Design and Analysis to Enhance Directional Stability with a Centrally Suspended Cage-Less Slip Differential and Assessment of Steering Geometry Effectiveness

Author1Prof. Vaibhav Bankar, Dept.of Mechanical Engineering
Vidarbha Institute of Technology, Nagpur,440026,
Nagpur, vhbankar@gmail.com

Author2Mr.Unmesh Madhukarrao Pokley,
pokleyunm@gmail.com, Nagpur,440026,

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 Solid Works 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.

2. DESIGN CALCULATIONS FOR CAGE-LESS LIMITED SLIPDIFFERENTIAL

The design of a cage-less limited slip differential (LSD) aims to enhance vehicle performance by improving torque distribution and stability while eliminating the traditional cage structure. This section outlines the key design calculations necessary for developing a cage-less LSD, including torque distribution, gear dimensions, and stress analysis.

2. Torque Distribution

Objective: Calculate the torque distribution between the wheels through the differential.

Given Data

Engine torque (T_engine): 122 N·m

Differential gear ratio (R): Typically, the gear ratio is given or calculated based on the number of teeth on the gears.

Calculation: The torque distributed to each wheel depends on the differential's design. For a simple calculation, assuming a standard open differential:

$T_{wheel1}=T_{Engine}/2$ $T_{Wheel2}=T_{Engine}/2$

For a limited-slip differential, the torque distribution may vary based on the slip characteristics and design specifics. If the LSD provides a certain percentage of torque transfer, the calculation will include that factor.

3. Gear Dimensions and Parameters

Objective: Determine the dimensions and parameters of the gears used in the cage-less LSD.

- Given Data:
  - Number of teeth on the gears (e.g., Final gear, Crown gear, Side gear, Ring gear)
  - Gear material: 20MnCr5
  - Operating speed: 4000 rpm

Calculation:

Gear Tooth Profile: Using the gear tooth profile formula, determine the pitch diameter and other gear dimensions.

Dp=N/Diametral Pitch where N is the number of teeth.

Gear Torque: For calculating the gear torque, use the formula: $T_{Gear}=T_{Engine/R}$ where R is the gear ratio.

These calculations provide the foundation for designing and analyzing a cage-less limited slip differential. The calculations ensure that the differential components can handle the expected loads and stresses while optimizing performance and durability. Future work may involve validation through physical testing and refinement of the design based on real-world performance data.

Numberofteeth on pinion	-Z_p
Numberofteeth ongear	-Z_g
Pitchangleofpinion	-γ
Module	-m
Diameterofpinion	-D_p
Diameterofgear	-D_g
Pressureangle	-α
Facewidth	-b
Meanradius	-R_m
Tangentialload	-P_t
Radialload	-P_r
Axial/Thrust load	-P_a
Torque	-M_t
Pitchofgear	-Γ
Formativespur geartooth	-Z_p’
Ultimatestrength	-σ_u
Allowablebendingstress	-σ_b
Workingstress	-σ_w
Beamstrength	-S_b
Lewisformfactor	-Y
Conedistance	-A_o
Wearstrength	-S_w
Ratiofactor	-Q
Materialconstant	-K
Brinellhardnessnumber	-BHN
Sumoferrorsbetween	

Twomeshinggearteeth	-e
Deformationfactor	-C
Effectiveload	-Peff
Dynamicload	$-P_d$
Speedofpinion	$-N_p$
Factor of safety against bending failure	$-FS_b$
Factorofsafetyagainstpittingfailure	$-FS_w$
Factorof safety	-Fs

RESULT

In Chapter III, the design calculations for determining the tangential, radial, and axial forces, as well as the factor of safety, are performed for the differential gears of a centrally suspended cage-less limited slip differential. These calculations are based on the input torque provided to the final drive gear. The results of these calculations are presented in Table 1.

Table1: Theoreticallycalculatedforces

Sl.No	Gear name	Tangential Forces(N)	RadialF orces(N)	Axial/Thrust Forces(N)	Factorof safety
1	Finaldrive gear	1310.89	396.99	264.66	>10
2	Crown gears	2126.127	547.1929	547.1929	6.9
3	Sidegears	2126.127	547.1929	547.1929	6.9
4	Ringgear	1310.89	264.66	396.99	>10

Table2. BeamandWearstrengthof differentialgears

Sl.No	Gearname	Beam strength (N)	Wearstrength (N)	FS_b	FS_w	Effectiveload (N)
1	Finaldrive gear	20,178.32	35,954.53	3.46	6.1714	5825.962
2	Crowngears	11,204.9296	10,800	1.6048	1.5468	4855.786
3	Sidegears	11,204.9296	10,800	1.6048	1.5468	4855.786
4	Ringgear	20,178.32	35,954.53	3.46	6.1714	5825.962

Table3 . von-Misesstresses

Sl.No	Gear name	Minimum stress(Pa)	Maximum stress(Pa)	Allowable stress(Pa)	Factor ofsafety
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

The beam and wear strength of the differential gears, along with the safety factors against bending failure and pitting failure, are calculated based on the tangential forces acting on the gears. These results are summarized in Table 4.

Table.4. Deformationofdifferentialgears

Sl.No	Gearname	Minimum(mm)	Maximum(mm)
1	Finaldrivegear	0	1.8321e-5
2	Crowngears	0	1.2678e-5
3	Sidegears	0	1.2499e-5
4	Ringgear	0	3.8695e-6

The beam strengths calculated are greater than the actual working tangential loads acting on the differential gears

. Additionally, the beam and wear strengths of the gear teeth exceed the effective load between the meshing teeth. Therefore, the design is considered safe.

The safety factors against bending and pitting failures are greater than 1 but less than 7, ensuring that the components avoid excessive weight. This balance helps prevent unnecessary increases in the overall weight of the vehicle.

Static structural analysis of the differential gears yields the maximum and minimum von-Mises stresses and safety factors. The results of these analyses are summarized in Table

CONCLUSION

The maximum tangential force of 2126.127 N and the axial and radial force of 547.1929 N were observed for the Crown and Side gears. This is attributed to their smaller size, which, while handling more torque, results in higher force concentrations.

The Final and Ring gears experience a maximum effective load of 5825.962 N. Their beam and wear strengths are 20,178.32 N and 35,954.53 N, respectively.

Therefore, a factor of safety is essential to ensure the gears' reliability and durability.
In static structural analysis, the maximum von-Mises stresses for the Final, Crown, Side, and Ring gears are significantly below the allowable stress limit of 5.5 × 10^8 Pa.
The theoretical factor of safety for the Crown gears (6.9) and Side gears (6.9) is comparable to the factor of safety obtained from Finite Element Analysis (FEA) for Crown gears (5.3794) and Side gears (6.7753). This consistency is also observed for the Final drive and Ring gears.
These results are specific to a torque of 122 N·m and a speed of 4000 rpm.
The current study is based on a single torque, speed, and gear material (20MnCr5). Future research could explore other materials and different torque and speed conditions.

REFERENCES

[1] Prof.A. S.Todkar,R.S.Kapare,2013,Design Development& Testing Of Automatic Differential Locking System-International Journal Of Advanced Technology
[2]VHariBabu, Dr BDurgaPrasad, 2017,Failure Analysis Of Rear Axle Differential Pinion Shaft- International Journal Of Pure And Applied Mathematics, Volume117,Paper No.10

[3] Amir Khan, Sankalp Verma, 2015, Design And Analysis Of Automobile CentralDifferential Having Two Different Side Gear, International Journal For ScientificResearch&Development(IJSRD), Vol. 3
[4] Daniel Das.A, Seenivasan.S, Karthick.S, 2016, Structural Analysis of Differential Gearbox, International JournalofInnovationsin Engineering and Technology(IJIET),Vol2
[5] Shashank Pandey, Nikhilesh N. Singh, Dr. Prabhat Kumar Sinha, 2017, Modeling, Design&Analysis OfDifferential GearBox And Itshousing Through FEM ,Solidwork & Ansys Benchwork 14.0,International Journal Of Engineering Sciences &Research technology
[6] N.Vijayababu, Ch.Sekhar,2015, Design And Analysis Of Differential Gear Box Used In Heavy Vehicle, Proceedings Of International Conference On Recent TrendsIn Mechanical Engineering, NECICRTME-2K15, Vol.2,No.1

[7]Mayank Bansal,Nidhi Sindhu,Santosh Anand,2016,Structura lAnd Model Analysis OfA Composite Material differential Gearbox Assembly,International JournalOf Engineering Sciences& Research Technology