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VIBRATION ANALYSIS OF A TIRE

B.Sc. Engineering (Mechanical) Thesis

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CERTIFICATE OF RESEARCH

The thesis title "**VIBRATION ANALYSIS OF A TIRE"** submitted by **MUTASIM FUAD NUHASH (151413)** and **MD. SHAMS MASUD (151420)** has been accepted as satisfactory in partial fulfillment of the requirement for the Degree of Bachelor of Science in Mechanical and Production Engineering on November, 2019.

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DECLARATION

This is to clarify that the work presented in this thesis is an outcome of the analysis, simulation, experiment and research carried out by the author themselves under the watchful supervision of Prof. Dr. Md. Zahid Hossain.

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ABSTRACT

Noise and vibration, transmitted from road to the body structure of a typical automotive wheel, considered as an important parameter in automotive NVH (Noise, Vibration and Harshness) performance optimization. Having a reliable and simple finite element model of the wheel structure can significantly reduce time and cost of design. Based on the results of experimental and numerical analyses, the effect of inflation pressure is investigated on the behaviour of a tire in our work. The natural frequencies are measured to describe free vibration of the tire. For observation of the dynamic behavior, harmonic analysis is also carried out. Comparison between numerical and experimental modal analyses shows an acceptable accuracy. Better understanding of the complex tire characteristics will contribute to develop tire design strategies to lower the tire/road vibration while less affecting other tire performances.

Keywords: Automobile Tire, Vibration, Modal Analysis, Tire Finite Element Analysis, Harmonic Analysis, Inflation Pressure.

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1 Introduction

Tire is a rubber member which gives the cushion to the automobile. It is the only means to transfer forces between the road and vehicle. It is required to produce the forces necessary to control the vehicle, and hence, they are an important component of a vehicle. It performs mainly three functions:

1) Support vertical loads while cushioning against shocks.
2) Develop / transfer longitudinal forces for acceleration and braking.
3) Develop lateral forces for cornering power for smooth steering.

Pneumatic tires greatly influence the riding comfort and noise level in cars. Tire/road interaction is a significant operative parameter for vehicle manufacturers, because tires are the only member of an automotive having contact with road. The undesirable transmitted vibrations negatively influence on passengers and would be annoying in long term. The previous studies show that in vehicle dynamics interaction of tire resonance frequencies with road disturbance and surrounding air can easily magnify the level of interior noise and vibrations [1]. Hence, the NVH (Noise, Vibration and Harshness) performance of a vehicle has become an important parameter in automotive structural dynamics that need to be carefully designed and optimized in early phase of design [1-3].

The structural vibrations of the tire are generated by the interactions between tire and road that are created by road irregularities and brake torque changes. Vibrations would be transmitted from tire to the automotive body through suspension system [4]. Type of vibration depends on the plane that vibration is studied on and it could be bending, longitudinal and torsion. The inflation pressure also plays a vital role in the behavioral characteristics of a tire. It stresses the structure in such a way that any external force causing deformation in the carcass results in a tire reaction force. The characteristics of the tire depend not only on the operating conditions, but on the type of construction as well. So, in order to perform our research work, a clear insight into vibration, tire construction, tire properties are necessary.

1.1 Construction of a Tire

A tire is an advanced engineering product made of rubber and a series of synthetic materials cooked together. They are combined in such a way to achieve different objectives. The objective may be performance optimization, traction maximization, or better rolling resistance. Fiber, textile, and steel cords are some of the components that go into the tire's inner liner, body plies, bead bundle, belts, sidewalls, and tread. *Figure 1* illustrates a sample of tire interior components and their arrangement.

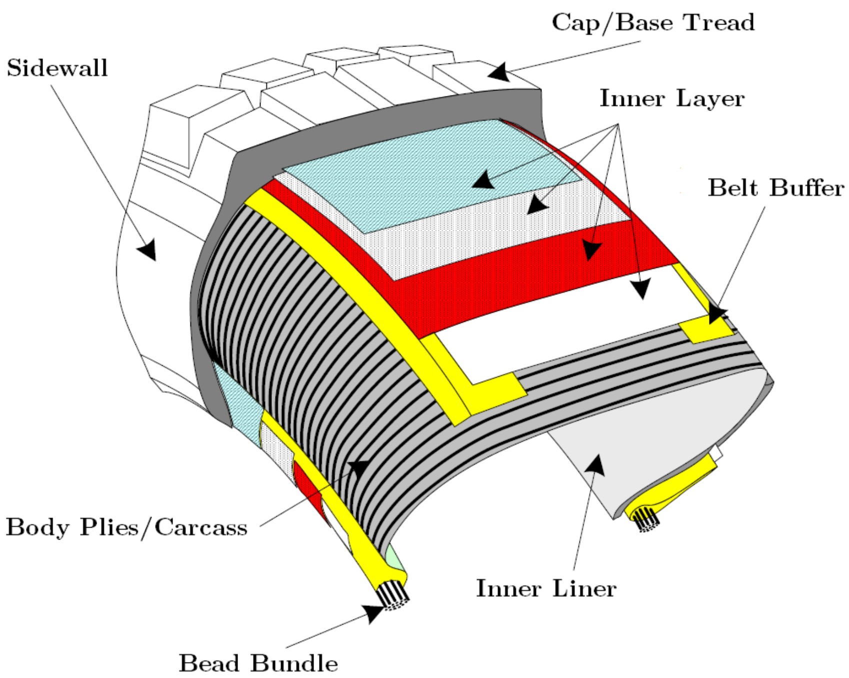


Figure 1. Construction of a tire [5]

The main components of a tire are explained below:

Bead or bead bundle is a loop of high strength steel cable coated with rubber. It gives the tire the strength it needs to stay seated on the wheel rim and to transfer the tire forces to the rim.

Inner layers are made up of different fabrics, called plies. The most common ply fabric is polyester cord. The top layers are also called cap plies. Cap plies are polyesteric fabric that help hold everything in place.

Cap plies are not found on all tires; they are mostly used on tires with higher speed ratings to help all the components stay in place at high speeds.

An ***inner liner*** is a specially compounded rubber that forms the inside of a tubeless tire. It inhibits loss of air pressure.

Belts or belt buffers are one or more rubber-coated layers of steel, polyester, nylon, Kevlar or other materials running circumferentially around the tire under the tread. They are designed to reinforce body plies to hold the tread flat on the road and make the best contact with the road. Belts reduce squirm to improve tread wear and resist damage from impacts and penetration.

The ***carcass or body plies*** are the main part in supporting the tension forces generated by tire air pressure. The carcass is made of rubber-coated steel or other high strength cords tied to bead bundles. The cords in a radial tire, as shown in Figure 1, run perpendicular to the tread. The plies are coated with rubber to help them bond with the other components and to seal in the air. A tire's strength is often described by the number of carcass plies. Most car tires have two carcass plies. By comparison, large commercial jetliners often have tires with 30 or more carcass plies.

The ***sidewall*** provides lateral stability for the tire, protects the body plies, and helps to keep the air from escaping from the tire. It may contain additional components to help increase the lateral stability.

The ***tread*** is the portion of the tire that comes in contact with the road. Tread designs vary widely depending on the specific purpose of the tire. The tread is made from a mixture of different kinds of natural and synthetic rubbers. The outer perimeter of a tire is also called the crown.

The ***tread groove*** is the space or area between two tread rows or blocks. The tread groove gives the tire traction and is especially useful during rain or snow.

1.2 Classification of Tire

Tires are divided in two classes: ***radial*** and ***non-radial***, depending on the angle between carcass metallic cords and the tire-plane. Each type of tire construction has its own set of characteristics that are the key to its performance.

The *radial* tire is constructed with reinforcing steel cable belts that are assembled in parallel and run side to side, from one bead to another bead at an angle of 90° to the circumferential centerline of the tire. This makes the tire more flexible radially, which reduces rolling resistance and improves cornering capability. The tire being used for our research work is a radial one.

The *non-radial* tires are also called bias-ply and cross-ply tires. The plies are layered diagonal from one bead to the other bead at about a 30° angle, although any other angles may also be applied. One ply is set on a bias in one direction as succeeding plies are set alternately in opposing directions as they cross each other. The ends of the plies are wrapped around the bead wires, anchoring them to the rim of the wheel.

The most important difference in the dynamics of radial and non-radial tires is their different ground sticking behavior when a lateral force is applied on the wheel. The radial tire, shown in *Figure 2*, flexes mostly in the sidewall and keeps the tread flat on the road. The bias-ply tire, shown in *Figure 3* has less contact with the road as both tread and sidewalls distort under a lateral load.

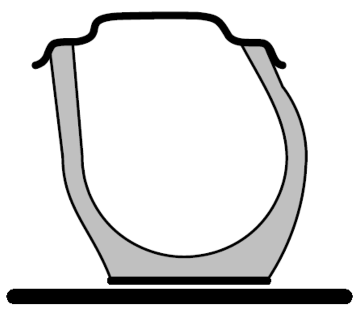


Figure 2. Radial tire [5]

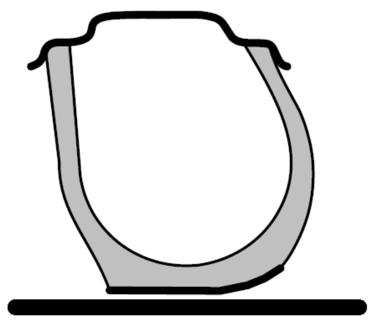


Figure 3. Non-radial tire [5]

The radial arrangement of carcass in a radial tire allows the tread and sidewall act independently. The sidewall flexes more easily under the weight of the vehicle. So, more vertical deflection is achieved with radial tires. As the sidewall flexes under the load, the belts hold the tread firmly and evenly on the ground and reduces tread scrub. In a cornering maneuver, the independent action of the tread and sidewalls keeps the tread flat on the road. This allows the tire to hold its path. Radial tires are the preferred tire in most applications today.

The cross arrangement of carcass in bias-ply tires allows it act as a unit. When the sidewalls deflect or bend under load, the tread squeezes in and distorts. This distortion affects the tireprint and decrease traction. Because of the bias-ply inherent construction, sidewall strength is less than that of a radial tire's construction and cornering is less effective.

1.3 Tire Code

Tires are required to have certain information printed on the tire sidewall. *Figure 4* illustrates a side view of a sample tire to show the important information printed on a tire sidewall.

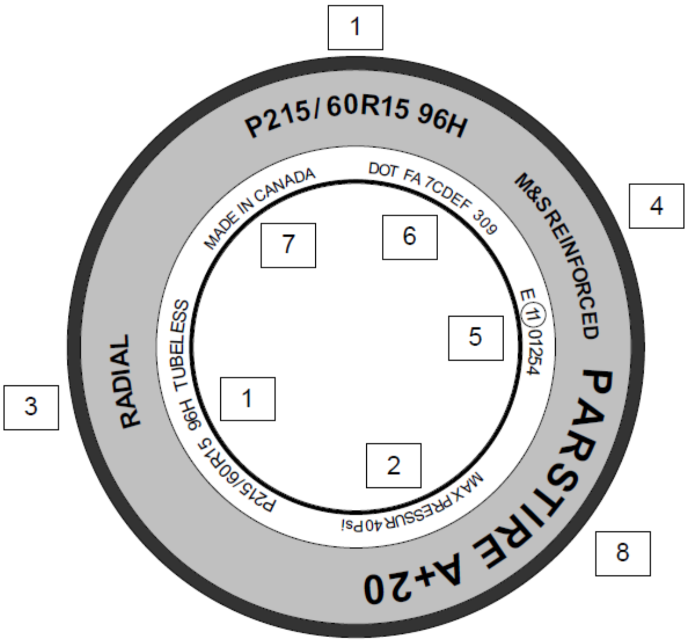


Figure 4. Side view of a tire and the most important information printed on a tire sidewall [5]

The codes in Figure 2 are:

$\boxed{1}$	Size number.
$\boxed{2}$	Maximum allowed inflation pressure.
$\boxed{3}$	Type of tire construction.
$\boxed{4}$	M&S denotes a tire for mud and snow.
$\boxed{5}$	E-Mark is the Europe type approval mark and number.
$\boxed{6}$	US Department of Transport (DOT) identification numbers.
$\boxed{7}$	Country of manufacture.
$\boxed{8}$	Manufacturers, brand name, or commercial name.

The most important information on the sidewall of a tire is the size number, indicated by $\boxed{1}$. To see the format of the size number, the tire code of the tire used for our analysis is shown below and their definitions are explained as follows.

P 175 / 70 R 13 82 S

P : The first letter indicates the proper type of car that the tire is made for. P indicates passenger tire.

175 : This three-number code is the width of the unloaded tire from sidewall to sidewall measured in [mm].

70 : This two-number code is the ratio of the tire section height to tire width, expressed as a percentage.

R : The letter R indicates that the tire has a radial construction. It may also be B for bias belt or bias ply, and D for diagonal.

13 : This is a number in [in] to indicate diameter of the rim that the tire is designed to fit on.

82 : Load rate or load index. Many tires come with a service description at the end of the tire size. The service description is made of a two-digit number (load index) and a letter (speed rating). The load index is a representation of the maximum load each tire is designed to support.

S : It indicates speed rate. Speed rate is the maximum speed that the tire can sustain for a ten minute endurance without breaking down.

2 Literature Review

Tire is the most representative product of composite structures. It is a very complex system to study [l]. The tire is under vertical load, lateral force, driving force, braking force, and other loads when the car is in motion. Meanwhile, the tire frictions and impacts with the ground dramatically, which causes greater stress, strain, and vibration. Tires and suspension system absorbs a part of the vibration, the remainder affects comfort, handling stability, safety of vehicles, and produces noise, and even make the tires have a resonance. To improve the vibration and noise characteristics of the tire is an important way to enhance the driving performance of vehicles. Thus, it is necessary to study vibration characteristics of tires and the relationship between the vibration modes and the vehicle vibration. Much research has been conducted on the vibration characteristics of radial tires.

Experimental modal analysis of a non-rotating tire for two boundary conditions is presented in [6]. The tire was excited by a hammer and the responses were measured in tangential and radial direction with accelerometers. Mode shapes and frequencies were assessed from the measured frequency response functions. These experimental results were compared with the modes of a theoretical tire ring model, where tire was modeled as a circular beam that was able to deform in radial and tangential direction. He obtained smooth and accurate mode shapes by measuring the responses at only ten points on the tire circumference. The modes of the free tire were symmetric. Each mode was double, that is for each natural frequency two identical mode shapes exist. The only difference in the two identical mode shapes was an offset in the angular position of the (anti-)nodes.

The investigation into tire–road interaction and radial tire vibrations for tire–road noise characterization was done in [7]. Experimental measurements were performed on a rolling smooth tire with test laboratory facilities. Both tread band and sidewall responses of the tire were measured and compared to each other. High concentration of vibrations was observed in the vicinity of the contact area.

Lopez et al. [8] examined an approach to model the vibrations of deformed rotating tire in the lower frequency range. Determining the eigenvalues and eigenmodes of a detailed FE-model of the tire and then using these to construct a modal base of the tire seems a computationally efficient way of calculating the dynamic response of the tire taking its complex build-up into account. The presented methodology allows for the calculation of the response of the rotating tire in a fixed (Eulerian) reference frame, including the influence of gyroscopic and centrifugal forces.

Lee and Kim [9] modeled the tire to a 7-degree of freedom system according to design factor, and vibration energy change due to design factor change was examined. Using the model, it was concluded that the side part, which transmits the vibration of road surface (bump) to the rim, has an important effect on vibration energy, and it can be proposed as a solution for reducing vibration energy when a tire passes the cleat.

Guan et al. [10] used MSC.MARC software for the modal analysis of practical structure of 195/60R14 radial tire. The model was employed to simulate complex multilayer rubber-cord composites. The model considers the geometric non-linearity and the non-linear boundary conditions from tire-rim contact and tire-road contact. It was found that first mode shape has two lobes, the second mode shape has three lobes, and so on. Changes of the inflation pressure did not affect the mode shape, but the natural frequency of higher mode shape was sensitive to the change of the inflation pressure.

Duhamel, Erlicher and Nguyen [11] applied the recursive method for the computation of tire vibrations for medium and high frequencies. They described the recursive method for curve periodic structures and its application to the computation of frequency response functions is also explained.

The analysis for a truck tire has also been carried out in [12]. The aim of this work was to investigate the possibility of building a numerical model that simulates the vibration behavior of a truck tire at low-mid frequencies. The simulation was performed on a three-dimension geometric model of truck tire, in this case all the parts of truck tire influence on the vibration mechanism.

The model of a wheel with a reinforced tyre was considered in [13]. Then, the equations of motion and the conditions on the boundary of an unknown in advance contact area were obtained. Next, the vibrations of unloaded non-rotating, unloaded rotating , loaded non-rotating and loaded rotating tyre were considered. The results for the unloaded non-rotating and loaded non-rotating cases were compared with experiment.

Abd_Elsalam, Gohary and El-Gamal [14] investigated some aspects in the experimental modal analysis of the tires such as the type of support of the tire (elastic light band, soft springs carrying the assembly, soft cushion, free support in axial direction), the means of excitation, he selection of the sensors to reduce the additional mass and stiffness of the tested object as much as possible. The response of the tire was quite similar to the response of viscously damped mass system subjected to an impulse excitation for impulse force which is provided by the impact hammer. The results showed that the system modal parameters can be obtained respective of loading or unloading conditions with a maximum difference of 1.992% for frequency values and 3.66% for damping values. This study had a practical value for the description of mechanical properties of tires.

Karakus, Cavus and Colakoglu [15] analyzed the free vibration of a radial pneumatic tire, P175/70R13 using solid finite element models (FEM) . Effects inflation pressure, vertical load and co-efficient of friction of the tire to natural frequencies were also studied. Experiments were run under certain conditions to check the accuracy of the numerical model. The natural frequencies were measured to describe free vibration and vibration of the tire contacted by ground, using a damping monitoring method. According to the results, the inflation pressure was the most effective parameter on the natural frequencies which increase with increased inflation pressure. On the other hand, the effects of the coefficient of friction and the vertical load were different and much more complex on the first six natural frequencies.

Farahani and Mahjoob [16] validated finite element model of an automotive wheel structure by experimental modal analysis. Validation was conducted via frequency response functions and resonance frequencies. The shift of resonance frequencies in FRF diagram was also studied and discussed for different conditions. FEM model of the tire was also developed consisting of a Neo-Hookean model for the tire and linear elastic model for the rim.

Our work aims to study the vibration characteristics of a 175/70 R13 tire. We have to analyze the characteristics both numerically and experientially. Modal analysis as well as harmonic analysis will be performed. The effect of inflation pressure will be taken into consideration.

3 Methodology

3.1 Numerical Analysis

3.1.1 Modeling

The modelling was done on SOLIDWORKS 2016 based on the measurements extracted from commercially available tire (Bridgestone P175/70R13 82S). For the simplification of modelling, inner layer, belt buffer, carcass and inner liner are considered to be a single composite part. We will be calling it main body throughout our report. So, there will be mainly four different parts in this composite tire model: treads, sidewall, bead bundle and main composite body.

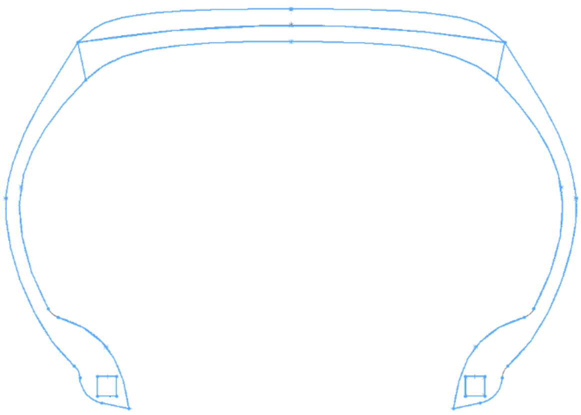


Figure 5. 2D model of the tire

3.1.2 Material Properties

For our analysis, we have considered tread as isentropic (the material properties stays constant in all directions) and sidewall, main body and bead bundle as orthotropic (the material properties changes in orthogonal directions only). The material properties were collected from a previous work for the same tire [15] as the properties could not be measured experimentally.

Table 1. Material properties of the tire [15]

Tire Parts	**Material type**	**Elastic Modulus E (MPa)**	**Poisson's Ratio υ**	**Shear Modulus G (MPa)**
Tread	Isotropic	E_x=14 E_y=14 E_z=14	υ= 0.45	G=5
Sidewall	Orthotropic	E_x=14.7 E_y=113 E_z=113	υ_{xy}=0.049 υ_{xz}=0.049 υ_{yz}=0.057	G_{xy}=5.3 G_{yz}=5.3 G_{xz}=5.3
Main Body	Orthotropic	E_x=18 E_y=170 E_z=1844	υ_{xy}=0.044 υ_{xz}=0.13 υ_{yz}=0.13	G_{xy}=6.2 G_{yz}=364 G_{xz}=350
Bead Bundle	Orthotropic	E_x=21.5 E_y=21.5 E_z=70000	υ_{xy}=0.38 υ_{xz}=0.0012 υ_{yz}=0.0012	G_{xy}=5.3 G_{yz}=5.3 G_{xz}=5.3

3.1.3 Meshing

The accuracy of the solution is linked to the mesh quality. With an appropriate mesh, the solution will converge toward the approximated accepted solution. Meshing was done on ANSYS Mechanical. Air cavity and rim were excluded from the vibration analysis. However, the air pressure has been modelled as load per unit area acting on the internal boundary of the tire structure, where the rim displayed as a fixed support boundary blocking the motion of tire beads in 3D directions. the tire which has four different parts is meshed using 10-node tetrahedral elements, having three degrees of freedom at each node: translations in the nodal x, y, and z directions and consists of 64793 elements and 122167 nodes. Also, this element has plasticity, creep, swelling, stress large deflection, and large strain capabilities.

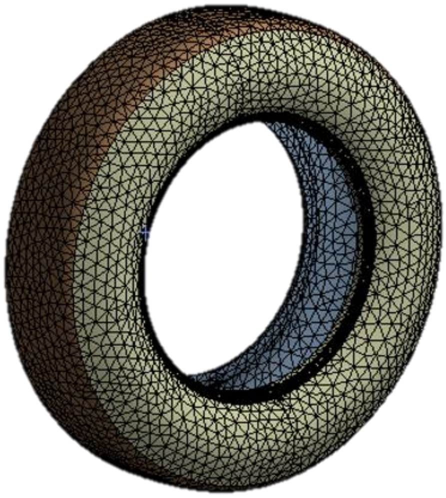


Figure 6. Meshed tire

3.1.4 Boundary Conditions

For a simulation to be executed, there need some boundary conditions to be set. For our case, we have considered the green highlighted portion in the following figure to be fixed. This is the portion of the tire that stays always attached to the rim. As we have excluded the rim from our 3D model, we have to consider the highlighted portion as fixed. It will cause the obstruction of movement to the bead bundle.

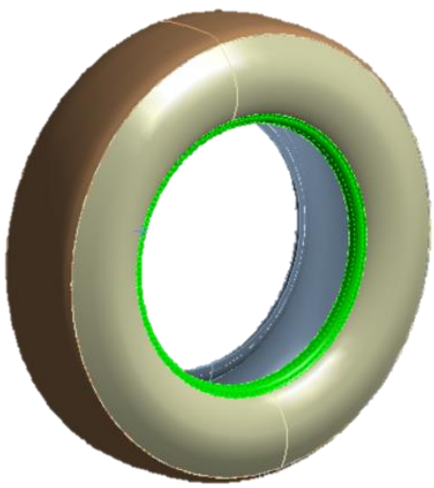


Figure 7. Boundary conditions

3.1.5 Modal Analysis

Modal analysis is the study of the dynamic properties of structures under vibrational excitation. This method is for measuring and analyzing the dynamic response of structures when they are excited by an input. Typical input excitation signals can be classified into impulse, sweep sine, broadband, chirp, etc. and each of them has advantages and disadvantages. The analysis of the signals typically relies on Fourier analysis. The resulting transfer function will show resonances and can estimate characteristic mass, frequency and damping properties. It can also determine structural mode shapes that are very useful to NVH (noise, vibration, and harshness) analysis [3]. However, it has been shown that at frequencies below 500 Hz the tire shows modal behavior [1]. Therefore, modal analysis can be performed to extract its dynamic properties such as mode shapes and natural frequencies.

The stress distribution, which caused by the intake pressure, influences the calculation results of the dynamic behavior of the tire. Simulating the inflation process was done by performing a boundary load per unit area on the internal boundaries of the tire model, that resemble the air pressure of the inflated tire. The solver allowed to extract 5 modes for each inflation pressure.

3.1.6 Harmonic Analysis

To understand the dynamic characteristics of a model, harmonic analysis is performed along with free vibraion analysis or modal analysis. It is used to determine the response of structure under a steady state sinusoidal (harmonic) loading. The analysis considers loading at one frequency only. Loads may be out of phase with one another, but the excitation is at a known frequency. This procedure is not used for arbitrary loading.

Harmonic analysis was also carried out for each of the inflation pressure. A node was created through named selection. A nodal force of magnitude 31 N was applied to the node to observe the harmonic behavior, as the maximum force the mini shaker used in the laboratory can exert is 31 N.

3.2 Experimental Analysis

The basic idea of experimental modal analysis is the excitation of a structure by a measurable dynamic force and measuring the dynamic responses at several points of the structure. The obtained Frequency Response Functions (FRF) show the resonance frequencies of the structure. The mode shapes result from the amplitude of vibration at the resonance frequencies at several points of the structure.

Bridgestone P175/70R13 82S tire, which has maximum vertical load capacity of 4660N (475 kg), was used for our analysis. A ECL 202e sensor was used to sense the exications and a GW Instek oscilloscope was used to display the results.

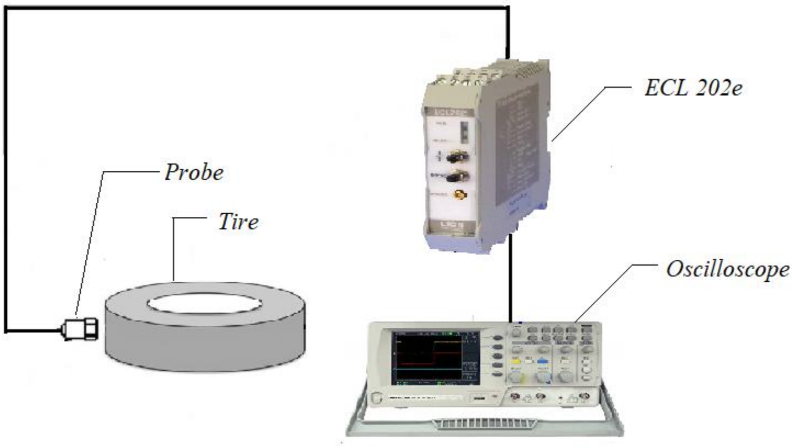


Figure 8. Overview of experimental setup

3.2.1 Determination of Material Properties

To determine the material properties of the tire, the tire was cut into various sections. The standard specimen for material testing could not be prepared due to the difficulties in separation of the parts of the tire. But the laboratory facilities were not enough to determine the properties. To mitigate this problem, the material properties collected from a study [15] of the same model of the tire are used for the analysis.

Figure 9. Main body and tread

Figure 10. Sidewall

Figure 11. Bead bundle

3.2.2 Measurement of Natural Frequency (Initial Setup)

For the free vibration analysis, the tire was fixed at the rear wheel of the car, where the car was upheld with a jackscrew. A L-shaped stand was built to hold the probe of the sensor to provide stability to the sensor.

Figure 12. L-shaped stand

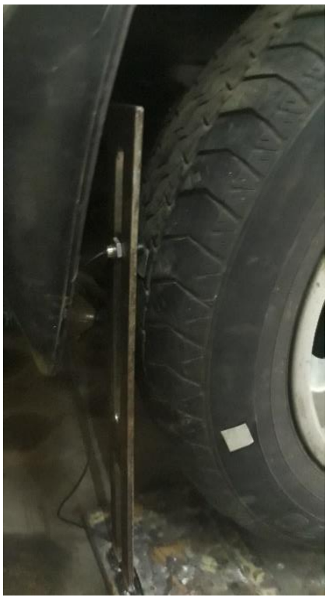


Figure 13. Mounting of the probe

The probe was located between 4 mm from the tire. The sensor could sense only non-ferrous metal. So, an aluminum cross section of 20mm x 20mm was cut with a scissor. Then the foil was attached to the tire with the help of Super Glue.

Figure 14. Aluminum foil strip attached with the tread

The vibration was induced in the tire using a small steel hammer. The ECL 202e sensor measures the vibration and produces an electrical signal which is received in the oscilloscope.
The problem with that setup was the presence of the vertical load or self-weight exerted by the car which hampered the determination of our desired results.

3.2.3 Measurement of Natural Frequency (Intermediate Setup)

This time we hung the tire with nylon cable from four stands fixed on a table. The stress distribution in each cable was maintained equal as far as possible. The setup was able to provide the necessary support to the tire for free vibration analysis. Aluminum strip was attached to the tire. Through a small hammer, vibration was induced and the results were processed and presented through the sensor and the oscilloscope respectively.

The shortcoming of the setup was the table's instability which affected the vibration of the tire also. Thus the results achieved were not desirable.

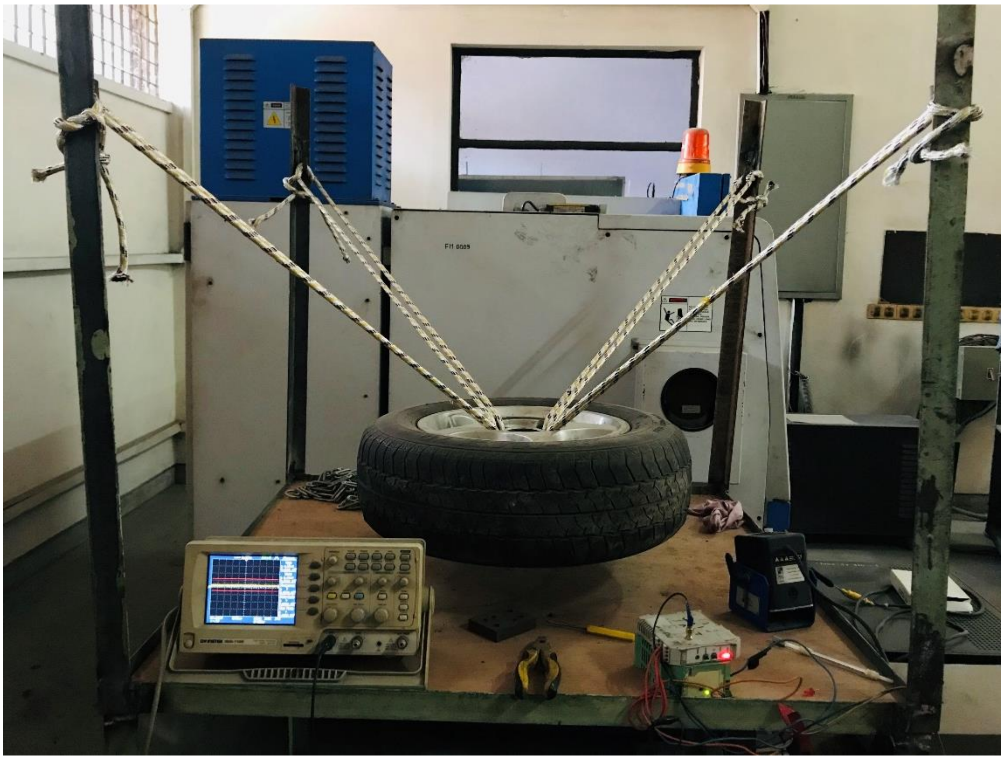


Figure 15. Intermediate setup

3.2.4 Measurement of Natural Frequency (Final Setup)

A stand with four legs was fabricated to provide a base to the tire. The dimensions were such that the tire gets perfectly attached to the stand. Now, the tire with the aluminum strip attached with it was seated in the stand and force necessary to cause vibration was applied through a small hammer.

The measurements are carried out using three different inflation pressures which are 23 psi, 29 psi and 35 psi to describe the effect of the inflation pressure in the natural frequencies.

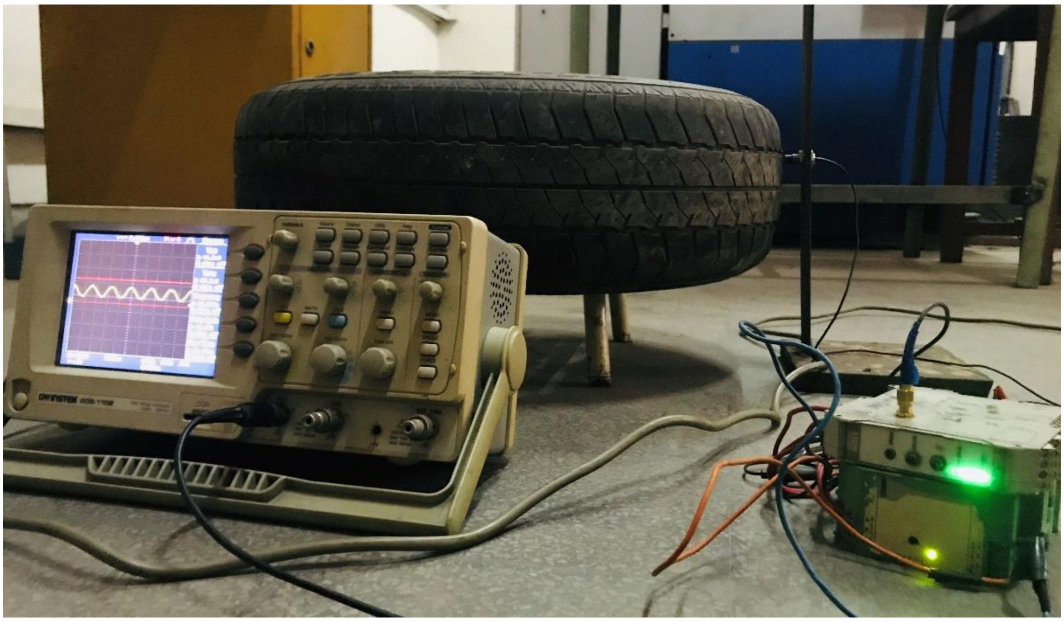


Figure 16. Final setup

The results generated in this setup only is discussed in this paper. The outcomes of the other setups are not considered due to their shortcomings.

4 Results and Discussion

4.1 Numerical Analysis

4.1.1 Modal Analysis

Modes are inherent properties of a structure. They were determined by the material properties (mass, stiffness and damping properties), and boundary conditions of the structure. Each mode is defined by a natural frequency. The solver allowed to extract 5 modes for each inflation pressure.

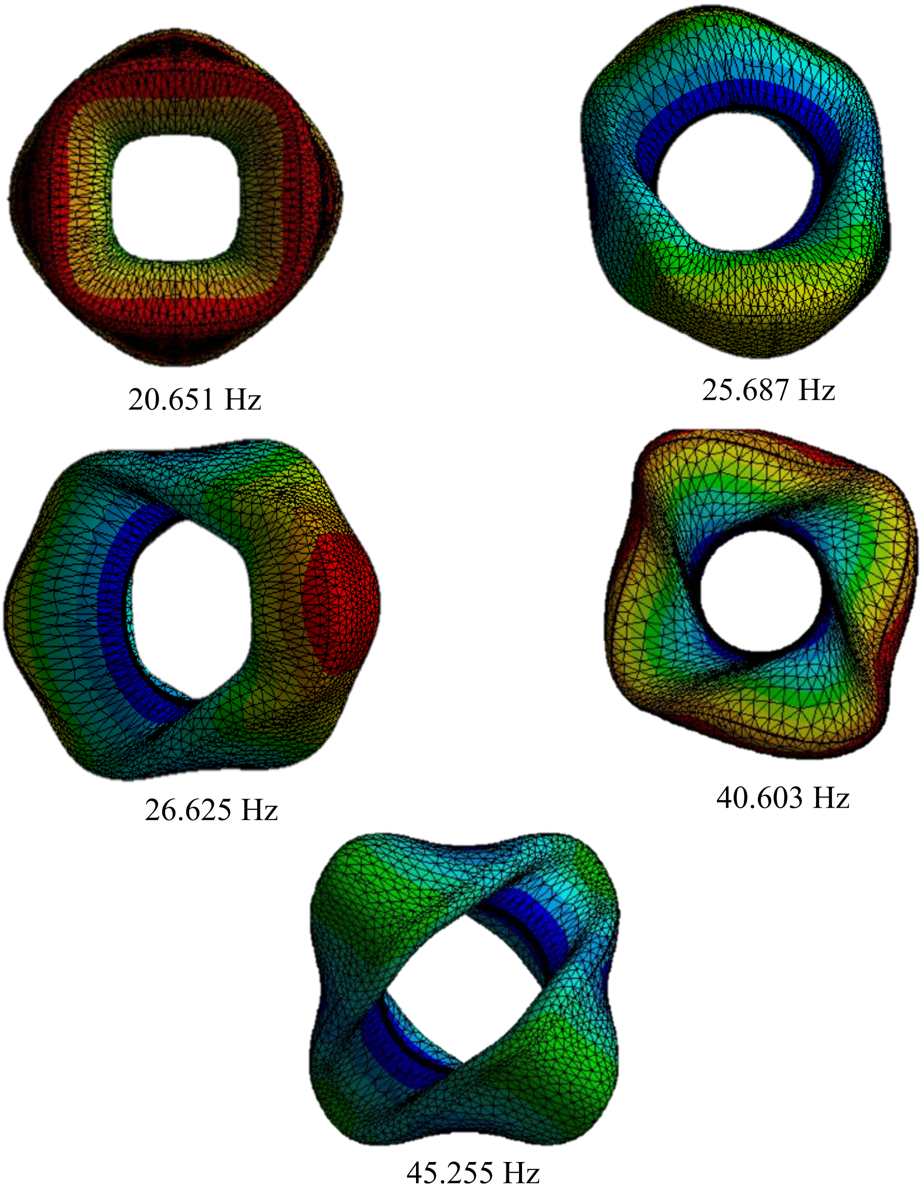


Figure 17. Mode shapes for the inflation pressure of 23 psi

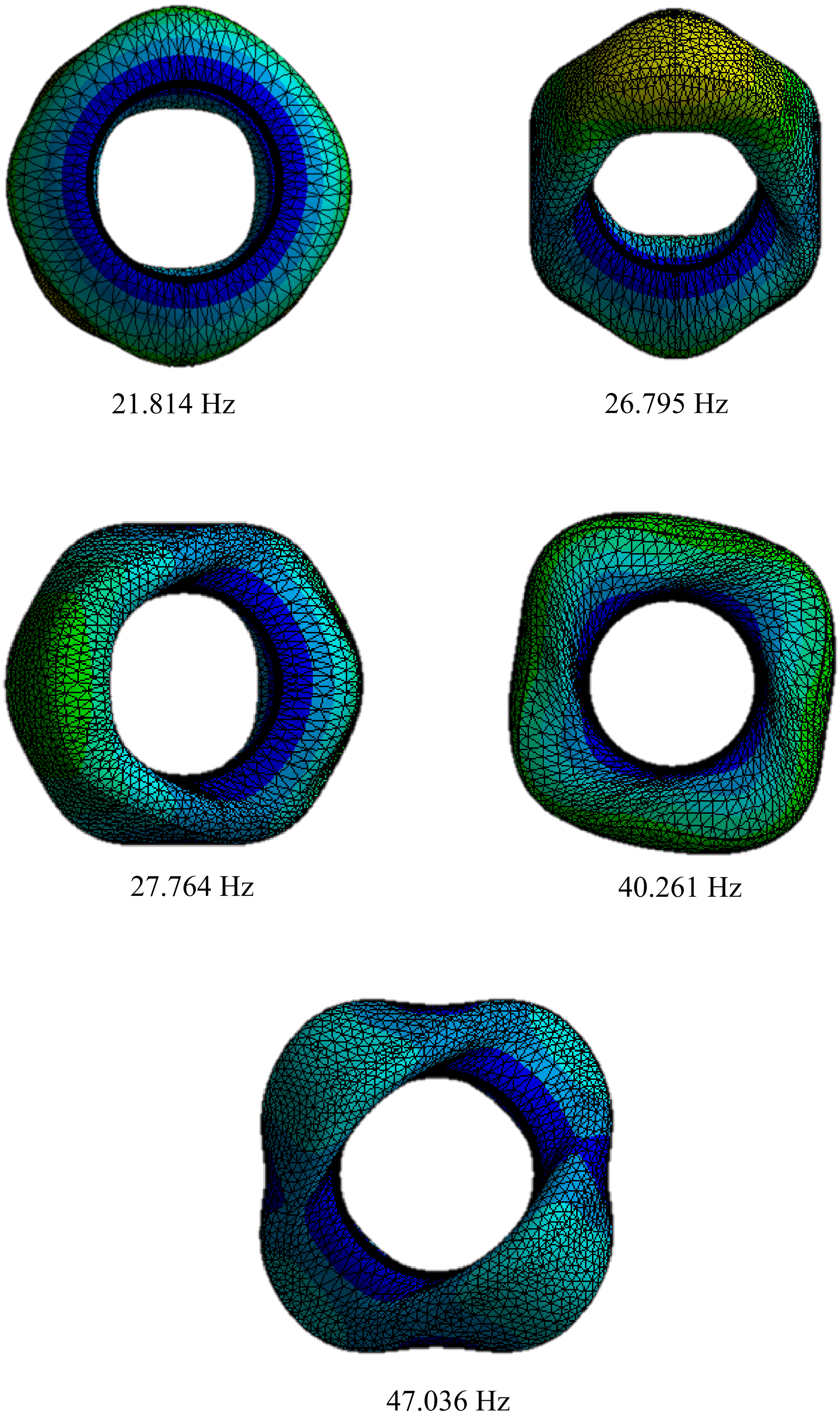
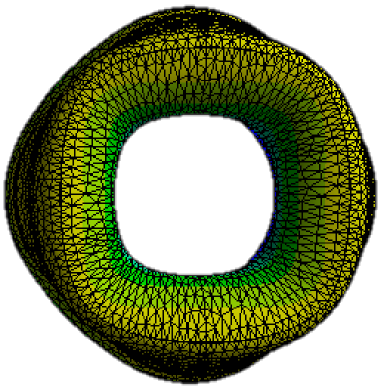
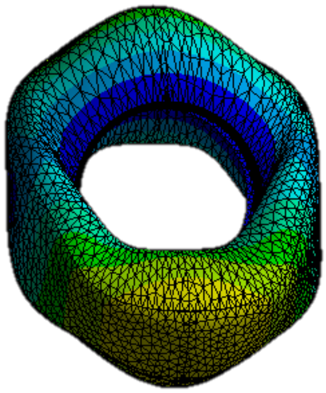


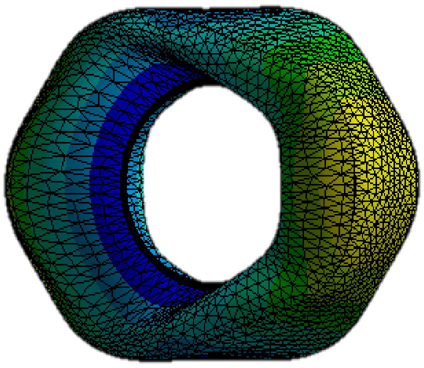
Figure 18. Mode shapes for inflation pressure of 29 psi



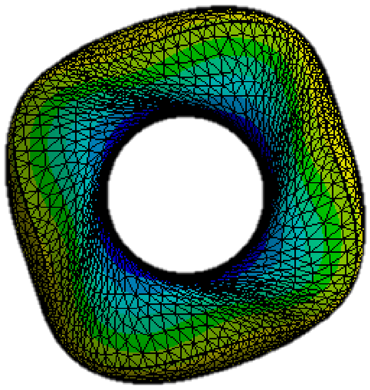
22.673 Hz



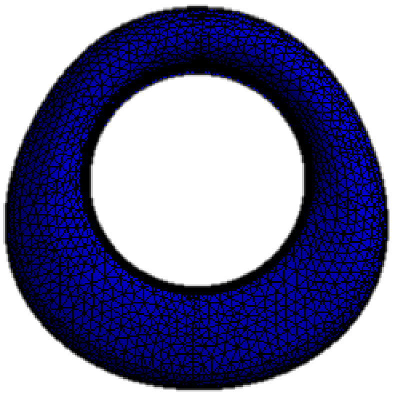
27.666 Hz



28.667 Hz



39.803 Hz



47.922 Hz

Figure 19. Mode shapes for inflation pressure of 35 psi

Modal analysis is carried out using 3D numerical model for each inflation pressure. According to the results, the natural frequencies increase with increased inflation pressure. The results are tabulated below:

Table 2. The natural frequencies of the tire under three different inflation pressures

Mode	Natural Frequency (Hz)		
	Pressure (23 psi)	Pressure (29 psi)	Pressure (35 psi)
1	20.651	21.814	22.673
2	25.687	26.795	27.666
3	26.625	27.764	28.667
4	39.803	40.261	40.603
5	45.255	47.036	47.922
6	46.345	47.321	48.599

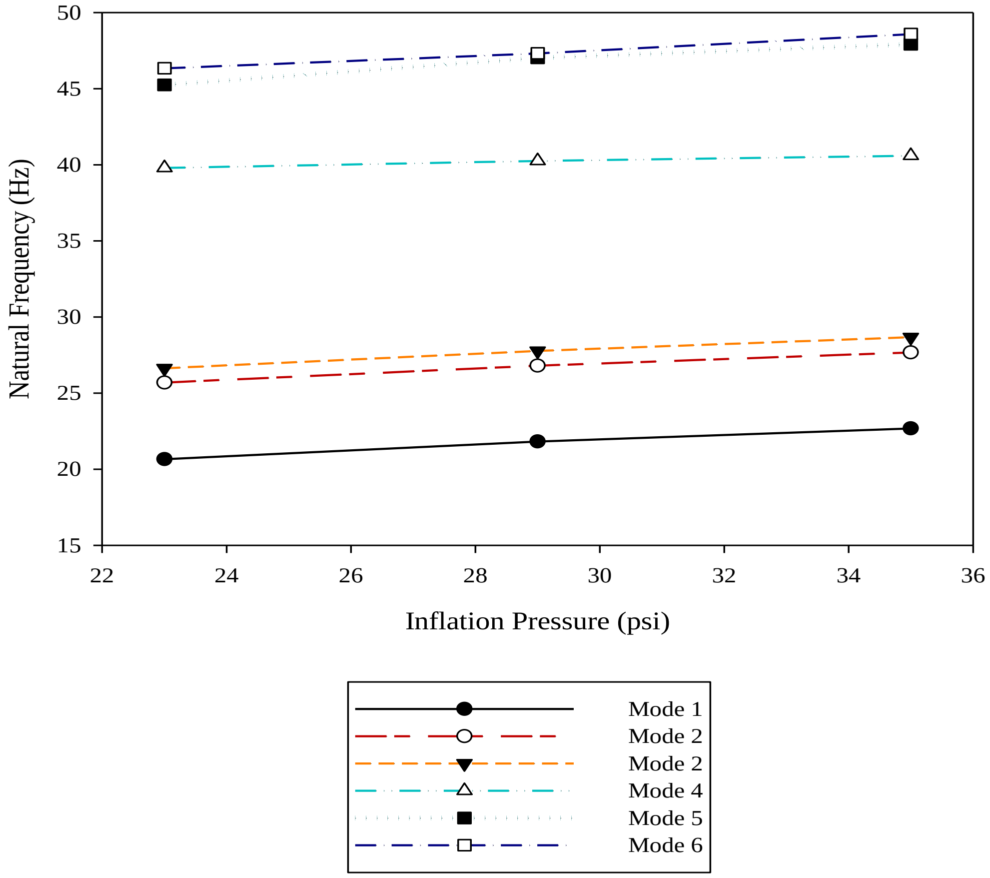


Figure 20. The natural frequencies of the tire under three different inflation pressures

4.1.2 Harmonic Analysis

The analysis shows if the peak amplitudes are at the modal frequencies or not. The following frequency response graphs were generated for corresponding inflation pressure to show variation in deformation:

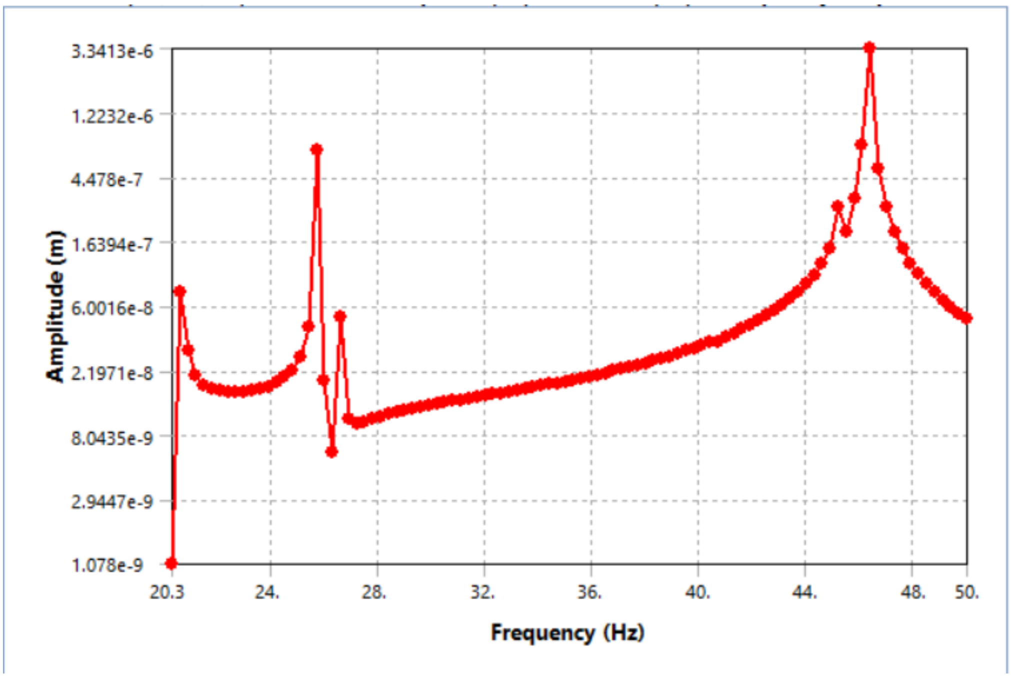


Figure 21. Harmonic frequency response for 23 psi

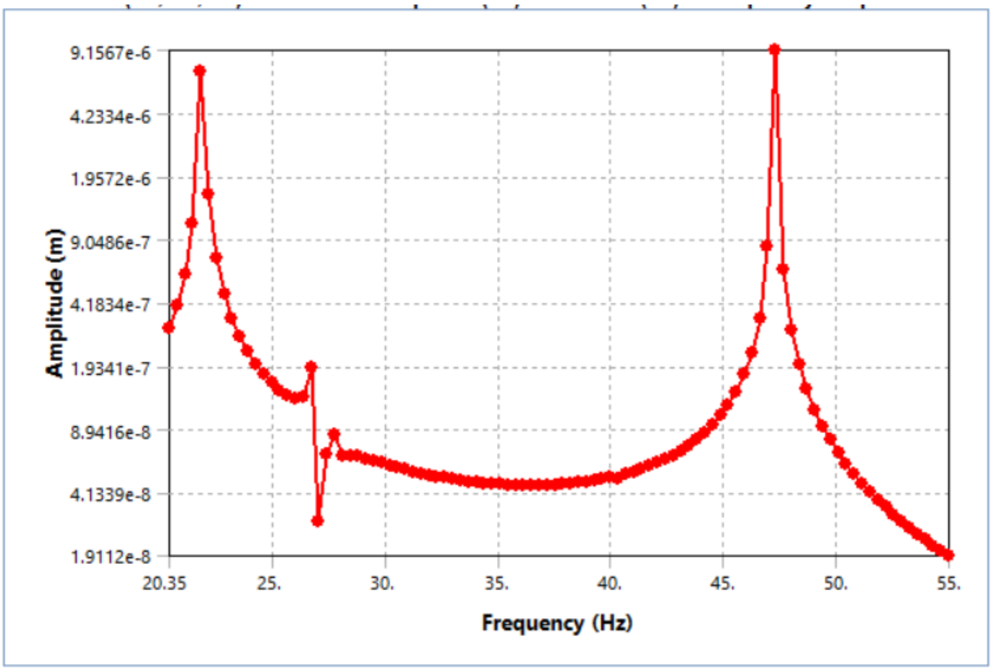


Figure 22. Harmonic frequency response for 29 psi

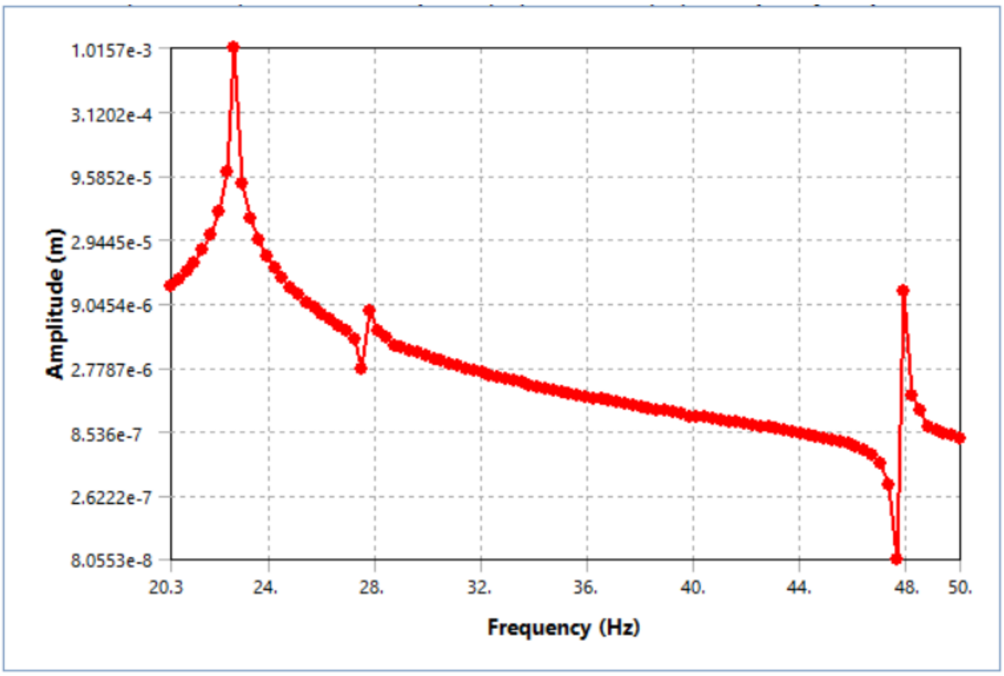


Figure 23. Harmonic frequency response for 35 psi

The graphs obtained through numerical harmonic analysis reveals that the amplitudes are high at the modal frequencies. The highest amplitude is at 46.345 Hz for 23 psi. For 29 psi and 35 psi, the highest amplitudes are at 47.321 Hz and 22.673 Hz respectively.

4.2 Experimental Analysis

The natural frequencies measured for each inflation is tabulated below:

Table 3. Experimental data

Inflation Pressure (psi)	Experimental Data (Hz)
23	22.95
29	23.64
35	24.6

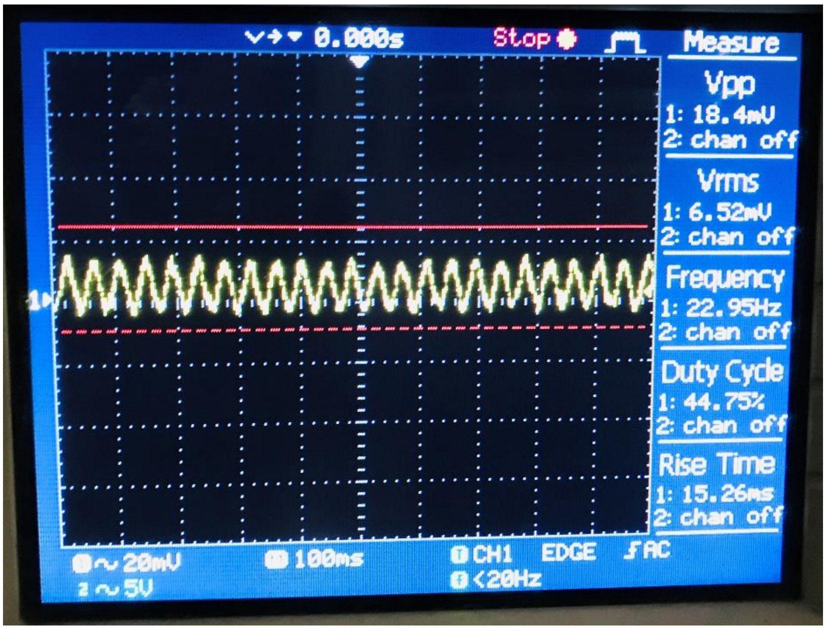


Figure 24. Measured frequency for inflation pressure of 23 psi

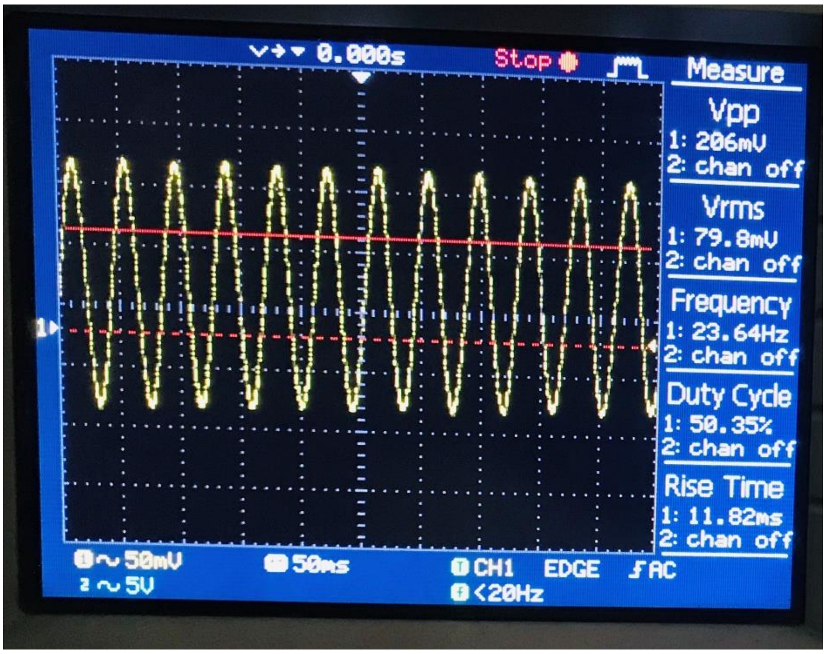


Figure 25. Measured frequency for inflation pressure of 29 psi

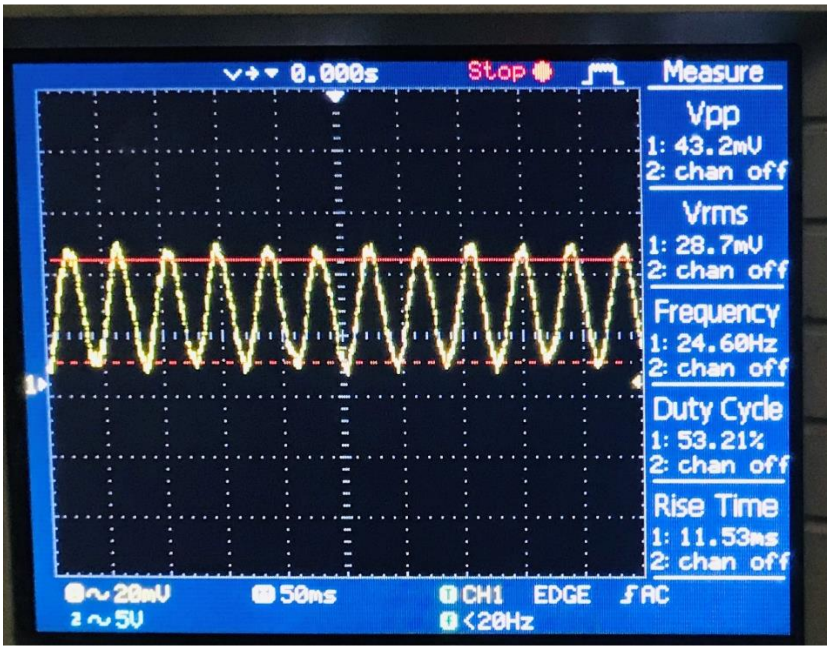


Figure 26. Measured frequency for inflation pressure of 35 psi

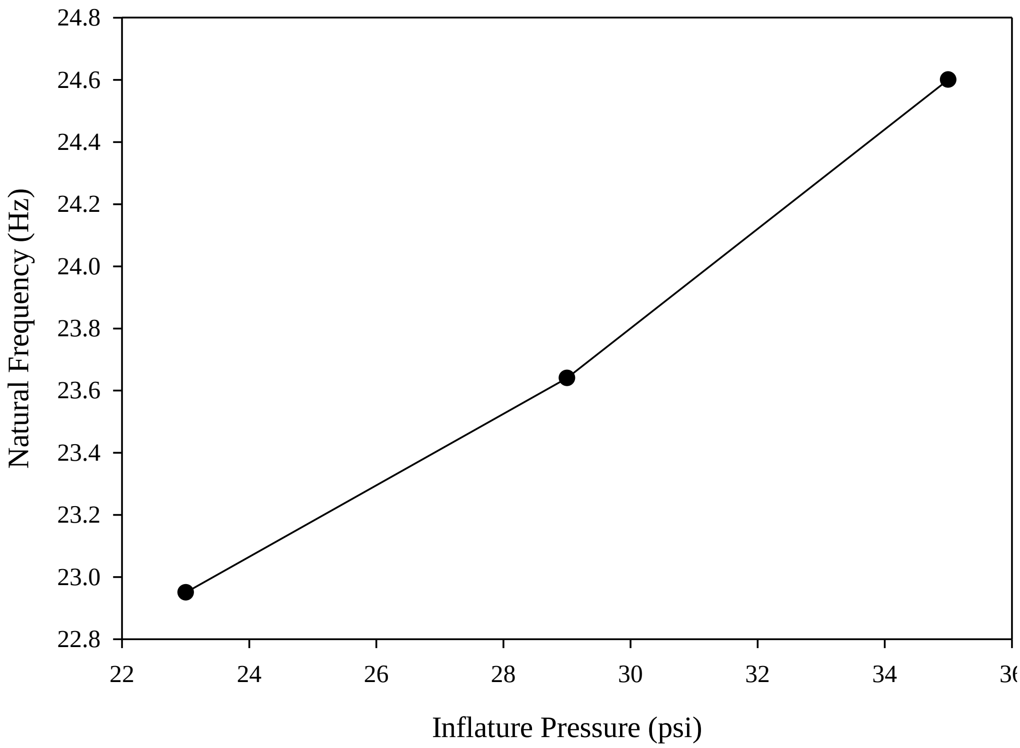


Figure 27. The experimental natural frequencies of the tire under three different inflation pressures

Our findings demonstrate that the frequency increases with the increasing pressure. The relationship is almost linear.

4.3 Validation

The discrepancy between the numerical and experimental data is negligible. The variation is due to the lack of soundproof environment during the measurement of experimental data. Besides, the base used for holding the tire could not be properly fixed. This factor may be responsible for the results achieved.

Table 4. Comparison of numerical and experimental first natural frequency

Inflation Pressure (psi)	Numerical Data (Hz)	Experimental Data (Hz)	Error (%)
23	20.651	22.95	10.02
29	21.814	23.64	7.72
35	22.673	24.6	7.83

In the case of numerical analysis, the inaccuracy in the modeling may play a vital role in the unexpected results. The dimensions are tried to kept as similar as possible to an actual tire. The variation may also be due to our inability to get the right mechanical properties of the compound materials. As the tire manufacturing companies keep this information to themselves, it is very difficult to make an exact model of the commercially available tire.

5 Conclusion

We have studied an automotive wheel vibration behavior using experimental and numerical modal analysis on a commercially available tire. Harmonic analysis is performed only numerically. Our work has led to the conclusion that:

1) The natural frequency increases with the increase of inflation pressure.
2) The developed finite element mode is verified with experimental results via comparison of resonance frequencies and mode shapes. The amount of error is around 10%.
3) Although the initial simulation results show some deviation from experimental measurements, still the dynamic behavior of the model is taking the same pattern compared to measurement. The potential reasons for this division can be referred to the low mesh quality, which has effect on the accuracy in the first step of the simulation, this lead to an error in the stress computations especially in the hot spot areas like belts, and ply, which has even lower mesh quality.
4) The harmonic analysis demonstrates that the amplitudes are high at the modal frequencies.

6 Future Scope

The study is the first step towards enhancing our understanding towards various factors affecting the vibration of a tire. Further work needs to be carried out to estimate the other parameters' effect on the tire vibration. To improve stability and reduce vibration of the tire, analysis can be performed by changing the boundary conditions. Tire can be contacted by the ground to have a more realistic analysis. In this case, the effect of coefficient of friction will also be accountable. The tire can also be tested by mounting to the car to have the effect of the self-weight of the car included. The effect of rotational speed can be considered for the monitoring of the tire behavior under continuous loads. The prospect of being able to understand and reduce vibration, should serve as a continuous incentive for future research.

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