The Influence of Belt and Tread Band Stiffness on the Tyre Noise Generation Mechanisms

Wolfgang Kropp, Krister Larsson and Stéphane Barrelet

Department of Applied Acoustics, Chalmers University of Technology, S-41296, Sweden

Abstract: A two dimensional rolling model is briefly presented which describes a smooth tyre rolling on a rough surface. A parameter study is presented which shows the influence of the bending stiffness of the belt and the stiffness of the tread band on the generation of tyre vibrations and the radiation of sound from the tyre. The results indicate that both stiffness and mass of the belt should be modified when aiming for a reduction of tyre noise.

INTRODUCTION

The noise generation mechanisms are basically divided into two categories. The first class called "radial tyre vibrations", covers all forms of interaction between tyre and road which lead to vibrations of the tyre belt and radiated sound (e.g. (1)). These vibrations, for instance, can be caused by discontinuities of the tyre structure or by the roughness of the road surface.

The second class called "air resonance phenomena" include resonance effects between the grooves of the tread pattern and the rough road surface (e.g., (2)) - working as λ/2 resonators or as Helmholtz resonators - as well as the controversially discussed "air pumping" effect (e.g. Hayden 1971).

An additional mechanism not properly classed in either of the two categories above is the "deformation of the tread" by the roughness peaks of the road surface. In this way air volumes are displaced and can be considered as monopoles Ronneberger (3). The calculated sound radiated by all the monopoles in the contact area corresponds well with the measured sound pressure for specific parameters (i.e. rolling speed, type of tyre, etc.) at frequencies above 1000 - 2000 Hz.

Other mechanisms are certainly conceivable. In any case the question arises as to which of the sound generation mechanisms are dominant for the radiated sound of a rolling tyre. The answer to this question obviously depends on the considered frequency range as well as on several parameters of the tyre and the road surface (e.g. material parameters of the belt, roughness amplitude of the road surface or tread pattern of the tyre).

ACOUSTIC ROLLING MODEL

This paper deals with the first category of the noise generating mechanisms, the "radial tyre vibrations". The paper makes use of a two-dimensional model as described in (4). This model only takes into account the radial and the circumferential directions of the belt. In the lateral direction of the belt all quantities are assumed to be identical. The model is of a modular design and consists of three different parts. These parts are:

- A "tyre model" describing the structure-borne sound properties of a smooth tyre. The tyre belt is modelled as an orthotropic plate under tension due to the interior air pressure. The plate is simply supported on both sides in the width direction. Velocities and bending angles at both ends of the plate are identical. The plate model has been tested against measurements and showed good agreement at least for the radial driving point mobility in a frequency range up to about 3 kHz.

- A "contact model" simulating the non-linear contact between tyre and road. The tread band of the tyre is described as a "Winkler" bedding model, i.e. in form of springs which do not interact with each other. A more detailed description of the basic procedure of the contact model can be found in (5).

- A "radiation model" for calculating the radiated sound considering the case of a tyre placed on a hard surface. A multipole expansion is used to approximate the velocity field on the tyre including the ground reflections.

The model has been verified by measurements and it has been extended by the local deformation of the tread band and the sound generation due to these deformations. The model can be applied depending on the rolling speed in frequency ranges up to ca 3 kHz (at about 70 km/h).

INFLUENCE OF THE BENDING STIFFNESS OF THE BELT

One possible way to reduce the tyre noise generation due to tyre vibrations would be to increase the belt stiffness. In this way the radial driving point mobility of the tyre and also the vibration levels on the tyre are
decreased. Figure 1 shows the driving point mobility in radial direction in the middle of the belt for five different "tyre constructions". The bending stiffness is varied from $B_r = 0 - 40$ Nm in circumferential direction and from $B_y = 0 - 6$ in the width direction. Normal values of standard tyres are in the order of $B_r = 2 - 5$ Nm and $B_y = 1 - 3$ Nm. The rolling model was used to calculate the contact forces, vibration velocities and the radiated sound. The rolling speed was 70 km/h, the roughness of the road was assumed to be stochastic with an even distribution and maximum amplitude of 0.5 mm. The third octave spectra of the velocity in a point close to the contact area are shown in Figure 2.

![Figure 1](image1.png)  
**Figure 1** Radial driving point mobility at the middle of the belt, $F_o=1N$, $v_o=1m/s$

The velocity amplitude clearly decreases with increasing bending stiffness. Only the last third octave band shows an opposite trend. However, while the velocity decreases, the radiated sound does not change substantially (Figure 3). This is not too surprising since an increase of the bending stiffness also leads to an increase of the radiation efficiency, which compensates for the reduction in velocity. To avoid this trade off an increase of the bending stiffness must be accompanied by an increase of mass per square meter of the belt. Keeping the ratio between mass and bending stiffness constant will lead to a decrease in the mobility of the belt but will not change the wavenumbers on the belt. Figure 4 shows the results for three different tyre constructions.

![Figure 2](image2.png)  
**Figure 2** Radial velocity in a point close to the contact patch, re 5e-8m/s

![Figure 3](image3.png)  
**Figure 3** Pressure level (third octave bands) at 1 m distance to the tyre centre for different bending stiffness but identical mass, re 2e-5 Pa

![Figure 4](image4.png)  
**Figure 4** Pressure level at 1 m distance to the tyre centre for different bending stiffness with constant mass to bending stiffness ratio, re 2e-5 Pa

**CONCLUSIONS**

Increasing the bending stiffness of the belt must be accompanied by an increase of the mass of the belt in order to have an substantial influence on the radiated sound from rolling tyres. However, the improvements shown above could be compromised by an increase of the sound radiation due to local deformation of the tread.

**REFERENCES**