Mechanical Systems and Signal Processing 50-51 (2015) 498–509

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

A study of tyre cavity resonance and noise reduction using inner trim

Zamri Mohamed [a,b], Xu Wang [a,*]

[a] School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University, Bundoora East, Vic 3083, Australia
[b] Faculty of Mechanical Engineering, Universiti Malaysia Pahang, Pekan, Malaysia

ARTICLE INFO

Article history:
Received 30 September 2013
Received in revised form
15 May 2014
Accepted 30 May 2014
Available online 28 June 2014

Keywords:
Tyre cavity
Resonance
Trim

ABSTRACT

A study of tyre inner trim as a method for reducing tyre cavity resonance noise is presented. The tyre is modelled as a rectangular toroid where only the outside shell is flexible. A modal series solution of the sound pressure frequency response inside the tyre cavity is derived from the wave equation using modal superposition. In the solution with the rigid and flexible wall boundary condition, the effect of placing a trim layer onto the inner surface of the tyre tread plate wall is reflected by adding a damping loss term in the sound pressure frequency response function. The numerical simulation result was then compared with the result obtained from a roving impact test performed on a tyre. The results show that selective trim material may be effective for reducing the structure-borne noise magnitude resulting from the tyre cavity resonance.

1. Introduction

The vibration transmitted from the excitation sources of tyre/road interaction and powertrain into vehicle cabin through the vehicle structure reside below 500 Hz frequency range. In comparison to the many noise sources, the tyre cavity resonance has been identified as a tonal noise that can be clearly heard inside the vehicle cabin which contributes to the increased level of annoyance. Physically, the tyre cavity resonance is a phenomenon generated by the standing wave occurring inside tyre cavity as a result of tyre tread/road excitation. The main adverse effect is the transmission of vibration to the wheel hub which then propagates into the passenger cabin. Several authors have investigated the phenomenon by theory, simulation, and experiment [1–11] since it was first reported by Sakata [12] (for a more comprehensive review, please read Mohamed [13]).

One of the significant findings on tyre cavity resonance includes the work conducted by Yamauchi et al. [5] where they proposed a change in tyre wheel shape that proved to be effective in eliminating the resonance peaks. In other study, Molisani [6] presented a deeper understanding of how the tyre cavity resonance could couple to the tyre structure resonance. Fernandez [7] provided a comprehensive experimental study with regard to the use of absorbing material inside the tyre cavity to mitigate the effect. Feng [10,11] used a wireless microphone inside the tyre cavity to measure sound pressure of static and rolling tyre.

To the author's knowledge, majority of cars sold in the market do not have the tyres with sound absorbing materials in them. The study involving insertion of absorbent materials onto the tyre inner surface was done previously but without any

* Corresponding author. Tel.: +61 3 99256028; fax: +61 3 99256108.
E-mail addresses: s3308550@student.rmit.eu.au (Z. Mohamed), xu.wang@mit.edu.au (X. Wang).

http://dx.doi.org/10.1016/j.ymssp.2014.05.044
0888-3270/

guideline of the attachment method and the detailed parameters of materials. In [7], the authors explored various methods to apply noise absorbent materials inside the tyre cavity although it was arguable that the method conformed to the tyre manufacturer guideline and specification. As outlined in [15], the automotive industries are reluctant to adopt such countermeasure as it increases costs while at the same time prefer a primary integrated countermeasure with the tyre or wheel construction.

In this work, tyre is simplified as an annular cavity where the sound pressure equation inside the tyre cavity and the vibration response on the flexible outer annular plate representing tyre tread are derived. The effect of absorbent material added inside the annular cavity is investigated in the equation to compare the result with that without the absorbent material as illustrated in previous work [3,7]. An experimental modal test was done to get the spatial response of the tyre structure and cavity by a roving impact test method. This is to verify the effect of the added trim on the sound pressure level inside the tyre cavity. The transfer function amplitude from the impact test describes the response of the tyre structure and cavity when the tyre tread surface is excited. The purpose of the roving impact test is to correlate the measured tyre structure and cavity resonance mode shapes to those obtained from the analytical method.

2. Tyre cavity resonance

2.1. Theory

Tyre and cavity geometry can be constructed from two cylinder shells with two annular side plates as depicted in Fig. 1. For simplification, tyre inner shell and side walls can be regarded as rigid reverberation surfaces without sound absorption material boundary. Eq. (1) represents the wave equation where p is the acoustic pressure.

$$\nabla^2 p-(1/c^2)(\partial^2 p/\partial t^2)=0 \tag{1}$$

It is convenient to remove the time-dependence by substituting $p(r,\theta,z,t)=p(r,\theta,z,\omega)e^{i\omega t}$ into Eq. (1), where $p(r,\theta,z,\omega)$ is given by

$$p(r,\theta,z,\omega)=\sum_s D_s\varphi_s(r,\theta,z) \tag{2}$$

where φ_s is the mode shape of the tyre cavity torus and D_s is a coefficient. This results in a reduced wave equation such as

$$\nabla^2\varphi_s+k^2\varphi_s=0 \tag{3}$$

where $k=\omega/c$. k is the wave number, ω is circular frequency in rad/s, and c is the speed of sound at 343 m/s. In cylindrical polar coordinates (r,θ,z), Eq. (3) becomes

$$\frac{\partial^2\varphi_s}{\partial r^2}+\frac{1}{r}\frac{\partial\varphi_s}{\partial r}+\frac{1}{r^2}\frac{\partial^2\varphi_s}{\partial\theta^2}+\frac{\partial^2\varphi_s}{\partial z^2}+k^2\varphi_s=0 \tag{4}$$

Using separation of variables and to let $\varphi_s(r,\theta,z)=R(r)\Theta(\theta)Z(z)$ which leads to three differential systems related to axial, radial, and azimuthal direction, a general solution can be written as

$$\varphi_s(r,\theta,z)=A_{s_m s_n s_l}[A_m J_m(k_{ml}r)+B_m Y_m(k_{ml}r)][e^{-im\theta}+d_0e^{im\theta}][e^{-ik_lz}+c_0e^{ik_lz}] \tag{5}$$

where J_m and Y_m are respectively the Bessel functions of the first and second kind, both of order m. $A_{s_m s_n s_l}$ is a constant, while A_m and B_m are constants for all the three sound wave components which depend on the boundary conditions. For this work,

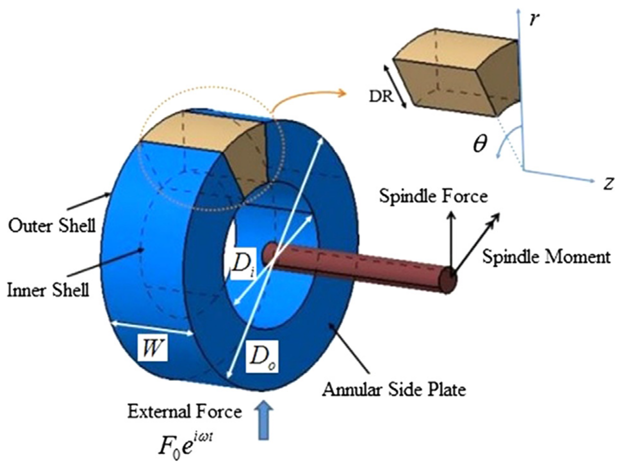

Fig. 1. A simplified tyre model – toroid.