# Experiments on the viscoelastic properties of a car tyre

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## Introduction

An outstanding problem in any prediction of dynamic response of an engineering structure is the actual magnitude, frequency dependence and distribution of its damping. The current work considers the viscoelastic properties of a radial car tyre. It is a complicated composite structure, built up by many different materials, and a full experimental evaluation of its dynamic properties is clearly impossible. It is therefore described by an 'equivalent structure' built up by steel wires and isotropic rubber. The wires have frequency independent properties while the rubber is described by a viscoelastic fractional Kelvin-Voigt model. It has rather few parameters, which are determined by inverse procedures applied to experimental data for a piece of rubber, a tyre sample and the full tyre structure. A Waveguide FE model based on the determined viscoelastic data, and the geometry and static stiffness supplied by a tyre manufacturer, predicts dynamic response that agrees favourably with experiments.

## Car Tyre Modelling

Car tyres are made of several different materials including steel, fabric and of course numerous rubber compounds, see Figure 1. To get different dynamic properties in the tyre sub regions the materials are used in many ways. The three major sub regions of the tyre are the upper side wall, the lower side wall and the central area. The ply is a layer of embedded fabric in the rubber. At the lower side walls the ply encloses a volume filled with both steel wires and hard rubber materials; this makes the lower side walls relatively stiff. The upper side walls are on the other hand quite flexible, since the ply layer there is simple and there is less steel in there. The central area consists of the belt and the tread. The belt consists of a rubber embedded steel lining in the circumferential direction to give support and rigidity. The tread is an about 13 mm thick rubber layer which is there to provide the grip. This makes the central area rigid with respect to bending waves in the circumferential direction but fairly flexible when it comes to motion within the cross-section. The high loss factor of the tread rubber makes the latter motion highly damped.

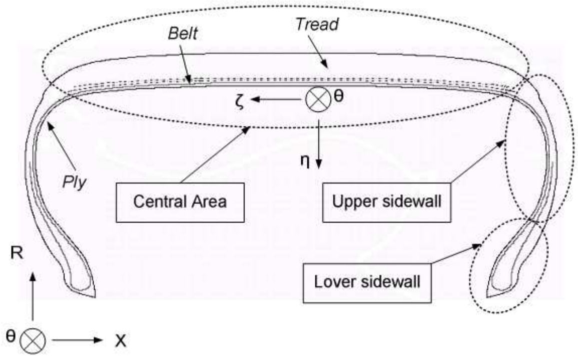


Figure 1: The tyre consists of three major sub regions. Upper side wall, lower side wall and the central area.

The Waveguide Finite Element Method (WFEM) yields equations of motion for systems with wave-propagation along a single direction, in which the structure is uniform. It is then possible to separate the solution to the wave equation into one part depending on the cross-section, one part depending on the coordinate along the waveguide and one part depending on time. Here, the cross sectional part is described by standard quadratic deep shell elements, for the belt and sidewalls, and bi-quadratic solid elements for the tread. The circumferential part is described with an exponential Fourier series and harmonic time dependence is assumed. This ansatz is inserted into the variational statement that describes the tyre motion and upon standard FE procedures a matrix equation for the harmonic motion follows [3]. One advantage with this direct methodology in the frequency domain is that it is uncomplicated to handle fluid-structure interactions [2] and also any frequency dependant material data.

## Viscoelastic Modelling

The two-dimensional FE mesh employed is shown in Fig. 2; it is equivalent to a standard FE model engaging some 180.000 degrees of freedom. The geometry and static

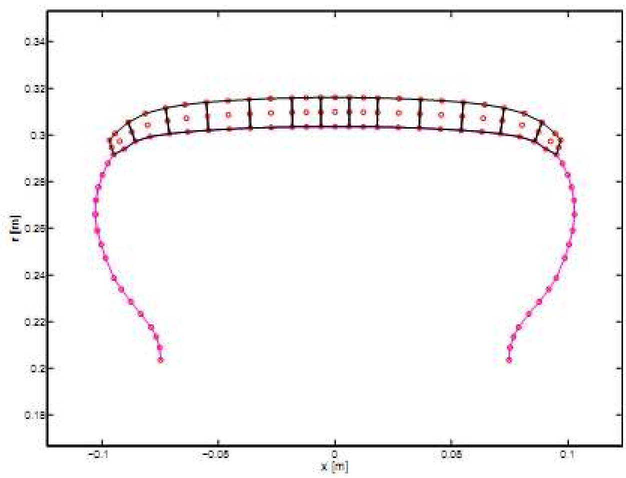


Figure 2: Medium mesh.

stiffness is given by a tyre manufacturer, however, the rubber in the tyre is highly damped and the viscoelastic properties are needed too. For structure borne sound applications a frequency independent loss factor, is widely used. This model is, however, physically unrealistic since it leads to non-casual behaviour. The standard linear model, where the response depends on a convolution between the response history and relaxation functions, first introduced by Boltzman [4], is causal, however, many relaxation functions, and therefore many unknown parameters, are needed. The fractional derivative model [5] is more efficient and is used here. Thus, as an example, the shear modulus is given by

$$G(\omega) = G_0\left(1 + (\mathrm{i}\omega/\omega_0)^{\alpha}\right), \qquad (1)$$

where $G_0$ is static shear modulus, $\omega$ is frequency and $\omega_0$ and $\alpha$ are parameters. The shear modulus of samples cut from the tyre tread were measured and the resulting shear modulus and loss factor are shown in the figures below.

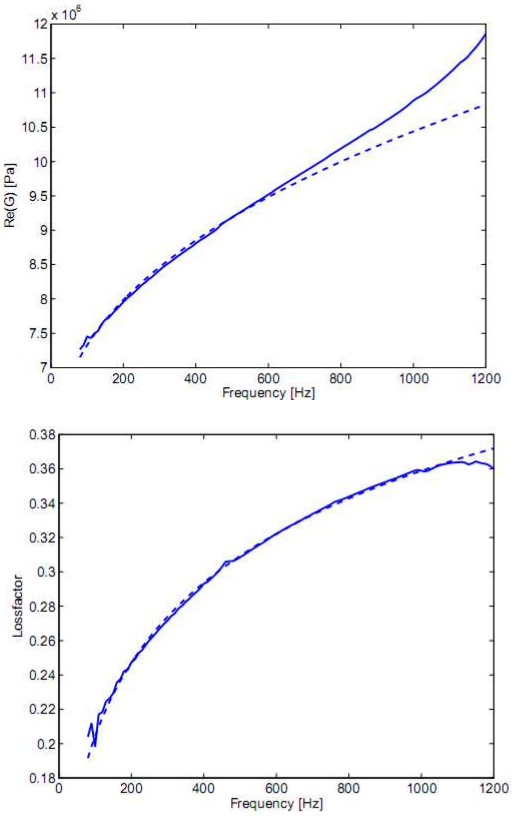


Fig. 3 Measured (solid) and estimated with Eq. (1) (dashed) dynamic shear modulus (top) and loss factor (bottom)

The deep shell elements that describe the belt and sidewalls are defined by 23 distinct stiffness parameters and clearly it is not possible to identify so many frequency dependant lossfactors. Instead, each shell element is described by an equivalent structure made up of rubber embedded steel wires, sandwiched between two solid layers of rubber, as in reference [43]. The equivalent structure's stiffness depends on a number of geometrical parameters: layer thicknesses, angle of wires and steel to rubber volume ratios, see Fig 4. It also depends on rubber's shear modulus while the properties of the steel wires are known. The equivalent structure is first determined for the static case based on the given static stiffness matrix. The parameters $\omega_0$ and $\alpha$ are then defined by inverse procedures applied to measured frequencies and modal loss determined for a sample cut out of the belt and a modal analysis for the complete tyre [1].

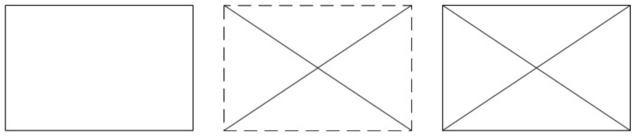

Fig. 8. Components in equivalent structure. Left, rubber; middle, steel wires; right, sum of components.

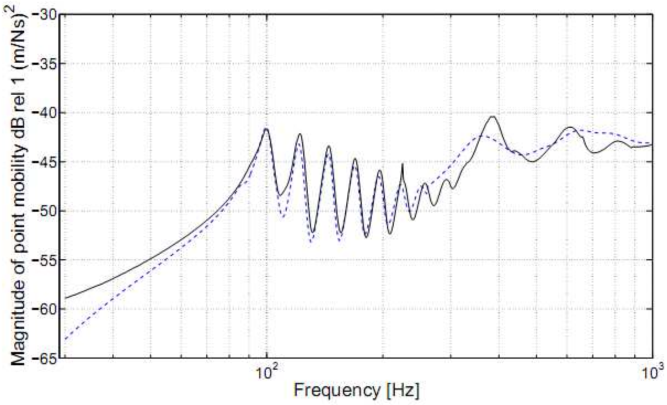


Fig. 5. Measured (solid) and calculated (dashed) point mobility.

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