Assessment of Corrugation Growth and derivation of maintenance measures by Simulation using *SFE AKUSRAIL*

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Abstract

With simulation tools for vehicle/track interactions, which are readily available, it is possible to assess track constructions in terms of their dynamic load and their susceptibility to form corrugation. Furthermore the results of such simulations are suitable to derivate optimized maintenance measures in order to reduce life cycle costs of track and wheel.

By introducing modern vehicles on small line a corrugation problem arose, which formerly has not been observed. The investigations performed aimed for the identification of the causes of corrugation growth using ***SFE AKUSRAIL***. Thorough parameter measurements of the line have been used to adjust model parameters of ***SFE AKUSRAIL*** in order to obtain a validated model, which gave dynamical equivalent results.

Based on this validated ***SFE AKUSRAIL*** model analyzing the vehicle/track interaction parameter studies have been performed to evaluate critical parameters. By identifying these parameters optimised maintenance procedures for the vehicle have been derivated.

Simulation with *SFE AKUSRAIL*

SFE AKUSRAIL represents a software tool to generate and assess models, predicting the high frequency interactions between vehicle and track. ***SFE AKUSRAIL*** aims for the simulation of the whole chain leading to dynamic excitation and noise in railway operation [1]. It consists of several functional modules regarding track, wheelset, contact mechanics, interior and exterior noise behaviour. The combination of the track-, wheel- and contact mechanics module represents their dynamic interaction. Furthermore the acoustic modules enable the prediction of the interior noise level inside the wagon body and the exterior noise radiation caused by the track/wheel excitation [2]. Figure 1 gives an overview of the functionality modules and the features of ***SFE AKUSRAIL***.

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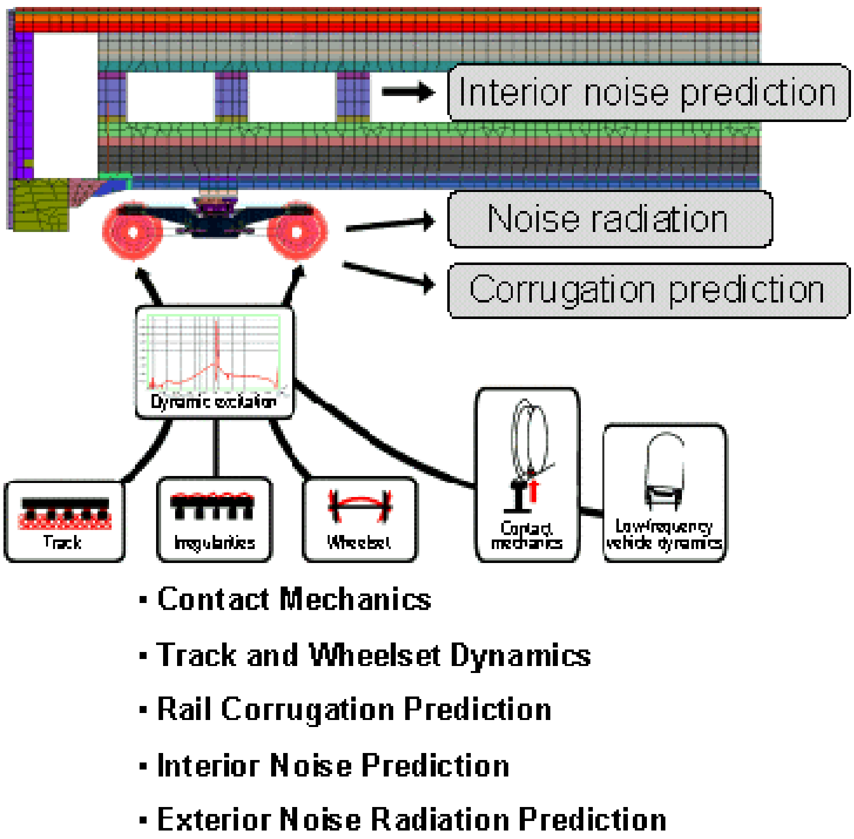

Figure 1 Functionality modules and features of *SFE AKUSRAIL*

The track module allows for the simulation of a track being infinitely long, discretely supported. Ballasted track as well as slab track can be considered. The track module is a three dimensional model, providing results for longitudinal, lateral and vertical dynamics.

The wheelset module provides a very fast and efficient way to calculate wheelset dynamics using a specialized FE approach. Results from commercial FE solvers like NASTRAN can also be included.

The contact mechanics module is an extension of Kalker's three dimensional linear theory. Extensions have been applied in order to allow for the high frequency range [3].

The dynamics module combines these three modules, calculating forces and deformations in the contact point as well as on wheelset and track. Also parameters for predicting corrugation growth and noise emission are calculated [4]. Results can directly be used for prediction of interior noise levels inside coaches and for maintenance and design applications.

SFE AKUSRAIL generates entire three dimensional models and works in the frequency domain. Predictions are valid in the frequency range between 50 and 3500 Hz.

SFE AKUSRAIL treats the high frequency dynamics as small fluctuations on top of a possibly non linear reference state, which is given by the vehicle running dynamics. Therefore it offers an interface to ADAMS Rail/MEDYNA to easily include the results of vehicle running dynamics simulation.

The investigated corrugation problem

Introducing a new vehicle on a small line severe corrugation problems have been observed on both straight tracks and in curves. On straight track, main wavelength of corrugation were spread between 4 and 8 cm generating an irregular pattern on both rails. In curves the wavelength was about 9 cm consisting of almost only one wavelength. Corrugation was only found on low rail, whereas on high rail the amplitude of corrugation was much smaller. The pattern observed on low rail was very regular (see Figure 2).

The investigated line mostly has S49 rails, steel sleepers and wooden rail pads. Track was maintained to the applicable standards. The rails are quite old and overall track quality was poor. The investigated site is situated in a 600 m curve. Line speed was about 50 km/h.

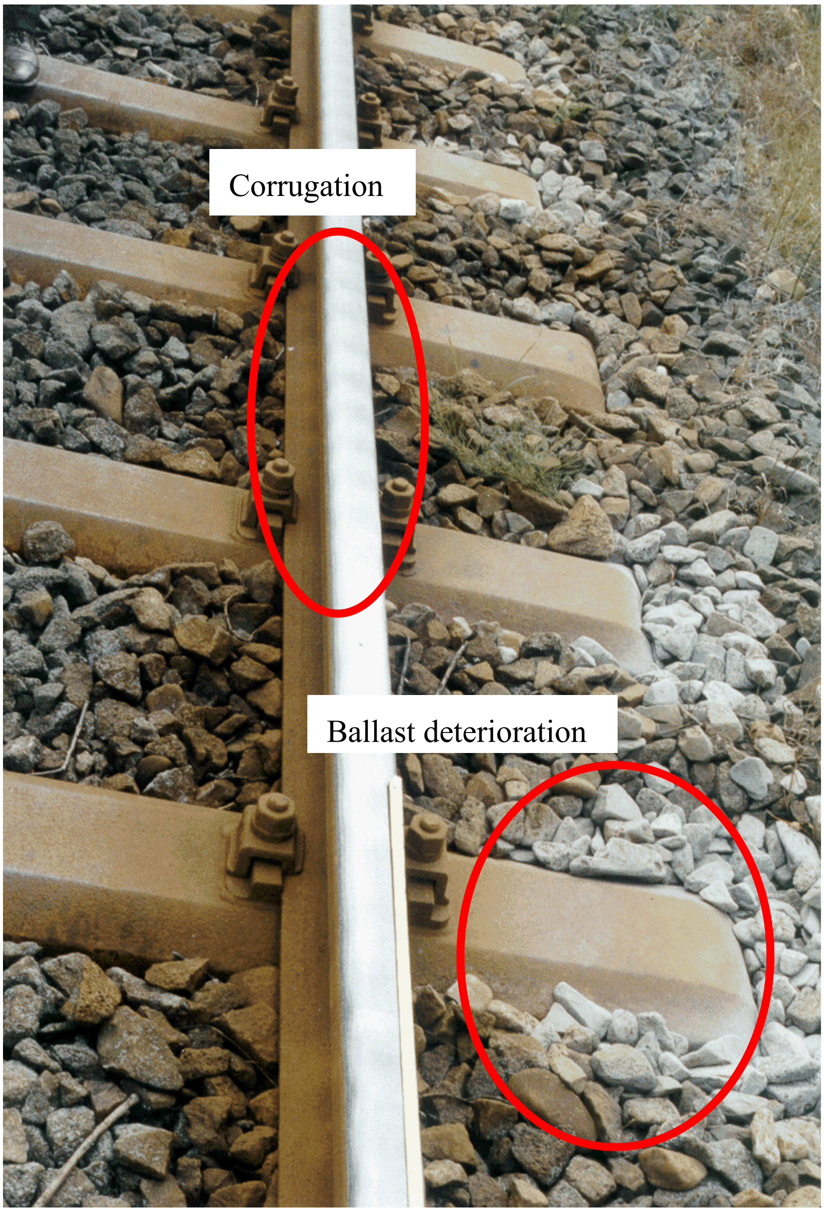

Figure 2 Corrugation on low rail of 600 m curve

Figure 3 shows the profile irregularities measured for both rails. The extremely regular corrugation patterns on low rail are obvious. High rail was free of corrugation.

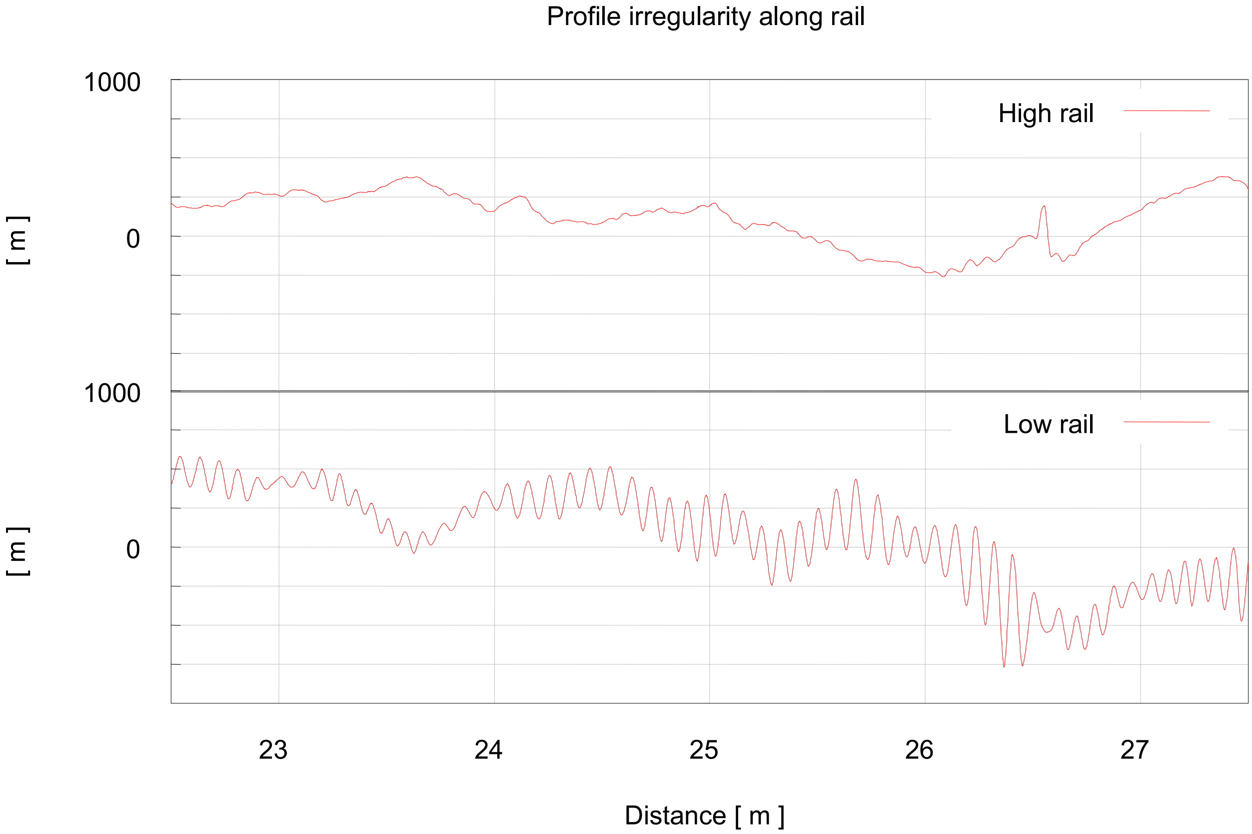

Figure 3: Measured profile irregularity on high and low rail of 600 m curve.

Assessment of the corrugation problem

Figure 4 shows an example of measured rail head profile. It is obvious from measurement that the rails are fairly old. Both rails show a very flat crown. The measured profile data of both wheel and rail have been used in the simulation of the vehicle running dynamics.

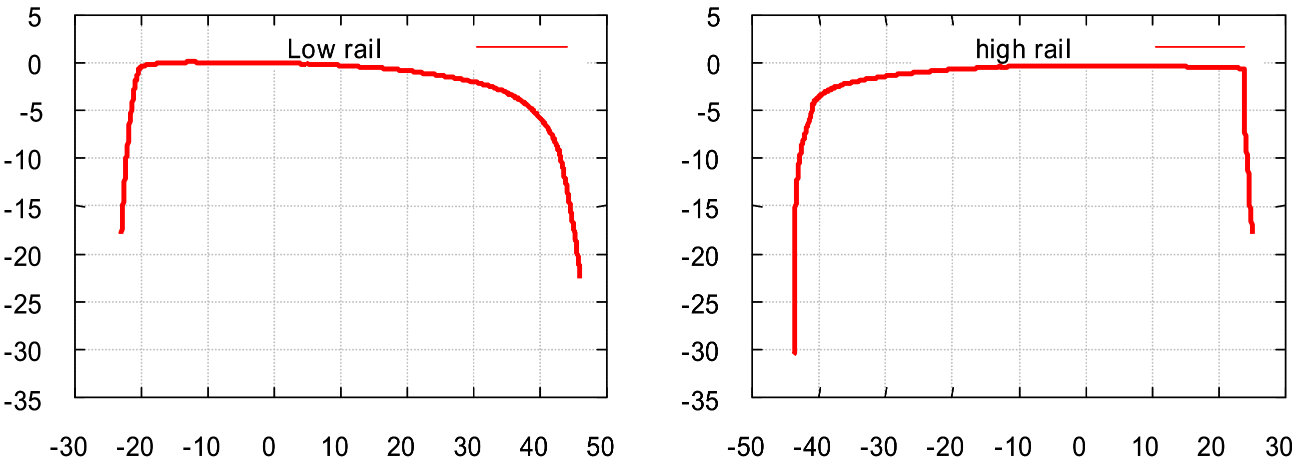

Figure 4: Measured rail profiles in 600 m curve

Figure 5 shows a comparison between measured wheel profile and a theoretical profile shape S1002. Most noticeable are the flat, slightly hollow running tread and the small radius occurring in the transition of tread to flange.

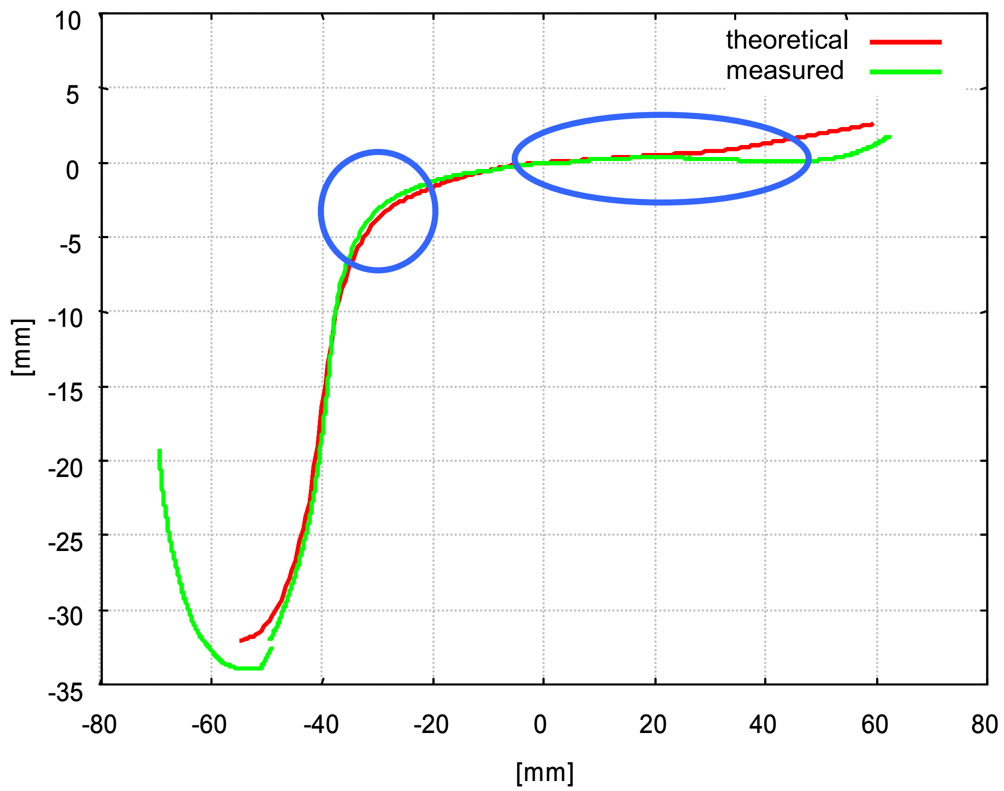

Figure 5: Wheel profiles (measurement and theoretical profile)

Creating a validated model in *SFE AKUSRAIL*

Main purpose of the first step of investigation was the creation of a dynamical equivalent simulation model with ***SFE AKUSRAIL***, which was able to predict the measured dynamics of track and wheelset. The vehicle run has been predicted using a vehicle model and the measured profile combination of wheel and rail.

The steps of validation, which have been performed, are:

1. Building a finite element model for both different wheelsets (driven, non-driven) of the vehicle and compare the results of the simulation with measurement. A commercial finite element package (NASTRAN) has been used for this investigation. Via interface these results have later been used in the dynamics module for corrugation prediction.
2. Track model parameters like rail geometry, pad and ballast parameter and others have been adjusted to obtain a model, which gives results of good agreement between measurement and model prediction. Such a process is very successful in most cases.
3. The vehicle running dynamics and the corresponding contact situation, contact patch size, location of contact point and contact forces have been predicted by using the measured wheel and rail profile. ***SFE AKUSRAIL*** offers an interface to the MEDYNA solver and considers all parameters of the contact situation in the corrugation prediction.

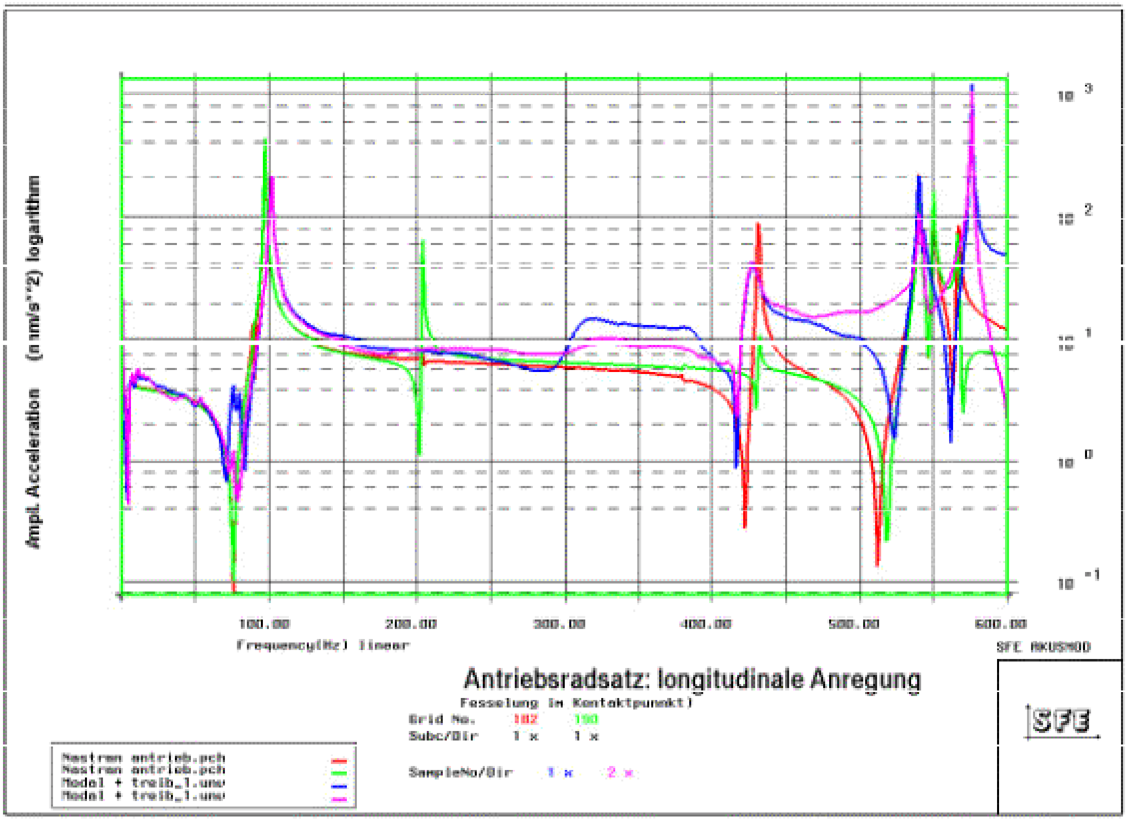

Figure 6: Longitudinal direct receptances for driven wheelset. Comparison of measured (blue, purple) and simulated (green, red) results for two neighboured points on wheel tread.

Figure 6 shows a comparison between measured receptances (blue and purple lines) and simulation results (red and green lines) for a driven wheelset. Excitation and measurement of displacement have both been in longitudinal direction. The first peak at about 100 Hz shows the first torsional mode where both wheels rotate against each other using the axle as a rotational spring. This peak is mainly influenced by the mass of the wheels and the geometry of the axle.

The correlation between measured and simulated results is satisfactory. The wheelset model used in ***SFE AKUSRAIL*** is able to reproduce the dynamic characteristics of the investigated wheelset.

Track receptance measurements have also been performed in order to adjust model parameters of the track in ***SFE AKUSRAIL*** and thus to obtain a validated track model, which again is dynamical equivalent to reality.

Corrugation prediction

Using these model parameter the development of the profile irregularity has been performed by ***SFE AKUSRAIL***. Starting from a random like initial profile the growth of the irregularity is observed for about 1.5 years of operation. Figure 7 and Figure 8 show the comparison between measurement and simulation results. Presented are profile amplitude spectra for low and high rail. The main points were, whether the model is able to correctly predict the extremely different growth on low and high rail, and whether the model is able to predict the correct wavelength spectrum of the final corrugation pattern. Here the model provides very good results for both, the different growth on low and high rail as well as the final wavelengths.

A closer look at the results revealed that the corrugation wavelength of about 9 cm is caused by the first torsional resonance of the non driven wheelset. Considering the stiffness of the contact point this resonance is found at about 170 Hz.

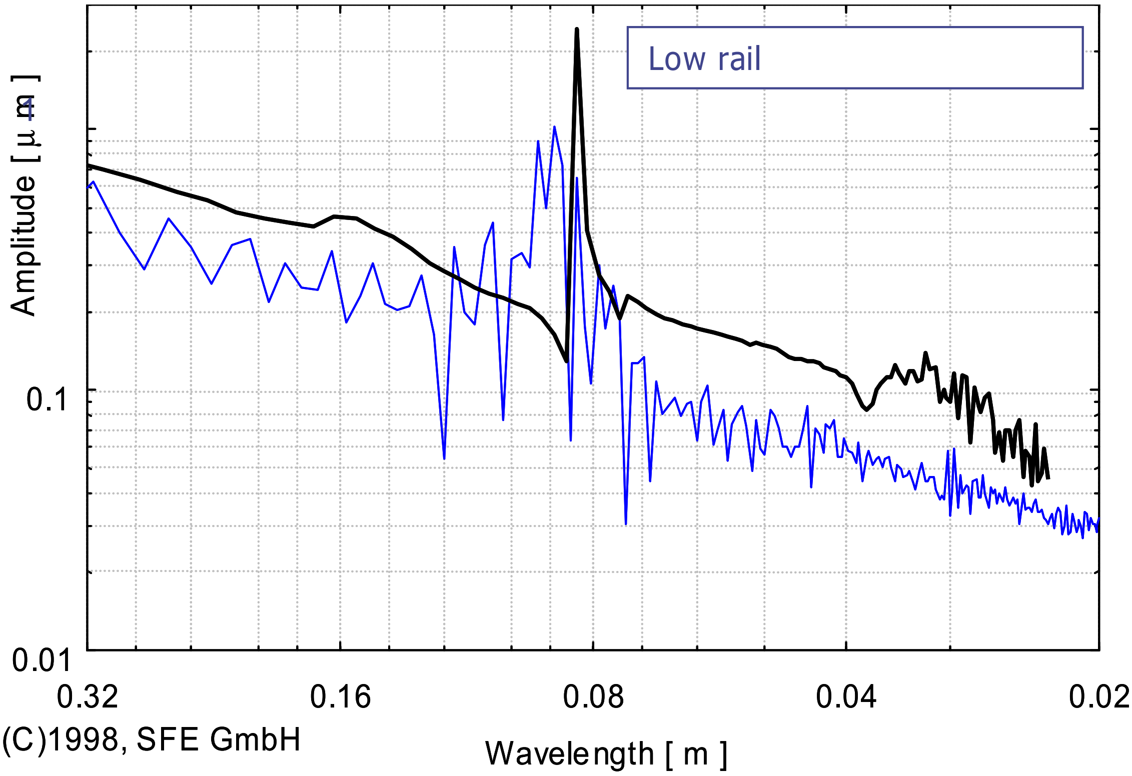

Figure 7: Validation of simulation model *SFE AKUSRAIL*. Comparison of amplitude spectra of high rail. Measured spectrum (blue) and result of *SFE AKUSRAIL* simulation (black).

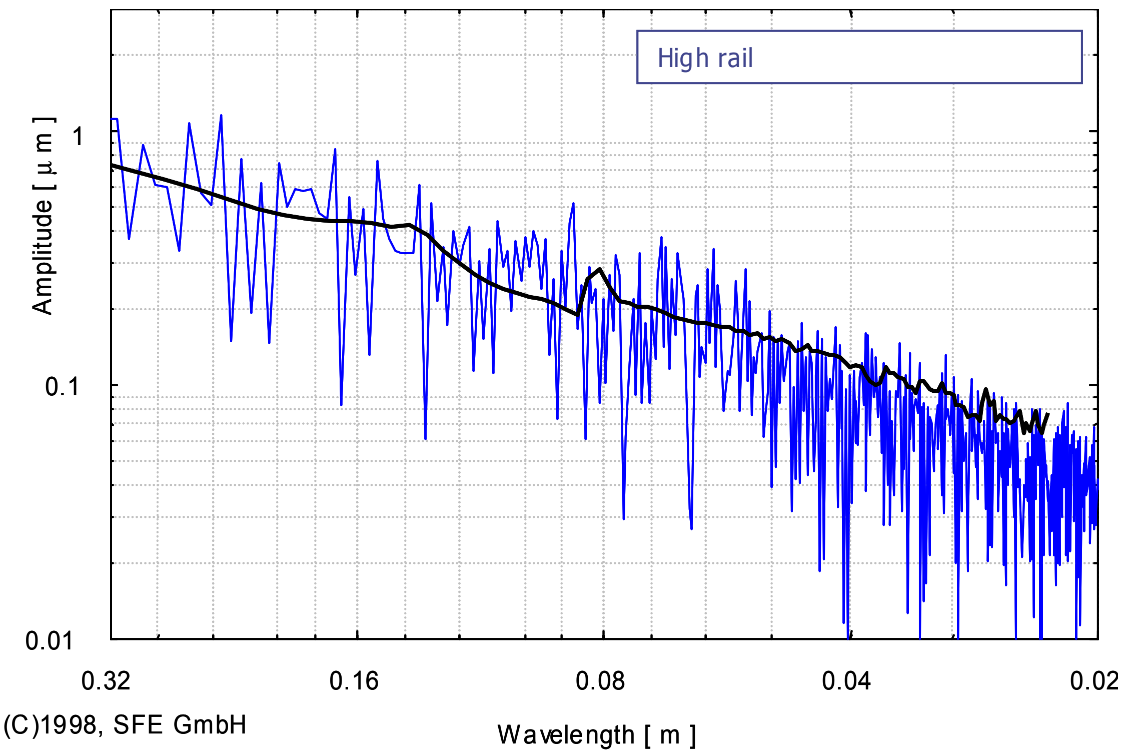

Figure 8: Validation of simulation model *SFE AKUSRAIL*. Comparison of amplitude spectra of high rail. Measured spectrum (blue) and result of *SFE AKUSRAIL* simulation (black).

Suggested measures for reducing corrugation growth

The mechanism, which forms corrugation at the investigated site, relies on several parameters: The vehicle running dynamics provide very high creepages. Main contributors are poor steering, large contact patches due to flat rail and wheel profiles.

Therefore the influence of the wheel profile has been investigated, since it provides the possibility for comparatively easy changes at small costs.

A first result of the influence of wheelset profiles on the angle of attack are shown in Figure 9. A variation of the curve radius is performed. Investigated are the current profile combination (black line, named “alt/alt”) and different new profiles on existing and new rail. For a profile combination of the current state (“alt/alt”) a sharp increase of angle of attack is observed for curve radii smaller than about 650 m. Changing the wheel profile to a new S1002 shape this increase is considerably delayed to curve radii of less than 400 m, which means that the corresponding creepages are reduced to a great extent.

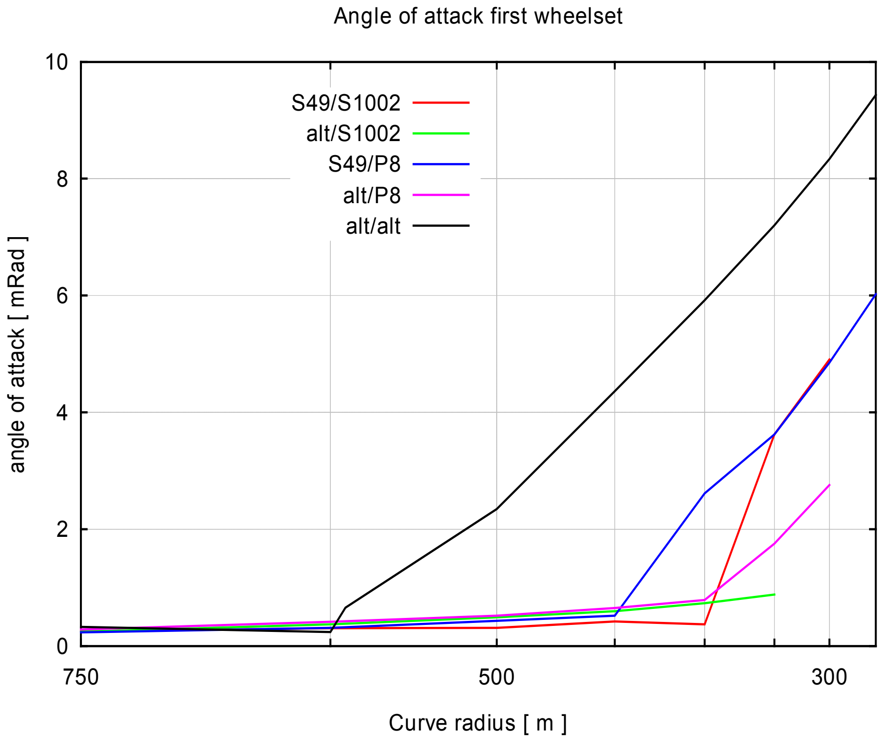

Figure 9: Effect of wheel rail profile combination. Angle of attack of first wheelset. Simulation results from ADAMS Rail/MEDYNA using measured wheel and rail transverse profiles.

Corrugation growth usually is described by an exponential growth law. The amplitude of a certain wavelength resp. frequency Δz is described by the initial amplitude Δz_0 and an exponential growth depending on a corrugation growth rate $\lambda(f)$ for that frequency and the number *n* of wheelset passages:

$$\Delta z(f,n) = \Delta z_0(f)\ \exp(\lambda(f)\ n)$$

Following this formula, positive corrugation growth rates denote growth of corrugation for this frequency resp. wavelength, negative values denote reduction of a given amplitude. Corrugation growth rates equal to zero represent no change in amplitude.

For the both profile combination discussed in Figure 9 corrugation growth $\lambda(f)$ rates are plotted versus the frequency. A variation of the curve radius has been performed as in Figure 9. Results Figure 10 are shown for curve radii of 6000 m (1, black) down to 272 m (13, red). For smaller curve radii corrugation growth greatly increases. Main corrugation growth is found at about 200 Hz with a broad peak in the growth rate.

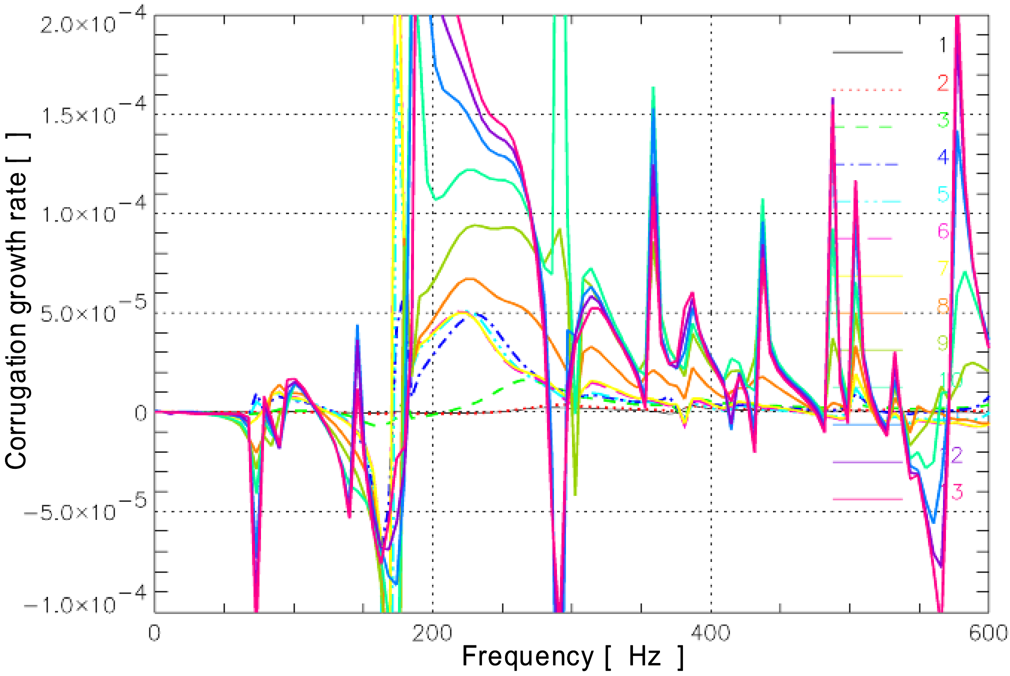

Figure 10: Corrugation growth rate for existing profile combination. Simulation results from *SFE AKUSRAIL*. Different colours denote change in curve radius from 6000 m (1) to 300 m (12).

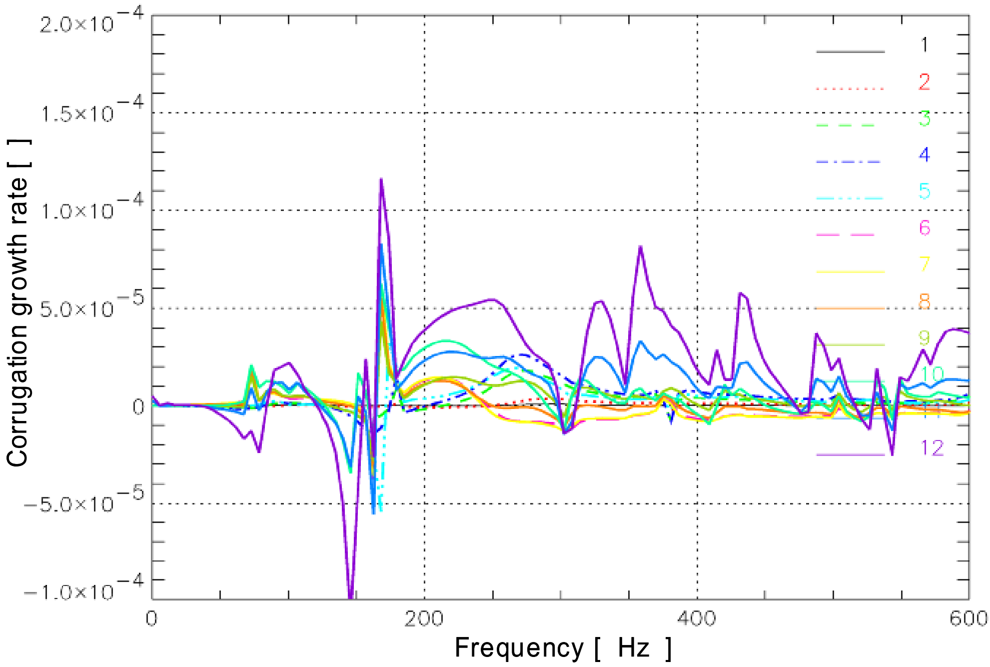

Figure 11: Corrugation growth rate for proposed profile combination S49/S1002. Simulation results from *SFE AKUSRAIL*. Different colours denote change in curve radius from 6000 m (1) to 300 m (12).

Figure 11 shows the same investigation as presented in Figure 10. This time a new wheel profile S1002 and a new rail profile S49 have been used in the prediction. The scaling of the two plots in Figure 10 and Figure 11 are identical for a better comparison. The growth rates are considerably smaller for the new profile combination. In the critical frequency range about 200 Hz, values drop by a factor of 3 (from 1.5e-4 to 0.5 e-4) This is due to the reduction of creepage mainly achieved with the new wheel profile, which provides better steering and less creepage.

Because the corrugation growth rate denotes an exponent in an exponential growth law, the reduction in the frequency range of about 200 Hz from 1.5e-4 to 0.5e-4 means a delay of corrugation growth by a factor of about 10. Assuming 5000 vehicle passages (about one year of operation) an initial amplitude of 5 microns will in the first case grow to 100 microns, in the latter case it will grow to about 15 microns. Accordingly grinding intervals could be expanded from about 6 months to about three years.

On the basis of these results it has been recommended to change the maintenance procedure for monitoring and reprofiling the wheel profiles. Wheel profiles should be maintained in such a way that the theoretical profile is preserved as close as possible. Inspection of the wheel profiles by measurement should be performed on a regular basis.

Conclusion

SFE AKUSRAIL greatly helps to identify causes of problems, which are generated by the high frequency interaction between vehicle and track. The presented assessment of corrugation growth is one of several results in vehicle track interaction, which can be investigated using simulation with ***SFE AKUSRAIL***.

By assessing the current state of the system by measurement and by creating validated models on the basis of these measurements proof is achieved, that ***SFE AKUSRAIL*** is able to correctly predict the current state.

This validated model is the basis for parameter investigation to identify the most effective changes in design and maintenance measures. Achievable results and related costs are considered in the proposed changes.

Further comfort-determining effects like contact forces to assess interior noise levels, exterior noise radiation of a vehicle and contact stresses can also be assessed with the help of ***SFE AKUSRAIL***. Such investigations have been successfully completed already.

Simulation based investigations like the presented one with ***SFE AKUSRAIL*** can be performed even in early design stages for new vehicles comparing virtual prototype variants of new vehicles in terms of noise generation, dynamic impact on the track, corrugation growth, acoustics and other aspects. Beside the assessment of the track/wheel interactions and noise behaviour by simulation, ***SFE*** supports the generation of virtual prototypes for design variants with the concept design tools ***SFE CONCEPT*** [5] and ***SFE CONCEPT RAIL***. These concept design tools enable the fast generation and modification of parametrical design models for car and railway wagon bodies with a high geometric accuracy. These virtual prototypes can be used for statical, dynamical and acoustical investigations using the finite element method.

With the growing cost awareness and the requirements for short development cycles in the railway market the application for simulation tools like ***SFE AKUSRAIL*** and ***SFE CONCEPT RAIL*** will become more and more useful in order to design track and environmentally friendly, comfortable and economic vehicles with reduced development effort.

References

[1] Zimmer, H.; Hövelmann, A.: Cause Research and Assessment of the Acoustic Behaviour of Rail Vehicles using SFE AKUSRAIL. Proc. of Joint ASA/EAA/DEGA Meeting on Acoustics, Berlin, 1999

[2] Hempelmann, K., Groß-Thebing, A., Hövelmann, A., Zimmer, H.: ***SFE AKUSRAIL*** – A High Frequency Wheel-Rail Interaction model for the Prediction of Rail Corrugation Growth and Noise. Proc. Of 2nd. Mini conference of Contact Mechanics of Rail/Wheel Systems, Budapest, 1996

[3] Groß-Thebing, A.: Lineare Modellierung des instationären Rollkontaktes von Rad und Schiene. VDI Fortschrittberichte, Reihe 12, Nummer 199, VDI-Verlag, Düsseldorf, 1993

[4] Hempelmann, K.: Short Pitch Corrugation on Railway Rails – A linear model for prediction. VDI Fortschrittberichte, Reihe 12, Nummer 231, VDI-Verlag, Düsseldorf, 1995

[5] Zimmer, H.; Umlauf, U.; Schmidt, H.: Parametrisches Entwurfstool zur schnellen und flexiblen Generierung virtueller Prototypen im Fahrzeugbau SFE CONCEPT. Proc. of VDI conference „Berechnung und Simulation im Fahrzeugbau“, Würzburg, 2000

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