

Vibration Field on a rolling tyre – results from a simulation model

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Introduction

Tyre road noise is the dominant source for traffic noise at driving speeds above 30 km/h. In order to achieve a substantial reduction of tyre/road noise a sound understanding of the noise generation mechanisms is required. At the Department of Applied Acoustics, Chalmers University of Technology, a simulation model for tyre/road noise generation is under development. With this model it is possible to calculate the vibration field on the tyre structure for a tyre rolling as a function of tyre properties such as tyre design, tread pattern and road parameters (i.e. road texture).

The simulation model is used to predict the vibration field for different tyres at different rolling speeds. A qualitative comparison is made between simulation results and results from near field holography.

Prediction of tyre vibrations

There are certainly different ways to design an acoustic rolling model. The main requirements with respect to frequency range (at least up to 3000 Hz) and low computational effort still excludes models purely based on FE. The strategy used by the authors is based on work published by McIntyre et al in the area of musical acoustics. They were interested in the interaction between violin bow and string. This interaction is of non-linear nature since tangential forces will excite the string to vibrations and at the same time the vibrations (i.e. velocity) of the string will determine the friction forces. Their main idea was to describe the string as linear system by its impulse response function (i.e. the velocity response to a force pulse with unit amplitude). This leads to a very simple equation system, which can be solved for each time step (see for instance [1]). Following this idea one can win two important features for the rolling model, an elegant way to solve the contact problem and the use of pre-calculated impulse response functions, which reduces the numerical effort substantial.

The model has been validated for by acceleration measurements on tyres rolling on a test drum with a replica surface. In order to carry out the validation a substantial amount of information is necessary. The tyre model has to be adapted to the tyre used in the validation process. A model updating procedure is used to determine the material parameters for the tyre model of the orthotropic plate as described in [2]. Additionally a careful characterisation of the road surface (i.e. the surface of the drum) is needed. For the simulations used here a ISO replica on the drum was scanned in 15 parallel track with 1 cm distance between each track. The surface roughness was pre-processed in order to adapt the data to the spatial resolution used in the rolling

model. Additionally the surface of the tyre was scanned in this way both tread pattern and variations in the roundness of the tyre are included in the model as an additional roughness. In the following two different tyres have been used one with longitudinal grooves only and one with cross bars only. Accelerometers have been placed in the grooves and acceleration has been measured during rolling. The spectra of the acceleration are compared in Figure 1 and Figure 2 for these both cases.

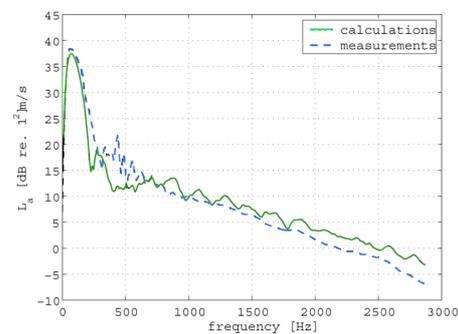


Figure 1: Comparison between measured and calculated acceleration signals on the tyre structure: tyre with circumferential grooves rolling on ISO road at 80 km/h

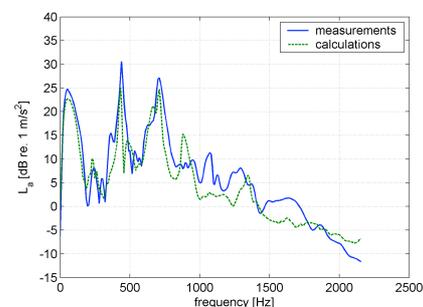


Figure 2: Comparison between measured and calculated acceleration signals on the tyre structure for crossbar tyre (64 blocks evenly distributed) rolling on ISO road at 60 km/h.

The agreement is acceptable. Although these both tyres are extreme cases with respect to their tread pattern, one can expect that commercial tyres will be similar well simulated. They can be considered as a combination of longitudinal pattern and tread pattern.

Vibrations responsible for radiation of sound

The acceleration, which measured on the rolling tyre with accelerometers glued in between the tread pattern, is affected by the Doppler effect. For the accelerometer the contact forces are moving around the tyre. Vibrations observed in this way cannot be directly interpreted with respect to their

contribution to the sound radiation from the tyre. For this the motion in the coordinate system of an external observer (i.e. us as listener observing the rotating tyre) is required. This is done by a simple coordination transform knowing the acceleration at each point of the tyre surface. Figure 3 shows typical results for the tyre vibrations in the coordinate system of an external observer for three different frequencies.

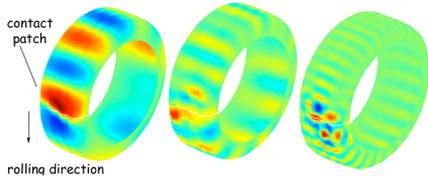


Figure 3: Calculated vibration of the tyre for 125 Hz (left), 500 Hz and 1500 Hz

It is visible that the highest vibration amplitudes are located around the contact area. At the same time one might be surprised that with some distance from the contact there are only plane waves observed. The question arise how far such results agree with reality. In the following a brief comparison with measurements using acoustic holography is presented. Figure 4 shows a typical measurement setup as used at Continental. From the measured sound pressure in the nearfield of the tyre the velocity field on the tyre is obtained by applying the Inverse Boundary Element Method. A principal component analysis is carried out to find the vibration pattern of the tyre in a certain frequency range.



Figure 4: Microphone array for near field holography

A comparison of the in this way measured velocities is compared with the calculated velocity field. One should have in mind, that only a qualitative comparison is possible since both tyres and surfaces are not identical for measurement and calculation. Despite this there is a fair agreement at higher frequencies (see Figure 5), while at lower frequencies the simulations show standing wave patterns, which cannot be observed in the measurements.

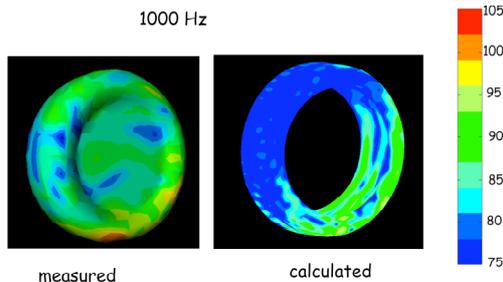


Figure 5: Comparison between measured and calculated tyre vibrations

This might be due to the fact that the simulation only contains one revolution while the measurements contains a high number of revolutions and an inevitable variation of the rolling speed might lead to a “smearing out of the vibration pattern.”

Conclusions

The main questions arise which of the vibrations visible on the tyre structure are responsible for the radiation. Studying the radiation from cylinders one comes to the conclusion that most of the circumferential modes on the tyre are actually (fortunately) very inefficient radiators. The radiation efficiency is increased by the horn effect.

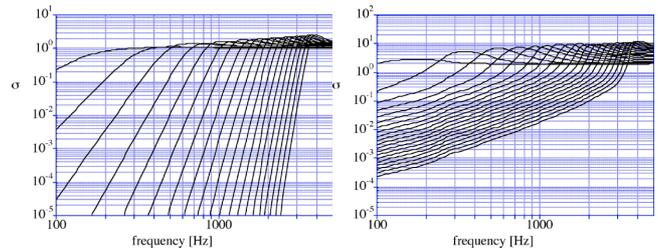


Figure 6: Radiation efficiency of the first 20 circumferential modes (order $n=0-19$) for a freely suspended cylinder (left) and a cylinder on a rigid ground (right)

From Figure 6 it is obvious that low order modes are radiating much better in the frequency range of interest than high order modes. The question arises how strongly these low order modes are excited. This is difficult to conclude from Figure 3 where a linear scale for the vibration amplitude is used. When inspecting the energy contribution in the wavenumber spectrum for instance for the middle track of the tyre, one can observe a maximum for the free waves (bending waves following the square root of frequency) but also a substantial part of energy distributed to other wavenumbers due to the forced excitation in the contact. The presence of wave components with lower wavenumbers is due to the fact that the tyre is exposed to a forced excitation. From the radiation efficiencies shown in Figure 6 it is obvious that although the amplitudes of these lower order wave components are lower they will contribute substantially to the radiation from the tyre surface.

References

- [1] F. Wullens, W Kropp, A three dimensional contact model for the description of tyre/road interaction. Proceedings 10th ICSV, Stockholm, Sweden, 2003.
- [2] W. Kropp, Ein Modell zur Beschreibung des Rollgeräusches eines unprofilierten Gürtelreifens auf rauher Straßenoberfläche, Thesis, Fortschritt-Berichte Reihe 11, Nr 166, VDI Verlag, (Düsseldorf 1992)