Design and Analysis of Two Stage Reduction Gear Box for Formula EV

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Abstract - *This paper presents the design and analysis of a two-stage reduction gearbox for a Formula Electric Vehicle (FEV). The gearbox is designed to meet the specific performance requirements of the FEV, focusing on efficiency, weight reduction, and compactness. The design process includes selecting appropriate gear ratios to optimize torque and speed based on the vehicle's electric motor characteristics. A detailed analysis using Finite Element Analysis (FEA) is conducted to evaluate the structural integrity and durability of the gearbox components under operational loads. Additionally, material selection is performed to ensure lightweight construction without compromising strength. The gearbox's thermal performance is also assessed to ensure reliable operation under varying conditions. The final design demonstrates a significant improvement in power transmission efficiency and vehicle performance. Results indicate that the two-stage reduction gearbox effectively balances the trade-offs between torque amplification and speed reduction, contributing to the overall enhancement of the FEV's dynamic performance. This study provides a comprehensive approach to gearbox design in electric vehicles, offering insights into achieving high efficiency and robustness in high-performance applications*.

Key Words: FEV, Gears, Gear ratios, shaft, Bearing, Power transmission efficiency

INTRODUCTION

The rapid evolution of Formula Electric Vehicles (FEVs) has necessitated advancements in powertrain components to enhance performance, efficiency, and reliability. A critical component in this evolution is the gearbox, which must efficiently translate the high-speed, low-torque output of electric motors into the optimal torque and speed required by the vehicle's wheels. This paper focuses on the design and analysis of a two-stage reduction gearbox tailored for FEVs. The primary objective is to develop a gearbox that maximizes power transmission efficiency while minimizing weight and spatial footprint, essential for the competitive edge in FEV racing.

The design process begins with selecting appropriate gear ratios to achieve the desired balance between torque amplification and speed reduction, considering the specific characteristics of the electric motor used in the FEV. Advanced computational tools, including Finite Element Analysis (FEA), are employed to assess the structural integrity and durability of the gearbox under dynamic loads. Material selection is critical, aiming for lightweight yet robust components to withstand the demanding operational conditions. This study also addresses thermal management to ensure consistent performance. The resulting gearbox design aims to significantly enhance the FEV's dynamic performance, providing a comprehensive approach to efficient and robust gearbox design in high-performance electric vehicles.

1. DESIGN PARAMETER

1.1 Material Selection

Material selection focuses on lightweight yet strong materials, such as high-strength aluminum alloys and advanced composites, to reduce the gearbox's overall weight without compromising durability. These materials provide excellent mechanical properties, including high strength-to-weight ratios and good thermal conductivity, ensuring the gearbox can withstand the demanding operational conditions of Formula Electric Vehicles (FEVs).

TABLE: MATERIAL PROPERTY

PROPERTIES	VALUE
Material selected	EN24
Young's Modulus	207Gpa
BHN	650
Tensile strength	1300Mpa
Yield strength	1100Mpa

In this paper, we choose **EN24** material for the gearbox components due to its optimal balance of strength, toughness, and wear resistance, crucial for the demanding conditions of Formula Electric Vehicles (FEVs). EN24 offers high tensile strength and excellent fatigue resistance, ensuring the gearbox can withstand substantial operational stresses while maintaining reliability and performance. This material selection enhances the gearbox's capability, significantly improving the overall efficiency and competitive edge of the FEV.

1.2 Input Parameter

input parameters for the design and analysis of the two-stage reduction gearbox for a Formula Electric Vehicle (FEV):

TABLE I: MOTOR DATA

PARAMETER	VALUE
Motor Peak Torque	120Nm
Motor Continuous Torque	55Nm
Motor Maximum RPM	8000
Motor Continuous RPM	6000
Peak output Power	66KW

Graph: Motor Data

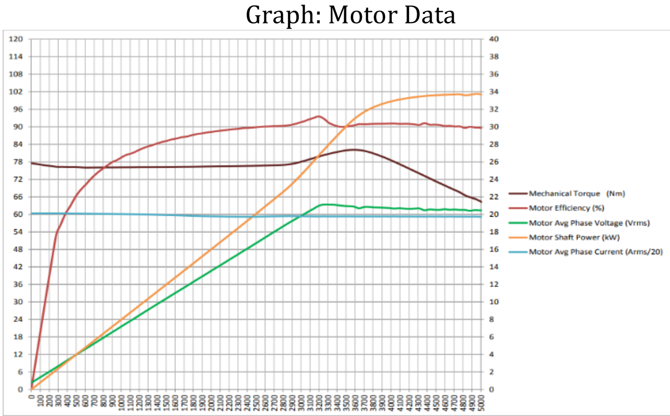

TABLE II: FOR 1st REDUCTION

Parameter	Gear 1	Gear 2
Input Teeth	18	42
Torque output	120	280
RPM at this Torque	3000	1287

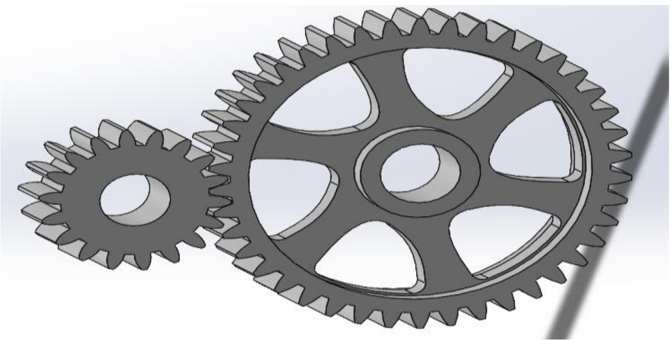

Figure: Gear 1 & Gear 2

TABLE III: FOR 2ND REDUCTION

Parameter	Gear 3	Gear 4
Input Teeth	20	60
Torque output	280 Nm	840 Nm
RPM at this Torque	1287	428

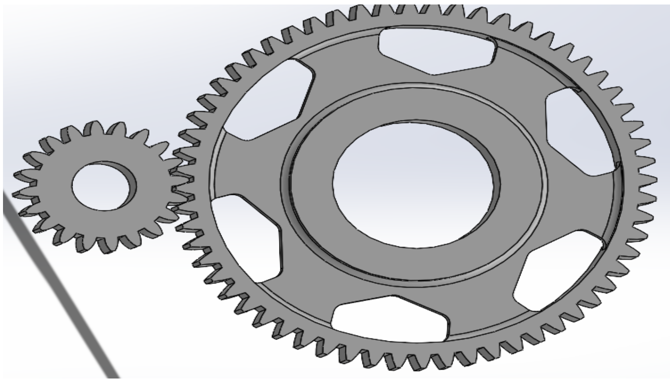

Figure: Gear 3 & Gear 4

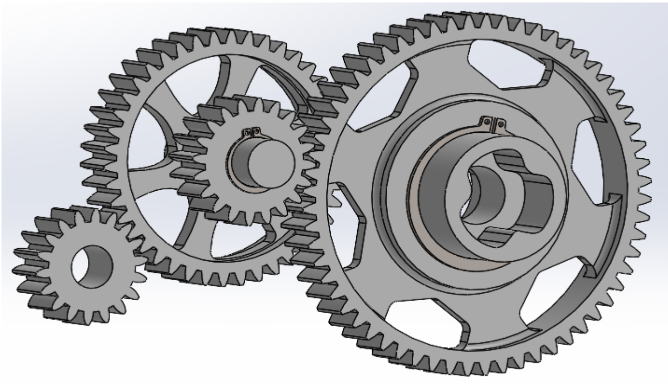

Figure: Compound Gears

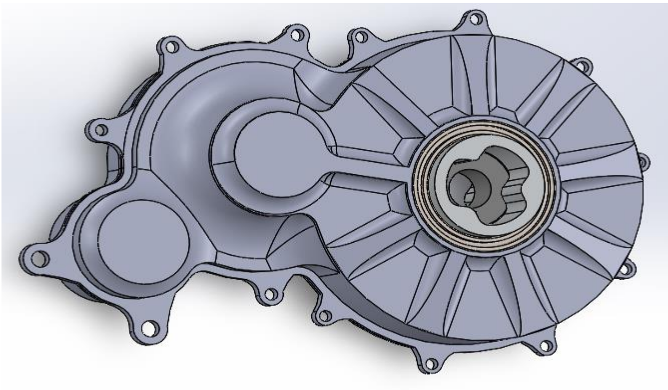

Figure: Gearbox Casing

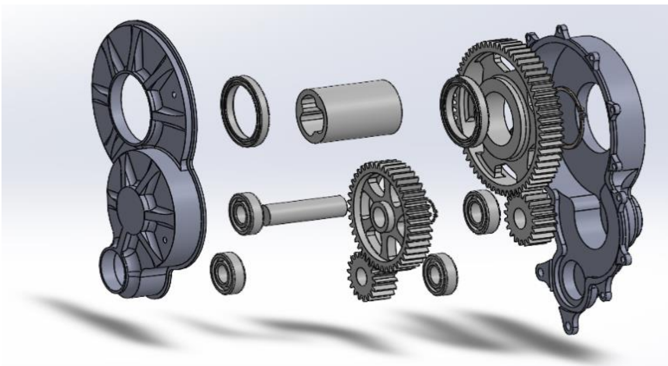

Figure: Gearbox

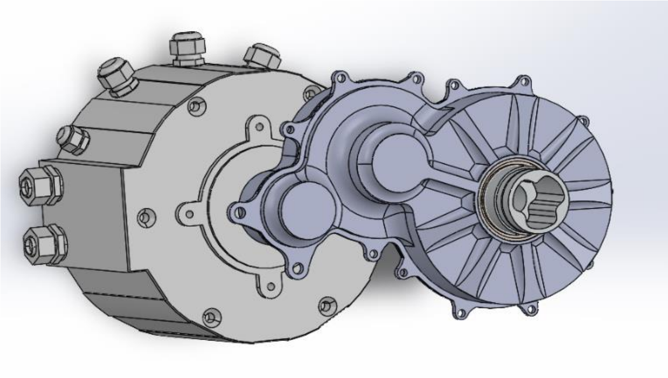

Figure: Motor with Gearbox

2. CALCULATIONS

2.1 Design Calculation for Gear 1 and Gear 2

Module of Gears = m

Pitch line velocity(v)

v = πDN/60

v = (3.14.18m.3000)/60

v = 2.826 m mm/s

velocity factor (Cv)

Cv = 6/(6+v)

Cv = 6/(6+2.826m)

Tangential force due to rated torque (Pt)

Pt = 2T/D

Pt = 13333/m

Cs = 1

Effective load on tooth (Peff)

Peff = (Cs.Pt)/Cv

Peff = 13333(6+2.826m)/6m

BEAM STRENGTH

Factor of Safety = 2

Endurance limit stress(σ) = Sut/Factor of safety

Lewis Factor(Y) = 0.302

Sb = m*b*σ*Y

Sb = 1661 m^2

Now,

Beam Strength = Effective load* Factor of Safety

1661 m^2= (13333(6+2.826m)/6m).2

m = 3.5

WEAR STRENGTH

Ratio Factor for internal gear (Q)= 2.T1/(T1+T2)

Q = 0.620

Load stress factor(K) = (0.16(BHN)^2)/10000

K = 6.76

Sw = D*b*Q*K

Sw = 18(m)*8(m)*0.620*6.76

Sw = 18(3.5) *8(3.5) *0.620*6.76

Sw = 7393 N

Similarly,

Beam Strength

Sb = 1661 m^2

Sb = 20347.25 N

Effective load,

Peff = 13333(6+2.826m)/6m

Peff = 10090 N

Since,

Sw>Peff, Sb >Peff

Design is safe

Factor of Safety,

Sb = Peff. Fos

Fos = 20347.25/10090

Factor of safety = 2.01

(Note: We can adjust factor of safety by increasing width of Gear)

1st stage reduction = 42/18 = 2.33

2.2 Design Calculation for Gear 3 and Gear 4

Module of Gears = m

Pitch line velocity(v)

v = πDN/60

v = (3.14.20m.1287)/60

v = 1.347 m mm/s

velocity factor (Cv)

Cv = 6/(6+v)

Cv = 6/ (6+1.347m)

Tangential force due to rated torque (Pt)

Pt = 2T/D

Pt = 26667/m

Effective load on tooth (Peff)

Peff = (Cs.Pt)/Cv

Peff = 26667(6+1.347m)/6m

BEAM STRENGTH

Factor of Safety = 2

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Endurance limit stress(σ) = Sut/Factor of safety

Lewis Factor(Y) = 0.330

Sb = m.b.σ.Y

Sb = 1815 m^2

Now,

Beam Strength = Effective load* Factor of Safety

1815 m^2= (26667(6+1.347m)/6m).2

m = 3.5

WEAR STRENGTH

Ratio Factor for internal gear (Q)= 2.T1/(T1+T2)

Q = 0.5

Load stress factor(K) = (0.16(BHN)^2)/10000

K = 6.76

Sw = D.b.Q.K

Sw = 20(m)*8(m)*0.5*6.76

Sw = 20(3.5) *8(3.5) *0.5*6.76

Sw = 8281 N

Similarly,

Beam Strength = 1815 m^2

Sb = 22234 N

Effective load,

Peff = 13333(6+1.347m)/6m

Peff = 6802 N

Since,

Sw>Peff, Sb >Peff

Design is safe

Factor of Safety,

Sb = Peff. Fos

Fos = 22234/6802

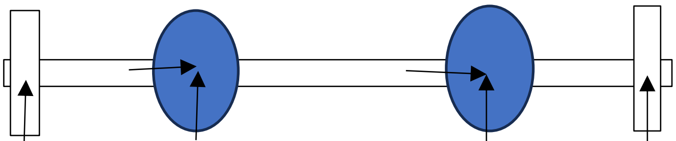
Factor of safety = 3.2

2nd stage reduction = 60/20 = 3

Table: Gears Detail

Parameter	Gear 1 & Gear 2	Gear 3 & Gear 4
Module	3.5	3.5
Pressure angle	20	20
Face width	30 mm	30 mm
RPM at end	3433	1143
Torque at end	240 Nm	840 Nm
Reduction	2.33	3

2.3 Shaft Design



Torque at Gear 2 = 280Nm

Tangential Force on gear 2

Pt = $T/(d2/2)$

Pt = 280000/ (147/2)

Pt = 3809.5 N

Radial force on gear 2

Pr = Pt*tan20

Pr = 1386.5 N

Tangential Force on gear 3

Pt = $T/(d3/2)$

Pt = 280000/ (70/2)

Pt = 8000 N

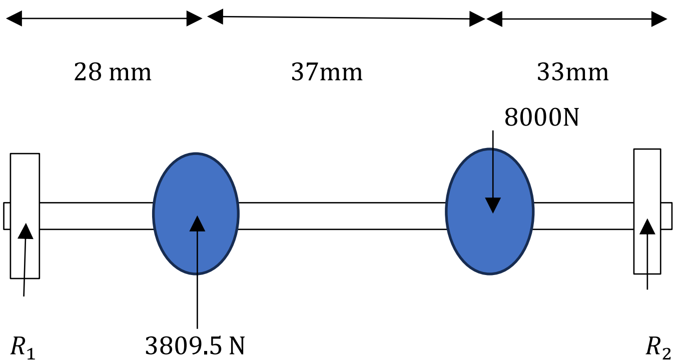
Radial force on gear 3

Pr = Pt*tan20

Pr = 2911 N

Horizontal plane:

Bearing At A — B — C — Bearing At D



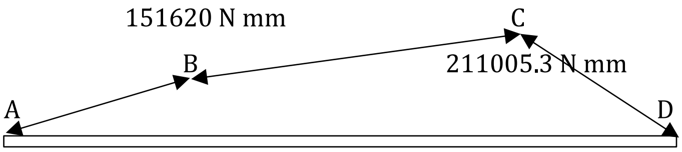


Figure: Bending Moment Diagram for Horizontal Plane

R1 + R2 = 11809.5 N

Moment about A= 0

3809.5*28+ 8000*65 -R2*98= 0

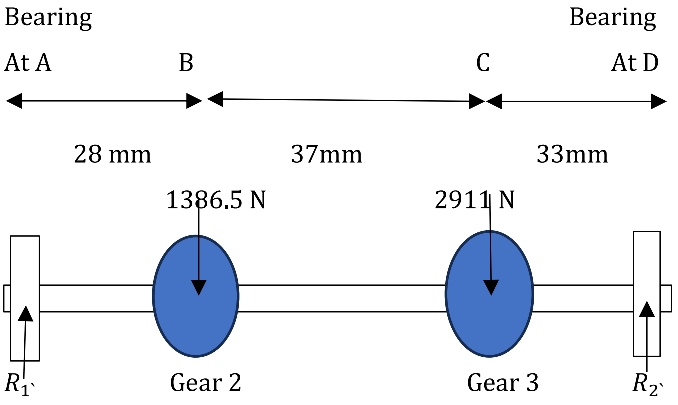
R2 = 6394.1 N

R1 = 5415 N

Mb= 5415*28 = 151620 N mm

Mc= 6394.1*33 = 211005.3 N mm

Vertical plane:



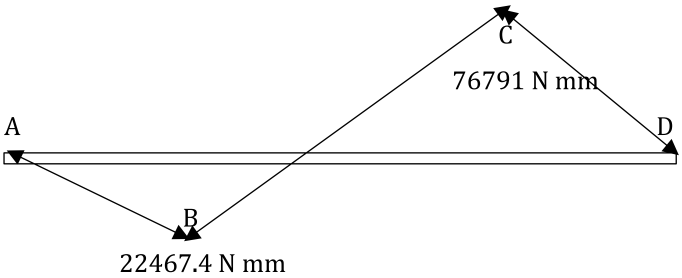


Figure: Bending Moment Diagram for Vertical Plane

R1` + R2`= 1524.5 N

Moment about A= 0

-1386.5*28+R2`*98-2911*65 = 0

R2` = 2327 N

R1` = -802N

Mb`= -802*28 = -22467.4 N mm

Mc`= 2327*33= 76791 N mm

Maximum resultant bending moment at c =

{(211005.3) ^2 + (76791) ^2} ^1/2

= 224544.2 N mm

Resultant Torsional moment = 240000 N mm

Maximum allowable shear stress ($\tau_{\max}$) = 0.75*0.18*1100

τ_{max} = 148.5 M pa

Shaft diameter:

$$\tau_{max} = \frac{16\sqrt{(KbMb)^2+(KtMt)^{\wedge}2}}{\pi d^3}$$

d = 25 mm

2.3 Bearing Design

Bearing at A:

$R_A = \sqrt{{R_1}^2 + {R_1`}^2}$

R_A = 5474 N

Hence,

Radial Force on Bearing (P)= 5474 N

Life of Bearing to be needed = 500 hr

Rpm at which Radial Force is acting(N)= 1287 rpm

$L_{10} = \frac{60.N.Life}{10^6}$

L_{10} = 38

Dynamic load Capacity(C)

C = P.$(L_{10})^{\frac{1}{3}}$

C = 18403 N

Deep Groove Ball Bearing SKF63005-2RS1 is Selected

Bearing at D:

$R_D = \sqrt{{R_2}^2 + {R_2`}^2}$

R_D = 5128 N

Hence,

Radial Force on Bearing (P)= 5128 N

Life of Bearing to be needed = 500 hr

Rpm at which Radial Force is acting = 1287 rpm

$L_{10} = \frac{60.N.Life}{10^6}$

L_{10} = 38

Dynamic load Capacity(C)

C = P.$(L_{10})^{\frac{1}{3}}$

C = 16922.4 N

Deep Groove Ball Bearing SKF63005-2RS1 is Selected

TABLE: BEARING SELECTION (SKF 63005-2RS1)

Parameter	Value
Material	Mild Steel
Inner Diameter	25mm
Outer Diameter	52mm
Thickness	15mm
Dynamic load capacity	15kN-25KN

3. DESIGN ANALYSIS

In this section, we delve into the detailed analysis of the two-stage reduction gearbox designed for the Formula Electric Vehicle (FEV). The primary objective of this analysis is to ensure the gearbox's structural integrity, efficiency, and reliability under various operating conditions. Advanced simulation techniques, particularly using ANSYS software, are employed to perform comprehensive Finite Element Analysis (FEA) on the gearbox components. This analysis includes assessing the stress distribution, deformation, and fatigue life of the gears and associated parts.

3.1 Design Report for Gear Analysis in ANSYS

This design report outlines the analysis and validation of an EN24 steel gear system using ANSYS simulation. The gear system comprises a driver gear with 18 teeth and a driven gear with 42 teeth. The primary objectives of the analysis were to determine the maximum stress and the factor of safety (FOS) under specified operational conditions.

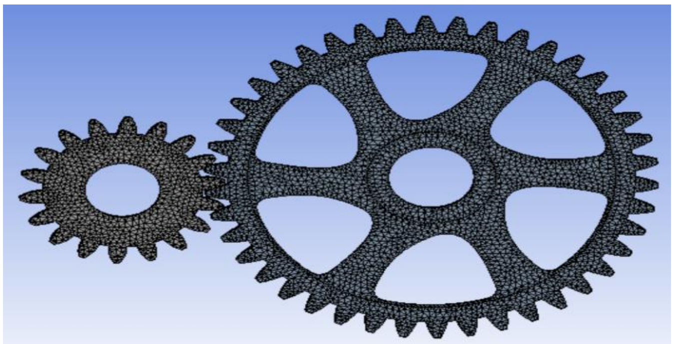


Figure: Geometry and Mesh 1st stage

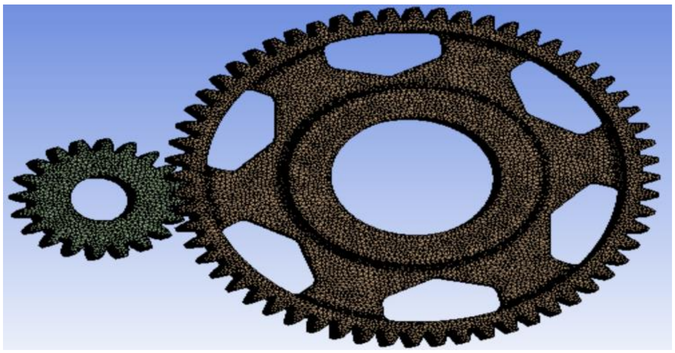


Figure: Geometry and mesh in 2nd stage

3.1.1 Geometry and mesh

1) **Gear Details**:
   a) **Driver Gear1**: 18 teeth
   b) **Driven Gear2**: 42 teeth
   c) **Driver Gear3**: 20 teeth
   d) **Driven Gear4**: 60 teeth
2) **Mesh Size**: 1 mm element size
3) **Mesh Type**: High-quality tetrahedral mesh for accurate stress distribution and contact simulation.
4) **Statistics For 1st Stage**:
   a) **Node**: 555083
   b) **Elements**: 348871
5) **Statistics For 2st Stage**:
   a) **Node**: 653831
   b) **Elements**: 383191

3.1.2 Boundary Conditions

1. **Driver Gear 1 and Gear 3**:
   - **Rotational Velocity**: 3000 RPM applied to simulate operational speed for gear 1 and 1287 RPM for Gear 3.
   - **Moment**: 120 Nm torque applied to the driving shaft for gear 1 and 280 Nm for Gear 3.
   - **Support**: Remote displacement allowing free rotation around the x-axis.
2. **Driven Gear 2 and Gear 4**
   - **Support**: Cylindrical support applied to simulate realistic boundary conditions without restricting rotational movement.

3.1.3 Results

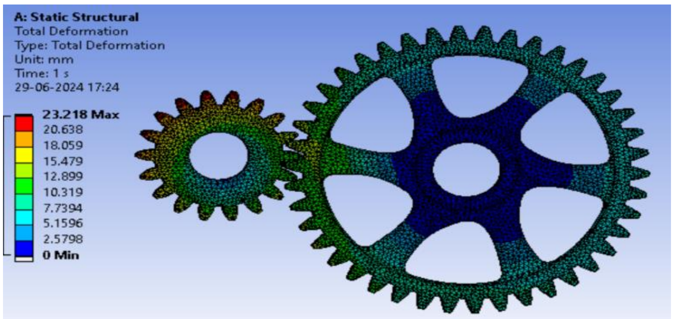


Figure: Total Deformation of Gear 1 and Gear 2

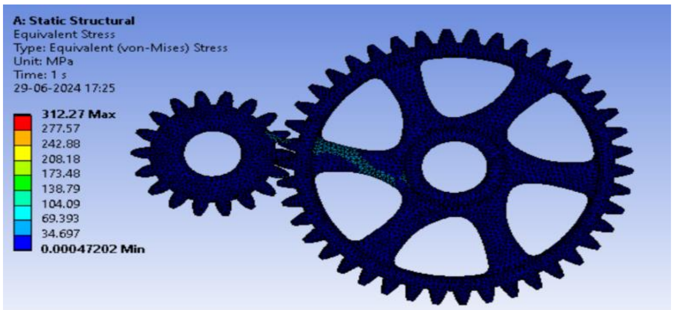


Figure: Equivalent stresses in Gear 1 and Gear 2

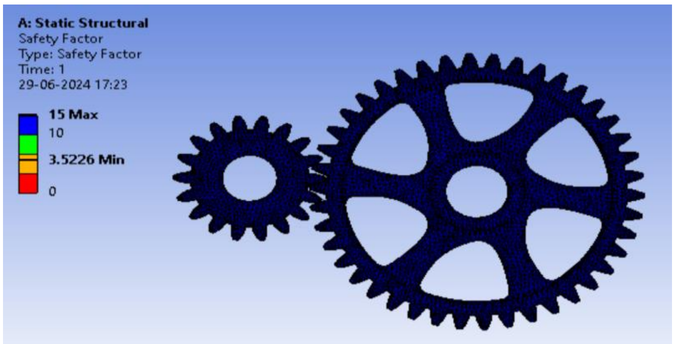


Figure: FOS of 1st stage

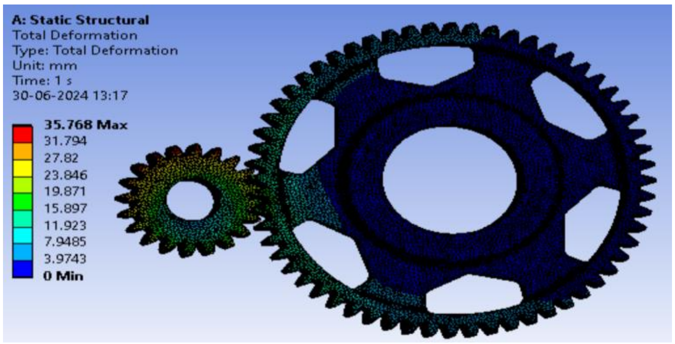


Figure: Total Deformation of Gear 3 and Gear 4

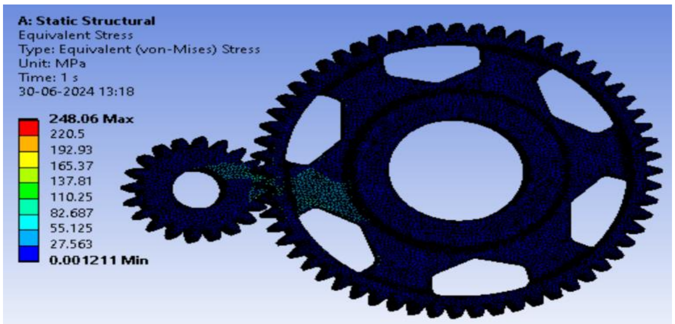


Figure: Equivalent stresses in Gear 3 and Gear 4

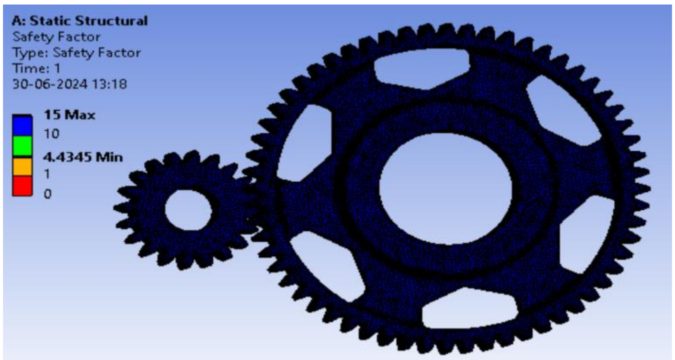


Figure: FOS of 2nd stage

- **Maximum Stress**: 312 MPa, observed at the gear teeth contact points in 1st Stage and 248 MPa in 2nd Stage.
- **Factor of Safety (FOS)**: 3.5 in 1st stage and 4.4 in 2nd stage, indicating the design is safe and meets the required safety margin.
- The analysis demonstrates that the gears can withstand the applied loads with a sufficient safety margin, ensuring reliable performance in operational settings.

3.2 Gear Optimization Using Fusion 360

In this section, we focus on the optimization of the spur gears used in the two-stage reduction gearbox for the Formula Electric Vehicle (FEV) utilizing Autodesk Fusion 360. The goal of this optimization process is to enhance the performance, efficiency, and durability of the gearbox by refining the gear design.

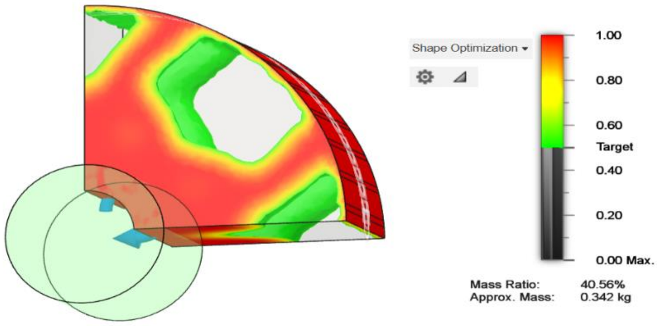


Figure: Gear Optimize in Fusion 360

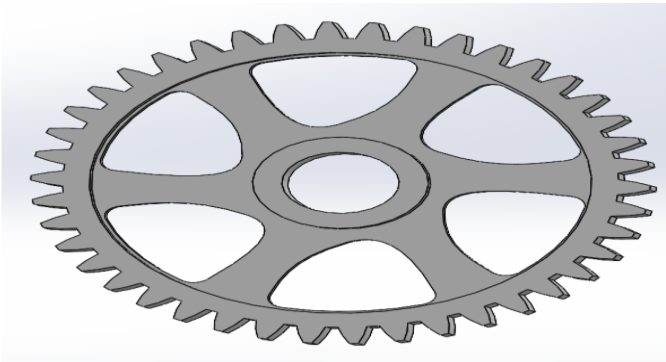


Figure: Gear 2 After Optimize

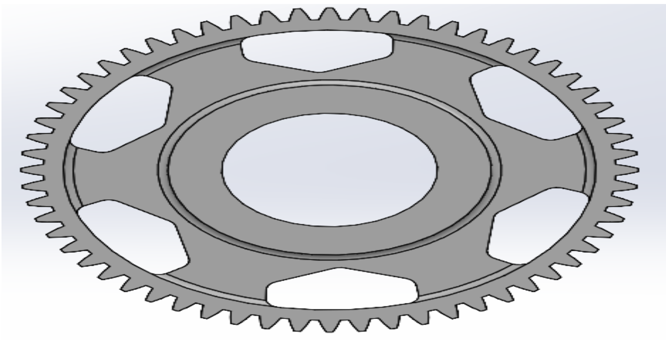


Figure: Gear 4 After optimize

3.2.1 Optimization Parameters:

Parameter	Gear 1 & Gear 2	Gear 3 & Gear 4
Young Modulus	207Gpa	207Gpa
Poisson Ratio	0.35	0.35
Mass Ratio	60%	60%

3.2.2 Process Overview:

1. **Modeling and Initial Design:**
   - The initial spur gear models are created in Fusion 360, incorporating the basic design parameters and constraints.
2. **Simulation Setup:**
   - Operational conditions and material properties are defined, and static structural analysis is performed to identify stress distribution and potential deformation.
3. **Optimization Iterations:**
   - Using Fusion 360's optimization tools, multiple iterations are conducted to refine the gear geometry. This involves adjusting parameters such as the number of teeth, face width, and pressure angle to achieve the desired balance between strength and weight.
4. **Dynamic Simulation:**
   - The optimized gear design is then subjected to dynamic simulations to assess its performance under realistic operating conditions, including varying loads and speeds.
5. **Fatigue Analysis:**
   - Fatigue life predictions are carried out to ensure the gears can withstand prolonged usage without failure, focusing on areas prone to high stress and cyclic loading.
6. **Validation:**
   - The final optimized design is validated through a comprehensive review of the simulation results, ensuring all performance criteria and constraints are met.

The use of Fusion 360 for gear optimization enables a streamlined and efficient design process, resulting in a high-performance gearbox tailored for the rigorous demands of Formula Electric Vehicle racing. The insights gained from the optimization process contribute significantly to the overall enhancement of the gearbox design.

4. CONCLUSIONS

In this paper, the design and analysis of a two-stage reduction gearbox for a Formula Electric Vehicle (FEV) were presented, with a specific focus on utilizing EN24 material for its components. The design aimed to maximize power transmission efficiency while minimizing weight and spatial footprint, essential for high-performance electric racing. By selecting appropriate gear ratios and conducting a detailed structural analysis using Finite Element Analysis (FEA), we ensured the gearbox's durability and reliability under operational stresses. Material properties of EN24, such as high tensile strength and excellent fatigue resistance, were crucial in achieving a robust and efficient gearbox design. The final design demonstrated significant improvements in torque amplification and speed reduction, contributing to the overall dynamic performance of the FEV. This study provides a comprehensive approach to gearbox design, offering valuable insights into achieving high efficiency and robustness in electric vehicle applications. The successful implementation of this two-stage reduction gearbox underscores its potential to enhance the competitive edge and performance of Formula Electric Vehicles.

REFERENCES

[1] Norton, R. L. (2006). *Machine Design: An Integrated Approach*. Prentice Hall. Pages: 650-670

[2] Budynas, R. G., & Nisbett, J. K. (2011). *Shigley's Mechanical Engineering Design*. McGraw-Hill Education.

Pages: 472-500

[3] Mott, R. L. (2013). Machine Elements in Mechanical Design. Pearson. Pages: 520-540

[4] Doughty, S., & Vallance, A. (1999). *Design of Machine Elements*. Tata McGraw-Hill. Pages: 310-330

[5] Juvinall, R. C., & Marshek, K. M. (2011). *Fundamentals of Machine Component Design*. John Wiley & Sons. Pages: 425-450

[6] Spotts, M. F., & Shoup, T. E. (2004). *Design of Machine Elements*. Pearson. Pages: 400-420

[7] Collins, J. A., Busby, H., & Staab, G. H. (2010). Mechanical Design of Machine Elements and Machines: A Failure Prevention Perspective. John Wiley & Sons. Pages: 370-390

[8] Hamrock, B. J., Schmid, S. R., & Jacobson, B. O. (2013). *Fundamentals of Machine Elements*. McGraw-Hill Education. Pages: 500-520

[9] Gopinath, K., & Shanmugham, M. S. (2014). *Machine Design*. Anuradha Publications. Pages: 260-280

[10] Bhandari, V. B. (2010). *Design of Machine Elements*. Tata McGraw-Hill. Pages: 550-570

[11] Jung, D. (2018). *Gear Design Simplified*. Industrial Press.

Pages: 180-200