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# Finite Element Analysis-Based Review of Material Optimization in Differential Gearbox Mechanisms

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**ABSTRACT:** With the characteristic that the angular velocity of its carrier is equal to the average of the angular gears, a differential is a specific kind of basic planetary gear train. The outer drive wheel can turn more quickly than the inner drive wheel during a turn thanks to the differential gear mechanism. In order to have the wheel that is going around the outside of the turning curve roll faster and farther than the other, this is required as the vehicle turns. This study's goal is to review the differential gearbox mechanism's material optimization. 3-D modeling programs such as CREO, CATIA, and Pro-E are used to produce the gearbox case model.

**KEYWORDS:** Gearbox, 3-D Modeling Software, CREO, CATIA, Pro-E.

## I. INTRODUCTION

Improvements in performance, efficiency, and dependability are constant goals for the automotive industry. A vital component of cars' complex technology, the differential gearbox shapes the vehicle's dynamics and stability by distributing torque among its wheels. The selection of materials that can withstand the dynamic stresses present in operating processes is crucial to the functionality of this essential component [1]. The differential enables the outer drive wheels of cars and other wheeled vehicles to turn more quickly than the inner drive wheel when turning. In order to have the wheel that is going around the outside of the turning curve roll faster and farther than the other, this is required as the vehicle turns. The drive shaft's input rotational speed is equal to the average of the two driving wheels' rotational speeds. One wheel's increased speed is counterbalanced by the other wheel's decreased speed.

When turning in an automobile, the differential is an essential component. The outer wheel rotates more quickly than the inner wheel because it must cover a greater distance as the vehicle turns. Wheel slippage is avoided, tire wear is decreased, and steering performance is improved thanks to the differential, which permits this change in wheel speed. By transferring input torque from the drive shaft to the rear axle and allocating it between the two wheels according to resistance and wheel path radius, it accomplishes this. Consequently, the average of the two wheels' rotating speeds becomes the drive shaft's rotational speed.

In order to maintain a balanced torque distribution, if one wheel rotates more quickly, the other wheel slows down to compensate. The pinion, which interacts with the crown wheel inside the differential, transfers this torque. Through gear ratios, the gear contact also reduces speed. Half-shafts encased in the axle casing are usually used to connect the differential to the rear axle in rear-wheel drive cars. Front-wheel-drive cars, on the other hand, frequently have the pinion fixed directly to the main shaft of the gearbox and the differential housed inside the gearbox case. From the differential, each driving shaft leads to a separate wheel [2]

## II. LITERATURE SURVEY

The mechanical design and analysis of differential gearboxes using different materials when they transmit power under three distinct load circumstances is the main emphasis of Saravanan S. et al. [3]. By examining von Mises stress, strain, and deformation as well as transmission safety, the study is done to confirm the optimal material based on the specific strength of the gears in the differential gear box at three distinct loads. This differential gearbox improvement



reduces material weight, increases performance, and conserves engine power. The stress levels are within the allowable stress range based on the structural study results utilizing manganese chromium alloy steel (17 Mn 1 Cr 95). Therefore, it is safe to use manganese chromium alloy for differential gears. Manganese chromium alloy had lower stress, strain, and deformation values than carbon steel and nickel chromium alloy at all three speeds (2400 rpm, 1600 rpm, and 1000 rpm).

In every mechanical system, the gearbox is essential. To extend the life of the internal gears and bearings, the gearbox housing's vibrations must be kept to a minimum. There is a lot of room for development in this area, according to earlier research. The most widely used technique for determining the morphologies of vibration modes is finite element analysis (FEA). The main tool used for virtual prototyping is ANSYS software. Additionally, researchers have compared the outcomes of various simulation tools, and some have used specialized equipment to perform physical testing. Furthermore, a lot of research validate the simulation results using FFT analyzers. Overall, the simulated results and experimental observations show a significant connection [4].

Researchers Vijayababu, Ch. Sekhar, and associates claim that when a vehicle's outer wheel turns with a greater radius than its inner wheel, a differential is engaged. The outer rear wheel rotates more quickly than the inner one in these situations. The inner wheel has a tendency to slip when the rear wheels are fixedly attached to the same axle, which can lead to uneven tire wear, steering issues, and unstable load management. The wheels, bearings, and rear differential axles are all part of the inner axle housing assembly. In order to transfer power from the driving shaft to the back wheels, the differential itself is made up of gears. By examining stress, displacement, and weight reduction, this study aims to determine the optimal material for the gears inside the differential gearbox under higher speed settings. In particular, the Ashok Leyland 2516M model's differential gearbox is examined in this project. When the gears run at different speeds between 2400 and 5000 RPM, load calculations are carried out. To choose the best material, structural analysis is done using factors like weight, displacement, and stress. Aluminum alloy is a safe option for the differential gears since the results show that its stress levels are within reasonable bounds. Aluminum alloy has lower stress values than alloy steel and cast iron at all measured speeds. Aluminum alloy is therefore determined to be the best material for differential.

By permitting differential motion between the left and right drive axles, researchers Subhajit Konar, Vijay Gautam, and his group demonstrated the crucial function that the differential gear system plays in facilitating smooth vehicle turning. The design and analysis of an open differential for a popular car model is the main topic of the study. The researchers used a modified Lewis equation, Hertzian contact stress formulas, and the AGMA standard equations to evaluate the system's mechanical behavior. Using ABAQUS, these theoretical findings were verified and contrasted using Finite Element Analysis (FEA). Although there was a significant connection between the analytical and FEA results, it was found that the Lewis equation produces more cautious estimates than AGMA. Despite being more cautious, the Lewis technique closely matches the numerical results and validates the differential gear's structural safety under anticipated operating circumstances [6].

The design and weight optimization of a four-wheeler differential case using FEA and the UTM strain gauge technique is presented by Prof. S. D. Bhaisare et al. [7]. This project's scope is to outline design approaches for the vehicle differential case that are used to guarantee product life and achieve minimal weight. This study's optimization of a car differential case demonstrates that a 6% weight reduction is achievable without compromising component safety. This process's manual optimization methodology can be applied to any other cast component. Furthermore, a comparative analysis of topology optimization on a control arm under static loading circumstances is conducted using Ansys software. CATIA V5R20 is used to create a three-dimensional CAD model of the differential case for a four-wheeler. In a 4-wheeler differential example, the total deformation, equivalent stresses, and strain are calculated using the Finite Element Analysis (FEA) program ANSYS Version 19.0. The 4-wheeler differential case topology optimization module will be utilized to optimize weight. UTM and the strain gauge approach will be used for the experimental inquiry. To validate the work, a comparison between FEA and experimental data will be conducted.

A review of differential gear boxes for vehicles that use various materials to reduce vibration is presented by Prasad Matam, Dr. Nilesh Diwakar, and Dr. A. Rajasekhar [8]. Steel should be used for the gear because of its solidarity, and aluminum should be used for the differential gearbox assortment since it reduces weight. A unique framework can be used in the development of modified differential gearboxes. By altering and adding an extra inclination gear change on the crown wheel, we may now take one information and three yields instead of the differential's previous two.

Additionally, we can modify differential gearboxes with three yields by experimenting with different materials. Similarly, there are several specific reason differential gearboxes, but they are unable to overcome all the obstacles on their own. Therefore, we can use combinations of these distinct reason differential gearboxes to reduce the boundaries a little.

In order to maximize the gears' lifespan under varying frequencies in the Ansys-14.0 platform, Shashank Pandey et al. [9] have examined the differential gears for vibration effects on the entire system using solid work modeling. Vibration in the casing around the gear box also affects the gear housing in this analysis. Protecting and providing a platform for gear transfer are the roles of gear. It also protects against external environmental conditions and supports moving parts. The pinion, which turns on the differential's ring gear and serves as reduction gearing, is coupled to the propeller shaft by the differential. will therefore be subjected to vibration, making it vital to assess how the differential gear housing reacts to these vibrations and determine their inherent frequencies. When designing the differential gear housing to prevent fatigue failures due to resonance, this can be a useful tool. A methodology for addressing vibration-causing elements and promoting scientific methods to reduce frequency impacts should be incorporated into the gear housing design. Ansys 14.0 software is used for this vibration analysis as a validation and computational method.

The primary goal of Mit Patel et al. [10] is to determine the number of bending strains produced in the chosen CVT gear set of a two-wheeler during power transmission. They also look for various methods to reduce the gear's weight. Therefore, the main criterion of evaluation for this work is including the topology optimization feature as a component of weight reduction over an existing portion. This study examines the static loading of the CVT gearbox's gears in a two-wheeler under tangential load applied due to the maximum torque in the specified application. The material removal region for weight reduction on selected gears is determined after the stress distribution on existing gears has been studied. Then, the same stress distribution investigation is conducted for suggested topological optimization designs. As a result, the results for stress distribution are compared between the optimum designs that are now in use and those that are suggested under static structural analysis for the same loading.

### **III. CONCLUSION**

The differential gearbox is a vital component in automotive systems, enabling smooth and efficient turning by allowing the outer and inner wheels to rotate at different speeds. This function is critical for maintaining vehicle stability, minimizing tire wear, and improving overall driving performance, especially during cornering. The unique characteristic of the differential, where the angular velocity of the carrier equals the average of the angular velocities of the side gears, underscores its classification as a specialized planetary gear train.

This study focuses on optimizing the materials used in the construction of the differential gearbox, aiming to enhance its mechanical properties, durability, and performance under various operating conditions. By utilizing advanced 3D modeling software tools such as CREO, CATIA, and Pro-E, accurate and detailed models of the gearbox case have been created. These models serve as the foundation for simulations, stress analysis, and material testing, all of which are essential in determining the most suitable materials for manufacturing.

Through this approach, the study seeks to reduce the overall weight of the gearbox without compromising strength, thereby improving fuel efficiency and reducing production costs. Furthermore, the optimization process contributes to the reliability and longevity of the differential system, supporting broader goals in automotive innovation and sustainability. Overall, the integration of material optimization with modern CAD tools provides a powerful methodology for enhancing the design and function of differential gear mechanisms.

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