Study of Tyre Cavity Resonance Noise using Modal Analysis Method

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Abstract— **There are numerous variables that influence the noise transmitted to vehicle cabin; the engine, transmission, driveline and also other sources like coupling modes of structure, tyre air cavity. To reduce the impact of said noise sources, there are plenty of active and passive noise control methods; importance should be given at the plan and during the design level so as to mitigate the cavity resonance effects. In this paper Finite Element Method (FEM) analysis is done on a standard tyre, steel rim and tyre-rim assembly to find out the resonance frequencies and modes of vibration of tyre rim and cavity which is used to find out the modal coupling which will cause the amplification of noise and vibration transmission. Suitable design modifications are suggested to ensure reduction in this noise.**

Keywords: ***Tyre cavity resonance, coupling modes, noise reduction***

I. INTRODUCTION

The noises transmitted to vehicle cabin are influenced by many major factors; which are noise generated by major components such as vehicle engine, transmission system, driveline components and finally tires. The noise generation and its mitigation in tires are of great importance in the recent times as the advent of electric vehicles also demands less noisy tires.

Further, there are several noise generation mechanisms in tires and broadly they can be categorized as those occurring in the contact patch, in the rim or wheel structures and in the cavities. One of the major noise sources is the coupling mode of structure, tire air cavity. Hence, to eliminate the impact of cavity resonances, proper care needs to take at design level itself. Analysis can be used to find out the modes of coupling, resonant frequencies of tire rim and cavity which is then used to find out the modal coupling which will cause the amplification of noise and vibration transmission. Incorporating suitable design changes can lead to significant reduction in the generated noise levels.

II. LITERATURE REVIEW

Our environment is not only affected by pollution of exhaust from vehicles, but also by external noise generated due to vehicles. Tire cavity noise is the excitation of the noise mode of cavity. Among the different noise generation sources tire acoustic contributes 10-15%. The tire-road surface resistance noises can be associated to two primary drivers: basic and acoustical. The basic modes allude to the vibration of the deformable strong constituting the tire structure. The vibration of the air molecules inside the cavity of tyre causes the acoustic modes. Though tire noise can be reduced by taking appropriate correction in the construction of tires, it is difficult to be implemented as it takes longer development cycles during manufacturing. Some simple soft rubber bush used at lower arm has resulted in lower noise level at cabin [1, 2, 3, 4, 16, 20]

FEM analysis can be used to find out the coupling modes, resonance frequencies of tyre rim and cavity which is then used to find out the modal coupling which will cause the amplification of noise and vibration transmission. Incorporating suitable design changes can lead to significant reduction in the generated noise levels. A phenomenological model can be used for the cavity noise modes. This model considered the effect of the tire static load for rolling tire. The resulting equations are transformed into a standard reference frame. The resonance frequencies are obtained. By calculating the First acoustic cavity mode of tire theoretically and compared both excitation techniques [5, 6, 7, 8, 10, 12, 15]

Another methodology they have used is drop test. From testing it is observed that two tire shows different tonal characteristics when dropped on floor, two microphones are used to record the frequencies. Vibro-acoustic model is used to verify the result by numerical prediction of the tyre cavity coupling modal frequency [9, 11]

The tire cavity and wheel structure modes get coupled and produce the unwanted noise at range of 200 to 250Hz frequencies. The sharp rise in frequencies which is around the range of 200-250Hz under normal 70-80 km/h cruising condition. Natural frequencies of a tire are greatly influenced by the change in the inflation pressure and this effect intensifies for higher order frequencies. Also, the natural frequencies were found to increase as a result of the restraint imposed on the total mass of the model under vibration. [7, 13, 14, 17, 18, 19]

New innovation for using Helmholtz resonators on wheels, empowering lessening of tire pit clamour without putting limitations on the tire. At that resonant frequency of the Helmholtz resonator, the reduction is approximately 10dB, while at a location 25-50Hz away, only approximately 2dB is obtained. [13, 14]

III. METHODOLOGY

As per the methodology, problem statement is defined after the literature study. Bridgestone tyre model (205/65/R15) is selected for the study. According specifications tire structure and rim are modelled in the CATIA V5 software. These models are exported to ANSYS workbench for the modal analysis and analysis is done on each model for finding out their respective natural frequencies and mode shapes. From the obtained data coupling modes which are capable of transmitting the noise is determined and suitable changes in the rim model is made to prevent the coupling mode formation. Fig. 1 shows the methodology flowchart and Fig. 2a-d show the modelled parts.

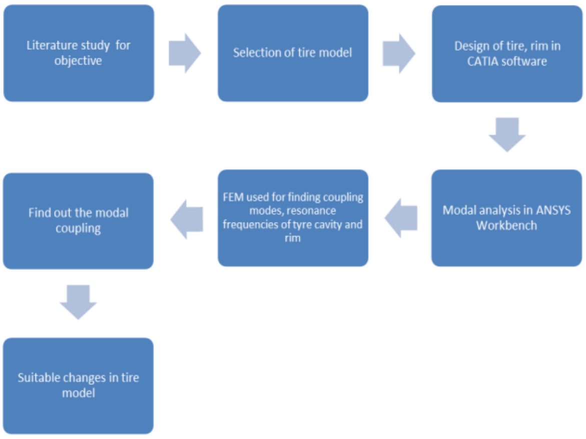


Fig. 1. Methodology flow chart

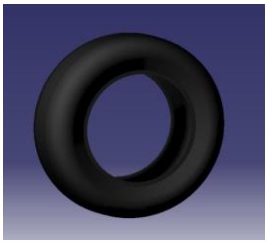


Fig. 2a. Tire structure

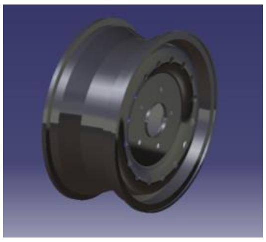


Fig. 2b. Steel rim

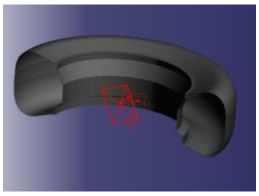


Fig. 2c. Air cavity

Fig. 2d. Aluminium alloy rim

IV. MODAL ANALYSIS AND DISCUSSION

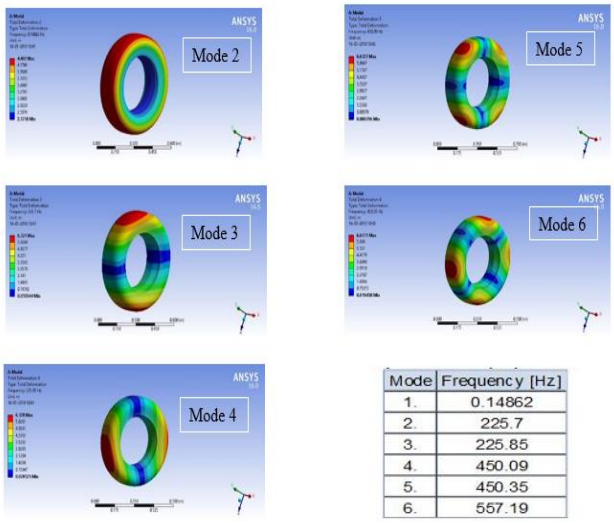
From literature study by selecting standard properties of tyre material the modal analysis has been done. For structural and acoustic simulations, the properties of tyre, cavity, and rim were adopted from ANSYS workbench. The, rim structure, tyre structure and tyre cavity was analysed individually by defining the boundary conditions. The material properties used for the analysis is as mentioned in table1.

Table 1: Properties of materials

Sr. no.	Type	Young's modulus	Poisson's ratio	Density
1	Tyre	45 MPa	0.49	1150
2	Air cavity			2.2
3	Steel rim	210 GPa	0.3	7850
4	Aluminium rim	70 GPa	0.32	2350

A. Air Cavity

The air cavity was modelled as solid section and properties of air are assigned to this section. And "compression only" support is given to outer circumference of cavity. For the tyre cavity FEA modal analysis was done, and natural frequencies are obtained as shown in the figure. The second and third resonant frequencies are 225.7 Hz and 225.87Hz. The mode shapes are obtained as shown in the below figure. From the obtained third mode shape, it is seen that the cavity is exited in the upward direction which will transmit the exited forces along positive y axis. Fig. 3. Shows the different mode shapes and corresponding frequencies.

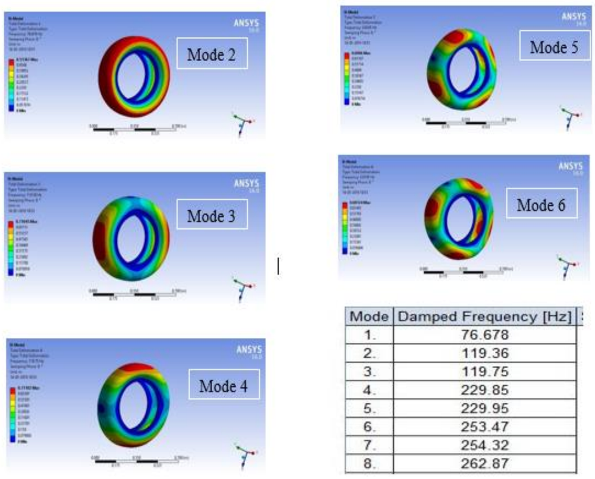


Mode	Frequency [Hz]
1.	0.14862
2.	225.7
3.	225.85
4.	450.09
5.	450.35
6.	557.19

Fig. 3. Frequencies and mode shapes of air cavity

B. Tire Structure

The tire model used for analysis is Bridgestone (P205/65/R15). Tire structure is imported to the workbench and then rubber material properties are assigned to it and boundary conditions are applied. Fixed support is applied at the bead region of the tire and air pressure is given at inner surface of tire as 220 KPa and FEA analysis is done. Results are obtained as shown in the figure 7. The natural frequency of 5th mode shape is around 229 Hz and it is seen that the tire is exited more at the upper region and this also results in the force transfer along positive y axis. Fig. 4. shows the different mode shapes and corresponding frequencies obtained for tire structure.



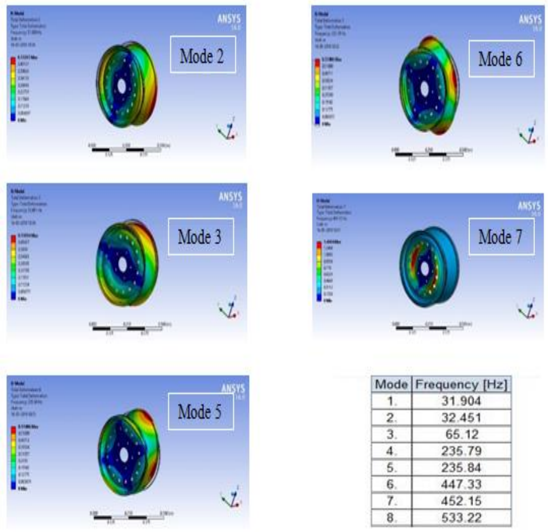
Mode	Damped Frequency [Hz]
1.	76.678
2.	119.36
3.	119.75
4.	229.85
5.	229.95
6.	253.47
7.	254.32
8.	262.87

Fig. 4. Frequencies and mode shapes of tire structure

From the workbench modal analysis results, it is clear that the coupling of the modes of tyre structure and cavity will take place as the modal frequency of tyre and cavity is very close to each other.

C. Steel rim

FEA was done on the steel rim. The CAD model was imported to ANSYS workbench and boundary conditions were given, 220 KPa air pressure at outer circumference of the rim and fixed constraints at mounting bolt holes of hub. Figure 5 shoes the mode shapes and natural frequencies of steel rim.



Mode	Frequency [Hz]
1.	31.904
2.	32.451
3.	65.12
4.	235.79
5.	235.84
6.	447.33
7.	452.15
8.	533.22

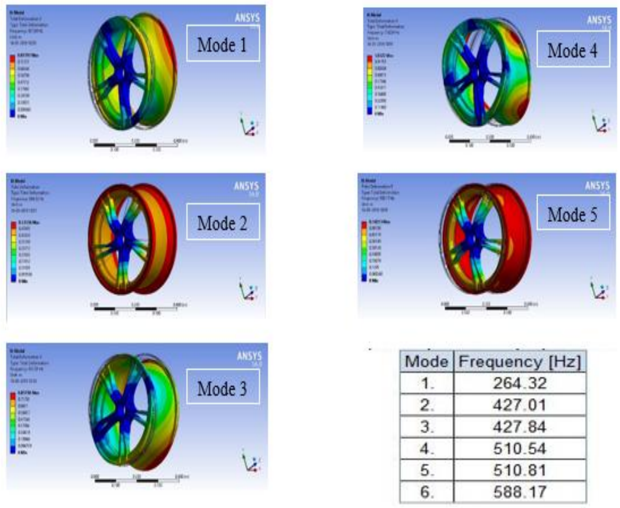
Fig. 5. Frequencies and mode shapes of steel rim

From Fig. 5., the 5th mode shape of the steel rim has a natural frequency of 235.79 Hz. This frequency is close to the cavity resonance frequency of 225.7 Hz and tyre structure resonant frequency 229.85 Hz. Hence these three modes will form the modal coupling as they are vibrating near same frequencies. There will be transfer of the forces in the positive y direction of the wheel assembly due to this modal coupling. These forces will be transmitted along the wheel hub, chassis and finally to the cabin which will cause a structure borne noise transmission.

Therefore, it is necessary to avoid this modal coupling to reduce the noise. As frequencies are functions of material properties and shape. Rim frequency can be shifted to the higher side by changing the material and shape. To achieve this, aluminium alloy rim is used for further analysis.

D. Aluminium alloy rim

Aluminium alloy rim is modelled in CATIA and imported to the ANSYS workbench for FEA analysis. Analysis is done on the rim with the same boundary condition and load as applied on the steel rim so that we can compare the obtained results. The natural frequencies and mode shapes are obtained as shown in the Fig. 6.



Mode	Frequency [Hz]
1.	264.32
2.	427.01
3.	427.84
4.	510.54
5.	510.81
6.	588.17

Fig. 6. Frequencies and mode shapes of Aluminium alloy rim

Fig. 6. shows the mode shapes and natural frequencies of aluminium rim. First mode is observed at a natural frequency of 264.32 Hz and it is far from the resonance frequency of tire cavity 225.70 Hz and from the literature survey it is clear that the cavity noise is predominant in the frequencies below 250 Hz. Hence modal coupling will not form with aluminium rim as result there will be no transmission of vibration to cabin which provides comfort and pleasant driving.

V. CONCLUSION

The steel rim and tyre cavity resonance frequencies are close to each other, which leads to the generation of a modal coupling. Thus, the noise and vibration transmission are increased due to the formation of the coupling modes of air cavity and steel rim. Consequently, the alleviation of noise is done by moving modal frequencies of the rim, tire air cavity and tire structure, one such method here adopted is changing the material of the rim. Due to changing of the material the resonance frequencies are shifted away as shown in the Fig. 6. and this will avoid the formation of the modal coupling and will mitigate the noise transmission.

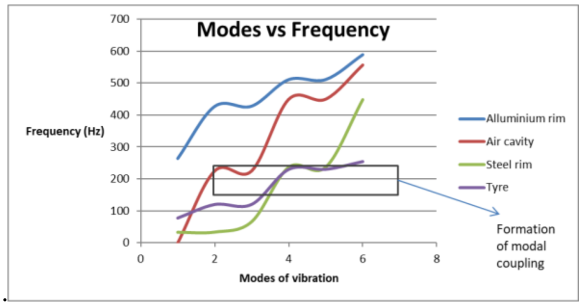


Fig. 7. Graph of frequencies verses modes of vibration

Therefore, from the graph we can see that how modal coupling is forming with steel rim and how it is avoided with the aluminium rim of different shapes. Hence, it can be concluded that mitigation of noise and vibration is possible by using the aluminium rim of different shape.

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