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On Evaluation of the Wheelsets-Track Interaction Quality in Railway Engineering

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Abstract

The paper is devoted to the evaluation of wheel-rail interaction quality and possibility of utilize of acceleration measurement for the determination of quality of tracks. After review of methods used for this purpose in Germany, Austria and other countries, the proposal used for experimental investigation by PESA S.A. will be reported and some theoretical analysis for the track quality evaluation will be given.

Keywords: railway wheel, railway track, monitoring, wheel-rail dynamics.

1 Introduction

The cost of maintenance and the safety of railway operation depend on the quality of the wheelsets-track interaction. Therrfore it is a necessity for a monitoring of the rolling behaviour of regular vehicles. Most important is the time behaviour of the travelling wheel-raill contact forces. The rolling wheelset obtains very different position - relatively to the track creates restraints in the wheelset and the track panel structure - which will discharge continuously by kinematic induced vibration. Those vibration cause corrugation, ballast deterioration, wear, squealing noise and other environmental impact.

There is the need for a monitoring of the wheel-rail dynamic behaviour, because from the results of determination of the geometrical track irregularity no prediction of the rolling behaviour seems to be possible. Also the vibration, noise and the recurrent maintenance needs of pavement, sleepers and rails depend strongly on the traffic, causing interaction between vehicle and track and creating its specific wear. Most important is the time behaviour of the travelling contact forces between the wheelsets and the track as an origin of load and excitation of the track. The smooth rolling of the wheelset is disturbed due to the varying parameters along the track bed and various position of the wheelset relatively to the track creates friction induced vibration of wheel-rail system. The vibration caused by rails corrugation is responsible for ballast deterioration, wear of wheels, squealing noise and other environmental impact. The wheelset rolling under bed conditions in not proper way and the corrugation of rails or sleep waves formation accuring usualy in curved track shown in Fig.1 should be detected by a monitoring system.

A system of sensors should be used to detect quality of rolling of the wheelset, indicating such undesirable impact on the track, the vehicle and the environment. The mentioned system of sensors should be installed on regular trains for the above reasons.

Fig. 1. Typical rail corrugation due to bad rolling conditions [Photo R. Konowrocki]

The temporary evaluated rolling conditions should be reported together with the corresponding locations of the vehicle on the track towards the train computer and an information centre, for a medium term improvement and for maintening the track.

Structural vibration arises from external excitations sources like periodic fluctuations of the track bed stiffness or singular failures of the sleeper bedding (vertical dynamics) or flange contacts connected with lateral dynamics and friction induced vibration of the wheel/rail system.

2 Quality of the wheelset – track interaction

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

In the paper [1] and paper [2, 3, 10] interaction for high speed-frequency range and some special wordings are used to describe various states in rail vehicle – track diagnostics. A rolling status is described as proper, if no complaints can be made, whereas in the case of a unsatifactory status measures for the elimination of the malfunction are imposed. An unsatisfactory rolling status can only be tolerated for relatively short time, but it will be critical, if it threatens the operational safety. In this case the defect must be eliminated immediately.

We would like to pay attention that it is not reasonable, to use the traditional Y/Q-force-criteria for the evaluation of the dynamical rolling performance [4]. We will use some criteria of motion, because in fact it is irrelevant, which of the representing characteristics of the rolling performance may be selected out of the criterion of forces and the criterion of speed of motion. The idea, not to use the contact forces between wheel and rail for the assessment, is connected with measurement difficulties and costs. We will look to the vibration intensity of the axle bearings as proper signals for the quality of the rolling state of the wheelset. This concept ought take into account, that friction induced vibration occur mainly in the medium and higher frequency range. By formulating this approach the motion of the wheelset is divided into four components, which are superimposed. We devide components of the wheelset motion into:

a) rotational motion of wheelset as rigid body,
b) translatoric motion,
c) external excited disturbance.

Repeated excitation of the medium - frequency structural dynamics of the wheelset due to track and rail surface irregularities is connected with out of roundness wheels.

The self-excitation and parametric excitation in the medium and high frequency range - d), are connected with not proper profiles, curved track, variable travelling speed and others.

The term "medium - and high frequency structural dynamics", which is used above in the text follows the habitual language use of railway vehicle dynamics and is explained in more detail as follows:

Frequency regions of wheel-rail system dynamics:

1. Low 0 - 30 Hz, Modelling: Rigid-body-dynamics
2. Medium 30 - 300 Hz, Modelling: Elastic multi-body-motion
3. High, 300 - 30 000 Hz, Modelling: Elastic continuum dynamics, eg. FEM

For explanation of the wheelset structural dynamics in [1] some medium frequency self-excited vibration of wheelsets on straight tracks are shown as an example. It is necessary to understand that for the assessment of the wheelset 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 kinematic excited or self-excited vibration is the general evidence of a malfunction in the rolling process.

The dynamic reaction of the axle bearings are rather large in the case of a critical rolling state of the wheelset. Particularly in the case of track-related variation or defects only a temporary existence of large vibration intensity will be measured indicating a local track deficiency.

3 Evaluation of the wheelset track interaction quality

For measuring the axle bearing vibration acceleration sensors have been used. At the German wheelset roller test rig (DB AG) in Kirchmöser shown in Fig. 2 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 wheelset. Also measured the axle bearing vibration of regular ICE trains traveling with high speed on tracks has been evaluated. In our case the track quality was very bad – at ncritical state, that is why it was interesting to compare the state with indication of evaluation algorithm. The measurements are performed using several trains. One of trains used for the track testing is shown in Fig. 3.

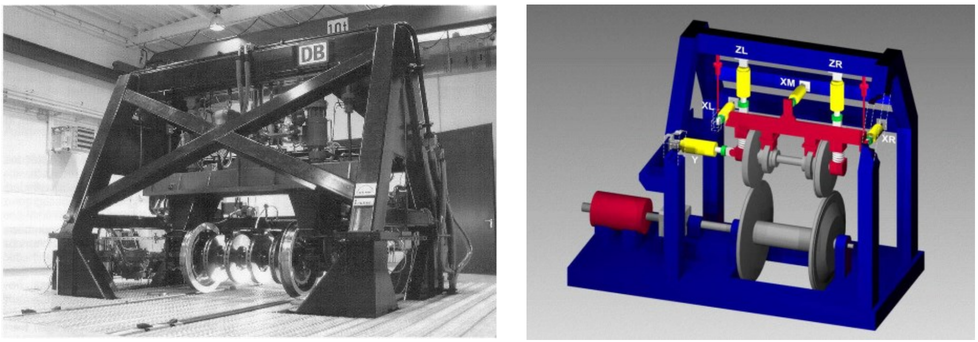


Fig. 2. Wheelset roller test rig (DB AG) in Kirchmöser and schematic view [11]

Fig. 3. One of trains used for the track quality measurement

The train made by PESA S.A. used in the experimental track testing was equipped in 3D acceleration sensors which are located as is schematic shown in Fig. 4.

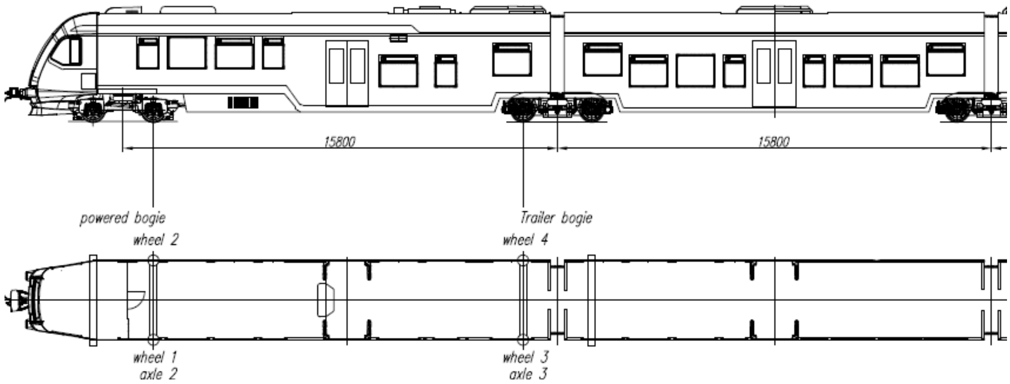


Fig. 4. Scheme of sensors location in the car body of train 219M made by PESA S.A.

One wheelset of the powered bogie and one wheelset of the trailer bogie was equipped in two sensors each.

The real challenge of the assessment method is the evaluation algorithms of the sensor signals. After several trials the Karhunen- Loève transformation (also known as Proper Orthogonal Decomposition POD or Principle Component Analysis PCA), using signal-dependent characteristic functions, proved to be the adequate for this purpose. The comparison of the classic Fourier tranformation with the Karhunen-Loève transformation can be illustrated on the following equations:

The Fourier Transformation *The Karhunen-Loève Transformation*

$$a_k = \frac{1}{T}\int y(t)\, e^{-jk\omega t} dt\,, \qquad a_k = \frac{1}{T}\int y(t)\psi_k(t)dt\,. \qquad (1)$$

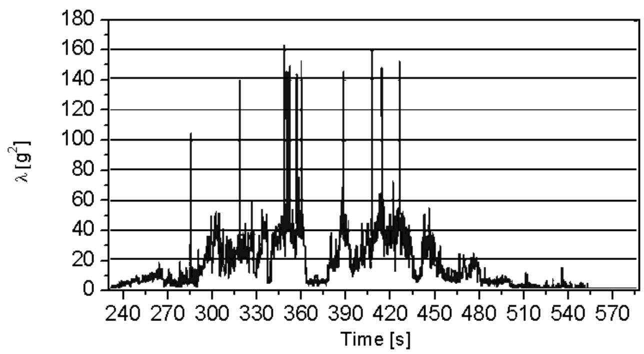
where: $j = (-1)^{1/2}$ and $\psi_k\,(t)$ are specially chosen functions.

The application of the Karhunen-Loève transformation to evolution of the track quality is relatively complicated and depondend on choise of functions $\Psi(t)$. The details of nonlinear system analysis with Karhunen-Loève Transform is described in [5]. The rolling performance can be divided into a few classes depending on K-L parameter λ.The modified proposal for five classes are given in the Table 1.

Table 1.

Class	Assessment/Quality	λ [g^2]
1	healthy (*good rolling performance*)	0 … 5
2	moderate (*poor rolling performance*)	6 … 25
3	unhealthy (*poor rolling performance*)	26 … 80
4	near to derailment (*critical rolling performance*)	81 … 150
5	derailment	150> λ> ∞

Examplary result of the track quality measurement with the train shown in Fig. 3 equipped with smart acceleration sensors on axle No. 2 is shown in Fig. 4 and Fig. 5. The intensity of the vibration of the wheelset axle bearings are taken for assessment of the rolling quality. As accelerometer signals are used, the measured values of K-L parameter have the dimension m^2/s^4.



6. Exemplary results of rolling performance measurement by sensors on axle No. 2

According to preliminary classification used in Germany shown in Table 1 the rolling performance on the track between Braniewo and Olsztyn is critical (near to derailment), becaue the K-L parameter exceed in several places the critical value of λ=80.

From this follows the classes of possible rolling qualities. But until additional results of running tests are available for insufficient rolling conditions, the classification can only be considered as preliminary [2], [9].

Author of ref. [8] proposed that, if the railway vehicle enters a critical rolling status, such an “event” should not only be transferred to the locomotive of the train for limiting the speed, but also to an “information centre” of the respective railway authority, using satellite communication as is shown in Fig. 9. Such a system was already successfully applied to railway vehicles, where the system deliver data from the event, and also the position and time -where and when - it was happened.

Instead of above system of the track-train interaction evaluation which as we state is not adapted to Polish conditions we introduced a system of quality evaluation using the spectral density of acceleration measured on wheelsets bearing casing. The quality index we can describe as follows:

$$W_t = c_t \left[\int_0^\infty S_{\ddot{w}}(\omega)\,\omega^{-2/3}\, d\omega \right]^{0,15} \tag{2}$$

where: Wt – denote quality index, ct - a selected constant parameter, S – spectral density of acceleration.

The dependence of the spectral density of acceleration on rail vehicle speed is evident, that is why we ought to introduce quality index dependent on the vehicle speed to compensate the change of speed. For the beter evaluation the quality of track the acceleration signal can divided into high and low frequeny as is shown in Fig. 7. Fourier amplitude spectrum of disturbed and smoothed time history of acceleration we can see in Fig. 8 and Fig. 9. The method of smoothing used in the signals is based on the discontinuous Galerkin-Golay approximation. The division is on the speed dependent, what allow to recognize the corrugation.

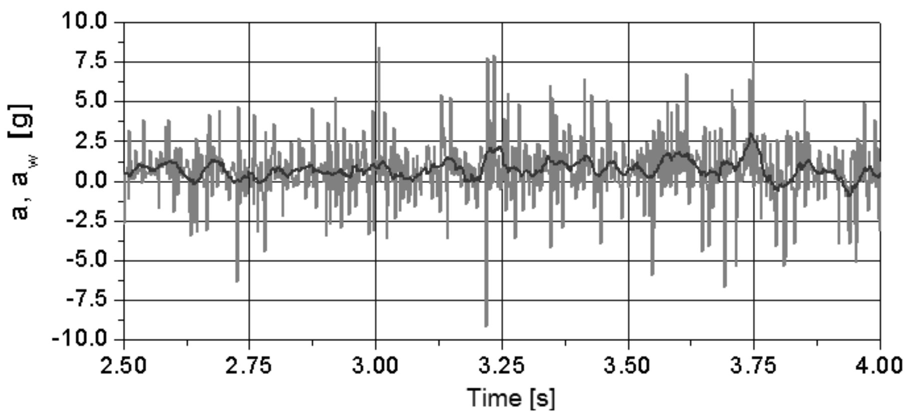


Fig. 7. Disturbed and smoothed time history of the acceleration

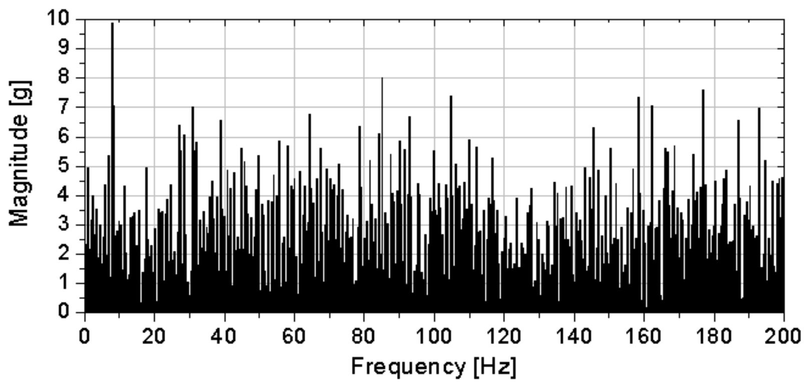


Fig. 8. Spectrum of disturbed time history of the acceleration

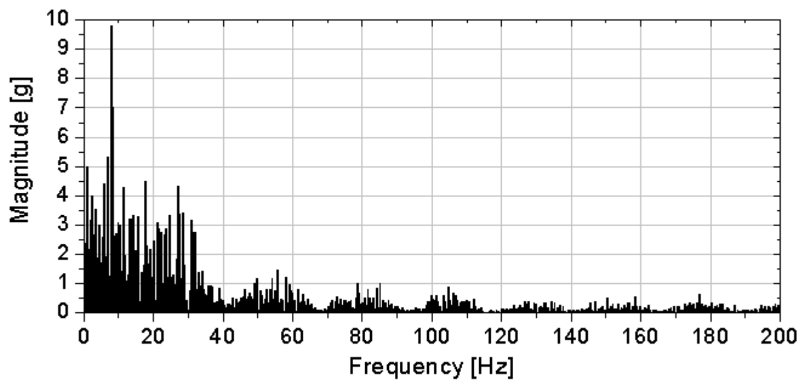


Fig. 9. Spectrum of smoothed time history of the acceleration

Now, it is possible to equip the train in the monitoring system elaborated by the SKF. One of examplary SKF system is illustrated on Fig. 10. The system is able to monitoring rolling performance and the drive system to.

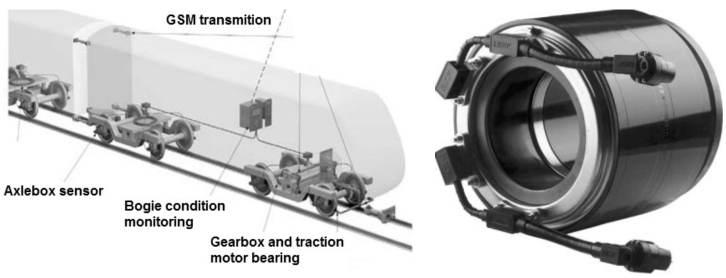


Fig. 10. Event monitoring of the rolling performance of wheelsets (source: www.skf.com)

By the described concept of the quality of the rolling performance evaluation we can use the signal for the wheelsets dynamics evaluation, but also to use the wheelset as a sensor for the evaluation of track quality.

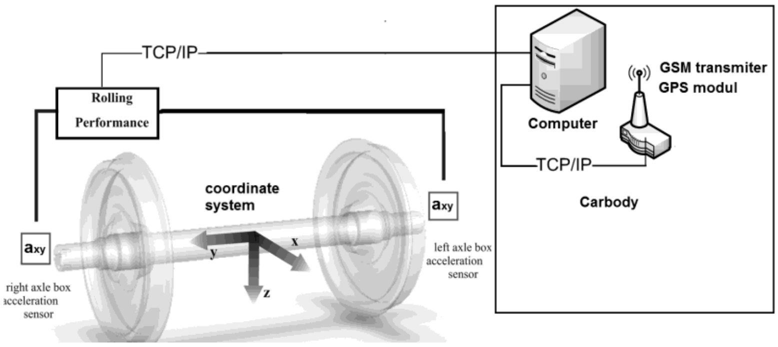


Fig. 11. Schema of system of data collection and transfer to the server with use of GPS system by the firms PESA Bydgoszcz and IAT, [8], [9]

Such a system detects a track defect in a certain range of about 100 meters. Then a track measurement device is necessary. By this a “demand-oriented maintenance” can be initiated, which might be cheaper than a costly interval maintenace along several kilometres.There is no doubt that by the application of the described concept of the assessment of the rolling quality meny accidents would have been avoidable.

4 Conclusion

A system of sensors should be used to detect quality of rolling of the wheelset, indicating undesirable impact on the track, the vehicle and the environment. During the recent years several European track operators have installed “local checkpoints” for the supervision of the actual rolling quality of surpassing trains. In such a case 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 wheelsets of the actual train, which should be of interest towards 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 become in the mid-term more improved and saver, which is not only in the interest of the railway authorities, but also in the interest of their customers.

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