TIRE-DYN

Experimental and Numerical Analyses of the Dynamic Behavior of Rolling Tires in order to Improve the Tire Modeling Accuracy

SEVENTH FRAMEWORK PROGRAMME — MARIE CURIE ACTIONS — GOODYEAR

Experimental and numerical characterization of the dynamic behavior of a rolling tire.

Stijn Vercammen[1] and Cristóbal G Díaz[2]

Goodyear Innovation Center Luxembourg

E-mail: 1. stijn_vercammen@goodyear.com, 2. cristobalgdiaz@yahoo.es

Introduction:

Noise resulting from road traffic has a severe impact on the environmental quality in urban areas all over the world. The noise generation from rolling tires is the most dominant source of vehicle noise for driving speeds above approximately 40 km/h for passenger cars.

Although tire/road noise and tire vibration phenomena have been studied for decades, there are still some missing links in the process of accurately predicting and controlling the overall tire/road noise and vibration. An important missing link is represented by the effect of rolling on the dynamic behavior of a tire. Consequently, inside the European seventh framework program, an industry-academia partnership project, named TIRE-DYN, has been founded. By means of experimental and numerical analyses, the effects of rolling on the tire dynamic behavior are quantified.

Modal parameters of the rolling tire are estimated from an operational modal analysis. In addition, the dispersion curves, which give detailed insight in the wave propagation behavior of a structure, are analyzed for the rolling tire.

The goal of these analyses is to deepen the understanding on the influence of rolling on the tire dynamic behavior.

Theoretical concepts:

Figure 1 shows the fundamental theoretical concepts to understand and characterize the dynamic behavior of a static tire. This theory forms the basis for the understanding of loaded, rotating tires under different operating conditions.

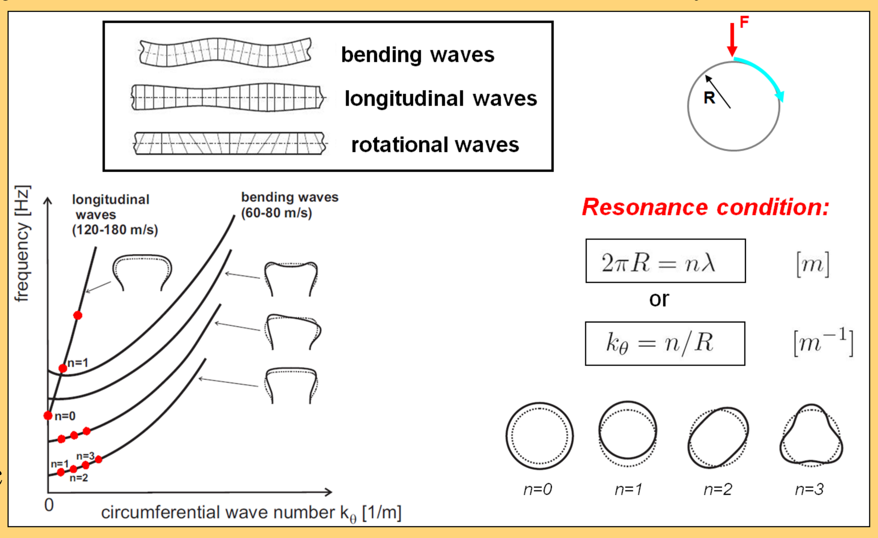

Figure 1: Theoretical concepts.

Approach and methodology:

The overall objective to obtain more accurate structural tire models through a better understanding of the influence of rolling translates into specific technical and scientific objectives:

- WP1: Development of an industrially applicable experimental method to characterize the dynamic behavior of rolling tires.
- WP2: Development of a detailed, validated tire model to predict the complex eigenmodes of a stationary rolling tire.
- WP3: Identification of the physical phenomena involved in the complex dynamic behavior of rolling tires.
- WP4: Implementation of the effects of rolling in more simplified existing structural tire models

Figure 2 represents the corresponding approach and methodology.

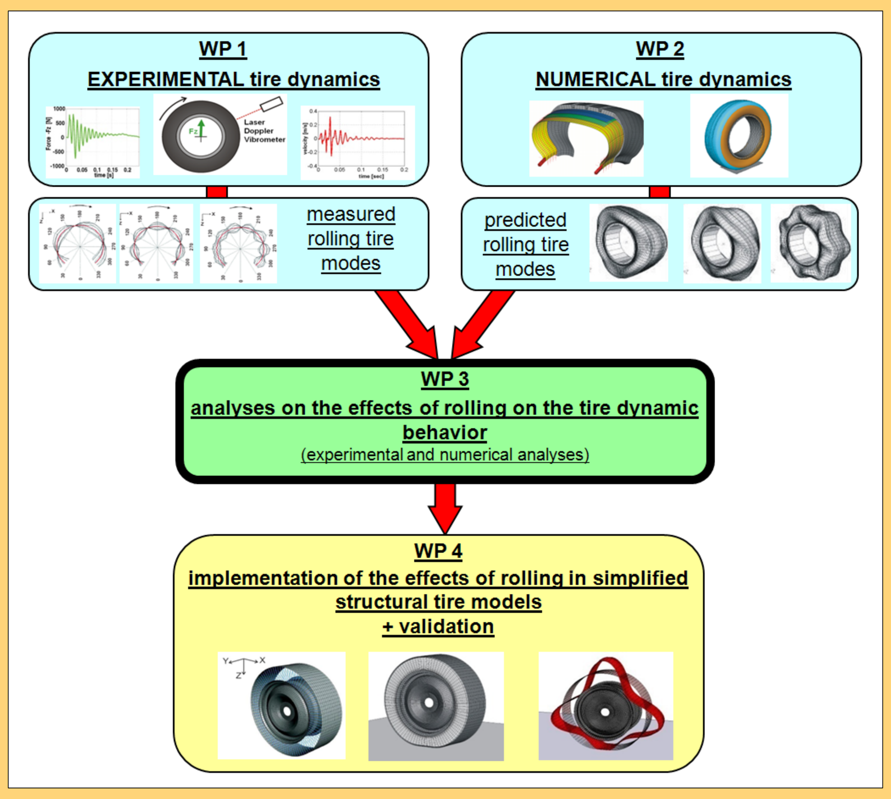

Figure 2: Approach and methodology of TIRE-DYN project.

WP1: Experimental characterization [1]:

Objectives:

1. Development of an industrially applicable experimental method to characterize the dynamic behavior of rolling tires.
2. Experimental characterization of rolling tire dynamic behavior.

Results:

This section describes the experimental characterization of the dynamic behavior of a tire in loaded and rolling conditions by means of accelerometer measurements. The tire is rolling on a steel drum and excited by a metal strip attached to the drum, called a cleat. The tire structural response is obtained from an accelerometer mounted at the center of the inner liner of the tire. The accelerometer is uniaxial, therefore only radial vibrations are measured.

The modes are identified by means of an Operational Modal Analysis. The polyreference least squares complex exponential method is applied to auto- and cross-correlation functions. Figure 3shows the identified mode shapes of a tire where as Table 1 represents the corresponding natural frequencies and modal damping.

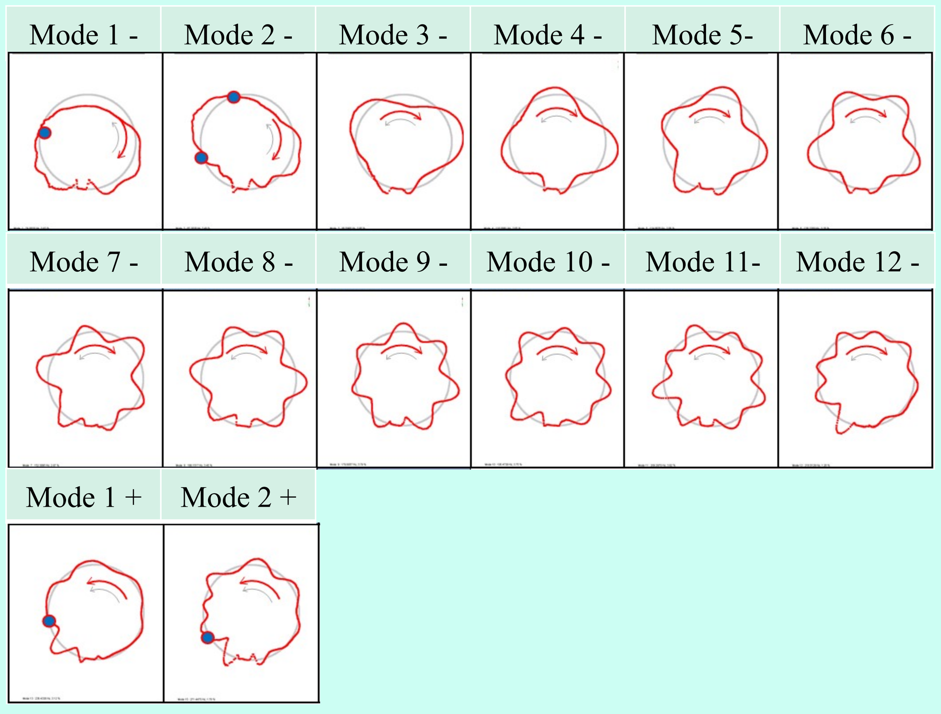

***Figure 3:* Identified mode shapes of a tire at the following conditions: 60 km/h, cleat 3x25 mm, 4000 N, 2.2 bar.**

Mode	f_{nat} [Hz]	ξ [%]
Mode 1 -	73.5	4.98%
Mode 2 -	87.4	3.75%
Mode 3 -	99.3	3.96%
Mode 4 -	111.7	3.42%
Mode 5 -	124.8	3.48%
Mode 6 -	138.2	3.28%
Mode 7 -	152.4	2.92%
Mode 8 -	166.2	3.45%
Mode 9 -	179.8	3.79%
Mode 10 -	195.5	3.75%
Mode 11 -	209.3	3.78%
Mode 12 -	218.5	1.28%
Mode 1 +	236.4	3.14%
Mode 2 +	271.6	1.82%

***Table 1:* Natural frequencies (fnat) and modal damping (ξ) of the identified modes.**

The analysis is done for different operating conditions. Figure 4 shows dispersion graphs for speeds 40, 60 & 80 km/h and figure 5 gives a graphical representation. Figure 6 compares the identified mode shapes at different speeds.

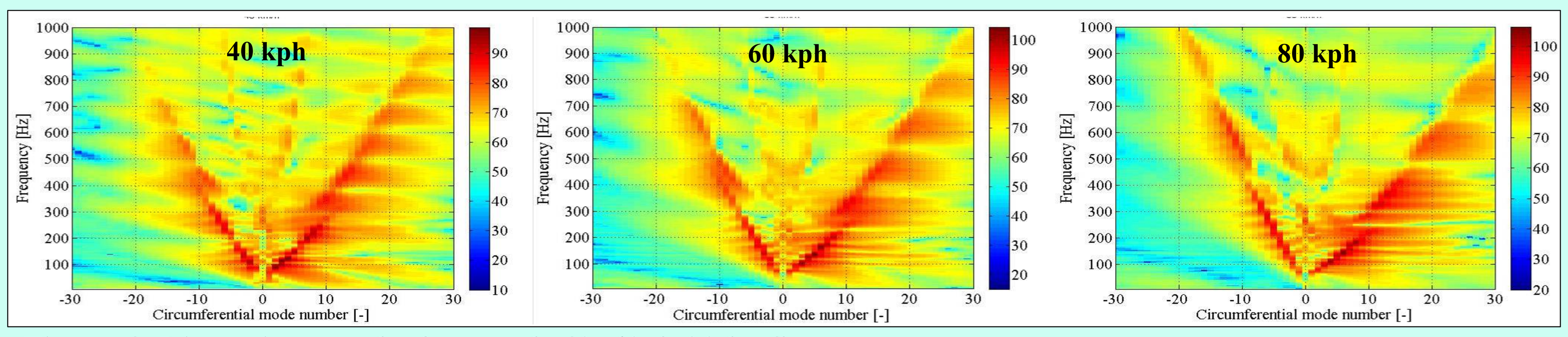

Figure 4: Dispersion graphs for speeds 40, 60 & 80 km/h.

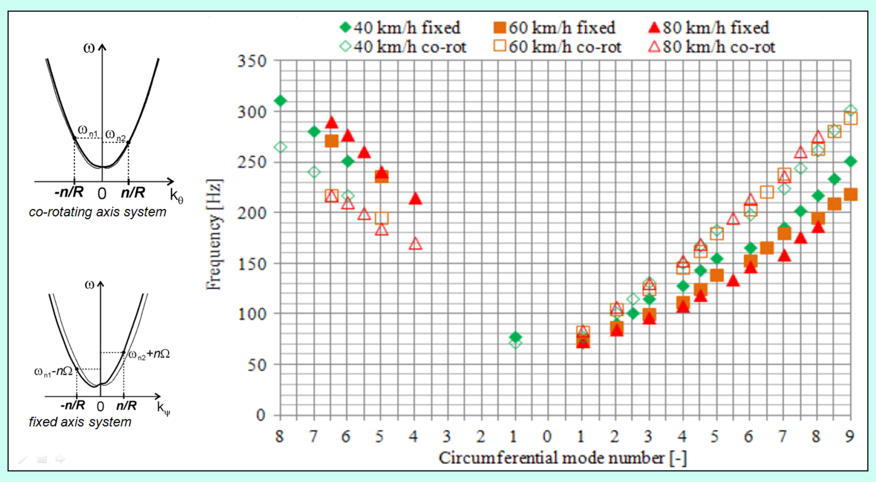

***Figure 5:* Graphical representation of the natural frequencies of the [n,0] modes for speeds 40, 60 & 80 km/h, in a fixed and co-rotating axis system.**

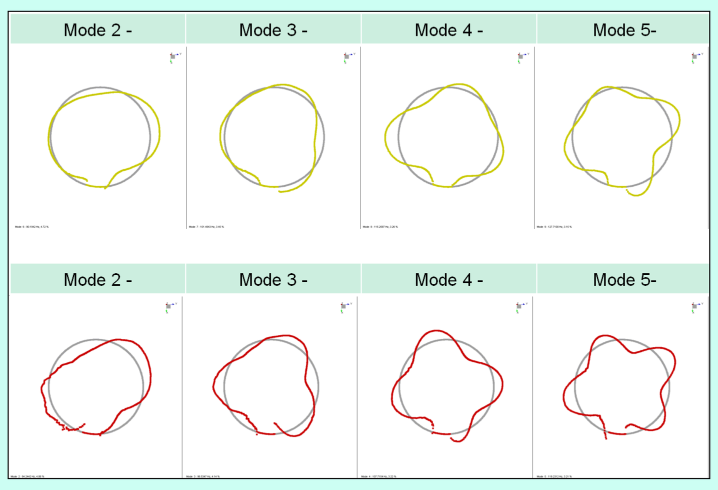

***Figure 6:* Comparison of first mode shapes for speeds 40 (yellow) & 80 km/h (red), in a fixed and co-rotating axis system.**

WP2: Numerical prediction [2]:

Objectives:

1. Development of an experimentally validated tire model for the non-rolling, loaded condition.
2. Numerical prediction of the complex eigenmodes of a stationary rolling tire under different operating conditions.

Results:

This section presents a numerical analysis that provides more understanding of the types of waves that propagate in an unloaded (not in contact with the ground) and loaded (4000 N) tyre of size 205/55R16. Results are shown for the non-rotating and rotating tyre at different speeds for both cases; unloaded and loaded tyre.

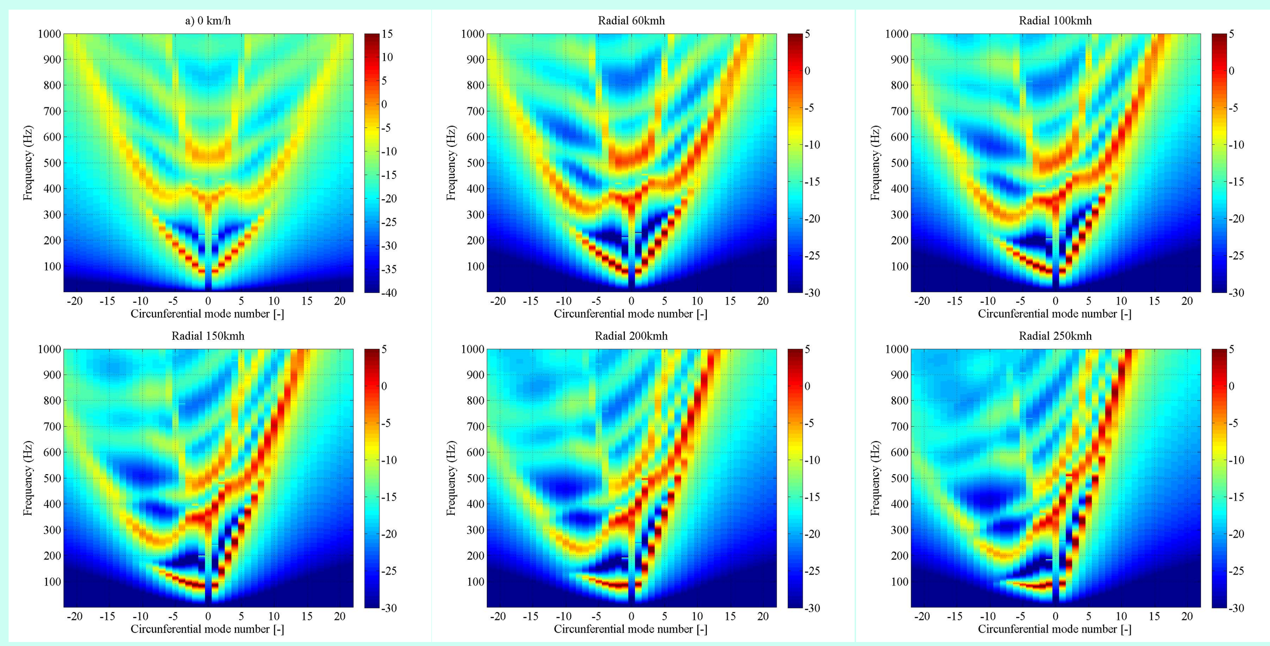

***Figure 7:* Frequency-wavenumber plots(dB) for different speeds (0km/h, 60km/h, 100km/h, 150km/h, 200km/h, 250km/h). Unloaded tyre. Positive wavenumbers correspond to waves travelling in the tyre rotation direction and negative wavenumbers to waves travelling in the direction opposite to the tyre rotation.**

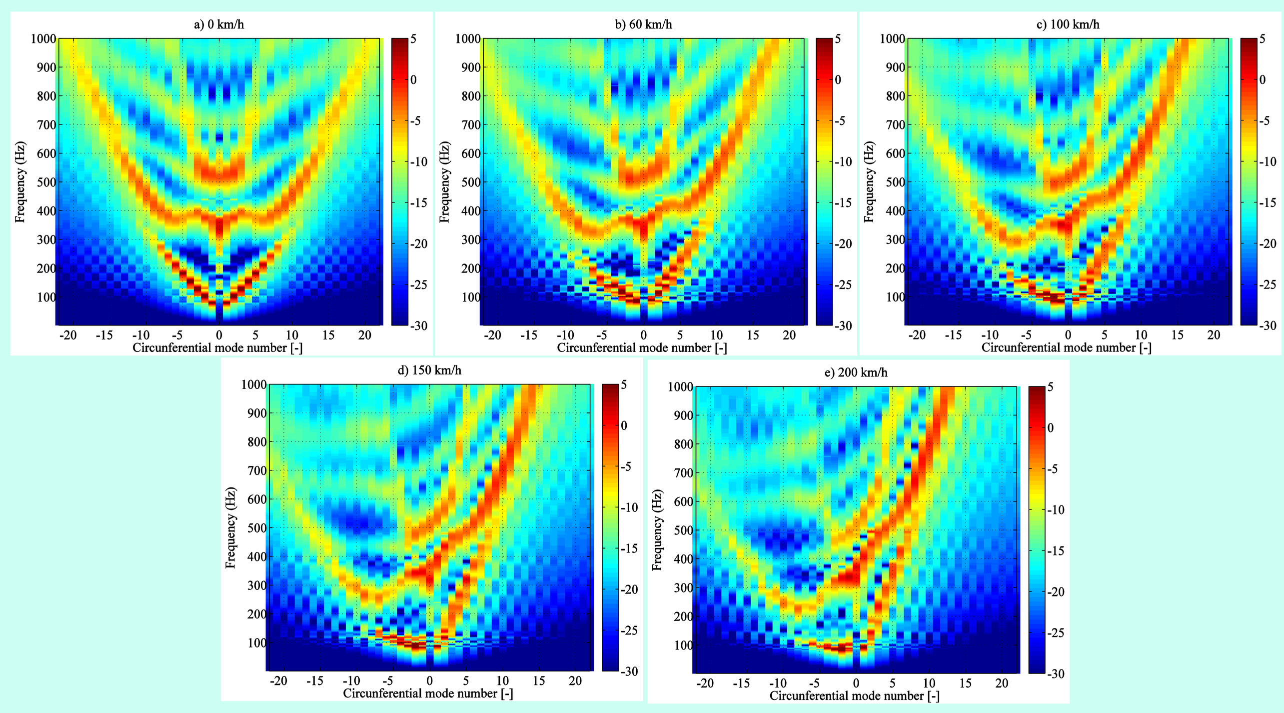

***Figure 8:* Frequency-wavenumber plots (dB) for different speeds (0km/h, 60km/h, 100km/h, 150km/h, 200km/h) Loaded tyre (4000 N). Positive wavenumbers correspond to waves travelling in the tyre rotation direction and negative wavenumbers to waves travelling in the direction opposite to the tyre rotation. Solid arrow indicates the tyre rotation direction while the fine arrow indicates the direction of the travelling wave.**

Conclusions:

- Experimental analyses show that a rotating tire is subjected to Coriolis accelerations which make the wave speed of the positive- and negative-going wave to diverge from each other.
- This leads to complex or travelling wave mode shapes. While for a non-rotating tire the mode shapes are real or standing waves.
- The modes associated with a positive and negative going wave with the same wavenumber, appear at a different frequency. This frequency difference increases with increasing rotation speed.
- The experimental results show how the footprint contact for the loaded tire acts as a boundary condition for the structural waves and thus influences the dynamic behavior of the rolling tire.

Acknowledgements:

The research leading to these results has received funding from the EU Seventh Framework Programma (FP7/2010) under grant agreement no 251211.

References:

1. Vercammen, S.,Gonzalez Diaz, C., Kindt, P., Middelberg, J., Leyssens, J. (2012). Experimental characterization of the dynamic behaviour of rolling tires. . ISMA. Leuven, 17-19 September 2012.
2. Gonzalez Diaz, C., Vercammen, S., Kindt, P., Middelberg, J., Thiry, C., Leyssens, J. (2012). Numerical prediction of the dynamic behaviour of rolling tires. . ISMA. Leuven, 17-19 September 2012.