Modal Analysis of Automotive Components

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Abstract - *This research paper explores the significance of modal analysis in engineering for unveiling dynamic characteristics like frequencies, mode shapes, and vibration responses. It holds cross-disciplinary value, aiding aerospace, civil, and mechanical engineering. The study employs both experimental and software-based modal analysis techniques. Experimental data is gathered through impact hammer and accelerometers, validating software analysis outcomes. The Finite Element Method is used for virtual structure creation, refining it iteratively based on alignment with experimental results. This methodology bridges the gap between physical and virtual models, enhancing accuracy. The validation process involves testing a plate with a hole under different conditions, followed by experiments on a Rim in Free-Free condition. Despite minor mode shape deviations, frequency matches are close in all conditions, affirming analysis reliability and its bridging role. The paper underscores the interdisciplinary nature of modal analysis, contributing to comprehensive engineering insights across various applications.*

Key Words: **Mode Shapes, Altair Hyper Mesh, Experimental, Validation.**

Nomenclature: **EMA: Experimental Modal Analysis. SMA: software Modal Analysis.**

1.INTRODUCTION

Modal analysis is an elementary technique used in structural and mechanical engineering which is essential to comprehend the dynamic behavior of the system. It involves identifying and examining the natural vibration modes, which are found in structures and mechanical components. These methods provide a detailed explanation of how a system deforms and moves in response to external forces or stimuli. Modal analysis is vital to recognize and solving vibration-related problems as well as providing insight into how structures react to different loading scenarios. It is essential for the reliable functioning of complex systems in the mechanical engineering, automobile design, industrial machinery, and aerospace industries.

Empirical modal analysis is an essential aspect of engineering and scientific research, dedicated to extracting dynamic properties which captures natural vibration modes and dynamic characteristics. EMA subjects' structures to controlled forces or stimuli, recording sensor data to capture system responses. Through a rigorous mathematical method, these data provide critical information on natural frequencies, mode shapes, and damping ratios. The importance of EMA extends to model validation, structural integrity assessments, fault identification and system performance improvements, with applications in civil engineering, automotive design and machinery maintenance.

In addition, software model analysis predicts and analyzes dynamic behaviors in mechanical systems and structures, which makes it an effective computational tool in structural analysis and engineering. In particular, it employs specific software to replicate and analyze natural frequencies, mode shapes, and damping ratios, thus prevents physical testing. Software model analysis helps engineers and researchers in assessing the system performance, improvised designs, and solving issues in fields such as aerospace, civil engineering, and automotive, accelerating the development much safer and more efficient systems.

In basically, empirical model analysis integrates computer models with experimental measurements to confirm the accuracy of the models, hence verifying model analysis software. This validation verifies the software's ability to forecast natural frequencies, mode shapes, and damping ratios with precision and serves as an accepted norm. Design optimization, structural health monitoring, and failure prediction represent a few of its effects. These help researchers and engineers make better decisions, enhance system performance, and produce better work, all of which advance the field of analysis of models and their various industrial applications.

1.1 Methodology

During our validation stage, we investigated three different scenarios: Fix-Free, Fix-Free, and Fix-Fix. A combination of computer models and experimental techniques were employed to carefully examine these situations. To ensure that our chosen approaches were accurate and trustworthy, at first, we analyzed frequencies and mode shapes. Afterwards we narrowed down our research to the Rim and focused on looking at the Free-Free condition. This comprehensive method not only confirmed the validity of our results but also made sure a significant addition to the abundance of knowledge already available about the system that was studied.

1.2 Plate Test Validation.

1.2.1 Experimental test setup: In this instance, in addition to the standard testing procedures and equipment which are explained below, we also test the object using the Impact Hammer method.

a) Data Acquisition system: DEWE43V
b) Accelerometer: DYNAMIX SN 18226
c) Impact hammer: PCB SN 22826
d) Software: Dewesoft

To obtain a response from the system in this testing method, we employed the rowing hammer approach. At first, we calculated it for 48 nodes, with node 1 serving as the response node. Then took 4 responses from each of the nodes to average the relevant frequencies.

The Steel Plate is 410 mm long, 210 mm broad, and has a 50 mm diameter hole. It's made of material with a density of 7.9e-9 and a Young's modulus of 200 GPa. This material is 2.3 mm thick with a Poisson's ratio of 0.3. These requirements, which are critical in engineering and material science, control the mechanical properties of the object and its' usability for various applications such as structural integrity tests or stress-strain investigations. The data supplied here is used to evaluate its performance and behaviour under various loads or situations.

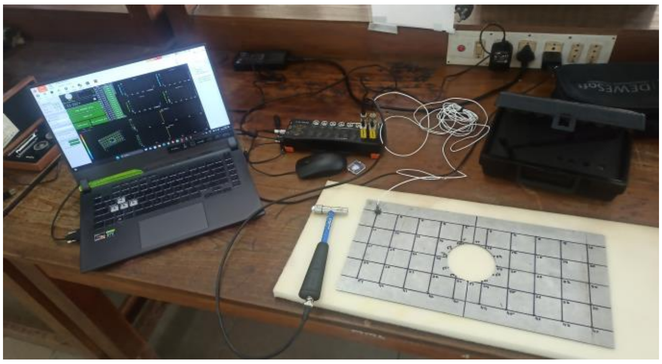

Fig 1: Plate setup for Free-Free test condition

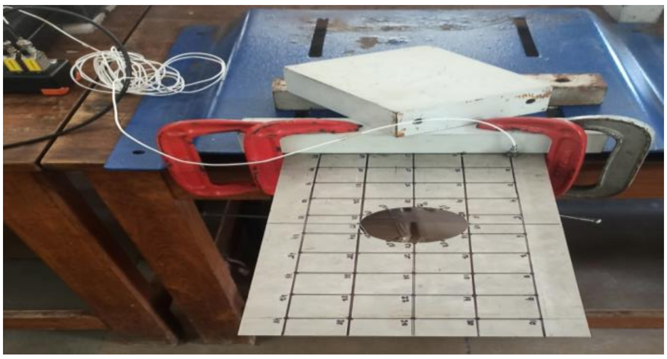

Fig 2: plate setup for Fix-Free test condition

Fig 3: Plate setup for Fix-Fix test condition

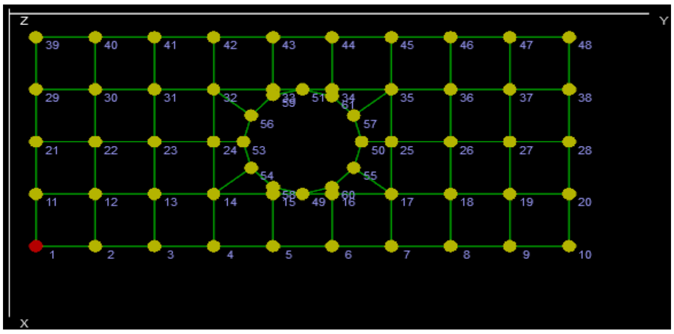

Fig 4: line geometry of plate for EMA

Figure 1 above shows a configuration for a Free-Free modal analysis of a plate, with a plate and sponge arranged on top of each other. Figure 2 shows a Fix-Free condition and was composed of a plate and a long solid metal bar with four C-clamps for fixing. Figure 3 shows the Fix-Fix condition, which consists of 8 C-clamps and 2 long solid bars. Figure 4 shows the line geometry of the plate, which was generated using Dewesoft software, and contains 48 nodes that may receive responses from the plate.

3. 1.2.2 Software simulation test setup.

The Plate's geometry was created using Solid Works, Hyper mesh was used to mesh for simulation purposes with Optistruct as solver.

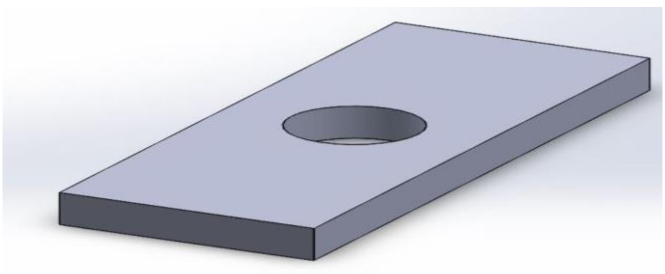

Fig. 5: CAD model of Plate

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 10 Issue: 11 | Nov 2023 www.irjet.net p-ISSN: 2395-0072

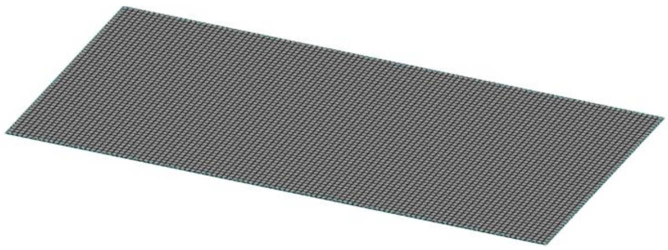

Fig. 6: Finate Element Model of Plate

The Opti Struct solver was used to perform a 2D modal analysis on a steel plate. The plate has a quad element count of 1300 and an aspect ratio of 4.3. The mesh elements had a maximum degree of skewness of 34 and a Jacobian value of 1, indicating that the mesh was well-structured. Modal analysis is required for the study of a structure's natural frequencies and mode shapes. This example provides engineers with insights into the structural behaviours and likely resonance frequencies of this steel plate, which is critical for applications that use steel plates in a variety of industries'

2. Frequencies and Mode Shapes of Plate

Table -1: Fix-Free modal analysis frequency

SL NO	EMA Frequency In Hz	SMA frequency In Hz	% Variation
1	7.8	8.6	9.3
2	30	32	6.25
3	47.6	54	11.85
4	101.2	112	0.78

Table -2: Fix-Fix modal analysis frequency

SL NO	EMA Frequency In Hz	SMA Frequency In Hz	% Variation
1	58	60	3.33
2	90	88	2.22
3	152	159	4.4
4	195	200	2.5

Table -3: Free-Free modal analysis frequency

SL NO	EMA Frequency In Hz	SMA Frequency In Hz	% Variation
1	47.6	46.90	1.47
2	66	57.52	12.84
3	122	133.84	8.84
4	178	186	4.30

2.1 Fix-Free mode shapes Validation

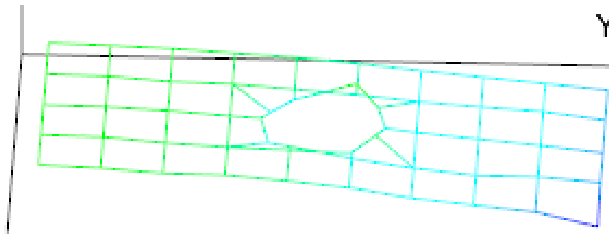

Fig. 5: Fix-Free plate mode 1 EMA

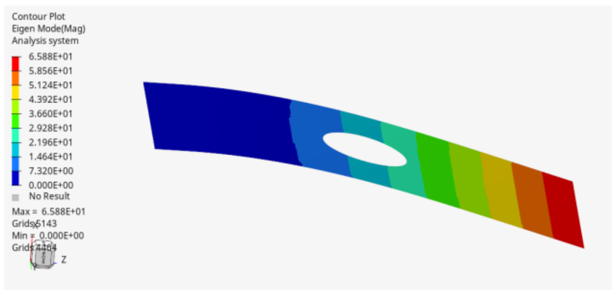

Fig. 6: Fix-Free plate mode 1 SMA

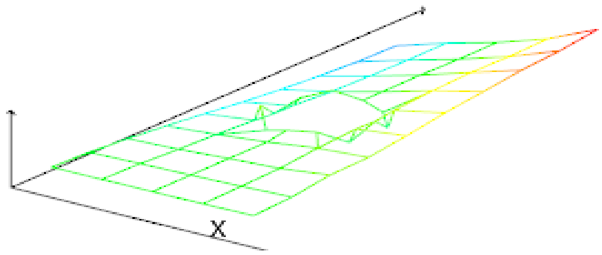

Fig. 7: Fix-Free plate mode 2 EMA

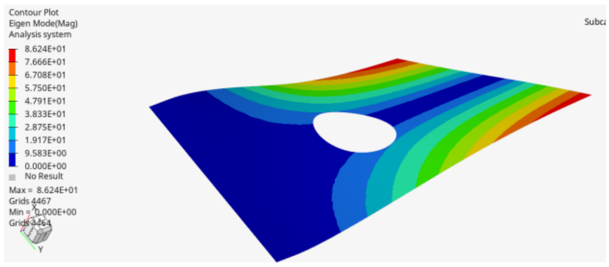

Fig. 8: Fix-Free plate mode 2 SMA

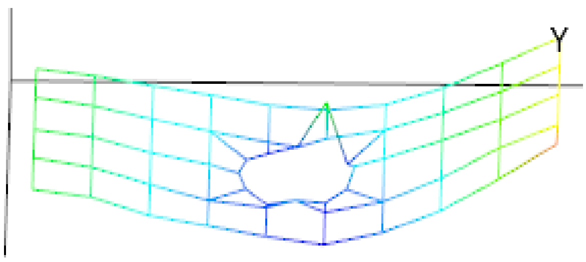

Fig. 9: Fix-Free plate mode 3 EMA

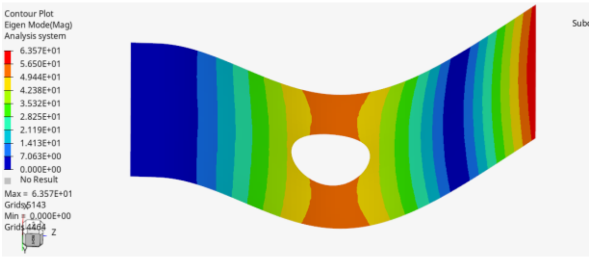

Fig. 10: Fix-Free plate mode 3 SMA

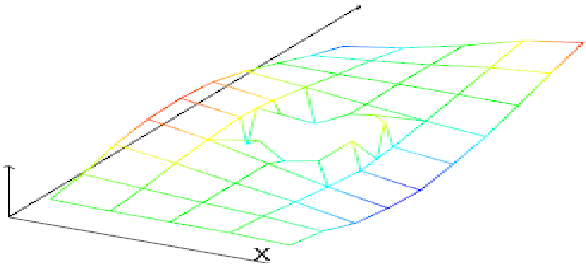

Fig. 11: Fix-Free plate mode 4 EMA

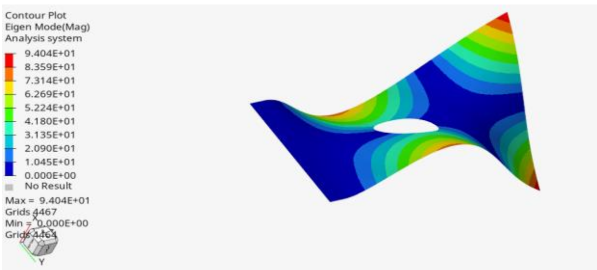

Fig. 12: Fix-Free plate mode 4 SMA

2.2 Fix-Fix mode shapes Validation Results

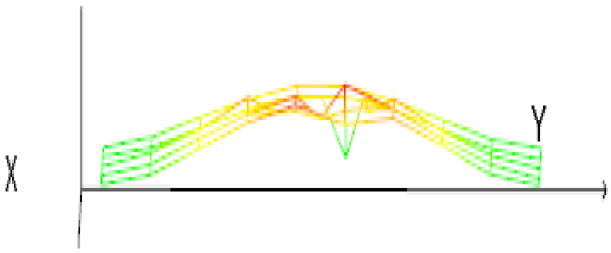

Fig. 13: Fix-Fix plate mode 1 EMA

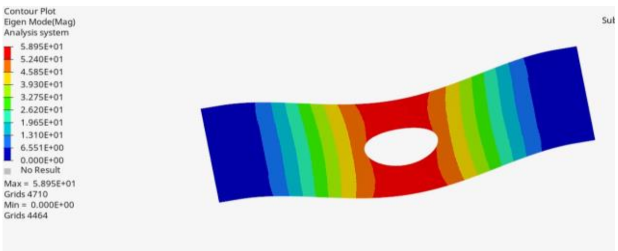

Fig. 14: Fix-Fix plate mode 1 SMA

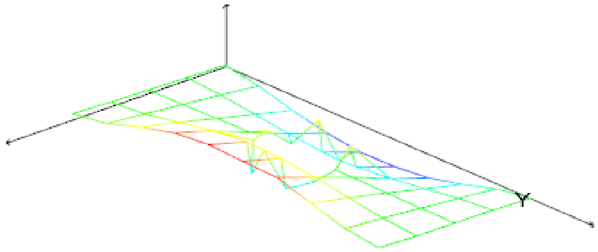

Fig. 15: Fix-Fix plate mode 2 EMA

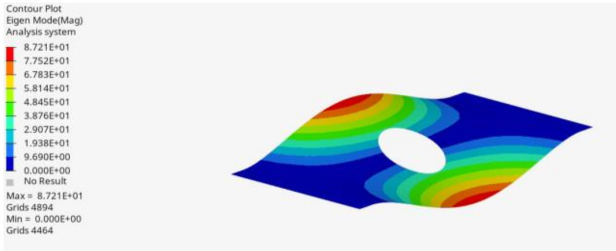

Fig. 16: Fix-Fix plate mode 2 SMA

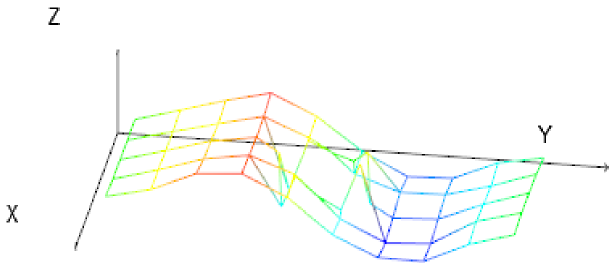

Fig. 17: Fix-Fix plate mode 3 EMA

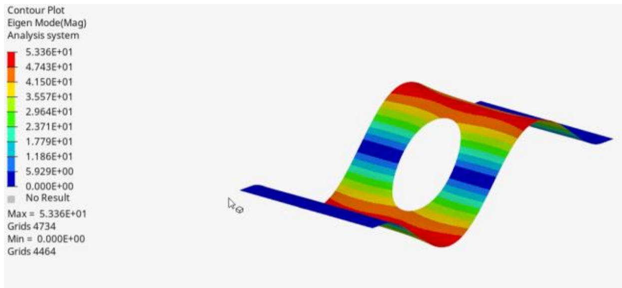

Fig. 18: Fix-Fix plate mode 3 SMA

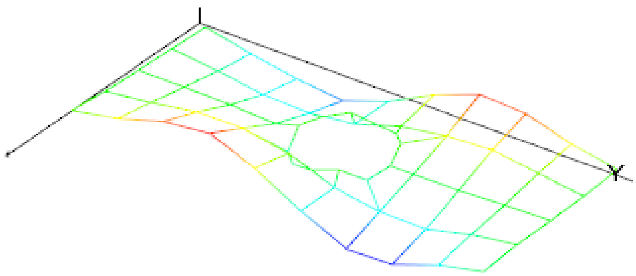

Fig. 19: Fix-Fix plate mode 4 EMA

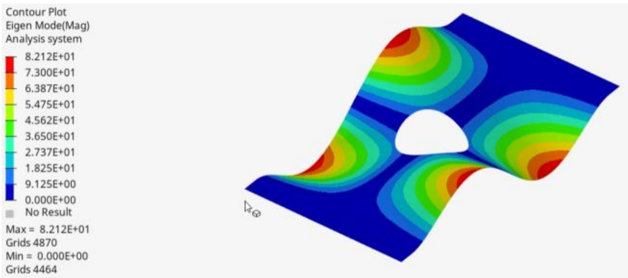

Fig. 20: Fix-Fix plate mode 4 SMA

2.3 Free-Free mode shapes Validation Results

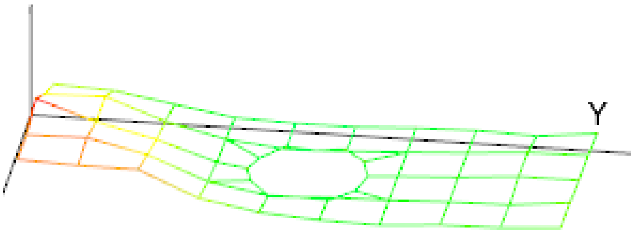

Fig. 21: Free-Free plate mode 1 EMA

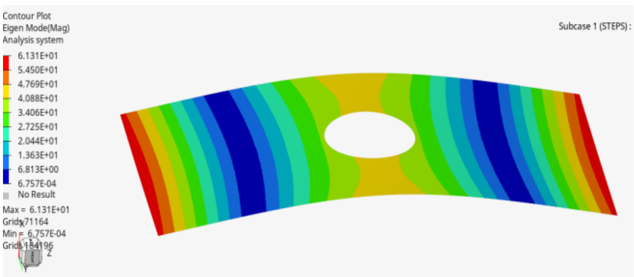

Fig. 22: Free-Free plate mode 1 SMA

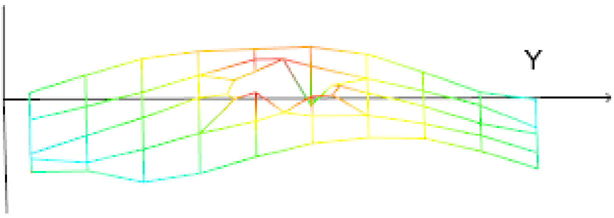

Fig. 23: Free-Free plate mode 2 EMA

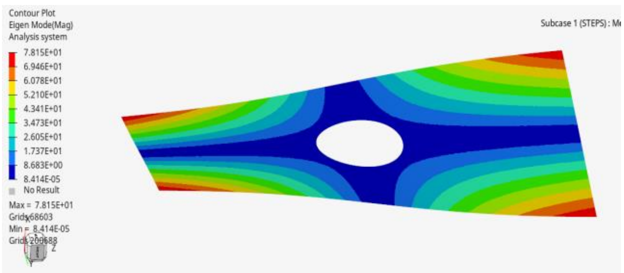

Fig. 24: Free-Free plate mode 2 SMA

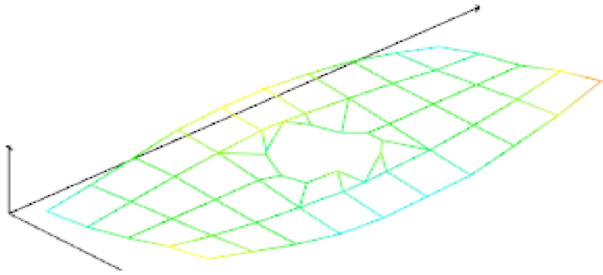

Fig. 25: Free-Free plate mode 3 EMA

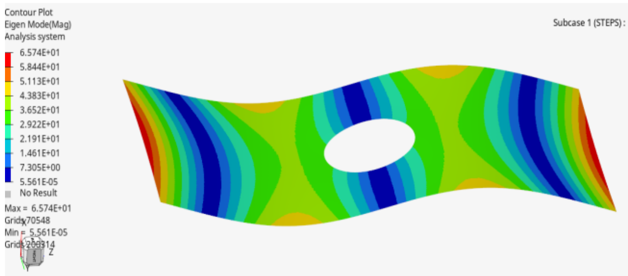

Fig. 26 Free-Free plate mode 3 SMA

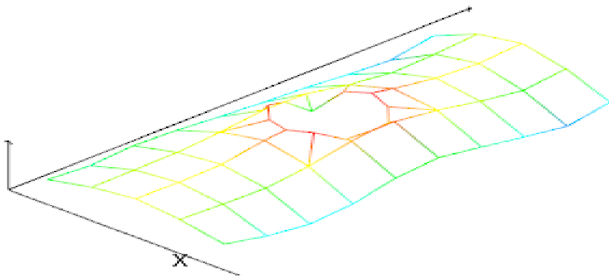

Fig. 27: Free-Free plate mode 4 EMA

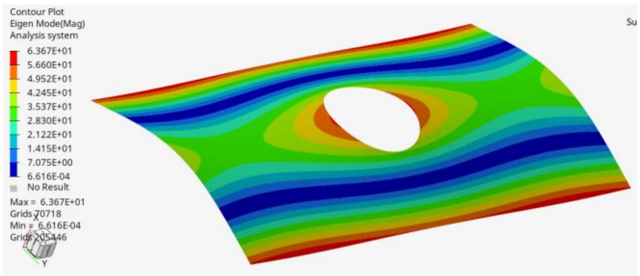

Fig. 28: Free-Free plate mode 4 SMA

3. Rim Experimental Setup

Steel is used to make the rims, which have a Young's modulus of 200 GPa, a density of 7.9e-9, and a Poisson's ratio of 0.3. With a diameter of 330mm and a length of 112mm, this steel rim is an essential component. These criteria are critical for constructing and assessing cylindrical components used in engineering and manufacturing applications, such as rims for automobiles or equipment. An evaluation of a material's mechanical properties is required to assess its strength, deformation characteristics, and overall performance under a variety of loads and circumstances, as well as to ensure the dependability and safety of the cylindrical structure it forms.

Fig. 29: Real Tested Steel Rim

Fig. 30: Free-Free Condition setup for Rim EMA

3.1 Rim Software Simulation Setup

The boundary condition and meshing part details will be shown below. The geometry of the Rim was created using Solid Works and Hyper mesh was utilized to mesh for simulation purposes with Opti struct as solver.

Fig. 29: CAD model of Rim

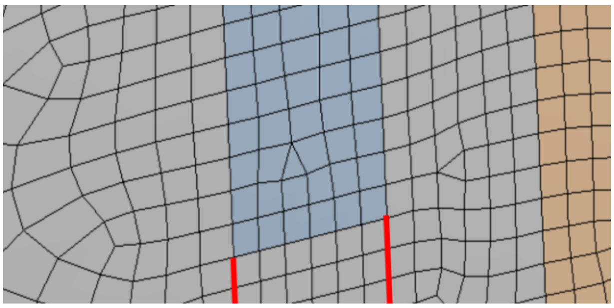

Fig. 30: Finate Element Model of Rim

The Opti Struct solver was used to perform a 2D mid-mesh free-free modal analysis with a massive quad mesh element count of 230,456. The mesh's quality and readiness for analysis were indicated by the aspect ratio of 4.1, maximum skewness of 49 degrees, and Jacobian value of 0.91. Understanding a structure's intrinsic vibrational modes and frequencies is crucial for a variety of engineering applications. This is possible because of free-free modal analysis. It provides engineers with insights into the dynamic behaviour of the examined system in this scenario, allowing them to analyse the system's susceptibility to external pressures, resonance frequencies, and likely modes of vibration, assisting in design optimisation and structural integrity assessments.

3.2 Mode Shapes and Frequencies of the Rim

3.2.1 Frequency Table

Table.4: Free-Free modal analysis frequency

SL NO	EMA Frequency In Hz	SMA frequency In Hz	% Variation
1	311	302.33	2.89
2	782	821.792	4.75
3	1242	1264.74	1.7
4	1458	1371.81 H	5.96

3.2.2 Rim Mode Shapes

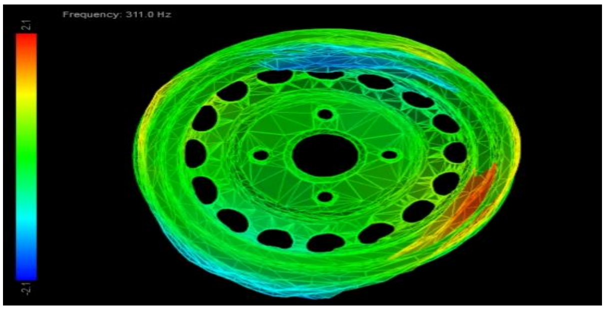

Fig. 31: Free-Free Rim mode 1 EMA

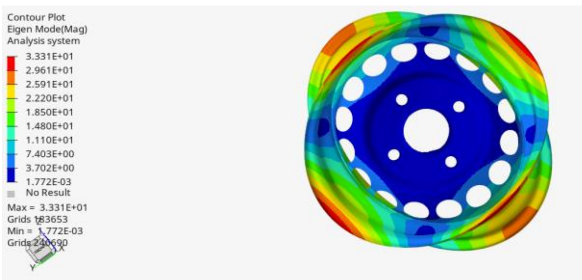

Fig. 32: Free-Free Rim mode 1 SMA

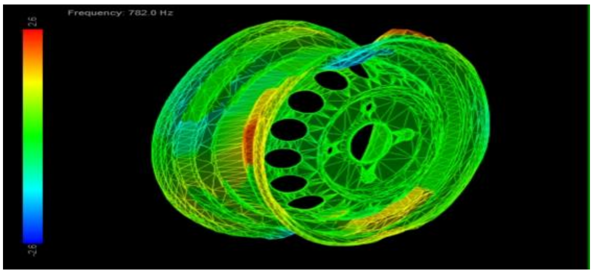

Fig. 33: Free-Free Rim mode 2 EMA

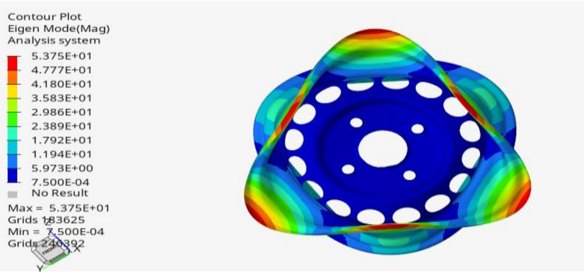

Fig. 34: Free-Free Rim mode 2 SMA

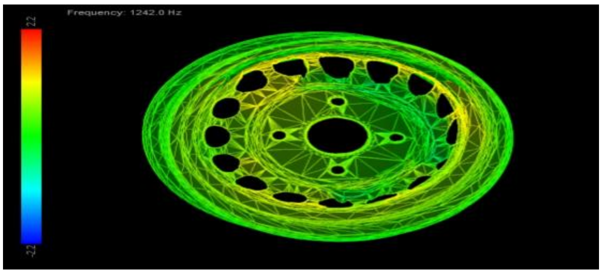

Fig. 35: Free-Free Rim mode 3 EMA

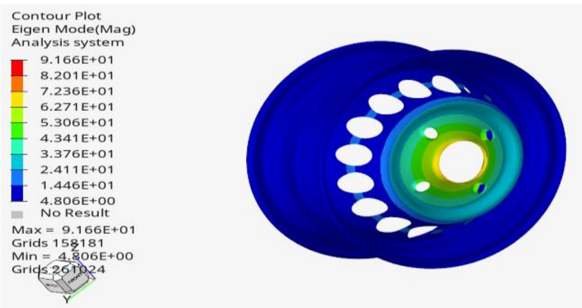

Fig. 36: Free-Free Rim mode 3 SMA

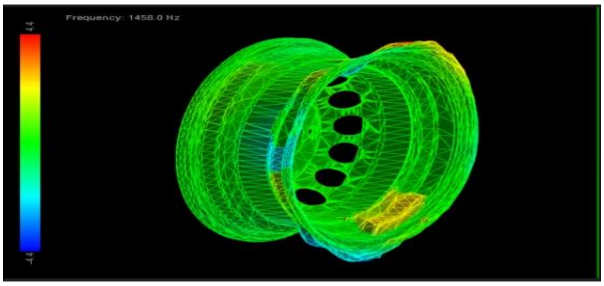

Fig. 37: Free-Free Rim mode 4 EMA

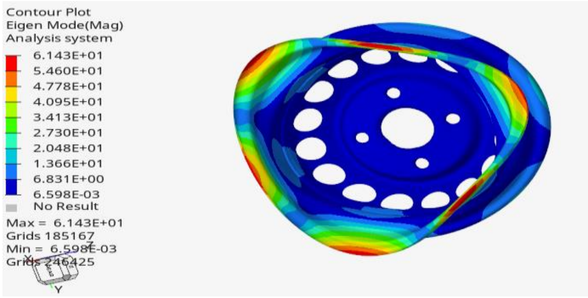

Fig. 38: Free-Free Rim mode 4 SMA

4. Conclusion

This research work has shown a striking convergence of frequencies for the three different conditions: Free-Free, Fixed-Free, and Fixed-Fixed. Even though slight differences in mode forms were seen in the Free-Free state, these differences are probably the outcome of the vacuum circumstances and material ageing. This finding highlights the resilience of the modal analysis techniques used in this study and their constant applicability in a range of contexts.

The adaptability of modal analysis has been demonstrated by this interdisciplinary approach, greatly advancing our understanding of dynamic behaviors in a range of applications. Through dependable modal analysis approaches, this research has emphasized the confluence of the virtual and physical realms, boosted our engineering insights and fostered confidence in the precision of predictive models.

This paper concludes by mentioning the importance of modal analysis in understanding structural behaviors. The frequency matching, which stay consistent despite minor variations, shows how reliable the approach is. These findings improve our knowledge of dynamic reactions while also supporting engineering practice. Thereby, this study extends the field's techniques and expands our understanding of dynamic processes, each of which beneficial effects on a variety of real-world applications.

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