



Research Paper

## Design and Structural Performance Assessment of a Shaft-Driven Transmission System for Low-Maintenance Two-Wheelers

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### Abstract

The evolution of automobile transmission systems has significantly influenced the efficiency and reliability of modern vehicles. Early developments in automotive engineering focused on basic mechanical power transfer mechanisms, with chain-driven systems becoming widely adopted in two-wheelers due to their simplicity and cost-effectiveness. However, traditional chain drive systems suffer from several limitations, including frequent maintenance, lubrication requirements, wear and tear, and power transmission losses. These drawbacks create a need for more efficient and durable alternatives in modern drivetrain design. This project addresses these challenges by proposing a shaft-driven transmission system for a two-wheeler main shaft assembly. The study focuses on improving performance, reliability, and maintenance efficiency by replacing the conventional chain mechanism with a shaft drive system. The proposed system is designed and modelled using SolidWorks, followed by detailed structural analysis using ANSYS to evaluate its mechanical behaviour under realistic loading conditions. Finite Element Analysis (FEA) is employed to analyse parameters such as stress distribution, deformation, strain, and fatigue life. A comparative analysis is conducted using three different materials structural steel, aluminium alloy, and grey cast iron to determine the most suitable material for the shaft system. The results indicate that structural steel offers superior performance with reduced deformation and improved load-bearing capacity. The proposed system demonstrates enhanced durability, smoother power transmission, and reduced maintenance requirements. This work contributes to the development of efficient and reliable drivetrain systems, supporting advancements in modern two-wheeler design and engineering.

**Keywords:** Shaft Drive System, Two-Wheeler Transmission, Finite Element Analysis (FEA), SolidWorks, ANSYS, Structural Analysis, Stress Analysis.

### 1. Introduction

The evolution of the automobile can be systematically categorized into distinct eras, each characterized by advancements in propulsion technology and subsequent developments in design, size, and functional utility. The earliest milestone in automotive history dates back to 1768, when Nicolas-Joseph Cugnot developed a steam-powered vehicle capable of transporting humans. This innovation marked the beginning of mechanized personal transportation. In 1807,

François Isaac de Rivaz introduced a vehicle powered by an internal combustion engine using hydrogen fuel, representing a significant step toward modern engine technology. A major breakthrough occurred in 1886 when Karl Benz invented the first petrol-powered automobile, widely recognized as the first practical and commercially produced vehicle, as multiple identical units were manufactured.

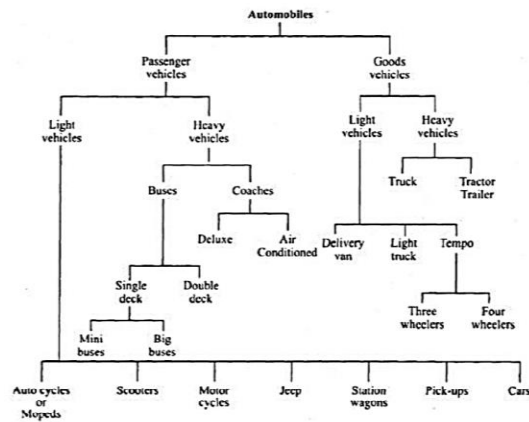


Figure. 1: Hierarchical classification of automobiles based on type and utility

At the beginning of the twentieth century, electric vehicles emerged as an alternative mode of transportation. However, due to technological and infrastructural limitations, they remained confined to niche markets for several decades, only gaining widespread attention again in the twenty-first century with advancements in battery technology and environmental awareness. Over time, automobiles have become integral to societal development, significantly influencing economic growth and improving living standards. As self-propelled vehicles, automobiles have played a crucial role in facilitating mobility and accessibility in everyday life. Since the seventeenth century, numerous attempts have been made to design and develop efficient and practical automobiles, leading to the sophisticated systems seen today.

Automobiles can be broadly classified based on their structural configuration and functional application. The primary categories include single-unit vehicles or load carriers, which consist of a single rigid structure designed for transporting goods or passengers; articulated vehicles, which are composed of multiple connected sections allowing greater flexibility and load capacity; and heavy tractor vehicles, which are specifically designed for hauling large trailers or heavy loads over long distances. This classification provides a comprehensive

understanding of the diverse types of vehicles operating on modern roadways.

## 2. Literature Review

Zhang et al. [1] explored how contact stress is distributed in gear-rack systems, offering valuable insights into how forces are transferred between meshing teeth. Their work highlights that uneven stress concentration is one of the main reasons for premature failure in mechanical transmission systems. By carefully examining how different materials behave under high-pressure contact conditions, they showed that material selection plays a crucial role in maintaining durability. In addition, they emphasized that tooth geometry significantly influences how loads are shared across the contact surface. A well-designed tooth profile can minimize localized stress peaks and improve overall performance. Their observations also point toward the importance of balancing strength and wear resistance in gear design. The discussion further reflects on how improper configurations can lead to excessive deformation and surface damage. Their contribution helps designers better understand how to enhance load-bearing capacity while reducing long-term degradation. This forms a strong basis for improving gear reliability in demanding industrial environments. Li et al. [2] examined the bending fatigue characteristics of large modulus gear-rack systems, particularly under heavy loading conditions. Their analysis shows that repeated stress cycles can gradually weaken gear teeth, eventually leading to cracks and failure. They discussed how geometric factors such as tooth thickness, module size, and root radius directly influence fatigue resistance. Material properties were also carefully considered, especially in relation to how they respond to cyclic loading. Their findings suggest that even small modifications in tooth design can significantly extend operational life. They also addressed how improper stress distribution can accelerate fatigue damage. Another important point raised is the need to consider real working

conditions rather than relying solely on ideal assumptions. Their work brings attention to the balance between strength and flexibility in gear design. Overall, it provides practical guidance for improving durability in systems exposed to continuous heavy loads.

Xiao et al. [3] introduced a detailed approach to understanding contact behavior by considering both elastic and plastic deformation. Their explanation goes beyond traditional models by acknowledging that materials do not always behave in a perfectly elastic manner under high loads. They demonstrated that plastic deformation becomes significant when contact pressures exceed certain limits. This has a direct impact on wear, surface damage, and long-term system efficiency. Their model captures how materials gradually deform and adapt under repeated contact conditions. They also discussed how ignoring plastic effects can lead to inaccurate predictions of performance. The approach provides a more realistic picture of how gear-rack systems behave in practical applications. Additionally, they highlighted how this understanding can help improve maintenance planning and system reliability. Their contribution is particularly useful for systems operating under extreme conditions where material limits are frequently tested. Wang and Li [4] presented a detailed explanation of vibration behavior in gear transmission systems, focusing on how motion irregularities develop during operation. They described how vibrations originate from gear meshing, manufacturing errors, and load variations. Their explanation connects these factors to noise generation and mechanical instability. By breaking down the causes of vibration, they provided a clearer understanding of how dynamic forces interact within the system. They also emphasized the importance of maintaining precise alignment and manufacturing accuracy. Another key point discussed is how vibration can gradually reduce efficiency and increase wear. Their work explains how different operating conditions influence

vibration intensity. It also highlights the relationship between system stiffness and dynamic response. Their contribution helps engineers identify and control unwanted vibrations in gear mechanisms.

Zhou et al. [5] focused on how torsional vibrations behave when gear systems operate under changing speeds, particularly during acceleration. They explained that sudden changes in speed introduce additional dynamic forces that can destabilize the system. Their findings show that these variations can significantly increase vibration amplitude. They also discussed how resonance can occur when operating conditions align with natural frequencies. This can lead to severe mechanical stress and potential damage. Their analysis highlights the importance of considering real-time operating conditions rather than constant-speed assumptions. They further explained how system inertia and damping influence vibration response. Their work also emphasizes the need for proper design to handle transient conditions. This understanding is essential for improving system stability in applications involving variable speeds. Xu et al. [6] carried out an in-depth examination of vibration characteristics in heavy-duty marine gearboxes by identifying their natural frequencies and mode shapes. Their findings explain how large mechanical systems behave under dynamic loading conditions. They showed that each structure has specific frequencies at which it naturally tends to vibrate. If operational forces match these frequencies, resonance can occur, leading to serious damage. They also highlighted the importance of identifying weak structural points. Their observations help in improving design strategies to avoid harmful vibration patterns. Another key aspect is their focus on real-world testing rather than purely theoretical assumptions. Their work provides practical insights into maintaining structural integrity in large-scale systems. This is especially important for applications where failure can have significant consequences.

Jyothirmai et al. [7] provided a comprehensive explanation of different stress types in spur gears, including bending, contact, and fatigue stresses. Their approach brings together multiple aspects of gear behavior into a single framework. They explained how each type of stress contributes to overall system performance and failure. By analyzing these factors together, they highlighted the importance of a balanced design approach. Their discussion also covers how stress concentrations develop at critical points. They emphasized that ignoring any one factor can lead to incomplete design understanding. Another key aspect is their focus on improving reliability through better stress management. Their work helps in identifying areas where improvements can be made. It offers a clearer perspective on designing gears for long-term operation. Krolkowski [8] examined how variations in tooth geometry influence torsional vibration behavior in gear systems. Their explanation shows that even minor geometric changes can significantly affect dynamic performance. They discussed how parameters such as tooth profile, spacing, and alignment contribute to vibration characteristics. Their findings highlight the importance of precision in gear design. They also explained how improper geometry can lead to increased noise and instability. Another important point is the relationship between design choices and system efficiency. Their work encourages designers to consider vibration effects early in the design process. It also shows how optimization can improve overall system behavior. This contribution is particularly useful for reducing unwanted mechanical disturbances. Prabhu Sekar and Muthuveerappan [9] explained how load is distributed across gear teeth and how it affects contact stress levels. Their discussion highlights that load is not always shared evenly among teeth. This uneven distribution can lead to localized stress concentration and potential failure. They also explored how material properties influence stress behavior under load. Their explanation emphasizes the importance of

understanding real contact conditions. Another key point is how design improvements can help achieve better load sharing. They also discussed how this directly impacts gear lifespan. Their work provides useful insights into improving mechanical performance. It helps in designing gears that can handle higher loads efficiently. Gu and Zhu [10] explored how vibrations in gear systems are influenced by interactions between different structural components. They explained that gears do not operate in isolation but are affected by surrounding structures such as housings. Their findings show that this interaction can significantly change vibration behavior. They also discussed how ignoring these effects can lead to inaccurate predictions. Their explanation highlights the importance of considering the entire system. Another key point is how structural coupling affects stability and performance. Their work provides a more complete understanding of system dynamics. It also helps in designing more stable and efficient gear systems.

Ligata et al. [11] carried out practical observations to understand how gear systems behave under real operating conditions. Their explanation highlights the importance of validating theoretical predictions with actual measurements. They showed that real-world conditions often introduce complexities not captured in models. Their findings help bridge the gap between theory and practice. They also discussed how measurement data can improve simulation accuracy. Another key aspect is their focus on improving confidence in design methods. Their work supports the development of more reliable gear systems. It also emphasizes the need for continuous testing and validation. Y. Zhang et al. [12] focused on improving gear-rack systems used in robotic applications by adjusting key design parameters. Their explanation highlights the importance of precision and efficiency in automation systems. They discussed how optimizing parameters can enhance both accuracy and load capacity. Their findings show

that proper design choices can significantly improve performance. They also emphasized the need for balancing speed and stability. Another important point is the role of optimization in modern engineering. Their work provides practical guidance for improving robotic systems. It also reflects the growing importance of advanced design techniques in industrial applications.

### 3. Proposed system

The proposed research establishes a comprehensive analytical framework for evaluating the mechanical behavior and performance of rack and pinion systems under various operating conditions using advanced simulation techniques. The analytical workflow begins with geometric modeling and material definition, followed by mesh generation using hexahedral elements to ensure higher accuracy in stress and deformation prediction.

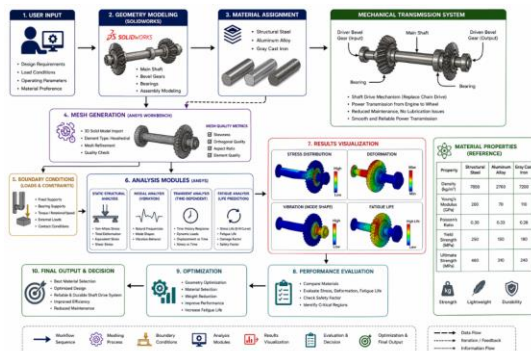


Figure. 2: System architecture.

The framework then incorporates multiple simulation approaches including static, modal, transient, and fatigue analysis to capture both steady-state and time-dependent system behavior. Different materials are evaluated under identical loading conditions to understand their structural response and to identify the most suitable material for gear manufacturing. The analysis further extends to realistic operating scenarios such as directional steering conditions, enabling a deeper understanding of dynamic load distribution. A structured workflow also integrates performance evaluation metrics such as stress concentration, deformation, contact

pressure, and fatigue life. The entire analytical process is supported by simulation tools that allow visualization, interpretation, and optimization of mechanical performance, as shown in Figure. 2.

### User Interface (Simulation Environment)

- The system interaction is carried out through a simulation interface that allows the user to define geometry, assign materials, and configure analysis settings.
- The interface supports operations such as model setup, meshing, boundary condition application, and result visualization.
- Users can modify parameters such as load conditions, contact definitions, and analysis type.
- All simulation inputs are processed within this environment and forwarded to the computational solver.

### Computational Solver (Analysis Engine)

- The solver acts as the core processing unit responsible for executing all structural analyses.
- It performs numerical computations based on finite element methods to determine stress, deformation, and dynamic response.
- The solver processes different analysis types including static, modal, transient, and fatigue evaluations.
- It ensures accurate representation of physical behavior under defined boundary and loading conditions.

### Material Property Module

- This module manages the definition and assignment of material properties used in the analysis.
- It includes parameters such as density, Young's modulus, Poisson's ratio, and thermal properties.
- Multiple materials such as gray cast iron and aluminium alloys are considered for comparative evaluation.

- The module ensures consistent application of material data across all simulation cases.

#### **Geometry and Mesh Generation**

- The geometric model of the rack and pinion system is prepared for analysis.
- The geometry is discretized into finite elements using hexahedral meshing techniques.
- Mesh refinement is applied in critical regions to improve accuracy in stress prediction.
- The quality of the mesh directly influences the precision and reliability of simulation results.

#### **Static Structural Analysis**

- This analysis evaluates the system behavior under constant loading conditions.
- A force of 1000 N is applied on a single tooth to simulate contact loading.
- The analysis computes parameters such as von Mises stress, total deformation, and contact pressure.
- It helps in identifying stress concentration zones and structural weaknesses.

#### **Modal Analysis**

- This analysis determines the natural frequencies and mode shapes of the system.
- The frequency range is evaluated up to 1000 Hz.
- It identifies potential resonance conditions that may affect system stability.
- The results provide insight into vibration characteristics and dynamic behavior.

#### **Transient Structural Analysis**

- This analysis simulates time-dependent loading conditions representing real-world steering scenarios.
- Load is applied in a cyclic manner corresponding to left and right steering motions.

- Contact between teeth is modeled with time intervals to capture dynamic interaction.
- The analysis evaluates stress, deformation, and pressure variation over time.

#### **Fatigue Analysis**

- Fatigue evaluation is performed based on transient loading conditions.
- It estimates the life cycle of the gear system under repeated stress variations.
- Parameters such as fatigue life, damage, and safety factor are determined.
- This analysis helps in predicting long-term reliability and failure risk.

#### **Mechanical Transmission Assembly**

- The system includes a shaft-driven transmission arrangement using bevel gears and a propeller shaft.
- Power is transferred from the gearbox shaft to the rear wheel through interconnected components.
- Bearings are used to support the shaft and ensure smooth rotational motion.
- Universal couplings accommodate angular misalignment caused by suspension movement.

#### **Power Transmission Mechanism**

- The transmission mechanism converts engine output into rotational motion at the rear wheel.
- Bevel gears enable directional change in power flow while maintaining efficiency.
- The propeller shaft transfers motion across the system with minimal energy loss.
- This arrangement ensures consistent and reliable power delivery under varying conditions.

#### **Performance Evaluation and Optimization**

- The system evaluates mechanical performance using parameters such as stress distribution, deformation, and fatigue resistance.

- Comparative analysis of materials helps in selecting the most suitable option for manufacturing.
- Visualization tools assist in interpreting simulation results effectively.
- The framework supports iterative improvement to enhance efficiency, durability, and overall system performance.

#### 4. Results and Description

The results and discussion section presents the outcomes of the finite element analysis carried out on the two-wheeler main shaft system under different loading conditions. The analysis was performed using ANSYS to evaluate key mechanical parameters such as stress distribution, deformation, strain, and fatigue life. Three different materials structural steel, aluminum alloy, and gray cast iron were analyzed to compare their performance under identical conditions. The obtained results are visualized through contour plots and graphical representations for better interpretation. A detailed comparison is carried out to identify the most suitable material based on strength, durability, and reliability. The discussion also highlights critical regions prone to failure and evaluates the overall structural behavior of the system. These findings provide a strong basis for material selection and design optimization.

Figure 3 illustrates the static structural analysis setup of the two-wheeler main shaft assembly performed in ANSYS to evaluate its mechanical behaviour under applied loading conditions. The model shows the meshed geometry of the shaft and bevel gear system, where appropriate boundary conditions such as cylindrical support, rotational acceleration, and applied force are defined to simulate real operating conditions. The hexahedral mesh distribution ensures accurate stress and deformation prediction, particularly in critical contact regions between gear teeth. The figure depicts how loads are transferred through the shaft and gear interface, enabling identification of stress concentration zones.

Additionally, the orientation of the coordinate system and applied constraints provides insight into the directional behavior of the structure. This setup forms the basis for subsequent evaluation of stress, strain, and deformation characteristics under static loading conditions.

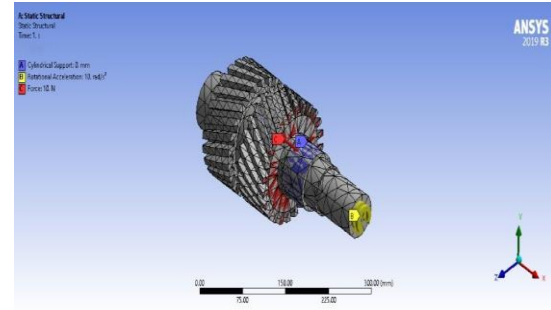


Figure. 3: Static structural analysis setup of Two-Wheeler main shaft using ANSYS

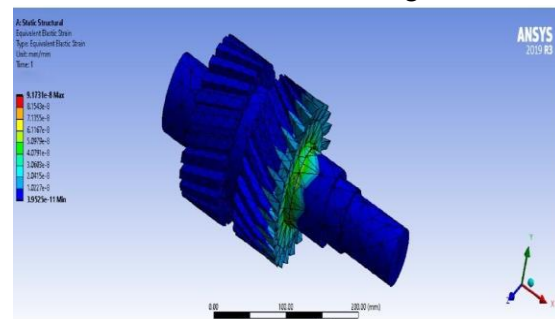


Figure. 4: Equivalent Elastic Strain Distribution of Two-Wheeler Main Shaft under Static Loading

Figure 4 illustrates the distribution of equivalent elastic strain in the two-wheeler main shaft assembly obtained through static structural analysis using ANSYS. The contour plot highlights the variation of strain across the shaft and bevel gear system, indicating regions subjected to different levels of deformation under applied loads. Higher strain concentrations are observed near the gear contact interface, suggesting critical zones where material deformation is more significant. The gradual transition of strain values along the shaft length reflects the load transfer mechanism from the gear to the shaft body. The visualization provides a clear understanding of how the structure responds elastically to external forces, aiding in identifying potential areas susceptible to fatigue.

This analysis is essential for evaluating structural integrity and ensuring the reliability of the shaft under operational conditions.

### ● Result Summary

| Results                   | Minimum      | Maximum     | Units | Time (s) |
|---------------------------|--------------|-------------|-------|----------|
| Total Deformation         | 0.           | 3.5565e-006 | mm    | 1.       |
| Equivalent Elastic Strain | 3.9525e-011  | 9.1731e-008 | mm/mm | 1.       |
| Equivalent Stress         | 1.4396e-006  | 1.1963e-002 | MPa   | 1.       |
| Shear Stress              | -5.4849e-003 | 4.4412e-003 | MPa   | 1.       |
| Shear Elastic Strain      | -7.1304e-008 | 5.7736e-008 | mm/mm | 1.       |

Figure. 5: Summary of Static Structural Analysis Results for Two-Wheeler Main Shaft

Figure 5 illustrates the summarized results obtained from the static structural analysis of the two-wheeler main shaft system. The table presents the minimum and maximum values of key mechanical parameters, including total deformation, equivalent elastic strain, equivalent stress, shear stress, and shear elastic strain. These values provide a quantitative understanding of the structural response under applied loading conditions. The maximum deformation and stress values indicate the critical limits experienced by the system during operation. The comparison of minimum and maximum ranges helps in identifying the variation of mechanical behavior across the model. This summary serves as a concise representation of the analysis outcomes, supporting effective evaluation of material performance and structural integrity.

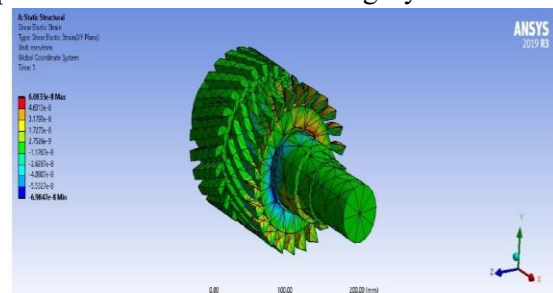


Figure. 6: Shear Elastic Strain (XY Plane) Distribution of Two-Wheeler Main Shaft under Static Loading

Figure 6 illustrates the shear elastic strain distribution in the XY plane for the two-wheeler main shaft assembly obtained through static structural analysis using ANSYS. The contour

plot represents the variation of shear strain across the shaft and bevel gear system, highlighting the influence of torsional and contact forces during operation. Higher shear strain concentrations are observed near the gear-shaft interface, indicating regions subjected to significant shear deformation due to load transmission. The distribution pattern shows a gradual reduction in strain values along the shaft away from the contact region, reflecting the dissipation of shear effects. This visualization provides important insight into the structural response under combined loading conditions. It aids in identifying critical zones that may be prone to shear-induced damage and supports the evaluation of overall system durability and performance.

### ● Result Summary

| Results                   | Minimum      | Maximum     | Units | Time (s) |
|---------------------------|--------------|-------------|-------|----------|
| Total Deformation         | 0.           | 6.4702e-006 | mm    | 1.       |
| Equivalent Elastic Strain | 4.0497e-011  | 1.3253e-007 | mm/mm | 1.       |
| Equivalent Stress         | 5.1772e-007  | 5.8249e-003 | MPa   | 1.       |
| Shear Stress              | -1.8643e-003 | 1.6237e-003 | MPa   | 1.       |
| Shear Elastic Strain      | -6.9847e-008 | 6.0833e-008 | mm/mm | 1.       |

Figure. 7: Summary of Static Structural Analysis Results for Alternate Material Configuration

Figure 7 illustrates the summarized results obtained from the static structural analysis of the two-wheeler main shaft assembly under an alternate material configuration. The table presents the minimum and maximum values of key parameters such as total deformation, equivalent elastic strain, equivalent stress, shear stress, and shear elastic strain. These values provide a quantitative comparison of the structural response under identical loading conditions. The variation in maximum deformation and stress values reflects the influence of material properties on system performance. The data enables identification of critical limits and helps assess the mechanical stability of the shaft assembly. This summary supports comparative evaluation and plays a significant role in selecting the most suitable material for improved durability and reliability.

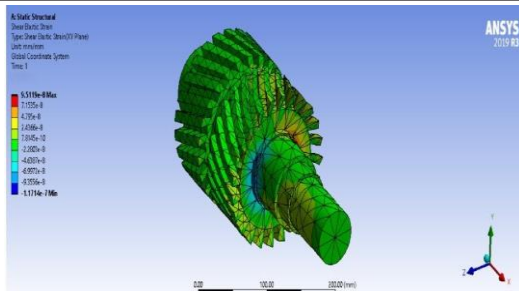


Figure. 8: Shear Elastic Strain (XY Plane)  
Distribution of Main Shaft for Alternate  
Material

Figure 8 illustrates the shear elastic strain distribution in the XY plane for the two-wheeler main shaft assembly under an alternate material condition obtained through static structural analysis using ANSYS. The contour representation shows the variation of shear strain across the shaft and bevel gear interface under applied loading conditions. Higher strain concentrations are observed near the gear engagement region, indicating areas experiencing significant shear deformation due to torque transmission. The strain values gradually decrease along the shaft length, reflecting the distribution and dissipation of applied loads. This pattern provides insight into how material properties influence the shear response of the structure. The analysis helps in identifying critical regions prone to shear-induced damage and supports the evaluation of structural performance and durability.

#### Result Summary

| Results                   | Minimum      | Maximum     | Units | Time (s) |
|---------------------------|--------------|-------------|-------|----------|
| Total Deformation         | 0.           | 6.1127e-006 | mm    | 1.       |
| Equivalent Elastic Strain | 6.481e-011   | 1.5615e-007 | mm/mm | 1.       |
| Equivalent Stress         | 1.288e-006   | 1.117e-002  | MPa   | 1.       |
| Shear Stress              | -5.0334e-003 | 4.0871e-003 | MPa   | 1.       |
| Shear Elastic Strain      | -1.1714e-007 | 9.5119e-008 | mm/mm | 1.       |

Figure. 9: Summary of Static Structural Analysis  
Results for Gray Cast Iron Main Shaft

Figure 9 illustrates the summarized results obtained from the static structural analysis of the two-wheeler main shaft assembly using gray cast iron as the material. The table presents the minimum and maximum values of important

mechanical parameters, including total deformation, equivalent elastic strain, equivalent stress, shear stress, and shear elastic strain under applied loading conditions. The results indicate the structural response of gray cast iron when subjected to operational loads, highlighting its deformation and stress characteristics. The variation between minimum and maximum values provides insight into the distribution of mechanical effects across the shaft and gear system. These results are useful for assessing the suitability of gray cast iron in terms of strength and durability. The summary supports comparative analysis with other materials for effective material selection and performance evaluation.

#### 5. Conclusion

The present study successfully demonstrates the design and structural analysis of a two-wheeler main shaft using a shaft-driven transmission system as an alternative to conventional chain drive mechanisms. The model was developed in SolidWorks and analyzed using ANSYS under realistic loading conditions to evaluate key parameters such as stress, deformation, strain, and fatigue behavior. A comparative analysis was performed using structural steel, aluminum alloy, and gray cast iron to determine the most suitable material. The results indicate that structural steel exhibits superior performance with minimum deformation and better resistance to stress concentration, ensuring improved alignment and stability of the gear system. The shaft drive mechanism enhances power transmission efficiency by reducing energy losses and eliminating the need for frequent lubrication. It also contributes to reduced maintenance and increased operational reliability. The simulation results further highlight critical regions in the gear contact zone, enabling better design optimization. Overall, the proposed system improves durability, performance consistency, and mechanical efficiency. This study provides a strong foundation for developing advanced and

reliable drivetrain systems in modern two-wheelers.

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