PASSIVE VIBRATION CONTROL OF TYRES USING EMBEDDED MECHANICAL RESONATORS

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ABSTRACT

An investigation is carried out on structure-borne vibration and noise propagation of tyres' models at low frequencies. The idea is to use embedded resonant meta-materials to damp the tyres' vibrations and thus reduce the transferred energy to the main attached structures. A simplified tyre model is used, being the investigation of the effects of the embedded substructures the main target of the work; internal pressure and tyre rotation effects are neglected at this stage. Different configurations are tested targeting different natural modes of the tyre, while mechanical excitation is assumed on one section of the tyres. The results show how the proposed designs are a feasible solution for vibration control.

1 INTRODUCTION

Tyre noise and vibrations are becoming some key comfort parameters in the automotive industry, even before 40 km/h [1, 2], because of the advent of hybrid and electric power-units [3]. In fact, the broadband noise distribution coming from an ICE (Internal Combustion Engine) is replaced by a generally high-frequency tonal whistling, which allows other noise sources, as tyre/road noise, to become dominant in other frequency ranges. Among these, the tyre noise, is dominant both in terms of structure-borne and air-borne propagations, respectively before and after 500Hz [4–6]. The structure-borne contributions derive mainly from the first natural modes of the tyre while the air-bone ones are mainly due to higher frequency circumferential modes of the tyre [6–9]. Modelling techniques based on finite elements (FEM) are often limited to low frequencies due to a high computational cost [6, 7]; wave-based approaches are also efficient to investigate the wave propagation in the tyre [10].

2 PROPOSED DESIGN

To investigate the effect of embedded resonant substructures on tyre vibrations, the configuration in Fig. 1b is proposed.

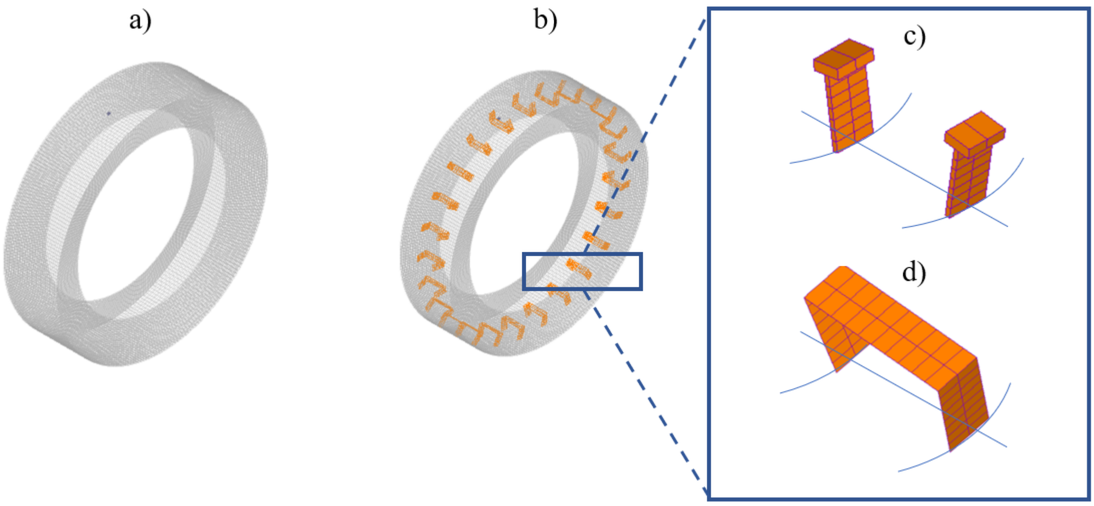

Figure 1: Simplified tyre model with shell elements. Tyre Configuration: a) Bare; b) Resonant. Target: c) Transversal Vibrations; d) Radial Vibrations.

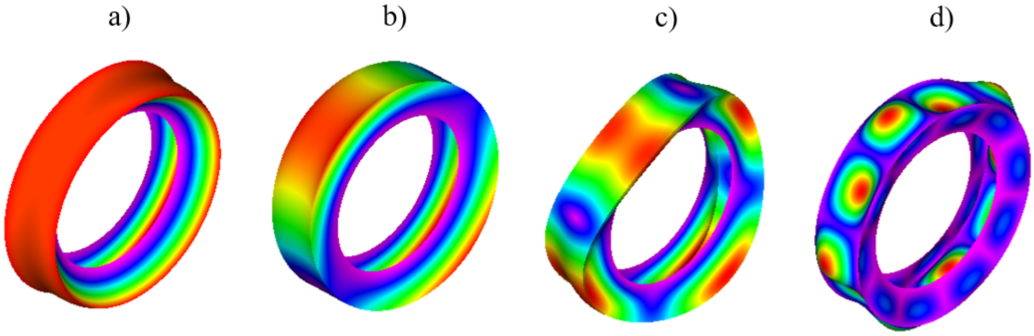

Figure 2: First four modes of the bare tyre. Transversal Modes: a) 243.6 Hz; b) 338.5 Hz; c) 610.6 Hz. Radial Mode: d) 702.4 Hz.

First, it is fundamental to know the frequencies or frequency bands to target with the embedded substructures. The transversal modes appear in lower band with respect to the mainly radial ones and thus the resonant configurations will be tuned depending on the needs. A modal analysis is conducted on the bare tyre configuration using NX NASTRAN shell elements (CQUAD4) and using more than 20 elements per wavelength at 2KHz. The first four modes of the structure at illustrated in Fig. 2. The material properties used are: E = 19.8 GPa, ν = 0.32 and ρ = 1850 Kg/m^3.

The targets of this work will be the first two modes in Fig. 2, for the transversal vibrations, and the fourth mode (and higher orders) in Fig. 2, for the radial vibrations. For this reason, when targeting the transversal motion of the tyre, the concept in Fig. 1c is used, while the one in Fig. 1d is employed when the radial motion of the tyre is targeted too. In the case of Fig. 1c, the first vibration modes of the embedded beams, which are classic cantilever-beam modes, are in the same direction of the transversal tyre motion. In the case of Fig. 1d, the resonator behanves as a bridge structure with two main vibration modes in the transversal direction (cantilever-beam modes of the pylon) and radial direction (simply-supported beam mode of the deck). The idea is to create resonance-induced band-gaps around the targeted tyre modes, in order to control vibrations in that region.

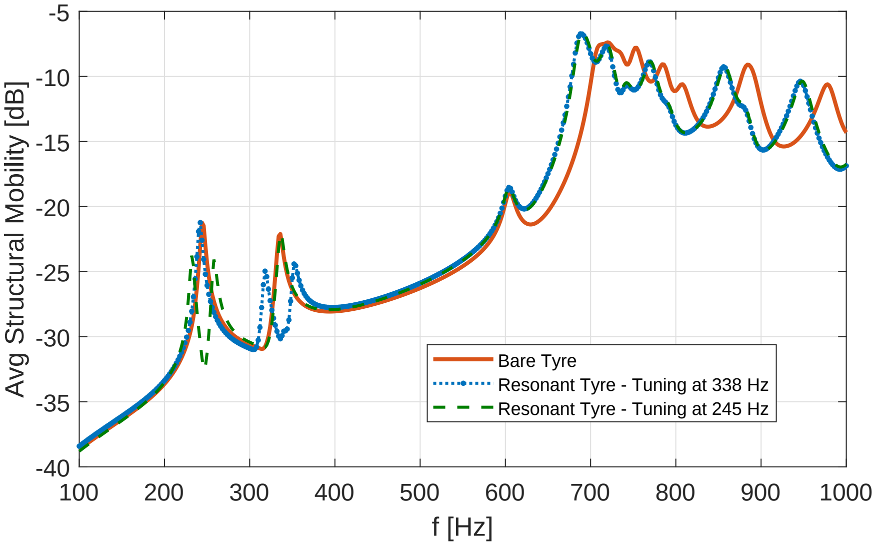

Figure 3: Average structural mobility of the tyre with and w/o mechanical resonators for transversal vibration control.

2.1 Force vibrations of resonant configurations

A set of forces normal to the tyres' plane, in order to simulate a mechanical road input, are used as white noise load. The response of the tyre is numerically calculated in a set of ten random point around the tyre and plotted in Figs. 3 and 4. Only structural damping is considered and the effect of pressure and tyre rotation is neglected.

In Fig. 3, the resonant configuration illustrated in Fig. 2c is tuned once on the first and once on the second transversal mode of the tyre. Two circumferential rows of 10 resonant elements are considered in both cases. The results show how the modal peaks in the response are strongly reduced, even if anti-resonances of the beams appear close to the modal frequencies, increasing the vibrations compared to the bare configuration. The effects, for both tuning conditions, are identical. No coupling between the tyre and the beam motion is observed and the resonators behave as classic TVAs (Tuned Vibration Absorbers) with avery narrow band effect.

In Fig. 4, the resonant configuration illustrated in Fig. 2d is tuned on the first purely radial mode of the tyre at $\approx$ 703 Hz and targets also the transversal vibration of the tyre at $\approx$ 330 Hz. A single circumferential row of 25 and then 5 resonant elements are considered, with added masses of $\approx 20\%$ and $\approx 3\%$ respectively. The average vibrations of the tyre in Fig. 4 show some main effects. First, the appearance of band-gaps around the targeted frequency bands with the second transversal mode of the tyre ($\approx$ 330 Hz) always well damped. In the configuration with five circumferential resonators, the band-gap opens also around the 600-750 Hz band, allowing a decrease of vibration levels of 15dBs. On the other hand, the same effect is not achieved when more resonators are added, since a strong coupling with the tyre dynamics is present, probably given by the excessive added mass. For this reason, there is a frequency shift to lower frequencies and vibrations are increased in the 400-500 Hz frequency band.

3 CONCLUDING REMARKS

The effects of embedded mechanical resonators in a tyre compound is analysed in terms of forced vibrations on a simplified tyre model. Two main configurations are analysed in order to target two main regions of tyre dynamics, strongly related to the structure-borne and air-borne issues respectively. Numerical simulations are carried out using a FEM approach and average vibrations on random tyre points are computed. The resonant substructures are observed to be very efficient when targeting the transversal motion of the tyre, while higher order coupling between the resonators and the tyre dynamics appears when targeting radial vibrations. The latter effect can be investigated with a detailed modelling of the tyre.

Further investigations could target the efficiency of the resonant configurations as a function of the resonators' shape and added mass.

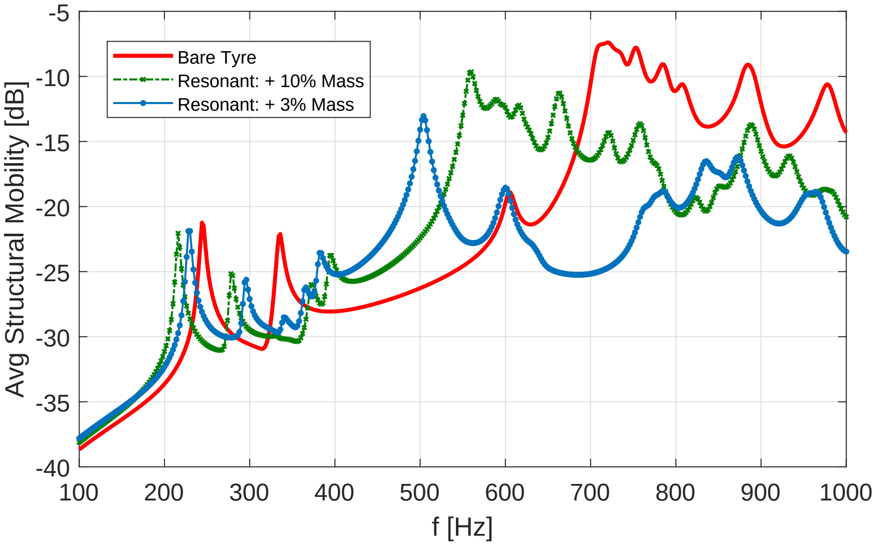

Figure 4: Average structural mobility of the tyre with and w/o mechanical resonators for radial vibration control.

Acknowledgments

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