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Determination of rolling tyre modal parameters using Finite Element techniques and Operational Modal Analysis

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ABSTRACT

In order to address various noise generation mechanisms and noise propagation phenomena of a tyre, it is necessary to study the tyre dynamic behaviour in terms of modal parameters. This paper enumerates a novel method of finding the modal parameters of a rolling tyre using an Explicit Finite Element Analysis and Operational Modal Analysis (OMA). ABAQUS Explicit, a commercial Finite Element (FE) software code has been used to simulate the experiment, a tyre rolling over a semi-circular straight and inclined cleat. The acceleration responses obtained from these simulations are used as input to the OMA. LMS test lab has been used for carrying out the Operational Modal Analysis. The modal results are compared with the published results of Kindt [22] and validated. Also, the modal results obtained from OMA are compared with FE modal results of stationary unloaded tyre, stationary loaded tyre and Steady State Transport rolling tyre.

1. Introduction

Tyre noise is an important source in automotive NVH. The mechanism of noise generation, experimental procedure and theoretical underpinning are well documented [1]. Tyre/road noise generation, amplification and reduction phenomena are basically divided into two groups: vibrational and aerodynamical [1]. When a tyre is excited at the treadband, structural waves such as bending waves, shear waves and longitudinal waves propagate along the circumference. The frequencies of these waves are below 3000 Hz [2,3]. The tyre dynamic behaviour is determined by the propagation and interaction characteristics of these structural waves in the tyre. Though various noise generation mechanisms and their propagation phenomena are well addressed in the literature, the relative importance of these mechanisms under different operating conditions are not yet fully understood [1]. Tyre/road interaction is the main source for tyre vibrations. Modal frequencies, damping and mode shapes describe the dynamic behaviour of a tyre and form the basis for one of the important mechanisms of noise generation. Hence, there is a need to understand and evaluate the mode shapes of a rolling tyre.

Traditionally, these quantities are found from Experimental Modal Analysis (EMA) and/or FE analysis of a non-rolling tyre with the basic assumption of system linearity and reciprocity, obtained from the estimation of Frequency Response Functions (FRFs) for the known dynamic excitation force. But, for a rolling tyre, it is difficult to measure the excitation force at the tyre road interface. Hence, Operational Modal Analysis (OMA) is preferred, as this technique does not require input excitation force. Operational Modal Analysis makes use of the crosspower sum of the output responses with a suitable reference, for modal parameter extraction [4].

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Zegelaar [5] showed that the modes of vibration of a tyre strongly depend on tyre construction, rotational velocity, spindle boundary conditions and contact patch boundary conditions. Yam et al. [6] have obtained three dimensional mode shapes (radial, tangential and lateral directional modal parameters) of a tyre using EMA. Lauwagie et al. [7] have done a comparative study of modal parameter extraction procedure viz., OMA and EMA, either individually or in combination, in a small hydraulic crane modal analysis study.

The modal results of transient vibration of rolling tyre make significant contributions to tyre/road interaction noise prediction. Tyre modal data are used directly in Boundary Element Method and Infinite Element Method based tyre models. Nakajima et al. [8] have used the tyre modal results to define the surface vibration boundary conditions in order to predict air borne noise fields. Constant et al. [9] have studied the vibro-acoustic interaction between tyre and car subsystems and have identified the main suspension parts affecting the structure borne interior noise. Operational deflection shapes of tyre wheel subsystem were used by Kido and Ueyama [10] to quantify the force transmitted through suspension sub-system to the vehicle body; further they addressed the structure borne interior noise of the vehicle.

Several techniques have been developed by researchers to measure rotating tyre vibrations. Burroughs and Dugan [11] used embedded accelerometers, which were placed into the tread block to measure the tyre vibration responses, as it rotates through the contact patch. Though this technique gave good results, the embedded accelerometer frequently failed due to high stress in the contact patch zone. Contrary to the direct measurement techniques, contactless measurement technique was used by Kindt et al. [12,13] to measure the rotating tyre vibration. They used Laser Doppler Vibrometer to measure the vibration velocity normal to the rotating tyre surface. The spindle forces and moments were measured by multi-axial wheel hub dynamometer with an inbuilt encoder and a circular cleat in a tyre-on-tyre arrangement, to have an equivalent scenario of tyre rolling over straight road with straight semi-circular cleat.

Narasimha Rao et al. [14] have used a FE tyre model based on a hyperelastic material that included all the reinforcements, to study cornering, braking and cornering cum braking dynamic behaviour of tyre. This approach is adapted to develop a FE model of tyre for the current research work of structure borne interior and exterior tyre/road interaction noise.

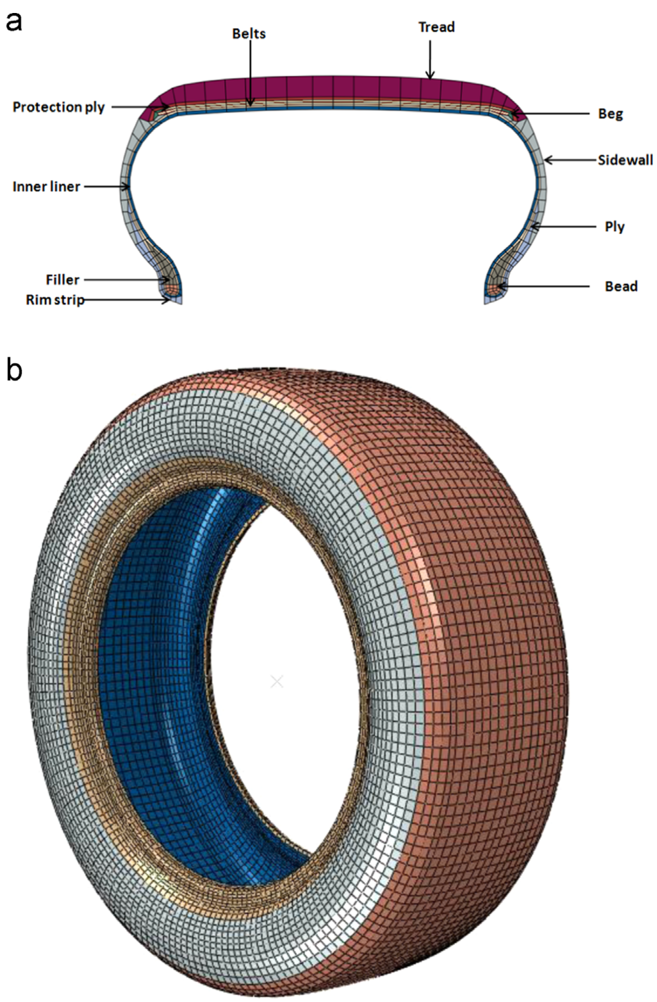

Fig. 1. (a) Section details of 205/55R16 radial passenger car tyre and (b) tyre FE model.

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