Simulation of curve squeal considering the vehicle dynamics

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Introduction

Curve squeal noise can occur when a railway vehicle passes through a tight curve. Because of its strong tonality and high intensity squeal noise has a severe potential to disturb the environment. Therefore the general aim is to avoid this kind of noise emission [1].

A reliable prediction depends on different parameters which influence the occurrence of squeal [2]. Influences are given from the vehicle dynamics, the wheel design and the track dynamics. To calculate the vehicle dynamics a multi-body program is used with a detailed model of the analyzed train. For the prediction of squeal noise the tools SFE-AKUSRAIL and TWINS-SLYNX are applied. As a result the unstable frequencies of the wheel from a stability analysis are obtained and a time domain analysis depending on different parameters from the vehicle dynamics simulation is performed.

First the wheel is build up in a FEM-system. In a second step the main input parameters for the curve squeal simulation tools are calculated using a simulation of the vehicle dynamics. The FEM model and these parameters are the main input during the simulation procedure for using the curve squeal simulation tools. Both form the basis for the curve squeal simulation tools.

FEM model of the wheel

An FE-model of the investigated rubber-sprung steel wheel (Figure 1) is used to calculate its eigenfrequencies and mode shapes. The radial and axial wheel receptances at the wheel rail contact point are calculated and form the basis for the curve squeal prediction. The wheel damping is adjusted to the measured modal damping factors of the wheel.

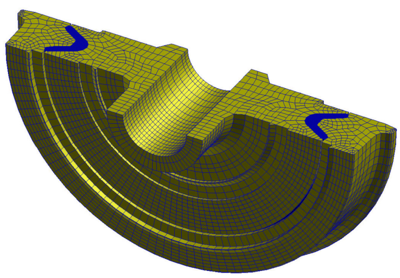

Figure 1: FEM model of the analyzed rubber-sprung wheel (blue: rubber layer)

The model is set up with 178203 hexader solid elements. The potential squealing modes are the axial vibrations at the wheel rim with zero nodal circles and n nodal diameters:

- second axial mode at 632 Hz, n = 2
- third axial mode at 1607 Hz, n = 3
- fourth axial mode at 2836 Hz, n = 4
- fifth axial mode at 4196 Hz, n = 5

The model is validated by receptance measurements of the wheel. Therefore the train is jacked up and the receptance of the wheel is measured with impact hammer excitation at the nominal contact point. During these measurements the wheel is not in contact with the rail. In Figure 2 the axial wheel receptances from calculation (blue) and measurement (red) are presented. The overall agreement is satisfying; there is only a slight frequency shift between measured and calculated eigenfrequencies at higher frequencies.

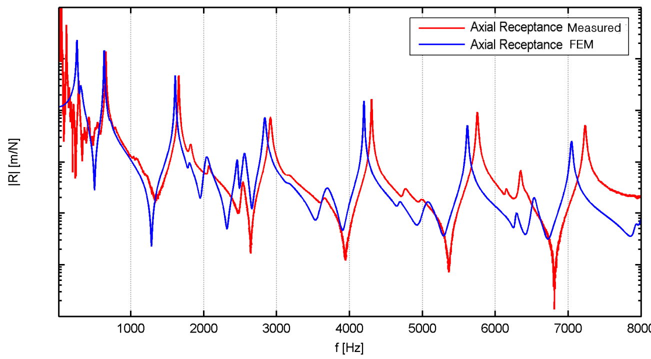

Figure 2: Comparison of measured and calculated axial receptance, y-axis log-scaled

Vehicle dynamics simulation

For curve squeal simulations the vehicle dynamics plays a decisive role so that a detailed multi-body model of the train has to be used. The vehicle dynamics of the analyzed train is simulated for a selected curve with a radius of 30 m. The left curve is analyzed for two different speeds (10 km/h and 20 km/h). The main input parameters for the squeal prediction tools, calculated with a multi-body program, are:

- contact point position on wheel
- lateral, longitudinal and spin creepages
- normal force on rail

These parameters are calculated for different friction values simulating different friction conditions in the wheel rail system.

The track length is about 50 m and the gauge is 1440 mm without superelevation. The simulation is done for a trailer bogie because there are no additional influences on the creepages from the traction system. The left inner front wheel of this trailer bogie is chosen to be analyzed because of the highest probability to squeal [3].

Curve squeal simulation results

SFE-AKUSRAIL

The curve squeal prediction software SFE-AKUSRAIL [4] is able to perform a complete time-domain squeal simulation for a curving vehicle. First a stability analysis for a three-dimensional parameter space is performed. The results are shown in stability plots in dependence of two parameters, the contact position on the wheel and the lateral creepage. The third parameter, the friction coefficient, is represented with different coloured curves for different eigenfrequencies, enclosing the instable regions. Figure 3 shows the stability plot for the analyzed wheel rail system and gives the potential instable regions for the eigenfrequencies. The result of the vehicle dynamics simulation for the investigated curve is illustrated by the gray circle in the lower left part of the plot and is located in the instable region for the two eigenfrequencies and all friction coefficients.

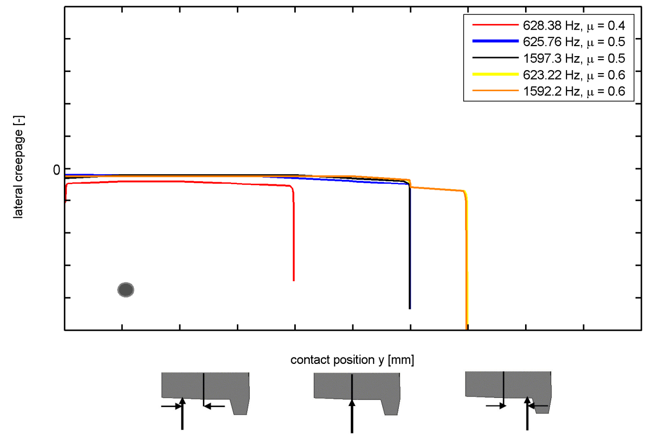

Figure 3: Stability plot of the wheel (SFE-AKUSRAIL result)

In a second step the whole left curve with the extracted time-dependent results of the vehicle dynamics simulation is analyzed. In this time domain simulation SFE-AKUSRAIL calculates whether one of the identified eigenfrequencies of the stability analysis will become instable in this curve. The colour plot in Figure 4 shows the frequency content vs. time of the axial wheel velocity in the contact point. At about 4s the instability of the second axial mode (632 Hz) arises and remains during the complete curving process. Higher harmonics of the excited axial mode are also visible in the plot.

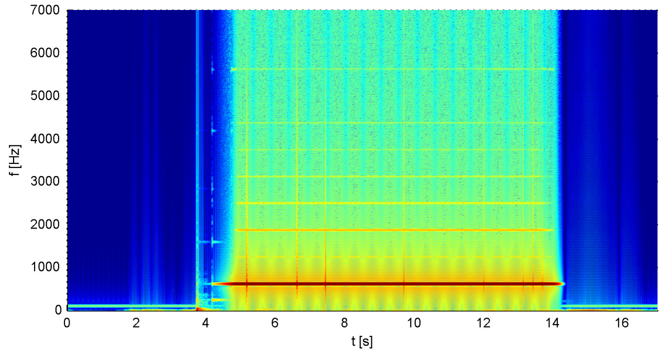

Figure 4: Colour plot of the axial wheel velocity in the time-frequency domain with 20 km/h train speed, instable frequency (dark red) of 632 Hz and higher harmonics

TWINS-SLYNX

The curve squeal prediction module SLYNX [5] is implemented in the rolling noise simulation tool TWINS. The SLYNX module also identifies the instable eigenfrequencies of the wheel in a stability analysis. The stability plots can be created by manually performing parameter variations. For the calculation the important parameters are entered manually for a selected (quasi-static) moment of the vehicle dynamics simulation. The lateral creepage and the contact point position are the main input parameters for the module. Longitudinal and spin creepage is not taken into account in the current SLYNX version. Friction curves for different conditions like track lubrication (Figure 5) have to be defined by the user. The friction curve depends on the friction coefficient and the saturated creepage.

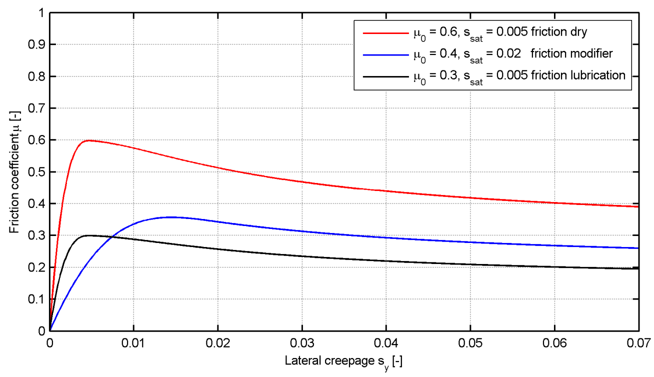

Figure 5: Friction curves assumed for various track conditions

With these parameters the program calculates the contact dynamics for the wheel rail contact point. Figure 6 shows an example of the identified frequencies. The one with the largest loop gain (red) becomes the dominant squeal noise frequency.

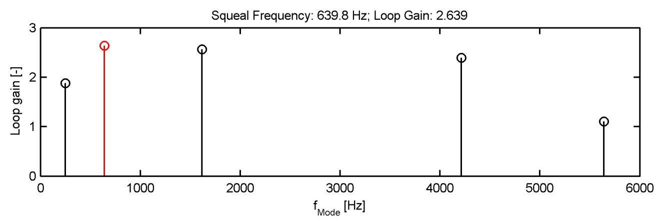

Figure 6: Identified instable frequencies with SLYNX

In the time domain the amplitude and the higher harmonics are calculated only for this identified squeal noise frequency. SLYNX is not able to calculate a whole curve as there is no interface to the output parameters of the vehicle dynamics simulation. Hence, only a quasi-static curving process can be analysed with SLYNX.

Comparison of the simulation tools

The two prediction tools SFE-AKUSRAIL and TWINS-SLYNX give comparable results for the instable regions in the stability analysis. Furthermore roughly the same instable frequencies are predicted in a stability analysis with a friction value of μ = 0.6 (Figure 7). Differences are the negative creepage region for the second axial wheel mode and the small instable area of the third axial wheel mode in TWINS-SLYNX. Figure 8 shows the identified wheel mode responsible for the squealing noise in the analyzed left curve in both simulation tools.

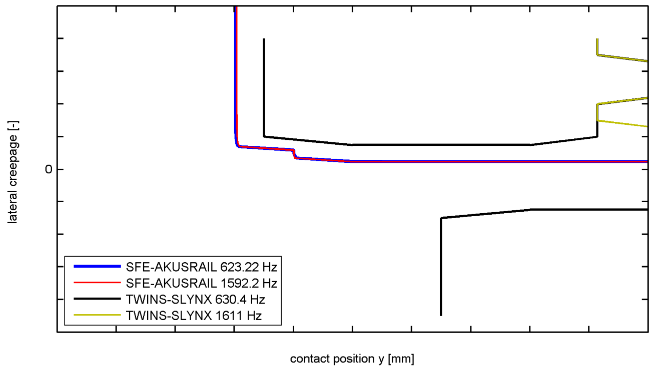

Figure 7: Curve squeal stability plot: Comparison of SFE-AKUSRAIL and SLNYX results, friction value μ = 0.6

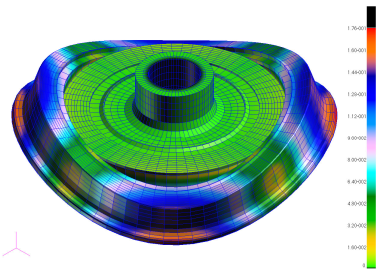

Figure 8: Identified instable wheel mode at 632 Hz

Figure 9 presents the comparison of SFE-AKUSRAIL and TWINS-SLYNX for the frequency spectrum of the axial wheel velocity including higher harmonics. Here the non-linear stick-slip process with the dominant eigenfrequency, the low first harmonic and intense higher harmonics is represented.

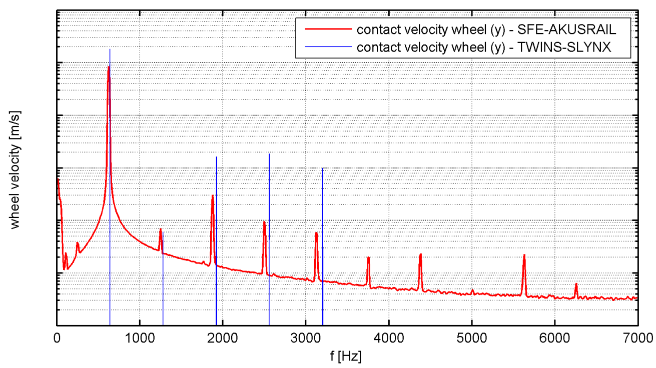

Figure 9: Comparison of axial wheel velocity in the frequency domain, y-axis log-scaled

To define the necessary damping to inhibit the squeal process the loss factors are gradually increased in both tools starting with the loss factors identified in the measurements. The lowest loss factor where squeal is prevented for the investigated curve is plotted in Figure 10 for the axial wheel modes. Major differences arise between both prediction tools for the lowest eigenfrequencies, where SLYNX proposes significantly higher loss factors to prevent curve squealing.

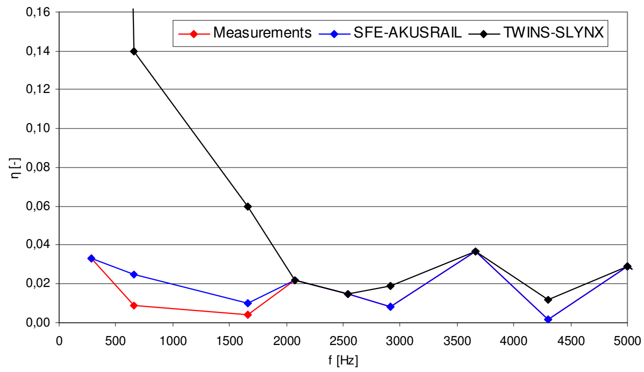

Figure 10: Necessary damping to inhibit squeal for the axial wheel modes, friction value μ = 0.6

Concluding remark

In both simulation tools the second axial wheel mode with a frequency of 632 Hz is identified as responsible squeal frequency for the considered left curve and vehicle. The same tendencies in the results of the two simulation programs show that both tools are able to predict the same frequencies in dependence on the vehicle dynamics parameters.

With respect to the necessary damping to prevent curve squeal, especially in the low frequency range, high loss factors are identified by TWINS-SLYNX. In SFE-AKUSRAIL only small adaptations are required to inhibit the squeal noise.

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References

[1] Forschungsverbund Leiser Verkehr: *Geräusche im Schienennahverkehr. Handbuch. Handlungsempfehlungen zur Verminderung der in Gleisbögen auftretenden Geräusche.* to be published in 2009.

[2] Huang, Z.: *Theoretical Modelling of Railway Curve Squeal*. Dissertation, University of Southampton, 2007.

[3] Vincent, N. et al.: „Curve squeal of urban rolling stock – Part 1: State of the art and field measurement.” In: *Journal of Sound and Vibration* 293, 2006, 691–700.

[4] SFE GmbH Berlin: „SFE AKUSRAIL online Hilfe“.

[5] Janssens, M.H.A. / de Beer, F. G.: *SLYNX v 1.0 - A squeal noise calculation module for usage with TWINS – User Manual*, 2003.