On the evaluation of wheel sets and railway track quality

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Abstract

The cost of maintenance and the safety of railway operation depend (among other things) on the quality of the wheel sets interaction with the rails. There is the necessity to monitor the rolling behaviour of regular vehicles. Of most importance is the time behaviour of the travelling contact forces between the wheel sets and the trucks. The rolling wheel set obtains a very different position relative to the track, which creates restraints in the wheel set and the track panel structure, and which will discharge continuously by friction induced vibration. Those vibrations cause corrugation, ballast deterioration, wear, squealing noise and other environmental impacts.
Keywords: wheel sets, railway track, monitoring, motion, rolling performance, system dynamics.

1 Introduction

There is the necessity for monitoring the rolling behaviour, because from the determination of the geometrical track irregularity measurement, no prediction of the rolling behaviour seems to be possible. Also the environmental impact (vibration, noise) and the recurrent maintenance needs of pavement, sleepers and rails depend strongly on the surpassing traffic, causing interaction between the vehicle and the track and creating its specific "footprint".

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Figure 1: Typical rail damages due to bad rolling conditions.

Of most importance is the time behaviour of the travelling contact forces between the wheel sets and the rails as an origin of load and excitation of the track panel. The rolling wheel set obtains not only the unique “outweighted” habitations of smooth rolling onto the varying parameters along the track bed, but every other position of the wheel set relatively to the track creates restraints in the wheel set and the track panel structure, which will discharge continuously by friction induced vibration. It is vibration that causes corrugation, ballast deterioration, wear, squealing noise and other environmental impacts. The wheel set might roll under the described conditions in an improper way and the mentioned conditions should be detected by a monitoring system.

A “smart sensor” should be used, geared to detect the quality of the rolling of the wheel set, indicating such undesirable impact on the track, the vehicle and the environment. The above-mentioned smart sensor should be installed on regular trains for the above reasons.

The temporary evaluated rolling conditions should be reported, together with the corresponding location of the vehicle on the track, to an information centre for a medium term improvement of the “footprint” and for maintaining the track (demand-oriented instead of interval maintenance).

In a similar fashion, friction induced vibration of other dynamical systems are those of the wheel/rail system also self excited. Structural vibration also arises from external excitations such as periodic fluctuations of the track bed stiffness or singular failures of the sleeper bedding (vertical dynamics) or flange contacts (horizontal dynamics).

2 Quality of the rolling performance

The quality of the rolling performance is a temporary status of the state of the system “wheel set–track”. Considering the state of the art the quality of rolling performance cannot be predicted from the geometrical track data. The behaviour ought to be measured and afterwards the rolling quality must be evaluated from the monitored raw data. For the intended classification some measures are introduced, which may help for the quality evaluation.

In paper [1] some special wordings are used to describe various states in rail vehicle–track diagnostics. A rolling status is “proper”, if no complaints can be made, whereas in the case of an unsatisfactory status measures for the elimination of the malfunction are imposed. An unsatisfactory rolling status can only be tolerated for some time, but it will be called “critical” if it threatens the operational safety. In this case the defect must be rectified immediately.

It is unreasonable to use the traditional (overstrained) Y/Q-force-criteria for the evaluation of the dynamical rolling performance [2]. We will use a motion-criteria, because which of the representing characteristics of the rolling performance may be selected out of the dualism of forces and motion velocities is in fact irrelevant.

The idea is, therefore, not to use the contact forces between wheel and rail for the assessment, because their measurement is difficult and expensive, but to look to the vibration amplitudes of the axle bearings as proper signals for the quality of the rolling performance of the wheel sets. This concept must take into account, that friction induced vibration occurs mainly in the medium frequency range.

By formulating this approach, the motion of the wheel set is divided into four components, which are in reality superimposed.

2.1 Components of motion of the wheel set

1. “Rigid body” rotational motion
2. “Rigid body” translatoric motion
3. “External excited disturbance”

Repeated transient excitation of the medium and high frequency structural dynamics of the wheel set due to track and surface irregularities, switches, out of round wheels,...,

4. “Self excited disturbance”

Occasional transient self excitation (or parametric excitation) of the medium and high frequency structural dynamics of the wheel set due to unfavourable profiles, curves, skews, gauges, travelling speeds,…,

The term “medium and high frequency structural dynamics”, which is used in this text, follows the habitual language use of railway vehicle dynamics, and is explained in more detail below. The frequency ranges are understood as a rough subsumption.

2.1.1 Wheel/rail–system dynamics

1. Low frequency region, 0–30 Hz, Modelling: Rigid-body-dynamics (RBD).

2. Medium frequency region, 30–300 Hz, Modelling: Elastic MBD.

3. High frequency region, 300–30 000 Hz, Modelling: Elastic Cont. Dynamics, e.g. FEM.

For an explanation of the wheel set structural dynamics in [3] some medium frequency self-excited vibration of wheel sets on straight tracks are shown as an example. It is necessary to understand that for the assessment of the wheel set rolling quality by monitoring of the axle bearing motion due to self-excited vibration at least the medium frequency range must be taken into account.

The rotational motion and the translatoric motion are essential for the railway operation, but not so important for the rolling performance: The appearance of remarkable external excited or self-excited vibration is the global evidence of a malfunction in the rolling process.

The dynamic reaction of the axle bearings is rather large in the case of a respectively critical rolling state of the wheel set. Particularly in the case of track-related variation or defects only a temporary existence of large amplitudes will be measured indicating a local track deficiency.

3 Evaluation of the wheel set rolling quality

Acceleration sensors have been used to measure the axle bearing vibration. At the German wheel set roller test rig (DB AG) in Kirchmöser wheel sets have been brought artificially into rolling states and the vibration of the axle bearings have been measured. Different skews have been set up, by open-loop control of force or movement, acting on the wheel set. Also measured axle bearing vibration of regular ICE trains traveling at high speed on tracks has been evaluated.

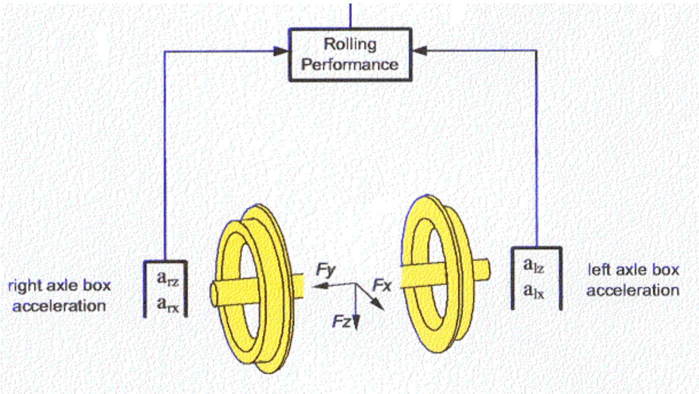

Figure 2: Assessment of the wheel set rolling performance (smart sensor).

The real challenge of the assessment method is the evaluation algorithms of the sensor signals. After several trials (e.g. wavelet analysis among others) the Karhunen Loève transformation (also known as Proper Orthogonal Decomposition POD or Principle Component Analysis PCA, [4]), using signal-dependent characteristic functions, proved to be the adequate for this purpose.

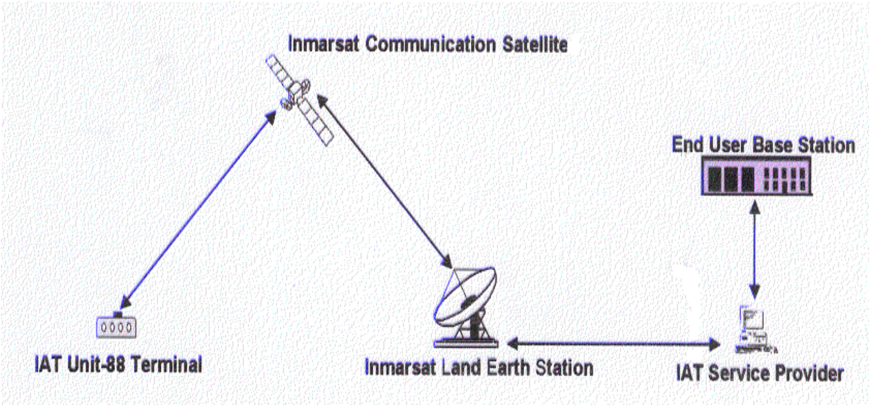

Figure 3: Satellite communication chain.

Figure 4: IAT's satellite transceiver and antenna (INMARSAT D+).

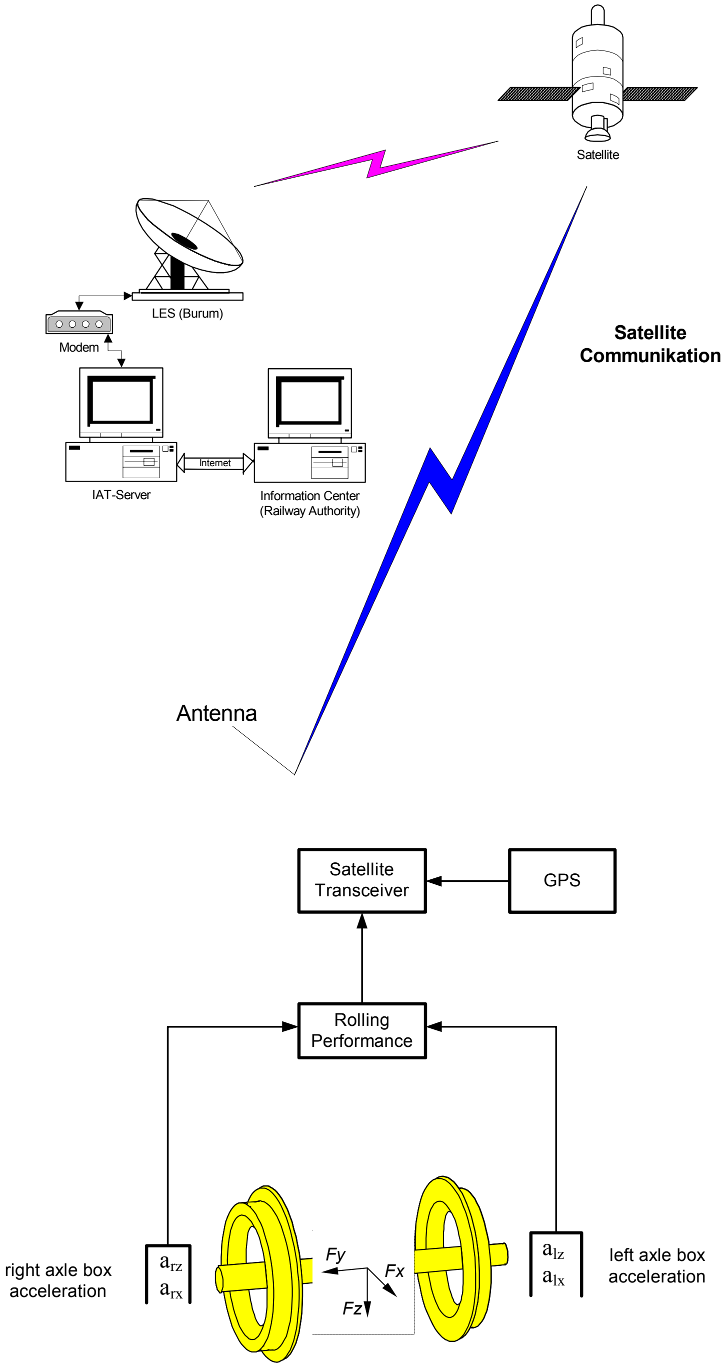

Figure 5: Event monitoring of the rolling performance of wheel sets.

4 Rolling performance and the information centre of the railway authority

The intensity of the vibration of the wheel set axle bearings are taken for assessment of the rolling quality. As accelerometer signals are used, the measured values have the dimension m^2/s^4. From this follows the classes of possible rolling qualities. But until additional results of running tests are available, this can only considered as preliminary [2].

If the railway vehicle enters a critical rolling status, such an "event" should not only be transferred to the locomotive of the train for eventually braking down the speed, but also to an "information centre" of the respective railway authority, e.g. a solution such as Fig. 3. Satellite communication is already successfully applied to railway vehicles [5] (Fig. 4) and cannot only deliver data from the event, but also the position, where and when it happened.

By the described concept it is not only possible, to assess the quality of the rolling performance of the wheel sets ("footprint"), but also to use the wheel set as a "sensor" for the track quality. But it detects only that there is a track defect in a certain range of about 100 meters. Then a track measurement device is necessary, for instance the one given in Fig. 5. By this "demand-oriented maintenance" can be initiated, which might be cheaper than costly interval maintenance along several kilometres. There is no doubt that by the application of the described concept of the assessment of the rolling quality the accident of Eschede would have been avoidable.

5 Local checkpoints for assessment of the rolling performance

During recent years several European track operators have installed "local checkpoints" (for example see Fig. 6) for the supervision of the actual rolling quality of surpassing trains and for the potential determination of a toll.

However, the track performance along the line before and after the local checkpoint remains the "secret" of the track operator as well as the performance of the wheel sets of the actual train, which should be of interest to the train operator for safety reasons.

Therefore the conclusion might be worth considering, that for a successful partnership of co-operating tracks and trains by two different companies "infrastructure" and "operation" (making up their own balances) the described method of assessment of the rolling quality might be more beneficial than "local checkpoints" only. Above all the operation of railway systems may then in the mid-term become better improved and safer, which is not only in the interest of the railway authorities, but also in the interest of their customers.

Figure 6: Local checkpoint (ÖBB, Himberg).

References

[1] Meinke P., Monitoring of the State Condition of Railway Wheel Set Rolling, 5th International Conference on Transport Systems Telematic Katowice, 2005.
[2] ERRI, Final Report of the European Project DYSAF, Utrecht 2003.
[3] Bogacz R., Meinke P. and Dzuła S., Vehicle/track interaction for high speed-frequency range. In: Dynamical Problems in Mechanical Systems, IPPT PAN, Warszawa, pp. 165–181,1993.
[4] Gloesmann, P., Kreuzer, E., Nonlinear System Analysis with Karhunen-Loève Transform, Kluwer Academic Publishers, 2004.
[5] Meinke, P., Laufzustands-Monitoring von Eisenbahn-Radsätzen, Schlußbericht zum BMBF-geförderten Verbundvorhaben "Laufzustandsmonitoring von Eisenbahnfahrzeugen", Starnberg 2005.
[6] Meinke, P., Monitoring of the State Conditions of Railway Vehicles by Satellite Communication, 4th International Conference on Transport Systems Telematic, Katowice 2004.