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Design and Manufacturing of 4WD ATV Gearbox

Dr. G. L. Allampallewar[1]; Pratik Kurumkar[2]; Aniket Gawade[3]; Satyam Shirke[4]

[1]Assistant Professor.
[2,3,4]UG Student.

[1,2,3,4]Mechanical Engineering, Marathwada Mitra Mandal's Institute of Technology, Pune, India

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Abstract: The main objective of this project was to design and fabricate a drivetrain for an intercollegiate competition, BAJA SAE. The motivation behind undertaking this project was to gain an in-depth understanding of All-Terrain Vehicles (ATVs) and to study various parameters influencing drivetrain design and performance. Multiple configurations and design options were explored. After detailed discussions and evaluations, alternative concepts were systematically eliminated, and the most feasible option was selected.

It was concluded that the transmission system would be automatic, incorporating a Continuously Variable Transmission (CVT) coupled with a two-stage gearbox, which in turn drives the half shafts for the four-wheel drive system. To ensure accurate design and efficient assembly, 3D modeling of the entire drivetrain was carried out using SolidWorks. The models were used to verify clearances, gear meshing, and alignment between components. Further, finite element analysis (FEA) was conducted to validate the strength and durability of critical parts such as gears and shafts under maximum load conditions.

Following fabrication, the complete system was thoroughly tested and demonstrated excellent performance, validating the design choices, CAD modeling, and analytical predictions. The project successfully met its objective of creating a reliable, efficient, and competition-ready drivetrain for an ATV.

Keywords: *CVT, 4WD, Gearbox, ATV, SolidWorks, FEA.*

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I. INTRODUCTION

Efficient drivetrain design is critical for enhancing the off-road performance of All-Terrain Vehicles (ATVs), particularly in competitions like BAJA SAEINDIA. This project focuses on the development of a robust drivetrain system powered by an engine producing 10 HP (7.46 kW) and 19.67 Nm of torque at 3800 RPM.

The drivetrain incorporates a custom-designed two-stage gearbox with a final reduction ratio of 8.4:1, specifically engineered to maximize torque output and meet the demands of challenging terrains. The first stage offers a gear ratio of 2.4:1 and the second stage a ratio of 3.5:1, using spur gears with a module of 2 mm, face width of 15 mm, and a 20° pressure angle for optimal strength and durability.

A Four-Wheel Drive (4WD) system is employed to improve traction, stability, and maneuverability, crucial for navigating uneven and rough surfaces. To ensure performance reliability, 3D CAD modeling and finite element analysis (FEA) were conducted using SolidWorks, focusing on gear strength, shaft deflections, and overall system efficiency.

This work presents a comprehensive design approach, integrating mechanical design, material selection, and validation techniques to develop a drivetrain capable of withstanding the extreme conditions encountered in off-road ATV competitions.

II. OBJECTIVE

The primary objective of this project is to increase the efficiency and reduce the weight of the drivetrain system for an All-Terrain Vehicle (ATV). The design focuses on a compact two-stage gearbox, enhanced fuel efficiency, and a Four-Wheel Drive (4WD) system to improve traction and stability. Material selection and SolidWorks modeling ensures optimal performance, durability, and weight

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reduction, validated through simulations and real-world testing.

III. PROBLEM STATEMENT

The design and manufacturing of a Four-Wheel Drive (4WD) gearbox for an All-Terrain Vehicle (ATV) presents a challenge in optimizing power delivery, traction, and durability under demanding off-road conditions. The primary problem is to develop a drivetrain system that effectively distributes power to all four wheels, ensuring maximum torque and traction while maintaining fuel efficiency and reducing weight.

Additionally, the gearbox must operate efficiently across varied terrains, providing the necessary torque multiplication and speed reduction to navigate rough, uneven surfaces. The challenge also involves selecting appropriate materials, minimizing mechanical losses, and ensuring the gearbox system is compact, lightweight, and capable of withstanding the stresses encountered during off-road operations.

➢ *Scope*

The scope of this project encompasses the comprehensive design, analysis, and optimization of a gearbox system aimed at enhancing vehicle performance by achieving both high torque and a target speed of 60 km/h. This involves determining appropriate gear ratios, selecting suitable materials, and ensuring efficient power transmission from the engine to the wheels.

IV. KEY COMPONENTS OF 4WD GEARBOX

➢ *Engine (Power Source)*

The engine generates the power required to propel the vehicle. The gearbox receives the power from the engine and adjusts it for optimal performance in off-road conditions.

➢ *Transmission*

The transmission regulates the engine speed and torque by using a set of gears to adjust the vehicle's velocity and power. In a 4WD system, the transmission typically includes both a primary gearbox and a transfer case.

➢ *Transfer Case*

The transfer case is a critical component in a 4WD system. It divides the engine power between the front and rear axles, directing power to all four wheels. It typically includes a high/low gear range to enable the vehicle to handle various terrains. Reduction gears inside the transfer case are used to reduce the speed of the engine output and increase torque for off-road driving.

➢ *Differentials*

Front and rear differentials are responsible for distributing power between the left and right wheels on the respective axles, allowing them to rotate at different speeds, especially during turns.

➢ *Bearings, Shafts, and Housing*

Bearings support rotating parts, ensuring smooth operation and minimizing friction. Shafts transmit torque and rotational force through the system. The housing provides structural support for the gearbox, transfer case, and other components, protecting them from debris and harsh environments.

V. METHODOLOGY

The methodology for designing and developing a 4WD gearbox involves several stages, starting with requirement analysis to define objectives and gather system specifications. The conceptual design focuses on selecting gear types, gear ratios, and gearbox configurations. Detailed design includes calculating gear geometry, performing strength analysis, and selecting appropriate bearings and shafts. CAD modeling and simulations (such as Finite Element Analysis) are used to optimize the design. Material selection prioritizes strength, durability, and weight reduction, with components fabricated using precision manufacturing techniques. Prototyping and testing validate the gearbox’s performance under load, efficiency, and durability, followed by optimization based on test results. Finally, the gearbox undergoes final validation to ensure it meets performance standards for the ATV’s drivetrain system.

➢ *Transmission Specifications*

- Engine Power: 10 HP (7.46 kW)
- Engine Torque (Te): 19.67 Nm
- Engine Speed (RPM): 3800 RPM
- Engine Type: Briggs & Stratton 305cc engine
- Wheel Diameter: 0.558 m (22 inches)
- Vehicle’s Curb Weight: 220 kg
- CVT Ratio: 0.6 to 3.9
- Rolling Resistance (μ): 0.08
- Transmission Efficiency (E): 75% (assumed, factoring in all losses).

VI. CALCULATIONS

➢ *Gear Ratios Calculations*

Target speed of vehicle is 60 Km/hr.

Torque on wheel is 500 N.m

Torque on wheel = Te*CR*GR*E

500 = 19.67*3.9*GR*0.75
= 8.69

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There for,

To achieve both high torque and high speed, we need to design a gearbox with a suitable gear ratio. In our case, we used a gear ratio of 8.4:1 to achieve a top speed of 60 km/h.

Table 1 Gear Ratios Calculations

Stage	**Gear Ratio**	**No of Teeth**
First stage	2.4	Teeth on pinion =20 Teeth on Gear = 48
Second stage	3.5	Teeth on pinion =20 Teeth on Gear = 70
Bevel Gear	1.4	Teeth on pinion =20 Teeth on Gear = 28
Differential	2.5	Differential Pinion=22 Differential Crown=55

Total reduction= First stage* Second stage
= 2.4*3.5 = 8.4

For bevel,

Total reduction = First stage* Bevel gear ratio
= 2.4*1.4 = 3.36

- *Design of Gears*

Pitch circle diameter (PCD) = Z*m

Z is the number of teeth on gear, and m is the module of the gear

First stage,

For pinion

Pitch circle diameter = 20*2 = 40mm

and for gear,
(PCD) = 48*2 = 96mm

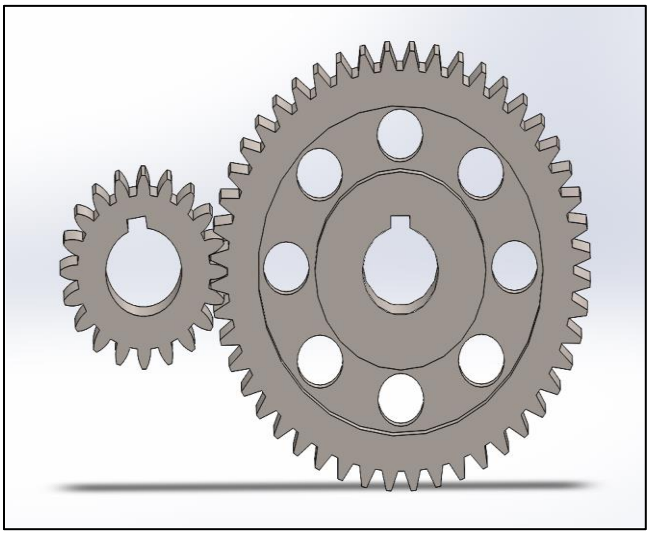

Fig 1 Design of Gears

Second stage,

For pinion

(PCD) = 20*2 = 40mm
For gear,

(PCD) = 70*2 = 140mm

- *Forces Acting on Gear*

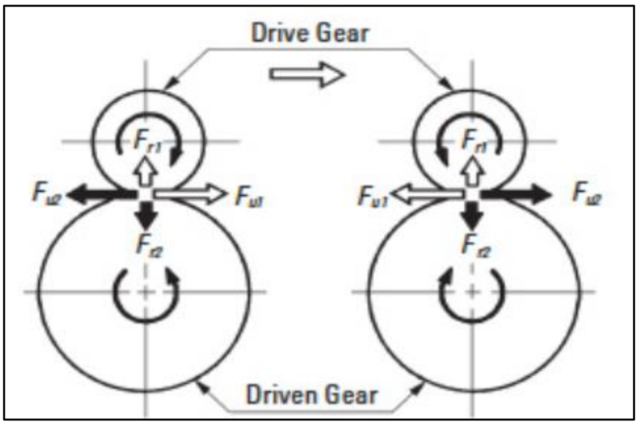

Fig 2 Forces Acting on Gear

For first stage,

- *Tangential force (Ft)*

Ft = 2000*T/(PCD)
T is the torque on this stage

T = Te* First stage gear ratio = 19.67*2.4
= 47.20 N.mm

PCD = 96 mm
Ft= 2000*47.20/96 = 983.33 N

- *Radial force (Fr)*

Fr = Ft* Tan(β)
β is the pressure angle = 20°

Fr = 983.33* Tan (20) = 357.90 N

For second stage,

- *Tangential force (Ft)*

T = Te* Second stage gear ratio = 19.67*3.5
= 68.84 N.m

PCD = 140 mm
Ft = 2000*68.84/140 = 983.42 N

- *Radial force (Fr)*

Fr = Ft* Tan(β)

Fr = 983.42* Tan (20) = 3357.93 N

For bevel gear,

- *Tangential force (Ft)*

Ft = 2000*T/Dm

Dm is the center reference diameter which is calculated as,
Dm = d – (b*Sin(δ))

δ is the cone angle and *b* is the face width oof gear.

$\delta = Tan^{-1}(z_1/z_2) = Tan^{-1}(20/28) = 35.53^o$

Dm = 56 – (15*Sin (35.53)) = 47.28 mm

Ft = 2000*56.64/47.28 = 2395.93 N

- *Radial force (Fr)*

Fr = Ft* Tan(β)* Cos(δ)
= 2395.93* Tan (20) * Cos (35.53) = 709.68 N

- *Axial force (Fx) = Ft* Tan(β) * Sin(δ)*

Fx = 2395.93* Tan (20) * Sin (35.53)
= 506.77 N

➢ *Factor Depending on Gearbox*

- Max speed of vehicle = N*C*E*3.6/CR*GR*60
= 3800*3.14*0.558*0.75*3.6/0.6*8.4*60
= 59.44 Km/hr

- Acceleration

Tractive Effort (TE) is the force exerted by a vehicle (like a car, tractor, or locomotive) at the point of contact between the driving wheels and the road or rail to overcome resistance and move the vehicle forward.

TE = Te*CR*GR*E/R = 19.67*3.9*8.4*0.75/0.279
= 1732.22 N
R is the wheel radius

Rolling resistance (RR) =W*µ
= 220*9.81*0.08 = 172.65 N

Total resistance (TR) = Air resistance (AR) + Rolling Resistance (RR)

Vehicle speed is 59.44 Km/hr, negligible air resistance is anticipated
TR = 0+172.65 = 172.65 N

Acceleration = TE-TR/m
= 1732.22-172.65/220 = 7.08 m/s^2

Torque on wheel = T*CR*GR*E
= 19.67*3.9*8.4*0.75
= 483.29 N.m

VII. DESIGN

➢ *Design Specification*

Key design elements include selecting an appropriate module (m) based on torque requirements and gear size, maintaining a standard pressure angle (α) of 20° for involute gears, and determining the face width (b) to handle transmitted loads without excessive deflection.

Table 2 Design Specification

Specification	Input pinion	Intermediate Gear	Intermediate pinion	Output gear
Number of teeth	20	48	20	70
Module	2	2	2	2
Pressure angle	20	20	20	20
Face width	15	15	15	15
PCD	40	96	40	140

Designing a gearbox in SolidWorks involves creating detailed models of gears, shafts, and housing components. The process typically starts with sketching the gear profiles, defining parameters such as module, number of teeth, and pressure angle. Once the individual parts are modeled, they are assembled using mates to define their spatial relationships and motion constraints. SolidWorks provides a Gear Mate" feature that allows you to simulate the rotational relationship between two gears.

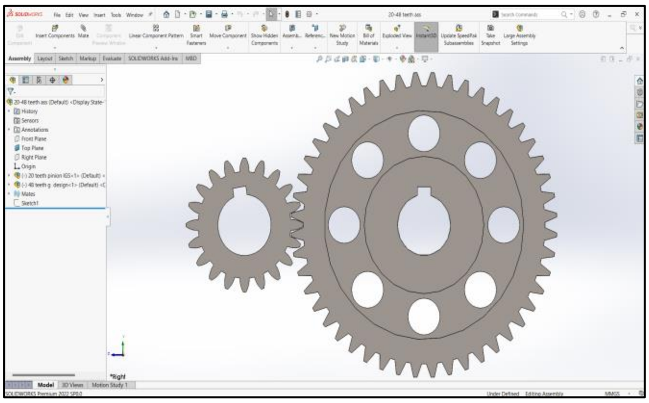

Fig 3 First Stage

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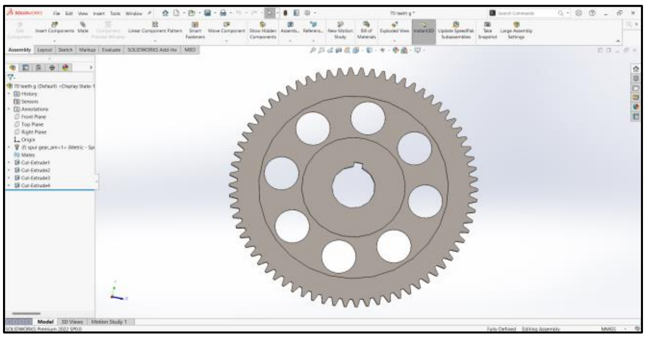

Fig 4 Second Stage Gear with 70 Teeth

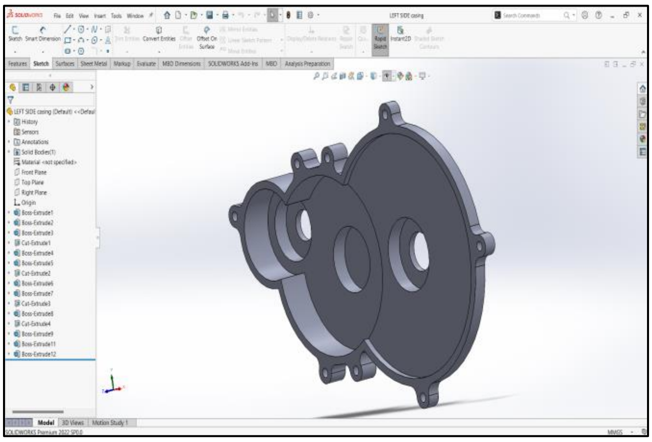

Fig 5 Casing of Gearbox

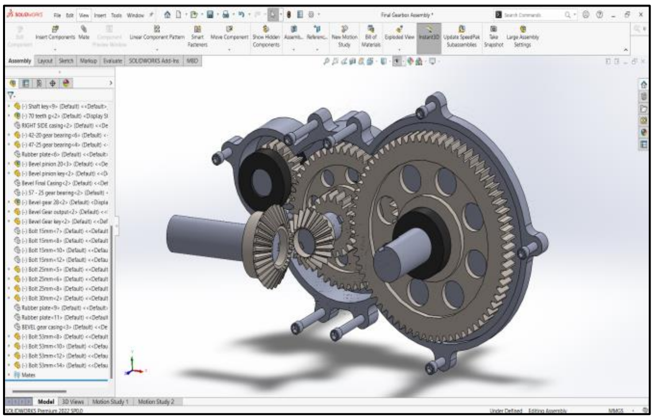

Fig 6 Bevel Gear

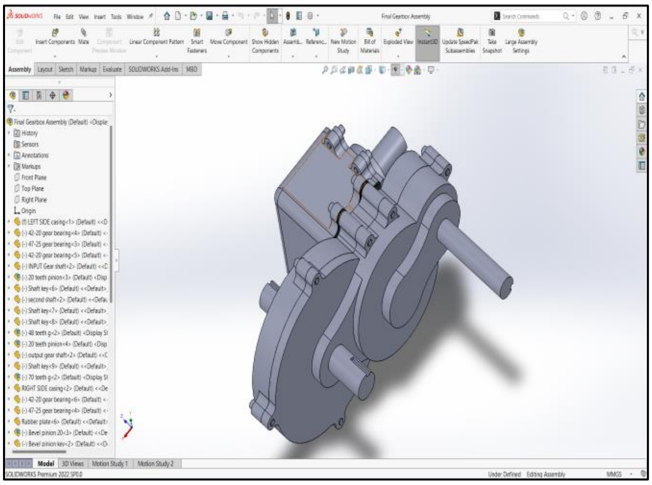

Fig 7 Full Assembly

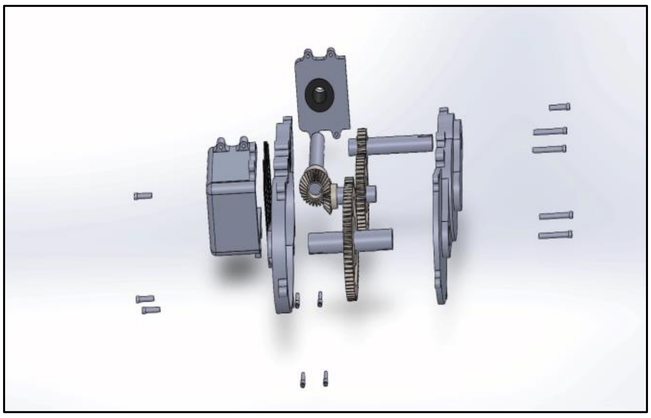

Fig 8 Explode View

VIII. MATERIAL SELECTION

Selecting appropriate materials for gearbox components is crucial to ensure durability, performance, and cost-effectiveness. The choice of materials depends on factors such as load conditions, operating environment, manufacturing processes, and cost considerations.

- *Gears*:

Gears are subjected to significant loads and require materials with high strength, hardness, and wear resistance. Common materials include alloy steels like EN19 which offer high strength and hardenability.

- *Housings*:

The gearbox housing provides structural support and protects internal components. Material selection depends on factors like strength, weight, thermal conductivity, and cost. AISI 7075 is favored for its excellent damping properties and ease of casting complex shapes.

- *Shafts:*

Shafts transmit torque and must possess high strength and toughness. Common materials include medium-carbon steels like AISI 1045 or 4140, which are cost-effective for industrial shafts.

Table 3 Material

	Gear material	Casing material	Shaft material
Material	EN19	Al 7075	AISI 4140 Alloy Steel
Tensile Strength	655 MPa	572 MPa	655 MPa
Yield Strength	415 MPA	503 MPa	415 MPa
Density	7.85 g/cm^3	2.81 g/cm^3	7.85 g/cm^3
Modulus of Elasticity	210 GPa	71.7 GPa	190 GPa
Poisson's Ratio	0.3	0.33	0.3

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IX. ANALYSIS

Analyzing a gearbox using ANSYS software involves a systematic approach to evaluate its structural integrity, performance under load, and dynamic behavior. The process begins with importing a detailed 3D model of the gearbox assembly, often created in CAD software like SolidWorks, into ANSYS Workbench. Once imported, the model undergoes meshing, where the geometry is divided into finite elements to facilitate accurate simulations. A finer mesh is typically applied to areas with high stress gradients, such as gear tooth contacts, to capture detailed stress distributions.

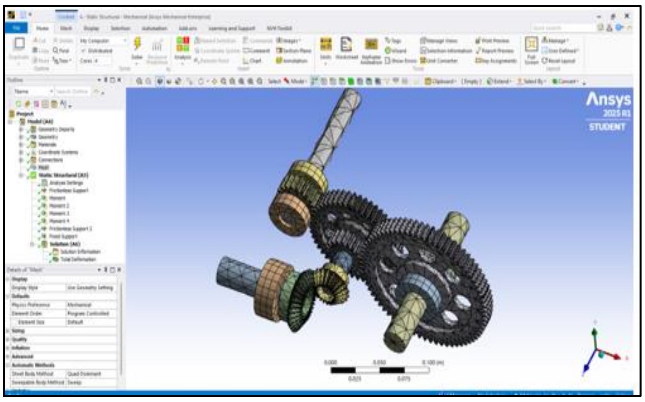

Fig 9 Meshing

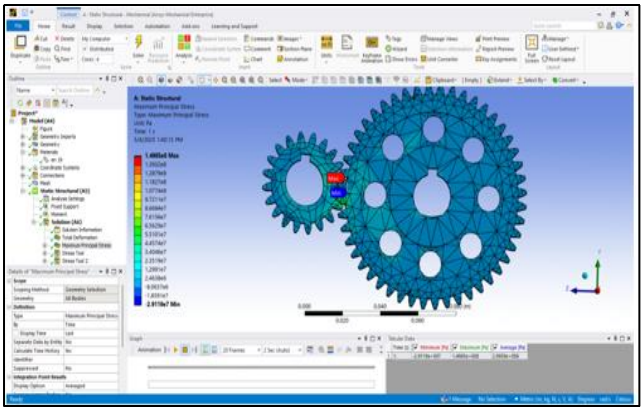

Fig 10 Maximum Principal Stress First Stage

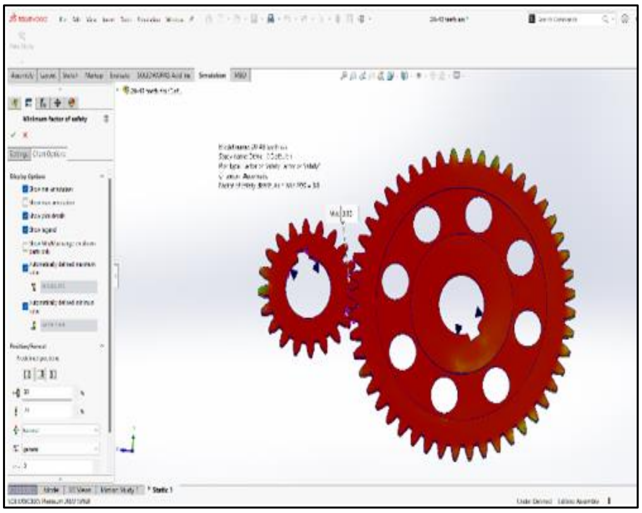

Fig 11 Factor of Safety-First Stage

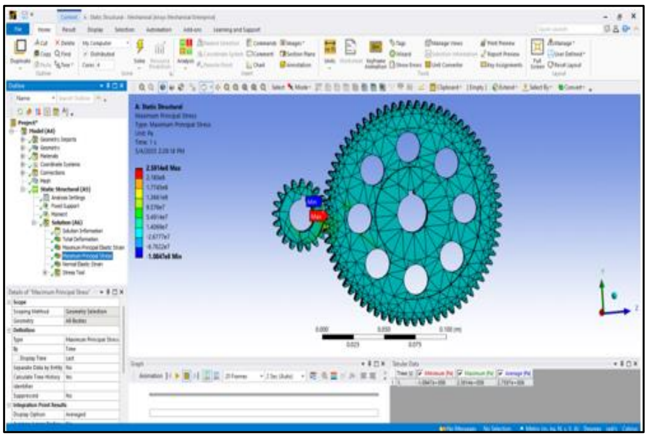

Fig 12 Maximum Principal Stress Second Stage

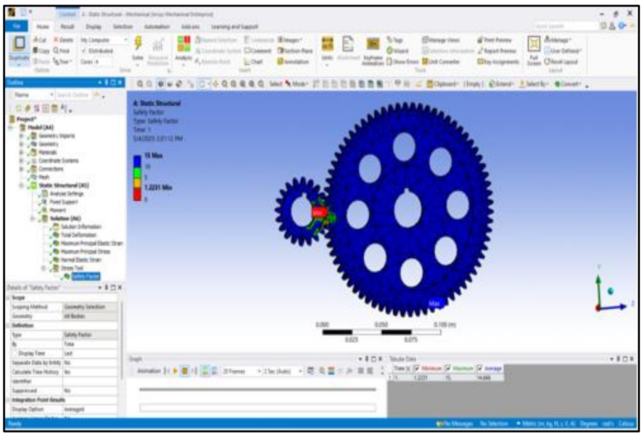

Fig 13 Factor of Safety Second Stage

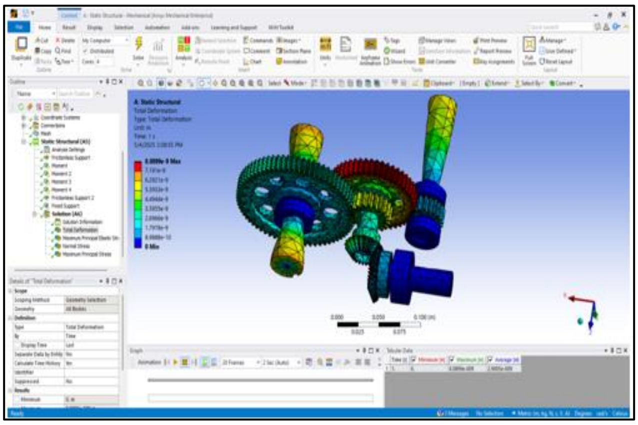

Fig 14 Total Deformation

X. RESULT

- *From the Above Analysis and Calculations, We Have Drawn the Following Conclusions:*

- Material of Gears - EN19
- Material of Gear Casing - AI 7075
- Type of Gearbox - 2 Stage Compound Gearbox
- Overall Gear Reduction Ratio - 8:4

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- First Stage Reduction Ratio – 2.4
- Second Stage Reduction Ratio – 3.5
- Bevels at Gearbox Reduction Ratio - 1.4
- Pressure Angle - 20 Degree
- No. of teeth in First Stage (Gear, Pinion) – 48, 20
- No. of teeth in Second Stage (Gear, Pinion) – 70, 20
- Max speed of vehicle – 59.44 Km/hr.
- Acceleration – 7.08 m/s2

XI. CONCLUSION

This research successfully met its objective of enhancing gearbox performance by increasing torque and speed through the design of a gearbox with a low gear ratio of 8.4:1, achieving a target speed of 60 km/h. Comprehensive analyses, including torque calculations considering friction and other parameters, were conducted to understand the forces acting on gears across all stages. The factor of safety for gearbox manufacturing was determined, ensuring reliability and durability. The maximum speed of the vehicle was calculated using the formula: Torque on Wheel = Te × CR × GR × E. Design specifications were meticulously developed, and advanced software tools such as SolidWorks and ANSYS were utilized for gearbox design, mates, and analysis. Material selection for gearbox components was carefully considered to optimize performance and longevity.

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