Project Report

Title: Design and Optimization of a Two-Stage Gearbox for a Small Electric Vehicle

Group: Group - 1

Course: Mechanical Engineering

Institution: MNIT Jaipur

1. Introduction

The increasing shift toward electric mobility has created demand for lightweight, efficient, and durable drivetrain components. This project focuses on the design and optimization of a **two-stage gearbox** specifically tailored for a small electric vehicle (EV) application. The goal is to develop a robust gearbox design that meets specified technical constraints while ensuring performance and manufacturability.

2. Objectives

- To design a two-stage gearbox compatible with a **2 kW** electric motor.
- To achieve a speed reduction ratio of **5:1**.
- To ensure the gearbox weighs no more than **10 kg**.
- To develop a weatherproof and vibration-resistant housing.
- To ensure a minimum lifespan of **50,000** operational hours.
- To create a CAD model and perform FEA simulations for strength and reliability assessment.

3. Design Requirements and Constraints

Parameter	Specification
Power Input	2 kW
Speed Reduction Ratio	5:1
Maximum Weight	10 kg
Environmental Protection	Weatherproof, vibration-resistant

Operational Lifespan	50,000 hours

4. Design Methodology

1. Preliminary Design:

Selection of gear type (spur/helical) and materials. Basic calculations for torque, gear ratios, and shaft design.

2. CAD Modeling:

Developed using Fusion 360. Complete assembly of two-stage gear system and housing.

3. Finite Element Analysis (FEA):

Imported CAD model into **Abaqus** for structural analysis. Simulation under real-world loading conditions to check for maximum stress, factor of safety, displacement.

4. Optimization:

Weight minimization through topology optimization.

The two-stage gearbox functions on the **principle of gear reduction**, enabling high torque delivery at reduced speed.

In the first stage, the high-speed input shaft turns a larger driven gear, reducing speed and increasing torque.

The intermediate shaft transmits this torque to the second-stage gear pair, further reducing speed.

The output shaft then delivers the final torque to the EV wheels at a **5:1 reduction ratio**.

This multi-stage setup reduces stress on individual gears and improves durability.

5. Working Principle of the Gearbox

A **two-stage gearbox** is used to reduce the high rotational speed of an electric motor to a lower speed with a corresponding increase in torque. This is essential for applications like electric vehicles where motors operate at high speeds, but the wheels require lower speeds and higher torque.

Stage 1: Initial Reduction

- The **input shaft**, connected to a 2 kW electric motor, drives a **small pinion gear**.
- This pinion meshes with a **larger gear** mounted on the **intermediate shaft**.
- As the pinion rotates, it turns the larger gear more slowly, reducing speed and multiplying torque.

Stage 2: Final Reduction

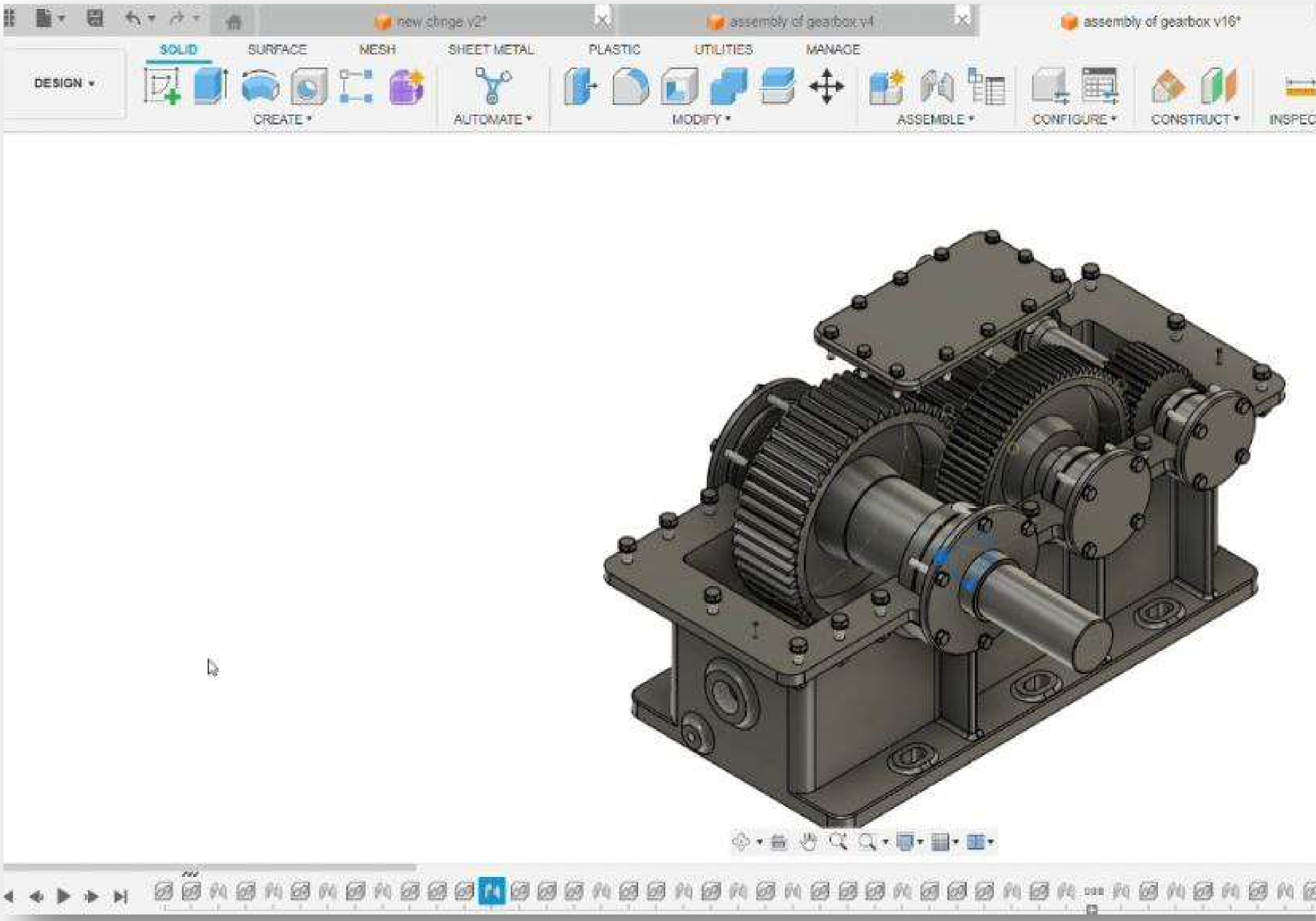
- The **intermediate shaft** now acts as the input for the second stage.
- It drives a second pinion, which meshes with a **larger output** gear on the **final shaft**.
- This gear pair provides additional speed reduction and torque amplification, completing the 5:1 reduction ratio.

6. CAD Model Details

The CAD model of the two-stage gearbox was developed using Fusion 360, focusing on both functional and manufacturable aspects of the design. The model includes:

- Input shaft connected to the 2 kW electric motor.
- First-stage gear pair for initial speed reduction.
- Intermediate shaft transmitting torque to the second stage.
- Second-stage gear pair achieving final reduction to obtain 5:1 overall ratio.
- Output shaft aligned with the wheel axis of the EV.
- Compact housing that encapsulates the full assembly with necessary clearances and mounting provisions.

- Seals and bearing placements for minimizing friction and preventing contamination.
- Provision for lubrication access and thermal expansion tolerances.



7. Results and Discussion

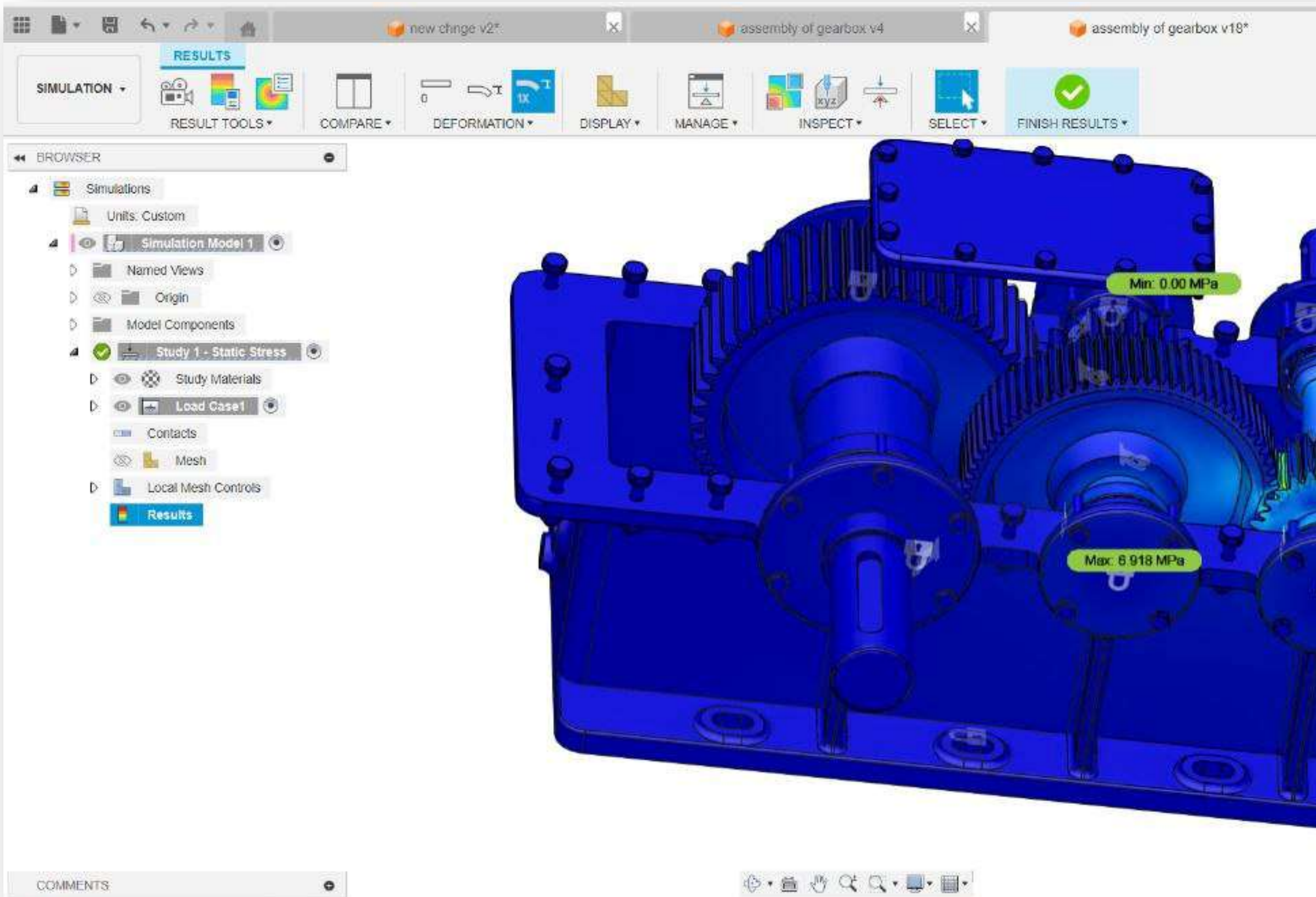
Gearbox Configuration:

Two-stage gear design with intermediate shaft.
Gear material: Steel

FEA Results:

Maximum stress observed: 6.918 MPa

Maximum displacement: 0.001 mm


new chnge v2*
assembly of gearbox v4
assembly of gearbox v18*
SIMULATION
RESULTS
RESULT TOOLS
COMPARE
DEFORMATION
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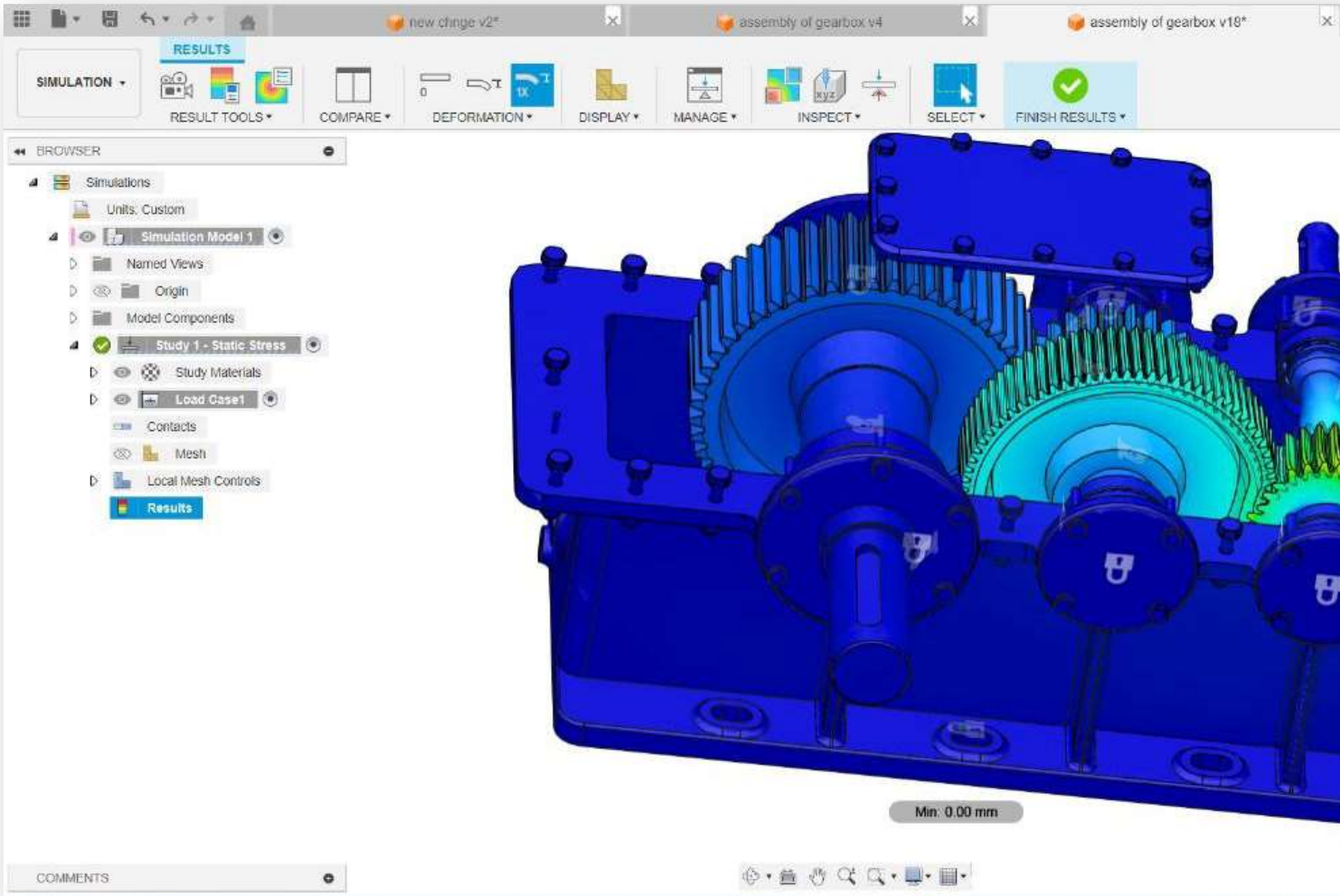
FINISH RESULTS
BROWSER
Simulations
Units: Custom
Simulation Model 1
Named Views
Origin
Model Components
Study 1 - Static Stress
Study Materials
Load Case1
Contacts
Mesh
Local Mesh Controls
Results
Min: 0.00 MPa
Max: 6.918 MPa
COMMENTS



8. Conclusion

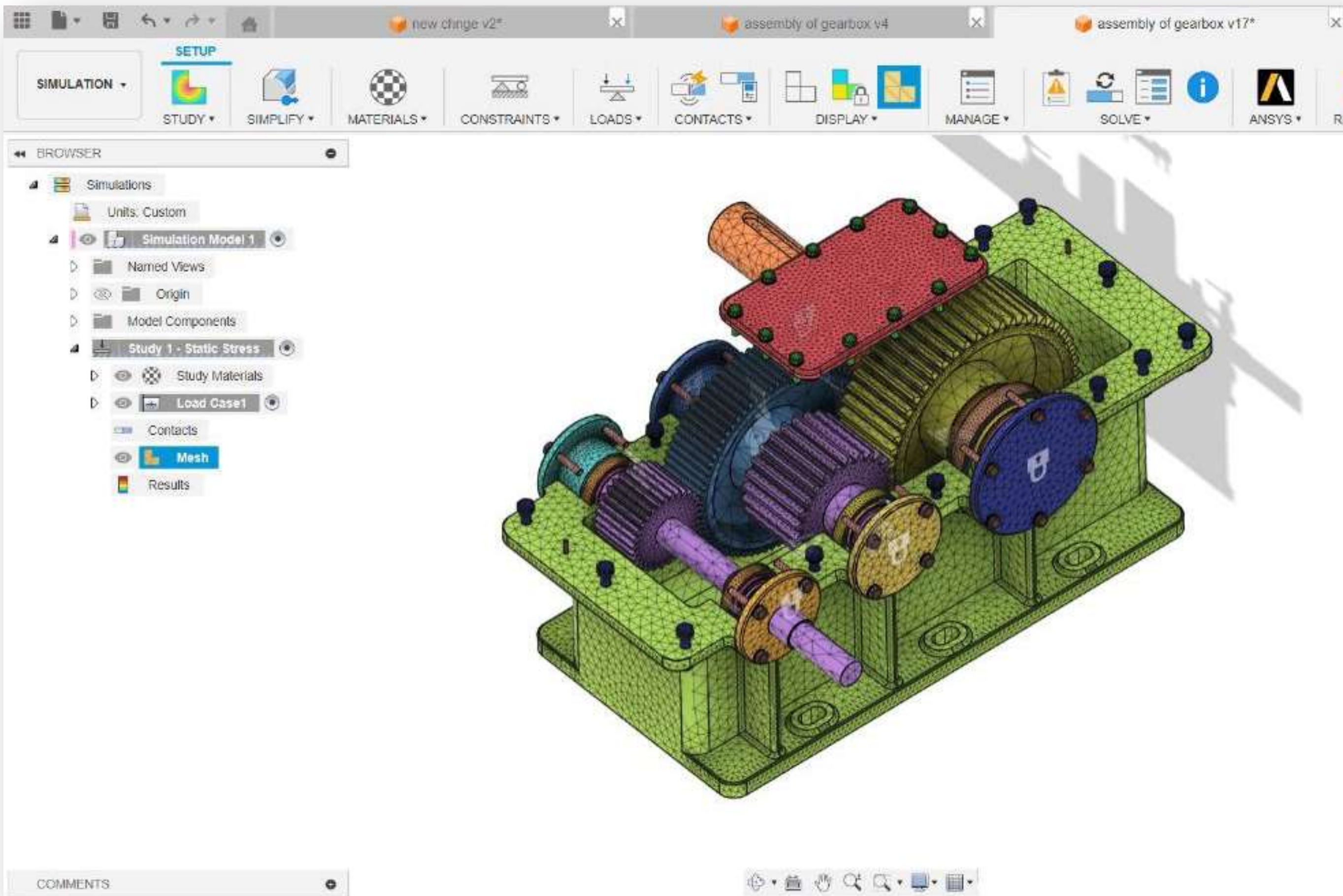
The project successfully delivers a CAD model and FEA simulation of a lightweight, efficient, and reliable two-stage gearbox for small electric vehicles. All design constraints were satisfied, including weight, performance, and environmental protection. The design demonstrates a strong foundation for further prototyping and testing.

9. References

- Norton, R. L., Machine Design

- AutoDesk Fusion 360 User Documentation
- ABAQUS User Documentation

10. Appendix



Calculations:

(1)

Material – Steel

Speed ratio = 5:1 *(Speed reduction)*

Stage 1

Np = 30, Ng = 75, dp = 90 mm, dg = 225 mm, m = 3

Stage 2

Np = 25, Ng = 50, dp = 125, dg = 250, m = 5

Given:

Power i/p = 2 kN, Speed reduction = 5:1 (overall), Max. wt = 10 kg, Min. lifespan = 50,000 hrs

Assuming:

Gear Profile = Involute, Pressure angle = 20°, Profile type = Stub

Design for 1st stage reduction

i_1 = Ng / Np = 75 / 30 = 2.5

Let o/p speed assume N = 3800 RPM

Center distance a_1 = m (dp + dg) / 2
= 3 (90 + 225) / 2
= 157.5 mm

Stage 2

i_2 = Ng / Np = 50 / 25 = 2

Center distance a_2 = m (Np + Ng) / 2
= 5 (25 + 50) / 2
= 187.5 mm

(2)

Total Gear Ratio:

$i = i_1 \times i_2 = 2 \times 2.5 = 5$

Let assume,

i/p speed = 3000 RPM
$(N_1)_{(ip)}$

$N_{0(op)} = N_1 / i = 3000 / 5 = 600$ RPM

Stage 1 o/p speed
$N_2 = N_1 / i_1 = 3000 / 2.5 = 1200$ RPM

Input Torque

$P = (2\pi \times N \times MT) / 60$

$2000 = (2\pi \times 3000 \times MT) / 60$

$(MT)_{(ip)} = 6.37$ N·m

o/p torque *(assuming 94% efficiency per stage)*

$(MT)_{(op)} = \eta \times (MT)_{(ip)} \times i / \eta$
$= (6.37 \times 5) / 0.94$
$= 33.88$ N·m

Intermediate shaft (after stage 1)
Speed = (3000 / 2.5) = 1200 RPM

Torque $(MT)_2 = (6.37 \times 5) / 0.97 = 16.42$ N·m

(3)

Gear strength:

Assume: face width, b = 10 m

- Stage 1 → $b_1 = 10 \times 3 = 30$ mm
- Stage 2 → $b_2 = 10 \times 5 = 50$ mm

Tangential force

→ Stage 1 (r_p = 45 mm)

$(F_t)_1 = (MT)_{(ip)} / r_p = 6.34 / 0.045 = 141.56$ N

→ Stage 2 (r_p = 62.5 mm)

$(F_t)_2 = (MT)_{(ip)} / 0.0625 = 262.72$ N

Bending stress

$\sigma = F_t / (b \times m \times y)$

Stage 1

Lewis form factor, Y = π·y

$y = (0.154 - 0.912 / N_p)$

$y = \pi(0.154 - 0.912 / 30)$

$y = 0.3883$

% $\sigma_1 = (141.56) / (30 \times 3 \times 0.3883) \times 1.5 = 6.0760$ MPa

Stage 2

$Y = \pi (0.154 - 0.912 / 25)$

$Y = 0.3691$

$\therefore \sigma_2 = (262.72) / (50 \times 5 \times 0.3691) \times 1.5 = 4.2707$ MPa

(% allowable bending strength for AISI 4340 steel = 400 MPa)

→ Here both for both stages it is less, so safe

Now, contact stress

$\sigma\_c = Cp \sqrt{(F_t(i+1) / (b \cdot dp \cdot i \cdot \mu))} \times 1$ (for open gear)

$Cp = 1910$ (elastic constant of steel)

$\therefore \sigma\_c_1 = 1910 \sqrt{(141.56(2.5+1) / (30 \times 90 \times 2.5 \times 1))} = 16.35$ MPa

$\therefore \sigma\_c_2 = 1910 \sqrt{(262.72(2+1) / (50 \times 125 \times 2 \times 1))} = 15.16$ MPa

($\therefore$ allowable contact stress = 1000 MPa)
→ Both stages are safe (as both are less)

(4)

Lifespan calculation

Fatigue life

→ 50000 hrs at 3000 rpm = $50000 \times 60 \times 3000 = 9 \times 10^9$ cycles

→ Stage 1 (Np = 30) each tooth =
$= 9 \times 10^9 / 30 = 3 \times 10^8$ cycles

→ Stage 2 (i = 2.5) each tooth =
$= 3 \times 10^9 / 2.5 = 1.4 \times 10^8$ cycles

(5)

Weight

Gear Volume

Stage 1

- Pinion $V = \pi \times (45)^2 \times 30 = 190852$ mm³

- Gear $V = \pi \times (112.5)^2 \times 30 = 1192826\ mm^3$

Stage 2

- Pinion $V = \pi \times (60.5)^2 \times 50 \approx 613592\ mm^3$
- Gear $V = \pi \times (95)^2 \times 50 \approx 2454360\ mm^3$

Gear weight (steel density = $7.85 \times 10^{-6}\ kg/mm^3$)

- Stage 1: $(190852 + 1192826) \times 7.85 \times 10^{-6} = 1.09$ kg
- Stage 2: ≈ 2.41 kg

Total gear weight = 1.09 + 2.41 kg = 3.50 kg

Let Assume:

- Shaft & bearing set = 2 kg
- Housing (Aluminium) = 3.5 kg

∴ **Total WT** = 3.50 + 2.0 + 3.5 = **9.0 kg**

which is less than 10 kg