Numerical method for the prediction and the assessment of rolling and curving noise

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Introduction

The programs SFE AKUSMOD and SFE AKUSRAIL aim for the simulation of the whole chain leading to noise in railway operation (Fig. 1). The tools generate models predicting the high frequency interaction between vehicle and track and consist of modules regarding track and wheelset dynamics, W/R contact mechanics, rolling noise, curve squeal and interior noise prediction [7]. The combination of track and wheelset dynamics, contact mechanics and vehicle structure dynamics represents their interaction taking into account physical properties of geometry, material and operational conditions.

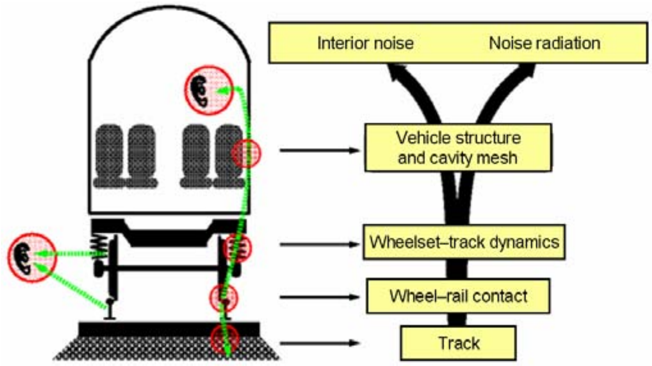

Figure 1: SFE AKUSMOD and SFE AKUSRAIL provide simulation models for the whole chain leading to noise in railway operation.

The basic system equations for the high frequency dynamics of a wheelset running in a curved track are already known and described by several authors (e.g. [1] and [2]). In the research project "Curve Noise" [8] the program SFE AKUSRAIL was extended by two numerical methods for the prediction of curve squeal. Apart from the development of algorithms a main task was to get reliable and consistent model data for the high number of parameters in the wheel-rail contact mechanics. Thereby it was helpful that a three-dimensional approach was already implemented for all modules including the wheel-rail contact. Additionally SFE AKUSRAIL provide model data for a number of validated wheel and track constructions.

Assessment of measures for a reduction of curve squeal

The following measures are largely used to reduce curve squealing noise:

- lubrication or friction modifier;
- self steering bogies;
- wheel absorbers;
- rail absorbers.

Fig. 2 illustrates the modules of SFE AKUSRAIL influenced by these measures. The lubrication and friction modifier can be investigated when the friction coefficient and the friction characteristic in the high frequency contact mechanics are modified.

The track and wheelset dynamics are calculated in a conventional FE-analysis. Rail and wheel absorbers are represented by standard FE-elements modeling geometry and frequency dependent material properties. For the FE-analysis a commercial FE-program or an integrated FE-solver can be used.

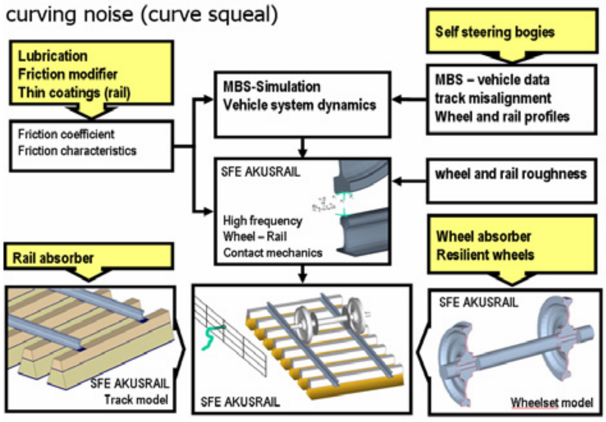

Figure 2: Modules in SFE AKUSRAIL related to measures for the reduction of curve squeal

The parameters of vehicle construction (e.g. bogie design, wheelset steering, measured wheel profiles) and track site (e.g. curve radius, track alignment, wheel and rail profiles) are considered by using the results of the vehicle running dynamics. The interface parameters are creepages, contact forces and contact point positions. Therefore investigations of self steering bogies have to consist of the prediction of vehicle run in curves.

Validation of simulation models for wheelset and track dynamics

All predictions should be based on measurements, which are used both as input data and for the validation of intermediate simulation results. This kind of validation gives all simulation results a high level of reliability.

In Fig. 3 a measured admittance of a resilient wheel is shown in comparison to the calculated results. The good agreement is due to consideration of frequency dependent material properties for the rubber between wheel disc and wheel rim. A comparison of measured and calculated track receptances provides validated model data in the relevant frequency range (Fig. 4). It has to be mentioned that the FE-analysis of wheelset dynamics has to provide transfer functions for the coupling between axial and radial components in the mode shapes responsible for curve squeal.

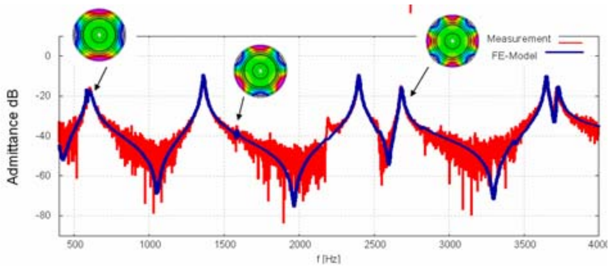

Figure 3: Validation of simulation results of SFE AKUSRAIL for the dynamics of a resilient wheel. (Measurements by TU Berlin).

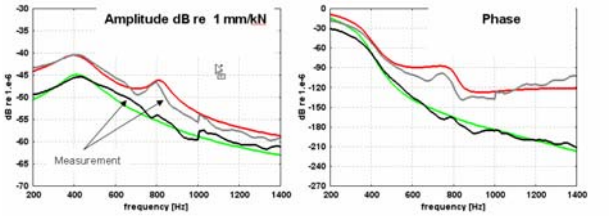

Figure 4: Validation of simulation results of SFE AKUSRAIL for the track dynamics (Measurements by TU Berlin).

Main influence factors on curve noise

In a first step the new algorithms are used to investigate the main influence factors on rolling noise and squealing in curves.

Roughness: The main relevant parameter for prediction of rolling noise in curves is roughness on wheel and rail tread. For a reliable prediction of rolling noise it is highly recommended to measure the roughness. Corrugation on rails and wheels may dominate sound generation and therefore modifications of the wheelset and track construction have a minor influence on noise generation.

For the prediction of curve squeal the roughness is related to the friction coefficient. A rough wheel or rail tread may indicate a high friction coefficient. More than roughness lubrication has an important influence on the friction coefficient.

Friction coefficient: The friction coefficient has a main influence on tangential contact forces in the high frequency dynamics of wheelset-track interaction if high values of creepages are present. On straight tracks creepages are small compared to the values in curves. Therefore the radiated noise induced by the high frequency dynamics of wheel and rail is mostly independent from the friction coefficient. The running behavior of vehicles in curves generates high values of creepages and therefore the friction coefficient can change the coupling of wheel and rail dynamics in a high extent.

Shift of contact point: The definition of the contact point shift is illustrated in Fig. 5. The contact point shift is related to the size of contact patch (wheel load) and the contact angle. To make clear the effect on wheel-rail dynamics and noise generation the contact parameter can be investigated independently. Some mode shapes of wheel may be excited by an eccentric excitation of the wheel only. Generally these resonances are not present in noise spectra on straight lines and occur in measured spectra in curves only when the lateral shift of contact point tends to special values.

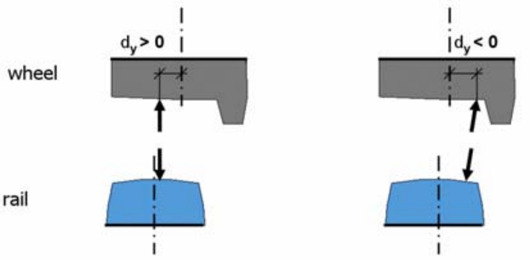

Figure 5: Main influence parameter from vehicle dynamics: Shift of contact point.

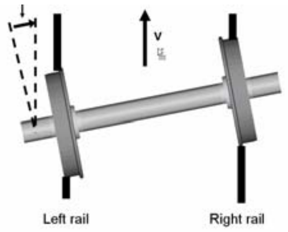

Figure 6: Main influence parameter from vehicle dynamics: yaw angle.

Yaw angle (lateral creepage): The wheel-rail contact mechanics is defined by creepages in longitudinal and lateral direction and by spin creepage. These creepages are the relative surface velocities of wheel and rail in the contact point. The quasi-stationary part can be calculated in a simulation run for the vehicle system dynamics whereby. lateral creepage is directly related to the yaw angle of the wheelset (Fig. 6) and spin creepage to the contact angle in the contact point.

If rolling noise on straight lines is predicted only small values of lateral creepages (resp. yaw angle) are present. Therefore contact parameters are not as important as roughness. On the contrary yaw angle is a key value for the noise radiation in curves. A necessary condition for curve squealing is a high level of lateral creepage. Radial steering bogies should roll with less value for the yaw angle through curves. It can be expected that the use of this type of bogies will reduce curve squealing.

Wheel absorber: For a high friction coefficient **t**he initiating mechanism for curve squeal excites the wheel structures by a “negative damping”. This can be compensated by the high damping provided by wheel absorbers. Of course twheel absorbers have to be trimmed for the wheel resonances responsible for curve squealing.

Numerical methods for the assessment of curve noise

The prediction method for the rolling noise in curves provides narrow band spectra, 1/3 octave band spectra and a A-weighted equivalent energy noise level in user defined positions nearby the track. As an example an assessment of rail absorbers on straight track is described in [5].

For the prediction of curve squeal two independent prediction methods filter the curve squeal frequency from all the possible wheel resonances. The methods show the sensitivity for variations of friction coefficient, wheel geometry, for application of wheel absorbers and for material properties of the rubber in resilient wheels.

The first method treats the linearized differential equations of the wheelset – track dynamics considering a completely three-dimensional model for wheelset-track interaction. Thereby the contact point position can be moved on wheel and rail tread. Complex eigenvalue analysis is used to calculate the eigenfrequencies of the damped and the undamped modes of the rolling wheel on the rail. The occurrence of an undamped mode points to a system behavior with high values of amplitudes in the corresponding non-linear system. An automatic parameter variation for the contact point position and the lateral creepage (yaw angle) performs instability regimes (Fig. 7).

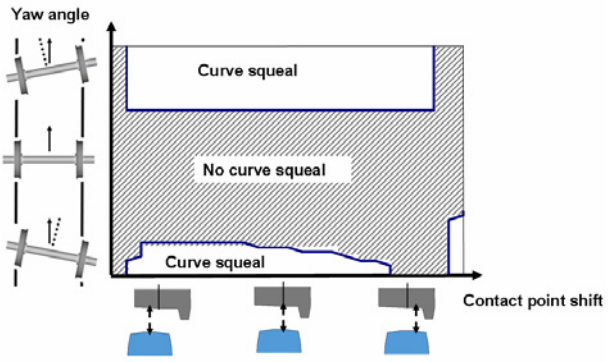

Figure 7: Stability plot for an automatic parameter variation for yaw angle and contact point shift using the linearized system equations.

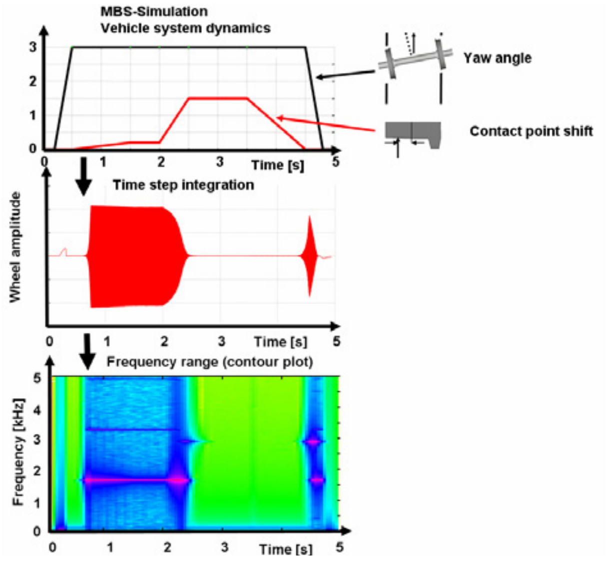

Figure 8: Time step integration of the non-linear system equations perform wheel amplitudes for a wheel running in curved track. The transformation of the time series in the frequency domain is shown in the contour plot.

The relation between tangential contact force and creepage is highly non-linear. This relation and further non-linear relations in the wheel-rail contact are considered in the second prediction method. Wheel and rail amplitudes are calculated by a time step integration of the non-linear system of equations (Fig. 8). A transformation of time series in the frequency domain provides a contour plot. The amplitude of the wheel can be identified by the vibration frequency and the position of wheel in the curve. Additionally the yaw angle and the contact point shift are documented to show how the wheel amplitude depends on parameters of the vehicle dynamics.

In the time step calculations curve squeal is observed for high level of yaw angle (lateral creepage) and a moderate shift of contact point. This condition is valid for wheels running through curves without flanging contact.

Acknowledgement

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