Design and Optimization of Open Differential in EFFIQUE-ADAS

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Abstract – *The purpose of this paper is to select, design, and analyze an open differential for EFFIQUE-ADAS vehicle for Team Stallion Effi-cycle. EFFIQUE-ADAS is a single-seater four-wheeled electric vehicle equipped with advanced drive assistance systems. The differentials play a crucial role in the power transmission of the vehicle at cornering conditions, improve stability enhance overall performance, thus improve vehicle dynamics which is essential in the competition. To focus on designing an efficient open differential, optimal standard design principles are used that eventually integrate with vehicle needs. The Design procedure is strictly followed from the SAE-NIS Effi-cycle's 2024 rulebook, ensuring overall compliance with restrictions and guidelines throughout the entire design procedure.*

***Key Words*: Open Differential, Effi que – ADAS, Stallion Effi cycle, Bevel Gear, Pinion, Centrepin, SOLIDWORKS, ANSYS.**

1. INTRODUCTION

An open differential is a part of a powertrain system consisting of gear assembly, casing, center pin, and bearings. The primary function of the system is to transmit variable speed to the wheels especially when making sharp turns. It is a critical component of the powertrain system it facilitates effortless turns while cornering conditions. During straight conditions, it maintains the same speed for both wheels whereas varies speed during cornering. It is widely preferred in automobiles due to its functions and simplicity.

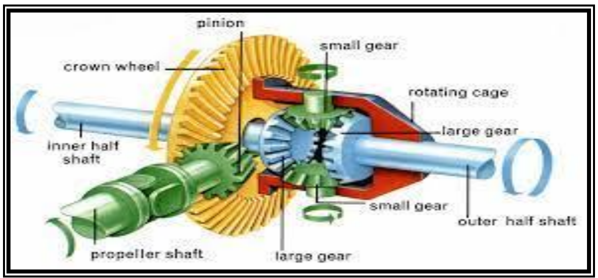

Fig -1: Conventional Open Differential

1.1 METHOD OF APPROACH

The research and studies of the differentials are done from various standard books. There are various categories of differentials as per their applications. We have several requirements such as Space efficiency, Easy Lubrication, Simplicity and 50%-50% torque distribution, etc. As the vehicle has limited track width, a compact size differential is essential. The Open differential was best suited for those applications and meets all of our requirements. For Designing each of the components we used SolidWorks software. The stress concentration analysis and factor of safety of each component is done on Ansys software. The final results are verified by all analytical calculations and softwares.

1.2 DIFFERENTIAL REQUIREMENTS IN EFFI QUE-ADAS VEHICLE.

1. Independent rotation for both wheels.
2. Proper Traction Control.
3. Proper Torque Distribution.
4. Compact size.
5. Equipped with Chain Drive.
6. Reduce Steering effort.

2. ANALYTICAL CALCULATIONS

2.1 Material Selection for Gears.

Table -1: Material Selection for gears.

Material Properties	EN24	EN36	20MnCr5 Steel
Ultimate Tensile Strength (N/mm^2)	850	1100	1300
Yield Strength (N/mm^2)	650	846	1000
BHN	350	400	500

2.2 Gear Teeth Calculations

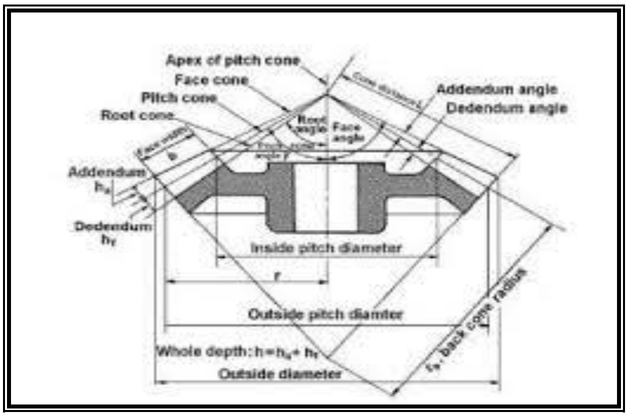

Fig -2: Gear tooth Terminology.

Module (m) = 2 mm

Power (P) = 0.6 kw

Np = 450 rpm

Material – 20MnCr5 Steel

BHN = 500

Sut = 1300 N/mm^2

Zp = 12

Zg = 16

Diameter of pinion and gear.

Dp = Zp × m = 12 × 2 = 24 mm

Dg = Zg × m = 16 × 2 = 32 mm

μp = tan^{-1} (Zp / Zg) = tan^{-1} (12 / 16) = 36.38

μg = 53.13

Virtual no. of teeth.

Zp' = Zp / cos (36.86) = 15

Lewis Form Factor Y = 0.289 from Standard Table

σb = Sut / 3 = 1300 / 3 = 433.33 N / mm^2

K = 0.16 × (BHN / 100)^2

= 0.16 × (500 / 100)^2

= 4

Q = 2 × Zg / Zg + Zp tan (36.86)

= 2 × 16 / 16 + 12 tan (36.86)

= 1.28

Ao = √(Dp/2)^2+(Dg/2)^2

= √(24 / 2)^2+(32 / 2)^2

= 20 mm

B = 10 m or Ao / 3 = 20 / 3 = 6.67 mm

Take whichever is smaller

P = 2πNpT / 60

0.6 × 10^3 = 2π × 450 × T / 60 × 10^3

T = 9610.32 N mm

Tangential Load

Pt = 2 T / Dp

= 2 × 9610.32 / 30

= 720.38 N

Bending Strength of Pinion

Sb = m ×b × σb× Y × (1 – b / Ao)

= 2 × 6.67 × 433.33 × 0.289 × (1 – 6.67 / 20)

= 1326.46 N

Wear Strength of Pinion

Sw = 0.75 × b × Q × K × Dp / cos (36.86)

= 0.75 × 6.67 × 1.28 × 4 × 24 / cos (36.86)

= 1038.29 N

V = π × Dp × Np / 60 × 10^3

= π × 24 × 450 / 60 × 10^3

= 0.56 m/s

C = 11400 N / mm^2 , e = 0.0125 mm

Dynamic Load,

Pd = 21 × V × (√ C × e × b × Pt) / 21 × V + √ (C × e × b × Pt)

= 21 × 0.56 × (√ (11400 × 0.0125 × 6.67 + 707.38) / 21 × 0.56 × √ (11400 × 0.0125 × 6.67 + 707.38)

= 228.33 N

Peff = Cs × Pt + Pd

= 1 × 720.38 + 228.33

= 948.71 N

For Bending failure,

Sb = Peff × Fos

1326.46 = 948.71 × Fos

Fos = 1.4

For Wearing / Pitting failure,

Sw = Peff × Fos

1038.46 = 948.71 × Fos

Fos = 1.10

Mean Radius,

Rm = (Dp / 2 – b × sinμ / 2)

= 24 / 2 – (6.67 × sin (36.86) / 2)

= 9.99 mm = 10 mm approx.

Tangential load,

Pt = T / Rm

= 9610.32 / 10

= 961.032 N

Radial load,

Pr = Pt tanα × cosβ

$= 961.32 \times \tan(20) \times \cos(36.86)$

$= 279.86$ N

Thrust load,

$P_a = P_t \times \tan\alpha \times \sin\beta$

$= 961.32 \times \tan(20) \times \sin(36.86)$

$= 209.88$ N

3. CAD MODELLING

3.1 Gear and Pinion

The model was prepared based on the space availability in the transmission system, after getting the analytical data by calculations. The gear pairs of bevel gears were designed that generally consist of two gears and two pinions for better torque distribution. The material selected for bevel gear manufacturing is 20mnCr5 steel due to its numerous advantages that include Ultimate Tensile strength, yield strength BHN, etc. The length of the gears was decided considering the available space in the transmission system. Splines are provided at the end of the gear for output speed.

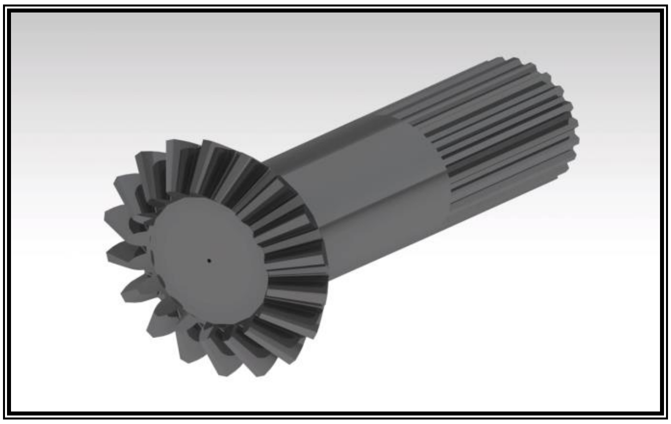

Fig -3: Gear Model

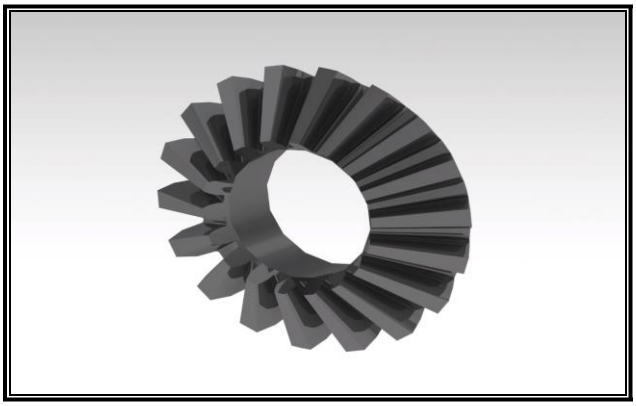

Fig -3: Pinion Model

3.2 Centre Pin

We made the center pin to fit neatly among the gear pairs and be easy to fix if needed. To keep it light but strong, we used 20MnCr5 steel. We also added a small hole at one end so we can attach it securely to the differential casing with a nut and bolt. That way, it stays in place and won't slip out.

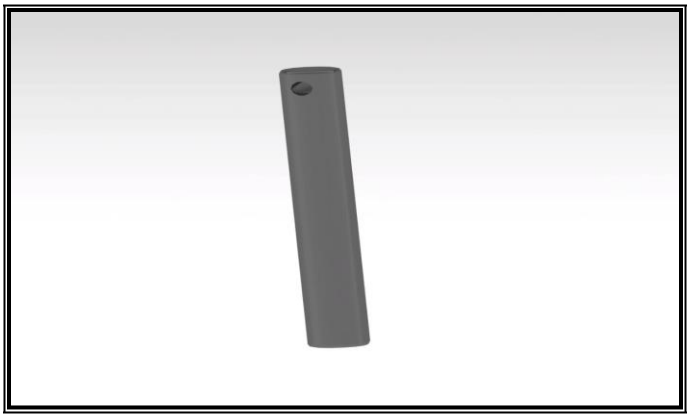

Fig -4: Centre Pin

3.3 Differential Casing

The decision was made to design the casing in two parts for easier assembly and servicing. We based the overall design on how everything fits inside. The length of the casing was determined by the size of the side gears and the placement of the sprocket. The two casings were connected to each other using pairs of nuts and bolts, and then the casing assembly was mounted onto a pair of bearings in the differential mount plates.

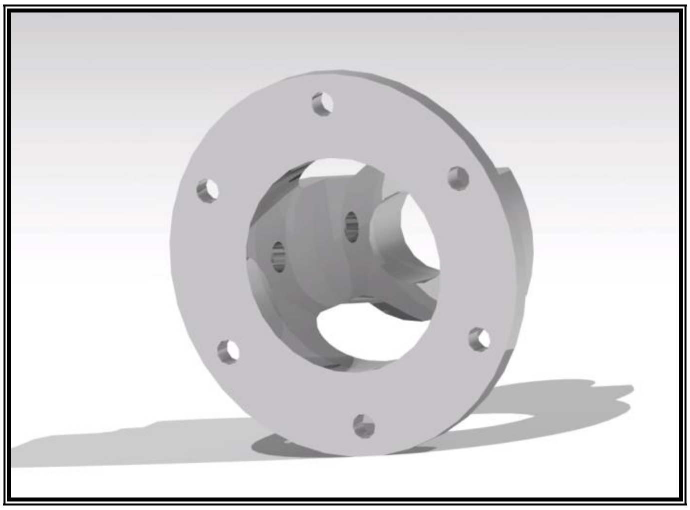

Fig -5 Differential Casing

The Material used for manufacturing the casing is EN 24.

3.4 Differential Mount Plates

The design of the differential plate took into account the space constraints imposed by the sprocket and the available mounting points on the chassis for attaching the differential. To ensure secure mounting, we added a small hole at one end of the differential plate for attaching a bolt that would pass through both mounting plates, keeping them firmly aligned in one plane.

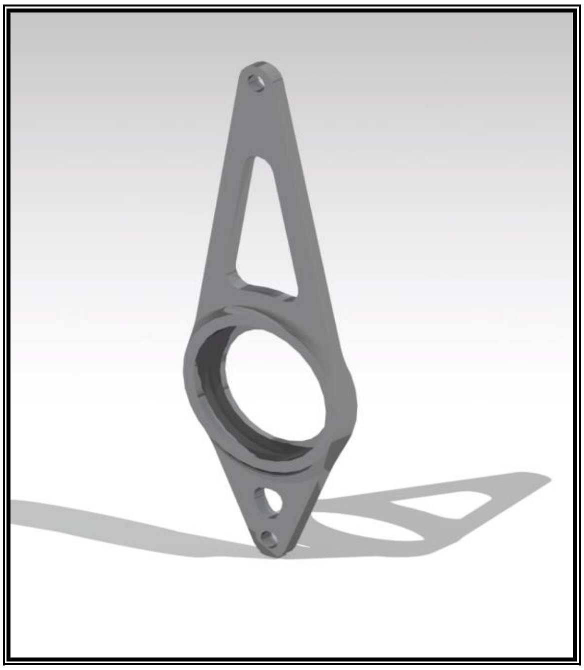

Fig -6: Differential Mount Plate

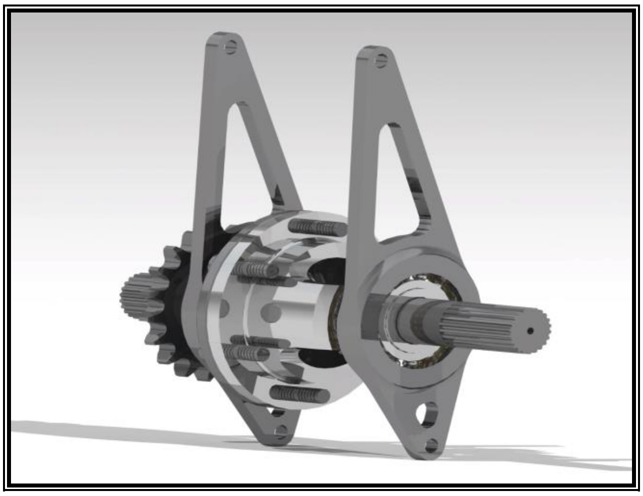

Fig -7: Final Assembly of Differential

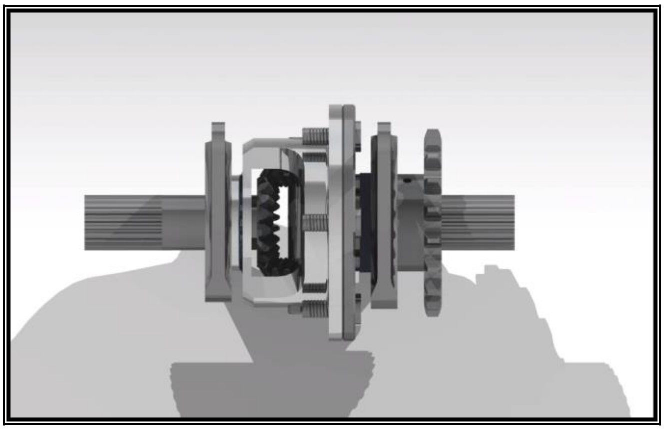

Fig -8: Top View of Differential

4. FINITE ELEMENT ANALYSIS

We conducted static structural simulations for all the components. Since the software didn't automatically select material properties, we inputted them manually. Once we determined the material properties, we imported the CAD model into ANSYS Workbench. Then, we created the mesh and applied analytical forces to the components. We chose the desired solutions, such as von Mises stresses and total deformation, and obtained the results we needed.

4.1 Gear pair of Material 20MnCr5 Steel

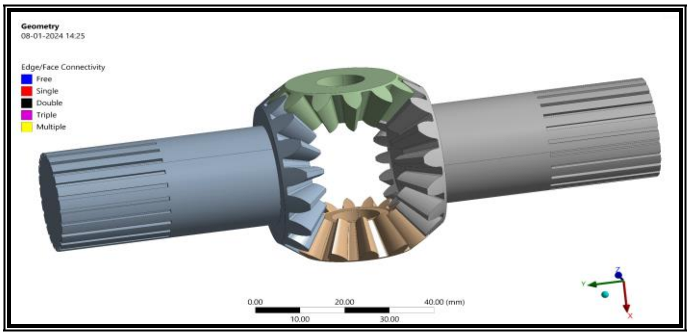

Fig -9: Differential gear pair

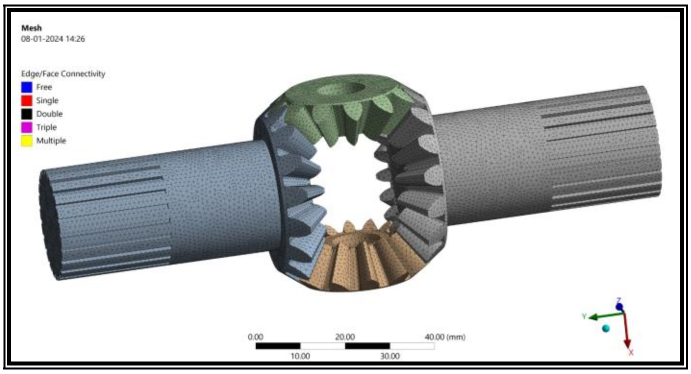

Fig -10: Gear Meshing

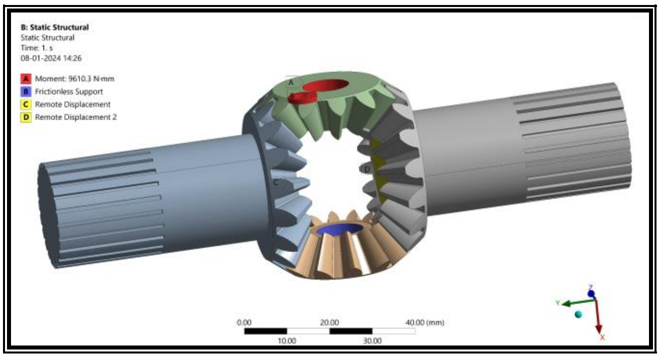

Fig -11: Boundary Conditions applied on Gears

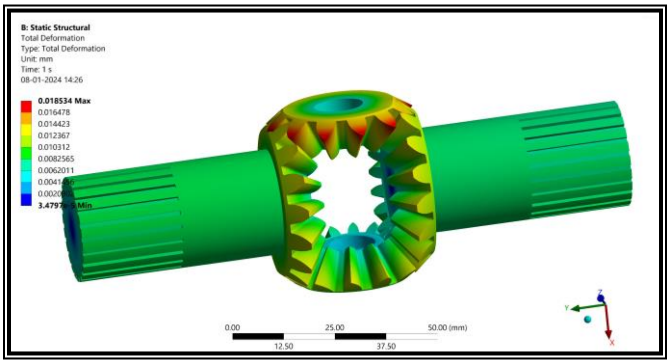

Fig -12: Deformation in Gear

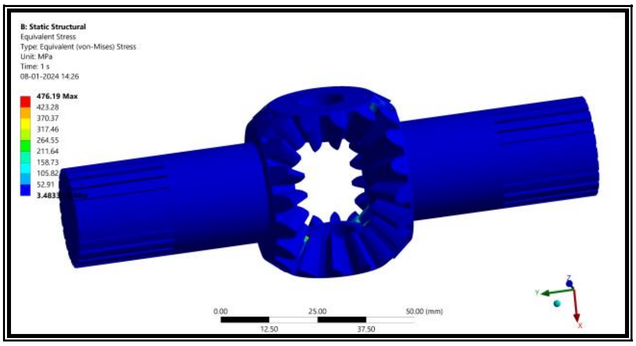

Fig -13: Stresses in Differential Gear

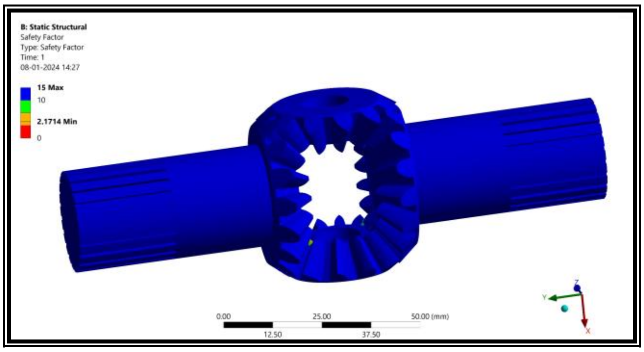

Fig -14: FOS of Differential Gear

4.2 Casing of Material EN 24

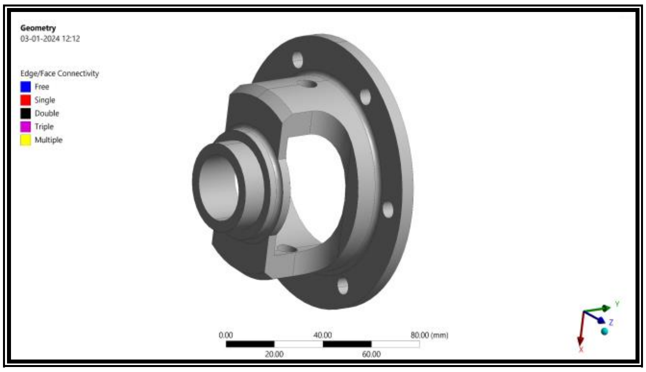

Fig -15: Casing Geometry

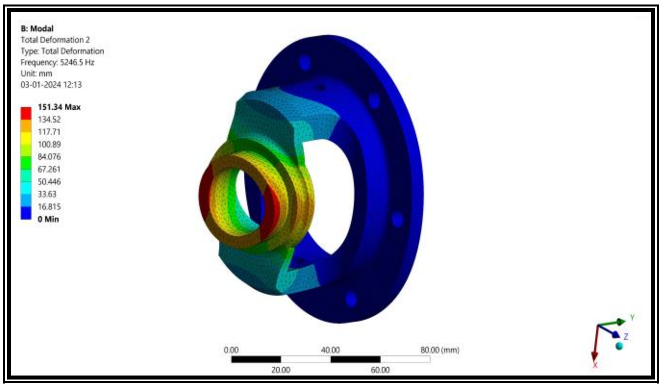

Fig – 16: Deformation in Differential Casing

4.3 Centre Pin of Material 20MnCr5 Steel

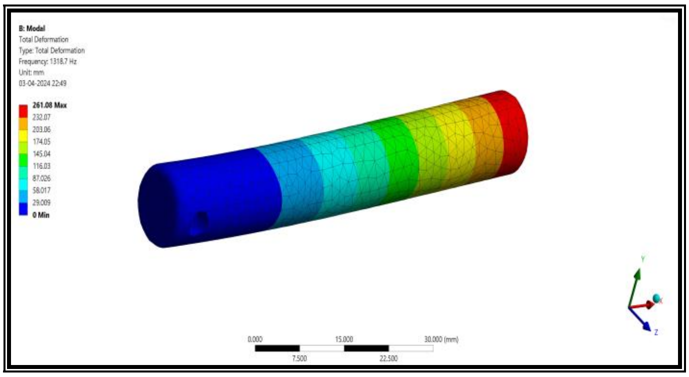

Fig -17: Deformation in Centre Pin

4.4 Differential Mount Plate of Material Aluminum 6061 T6

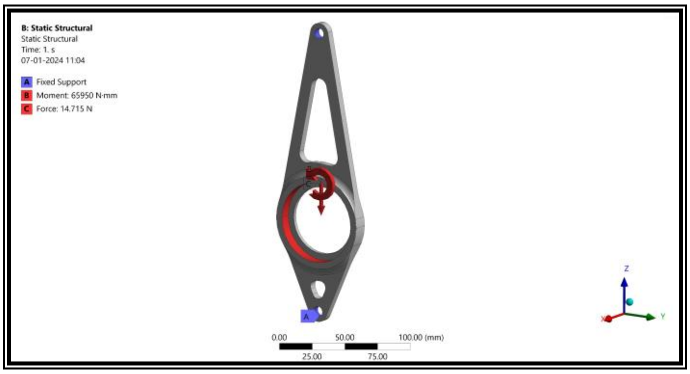

Fig -18: Boundary Condition on Differential Mounting

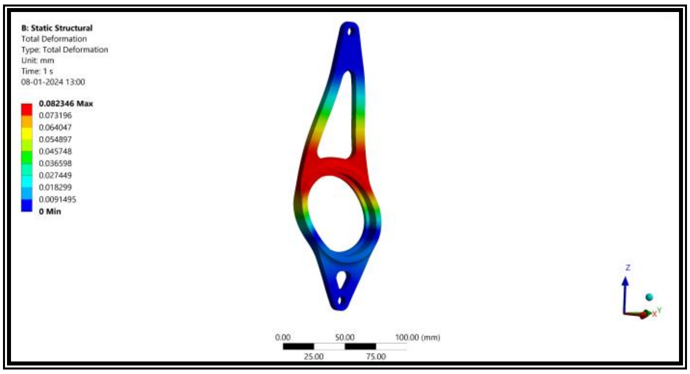

Fig -19: Deformation in Mount plate

4.5 Sprocket of Material Mild Steel

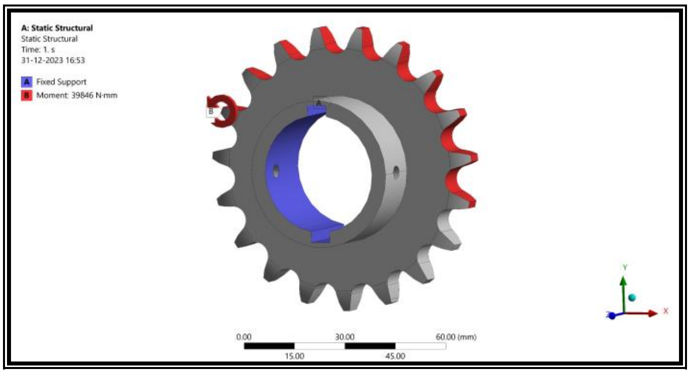

Fig – 20: Boundary Condition on Sprocket

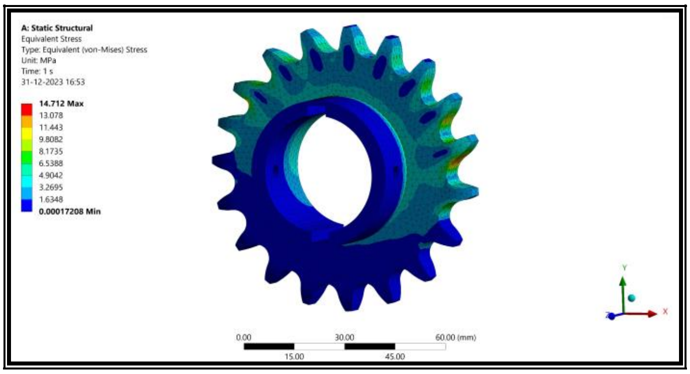

Fig -21: Static structural Analysis of Sprocket

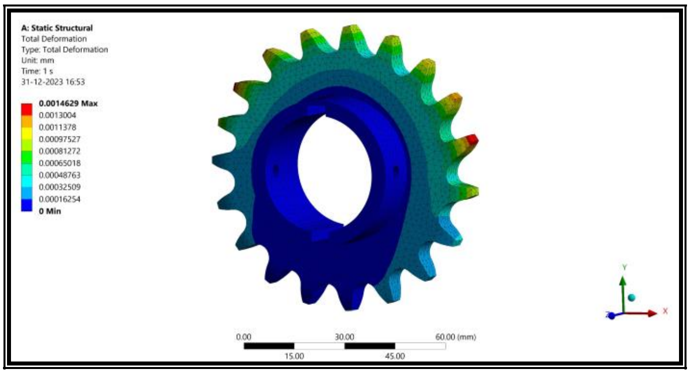

Fig -22: Deformation in Sprocket

5. EXPERIMENTAL SETUP AND TESTING

The pinion material was tougher than the differential casing, so we inserted bush between the pinions and the casing to prevent wear from metal-to-metal contact. Both the differential casing and mount plates were machined using a computer-controlled Vertical Machining Centre (VMC). When we measured the complete assembly on a weighing machine, it totaled 2.6 kg. We then assembled the entire unit onto the Effi-que ADAS vehicle.

We put the differential through rigorous testing for 30-40 days on off-road terrain, subjecting it to sharp corners, obstacles, sand, gravel, bumps, and depressions for 6-7hours each day. During testing, we observed the vehicle navigating sharp corners and visually inspected the tread pattern of the tires and the wear of the gear teeth.

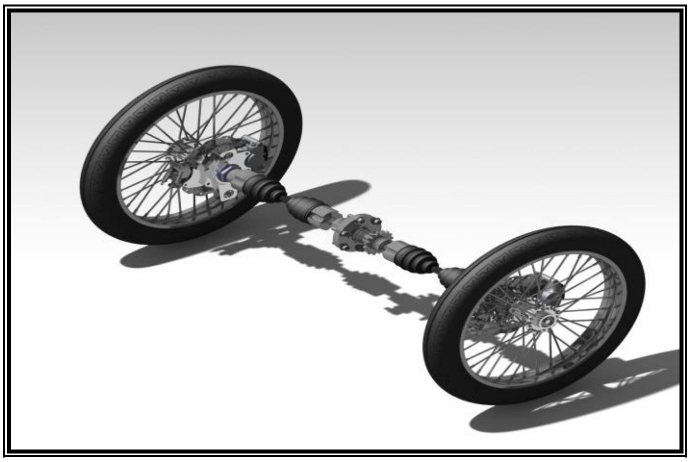

Fig -23: Assembly of Differential in Powertrain

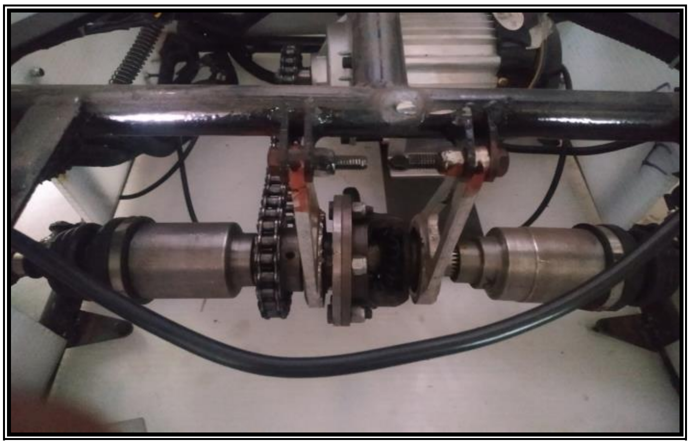

Fig -24: Final Assembly of Differential in vehicle

6. CONCLUSION

The differential assembly, once installed in the Effi-que ADAS vehicle, meets all the design requirements. It demonstrates remarkable durability on rough terrain and under critical operating conditions. Throughout testing, we didn't observe any traction issues, and the vehicle could navigate sharp turns without losing traction. This confirms that the initial objective of the differential for the transmission system of the Effi-que ADAS vehicle has been successfully achieved. This outcome paves the way for further research and development on the said system.

7. ACKNOWLEDGEMENT

I am profoundly grateful to Team STALLION EFFI-CYCLE and my college, SKNCOE, for their invaluable support in finalizing this paper within a short period and integrating it into their Effi-que ADAS vehicle. Their dedication and assistance have been instrumental in bringing this project to fruition, and I am truly thankful for their collaboration and expertise.

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