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Low frequency tyre noise mitigation in a vehicle using metal 3D printed resonant metamaterials

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Abstract: To comply with stringent environmental and noise standards in the automotive sector, a resonant metamaterial solution is applied to a vehicle to reduce the interior structure-borne noise due to the acoustic tyre resonances around 220Hz. This novel solution consists of metal 3D printed resonant elements applied on the rear wheel arches of a vehicle and replaces the commonly used dynamic damper solution that are typically installed on the suspension or the vehicle body. The objective is to reduce the structural energy propagation into the vehicle body, and in turn the acoustic energy radiated into the vehicle compartment. Numerical and experimental analyses show how 3D printed resonant metamaterials can be a performant lightweight alternative to the common noise and vibration solutions for the automotive sector.

Keywords: resonant metamaterials, structure-borne noise, automotive NVH, metal 3D printing

1. Introduction

The increasingly stringent norms with respect to the energy efficiency of vehicles leads to a strong push to reduce the vehicle's weight, which is often conflicting with noise, vibration and harshness (NVH) requirements. Resonant metamaterials have become an attractive alternative to classical NVH control solutions since they can combine lightweight design and performant NVH behaviour, particularly in targeted low frequency ranges, known as stop bands. These stop bands can be achieved through the addition of resonant elements onto a host structure in a subwavelength scale [1]. Recently, resonant metamaterials for vehicle applications were used in a thermoformed rooftop of a harvester [2], in car floor panels [3], onto the firewall of a car [4] and on the shock tower of an SUV [5]. Extending on the concept of the latter application, in this work, metal 3D printed resonant elements are added onto the rear wheel arches of a hatchback car model to reduce the interior tonal structure-borne noise issue due to the first acoustic tyre resonances around 220Hz. Different from the common dynamic damper solution which can be installed on the suspensions to mitigate this issue, the metamaterial solution is designed to hinder the structural energy from propagating into the vehicle body. For this work, a metamaterial design was made using finite element based structural intensity analyses simulations on the vehicle body. Resonant elements were printed and tested before addition to the rear wheel arches of the vehicle. Finally, the resonant metamaterial performance was verified experimentally in the vehicle using a standard testing procedure at three different speeds, on a road simulating dynamometer, in a semi-anechoic room.

2. Results and Discussion

The considered hatchback car model was mounted with tyres model 205/55 R16. When tested at 40-50-80kph on the dynamometer, the acoustic tyre resonances lead to outspoken peaks in the interior sound pressure level (SPL) between 224Hz to 241Hz. To achieve stop band behaviour in this frequency range and a more effective reduction of the structural energy propagation, each metal 3D printed resonant element was designed to have two bending resonance frequencies at 238Hz±6.2Hz and 248Hz±8.8Hz, (Fig. 1a). A total of 228 resonant elements (about 0.75kg, similar to that of a classical dynamic damper) are added around the top mounts and the body panels of the rear wheel arches, which are identified as the main energy transfer paths that contribute the most to the interior SPL. The structural intensity analyses (Fig. 1b) show that the resonant metamaterial solution leads to a strong reduction of the energy in the body panels of the rear wheel arches. The test results finally verify the resonant metamaterial potential (Fig. 1c) as confirmed by the ΔSPL, the difference in sound pressure level, between the vehicle without and with the resonant metamaterial, averaged across the frequency band 220-250Hz. The improvement depends on the speed and up to 2dB(A) improvement can be achieved. The SPL improvement in this frequency band is comparable to that achievable by a common dynamic damper solution.

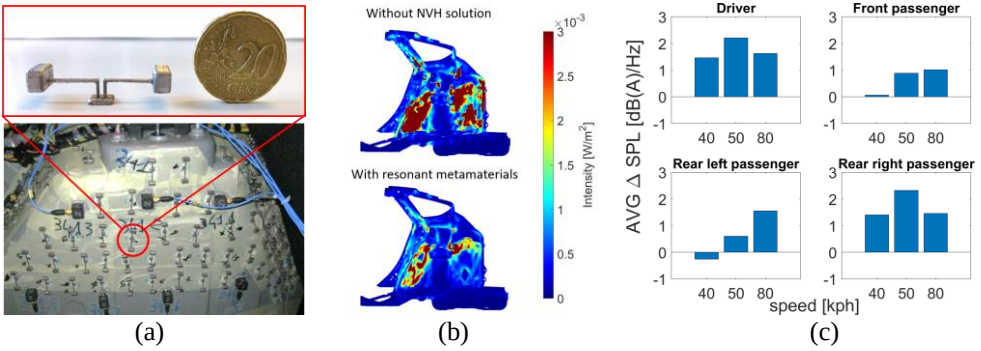

Fig. 1. Picture of the metal 3D printed resonators installed on the rear wheel arch (a). Structural intensity analyses in the rear right wheel arch at 238Hz (b). Measured averaged SPL difference between 220-250Hz of the vehicle without NVH solution and with the resonant metamaterial solution (c). Positive values indicate SPL improvement.

3. Concluding Remarks

A resonant metamaterial solution consisting of metal 3D printed resonant element was applied to the rear wheel arches of a hatchback car model to reduce the structure-borne noise due to the first tyre acoustic resonances. Numerical and experimental analyses demonstrate the potential of this novel solution as a lightweight and performant NVH alternative for the automotive sector.

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