Study of Crossbar Tyres in Rolling Conditions

Frédéric Wullens, Wolfgang Kropp

Department of Applied Acoustics, Chalmers University of Technology, SE-41296 Göteborg, Sweden, Email: frederic@ta.chalmers.se

Introduction

The study of crossbar tyres is a relevant one in the sense that crossbar tyres represent an extreme case of patterned tyres. In this work, accelerations signals measured in the normal and tangential directions on crossbar tyres are studied in rolling conditions and are compared with the acceleration signals calculated with a 3D contact model, previously validated for the case of an airplane tyre [1]. The model is good at predicting pitching frequencies induced by the periodicity of the crossbars. In terms of acceleration amplitude, the agreement is reasonably good with regard to the limited number of generation mechanisms implemented in the model

Measurements of acceleration

Measurements on crossbar tyres in rolling conditions were made in laboratory-controlled conditions on a test drum located in a semi-anechoic room. The measurements were made in the frame of the EC research project RATIN at Goodyear Technical Centre, Luxemburg. The measurement procedure concerns the recording of acceleration signals on the tyre structure in the normal and in the tangential direction while rolling. The crossbar tyre used for the measurements has 64 bars that are equally spaced. The tyre is fixed on an axle and is loaded by a static force of 3000 N on the drum before the drum is rolled.

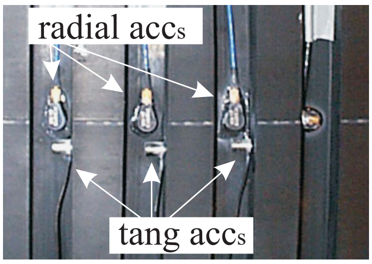

Figure 1: Mounting of the accelerometers

In order to perform acceleration measurements, accelerometers were glued on the tyre. To measure normal acceleration, accelerometers are glued on the tyre structure inside the grooves made by the bars, see Figure 1. For the tangential acceleration, the accelerometers are glued on the bars, in the tangential direction, which means that they mostly measure the tangential motion of the bars due to tangential forces and some rotational motion that can be due to the bending of the tyre structure.

Calculations

The acceleration from the vibrating tyre structure can be calculated in the normal direction with the time-domain formulated contact model developed by the authors. The contact model needs the tread profile (obtained by scanning), the road roughness (laser-measured), the tyre structure response and some material data as input in order to solve the 3D contact problem for each time step. As an example, Figure 2 shows a snapshot of the tyre/road interaction at a certain time step.

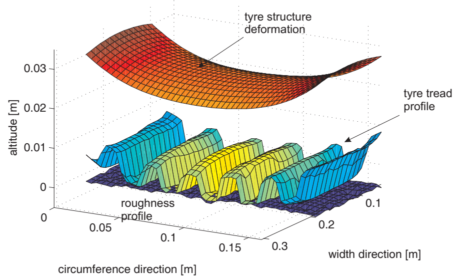

Figure 2: Snapshot of the tyre/road interaction between the crossbar tyre and the ISO road at 80 km/h

Analysis and comparison

Figure 3 shows a typical time acceleration signal measured in the normal and tangential directions for the case of the tyre rolling at 80 km/h on the ISO road. The figure shows the time averaged acceleration over all tyre loops completed during measurements and the time period corresponds to a fully completed tyre loop. At $t = 0$ s, the accelerometer is on the top of the tyre ($t = 0$ s) and moves through the front part of the tyre, approaching the leading edge ($t \approx 0.04$ s). From $t \approx 0.04$ to $t \approx 0.05$ s, the accelerometer travels through the contact patch (region 2). After $t \approx 0.05$ s, it travels through the back of the tyre towards the top again. While completing an entire loop, the normal accelerometer records an acceleration that is composed of three parts. The first part is the acceleration in stationary conditions, which is the shape of the acceleration signal that would be obtained in the case of the smooth tyre rolling on a smooth road (see [2]). The second part is composed of the waves produced ahead of the accelerometer by the tyre/road contact, which propagate in the opposite direction of the tyre rotation. This signal is the compressed wave visible in the part of the signal called region 1. Finally the third part is composed of the waves produced behind the accelerometer, propagating in the same direction as the tyre rotation. These waves have biggest amplitude from the trailing up to the top of the tyre, in the part of the signal called region 3.

Figure 4 shows the comparison between measured and calculated power spectrum density of the normal acceleration signals for several rolling speeds. At 60 km/h, a group of two peaks, one at $f_{l,n}$ below 500 Hz and one at $f_{u,n}$ around 700 Hz is visible. These two peaks are representative for the pitching frequency $f_{p,n}$ due to the periodicity of the crossbar tyre influenced by the Doppler effect as

$$\left(f_{l,n}; f_{u,n}\right) = \frac{f_{p,n}}{1 \pm \dfrac{u}{c\left(f_{p,n}\right)}} \qquad (1)$$

where u is the rolling velocity and $c\left(f_{p,n}\right)$ is the wave group velocity. $f_{l,n}$ is characteristic for the wave propagating in region 3 whereas $f_{u,n}$ represents the wave present in region 1. The spectrum below 250 Hz is characteristic for the acceleration in stationary conditions and is therefore not influenced by the Doppler effect. For higher frequencies, the signal is influenced by the higher harmonics of the pitching frequency.

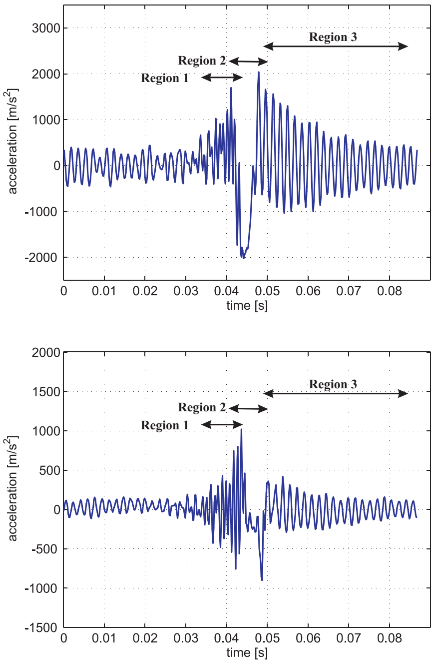

Figure 3: Normal (top) and tangential (bottom) acceleration time signals recorded for the tyre rolling at 80 km/h on ISO road

The agreement between measurements and calculations is good at 60 km/h in terms of shape and amplitude. At all speeds, the low frequency region is well captured, meaning that the contact time and length are well predicted.

At 80 km/h, the model fails in predicting the acceleration peak at $f_{u,n}$. A reason for this can be that the measurement peak is built of two peaks, the upper one of the pitching frequency plus the lower one of the first harmonic of the pitching frequency, present at about the same frequency whereas the model predicts the peaks at different frequencies. At 100 km/h, the agreement is globally better than 80 km/h.

Generally, as rolling velocity increases, the acceleration peak corresponding to $f_{l,n}$ remains constant whereas the peak corresponding to $f_{u,n}$ decreases. This means that the vibration amplitude at the leading edge decreases. An explanation for the actual decrease could be the importance of damping effects as the excitation frequency increases. Additionally, the fact that this trend is both observed in the measurements and predicted by the model talks against the effect of tangential forces on normal tyre structure vibrations since tangential force excitation is not implemented in the model.

The amplitude of the acceleration spectrum measured in the tangential direction (not shown here) decreases at $f_{u,n}$ for increasing rolling speed as for the normal direction, whereas the peak at $f_{l,n}$ increases. At this point of the study, it seems that the implementation of normal structure vibrations due to tangential excitation is not necessary since the model captures the right trends with normal force excitation only. A further step is the validation of the model for commercial tyres in order to verify this hypothesis.

Acknowledgements

The work presented in this paper has been financially supported by the EC research project RATIN, G3RD-CT 2000-00097.

References

1. Wullens, F., Kropp, W., *A three-dimensional contact model for tyre/road interaction in rolling conditions.* Submitted for publication, 2003.

2. Périsse, J., *A STUDY OF RADIAL VIBRATIONS OF A ROLLING TYRE FOR TYRE–ROAD NOISE CHARACTERISATION.* Mechanical Systems and Signal Processing, 2002. **16**(6): p. 1043-1058.

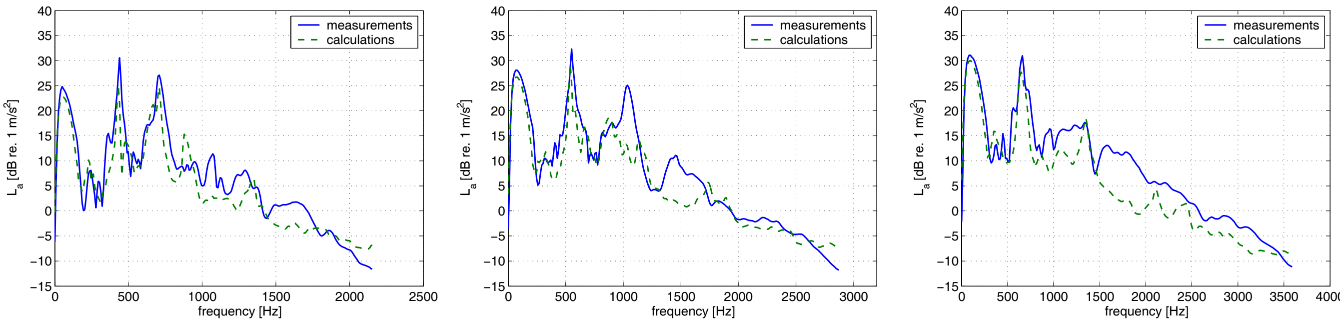

Figure 4: Comparison between the measured and calculated normal accelerations at 60 (left), 80 (middle) and 100 km/h (right)