

Two-Wheeler Crankshaft Stress Optimization Based on Experimental Design and Fea

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Abstract- The crankshaft is an essential component of a two-wheeler internal combustion engine, as it converts the reciprocating motion of the piston into rotational motion. Due to high-speed operation and cyclic loading conditions, the crankshaft experiences a complex combination of bending, torsional, and shear stresses during operation, making its design highly susceptible to fatigue failure. Therefore, accurate stress analysis and design optimization are essential to ensure durability, reliability, and efficient performance. This study focuses on the stress analysis and geometric optimization of a two-wheeler crankshaft using Finite Element Analysis (FEA). A three-dimensional model of the crankshaft is developed using CAD software and analyzed under realistic loading and boundary conditions. Special attention is given to critical regions such as fillets, crankpin, and journal interfaces, where stress concentration is most prominent. A parametric approach is adopted to modify key geometric features, particularly the fillet radius, to improve stress distribution and structural integrity. In addition to static structural analysis, modal and harmonic analyses are carried out to evaluate the dynamic behavior of the crankshaft under operating conditions. The study also incorporates experimental testing to understand material behavior and support the simulation process. By integrating computational analysis with design modification, this work aims to develop an optimized crankshaft design that achieves improved mechanical performance and enhanced service life for two-wheeler engine applications.

Key Words: Finite Element Analysis (FEA), Crankshaft Optimization, Stress Analysis, Fatigue Failure, Dynamic Analysis, Structural Integrity

I.INTRODUCTION

The crankshaft serves as a crucial element in internal combustion (IC) engines, tasked with transforming the reciprocating motion of the piston into the continuous rotary motion necessary for propelling the vehicle. In two-wheeler engines, where compactness, lightweight construction, and high rotational speeds are essential, the crankshaft operates under severe cyclic loading conditions. These include a combination of bending, torsional, and shear stresses generated due to combustion forces and inertia of moving components.

Such complex loading makes the crankshaft highly susceptible to stress concentration, fatigue damage, and eventual failure, particularly at critical regions like fillets and journal interfaces. Traditionally, crankshaft design has relied on empirical approaches and conservative safety factors to ensure reliability. While these methods provide safe designs, they often lead to over-dimensioned components, increasing weight and material usage. With the advancement of computational tools, Finite Element Analysis (FEA) has emerged as an effective technique for accurately predicting stress distribution, deformation, and structural behavior under realistic loading conditions. FEA enables identification of critical stress regions and supports informed design modifications without the need for extensive physical prototyping.



Fig-1: Crankshaft

Among various geometric features, the fillet radius at the junctions of crankpin, web, and main journal plays a crucial role in influencing stress concentration. Optimizing these regions can significantly enhance fatigue strength and overall durability of the crankshaft. In addition to static analysis, understanding the dynamic behavior through modal and harmonic analysis is essential to ensure that the crankshaft operates safely without encountering resonance conditions during service.

This study focuses on the stress analysis and geometric optimization of a two-wheeler crankshaft using FEA. A three-

dimensional model is developed and analyzed under realistic boundary conditions, followed by targeted design modifications to improve stress distribution. The work also considers experimental testing to support the numerical analysis. The objective is to develop an optimized crankshaft design that achieves improved strength, reduced stress concentration, and enhanced reliability while maintaining practical design constraints.

II. LITERATURE REVIEW

1. Dadhich (2024)

Dadhich et al. investigate the optimization of two-wheeler engine cooling by comparing three different fin and outer-body designs. The study uses a systematic experimental approach to analyze the effect of geometry and airflow conditions on heat transfer performance. Parameters such as wind velocity and fin configuration are evaluated in terms of Nusselt number and convective heat transfer coefficients. The results highlight how small geometric modifications can significantly influence engine cooling efficiency and temperature distribution. The work provides a practical framework for improving air-cooled engine designs while considering manufacturability and design constraints.

2. Zheng (2022)

Zheng et al. present a crankshaft optimization study linking geometric parameters to stress and deformation behavior. Key variables such as journal diameter and fillet radius are analyzed using finite element simulations. The study emphasizes efficient exploration of design parameters to improve stress distribution and reduce peak stresses. Sensitivity analysis identifies the most influential design variables, particularly fillet regions. The approach provides a practical method for achieving improved crankshaft performance with reduced computational effort.

3. Xu (2023)

Xu et al. propose a fatigue life prediction model for crankshafts under uncertain operating conditions. The study integrates physical fatigue models with data-driven techniques to account for variability in loads and material properties. A probabilistic approach is used to improve prediction accuracy compared to traditional deterministic methods. The model is validated against experimental observations and demonstrates better reliability in capturing real-world behavior. This work highlights the importance of considering uncertainty in fatigue analysis for improved reliability assessment.

4. Que (2023)

Que et al. present an experimental methodology for high-cycle bending fatigue testing of crankshafts. The study introduces an accelerated testing approach combined with predictive algorithms to estimate fatigue life efficiently. Crack initiation and growth are monitored using advanced signal-processing techniques. The method reduces testing time while maintaining accuracy in fatigue performance evaluation. The

research provides valuable insights into improving laboratory testing efficiency for crankshaft fatigue studies.

5. Wei (2025)

Wei et al. develop an advanced fatigue testing method using an Extended Kalman Filter (EKF) for real-time damage estimation. The study uses vibration and strain data to track crack growth and predict remaining life. Multiple failure indicators are combined to improve prediction accuracy and robustness. The approach allows early termination of tests while maintaining reliable fatigue life estimation. This method offers a practical solution for accelerating fatigue testing in engineering applications.

6. Rui (2023)

Rui proposes a stepwise accelerated fatigue testing method for crankshafts to reduce testing time and cost. The study focuses on maintaining realistic damage mechanisms while increasing loading rates. It discusses key factors such as surface finish, residual stresses, and crack detection techniques. Comparative results show that the method preserves fatigue life ranking among different designs. The work serves as a practical guide for efficient fatigue testing in industrial applications.

7. Al Ghifari (2024)

Al Ghifari presents a finite element-based study on crankshaft strength using ductile iron material. The work follows a standard simulation approach involving CAD modeling, meshing, and structural analysis under loading conditions. The influence of geometric parameters such as fillet radius on stress concentration is examined. Results suggest that ductile iron offers a good balance between strength and cost. The study highlights the usefulness of FEA for preliminary design evaluation.

8. Ferreira et al. (2024)

Ferreira et al. combine experimental testing and numerical simulation to evaluate crankshaft fatigue behavior. The study uses experimental data to calibrate fatigue models and improve prediction accuracy. Crack initiation and propagation are analyzed using both physical testing and computational methods. The hybrid approach reduces the need for extensive experimental campaigns. This work demonstrates an effective strategy for integrating experiments with simulation in fatigue analysis.

9. Yadav & Dwivedi (2025)

Yadav and Dwivedi focus on improving crankshaft fatigue life through geometric optimization using FEA. The study identifies fillet regions as critical stress concentration zones and modifies their geometry. Simulation results show a reduction in stress and a significant improvement in predicted fatigue life. The methodology emphasizes accurate meshing and realistic boundary conditions. The work demonstrates the

effectiveness of small geometric changes in enhancing crankshaft performance.

10. Husnain et al. (2025)

Husnain et al. investigate fatigue crack growth in bending using finite element methods and different crack-growth models. The study compares multiple fatigue models to identify the most accurate for predicting crack propagation. Results show that certain models provide better agreement with experimental data under bending conditions. The research highlights the importance of model selection and calibration in fatigue analysis. The findings are applicable to crankshaft fillet regions where bending-induced fatigue is critical.

Novelty of work: This study presents a focused optimization of a two-wheeler crankshaft by specifically improving the fillet geometry using Finite Element Analysis (FEA), targeting the most critical stress concentration regions. Unlike conventional approaches, the work integrates static, modal, and harmonic analyses to evaluate both structural and dynamic behavior of the crankshaft. The optimized design is further supported by experimental validation, ensuring reliability of the simulation results. The study provides a practical and efficient methodology for enhancing crankshaft performance without complex optimization techniques. This combined approach contributes to improved strength, reduced stress concentration, and better dynamic stability.

III. PROBLEM STATEMENT

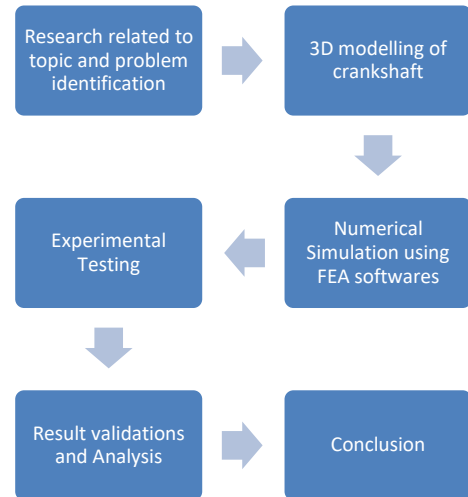
- In the highly competitive global automotive market, improving vehicle performance and efficiency remains a key challenge.
- Original Equipment Manufacturers (OEMs) are enforcing stringent design parameters to enhance vehicle performance while maintaining durability.
- The crankshaft is one of the most vital and highly stressed components in an internal combustion (IC) engine. It is subjected to repeated bending and torsional forces, making a strong and durable design essential to avoid failure.
- Therefore, designing a lightweight yet durable crankshaft is crucial to improve the efficiency and reliability of two-wheeler engines.

IV. OBJECTIVES

- **Weight Reduction:** To identify potential weight reduction opportunities in the crankshaft design without compromising performance.
- **Force and Stress Analysis:** To analyze the different forces exerted on the crankshaft and determine the maximum stress it experiences.
- **Material Substitution:** To evaluate alternative materials that can replace the existing crankshaft material while maintaining the same performance and durability.
- **Structural Optimization:** To optimize the crankshaft geometry to enhance its strength-to-weight ratio.

- **Performance Validation:** To use advanced simulation tools and experimental methods to validate the performance and reliability of the optimized crankshaft design.

RESEARCH METHODOLOGY



V. FINITE ELEMENT ANALYSIS

Finite Element Analysis (FEA) is a computational method used to analyze the mechanical behavior of components subjected to various loading conditions. It is based on the principle of discretizing a complex geometry into a discrete set of smaller elements interconnected at nodal points, forming a mesh. This discretization allows complex differential equations governing the behavior of the structure to be approximated and solved in a simplified manner.

In FEA, the governing equations are derived from fundamental principles such as equilibrium, compatibility, and material constitutive relations. For structural analysis, the relationship between applied forces and resulting displacements is expressed in matrix form as $[K]\{u\} = \{F\}$, where $[K]$ is the stiffness matrix, $\{u\}$ is the displacement vector, and $\{F\}$ is the applied force vector. By solving these equations, the displacement at each node is obtained, from which strains and stresses are calculated using appropriate material models. The accuracy of FEA depends on factors such as mesh quality, element type, boundary conditions, and material properties. Finer meshes generally provide more accurate results but increase computational cost. Proper application of boundary conditions and realistic loading is essential to obtain meaningful results.

FEA is widely used in engineering design to predict stress distribution, deformation, and failure locations in components. In this study, FEA is employed to analyze the stress behavior of the crankshaft and to evaluate the effect of geometric modifications, particularly fillet radius, on its structural performance.

Static analysis of Two-Wheeler Crankshaft

Material properties

Properties of Outline Row 3: EN8			
	A	B	C
1	Property	Value	Unit
2	Material Model Variables	Table	
3	Density	7845	kg m ⁻³
4	Isotropic Secant Coefficient of Thermal Expansion		
5	Isotropic Elasticity		
6	Derive from	Young's Modulu...	
7	Young's Modulus	207	MPa
8	Poisson's Ratio	0.3	
9	Bulk Modulus	1.725E+08	Pa
10	Shear Modulus	7.9619E+07	Pa
11	Tensile Yield Strength	415	MPa
12	Tensile Ultimate Strength	620	MPa
13	Compressive Ultimate Strength	415	MPa

Fig-2: Engineering details of material

Geometry

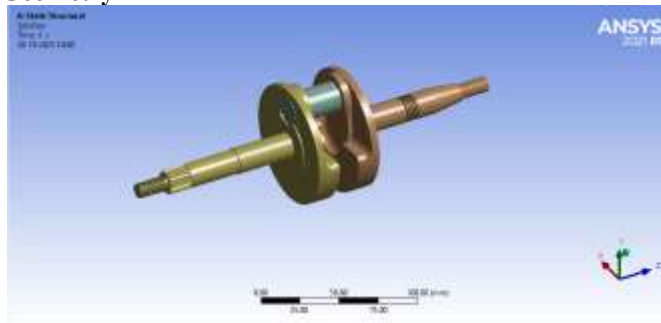


Fig-3: Geometry of crankshaft

Mesh

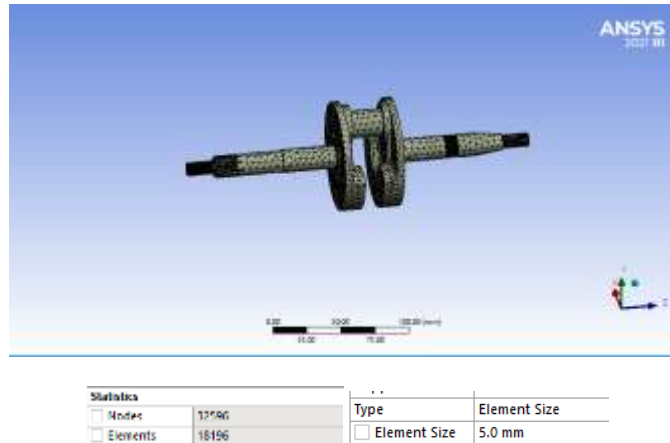


Fig-4: Finite mesh model of crankshaft

Calculation

- Pressure Calculations

Density of petrol (C8H18):

$$\rho = 750 \text{ kg/m}^3 = 750 \times 10^{-9} \text{ kg/mm}^3$$

Operating Temperature:

$$T = 20^\circ\text{C} = 273.15 + 20 = 293.15\text{K}$$

As Mass = Density $\times$ Volume

$$\text{Then } m = 750 \times 10^{-9} \times 124 \times 103$$

$$m = 0.093 \text{ kg}$$

Molecular Mass of Petrol:

$$M = 114.228 \times 10^{-3} \text{ kg/mole}$$

Gas Constant for Petrol:

$$R = 72.7868 \times 103 \text{ J/kg/mol K}$$

As $pV = mRT$

$$p \times 124 \times 103 = 0.093 \times 72.7868 \times 103 \times 293.15$$

Thus

$$p = 16.003 \text{ MPa} = 16.003 \text{ N/mm}^2$$

Design Calculation

Gas Force (FP): $FP = \text{Pressure (P)} \times \text{Cross Section Area of Piston (A)}$

$$FP = 16.003 \times (\pi/4) \times 53.52$$

$$FP = 35.9566 \times 10^3 \text{ N}$$

Boundary conditions

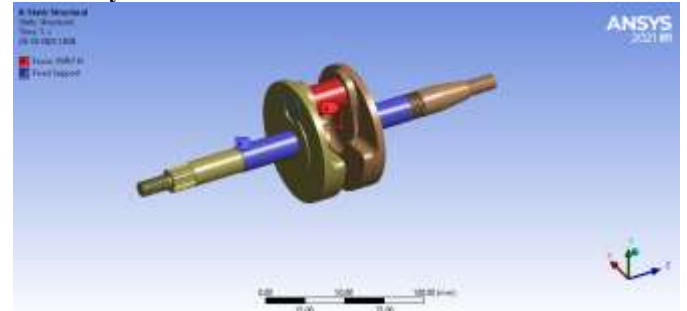


Fig-5: Boundary conditions of crankshaft

Result

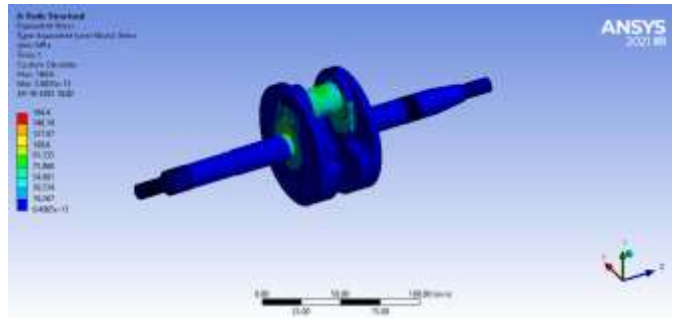


Fig-6: Equivalent stress of crankshaft

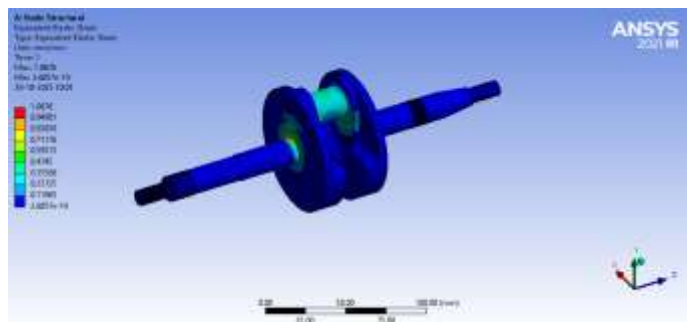


Fig-7: Equivalent strain of crankshaft

Results	Minimum	Maximum	Units	Time (s)
Equivalent Stress	3.8835e-013	164.4	MPa	1.
Equivalent Elastic Strain	2.6057e-014	1.0676	mm/mm	1.

Modal analysis of Two-Wheeler Crankshaft

Geometry

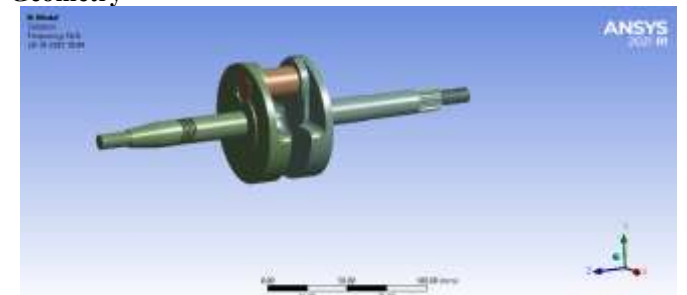


Fig-8: Geometry of crankshaft

Mesh

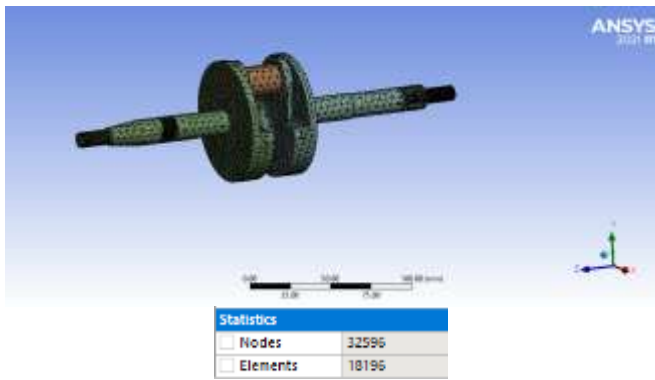


Fig-9: Finite mesh model of crankshaft

Boundary Conditions:

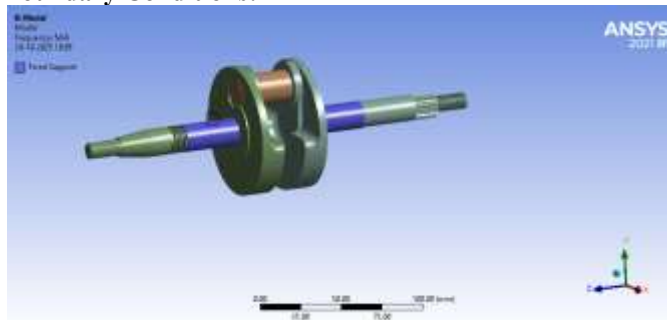


Fig-10: Boundary conditions for Modal Analysis.

Results:

Mode shape 1

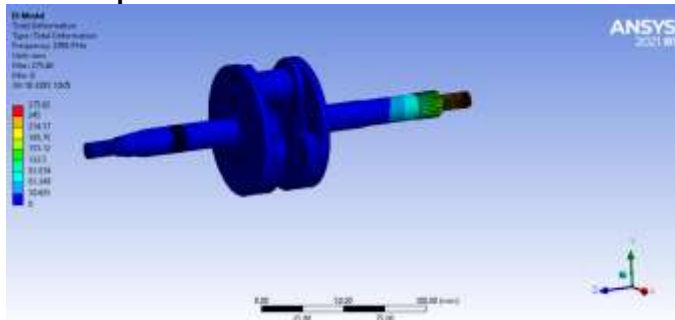


Fig-11: Frequency for Mode Shape 1.

Mode shape 2

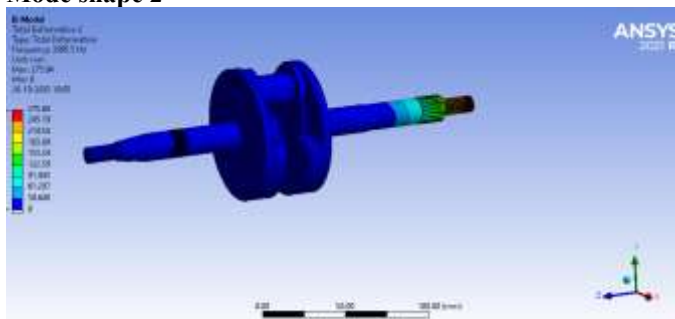


Fig-12: Frequency for Mode Shape 1.

Mode shape 3

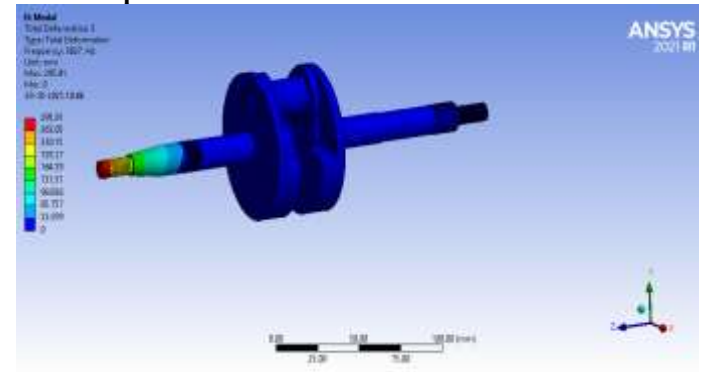


Fig-13: Frequency for Mode Shape 1.

Mode shape 4

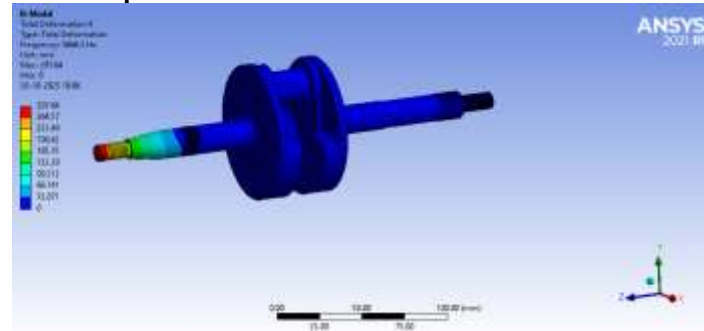


Fig-14: Frequency for Mode Shape 1.

Mode shape 5

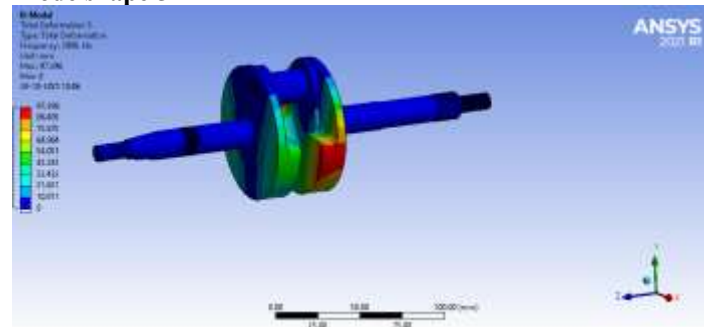


Fig-15: Frequency for Mode Shape 1.

Mode shape 6

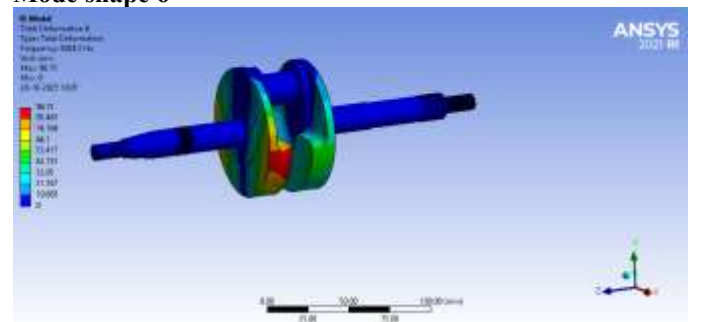


Fig-16: Frequency for Mode Shape 1.

Tabular Data		
	Mode	Frequency [Hz]
1	1.	2992.9
2	2.	2995.5
3	3.	3627.
4	4.	3666.3
5	5.	3998.
6	6.	4024.5

Table-1: Mode Shape vs Frequencies.

Harmonic response of Two-Wheeler Crankshaft Geometry

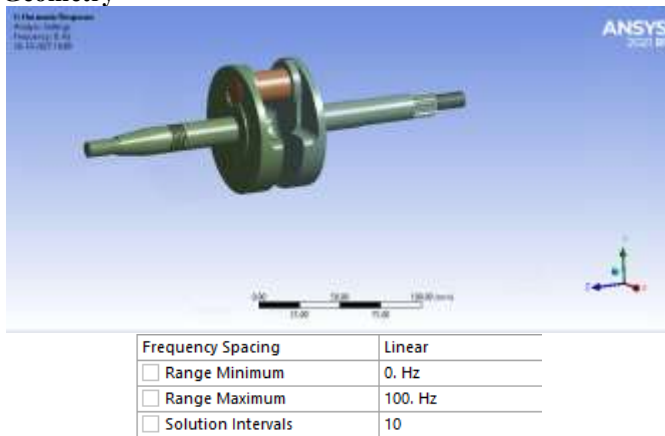


Fig-17: Geometry of Existing two-wheeler crankshaft.

BOUNDARY CONDITIDIONS

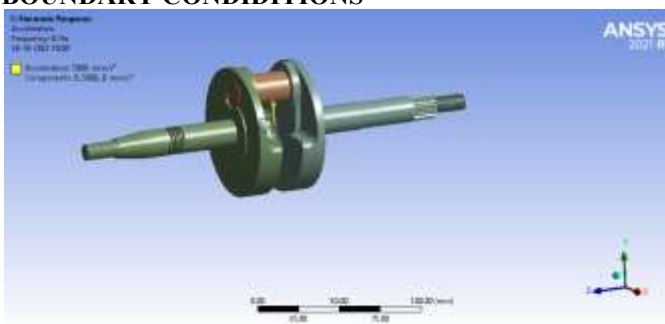


Fig-18: Boundary conditions for Harmonic Analysis.

RESULTS

TOTAL DEFORMATION

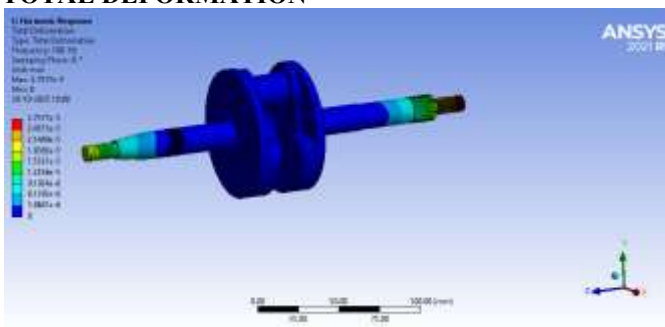


Fig-19: Total Deformation for Harmonic Response.

2. EQUIVALENT STRESS

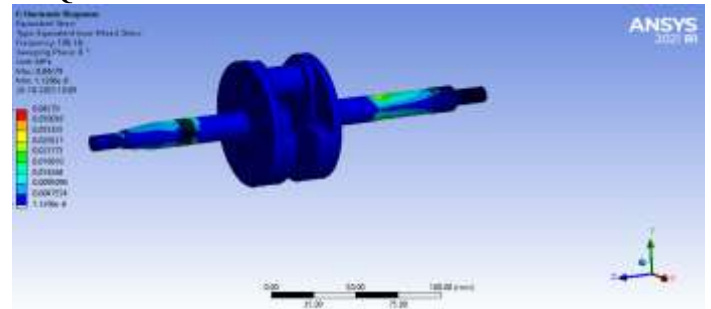


Fig-20: Equivalent Stress for Harmonic Response.

3. NORMAL STRESS

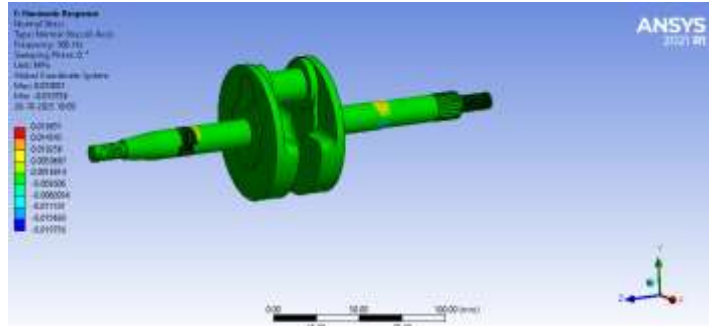


Fig-21: Normal Stress for harmonic response.

GRAPH1: FREQUENCY VS STRESS

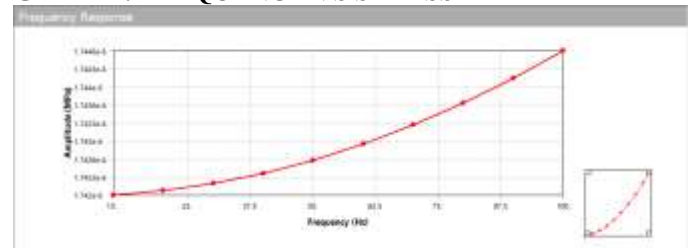


Fig-22: Frequency vs Stress graph.

GRAPH2: FREQUENCY VS DEFORMATION

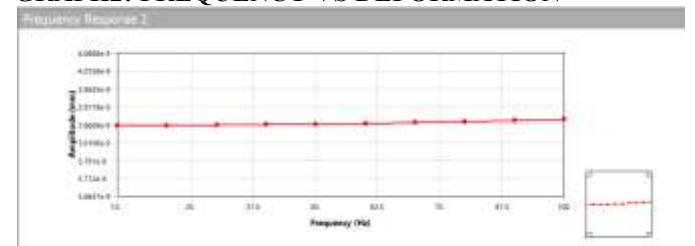


Fig-23: Frequency vs Deformation graph.

Static analysis of Optimized Two-Wheeler Crankshaft: Geometry:



Properties	
☐ Volume	1.5201e+005 mm ³
☐ Mass	1.1925 kg

Fig-24: Geometry of optimized two-wheeler crankshaft.

Meshing:

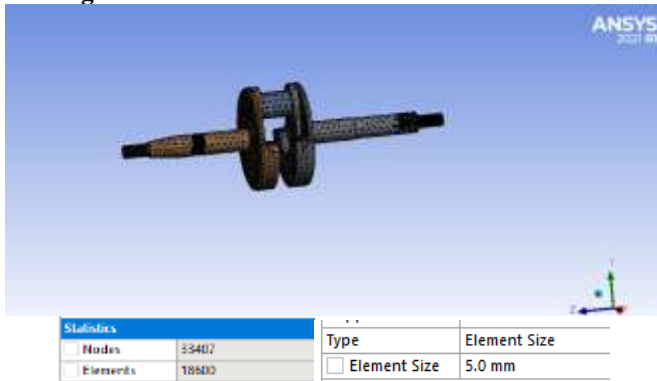


Fig-25: Meshing details of optimized two-wheeler crankshaft.

Boundary Conditions:

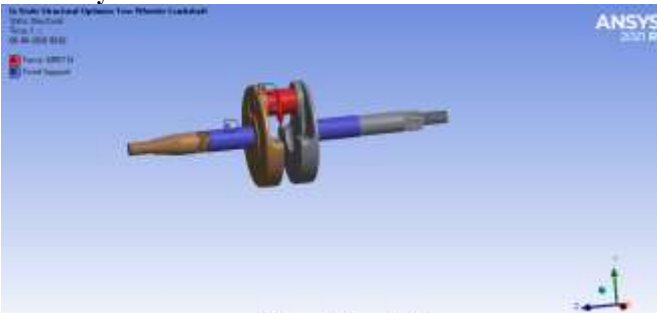


Fig-26: Boundary conditions for static structural analysis of optimized two-wheeler crankshaft.

Results:

Total Deformation:

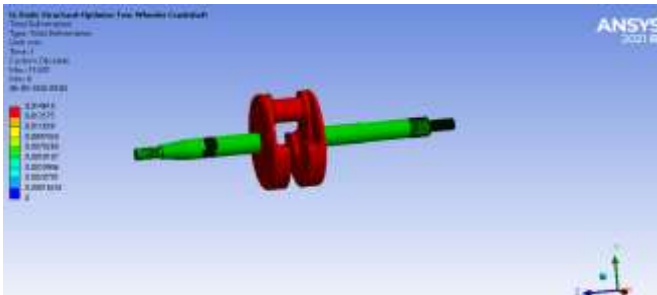


Fig-27: Total Deformation of optimized two-wheeler crankshaft.

Equivalent Stress:

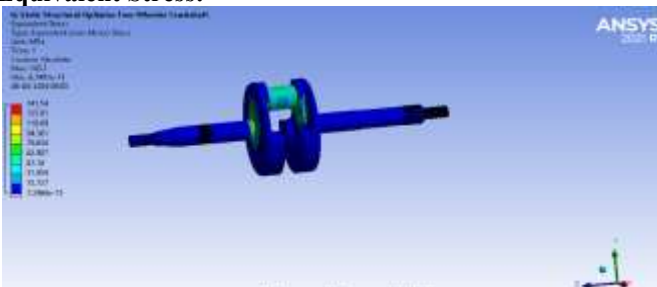


Fig-28: Equivalent Stress of optimized two-wheeler crankshaft.

Equivalent Elastic Stress:

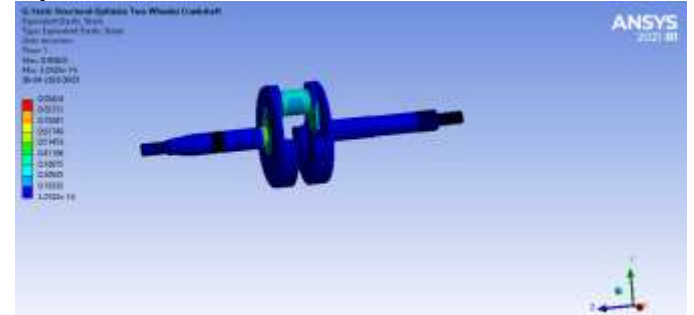


Fig-29: Equivalent Elastic Strain of optimized two-wheeler crankshaft.

Modal analysis of Optimized Two-Wheeler Crankshaft: Boundary Conditions:

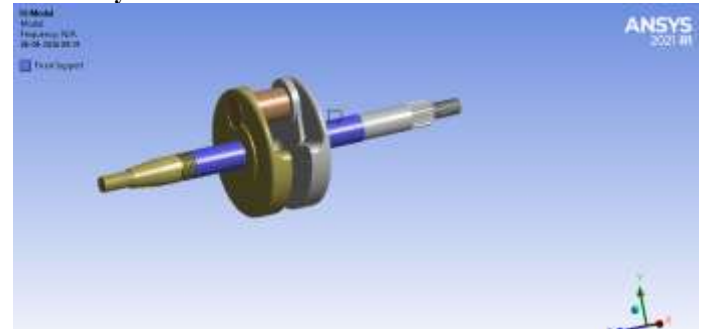


Fig-30: Boundary conditions for modal analysis of optimized two-wheeler crankshaft.

Results:

Mode Shape 1:

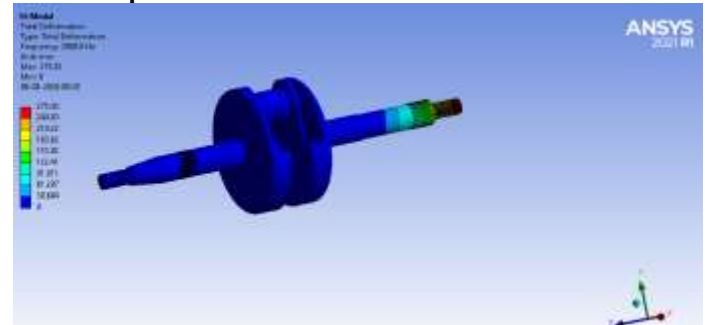


Fig-31: Frequency for Mode Shape 1.

Mode Shape 2:

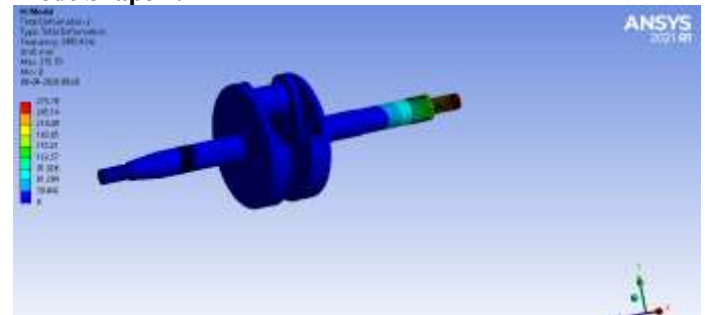


Fig-32: Frequency for Mode Shape 2.

Mode Shape 3:

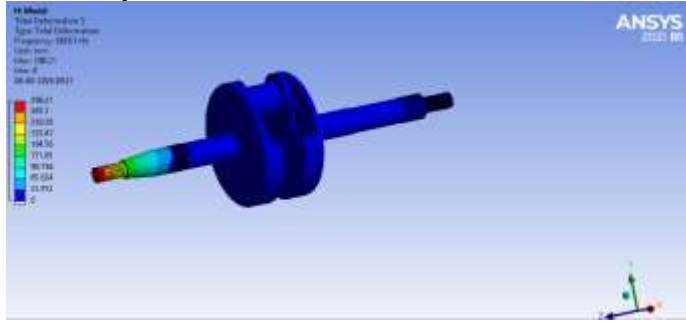


Fig-33: Frequency for Mode Shape 3.

Mode Shape 4:

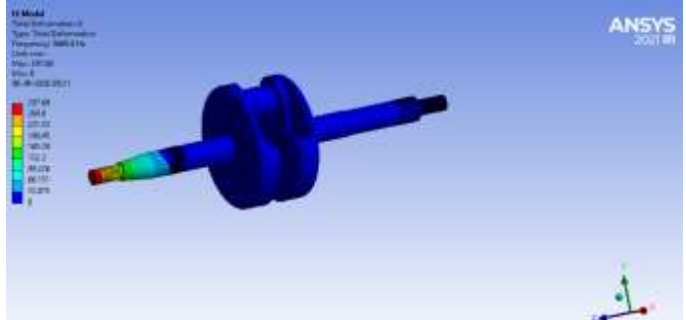


Fig-34: Frequency for Mode Shape 4.

Mode Shape 5:

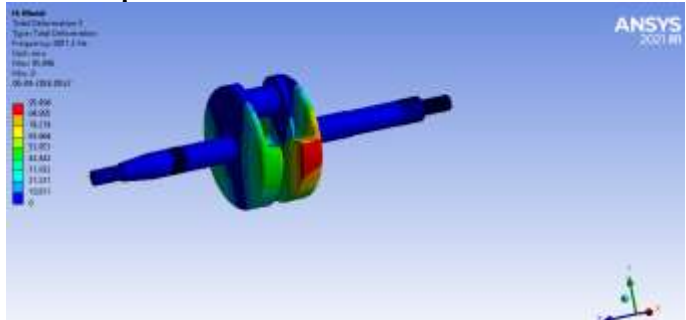


Fig-35: Frequency for Mode Shape 5.

Mode Shape 6:

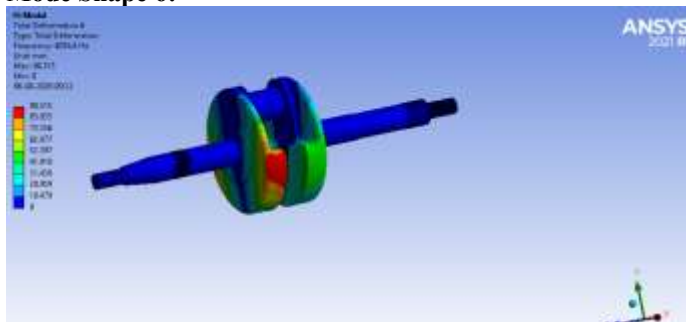


Fig-36: Frequency for Mode Shape 6.

Tabular Data		
	Mode	Frequency [Hz]
1	1.	2989.8
2	2.	2995.4
3	3.	3638.3
4	4.	3669.4
5	5.	4011.2
6	6.	4036.4

Table-2: Mode Shape vs Frequency.

Harmonic Analysis: Boundary Conditions:

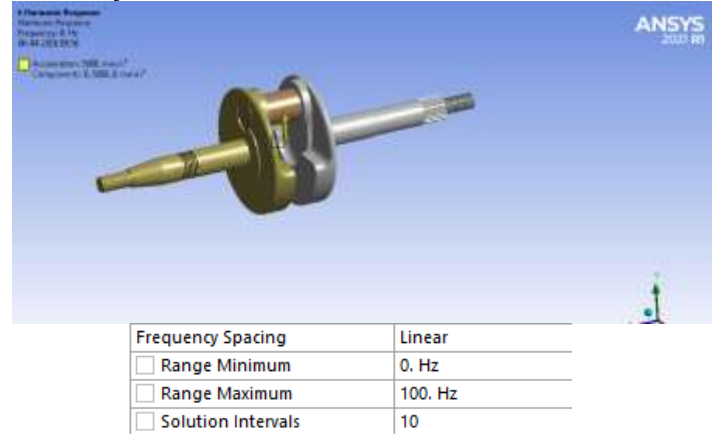


Fig-37: Boundary conditions for harmonic response of optimized two-wheeler crankshaft.

Results: Total Deformation:

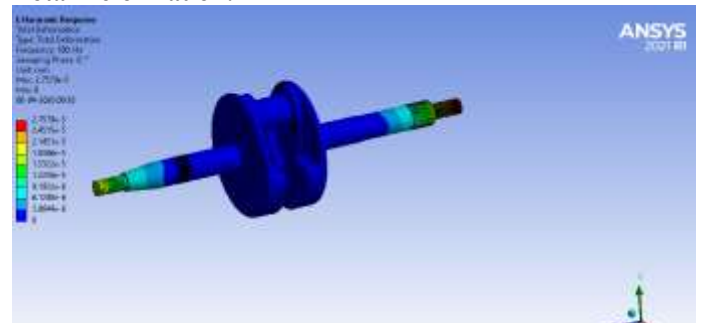


Fig-38: Total deformation of optimized two-wheeler crankshaft for harmonic response.

Equivalent Stress:

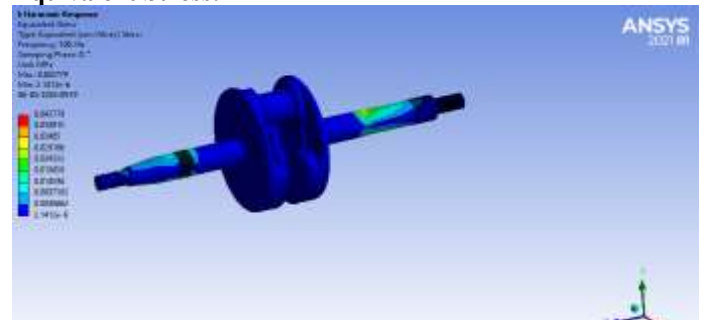


Fig-39: Equivalent Stress of optimized two-wheeler crankshaft for harmonic response.

FEA RESULTS

The structural performance of the crankshaft made of EN8 material was evaluated through static, modal, and harmonic analyses using Finite Element Analysis (FEA).

The initial static analysis showed that the maximum equivalent (von Mises) stress was 164.4 MPa, and the equivalent elastic strain was 1.0676 mm/mm, both within permissible limits of the material.

The calculated factor of safety (FOS) of approximately 2.52 confirmed that the crankshaft is structurally safe and capable of withstanding the applied loads without yielding or fatigue failure.

The modal analysis indicated that the crankshaft predominantly undergoes bending vibrations in the first six natural modes. It was observed that as the mode number increases, the regions of maximum deformation shift from the shaft ends towards the counterweight.

The harmonic response analysis further demonstrated that the crankshaft remains stable under dynamic loading conditions, with stress values remaining within safe limits.

However, higher stress concentrations were identified at the fillet regions, making them critical zones for design improvement. It was also noted that operation near natural frequencies should be avoided to prevent resonance.

Based on these observations, the fillet radius at critical junctions was optimized to reduce stress concentration.

FEA of the optimized geometry showed improved results, with the maximum total deformation reduced to 0.14618 mm, maximum equivalent stress reduced to 141.51 MPa, and maximum equivalent elastic strain reduced to 0.92624. These results indicate a significant improvement in stress distribution and structural performance compared to the initial design.

VI. EXPERIMENTAL TESTING

Experimental testing is used to validate numerical results by evaluating the actual mechanical behavior of a component under applied loads. In this study, a compression test is performed to determine the load-deformation characteristics and structural strength of the axle specimen.

The test is based on the principle of applying a gradually increasing load and measuring the corresponding deformation to understand stiffness, elasticity, and failure behavior. The resulting load-deformation curve helps identify key properties such as maximum load capacity, elastic region, and structural stability. This experimental approach ensures the reliability of FEA results by providing real-world performance data for comparison and validation.

A Universal Testing Machine (UTM) is a device used to test the mechanical properties of materials and components under different loading conditions such as tension, compression, and bending. It applies a controlled load to a specimen and measures the resulting deformation, helping determine properties like strength, stiffness, and elasticity. UTMs are widely used in material testing laboratories for validating design and simulation results.

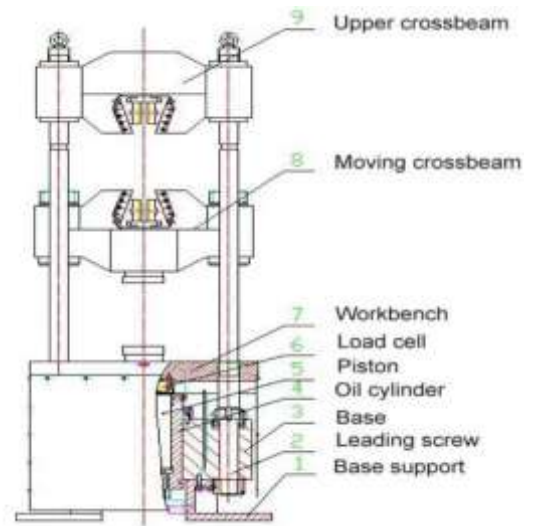


Fig-40: Schematic Diagram of a UTM.

EXPERIMENTAL PROCEDURE:

1. Determine the width and thickness of the sample.
2. Identify and mark the locations where the load is to be applied.
3. Carefully position the specimen on the fixture of the universal testing machine.
4. Ensure that the loading point aligns with the marked location.
5. Perform the test.

Testing photograph





Fig-41: Specimen under compression test using a UTM.

Testing graph

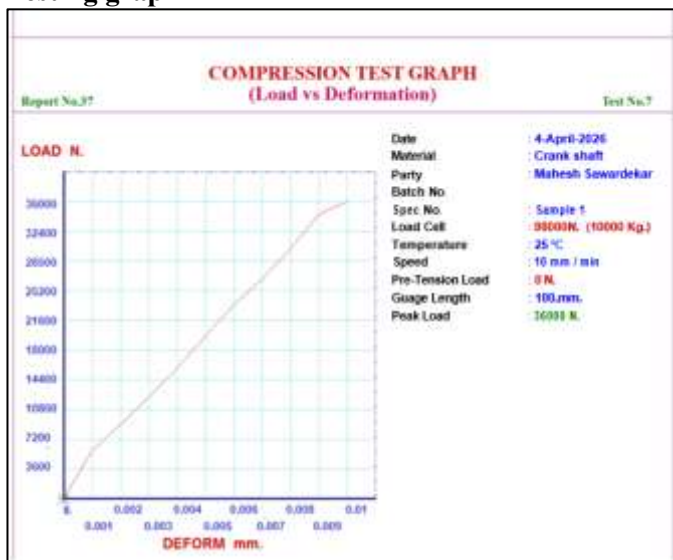


Fig-42: Graph shows load vs deformation during compression test

The above fig. shows the graph of displacement v/s load for two-wheeler crankshaft. Displacement is taken on X-axis and load in N is taken on Y-axis.

Experimental validation was carried out using a compression test on the optimized crankshaft, where a deformation of 0.1 mm was observed. The close agreement between experimental and FEA results verifies the precision and dependability of the simulation.

VII.CONCLUSION

- This study presented the stress analysis and geometric optimization of a two-wheeler crankshaft using Finite Element Analysis (FEA). The initial analysis identified critical stress concentration regions, particularly at the

fillet areas between the crankpin, web, and journal. Based on these observations, the fillet radius was modified to improve stress distribution and reduce peak stresses.

- The optimized crankshaft geometry demonstrated improved structural performance with reduced stress and deformation, indicating enhanced strength and durability. In addition to static analysis, modal and harmonic analyses confirmed better dynamic behavior, with increased stiffness and reduced vibration response under operating conditions.
- Experimental validation through compression testing showed close agreement with the FEA results, supporting the precision and dependability of the simulation approach.
- Overall, the study highlights that targeted geometric optimization, especially at fillet regions, can significantly improve crankshaft performance without major design changes. The methodology adopted provides a practical and effective approach for designing lightweight, reliable, and high-performance crankshafts for two-wheeler engines.

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