Modal Analysis of a Small Smooth Kart Tire — Numerical and Experimental Determination

Chukwuemeke William Isaac
University of Ibadan, Mechanical Engineering Department, Ibadan, Nigeria.

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The modal analysis of a kart tire was performed using the Abaqus/explicit finite element numerical software and the results obtained were validated by experimental testing. Frequency response functions, damping ratios, and modal shapes are the driving parameters for analysis. The investigation shows a very useful modal response of the kart tire such that a high frequency response function of approximately 301 Hz to 630 Hz was obtained for both the finite element solutions and experimental results. These results are much higher than that of the conventional tires therefore making it an excellent tire-type material that can be used for further analysis and study of tire-road contact problems, air-pumping, and noise radiation.

1. INTRODUCTION

A major source of noise generated from tire-road interaction has been attributed to vibration of air molecules inside the tire cavity. The vibration and dynamic response of tires have been investigated by a number of researchers by adopting both numerical and experiment methods. A numerical approach such as the finite element method (FEM) has proved to be an efficient modelling tool that is employed by researchers to overcome some of the inherent difficulties such as the complexity in the tire geometry and the material properties for which the modelling of tires by analytical methods remain intractable. Different authors have carried out finite element (FE) simulations and analyses to predict the dynamic response of tires. Also, the finite element approach was performed by Chatterjee and Ranjan to analyse the free vibration of radial pneumatic tires. The authors obtained the natural frequencies and mode shapes of tires. They also investigated the effects of some parameters such as the inflation pressure and tread patterns on the natural frequency of tires. In their findings, it was observed that an increase in inflation pressure resulted in an increase in both stiffness of the tire and its natural frequencies at some optimum values. Also, for lower modes, the natural frequencies did not vary significantly with smooth tires or patterned tires, but with higher modes, the natural frequencies for patterned tire increased significantly more than smooth tires. They concluded that the increase in the ply-angle and variation of belt thickness had no significant effect on the natural frequencies of the tires. The dynamics of rolling tires can also be described by an Arbitrary Lagrangian Eulerian (ALE) formulation. Brinkmeier et al. investigated the analysis of tire-road noise using the FEM. In their investigation, the non-linear stationary rolling case was described by an ALE formulation. The deformation of the motion into rigid body motion was described in an Eulerian manner whereas the large deformation was measured with respect to the intermediate reference in Lagrangian coordinates. The vibration of a tire model can also be analysed by the wave finite element method (WFEM). This approach has the advantage of modelling vibration at higher frequencies for which the classical FE model becomes impractically large. Yoshiyuki et al. applied this method to model the vibration of a tire using ANSYS by taking the material properties of the rubber as frequency dependent and the wave propagation characteristics were extracted from the dynamics stiffness matrix of the FE model. They determined the free and forced vibration of the tire and concluded that the WFEM is a powerful tool used for predicting the dynamic behaviour of a complex structure.

Modal analysis has been used to estimate tire parameters especially in the orthotropic plate model of the tire. Pèrissé and Hamet analytically modelled a radial tire vibration by comparing a 2D ring and 3D orthotropic plate for low and high frequency ranges. They derived the natural frequencies and mode shapes from the ring and plate theory. In their findings, the 2D ring model was valid at low and medium frequency range, i.e., 400 Hz, while the 3D plate model was valid over the whole frequency range, i.e., 0 to 2000 Hz and at higher frequencies. When the wavelength \( \lambda \) approximates the tread width \( l \) of the tire, i.e., \( \lambda \approx l \), the tire becomes a two-dimensional waveguide and the plate model has to be used. Modelling of tire-road interaction can be determined by evaluating the time response, also known as the Green’s Function of the tire, to a concentrated external force. The response of a tire to a contact force is mostly determined in the time domain because of the non-linearity of the contact problem. Lopez et al. determined the response of a rotating tire in a fixed reference frame using the Green’s Function. The authors found out that the Green’s Function for a rotational velocity 0 to 100 rad/s differs considerably both in frequency and amplitude. The frequency shift was correctly captured in the derived Green’s Function while the amplitude decreases due to rotational velocity caused by the increase of damping due to rotation. The effect of rotation on the dynamic behaviour of a rolling tire is also very crucial when modelling tire-road noise caused by vibration. Lopez et al. modelled vibrations on a deformed rolling tire at low frequencies and determined the eigenvalues and eigenmodes. The response of the rotating tire in a fixed reference frame and the gyroscopic and centrifugal effect were calculated. The authors also examined the deformation on the eigenfrequencies of a rotating tire. Their results showed that the eigenfrequencies of a deformed tire decreases rapidly with increase in velocity while for an undeformed tire, no modal reaction due to rotation was observed. Modal interactions increase as the load on the tires increases and decrease as the material damping increases. The characteristics of a rotating tire can also be predicted by determining the natural frequencies and their wave-like basis functions. Kim and Bolton modelled the treadband of an inflated, rotating circular cylindrical shell...