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CAE Methodology for Optimization of Automotive NVH Performance through Wheel Structure Modifications

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Abstract

Noise, Vibration and Harshness (NVH) has been considered as one of the biggest challenges in the automotive industry since it is a source of complaints from passengers for decades. A typical automotive wheel has a very important role in optimizing the NVH performance of the vehicle body. An automotive tire is the primary component which is directly in contact with road disturbances. If structural dynamics of the tire is optimized, it can significantly reduce the transmitted noise and vibration to the passenger cabin. Here frequency response analysis is conducted using a developed finite element model of the wheel (tire and rim). The frequency response has been derived using an impulse input force and measuring the acceleration in radial and axial directions. This analysis can give us the resonances and anti-resonances that can be tuned to achieve a desirable performance. Desirable output can be considered as a low noise and vibration inside the automotive cabin to have customer satisfaction.

Keywords: NVH optimization; Frequency Response Analysis; Resonance Frequencies; Structural Modification.

1. Introduction

Thanks to advancement in CAE methodology, a reliable and simple model can be very useful to predict the behavior (static and dynamics) of a typical system [1,2]. These days CAE has a lot of applications in automotive, aerospace, civil and robotics industries [3]. CAE provides amazing tools to optimize the dynamical performance of the structure in terms of geometry, materials and connections [4-6].

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Most recently,Tatari and etc. have shown that a reliable concept model of automotive Body. In-White (BIW) structure can be very beneficial to prevent mode interaction, tune resonance frequencies, and achieve appropriate mode shapes in early design phases [7,8].

The advantage of using a CAE concept model in early design phases is its capability to significantly reduce the time and cost of manufacturing process [9,10]. Another application of a these models is to reduce the structural borne noise in early stage of design process [11].

NVH (Noise, Vibration and Harshness) in the automotive industries is one of the most challenging components in design process since it is directly linked to the passenger satisfaction [12].

There are a lot of complaints from passengers due to the interior noise and vibrations of a vehicle cabin [13]. Generated noise are mostly due to seat structure vibrations and structural BSR (Buzz, Squeak and Rattle) [7], BIW mode interaction [9] and transmitted road disturbance to the automotive body structure through wheel [13] and suspension mechanism [14].

CAE provides an important tool to design the dynamics of the system as close as possible to a desired response [13, 15-16]. Here our focus is on the automotive wheel structure as one of the important sources in the generated noise.

A finite element (FE) model of the automotive wheel (developed in Hyperworks) is employed [13] to do a frequency response analysis (FRF) (via MDNastran software) and tune the resonance and anti-resonance frequencies of the wheel.

Tuning resonance and anti-resonance frequencies is conducted via some structural modifications to prevent mode interaction and reduce the generated noise.

2. Modeling

First a finite element model of the wheel is developed in Hyperworks [13]. All the components (rim, tire and connections) are modeled separately and the assembled to each other.

In order to characterize dynamics of the system Frequency Response Function (FRF) has been used. Frequency response is the quantitative measure of the output to the input as Eq. (1).

Input force is an impulsive force (containing all frequencies) and acceleration is measured in radial and axial direction. Here we have focused on the ratio of magnitude of the output to that of input.

$$\text{Frequency Response Function (FRF)} = \frac{\text{magnitude of the out put}}{\text{magnitude of the input}} = \frac{\text{Accelartion}}{\text{Force}} \tag{1}$$

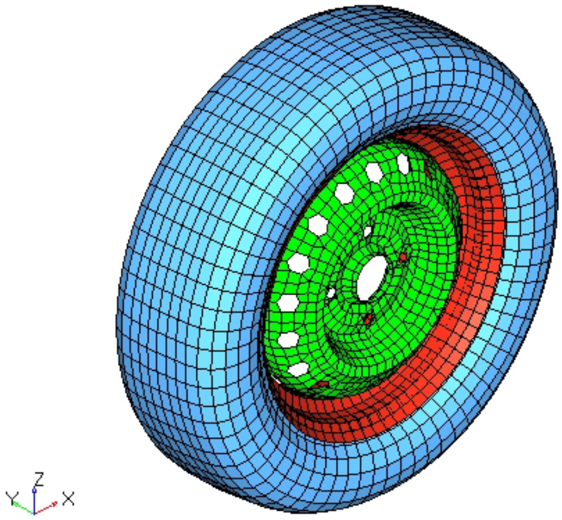


Figure 1: Finite element of the whole automotive wheel [13]

3. Results

Figure 2 illustrates the output acceleration of the rim measured in radial direction versus frequencies up to 1600 Hz. Input force is an impulsive force which swipes all the frequencies. Peaks show the resonance frequencies and relative minimum values show the anti-resonances or nodes which would be stationary points of the structure in the dynamic domain. Table 1 is the values of resonance frequencies. Note that since we have measured the acceleration in radial direction, some frequencies cannot be seen in Table 1 [13]. This is due to the fact that lateral mode shapes (out of plane) do not get activated and measured in radial direction.

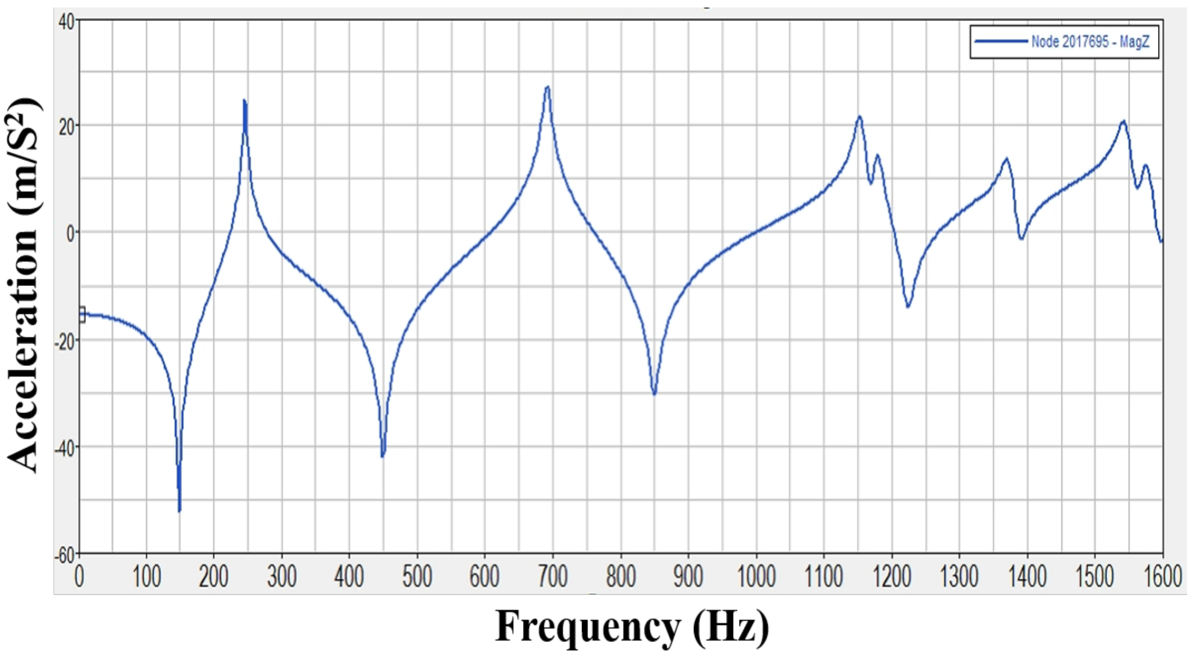


Figure 2: Frequency response function (FRF) for the rim

Table 3: Mode shape and resonance frequencies of the rim [13].

Mode Number	Mode Type	Frequency (Hz)
7th mode	Bending mode	245
8th mode	Torsion mode	257
9th mode	First triangle mode	685
10th mode	Second triangle mode	693
11th mode	First rectangular mode	1152
12th mode	Second rectangular mode	1178
13th mode	Axial mode	1370
High frequency modes	-	-

In the next step, the whole wheel (Tire and rim) gets activated with an impulse force and the response has been measured in radial direction.

Figure 3 shows the acceleration versus frequency for the wheel structure. Peaks values demonstrate the resonance frequencies. Table 2 is the values for resonance frequencies of the wheel and also mode shapes.

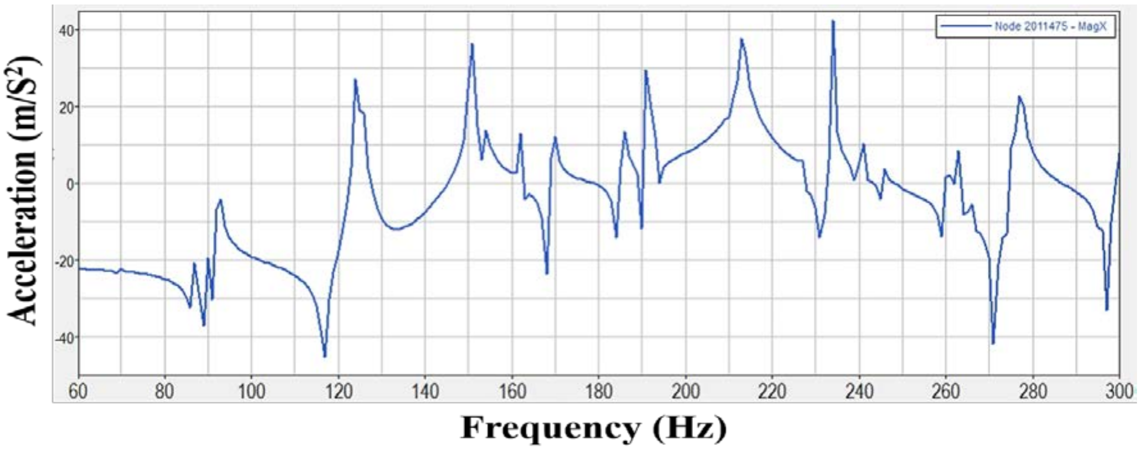


Figure 3: Frequency response function of the rim in radial direction.

Table 5: Mode shapes and resonance frequencies of the modeled wheel [13].

Mode number	Shape of the mode	Resonance Frequency (Hz)
7th mode	Axial mode	68
8th mode	Twisting mode	93
9th mode	Elliptical mode	124
10th mode	Triangular mode	152
11th mode	Rectangular mode	190
12th mode	Pentagonal mode	213
13th mode	Hexagonal mode	234

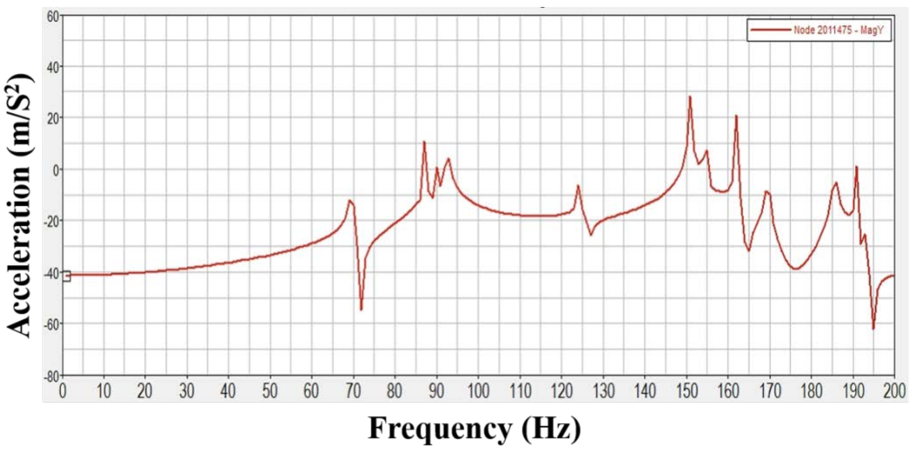


Figure 4: FRF in lateral direction

Figure 4 shows the frequency response function of the wheel structure when it is excited in lateral direction. As it was expected, some modes have not been activated when there is a lateral excitation. The modes that have radial motions are missed in lateral excitation. Therefore, in a comprehensive frequency response analysis, a typical structure should be excite in different direction to gain all dynamical properties of the system.

4. Wheel Structure Optimization

[18, 19]. As it is shown in Figure 3, the wheel has two resonance frequencies in 213 and 234 Hz. Now CAE methodology can be employed to move resonance frequencies away from the zone of 200 to 250 Hz. Our proposed method is to use o lateral elements as shown in Fig. 5 to reduce the stiffness of the structure and therefore resonance frequencies take place earlier. Fig. 6 illustrates the frequency response function of the wheel structure after modifications. It can be seen that after modification 6^{th} resonance frequency would be lower than 200 Hz and 7^{th} resonance frequency would increase to more than 250 Hz. There is just one local mode after modification and it would not be dangerous since it is not a main mode shape.

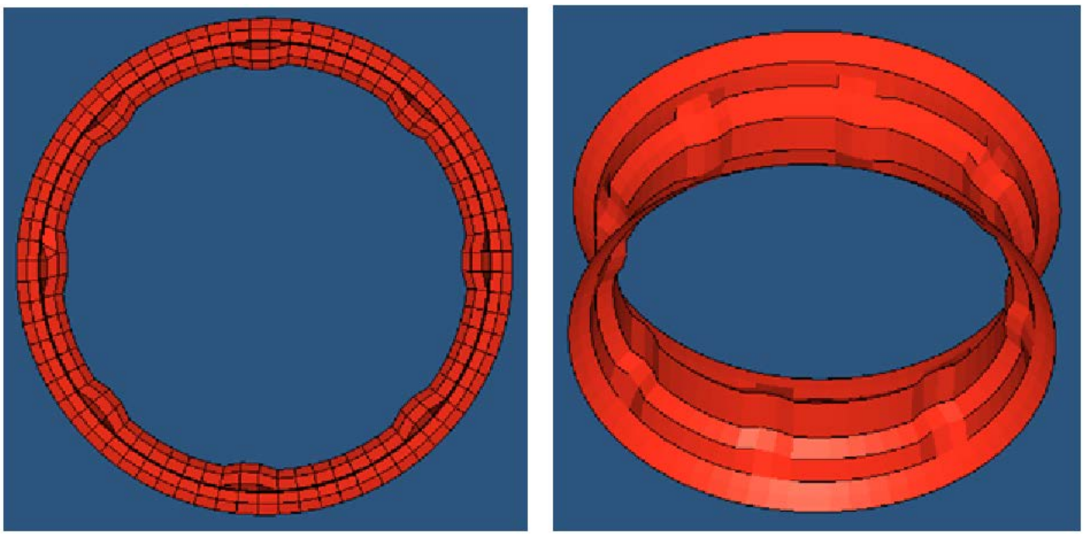
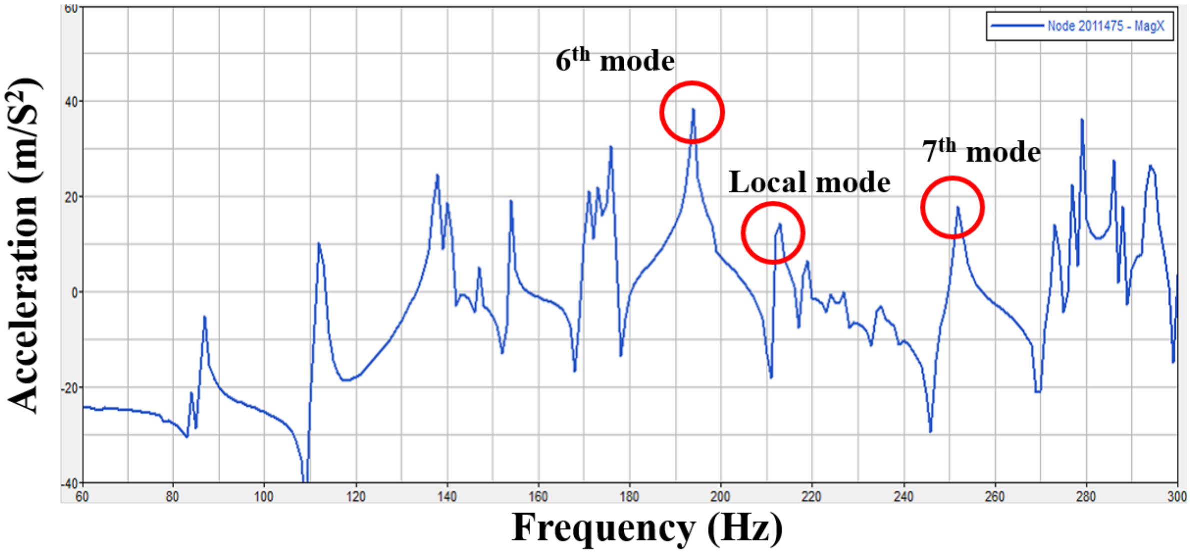


Figure 5: Modification of the wheel structure

It has been shown that tire air has two resonance frequencies less than 500 Hz [17] and the first one happens between 200 to 250 Hz which is significant. Previous studies have shown that when the resonance frequencies of the tire wheel and tire air are close to each other, resonance happens and interior noise cabin will be increased [18, 19]. As it



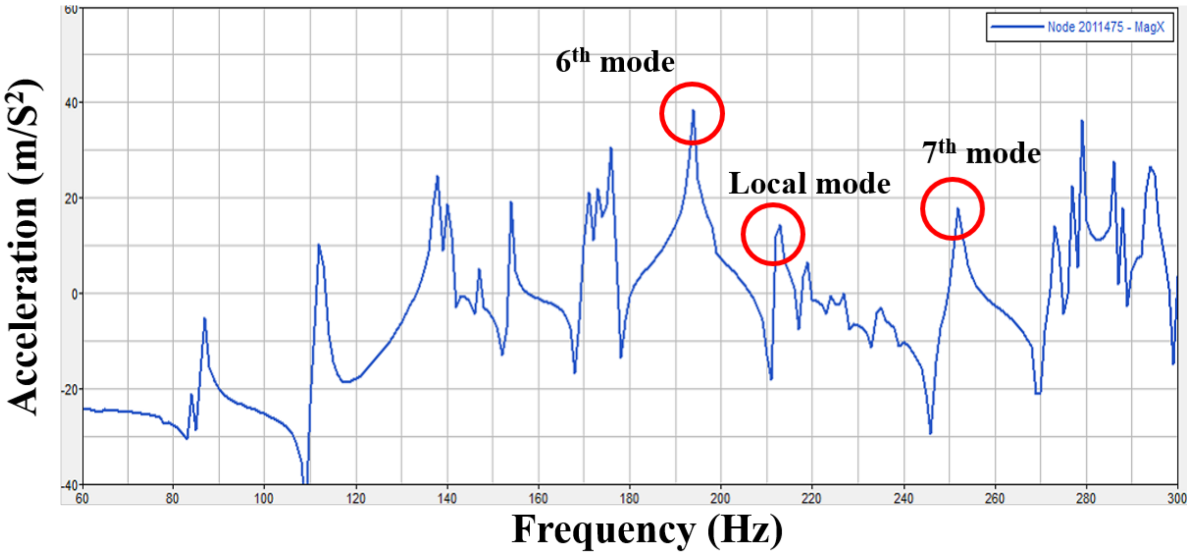


Figure 6: FRF of the whole wheel structure after modification.

5. Conclusion

In conclusion, the pneumatic tire forms a vital component of a road vehicle as it interacts with the road to produce the forces necessary for support and movement of the vehicle. Tire as one of the most important components of vehicles requires fulfilling a fundamental set of functions such as: provide load-carrying capacity, cushioning and dampening, stability, reducing noise and vibration, transmit driving and braking torque, resist abrasion, generate steering response, have low rolling resistance, durability throughout the expected life span. Therefore NVH performance of the wheel (including tire and rim) is important to be analyzed. Here, as the first step, a finite element model of the wheel has been derived using Hyperworks software. Then, dynamic analysis of the structure is conducted to derive mode shapes and resonance frequencies. These resonance frequencies and mode shapes can be used in early design phase of the automotive body, since when they are coupled with resonance frequencies of the automotive body structure, interior noise level can be magnified.

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