Vibration Characteristics of Rolling Tires

Summary
Tires are the only load transfer mechanism between a vehicle's suspension and the road. Consequently, tire vibration has a significant impact on ride quality and vehicle interior noise.

To accurately predict the frequencies and mode shapes of a rolling tire, Abaqus allows pre-loading and gyroscopic effects to be included in a complex frequency extraction. These effects can also be included in a forced response analysis of the rolling tire to predict the spindle forces contributing to vehicle noise and vibration.

In this Technology Brief, we outline the analysis methodology for determining the vibration characteristics of stationary and steadily rolling tires.

Background
The small amplitude vibrations of a tire on the road can be considered to be the linear superposition of small amplitude steady state vibrations onto a highly non-linear base state.

For stationary tires, the base state is the footprint configuration and contains the nonlinear effects arising from the contact between the tire and the road, the load-deflection behavior of the rubber compounds, and the reinforcement behavior. For steady rolling tires, the base state additionally includes gyroscopic effects.

It is common practice to employ a mixed Eulerian-Lagrangian scheme to compute the steady-state rolling base configuration of the tire. This methodology uses a reference frame that is attached to the axle of the tire but does not rotate with the tire; thus, the material of the tire is rotating through this reference frame. An observer in this frame sees the tire as points that are not moving, although the material constituting the tire is moving through those points.

The rotational velocity of a rolling tire causes its vibration characteristics to be considerably different from those of a stationary tire. To an observer in the aforementioned reference frame, the modes of a stationary tire appear as standing vibrations while the modes of a rolling tire appear as waves traveling in the circumferential direction. Some of these modes share the sense of the tire's rotation, while others rotate in the opposite sense. As the rotational velocity of the tire increases, the modes with the same sense of rotation as the tire increase in frequency while the modes with the opposite sense of rotation decrease in frequency. The bifurcation in frequency arises from the gyroscopic effects.

Finite Element Analysis Approach
The tire model under consideration is shown in Figure 1. The tire is shown in a sectional view and is representative of a passenger car tire. The rim and road are modeled as analytical rigid surfaces. Contact is defined between these surfaces and the tire. A simple Mooney-Rivlin law is used to model the strain energy potential of the rubber materials. The viscoelastic nature of rubber is ignored in this simulation. A small amount of material damping is applied to the rubber in the form of Rayleigh damping. The plies and belts are modeled using rebar layers that are embedded in the surrounding rubber matrix. Linear