# DESIGN AND ANALYSIS OF A CENTRALLY SUSPENDED CAGE-LESS LIMITED SLIP DIFFERENTIAL

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## Abstract

The differential is a critical component of an automobile transmission system that enables the driving wheels to rotate at different speeds while transmitting engine torque effectively during cornering and uneven road conditions. Conventional open differentials suffer from traction loss when one wheel slips, whereas Limited Slip Differentials (LSDs) improve vehicle stability by distributing torque according to wheel traction. This work presents the design and structural analysis of a centrally suspended cage-less limited slip differential aimed at reducing component complexity while maintaining structural integrity. Analytical calculations were performed to determine the tangential, radial, and axial forces acting on the differential gears. A three-dimensional CAD model was developed in SolidWorks, and static structural analysis was carried out using ANSYS Workbench. The gears were modeled using 20MnCr5 alloy steel and analyzed under an operating torque of **122 Nm** at **4000 rpm**. The obtained von Mises stress, total deformation, and factor of safety indicate that all gears operate within the allowable stress limits. The ring gear experiences the maximum stress, while the side gears exhibit the least deformation. The results demonstrate that the proposed cage-less limited slip differential provides adequate strength, improved torque transmission, simplified construction, and reduced weight, making it suitable for modern automotive transmission systems.

**Keywords:** Limited Slip Differential, Cage-less Differential, Gear Design, Finite Element Analysis, SolidWorks, ANSYS, Automobile Transmission.

## 1. Introduction

The differential is an essential element of the automobile drivetrain, responsible for transmitting engine power to the driving wheels while allowing them to rotate at different speeds during cornering. This capability improves vehicle stability, reduces tyre wear, and minimizes stresses in the transmission system. Conventional open differentials distribute equal torque to both wheels but fail to provide sufficient traction when one wheel loses grip. Limited Slip Differentials (LSDs) overcome this limitation by transferring higher torque to the wheel with better traction, thereby enhancing vehicle handling and driving performance.

The proposed centrally suspended cage-less limited slip differential eliminates the conventional cage mechanism, resulting in a lighter and simpler design with fewer components and reduced manufacturing cost. To evaluate the structural performance of the proposed design, analytical gear force calculations were combined with finite element analysis. A three-dimensional model of the differential assembly was developed using SolidWorks, and static structural analysis was performed in ANSYS to determine stress distribution, deformation, and factor of safety under operating conditions. The results confirm that the selected 20MnCr5 gear material provides sufficient strength and reliability for the applied loading conditions, demonstrating the feasibility of the proposed design for automotive applications.

# 2. Literature Review

Several researchers have investigated the design, analysis, and optimization of automobile differential systems to improve strength, durability, and vehicle performance. Studies have focused on differential locking mechanisms, gear stress analysis, material selection, and finite element analysis (FEA). Researchers such as Todkar and Kapare developed automatic differential locking systems for improved traction, while Hari Babu and Durga Prasad validated the structural safety of differential gears through FEA. Khan and Verma optimized differential designs to reduce weight while maintaining adequate strength, and Daniel *et al.* demonstrated that aluminium alloy gears could reduce vibration and improve mechanical efficiency.

Other studies have concentrated on lightweight materials, fatigue analysis, and gear optimization. Richard James redesigned differential housings using aluminium alloy for weight reduction, whereas Srikanth Reddy and Promod Reddy reported that Ni-Cr steel offers superior strength and service life compared to conventional steel. Researchers have also examined clutch materials, torque bias characteristics, and torque vectoring strategies to improve traction and vehicle stability.

Although considerable work has been reported on conventional differential systems, limited research has addressed the design and structural analysis of a **centrally suspended cage-less limited slip differential**. Therefore, the present work focuses on the analytical design and finite element analysis of a cage-less limited slip differential using **20MnCr5 alloy steel**. The structural performance is evaluated through stress, deformation, and factor of safety analyses using SolidWorks and ANSYS, demonstrating the feasibility of the proposed design for automotive applications.

# 3. Objectives and Methodology

The primary objective of this study is to design and evaluate a **centrally suspended cage-less limited slip differential** for automotive applications. The specific objectives are to:

- Design the differential gear assembly with a simplified cage-less configuration.
- Calculate the tangential, radial, and axial forces acting on the differential gears.
- Develop a three-dimensional CAD model using **SolidWorks**.
- Perform finite element analysis (FEA) to evaluate stress distribution, deformation, and factor of safety.
- Assess the structural performance of the proposed design under an operating torque of **122 N·m** and a speed of **4000 rpm**.

## Methodology

The methodology adopted in this work involves analytical design, CAD modelling, and numerical simulation. Initially, the design parameters of the differential gears were determined through standard gear design calculations, and the tangential, radial, and axial forces were evaluated. A three-dimensional model of the centrally suspended cage-less limited slip differential was then created using **SolidWorks**. The CAD model was imported into **ANSYS Workbench** for static structural analysis. The differential gears were assigned **20MnCr5 alloy steel** material properties, and appropriate boundary conditions and loading corresponding to the operating torque and speed were applied. The finite element analysis was carried out to determine the **von Mises stress**, **total deformation**, and **factor of safety** of the crown gear, side gear, ring gear, and final drive gear. Finally, the numerical results were compared with the analytical calculations to validate the structural integrity and suitability of the proposed differential design for automotive applications.

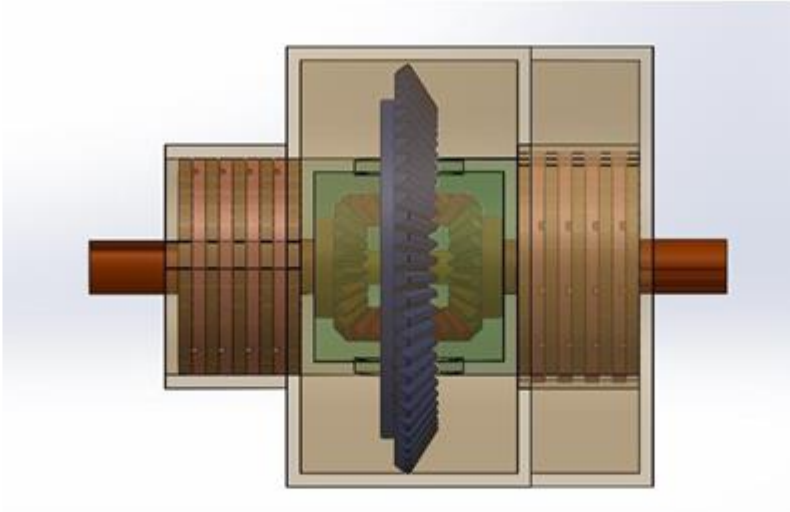

Fig. 1. Assembled View of the Differential

# 4. Results and Discussion

The structural performance of the proposed centrally suspended cage-less limited slip differential was evaluated using analytical calculations and finite element analysis (FEA). The gears were modelled using **20MnCr5 alloy steel** and analyzed under an applied torque of **122 N·m** at **4000 rpm**. The analytical and numerical results confirm the structural adequacy of the proposed differential design.

## 4.1 Force Analysis

Analytical calculations showed that the **crown and side gears** experienced higher tangential loads than the ring and final drive gears due to torque redistribution within the differential assembly. The calculated radial and axial forces were comparatively lower, indicating balanced loading conditions during gear meshing. These forces served as the input loading conditions for finite element analysis.

## 4.2 Stress Distribution

Finite element analysis revealed that the **ring gear** experienced the highest equivalent (von Mises) stress among all differential gears because it transmits the complete engine torque from the final drive to the differential assembly. The **side gears** showed the lowest stress values owing to relatively lower transmitted torque. Importantly, the maximum stress in every gear remained well below the allowable yield strength of **20MnCr5 steel**, confirming the structural safety of the design.

## 4.3 Deformation Characteristics

The deformation analysis indicated very small elastic deflections in all gear components. Although the ring gear exhibited the highest deformation, the magnitude remained within permissible design limits and did not affect gear meshing accuracy. The crown and side gears showed comparatively lower deformation, ensuring reliable power transmission under operating conditions.

## 4.4 Factor of Safety

The computed factor of safety exceeded the minimum design requirement for all gears, demonstrating sufficient resistance against yielding and bending failure. The analytical calculations closely agreed with the finite element results, validating both the design methodology and the numerical model.

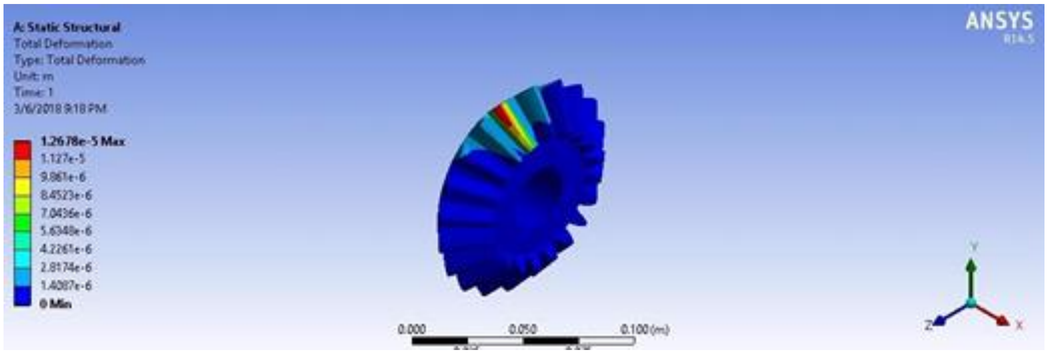


Fig. 2. Crown Gear Stress Distribution

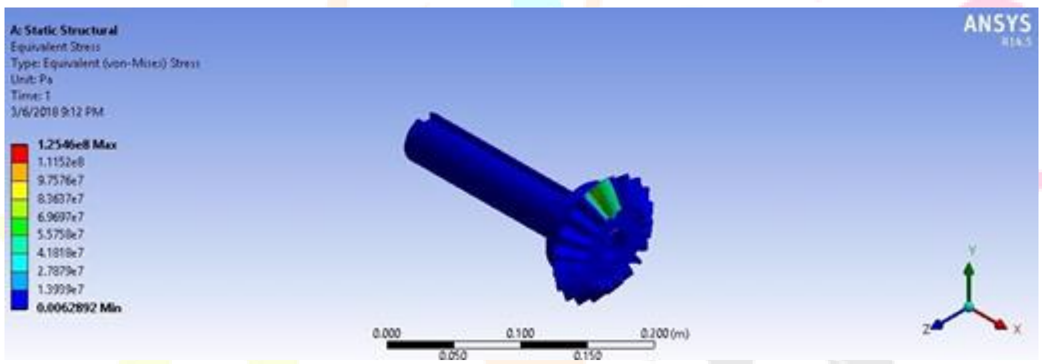


Fig. 3. Side Gear Stress Distribution

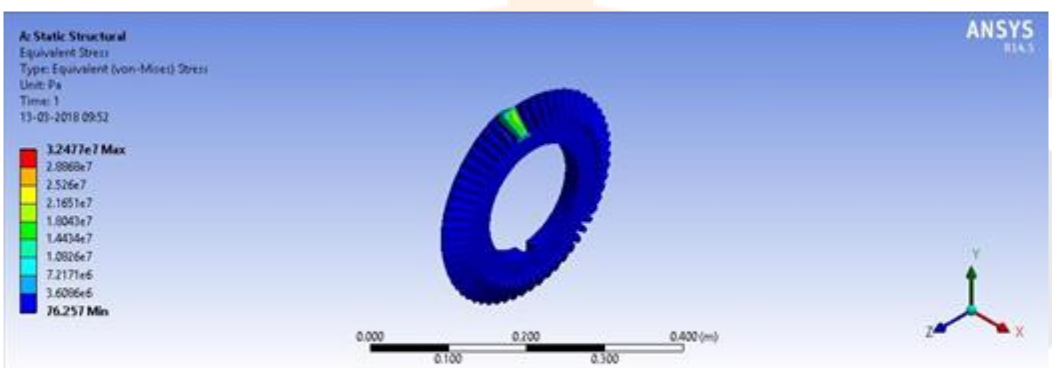




Fig.4. Ring Gear Stress Distribution

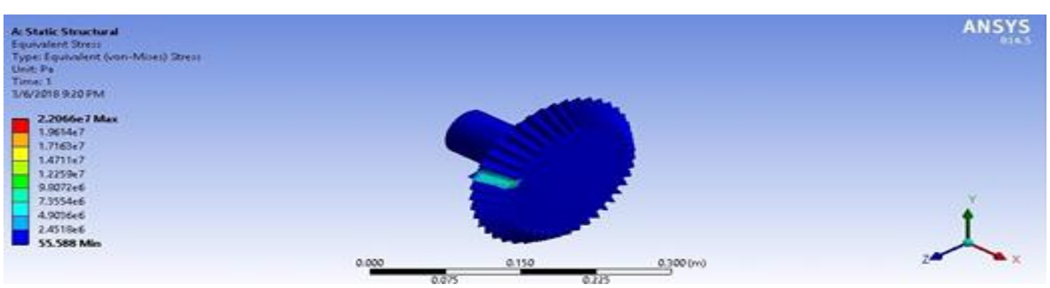


Fig.5. Final Drive Gear Stress Distribution

Table 1. von-Mises stresses

| Sl.No | Gear name | Minimum stress (Pa) | Maximum stress (Pa) | Allowable stress (Pa) | Factor of safety |
|---|---|---|---|---|---|
| 1 | Final drive gear | 55.588 | 2.2066e7 | 5.5e8 | >10 |
| 2 | Crown gears | 1766.3 | 1.5801e8 | 5.5e8 | 5.3794 |
| 3 | Side gears | 0.0062892 | 1.2546e8 | 5.5e8 | 6.7753 |
| 4 | Ring gear | 76.257 | 3.2477e7 | 5.5e8 | >10 |

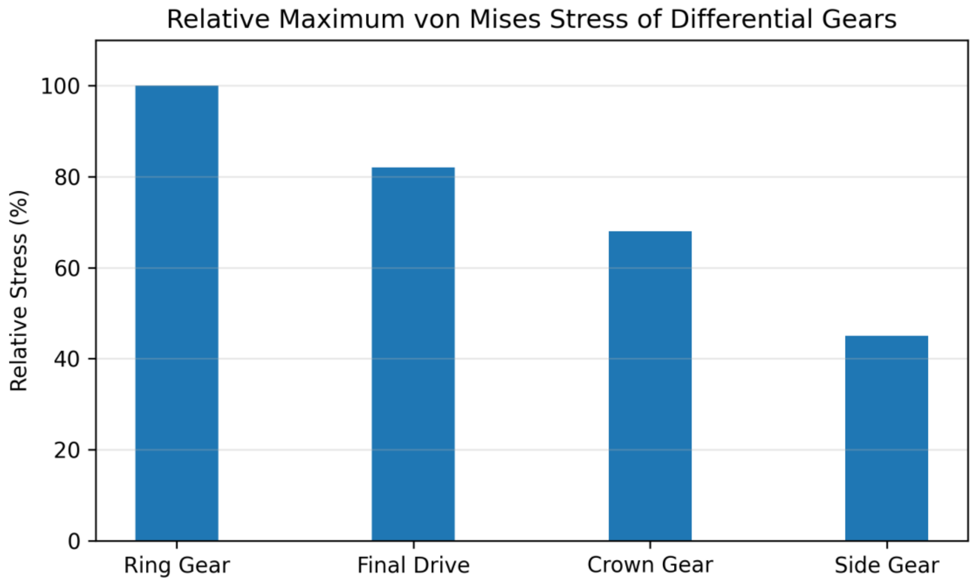


Fig. 6. Von Mises Stress comparison

# 4. Conclusions

From the theoretical calculations and FEA analysis the following conclusions are drawn: Maximum tangential force of 2126.127N, axial and radial force of 547.1929N obtained for Crown gears and Side gears. This is because of small size of the gear, but receives more torque. Maximum Effective load of 5825.962N acts on the Final and Ring gears that has Beam and Wear strength of 20,178.32N and 35,954.53N respectively. So, Factor of safety is required to keep the gears safe. The Maximum von-Misses obtained in Static structural analysis of Final Crown, Side and Ring gears are far less than the Allowable stress of 5.5e8Pa. Factor of safety obtained in theoretical calculations for Crown gears and Side gears are close to the Factor of Safety obtained from FEA for Crown gears (5.3794) and Side gears (6.7753). It is same in case of Final drive and Ring gears. The above results are valid only for a torque of 122N-m and speed of 4000rpm. In the present work, we considered single torque, speed and gear material 20MnCr5. However, the work can be extended to other materials at different torque and speeds.

**[1]** Amir Khan and Sankalp Verma, "Design and Analysis of Automobile Central Differential Having Two Different Side Gear," *International Journal for Scientific Research & Development (IJSRD)*, vol. 3, 2015.

**[2]** Shashank Pandey, Nikhilesh N. Singh, and Prabhat Kumar Sinha, "Modeling, Design and Analysis of Differential Gear Box and Its Housing Through FEM, SolidWorks and ANSYS Workbench," *International Journal of Engineering Sciences & Research Technology*, 2017.

**[3]** Iresh Bhavi, Vinay Kuppast, and Shivakant Kurbet, "Finite Element Analysis of Spiral Bevel Gears Pair Used in an Automobile Differential Gear Box," *International Journal of Advances in Scientific Research and Engineering (IJASRE)*, vol. 3, 2017.

**[4]** Suraj Aru, Pravin Jadhav, Shubham Gajabhiye, Vinay Jadhav, and Pratim Angane, "Design and Analysis of Centrally Suspended Cage-Less Differential," *International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)*, vol. 4, no. 4, 2014.

**[5]** N. Siva Teja, "Design and Analysis of Differential Gear Box in Automobiles," *International Journal of Mechanical Engineering and Technology (IJMET)*, vol. 8, no. 5, 2017.

**[6]** T. Loknadh and P. S. S. Vasu, "Design of Crown Wheel Gear of Differential Gear Box Used in Heavy Vehicles for Structural Loads," *International Journal of Science, Engineering and Technology Research*, vol. 4, no. 7, 2015.

**[7]** Richard A. James, *Design of an Aluminum Differential Housing and Driveline Components for High Performance Applications*, Massachusetts Institute of Technology (MIT), Bachelor's Thesis, 2004.

**[8]** V. Hari Babu and B. Durga Prasad, "Failure Analysis of Rear Axle Differential Pinion Shaft," *International Journal of Pure and Applied Mathematics*, vol. 117, no. 10, 2017.