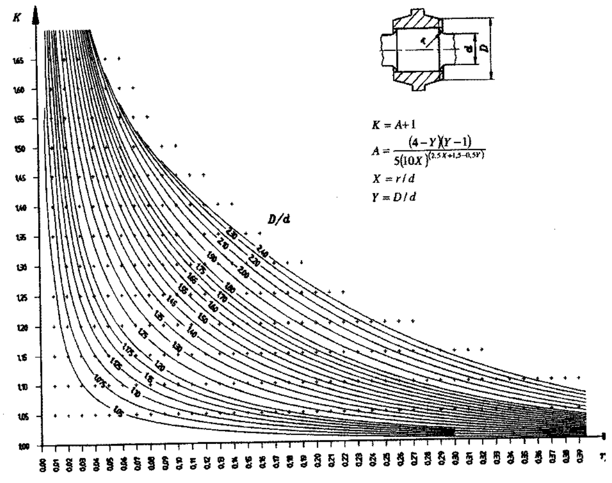


Fig. 3 Nomographs of K factor

It must be noted that the maximum principal stress corresponds to the maximum radial stress.

The surface roughness of the wheel centre (Ra ≤ 3.2 μm or Ra ≤ 12.5 μm) is taken into account in the permissible stresses.

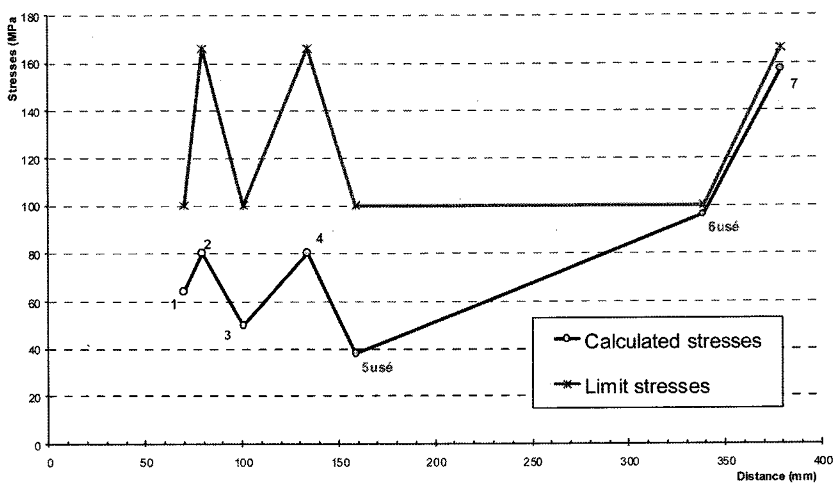


Fig. 4 Evolution of the calculated stresses

The principle of conventional loading defined in RP11 of ERRI Committee B136 and in UIC Leaflet 515-3 is characterised by the vertical and transverse forces on straight track, curves and reverse curves.

The stresses are analysed according to B12/RP17 or UIC 510-5 in what can be broken down into five steps:

- search for principal stresses at all points of the wheel centre under each of the load cases (straight, curved, reverse-curved track);
- determine for each node the maximum stress (σ_{max}) and its direction (δ);
- determine for each node the minimum stress (σ_{min}) in the direction (δ);
- determine for each node the mean stress and the stress range; $\sigma_{moy} = (\sigma_{max} + \sigma_{min})/2$ et $\Delta\sigma = \sigma_{max} - \sigma_{min}$
- verify that, for the entire wheel, the stress range thus calculated remains less than the permissible stress range, that is 360 MPa or 290 MPa depending on the roughness of the wheel centres.

All these calculations must integrate the geometrical parameters of interchangeability tied to the functional requirements (nominal diameter at the bearing, width of wheel rim, profile, etc.), to the assembly requirements (bore

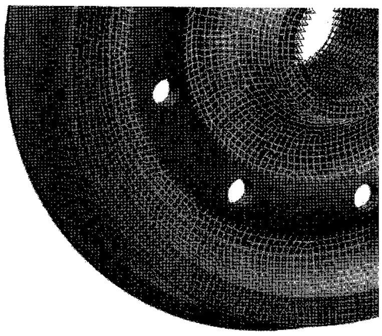


Fig. 5 Example for Wheel mesh

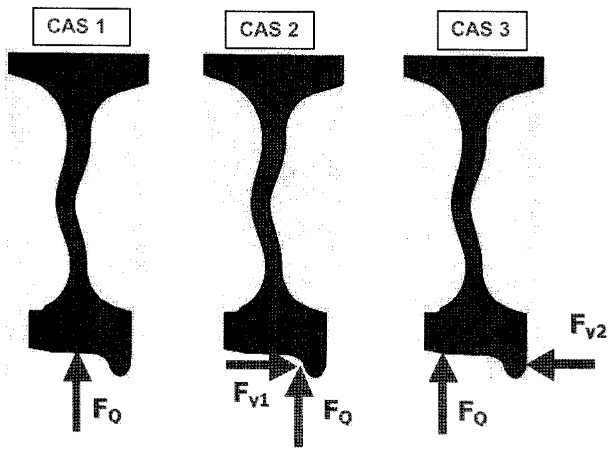


Fig. 6 The conventional loading

diameter, length of the wheel boss...) and to the maintenance requirements (wheel wear limit diameter, position of oil injection hole...), which leaves little latitude for creativeness except as concerns the wheel centre.

In parallel with this mechanical calculation of wheel fatigue, a thermomechanical assessment is made in accordance with RP17 of ERRI Committee B169 for braked wheels in order to comply with the permitted deflection thresholds, for cold and hot wheels, and with the permissible residual stresses.

To date, the experimental procedure remains essential in the railway wheel product acceptance process.

3.3 Future outlook

3.3.1 Loads

As mentioned previously, the conventional loads considered in the specifications are defined on the basis of the axleload on the rail.

Research done in the ERRI/B169 committee for the UIC has helped to develop the ERRI/B169 RP12 method for determining a set of loads or "load case" that depends on the track quality and geometry and the vehicle's duty.

New works should allow to develop different load cases expressed as probabilities of appearance based on on-line tests of the most-relevant traffics for Europe, namely:

- freight,
- locomotive,
- tilting stock,
- high-speed stock,
- suburban stock.

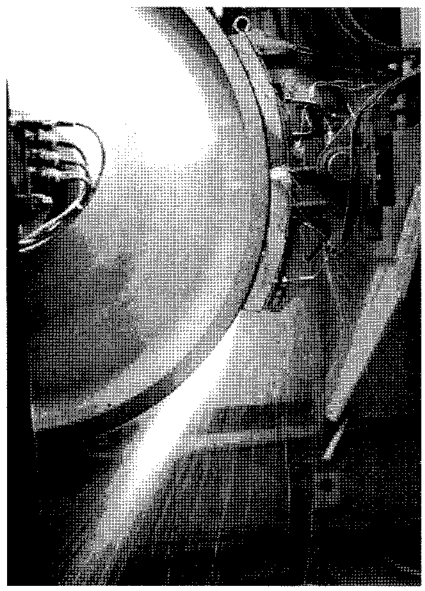


Photo 2 Breaking test

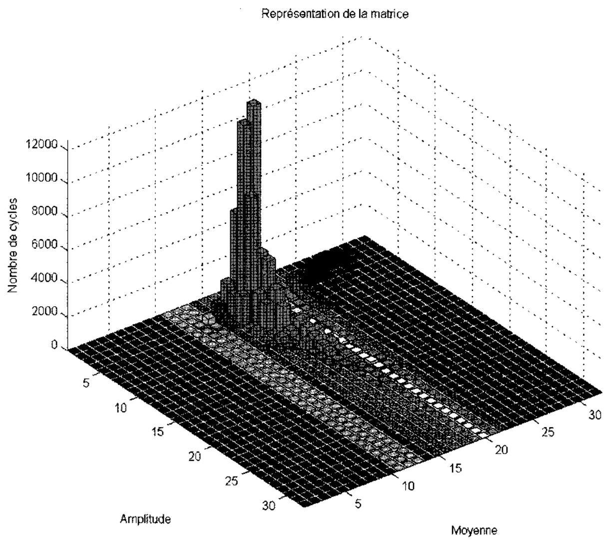


Fig. 7 Example for rainflow matrix

Moreover, weighting these load case components should allow to assess damage to other rolling stock without testing and there by speed development work.

3.3.2 Fatigue criteria

To day, the rotating-bending fatigue criteria for axles put in place in Europe concern two materials. An evolution will consist to express them as cracks appearance probability or survival probability.

The reverse-bending fatigue criteria for wheels put forward so far by ERRI Committee B169 concern only the material ER7 from the standpoint of mono-axial fatigue of the wheel centres – the Wöhler curves and Haigh or Goodman diagrams at 10^7 cycles.

Works have been done to propose multi-axial fatigue criteria for wheel designing (RP19) and the different threshold to consider for ER7 steel [1]. Fatigue limits have been determined for other wheel materials, more resistant to Hertzian stresses or thermomechanical loads (ER6 and ER8).

However, in order to find out how the material will react to long-life fatigue (polycyclic fatigue), and to take into account the loads applied to the test piece which are most often multi-axial (due at least to residual stresses), it is necessary to use fatigue criteria that take into account the multi-axiality of stresses.

Most often, loads are multi-axial, non-proportional and of variable amplitude. That is why fatigue criteria integrating these parameters were ultimately developed. The first multi-axial fatigue criteria, essentially empirical, appeared in the 1930s.

Beginning in the 1950s the less than negligible role of normal stress in the initiation of fatigue cracks was considered. From then on the criteria were essentially in the form of a linear combination of the shear stress and the normal stress on a particular fascia, in the so-called critical plane approaches. As concerns the "global" approaches, their formulation is rather based on a linear combination between the first invariant of the stress tensor and the second invariant of the stress deviator tensor.

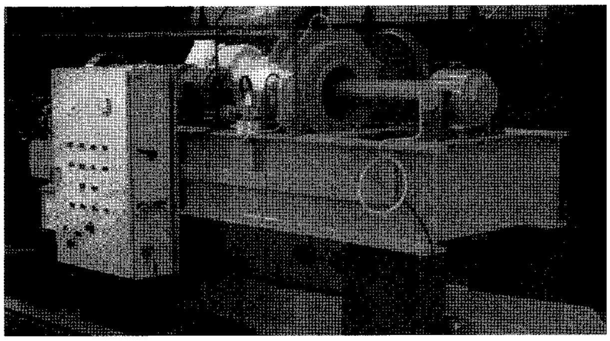


Photo 3 Axle fatigue test

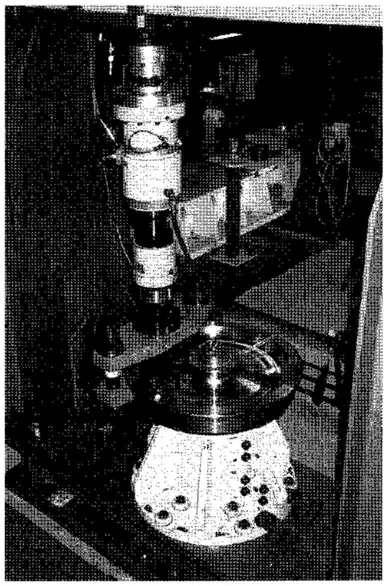


Photo 4 Wheel fatigue test

The microscopic theories arose in the 1980s. The use of criteria viewing all material planes through a point was made possible thanks to the step-up in computer number-crunching capability.

Energy approaches were also developed whose principal damage parameter is the work supplied.

Traditionally, the multi-axial fatigue criteria have been classified as follows:

- empirical approach;
- global approach;
- critical plane approach.

Among the more than 50 criteria formulations, that of

Dang Van (critical plane approach) is often preferred in the industrial environment, that is

$$\max_{\vec{n}} \max_{t} \left(\tau_{a,\vec{n}}(t) + A \cdot \Sigma_H(t) \right) \leq B$$

where the coefficients A and B of the criterion are determined for example by the D fatigue limit in traction or bending for a given R load ratio σ_R^D and the fatigue limit in D reverse bending τ_{-1}^D by:

$$A = \frac{3}{2} \cdot (1-R) \cdot \left(\frac{\tau_{-1}^D}{\sigma_R^D} - \frac{1}{2} \right) \qquad B = \tau_{-1}^D$$

3.3.3 Calculation methodologies for wheels

The wheel's function is changing. The wheel itself is becoming a braking component thanks to the mounting of discs on wheel centres (cheek mounting); it becomes a noise damper when certain products are incorporated in the centre or along the rim. The current calculation methods are not suited to interpret the behaviour of such wheels in multi-axial fatigue.

Analysis of cracks in wheel centres of suburban trains has shown that coupling of thermal stresses with mechanical stresses can be the cause of failure.

One development project consists in validating the use of finite element computing codes.

The calculation methods will be validated by correlation with special purpose tests during which the uncertainty of the results will be defined.

It will be necessary to determine the specific behavioural laws of the different materials investigated under cyclical loading to develop the computer models.

Lastly, service loads correspond to multi-axial loads of variable amplitudes for which the notions of equivalent loads are as yet quite difficult to define. In fact, it would be more accurate to speak of damage and accumulated

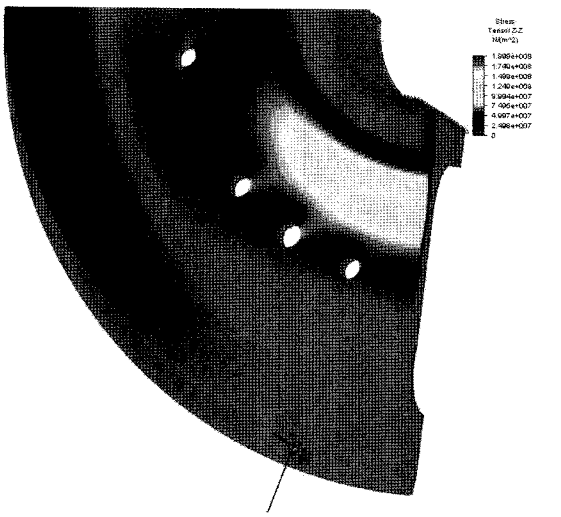


Fig. 8 example of stress field of nonaxisymetric wheel

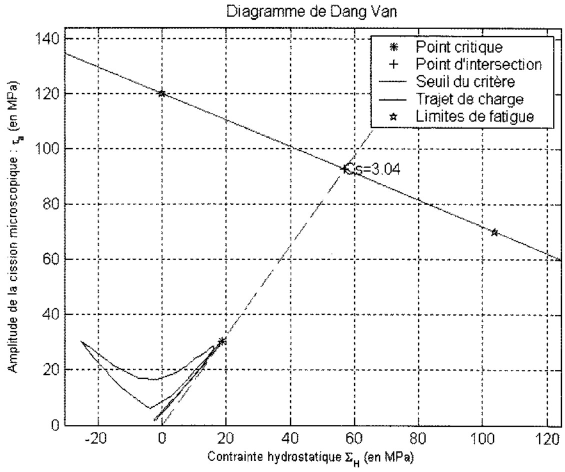


Fig. 9 Loading path in the Dang Van axis

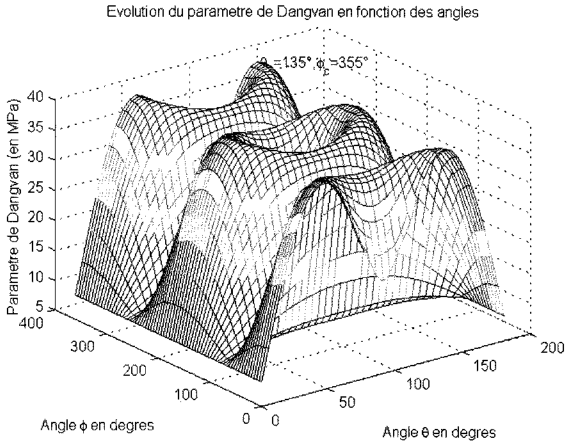


Fig. 10 Visualisation of the critical plane

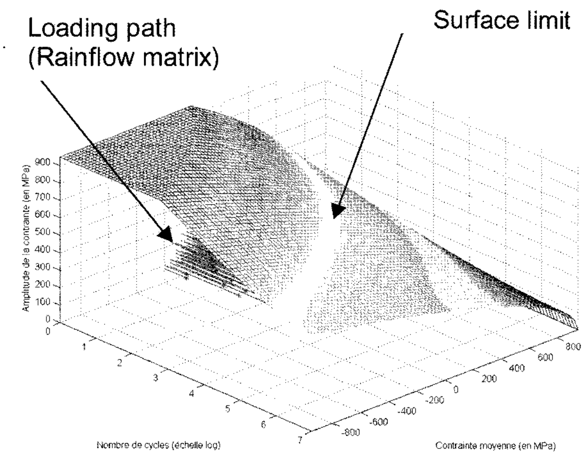
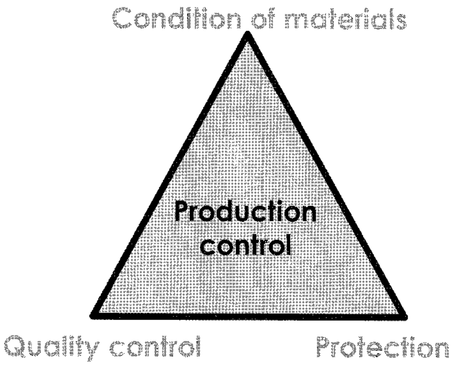


Fig. 11 Damage Cumul in monoaxial



damage in multi-axial – a field being investigated.

Currently, the damage under mono-axial fatigue can be estimated by calculation and checked by experimentation, whereas taking into account the damage incurred from multi-axial fatigue calls for much more complex approaches that enjoy only limited, highly specialised application in industry.

4. Manufacture

Once the running gear is designed following the concepts outlined above, command of manufacturing relies on three principal parameters as diagrammed opposite.

The European standardisation underway today covers this topic almost completely. French railway experience is incorporated into the standards NF EN 13261 on axles, NF EN 13260 on wheelsets and NF EN 13262 on wheels.

The material must not only have minimum characteristics of resistance to tensile loads, to fatigue, to toughness for the wheels – the idea of the latter characteristic being to preclude radial fractures of wheels subjected to high thermal loads – but also not present any internal or external flaws where cracks can initiate and then propagate. In particular, inclusions in wheel rims can be the source of cracks parallel to the wheel tread [2].

The quality of the machining must be controlled to guarantee the previously determined minimum level of fatigue strength.

The protection of the axle shaft must be carefully applied to prevent their corrosion and/or dents that considerably weaken their fatigue characteristics [3]. Numerous cases of fatigue cracking and propagation have been seen in service in the last ten years when the axle dimensioning did not include such protections.

SNCF has therefore taken to qualify wheel, axle and wheelset products from its various European suppliers. This qualification process comprises both qualification of the product, the supplier's manufacture plant and equipment, especially that used for non-destructive testing, and

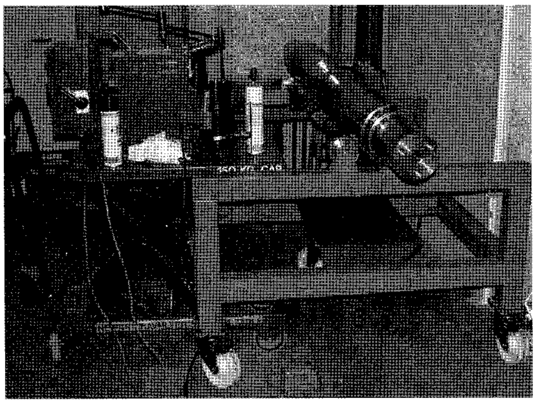


Photo 5 Magnetic testing on axle

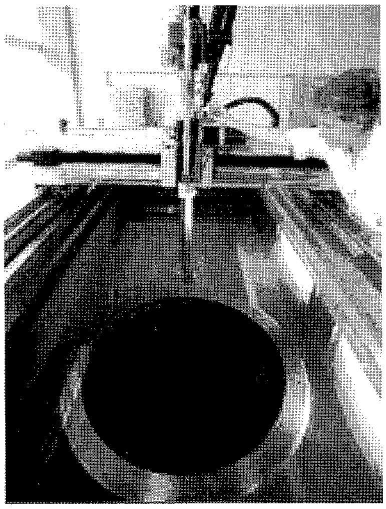


Photo 6 Ultrasonic inspection on wheel

destructive tests in the laboratory. Inspection for rim inclusions, by immersion in an ultrasonic inspection tank, and magnetic particle inspection of the wheel centre are two examples of tests to verify the internal and external soundness of the products to be qualified.

5. Maintenance

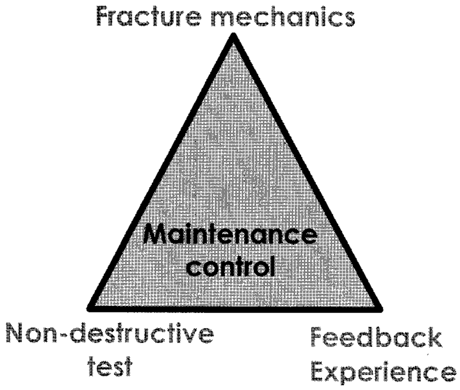
Command of the maintenance of running gear relies on three main parameters as diagrammed opposite:

There is actually little standardisation in the field of maintenance, or practically none. Some prescriptions have been put in place, mainly for freight rolling stock, in the context of the UIC.

For running gear, it is worth mentioning

- regarding wheelsets for freight : UIC Leaflets 510-2 and 579-2
- regarding wheelsets in general : a draft prEN 15313

Control of the non-destructive testing techniques is



assured by different standards, in particular standard NF EN 473 for the certification of operators.

Maintenance therefore relies almost exclusively on the standards or codes of practice of the historical railways, and of SNCF in particular.

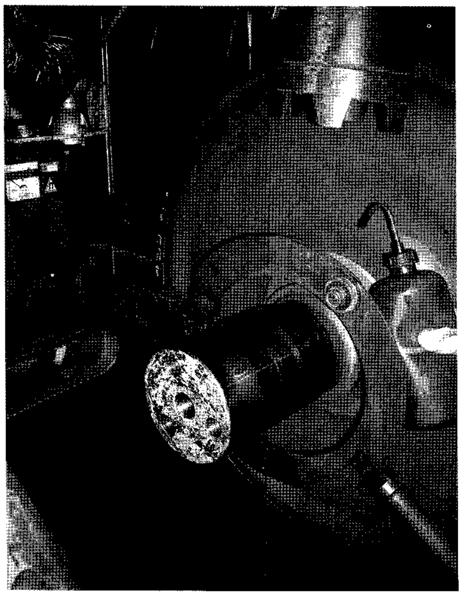


Photo 7 Magnetic particle inspection of a wheelset

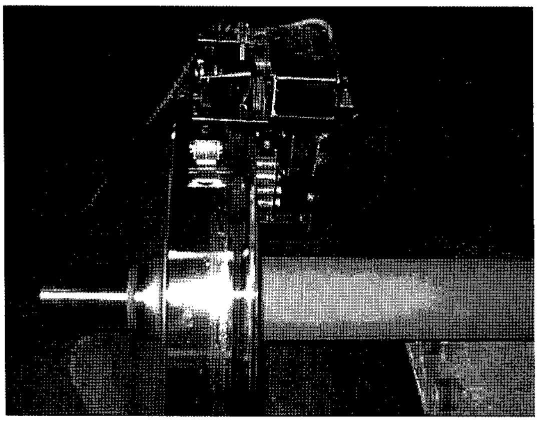


Photo 8 EMAT apparatus for residual stresses in wheel rim

5.1 Non destructive tests

Historically, SNCF began to set up non-destructive tests in the 1960s, in particular magnetic particle and/or dye penetrant inspection for external flaws and ultrasonic testing for internal flaws. These choices have practically not changed fundamentally, except for the measurement of residual stresses in wheel rims using EMAT-generated ultrasonic waves.

Since that, SNCF has committed itself to a policy of quality assurance. It has chosen to apply standard EN 473 for the certification of its Levels 1, 2 and 3 operators in the field of railway maintenance. A qualification Centre has even been set up in Vitry-sur-Seine This Centre is connected with the COFREND/CFCM which is the French body for the NDT certification in railway maintenance [4].

Moreover, SNCF has imposed, in the context of the same policy, qualification of all the operating procedures and NDT equipments used in its maintenance facilities. The level 3 agents carry out these qualifications.

SNCF goes even beyond that, to qualify all the operators, equipment and products necessary for NDT in maintenance, as it asks its suppliers to do also, in the context of qualification of axles and wheels.

5.2. Experience feedback

Up to now, the intervals for monitoring safety-critical components are determined on the basis of experience in

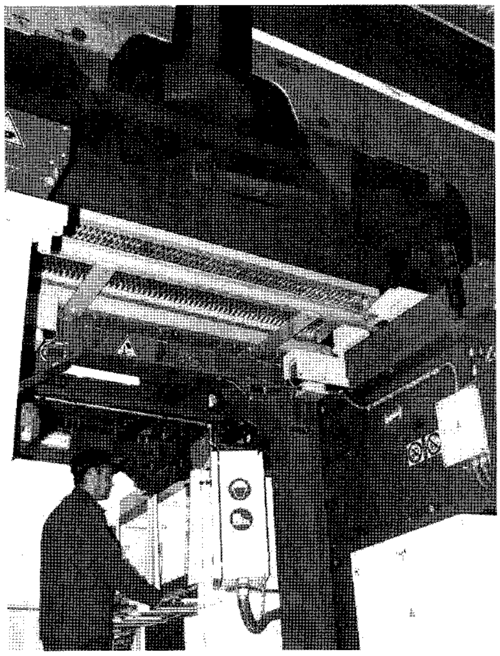


Photo 9 Automatic ultrasonic apparatus for wheel rim

service. They are formalised in operating procedures that make reference to the detection of potential cracks by appropriate NDT methods.

As we have explained in this paper, SNCF gives very careful attention during the design and manufacturing phases of safety-critical components in order to enjoy better control in maintenance and lighter maintenance. Our policy leads to fewer NDTs being performed on fitted axles in service, and rather privilege the NDT carried out when wheelsets are removed in workshop. The NDT is so practised in better conditions and with a better sensibility of detection. For TGV wheels, the research for possible apparitions of fatigue cracks in the rim is made by automatic ultrasonic benches. The extent and frequency of such nondestructive inspections are checked from time to time by analysing feedback information coming from the field.

5.3 Fracture mechanics

In order to better adapt the frequencies of maintenance operations to the potential failures and know the speed of response in the event of cracking in service, the fracture mechanics– the Paris law – is an adequate tool. It allows to define the propagation threshold and propagation speed of a crack from a critical defect [5].

Moreover, in the context of liberalisation of rail in Europe, more and more requests are being made for assessment of safety by application of the NF EN 50 126

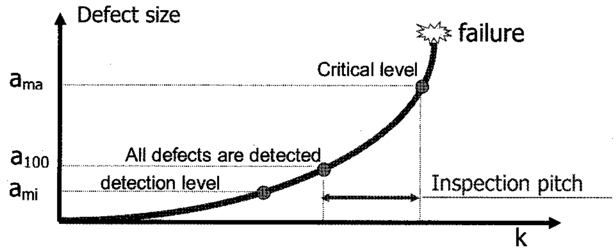


Fig. 13 Determination of the inspection pitch

series of standards to determine the levels of safety, reliability and availability achieved.

We have shown in the different perspectives explained above that to accomplish this, the service load cases and fatigue laws will be expressed in probabilistic terms. The same is true for the laws of crack propagation.

The diagram below shows the principle according to which a maintenance policy addressing the issue of operating safety and dependability can be developed.

6. The Special-purpose Organisation Set Up at Sncf

Considering the heavy fatigue and wear loading seen by axles and their prime safety role, SNCF created 30 years ago an in-house body to verify for purposes of harmonising and mastering the rules of design, calculation and maintenance of axles.

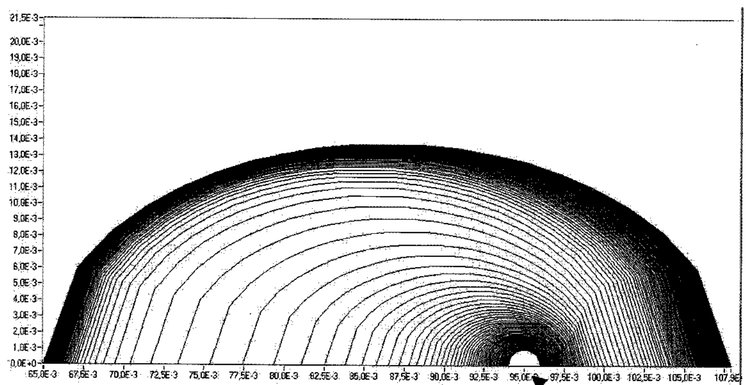


Fig. 12 Crack front evolution simulation

Photo 10 Real crack

That body has been given a triple management, empowered by three distinct departments of SNCF's Rolling Stock Department: Design Engineering, Testing Laboratories and Maintenance.

The missions of this pool of experts are to gain control of the processes governing reliability, dependability and safety, to supervise and rationalise axle and wheelset design and to make sure that the diversification of railway rolling stock on the market today does not translate into a multiplication of axle types and associated equipment designs.

To date, over 660 files have been examined and processed, as the unavoidable condition for allowing equipment to run on the national territory.

7. Conclusion

The experience feedback to date shows that the policy followed at SNCF to ensure good control of safety, reliability/dependability and availability of rolling stock seems to be working. It is based partly on strict requirements concerning the design and qualification of running gear based on validated railway standards, most of which have since been carried over into European standards, and partly on analysis in real time of experience with rolling stock in service.

Yet as the rail context in Europe is evolving very quickly, some amendments to that policy are being tried in controlled steps and validated and particularly the following:

- assuring the interoperability of the wheels and axles of all rolling stock in Europe, in compliance with the directives of the European authorities, from the standpoints of design, qualification and maintenance;
- calculating the reliability level according to NF EN 50126 as requested by railway operators, taking into account the various aspects of probability such as load cases, fatigue limits, calculations and crack propagation;
- evaluating the level of safety required by the infrastructure managers.

Photo 11 TGV, still more quickly

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