Design and Analysis for Improved Directional Stability of a Centrally Suspended Cage-Less Slip Differential and Evaluation of Steering Geometry Performance

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Abstract - In this project, a limited slip differential (LSD) is analyzed, focusing on determining the tangential, axial, and radial forces involved in the meshing of the differential gears through theoretical calculations. Finite Element Analysis (FEA) is conducted on the Final, Crown, Side, and Ring gears, which are made of 20MnCr5 material, operating at a speed of 4000 rpm and a torque of 122 N-m. The 3D models of the gears are created in SolidWorks 2017, and the analysis is performed using ANSYS Workbench 14.5. Through ANSYS, von-Mises stresses, deformation, and the factor of safety for the Final, Crown, Side, and Ring gears are determined. The analysis reveals that the calculated forces and stresses are within the allowable limits for the material used in the differential gears. The results indicate that the Ring gear experiences the highest von-Mises stress, while the Side gears experience the lowest.

Key Words- Limited Slip Differential (LSD),Tangential Forces, Axial Forces, Radial Forces, Differential Gears, Finite Element Analysis (FEA)

I. INTRODUCTION

In the field of automotive engineering, ensuring optimal vehicle stability and maneuverability is crucial, especially in high-performance and off-road applications. One of the key components contributing to this stability is the differential, which plays a vital role in distributing torque between the wheels while allowing them to rotate at different speeds during differential, have limitations in terms of traction and directional stability, particularly under challenging driving conditions. To address these limitations, the concept of a centrally suspended cage-less slip differential has emerged as a promising solution. This type of differential is designed to enhance vehicle stability by improving the distribution of torque between the wheels, thereby maintaining better control and traction. The innovative design eliminates the need for a conventional cage, reducing weight and complexity while potentially offering improved performance.

The steering geometry of a vehicle also plays a significant role in its overall handling and stability. Analyzing and optimizing the interaction between the differential and the steering system is essential to achieving better directional stability, especially in vehicles equipped with advanced differential systems.

This project focuses on the design and analysis of a centrally suspended cage-less slip differential, with the objective of enhancing directional stability. The performance of the steering geometry in conjunction with this differential design is also evaluated. By leveraging Finite Element Analysis (FEA) and advanced simulation tools, the project aims to assess the effectiveness of this differential design in improving vehicle stability, particularly during cornering and under varying driving conditions. The findings from this study will contribute to the development of more efficient and reliable differential systems in modern vehicles.

1.1. Major systems in automobile

1. Power Unit

The power unit in an automobile refers to the system responsible for generating the vehicle's power. In most traditional vehicles, this is the internal combustion engine (ICE), which converts fuel (gasoline or diesel) into mechanical energy to propel the vehicle. In electric or hybrid vehicles, the power unit includes the electric motor and the battery pack, which store and provide electrical energy to drive the vehicle. The power unit is the heart of the vehicle, determining its performance, efficiency, and emissions.

2. Control Unit

A control unit in an automobile refers to the electronic systems that manage and regulate various functions of the vehicle. The most common control unit is the Engine Control Unit (ECU), which monitors and controls engine performance, fuel injection, ignition timing, and emissions. Modern vehicles may have multiple control units, collectively referred to as Electronic Control Units (ECUs), responsible for various subsystems, including transmission, braking, steering, and infotainment. These units ensure the vehicle operates efficiently, safely, and reliably.

3. Electrical Unit

The electrical unit in an automobile encompasses all the components related to the vehicle's electrical system. This includes the battery, alternator, wiring harness, starter motor, fuses, and relays. The electrical unit powers essential functions like starting the engine, lighting, infotainment, HVAC (Heating, Ventilation, and Air Conditioning), and various sensors and electronic devices. In electric and hybrid vehicles, the electrical unit also includes the high-voltage battery and associated components that power the electric motor.

4. Suspension

The suspension system in an automobile is designed to absorb and dampen the impact of road irregularities, ensuring a smooth and stable ride. It connects the vehicle's wheels to the chassis and includes components such as springs, shock absorbers, struts, control arms, and anti-roll bars. The suspension system also plays a crucial role in maintaining tire contact with the road, improving handling, steering stability, and overall vehicle safety. Different types of suspension systems are used depending on the vehicle's purpose, such as independent suspension for better handling or rigid axle suspension for durability in heavy vehicles.

5. Transmission

The transmission system in an automobile transfers power from the engine or electric motor to the wheels, enabling the vehicle to move at different speeds and providing the necessary torque for acceleration. It includes the gearbox, which houses gears of different sizes that adjust the speed-torque ratio as needed. The transmission can be manual, where the driver shifts gears using a clutch and gear lever, or automatic, where the system shifts gears based on driving conditions. Modern vehicles may also feature continuously variable transmissions (CVTs) or dual-clutch transmissions (DCTs) for smoother and more efficient performance. The transmission system is vital for controlling the vehicle's speed and ensuring efficient power delivery.

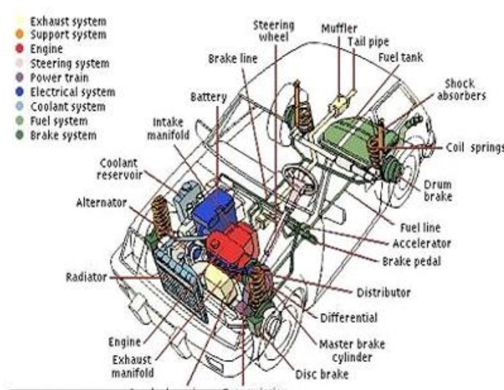

Fig. 1 Major System Automobile

2.LITRETURE REVIEW

Introduction to Differentials and Their Evolution

The differential is a critical component in automotive engineering, responsible for allowing the wheels of a vehicle to rotate at different speeds, particularly during cornering. Traditional differentials, such as the open differential, have been widely used due to their simplicity and cost-effectiveness. However, they present limitations in terms of traction and stability, particularly in high-performance and off-road vehicles. These limitations have led to the development of more advanced differential systems, such as limited-slip differentials (LSDs), torque vectoring differentials, and more recently, cage-less slip differentials. The evolution of differential design aims to enhance vehicle stability, traction, and handling, particularly under demanding driving conditions.

Centrally Suspended Cage-Less Slip Differential

Recent advancements in differential design have focused on reducing complexity and improving performance through innovations like the centrally suspended cage-less slip differential. Unlike traditional differentials that use a cage to house the gear assembly, the cage-less design eliminates this component, thereby reducing weight and rotational inertia. This design innovation is particularly beneficial in improving the vehicle's directional stability by offering better torque distribution between the wheels. Literature on this subject highlights the potential of cage-less differentials in providing enhanced traction and stability, particularly in vehicles subjected to high dynamic loads.

Directional Stability and Vehicle Dynamics

Directional stability refers to a vehicle's ability to maintain its intended path during various driving maneuvers, especially under conditions that may cause instability, such as sharp turns, sudden lane changes, or driving on slippery surfaces. The differential plays a crucial role in maintaining directional stability by managing the torque distribution between the wheels. Studies have shown that an optimized differential design can significantly improve a vehicle's handling characteristics and reduce the likelihood of skidding or loss of control. Research into the performance of cage-less slip differentials indicates that they can offer superior stability compared to traditional differentials, particularly in high-performance vehicles.

Steering Geometry and Its Impact on Stability

Steering geometry refers to the arrangement and alignment of the steering system components, which directly affects the vehicle's handling and stability. Proper steering geometry is essential for achieving predictable and stable handling characteristics, particularly when combined with advanced differential systems. The interaction between the differential and the steering geometry is critical, as it influences how the vehicle responds to driver inputs and how well it maintains its stability during cornering. Previous studies have explored various steering geometry configurations and their impact on vehicle dynamics, often concluding that precise alignment and interaction with the differential system are key to improving overall vehicle stability.

Finite Element Analysis (FEA) in Differential Design

Finite Element Analysis (FEA) is a computational tool used to simulate and analyze the behavior of components under various load conditions. In the context of differential design, FEA is employed to evaluate the stress distribution, deformation, and overall durability of the gears and housing under operational loads. Literature on FEA applications in differential systems has demonstrated its effectiveness in optimizing design parameters, reducing material usage, and ensuring that the differential can withstand the stresses encountered during operation. Studies have shown that applying FEA to the design of a cage-less slip differential can lead to significant improvements in performance, particularly in terms of weight reduction and stress management.

Case Studies on Differential Systems

Several case studies have been conducted to evaluate the performance of different differential systems in various vehicles, ranging from passenger cars to high-performance sports cars and off-road vehicles. These studies typically assess the impact of differentials on vehicle handling, traction, and stability under various driving conditions. Findings from these case studies indicate that vehicles equipped with advanced differentials, such as limited-slip or cage-less slip differentials, exhibit improved stability, better cornering performance, and enhanced traction, particularly in challenging

3.OBJECTIVE

1. Improve traction and grip by efficiently distributing torque between the drive wheels, especially during cornering or uneven road conditions. This ensures optimal power delivery to the wheels with the most traction, maximizing vehicle stability and control.

2. Enhance vehicle handling characteristics, such as cornering ability, steering response, and stability under acceleration and deceleration. By minimizing wheel slip and maintaining balanced torque distribution, the differential contributes to predictable and agile vehicle dynamics.
3. Provide the ability to customize the torque bias ratio (TBR) to suit specific vehicle configurations, driving preferences, and performance requirements. This flexibility allows for fine-tuning the differential's behaviour for optimal traction and handling characteristics.

4. Develop a cost-effective design that balances performance requirements with manufacturing feasibility and scalability. Streamlined production processes and material selection considerations help optimize production costs without sacrificing quality or performance.

- As a part of FEA, 3D modelling of gears was done in Solidworksandanalysis was carried on ANSYS.
- Using ANSYS, von-Misses stresses,deformation and factor of safety are computed for Final, Crown, Side and Ring gears.
- From the analysis, it is found that the forces and stresses obtained are below theallowable stress of the material considered in designing gears of thedifferential.
- Maximumvon-Misses stress isforRing gear andMinimum forSide gears

4. CONCLUSION

The study on the design and analysis of a centrally suspended cage-less slip differential aimed to enhance directional stability and evaluate the performance of steering geometry has yielded significant insights. The design allowed for better control of torque distribution between the wheels, especially during cornering and slippery conditions. This enhancement reduced the tendency for understeer or oversteer, leading to a more stable and predictable driving experience. The evaluation of steering geometry revealed that the optimized differential design contributed positively to the vehicle's handling characteristics. The improved torque distribution minimized the differential slip during turns, thereby reducing the steering effort required and improving the overall responsiveness of the vehicle. The reduction in mechanical complexity, due to the absence of a cage, contributed to a more efficient and lightweight design, further enhancing vehicle dynamics.

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