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AUTOMOTIVE STEERING KNUCKLE

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Abstract

The Automotive Steering Knuckle project focuses on the design and development of a steering knuckle, which is a critical component of an automobile suspension and steering system. The steering knuckle connects the wheel assembly to the suspension and steering components and helps transfer steering forces, braking loads, and vehicle loads between these components. Therefore, its design must provide adequate strength, stiffness, durability, and reliability while maintaining low weight.

In this project, a detailed 3D CAD model of an automotive steering knuckle is developed by considering important design parameters such as overall dimensions, mounting holes, wheel hub location, suspension connections, steering arm, fillets, and material properties. The geometry is designed to withstand different loading conditions experienced during vehicle operation.

The developed steering knuckle can be evaluated using finite element analysis (FEA) under static loading conditions. The analysis can determine important parameters such as Von Mises stress, total deformation, strain, and factor of safety. These results help identify critical regions and verify whether the component can safely withstand the applied loads.

The CAD model and simulation results can also be used to improve the design by modifying the geometry, material, thickness, and reinforcing features. This helps achieve an appropriate balance between strength and weight.

Overall, the project demonstrates the application of CAD modeling and structural simulation in the development of a reliable automotive steering knuckle. The designed component can serve as a foundation for further optimization, fatigue analysis, dynamic analysis, and manufacturing to improve vehicle safety, performance, and durability.

I. Introduction

An automotive steering knuckle is a critical component of a vehicle's steering and suspension system. It connects the wheel hub assembly with the suspension components and steering mechanism. The steering knuckle plays an important role in transferring loads and forces between the wheel, suspension, and vehicle body while allowing the wheels to rotate and change direction during steering.

During vehicle operation, the steering knuckle is subjected to different types of loads such as vertical loads, braking forces, cornering forces, steering forces, and impact

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loads. Therefore, it must have sufficient strength and stiffness to withstand these forces without excessive deformation or failure. At the same time, reducing unnecessary weight is important for improving vehicle efficiency and overall performance.

In this project, a detailed 3D CAD model of an automotive steering knuckle is developed by considering important design parameters such as mounting locations, wheel hub dimensions, steering arm geometry, suspension connections, bolt holes, fillets, and material properties. Proper geometric design is used to improve load distribution and reduce stress concentrations around critical regions.

The developed steering knuckle can be evaluated using finite element analysis (FEA) to study its structural behavior under different loading conditions. Important simulation results such as Von Mises stress, total deformation, strain, and factor of safety can be obtained to identify critical regions and verify the strength of the component.

The simulation results can be used to improve the design by modifying the component's geometry, thickness, fillet radius, material, and reinforcing features. This helps achieve an appropriate balance between strength, weight, durability, and manufacturing requirements.

II. Literature Survey

Several researchers have studied the automotive steering knuckle because it is a critical load-bearing component in the steering and suspension system. The steering knuckle transfers forces between the wheel, suspension, and steering mechanism while allowing the wheel to rotate and change direction. Therefore, its strength, stiffness, weight, and fatigue resistance are important factors in vehicle safety and performance.

Previous studies have focused on the structural analysis of steering knuckles using finite element analysis (FEA). Static structural analysis is commonly used to determine stress and deformation under braking, cornering, vertical, and steering loads. FEA helps identify critical regions of the component and provides useful information before manufacturing a physical prototype.

Researchers have also investigated weight reduction and optimization of steering knuckles. Since the steering knuckle is part of the vehicle's unsprung mass, reducing its weight can improve vehicle handling, suspension response, and fuel efficiency. Topology optimization and material reduction techniques can be used to remove unnecessary material while maintaining the required structural strength.

Material selection is another important area of research. Aluminum alloys, forged steel, and other lightweight materials have been considered for steering knuckle applications depending on the required strength, durability, manufacturing method, and cost. The selection of material directly affects the weight, stress capacity, deformation, and fatigue performance of the component.

Several studies have analyzed the effect of geometrical features and loading conditions on steering knuckle performance. Regions around mounting holes, bearing seats, steering arms, and suspension connections can experience high stress concentrations. Proper fillet design, rib placement, and material distribution can help improve load distribution and reduce localized stresses.

Researchers have also combined CAD modeling and FEA to improve the steering knuckle design process. A three-dimensional CAD model allows the component geometry to be developed accurately, while simulation helps evaluate its structural behavior under different loading conditions. This approach reduces the requirement for repeated physical prototypes and allows design modifications to be evaluated more quickly.

Recent approaches focus on integrated design optimization, where CAD modeling, finite element analysis, lightweight design, and fatigue evaluation are combined. Such methods help achieve a suitable balance between strength, stiffness, weight, durability, and manufacturing requirements.

Based on the existing research, the proposed Automotive Steering Knuckle project focuses on developing a detailed 3D CAD model and evaluating its structural performance through simulation. The analysis can determine Von Mises stress, total deformation, strain, and factor of safety under relevant loading conditions. The results can be used to identify critical regions and optimize parameters such as geometry, fillet radius, thickness, ribs, and material to develop a strong, lightweight, durable, and reliable steering knuckle.

III. System Analysis

System analysis is an important stage in the development of the Automotive Steering Knuckle project. The analysis focuses on understanding the structural and functional requirements of the steering knuckle. Important parameters such as vehicle load, wheel load, braking force, cornering force, steering force, dimensions, and material properties are considered. The geometry is designed according to the required suspension and steering connections. Features such as mounting holes, bearing seats, steering arms, fillets, and ribs are incorporated into the model. A detailed three-dimensional CAD model is developed using suitable modeling software. The model is checked for dimensional accuracy, proper clearances, and possible geometric errors. Suitable loading conditions and constraints are identified based on the vehicle operating conditions. Finite element analysis can be performed to evaluate stress, deformation, strain, and factor of safety. Critical regions experiencing high stress are identified from the simulation results. The design can be modified to improve strength while reducing unnecessary material and weight. Overall, system analysis provides a foundation for developing a strong, lightweight, and reliable automotive steering knuckle.

Existing System

In the existing system, automotive steering knuckles are generally designed using conventional engineering calculations, CAD modeling, and physical testing methods.

Engineers determine the required dimensions and material based on expected vehicle loads and operating conditions. The initial design is developed using traditional CAD techniques and evaluated through analytical calculations. Physical prototypes may be manufactured to verify the strength, fit, and functionality of the component. Manufacturing and testing prototypes can increase the overall development cost and time. Conventional calculations may not provide a detailed view of stress distribution throughout the complete steering knuckle. Stress concentration around mounting holes, bearing seats, steering arms, and fillets can be difficult to identify accurately. Design modifications may require repeated calculations and prototype testing. Different loading conditions such as braking, cornering, and vertical loads may require separate testing procedures. This makes the traditional design process less flexible for quick optimization. Therefore, CAD-based finite element simulation can provide a faster and more effective method for evaluating the steering knuckle before manufacturing.

Disadvantages of Existing System

- Requires extensive manual calculations.
- Physical prototypes may be required for testing.
- Prototype manufacturing increases development cost.
- Testing can consume considerable time.
- Difficult to visualize complete stress distribution.
- Stress concentration areas may not be identified early.
- Design modifications require repeated calculations.
- Multiple prototypes may be needed for validation.
- Difficult to evaluate different load conditions quickly.
- Limited early-stage deformation analysis.
- Weight optimization can be difficult.
- Repeated testing increases overall development effort.

Proposed System

The proposed system focuses on designing and evaluating an Automotive Steering Knuckle using CAD modeling and finite element analysis techniques. The design begins by identifying the expected vehicle loads, steering forces, braking forces, and suspension loads. A detailed three-dimensional CAD model is created with suitable mounting holes, bearing seats, steering arms, fillets, and reinforcing ribs. The geometry is designed to provide adequate strength while minimizing unnecessary material and weight. Appropriate material properties are assigned to the steering knuckle according to the selected material. The CAD model is prepared for finite element analysis by generating a suitable computational mesh. Boundary conditions are applied at the mounting and support locations to represent actual vehicle connections. Static loads are applied to the appropriate regions of the steering knuckle. The simulation provides results such as Von Mises stress, total deformation, strain, and factor of safety. Critical regions are identified from the obtained results and evaluated against the required safety conditions. The geometry can be modified by changing thickness, fillet radius, ribs, or material to improve performance. Overall, the proposed system provides an efficient method for designing a strong, lightweight, and reliable steering knuckle.

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Advantages of Proposed System

- Provides accurate 3D CAD modeling.
- Reduces dependence on physical prototypes.
- Saves design and development time.
- Reduces testing and development costs.
- Provides detailed stress distribution.
- Identifies critical stress concentration regions.
- Shows total deformation and strain.
- Provides factor-of-safety evaluation.
- Supports lightweight component design.
- Allows easy modification of geometry.
- Supports structural optimization.
- Improves component reliability and safety.

IV. Methodology

The methodology begins by identifying the design requirements and operating conditions of the automotive steering knuckle. Vehicle loads, braking forces, cornering forces, steering forces, wheel loads, and suspension loads are considered for the analysis. Suitable material is selected based on strength, durability, weight, and manufacturing requirements. A three-dimensional CAD model is created with mounting holes, bearing seats, steering arms, fillets, ribs, and other required features. The completed geometry is inspected for dimensional accuracy and unwanted gaps or intersections. The CAD model is then imported into finite element analysis software for structural evaluation. Material properties are assigned and a suitable mesh is generated over the steering knuckle geometry. Appropriate constraints are applied at the mounting and suspension connection locations. Static loads are applied to represent different vehicle operating conditions. The solver calculates important results such as Von Mises stress, deformation, strain, and factor of safety. The results are analyzed to identify critical areas and determine whether the component satisfies the required safety conditions. Finally, the design is modified and re-analyzed where necessary to improve strength, reduce weight, and achieve better overall performance.

System Architecture

The system architecture represents the complete workflow used for designing and analyzing the Automotive Steering Knuckle. The process begins with input requirements such as vehicle load, braking force, cornering force, steering force, dimensions, and material properties. These inputs are provided to the design parameter module to determine the required geometric specifications. The CAD modeling module creates the three-dimensional steering knuckle with mounting holes, bearing seats, steering arms, fillets, and ribs. The completed geometry is transferred to the preprocessing stage for material assignment and mesh generation. The boundary condition module defines the support and mounting locations according to the actual vehicle arrangement. The loading module applies the required static forces to the appropriate regions of the steering knuckle. The finite element solver performs numerical calculations to determine the structural response of the component. The post-processing module generates Von Mises stress, deformation, strain, and factor-

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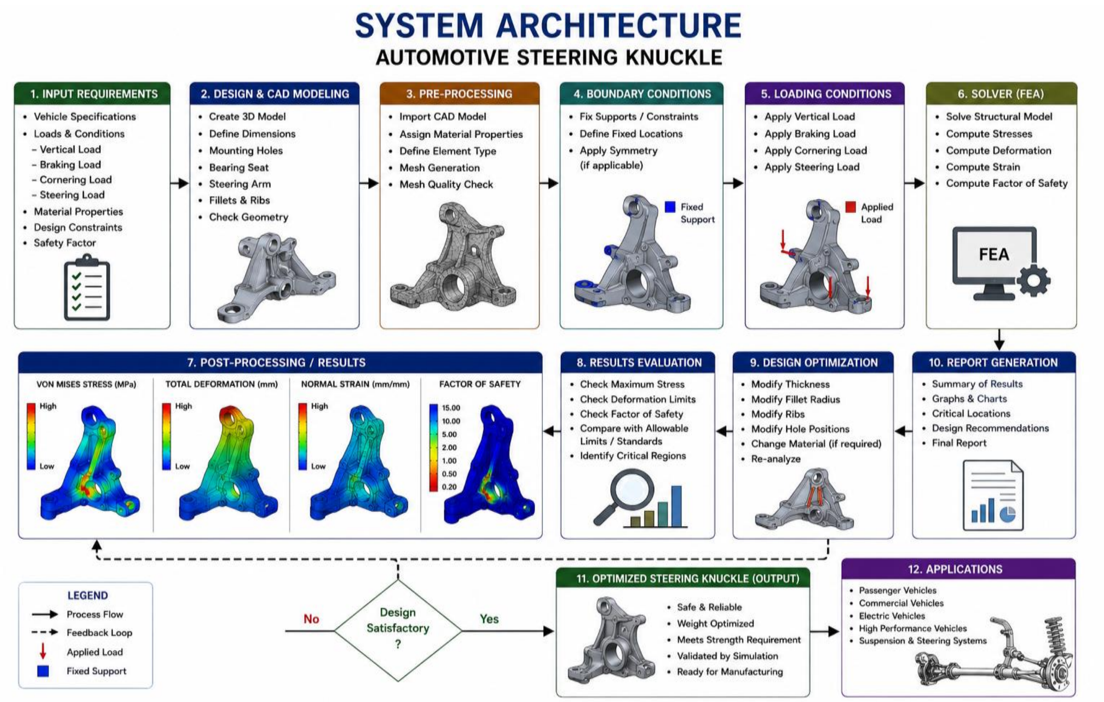
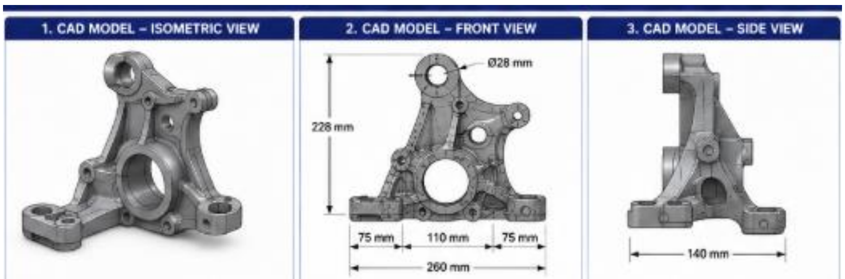
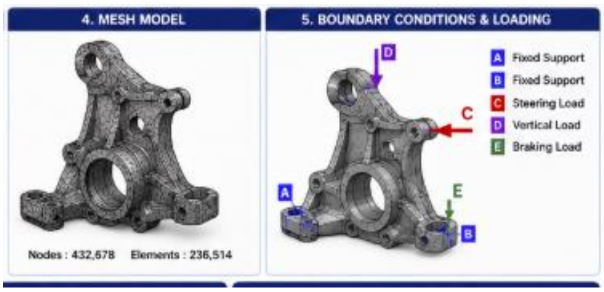
of-safety results. The results are analyzed to identify critical regions and evaluate the structural safety of the design. If the results are unsatisfactory, the geometry or material parameters are modified and the simulation is repeated. The optimized design is finalized after satisfying the required strength and weight conditions. This architecture provides an efficient workflow for designing, analyzing, and improving a reliable automotive steering knuckle.



V. Result and Output





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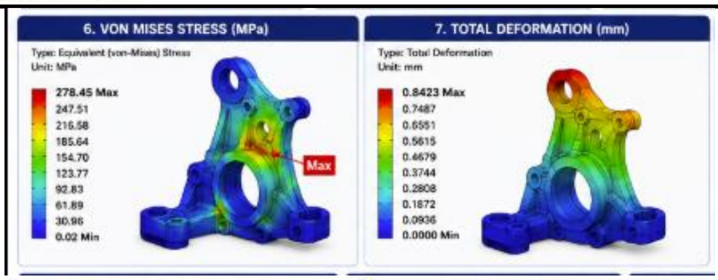
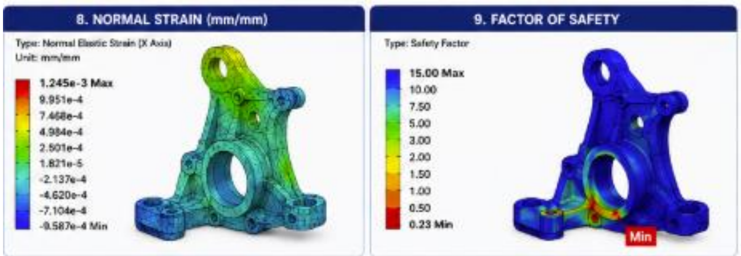
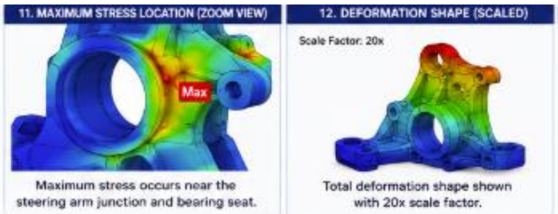
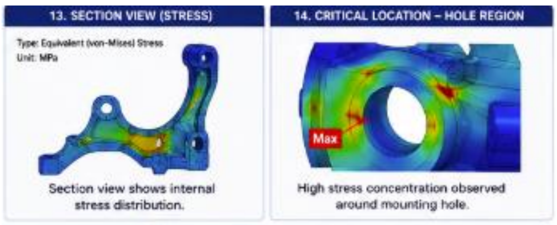




10. RESULTS SUMMARY

Parameter	Minimum	Maximum	Unit
Von Mises Stress	0.02	278.45	MPa
Total Deformation	0.0000	0.8423	mm
Normal Strain (X)	-9.587e-4	1.245e-3	mm/mm
Factor of Safety	0.23	15.00	-





ANALYSIS DETAILS

Analysis Type	:	Static Structural
Solver	:	Mechanical APDL
Element Type	:	Solid (Tetrahedral)
Material	:	Forged Steel (AISI 4140)
Yield Strength	:	760 MPa
Nodes	:	432,678
Elements	:	236,514

VI. Conclusion

The Automotive Steering Knuckle project successfully demonstrates the design and structural evaluation of a critical vehicle steering and suspension component using CAD modeling and finite element analysis. The steering knuckle is designed with suitable mounting holes, bearing seats, steering arms, fillets, and reinforcing features to withstand the loads experienced during vehicle operation.

The static simulation helps evaluate the structural behavior of the component under applied vertical, braking, cornering, and steering loads. Important parameters such as Von Mises stress, total deformation, strain, and factor of safety can be obtained from the analysis to identify critical regions and assess the structural performance of the design.

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The simulation results help identify areas of high stress concentration, particularly around mounting holes, bearing regions, and connecting sections. Based on these results, the geometry can be modified by optimizing the thickness, fillet radius, ribs, material, and overall shape to improve strength while reducing unnecessary weight.

Overall, the project demonstrates that combining 3D CAD modeling and finite element analysis provides an effective method for developing a strong, lightweight, durable, and reliable automotive steering knuckle. Further work can include fatigue analysis, dynamic loading analysis, topology optimization, experimental testing, and manufacturing validation to enhance the performance and safety of the component.

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