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MONITORING OF THE STATE CONDITION OF RAILWAY WHEELSET ROLLING

The load on passengers and transported goods in railway systems is mainly determined by the quality of the rolling performance of the wheel sets, which results from the interaction of wheels and rails in the medium frequency range. Also the cost-efficiency, the maintenance expenditure and the safety of railway operation depend strongly on the quality of the rolling status of the wheel sets, so that its continuous supervision presents one of the basic requirements of a to date railway operation. For the determination of the rolling quality of wheel sets an evaluation is undertaken by the KL-Transform of acceleration signals, measured at the axle bearing boxes.

MONITORING STANU ZESTAWU KOŁOWEGO W CZASIE JAZDY

Obciążenie wynikające z przewozu pasażerów i towarów w systemach kolejowych jest głównie zdeterminowane przez jakość toczenia się zestawu kołowego, która z kolei wynika z interakcji kół i szyn. Również efektywność kosztowa, wydatki na serwis i bezpieczeństwo pracy kolei, w dużym stopniu zależy od jakości stanu toczenia się zestawów kołowych, dlatego ciągły nadzór stanowi jedno z podstawowych wymagań nowoczesnej pracy kolei. W celu określenia jakości tocznej zestawów kołowych przedstawiono ocenę sygnałów przyspieszenia KL-transform mierzonych w skrzyniach łożyskowych osi.

1. INTRODUCTION

The load on passengers and transported goods in railway systems is mainly determined by the quality of the rolling performance of the wheel sets, which results from the *interaction of wheels and rails*. Also the cost-efficiency, the maintenance expenditure and the safety of railway operation depend strongly on the quality of the rolling status of the wheel sets, so that its continuous supervision presents one of the basic requirements of a to date railway operation. Herefrom derives the need for a monitoring of the rolling behaviour of regular vehicles, because from the determination of the track performance (eg. by a track irregularity measurement) no prediction of the rolling behaviour seems possible (leavelet UIC 518!).

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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 vehicle and track and creating its specific "Footprint".

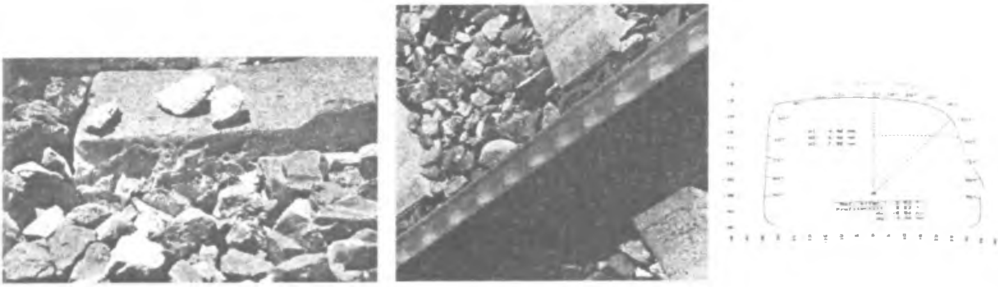

Fig. 1. Typical track damages due to bad rolling conditions

Most important is the time behaviour of the travelling contact forces between the wheelsets and the rails as an origin of load and excitation of the track panel. The wallowing wheelset (hereafter called "rolling") obtains not only one 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 wheelset- and the track panel structure, which will discharge continuously by *friction induced vibrations*. It are those vibrations, which cause corrugation, ballast deterioration, wear and noise/squealing and other environmental impact. The wheel set rolls under the described conditions "unhealthy" and the mentioned conditions should be detected by a monitoring system. A "smart sensor" should be used, reared to detect unhealthy rolling of the wheelset, indicating such undesirable impact on the track, the vehicle and the environment. The described smart sensor should be installed on regular trains for the above mentioned reasons. The temporary unhealthy rolling events should be reported together with their locations of the vehicle on the track towards a information centre, for a medium term improvement of the "footprint" and the rolling quality of the wheel sets.

As well as friction induced vibrations of other dynamical systems are those of the wheel/rail system nearly always *self excited*, with stable or unstable time behaviour. Additional structural vibrations arise from *foreign excitations* like 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

As already mentioned is the quality of the rolling performance a temporary status of the actual system "wheelset – track". Considering the state of the art the rolling performance cannot be predicted from the track data, but it must be measured and afterwards the rolling quality must be evaluated from the monitored data. For the intended classification some definitions are introduced, which may help for the evaluation (table 1).

In table 1 the wordings "healthy and "unhealthy" are used as usual in diagnostics. A rolling status is healthy, if no complaints can be made, whereas in the case of an unhealthy status measures for the elimination of the malfunction are imposed. An undesirable rolling status is called "insufficient", as it can only be tolerated for some time, but it will be called "critical", if it threatens the operational safety and must be deleted at once. "Near to derailment" will be used for a rolling status of the wheelset, which is close to a menacing derailment (eg a very heavy flange contact).

Table 1

Quality of the Rolling Performance

Classes are introduced for the quality of the rolling performance:

Class	Evaluation	Rolling Performance
1	very good	
		healthy
2	sufficient	
		poor
3	insufficient	
		unhealthy
4	near to derailment	
		critical

It is not reasonable, to use the traditional (overstrained) Y/Q-*force*-criteria for the evaluation of dynamical rolling performance [1]. We will use a *motion*-criteria, because in fact it is irrelevant, which of the representing characteristics of the rolling performance may be selected out of the dualism of forces and motion/velocities.

The idea is therefore, not to use the contact forces between wheel and rail for the evaluation, because their measurement is difficult and expensive, but to look to the vibration orbits of the axle bearings as proper signals for the quality of the rolling conditions of the wheel sets. This concept is supported by the fact, that friction induced vibrations occur in the medium frequency range!

By forming this approach the motion of the wheel set is divided into four components, which are in reality superimposed (table 2):

Table 2

Components of Motion of the wheelset

1. Rotational motion
2. Translatoric motion
3. „foreign 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 and in table 2, follows the habitual language use of railway vehicle dynamic people and is explained in more detail in table 3. The frequency ranges are understood as a rough estimation!

Table 3

Wheel/Rail – System Dynamics	
Low frequency region	**0.............30 Hz**
Modelling: Multi-body-dynamics (MBD)	
Medium frequency region	**50...........300 Hz**
Modelling: Elastic MBD	
High frequency region	**500. ......30 000 Hz**
Modelling: Elastic Dynamics, eg. FEM	

For explanation of the wheel set structural dynamics in Fig.2 medium frequency eigenforms of a free ICE wheel set ([2], 82 till 261 Hz) are shown as an example. It is necessary to understand (!) that for the evaluation of the wheel set rolling quality concerning friction induced vibrations by monitoring of the axle bearing orbits also the medium frequency region must be taken into account!

The rotational motion (not torsion!) and the translatoric motion from table 2 are essential for the railway operation and unimportant for the rolling performance. But the existence of remarkable foreign excited or self-/parametric excited vibrations are the *global* evidence of a rolling malfunction in the rolling process.

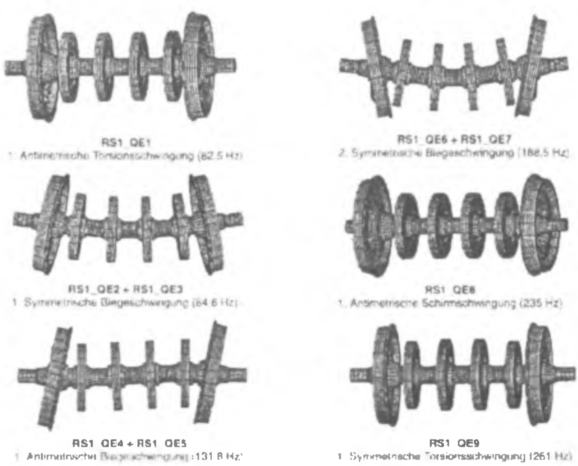

Fig.2. Medium frequency eigen-dynamics of an unbounded ICE wheel set [2]

The dynamic reaction of the axle bearings are rather large in the case of an unhealthy respectively critical rolling state of the wheel set. Fig.3 gives an impression of the axle bearing orbits under static and dynamic out-of-balance due to bending/torsion vibrations of an ICE wheel set (SZOLC 1995).

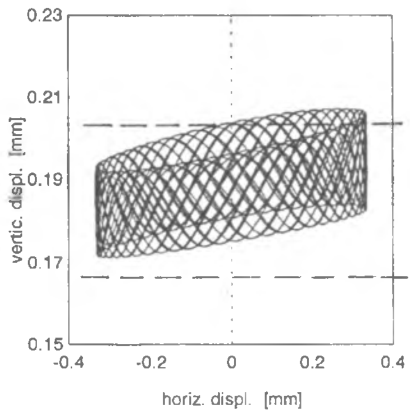

Fig.3. Simulation of the axle bearing orbits of an ICE wheel set, which undertakes bending/torsion vibrations due to static and dynamic out-of-balance (SZOLC 1995)

Remarkable vibrations will not always occur continously like in Fig.3 in the case of a wheel set specific cause. A wheelset of good properties will roll on a good track in accordance with „class 1" requirements and that are „zero-orbits" in a „inertial" reference frame moving with the vehicle. Particularly in the case of track-related variations or defects only a temporary existence of orbits will be measured indicating a local track deficiency.

3. EVALUATION OF THE WHEEL SET ROLLING QUALITY

For measuring the axle bearing orbits acceleration sensors have been used. At the German wheel set roller test rig (DB AG, Fig.4) in Kirchmöser wheel sets have been brought artificially into unhealthy rolling states and the orbits 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 orbits of regular ICE trains travelling on high speed tracks have been evaluated (Fig.5).

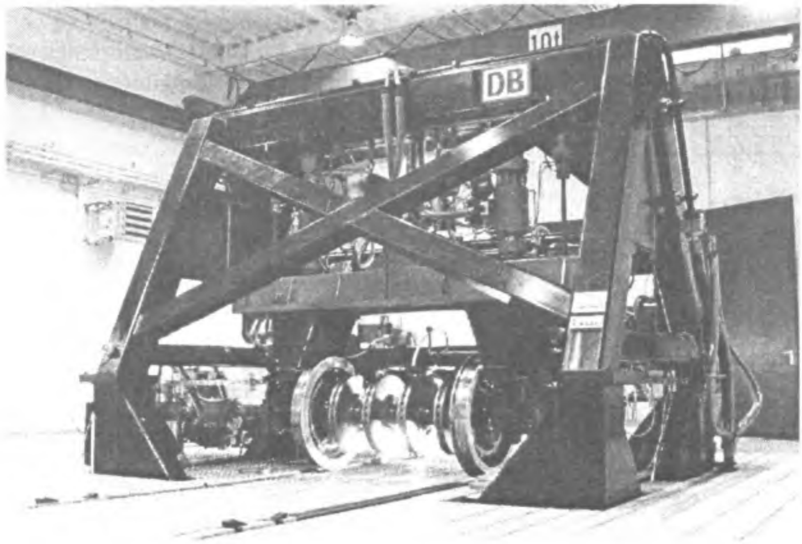

Fig.4. Wheel set roller test rig (DB AG) in Kirchmöser

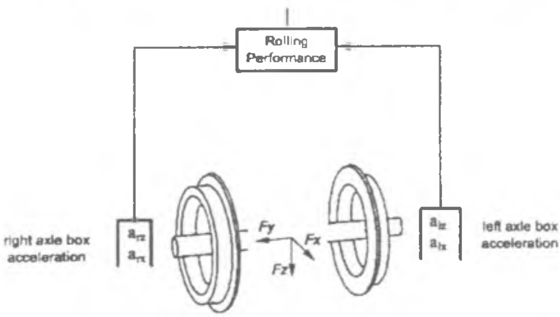

Fig.5. Prinziple of determination of wheel set rolling performance

The real challenge of the examination method are the evaluation algorithms of the sensor signals. After several trials (amongst others eg. Wavelet analysis) the Karhunen Loève transformation (also known as Proper Orthogonal Decomposition POD or Principle Component Analysis PCA, [3]), using signal-dependent characteristic functions, proved to be the most adequate for this purpose. The value of the rolling quality of the wheel set is given by the largest value of the eigenvalues λ_i of the covariance matrix of the analysed sensor signals (Fig.6). An online evaluation proved to be possible.

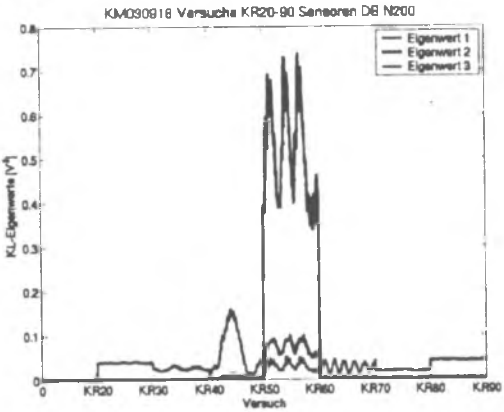

Fig.6. Analysis of a wheel set rolling trial by KL-transform (1 V^2 equals 100 g^2)

Another example is a measurement analysis of an ICE, running on a bad conditioned track section [4], Fig.7.

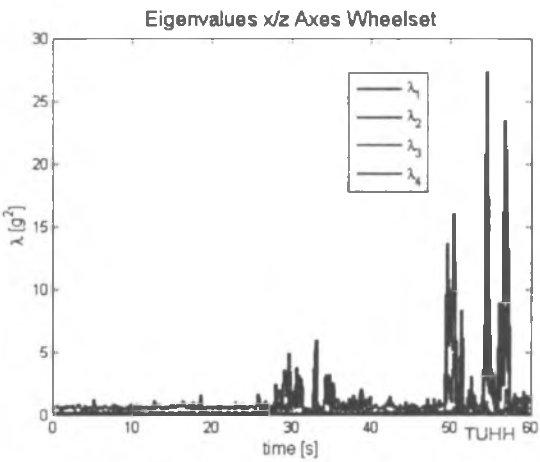

Fig.7. Rolling quality of an ICE wheel set, running on a bad conditioned track section

4. ROLLING PERFORMANCE

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

Table 4

Class	Evaluation/Quality	$\lambda^2 [g^2]$
1	Very good (healthy rolling performance)	**0....5**
2	Sufficient (poor rolling performance)	**6......25**
3	Insufficient (unhealthy rolling performance)	**26.....80**
4	**Near to derailment** **[critical rolling performance]** derailment	**81.. ≈ 150** „→ ∞"

Quality of rolling performance

5. INFORMATION CENTRE OF THE RAILWAY AUTHORITY

If the railway vehicle enters a critical rolling status, such an "event" should be transferred to an "information centre" of the respective railway authority, eg. by a solution like Fig.9. Satellite communication was already successfully applied to railway vehicles [5], Fig.8, and cannot only deliver data from the event, but also the position, where and when it happened.

Fig.8. Installation of the IAT-Terminal in a newly designed PESA-sleeping car (PKP), the antenna is visible on the roof of the vehicle [5]

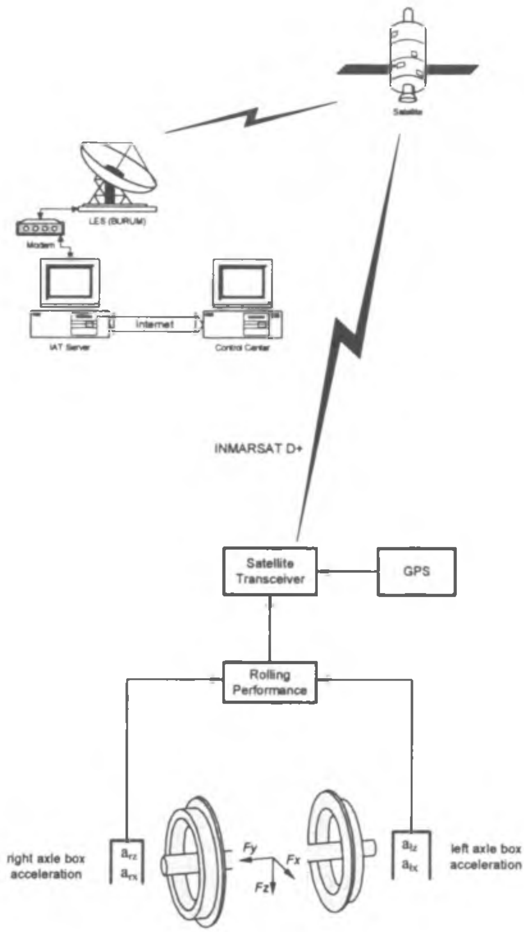

Fig. 9. Event monitoring of the rolling performance of wheelsets

6. ACKNOWLEDGEMENT

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