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# FEA (FINITE ELEMENT ANALYSIS) OF RAIL WHEEL OF VANDE-BHARAT EXPRESS WHEN ITS SPEED UPGRADED UP TO 400 KM/H

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## ABSTRACT

Vande-Bharat train is a semi-high speed train of India which is designed to run at a speed of 180 km/h. But according to the railway track infrastructure available in India, it can run at a maximum speed of 160 kilometers per hour. In the future, there are plans to build some special railway corridors on which the speed of trains is planned to be increased from 180 to 380 km/h .As announced by our current Railway Minister Shri Ashwin Vaishnav ji in IREE-2025, Since then a curiosity arises in the mind which is also the topic of this research. What modifications will we have to make to the design of the Vande-Bharat Express if we make it run at 400 km/h in its current design? This topic is very vast and requires a lot of research. But if we design and analyze any one part of the Vande-Bharat train, we can open the doors to many researches in this direction. In this research, we have designed a wheel of Vande-Bharat train and done its CAE analysis, the details of which are given in this research paper.

**Introduction-** To test the wheels of the Vande-Bharat train by running them at speeds of up to 400 km/h, we first needed to create a 3D model of the Vande-Bharat train's wheels. For this, we searched through the documents available on public platforms, and found a document titled "Vande-Bharat Volume-2." Upon reviewing "Vande-Bharat Volume-2," we found drawing number 455.0.164.000.30 on page number 377, which contained a drawing of the wheel used in the Vande-Bharat train. Using the dimensions provided, we created a 3D model of the rail wheel. The 3D model was created using software called Solidworks. After creating the 3D model, it was saved in IGES format and imported into Ansys software. The analysis of the research process is explained under the following headings.


**Fig-1 Layout of Analysis on Ansys Workbench**

**Methodology-**

First, creating 3D model using
3D modeling software
(SolidWorks)
↓
Converting the 3D model to IGES format and importing it into ANSYS software
↓
Performing Geometry Cleanup on the imported model using ANSYS Discovery
↓
After Geometry Cleanup, assigning material properties to the model and performing meshing
↓
After meshing, applying boundary conditions then
↓
Analyzing various parameters
↓
Determining the results
↓
Conclusion
↓
References

**Import Model and Geometry cleanup-** CAD models are often created for design purposes rather than analysis, so small flaws that can cause major problems in simulation are corrected. Fixing flaws such as gaps or overlaps makes the model simple and error-free, so that simulation results are reliable and can be obtained in less time. We used Ansys Discovery software for geometry cleanup. The model after geometry cleanup is shown in Figure-2.

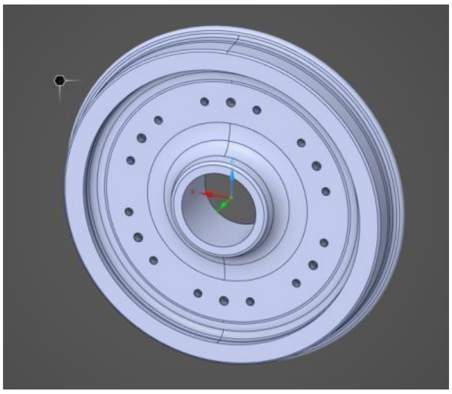


Fig-2

**Material Assignment-**Material Assignment is an important step to make the object realistic. You can go to Engineering Data in ANSYS and select the material as per your requirement which represents the physical properties of the object. Material ER8 as per EN13262 has been used in the rail wheel which is shown in figure number 3.

ER8 as per EN13262

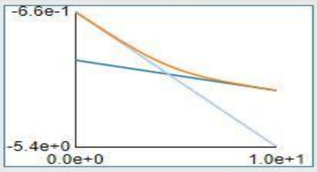
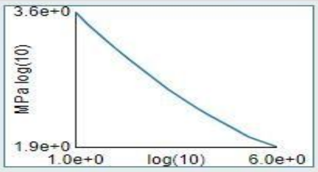
| | |
|---|---|
| Density | 7.85e-06 kg/mm³ |
| **Structural** | |
| Isotropic Elasticity | |
| Derive from | Young's Modulus and Poisson's Ratio |
| Young's Modulus | 2.1e+05 MPa |
| Poisson's Ratio | 0.3 |
| Bulk Modulus | 1.75e+05 MPa |
| Shear Modulus | 80769 MPa |
| Isotropic Secant Coefficient of Thermal Expansion | 1.2e-05 1/°C |
| Compressive Ultimate Strength | 0 MPa |
| Compressive Yield Strength | 250 MPa |
| Strain-Life Parameters |   |
| S-N Curve |   |
| Tensile Ultimate Strength | 460 MPa |
| Tensile Yield Strength | 250 MPa |

Fig-3

**Meshing-** Meshing is a crucial process in FEA simulations that breaks down a complex 3D CAD geometry into smaller, more precise shapes. This is essential for accurate FEA simulation calculations, making analysis of complex parts easier. Meshing directly affects the accuracy, convergence, and speed of FEA/CFD simulations. Rough meshing can lead to simulation errors, while fine meshing ensures accurate results. Meshing of a rail wheel is shown in Fig-4 & 5.

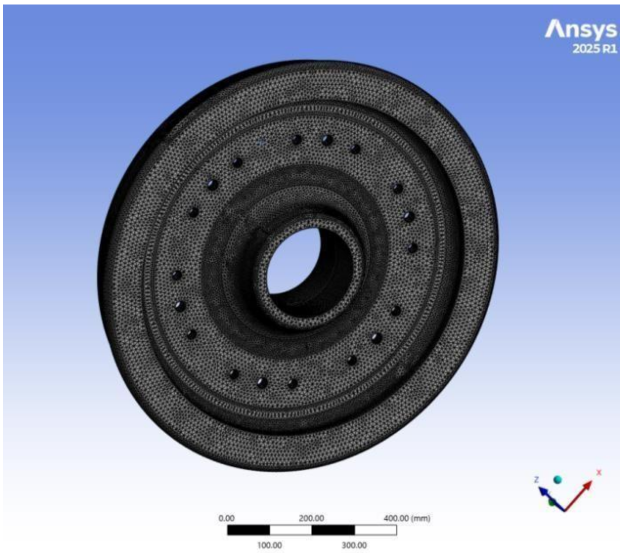



**Fig-4**

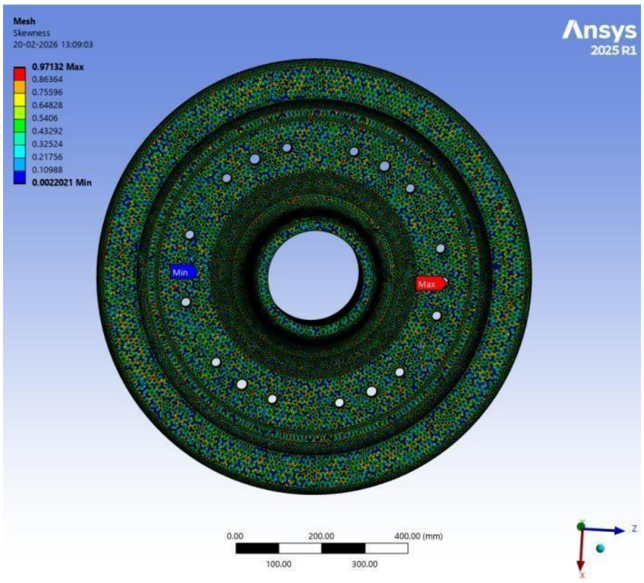



**Fig-5**

**Applying the boundary condition**

Applying boundary conditions is a crucial step in FEA (Finite Element Analysis), which determines where an object is stationary, how it can move, and what external forces are acting on it. Boundary conditions are applied as closely as possible to the actual physical situation. In our research, the boundary conditions are shown in Figure. In this study, an acceleration of 400 km/h is applied in the X-direction to the fixed support of the center proton of a rail wheel, which is shown in Fig-6.

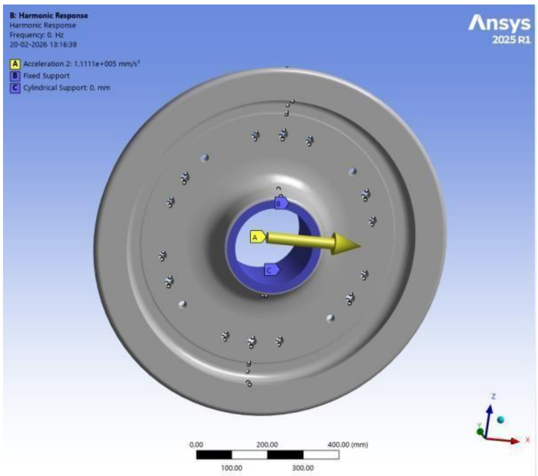



**Fig-6**

**Analyzing various parameters**

**1. Model Analysis**-Model analysis is done on a moving object which reveals how a moving object behaves at different speeds during its state of motion and how much deflection is produced inside it. In our research, if we have to make a rail wheel move at a speed of up to 400 km/h, then we have to test it at a frequency up to 2000 Hz. Here the rail wheel has been tested at 10 different frequencies which are shown in the 10 pictures shown below. Model testing of the rail wheel has been done at random frequencies in the range of 600 Hz to 2000 Hz and the deflection produced at all those frequencies is shown in the pictures shown below fig-7 to fig-17.

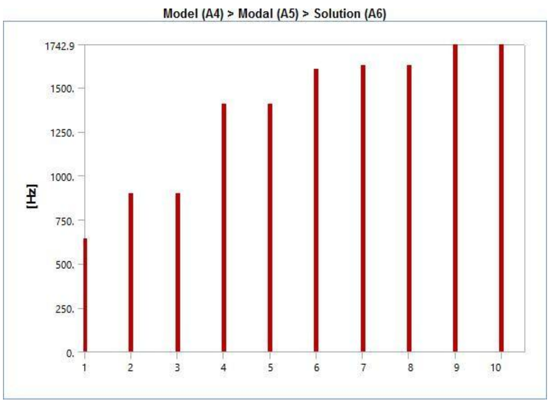



**Fig-7**

**Model Analysis mode-1** – Mode-1 displayed in figure -8, In this figure Natural frequency is 643.45 Hz and the maximum deformation 2.261 mm, In this figure Blue color show minimum displacement, Red color show maximum displacement (2.261 mm), the outer rim (red color) shows the largest vibration amplitude. It’s recommended for improve design as of stiffening rim, adding damping, and changing in geometry

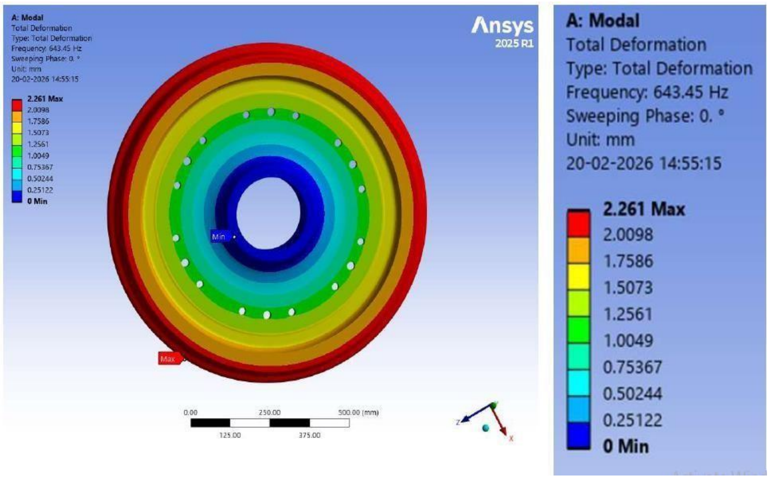



**Fig-8**

**Model Analysis mode-2 -** Mode -2displayed in figure -9, In this figure Natural frequency is 896.18 Hz and the maximum deformation 4.0233 mm, In this figure Blue color show minimum displacement, Red color show maximum displacement (4.0233 mm), wheel is vibrating in a specific pattern, In the figure show a specific wave pattern around the circumference of wheel, it indicates multiple lobes, typical of higher-order vibration modes. Its helps that identified the weak zones in wheel.

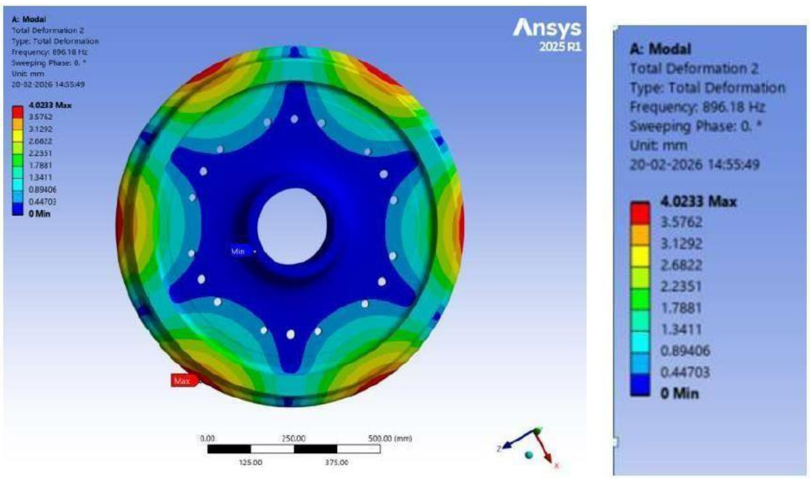



**Fig-9**

**Model Analysis mode-3** Mode -3 displayed in figure -10, in this figure Natural frequency is 896.55 Hz and the maximum deformation 4.0261 mm. In this figure Blue color show minimum displacement, Red color show maximum displacement (4.0261 mm), wheel is vibrating in a specific pattern as like mode -2 but the pattern seems rotating in 90º angle , In the figure show a specific wave pattern around the circumference of wheel, it indicates multiple lobes, typical of higher-order vibration modes. It's to identify the weak zones.

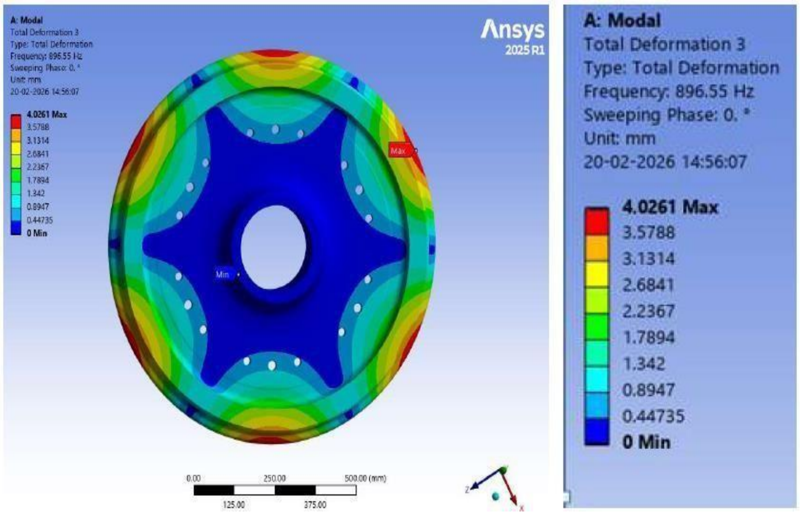



**Fig-10**

**Model Analysis mode-4** Mode -4 displayed in figure -11, in this figure Natural frequency is 1404.2 Hz and the maximum deformation 2.495 mm. In this figure Blue color show minimum displacement, Green &Yellow color show Medium deformation .Red color show maximum displacement (2.4951 mm), in this mode the pattern looks completely different from the previous modes the pattern looks like Concentric ring like deformation (radial mode).

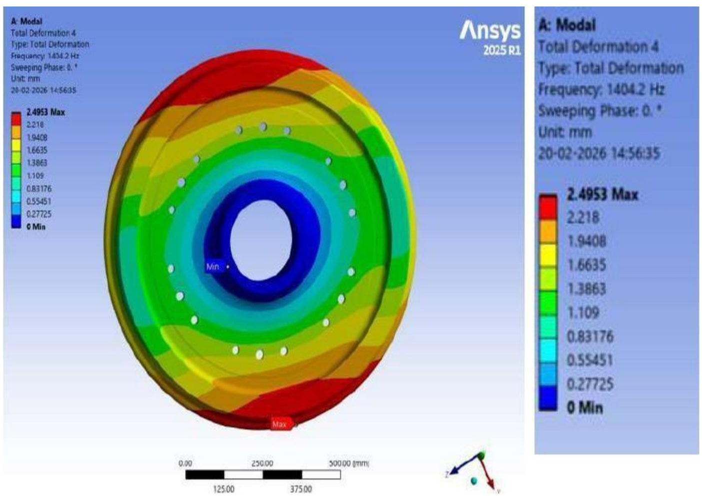



**Fig-11**

**Model Analysis mode-5** Mode -5 displayed in figure -12, in this figure Natural frequency is 1404.2 Hz as same as model-4and the maximum deformation 2.4956 mm. In this figure Blue color show minimum displacement, Green &Yellow color show Medium displacement .Red color show maximum displacement (2.4956 mm), in this mode the pattern seems similar looks like mode-4 but rotating approximately 90º angle. Looks like Concentric ring like deformation (radial mode).

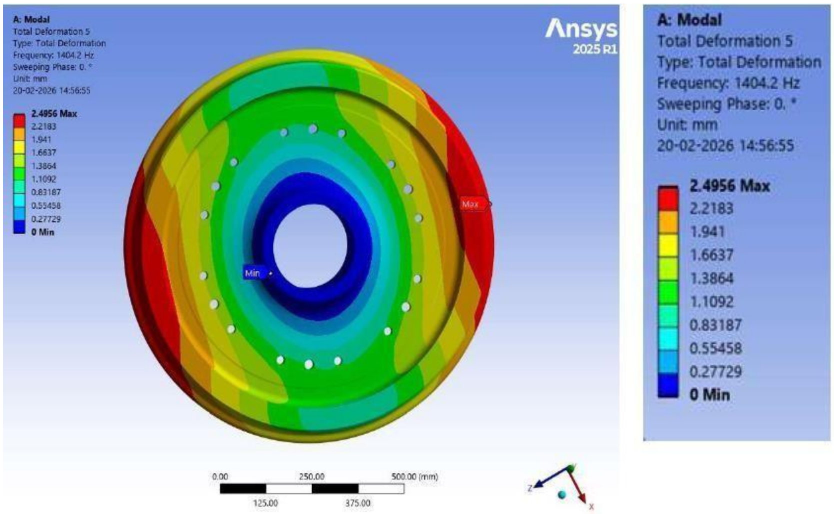



**Fig-12**

**Model Analysis mode-6** Mode -6 displayed in figure - 13, in this figure Natural frequency is 1606 Hz and the maximum deformation 3.0827 mm. In this figure blue color show minimum displacement, Green &Yellow color show medium displacement. Red color show maximum displacement (3.0827 mm), in this mode the pattern seems totally different to other mode. Looks like Concentric rings

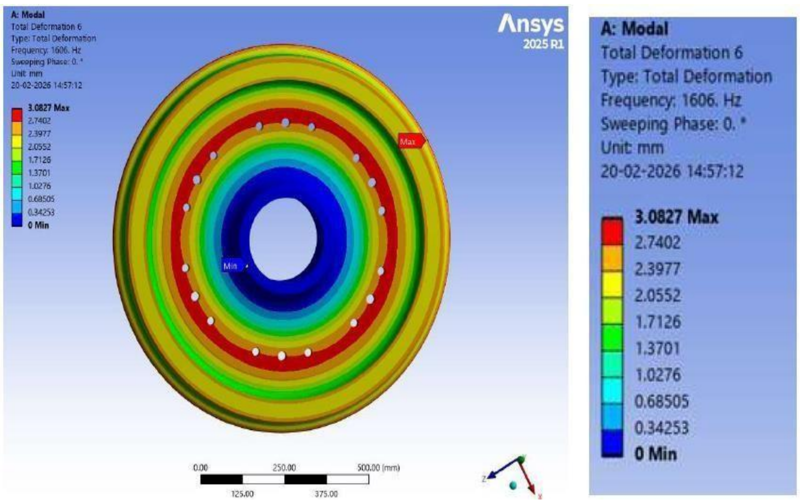



**Fig-13**

**Model Analysis mode-7** Mode -7 displayed in figure - 14, in this figure Natural frequency is 1625 Hz and the maximum deformation 4.2501 mm. In this figure Blue color show minimum displacement, Green &Yellow color show Medium displacement .Red color show maximum displacement (4.25 mm), The wheel is vibrating in a complex wave pattern around its circumference. In this figure a specific wave pattern around the circumference of wheel, it indicates multiple lobes, typical of higher-order vibration modes. It's to identify the weak zones.

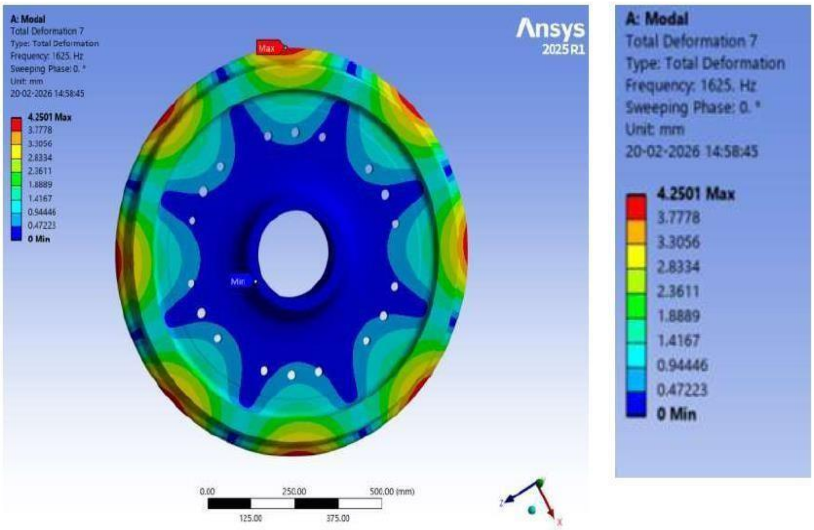



**Fig-14**

**Model Analysis mode-8** Mode -8 displayed in figure - 15, in this figure Natural frequency is 1625 Hz as similar mode-7 and the maximum deformation 4.2497 mm. In this figure Blue color show minimum displacement, Green &Yellow color show Medium displacement .Red color show maximum displacement (4.25 mm), the wheel is vibrating in a complex wave pattern around its circumference. In this figure a specific wave pattern around the circumference of wheel, it indicates multiple lobes, typical of higher-order vibration modes. It's to identify the weak zones.

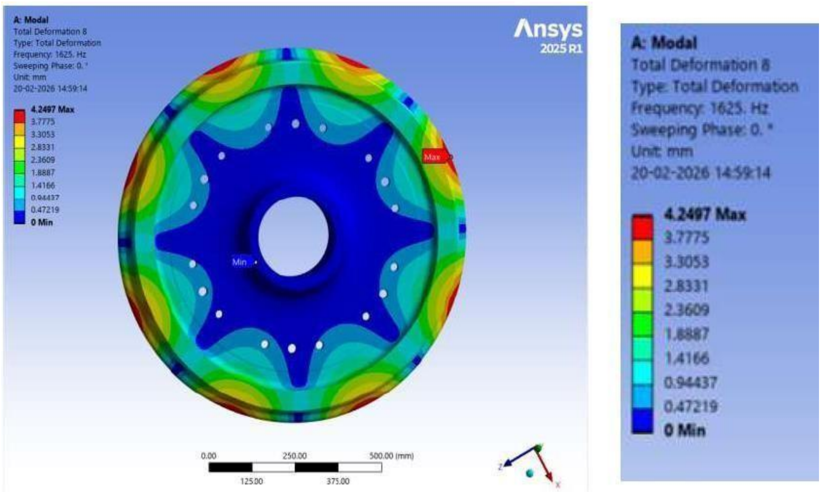



**Fig-15**

**Model Analysis mode-9** Mode -9 displayed in figure - 16, in this figure Natural frequency is 1742.8 Hz as and the maximum deformation 4.2497 mm. In this figure blue color show minimum displacement, Green &Yellow color show medium displacement. Red color show maximum displacement (4.204 mm), in this mode the vibration pattern is symmetric typical for modal shapes.

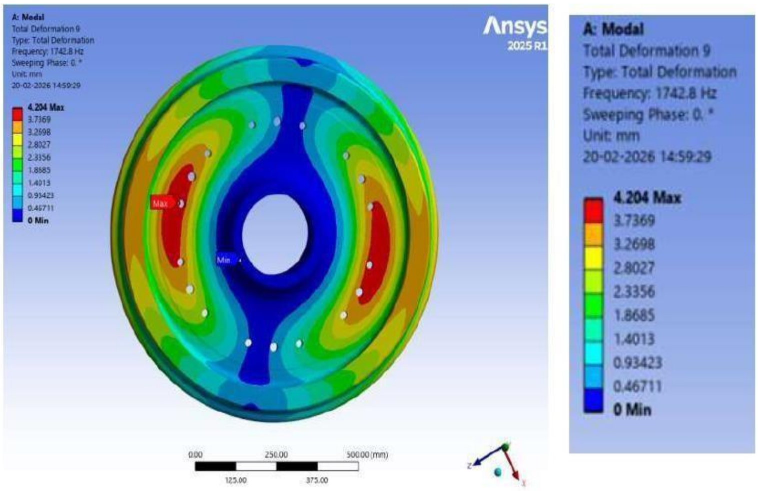



**Fig-16**

**Model Analysis mode-10** Mode - displayed in figure - 17, in this figure Natural frequency is 1742.9 Hz as and the maximum deformation 4.2266 mm. In this figure the pattern is similar as like mode-9 but as seems rotated to the 90º angle. Blue color show minimum displacement, Green &Yellow color show Medium displacement .Red color show maximum displacement (4.2266 mm), in this mode the vibration pattern is symmetric typical for modal shapes

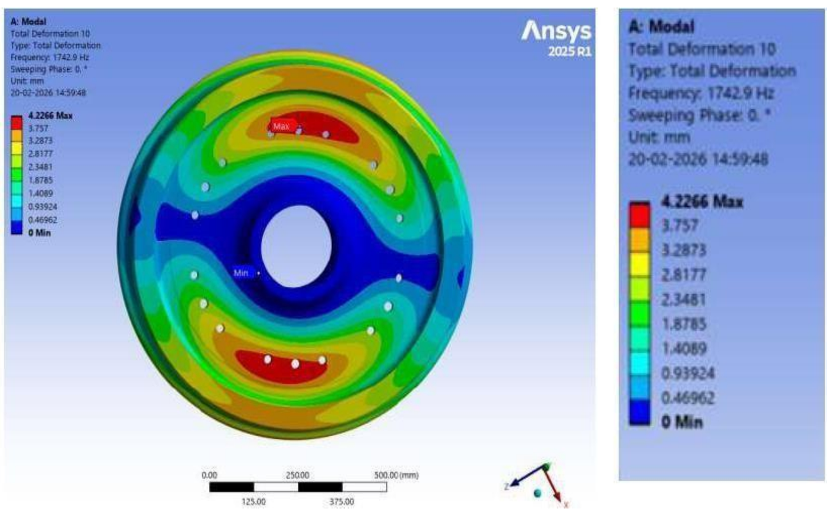



**Fig-17**

**Table of model analysis**

| A | B | C | D |
|---|---|---|---|
| | Mode | Frequncy(Hz) | Total Deformation max value (mm) |
| 1 | 1 | 643.45 | 2.261 |
| 2 | 2 | 896.18 | 4.0233 |
| 3 | 3 | 896.55 | 4.0261 |
| 4 | 4 | 1404.2 | 2.4953 |
| 5 | 5 | 1404.2 | 2.4956 |
| 6 | 6 | 1606 | 3.0827 |
| 7 | 7 | 1625 | 4.2501 |
| 8 | 8 | 1625 | 4.2497 |
| 9 | 9 | 1742.8 | 4.204 |
| 10 | 10 | 1742.9 | 4.2266 |

**Table-1**

**Harmonic Response Analysis -** In Harmonic Analysis It calculates the steady-state response of linear structures to sinusoidal varying loads over a frequency range. It determines the resonance frequencies, fatigue-inducing stresses and maximum campus amplitudes. In our research, the speed of the rail wheel has been kept at 400 km/h and the wheel has been tested at various positions at frequencies up to 2000 Hz. The objective of Harmonic Response Analysis is to determine whether a design will be able to withstand continuous cyclic loading without excessive noise or vibration or failure due to fatigue. In the figures shown below, the Frequency Response graphs are shown in the direction of X-Axis, Y-Axis and Z-Axis in Figures 18, 19 and 20 respectively

**Harmonic Response in X- axis-**

Two types of graphs are shown in the figure. The top graph shows amplitude versus frequency. The X-axis shows frequency and the Y-axis shows amplitude.

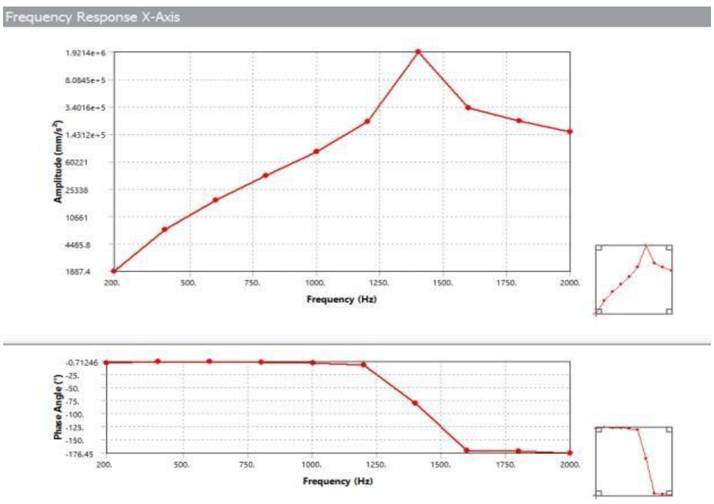



**Fig-18**

In this graph (Fig-18), the frequency increases from about 200 Hz to 1400 Hz, and the amplitude increases almost steadily. A sharp peak appears near 1400 Hz, which is called the wheel's resonance frequency. After this peak, the amplitude begins to decrease, meaning the wheel responds less strongly to higher frequencies.
It means the wheel vibrates most strongly at ~1400 Hz.
The second graph shows the difference between phase angle and frequency.
The X-axis represents frequency (in Hertz) and the Y-axis represents phase angle (in degrees).
At low frequencies, the phase is approximately 0°, meaning the input and output are in nearly the same order.
As the frequency approaches resonance (~1400 Hz), the phase begins to decrease.
After resonance, the phase reaches approximately -180°, meaning the output is almost completely in opposite phase to the input.

**Harmonic Response in Y- axis –**

At low frequencies of 200–400 Hz, the amplitude is low and reaches a minimum at about 400 Hz.
Above about 400 Hz, the amplitude gradually increases.
There is a strong peak around 1400 Hz. This is the main resonance in the Y direction.
After the peak, the amplitude decreases at about 1500-1600 Hz, then increases slightly at about 1700-1800 Hz, then decreases toward 2000 Hz.
In this graph has a major resonance at around 1400 Hz.

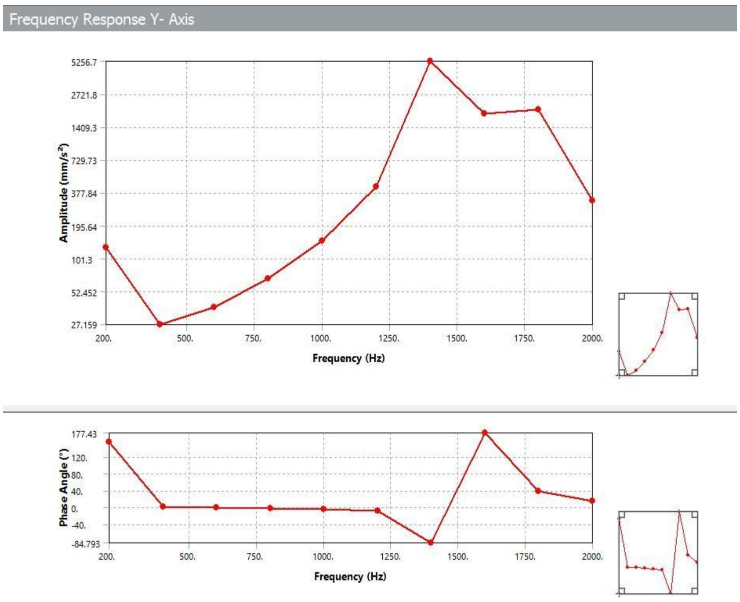



**Fig-19**

A slight increase around 1700-1800 Hz indicates a secondary mode, i.e., another vibration pattern.
A dip at a lower frequency of 400 Hz may indicate a counter- resonance, i.e., a frequency where motion is inhibited.
In Bottom graph who plotted with Phase vs. Frequency
At about 200 Hz, the pulse begins at approximately +180°

It rapidly decreases to approximately 0° and remains nearly constant until approximately 1200 Hz. At approximately 1400 Hz, the pulse begins to tilt toward negative values (approximately -90°). After this, it suddenly increases to +180° at approximately 1500 Hz. After this, the pulse gradually decreases and begins to approach 0° again.

**Harmonic Response in Z- axis –**

In the top graph the amplitude increases steadily as the frequency increases from about 200 Hz to about 1400 Hz.

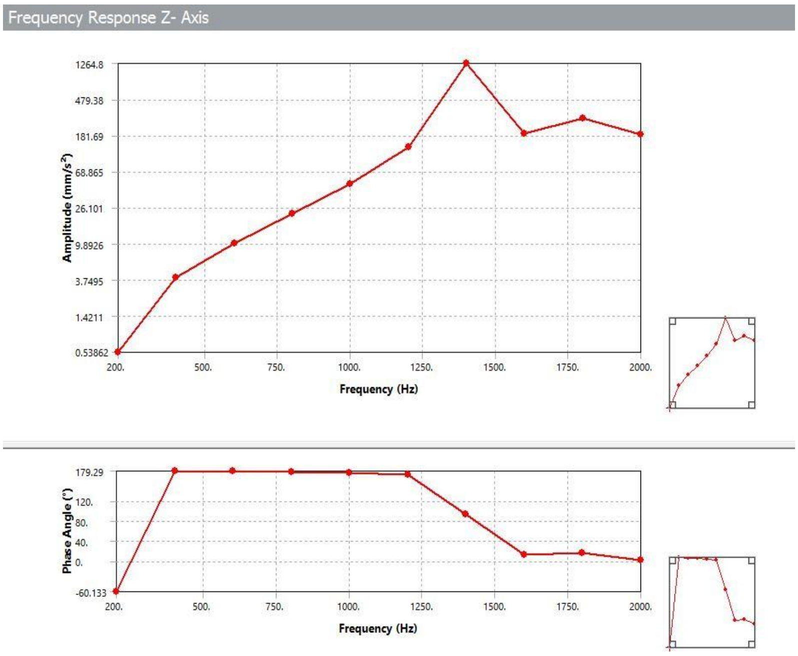



**Fig-20**

A sharp peak appears at about 1400 Hz, indicating the resonance frequency—the system vibrates most intensely at this frequency.
After 1400 Hz, the amplitude decreases, then fluctuates slightly but remains below the peak.
This wheel is most sensitive at about 1400 Hz. This is likely a natural frequency where energy input produces intense vibrations.
The bottom graph shows phase angle versus frequency.
At low frequencies around 200 Hz, the phase begins at about -60°.It rapidly increases to about 180° and remains constant until about 1200 Hz.
Around the resonance region of 1300–1500 Hz, the phase rapidly decreases. At higher frequencies, the phase stabilizes at about 0–20°.

**Static Structural Analysis** Displacement, stress, strain, and force are examined in structures subjected to static loads. The research here involves calculating stress, strain, and strain-hotel deflection, which are shown in Fig-21, 22 and 23.

**Stress Analysis** - applying boundary condition the acceleration 400k/h on wheel, analysis of the equivalent stress displayed in figure- 21. And the explanation is given following lines. There is very little stress on the component. There is no immediate risk of breakage. Stress concentrations are present around the holes. The design appears to be mechanically safe under applied static loads.

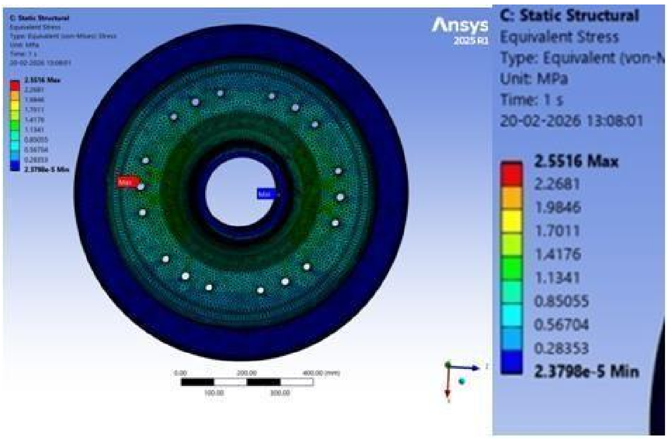



**Fig-21**

**Strain Analysis-** applying boundary condition the acceleration 400k/h on wheel, analysis of the strain displayed in figure- 22. And the explanation is given following lines. Equivalent elastic strain is a combined measure of deformation in all directions, often similar to a von Mises -type strain measure.

The diagram on the left shows the intensity of distortion Blue → Very little distortion
Green/Yellow → Moderate distortion
Red → highest distortion
Maximum strain → $1.2152 \times 10^{-5}$ Minimum strain → $2.157 \times 10^{-10}$
These are very low strain values, meaning that the structure experiences only minor elastic deformation under the applied load.

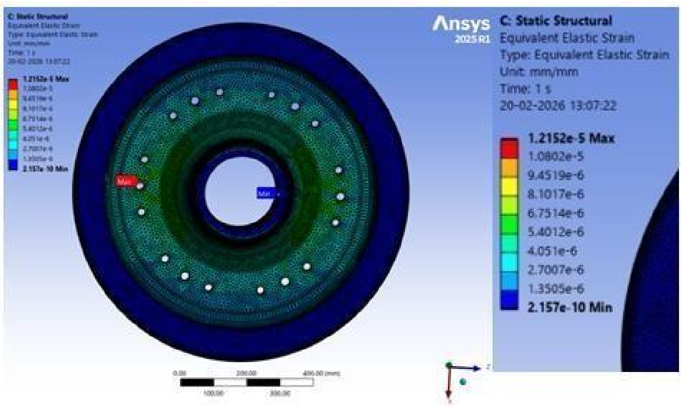



**Fig-22**

**Total Deformation Analysis-** total deformation analysis of rail wheel displayed in figure-23.The explanation of the wheel at boundary condition is given following lines.

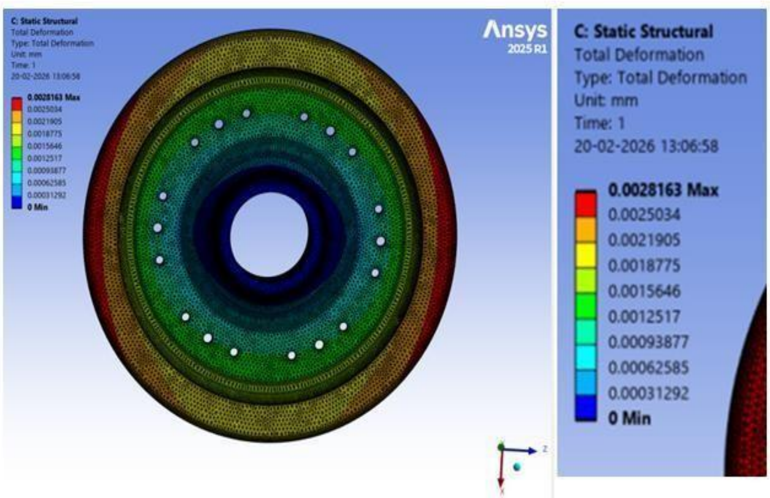



**Fig-23**

Red indicates the location where the greatest elastic strain occurs. It is located near one of the bolt-hole areas, indicating a local stress/strain concentration. This component is structurally stable under static loads. Most of the deformation occurs around geometric discontinuities near the bolt holes. Relatively little deformation occurs in the outer rim and inner bore. Since the deformation is approximately $10^{-5}$, assuming common engineering metals, the material is likely still within the elastic limit.

**Conclusion- -** As we analyzed the results of the analysis, which included model analysts analyzing random accelerometer vibrations, observing the deflection produced at different frequencies, and also performing a harmonic response analysis, it follows that the current wheel design, which is perfect for running at 180 km/h, can potentially produce frequencies up to 2000 Hz when speed up to 400 km/h. This results in significant wheel deflection at several random frequencies, requiring some modifications to the wheel geometry. This modification can be achieved by making some changes to the wheel's section profile. In this research, we found that

if the wheel can withstand frequencies up to 2000 Hz with some modifications to its profile, then the design would be perfect for 400 km/h. With this research, other types of research will be required which will include analysis of the wheel, axle with wheel, and the entire bogie in different parts.

**Terminology –**

IREE- International Railway Equipment Exhibition CAD- Computer Aided Design

CAM- Computer Aided Manufacturing CAE- Computer Aided Engineering FEA- Finite Element

**Analysis**

IGES-Initial Graphics Exchange Specification
RDSO -Research Designs and Standards Organization
CFD -Computational Fluid Dynamics

**Recommendations:** For 400 km/h:

- Increase Rim thickness from 135 to 150 mm.
- Upgrade to ER9 material.
- Add Tuned Mass Damper.
- Adopt Hollow Axle.

**References**

1. ANSYS, Inc. (n.d.). *ANSYS Workbench user's guide*. ANSYS, Inc.
2. Pegah Barkhordari and R. Galeazzi proposes a low-complexity statistical model for the switch panel of a railway turnout. *IFAC-Papers Online, 51*(24), 1278–1284. https://doi.org/10.1016/j.ifacol.2018.09.570
3. Boyalakuntla, S., & Gudipati, D. (2023). *A paper on static, modal, and harmonic analysis of alloy wheel using ANSYS.*
4. Cruceanu, I. C., & Sorohan, Ș. (2020). *Determination of the harmonic response of a railway wheelset using the finite element analysis method.*
5. Integral Coach Factory. (2019). *Annual report 2018–2019*. Ministry of Railways, Government of India.
6. Integral Coach Factory. (n.d.). *ICF MD SPEC-398 (Issue Status-01).* Ministry of Railways, Government of India.
7. International Union of Railways. (2020). *UIC Code 510-5: Technical approval of monobloc wheels.*
8. Indian Railways Institute of Civil Engineering and Mechanical Technology. (2020, August). *Vande Bharat Express Trainset (T-18) maintenance manual* (IRCAMTECH/GWL/2020-21/T-18/MM/1.0). Ministry of Railways, Government of India.
9. Jin, X. (2018). Research progress of high-speed wheel–rail relationship. *Journal of Modern Transportation, 26*(1), 1–14. https://doi.org/10.1007/s40534-018-0163-3
10. Lourenç, A., & Ferraz, C. (2023). *Adaptive time series representation for out-of-round railway wheels fault diagnosis in wayside monitoring.*
11. Murtaza, M. A. (2018). Modelling and simulation of a railroad wheel. *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD), 8*(2).
12. Raghu, T. S., & Kumar, J. (2020). *Static structural, modal and harmonic analysis of alloy car wheel rim using ANSYS Workbench.*
13. Research Designs and Standards Organization. (2009, December). *WD-02-WDA-2009 (Revision 2).* Ministry of Railways, Government of India.
14. Research Designs and Standards Organization. (n.d.). *Feasibility study and detailed project report (DPR) for Delhi–Alwar RRTS corridor.* Ministry of Railways, Government of India.