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Design and Analysis of Six Speed Constant Mesh Gearbox using Al 7075 Alloy as Gear Material

K Raghavendra[1], Girisha C[2], Karnam Bhargava[3], Khaja Hussain[4], Manoj C[5]
[1]Assistant professor, [2, 3, 4, 5]Students, Department of ME, BITM Ballari

Abstract: A design concept for a 6-speed constant mesh gearbox utilizing Al 7075 as the material for helical gears. The objective of this design is to enhance the performance and durability of the transmission system while reducing weight and improving overall efficiency. Al 7075 is chosen as the material for the helical gears due to its excellent strength-to-weight ratio and high fatigue resistance. These properties make it suitable for handling the demanding operating conditions and torque loads experienced in a gearbox. The helical gear configuration offers advantages such as smoother and quieter operation compared to other gear types, reducing noise and vibration levels. The gearbox is designed with six speeds to provide a wide range of gear ratios, enabling optimal engine performance at various vehicle speeds. The constant mesh design ensures quick and seamless gear shifting, enhancing the driving experience and minimizing power losses during gear changes.

I. INTRODUCTION

A gearbox, also known as a transmission, is a mechanical device that is used to transfer power form an engine to the wheels of a vehicle. The main function of a gearbox is to provide torque multiplication, speed reduction, or both, depending on the needs of the vehicle. Gearboxes typically contain a series of gears that are arranged in different ratios to provide different levels of torque and speed. The gears are usually mounted on shafts that rotate at different speeds, and the transmission of power from one gear to another is controlled by a series of clutches and synchronizers. Gearboxes are essentially components in a wide range of vehicles, including cars, trucks, buses, motorcycles, boats and aeroplanes. They are also used in industrial machinery such as wind turbines, generators and construction equipment. There are several types of gearboxes, including manual, automatic and continuously variable transmissions (CVTs). Each type has its own advantages and disadvantages and the choice of the gearbox depends on the specific application and requirements of the vehicle or machinery.

A six-speed constant mesh gearbox is a type of transmission used in motor vehicles that enables smooth shifting between gears while driving. It is designed with 6 forward gear ratios and one reverse gear. The term “Constant mesh” refers to the use of fixed gears that remain in constant engagement with one another, regardless of whether or not they are actively transmitting power. The primary advantage of a six-speed constant mesh gearbox is its ability to improve fuel efficiency and acceleration. By providing more gear ratios to choose from, the engine can operate at a more efficient speed range, resulting in better fuel economy. Additionally, the additional gear ratios allow for quicker acceleration and better performance, especially when paired with a high-powered engine.

The design of a six-speed constant mesh gear box consists of a series of gears that are mounted on shafts inside the transmission housing. These gears have teeth that interlock with one another and are engaged by a shifting mechanism that is controlled by the driver. In a constant mesh gear box, the gears are always in contact with each other, but only certain gears are transmitting power at any given time. The shifting mechanism in a six-speed constant mesh gear box typically consists of a shifter lever that is connected to a set of linkages and cables. When the driver moves the sifter, the linkages and cables translate that motion into a change in gear ratio. The driver must use a clutch to disengage the transmission from the engine momentarily when shifting gears. One key feature of constant mesh gear box is its synchronizers, which allow for smoother shifting between gears. The synchronizers are small devices that match the speeds of the gears being engaged, reducing the amount of force required to shift and minimizing wear on the transmission. They are especially important in constant mesh gear boxes, as the gears are always in contact with one another.

II. LITERATURE REVIEW

Santhanakrishnan M and Maniselvam N has prepared six speed constant gearboxes with the project title “Design and Fabrication of Six Speed Constant Mesh Gear Box”. This project mainly focuses on the design and fabrication of gear box that can transmit torque to the maximum and also helps to do some useful work in automobile where power transmission is a major factor.

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Dasari Ajay has prepared six speed constant gear boxes with the project title “Modelling and Analysis of Constant Mesh Transmission System”. In this project modelling is done using some operations like sketching, extrude, swept blend, round, etc., Spur gear is designed using involute curve method along with using some operations like angled datum plane and pattern commands. Helical gear is designed using involute curve method along with using some operations like angled datum plane, helical sweep, swept blend and pattern commands. Bevel gear is designed using some operations like revolve, helical sweep and pattern commands.

Ujjayan Majumdar, Sujit Maity, Gora Chand Chell has prepared six speed gear boxes with the project title “Design and Analysis of Six Speed Gear Box”. In this project they have designed a gear box and as per the design criteria, the design made by us is safe and satisfactory and can be proceeded with production process. Here we also conclude that we have made the design along with its stress, strain and force analysis and the design is concluded safe.

Aishwarya Dhawad et.al has designed a 4 speed 2 stage gearbox using spur gears with project title “Design of a Multispeed Multistage Gearbox”. Aim of the paper is to design a 4 speed 2 stage gearbox using spur gears so as to make the transmission highly efficient as well as to keep the gearbox economically feasible. Cad plot for the same was plotted and stress-strain analysis for each was done. The gearbox can be used efficiently for very low to medium power applications. The gearbox seems to be suitable for light load carrying machineries or low rpm machineries.

Rakesh V. Mulik et.al, this research work, one of the major field issues related to 1st gear and reverse gear pitting at very low life for 6 speed manual transmission for mining/ quarry application is studied. The purpose of this paper is to identify the causes of gear failure, bearing failure, source of noise and suggestions for improvement on gear, bearing, and shaft life and to minimize noise in the system.

Chetan et.al, one study by Chetan et.al analysed the dynamic behaviour of a constant mesh gearbox under various loading conditions. The researchers used a dynamic model of the gearbox to simulate its behaviour, and they found that the gearbox experienced significant vibration and noise at high speeds and loads. They also found that the gearbox had a relatively low efficiency, with loses due to friction and other factors.

Sivakumar et.al, the investigation on design and optimization of a constant mesh gearbox for a two-wheeler vehicle. The researchers used a multi-objective optimization approach to optimize the gearbox design for both performance and weight. They found that by optimizing the gear ratios and other design parameters, they were able to improve the performance and efficiency of the gearbox while reducing its weight.

Kaarthik et.al, a study by kaarthik evaluated the wear characteristics of the gear teeth in a constant mesh gearbox. The researchers used a microhardness tester to measure the surface hardness of the gear teeth and found that the hardness decreased with increasing distance from the surface. They also found that the wear rate of the gear teeth increased with increasing load and speed.

III. METHODOLOGY

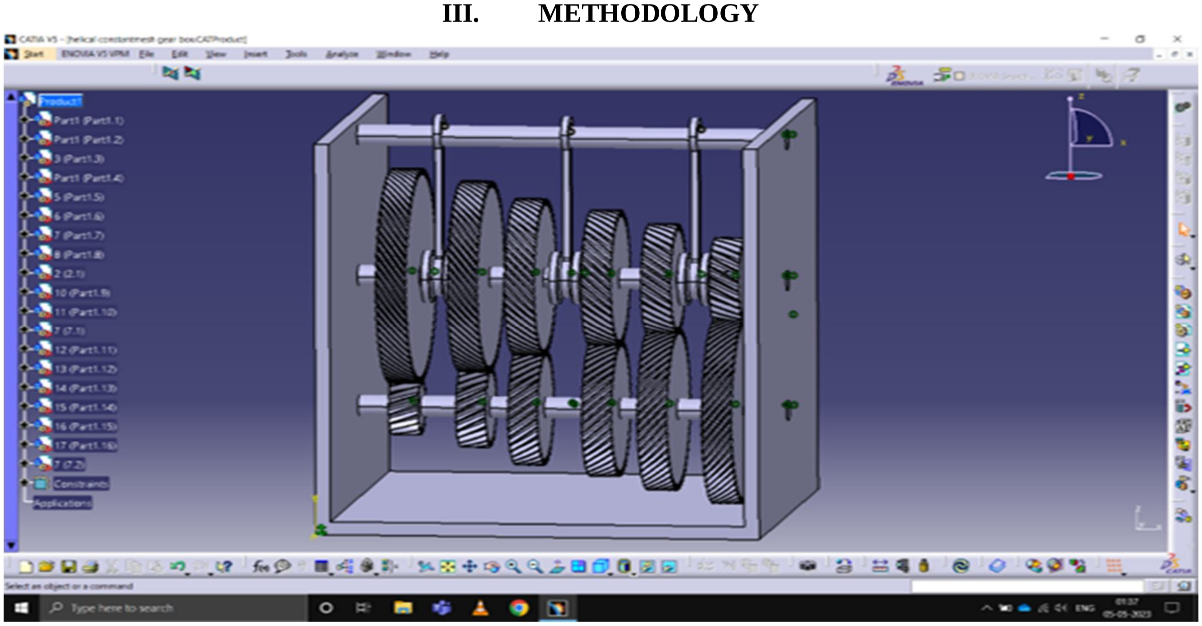

Fig 1 Assembly of constant mesh gearbox using CATIA V5

A constant mesh gearbox is a type of manual transmission commonly found in automobiles and motorcycles. It utilizes a system of gears and shafts to allow the driver to select different gear ratios to match the vehicle's speed and load requirements. The key characteristic of a constant mesh gearbox is that all the gears are constantly in mesh with one another, hence the name "constant mesh." The basic components of a constant mesh gearbox include the input shaft, the output shaft, and multiple gear pairs arranged on parallel shafts. Each gear pair consists of two gears: a layshaft gear and a main shaft gear. The layshaft is connected to the input shaft, while the main shaft is connected to the output shaft. When the engine is running, power is transmitted from the engine to the input shaft of the gearbox. The input shaft rotates continuously, and the driver selects the desired gear by moving the gear lever. The gear lever controls the movement of gear selector forks, which engage and disengage the gear pairs on the layshaft and main shaft.

In a constant mesh gearbox, the layshaft is always in motion, driven by the input shaft. The layshaft gears are in constant mesh with the corresponding gears on the main shaft. However, the gears on the main shaft are not fixed to the shaft; they can freely rotate on needle bearings. To engage a particular gear, the gear selector fork slides a collar, also known as a synchromesh cone or synchro, over the gear on the main shaft. The synchromesh cone has teeth that mesh with the corresponding teeth on the gear, effectively locking the gear to the main shaft. This creates a direct mechanical connection between the engine and the output shaft, transmitting power to the wheels. To shift gears, the driver depresses the clutch pedal, which disengages the engine from the input shaft, interrupting power transmission. With the clutch disengaged, the gear lever can be moved to select a different gear. When the driver releases the clutch pedal, the clutch engages, and power is re-established between the engine and the gearbox. The synchromesh cones, equipped with friction surfaces, facilitate the smooth and synchronized engagement of the selected gear by matching the rotational speeds of the layshaft and the main shaft gears.

IV. IMPLEMENTATION

A. Gear Material: Aluminium 7075 Alloy

7075 aluminum alloy's composition roughly includes 5.6% zinc, 2.1% magnesium, 1.6% copper, and less than a half percent of silicon, manganese, chromium, and other metals. Copper – One of the most important additions to aluminum. It has significant solubility and a substantial strengthening effect through the age-hardening characteristics it imparts to aluminum. Manganese – An addition that provides substantial strength. Silicon – In addition to lowering the melting point and increasing the fluidity of aluminum, silicon adds moderate strength. Magnesium – One of the most effective and widely used alloying elements, magnesium adds substantial strength and improves the work-hardening characteristics of aluminum. When combined with other elements such as copper and zinc, it adds even greater strength. Zinc – Used with magnesium, zinc helps to produce the high strength, heat-treatable aluminum alloys.

B. Shaft material: Mild steel

Mild steel is often chosen as a material for shafts due to its combination of properties that make it suitable for the intended application. Here are some reasons why mild steel is commonly used for shafts: Strength: Mild steel has good strength properties, allowing it to withstand the stresses and loads imposed on shafts during operation. It provides sufficient strength for many shaft applications without being overly expensive. Ductility: Mild steel is a relatively ductile material, meaning it can deform plastically before fracturing. This property is beneficial for shafts as they may be subjected to bending or torsional forces, and mild steel can better absorb such loads without breaking. Machinability: Mild steel is known for its excellent machinability, which refers to its ease of being shaped, cut, drilled, and machined. This makes it relatively straightforward to manufacture shafts from mild steel and achieve the desired dimensions and tolerances.

C. Key Material: Stainless Steel

Stainless steel is often considered suitable for keys used in shafts due to its specific properties that make it advantageous for this application. Here are some reasons why stainless steel is commonly used for shaft keys: Corrosion resistance: Stainless steel is highly resistant to corrosion, making it ideal for applications where the key may be exposed to moisture, chemicals, or other corrosive environments. This resistance helps prevent the key from deteriorating or getting stuck due to corrosion, ensuring smooth operation of the shaft. Strength and durability: Stainless steel has excellent strength and durability properties. It can withstand the stresses and loads placed on keys, such as shear forces or torque, without deforming or breaking. This ensures the key can effectively transmit the required power or torque without failure. Wear resistance: Stainless steel has good wear resistance, allowing the key to withstand repeated contact and sliding against mating components, such as keyways in shafts or key slots in gears or pulleys.

This property helps prevent excessive wear or damage to the key and ensures a longer service life. Hygiene and cleanliness: Stainless steel is often chosen for applications where cleanliness is crucial, such as in the food and pharmaceutical industries. Stainless steel keys can be easily cleaned and maintained, reducing the risk of contamination and ensuring compliance with hygiene standards.

V. RESULTS AND DISCUSSION

Motor specifications:

- Power P = 10.56 KW
- Speed N = 1400 rpm

Al 7075 alloy material Properties: From data hand book by Robert L Norton

- Yield strength = 503 MPa
- Ultimate tensile strength = 572 MPa
- Fatigue strength = 97 MPa
- Brinell hardness number = 150

Assuming the output speed N_2 = 350 rpm

Therefore, $i = N_1/N_2 = d_2/d_1 = Z_2/Z_1$

$i = 1400/350 = 4$

Since both pinion and gear are made of same material, pinion is going to be weaker and the design calculations will be based on pinion

$F_t \ \alpha \ (\sigma_d \times y)$

Assume, Z_1 =18 teeth's ………. DHB, Table 12.4(b)

$Z_2 = i \times Z_1 = 3.8 \times 18 = 68.4$ 69 teeth's

□ = 25^o,

$\alpha = 20^o$ FDI

$Z_e = Z/\cos^3\beta = 18/(\cos 25)^3$ ………. DHB, 12.22(a)

$Z_e = 24.1793$

Lewis equation for beam strength of tooth (m_n):

$m_n = 3\sqrt{\frac{2M_tC_w\cos\beta}{\sigma_d CbKYZ}}$ ………. DHB, 12.24(b)

$P = \frac{2\pi N_1 M_t}{60}$

$10.56 \times 10^3 = \frac{2\pi \times 1400 \times M_t}{60}$

$M_t = 72.0289$ N-m

$M_t = 72.0289 \times 10^3$ N-mm

Assume, $K = b/m_n = 15$

$C_v = 0.5$

$C_w = 1.15$

$Y = \pi \times [0.154 - \frac{0.912}{Z_{e1}}]$ ………. DHB, 12.5(d) [Y – Form factor]

$Y = \pi \times [\,0.154 - \frac{0.912}{24.1793}]$

$Y = 0.3653$ mm

$m_n = 3\sqrt{\frac{2 \times 72.0289 \times 10^3 \times 1.15 \times \cos 25}{503 \times 0.5 \times 15 \times 0.3653 \times 18}}$

$m_n = 1.8224$

Standard m_n = 2 mm ………. DHB, Table 12.2

$d_1 = 2 \times \frac{18}{\cos 25}$

$d_1 = 40$ mm

$d_2 = 4 \times 40$

$d_2 = 160$ mm

$b = 15\times2 = 30mm$

Check for b:

$b_{min} = \frac{1.15\pi\times2}{sin25}$ ………. DBH, 12.23(b)

$b_{min} = 17.0973$ mm

$b > b_{min}$

Therefore, face width of the gear is safe.

Check for σ_d:

$F_t = \frac{\sigma_d C_v b Y m_n}{C_w}$ ………. DHB, 12.24(a)

$V = \frac{\pi\times0.04\times1400}{60}$

$V = 2.9321$ m/s

For, V < 5 m/s

$C_v = \frac{4.58}{4.58+v}$ ………. DHB, 12.25(a) [C_v – Velocity factor]

$C_v = \frac{4.58}{4.58+2.9321}$

$C_v = 0.6096$

$F_t = 2M_t/d_1$

$F_t = \frac{2\times72.0289\times103}{40}$

$F_t = 3601.445$ N

$3601.445 = \frac{\sigma_d\times0.6096\times30\times0.3653\times2}{1.15}$

$\sigma_d = 309.9764 < 503$ MPa

Design is safe for allowable tensile stress.

Dynamic load on the gear tooth (F_d):

$F_d = F_t + \frac{K_3V(Cb\cos^2\beta+F_t)cos\beta}{K_3V+\sqrt{Cb\cos^2\beta+F_t}}$ ………. DHB, 12.26(a)

Here, $K_3 = 20.67$

For, V < 13 m/s

$C = \frac{50}{50+\sqrt{200\times v}}$ ………. DHB, 12.19si, Pg 714 [Dynamic factor]

$C = \frac{50}{50+\sqrt{200\times2.9321}}$

C = 673.7080 N/mm [Converted to N/mm]

$F_d = 3601.445 + \frac{20.67\times2.9321\times(673.7080\times30\times\cos^2 25+3601.445)\times cos25}{20.67\times2.9321+\sqrt{673.7080\times30\times\cos^2 25+3601.445}}$

$F_d = 9074.8932$ N

Dynamic strength of the gear (F_s):

$F_s = 1.25\times F_d$ ………… DHB, 12.13(b)

$F_s = 1.25\times9074.8932$

$F_s = 11.3436\times10^3$ N

$F_s > F_d$

The limiting load for wear (F_w):

$F_w = \frac{d_1 bQK}{\cos^2\beta}$ ………. DHB, 12.26(c)

Where, Q is ratio factor

$Q = \frac{2d_2}{d_2+d_1} = \frac{2Z_2}{Z_2+Z_1}$

$Q = \frac{2\times160}{160+40}$

Q = 1.6

Where, K is load-stress factor

Since we do not have data for σ_{en} and K for the material taken

The design might fail due to wear

To keep it safe we have,

$F_w >= F_d$

$\frac{d_1 bQK}{\cos^2 \beta} >= F_d$

$\frac{40\times30\times1.6\times K}{\cos^2 25} >= 9074.8932$ N

K >= 3.8823

Therefore, the design will be safe if the load-stress factor (K) for the material used must be greater than or equal to 3.8823 and the BHN value of the material should be increased.

Standard tooth proportions of involute helical gears:

Addendum $h_a = m_n$

$h_a = 2$ mm

Dedendum $h_f = 1.25m_n$

$h_f = 1.25\times2$

$h_f = 2.5$ mm

Tooth thickness $t = 1.5708\times m_n$

t = 1.5708×2

t = 3.1416 mm

Clearance = $0.25\times m_n$ = 0.25×2

Clearance = 0.5 mm

Centre distance $a = \left[\frac{Z_1+Z_2}{2}\right] \times \frac{m_n}{cos\beta}$ ………. DHB, 12.20

$a = \left[\frac{18+72}{2}\right] \times \frac{2}{cos25}$

a = 100 mm

Table 1 Result of 6 gear sets

Gear set	i	N_1 in rpm	N_2 in rpm	d_1 in mm	d_2 in mm	Z_1	Z_2
1	4	1400	350	40	160	18	72
2	2.44	1400	573.77	58	142	26	64
3	1.38	1400	1014.49	84	116	38	52
4	1	1400	1400	100	100	45	45
5	0.6667	1400	2100	120	80	54	36
6	0.4285	1400	3267.21	140	60	63	27

Design of shaft:

Mild steel material properties:

- Yield strength = 250 MPa
- Ultimate strength = 400-550 MPa
- Youngs modulus of elasticity = 200 GPa
- Brinell hardness number = 120

Assuming, the length of the shaft

l = 300 mm

Assuming, Factor of safety n = 2

Therefore, by the definition of FOS:

$$n = \frac{Yield\ stress}{Design\ stress} = \frac{\sigma_y}{\sigma_d}$$

$$2 = \frac{250}{\sigma_d}$$

$$\sigma_d = 125 \text{ MPa}$$

We know the relation between Shear stress and allowable or design stress,

i.e., $\tau_d = 0.5 \times \sigma_d$

Therefore, $\tau_d = 0.5 \times 125$

$$\tau_d = 62.5 \text{ MPa}$$

To find the torque:

$$T = \frac{9.55 \times 10^3 \times P}{N} \quad \text{………. DHB, 3.3(a)}$$

$$T = \frac{9.55 \times 10^3 \times 10.56}{1400}$$

$$T = 72.0342 \times 10^3 \text{ N-mm}$$

To find the diameter:

$$\tau_d = \frac{Tc}{J} = \frac{16T}{\pi d^3} \quad \text{………. DHB, 3.1}$$

$$62.5 = \frac{16 \times 72.0342 \times 10^3}{\pi \times d^3}$$

$$d = 18.0342 \text{ mm}$$

Standard diameter $d = 20$ mm ………. DHB, table 3.5(a)

Design of key:

The face width of the rectangular key

$$b = \frac{1}{4} \times d \quad \text{………. DHB, 4.2(a)}$$

Where, d is the diameter of the shaft

$$b = \frac{1}{4} \times 20$$

$$b = 5 \text{ mm}$$

The height of the rectangular key

$$h = \frac{1}{6} \times d \quad \text{………. DHB, 4.2(b)}$$

Where, d is the diameter of the shaft

$$h = \frac{1}{6} \times 20$$

$$h = 3.3333 \text{ mm}$$

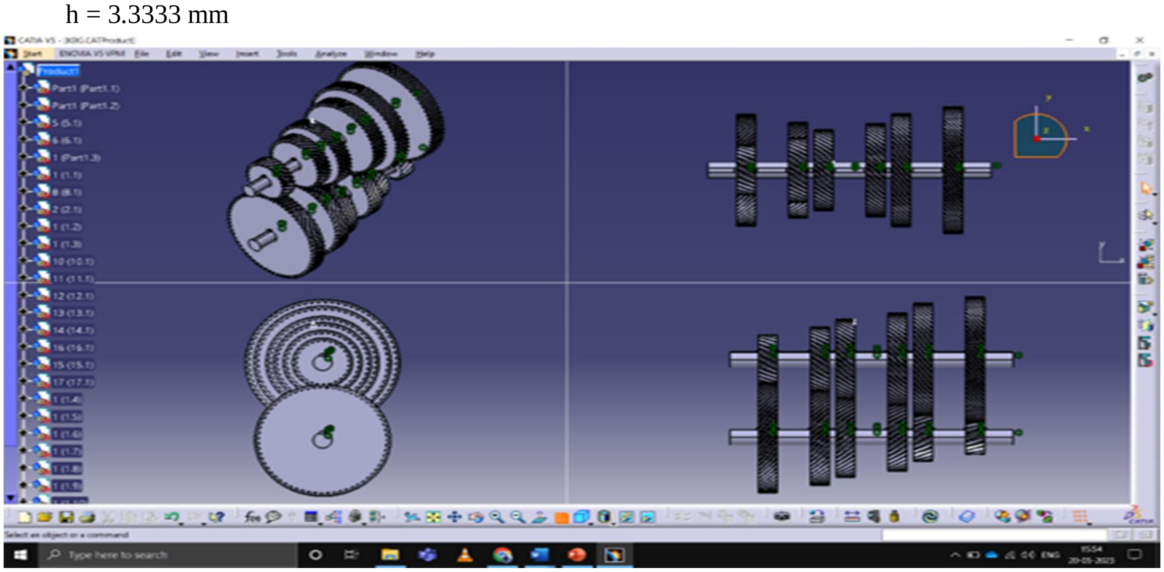

Fig 2 Assembly of gearbox in different views

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VI. ANALYSIS OF GEARS USING ANSYS WORKBENCH

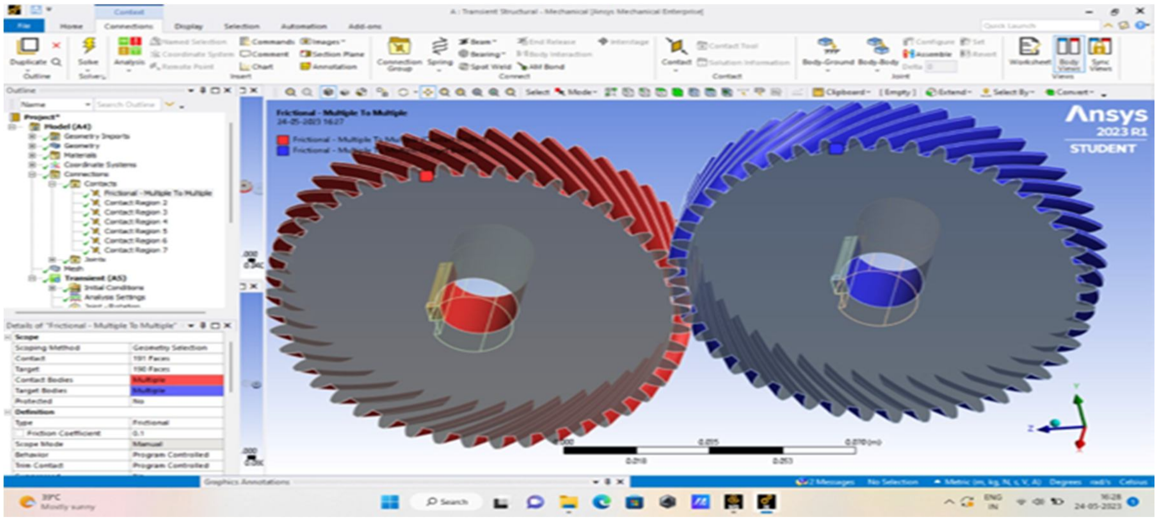

Fig 3 Contact area of the gear set

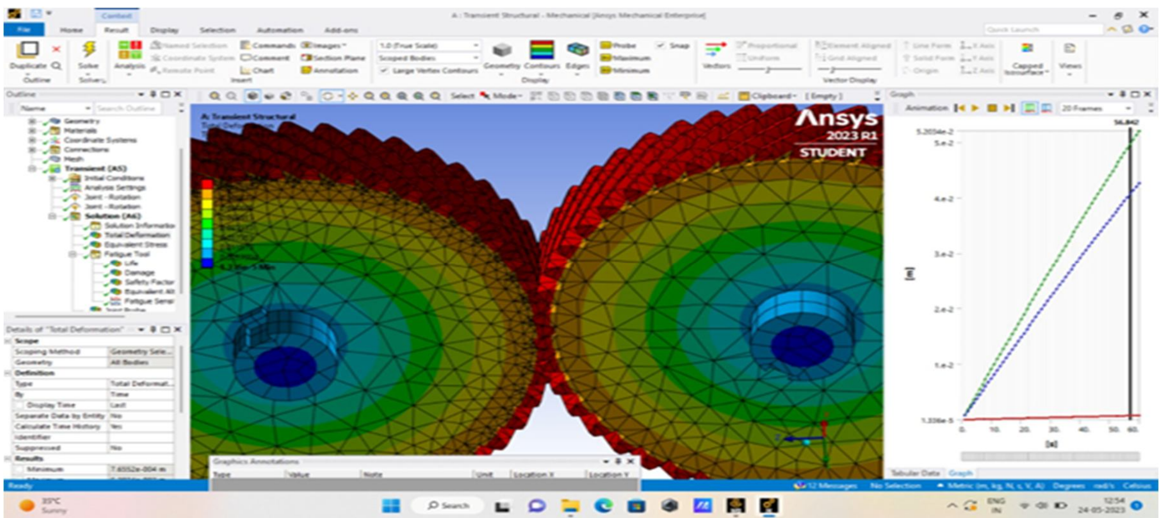

Fig 4 Meshing of gear teeth's

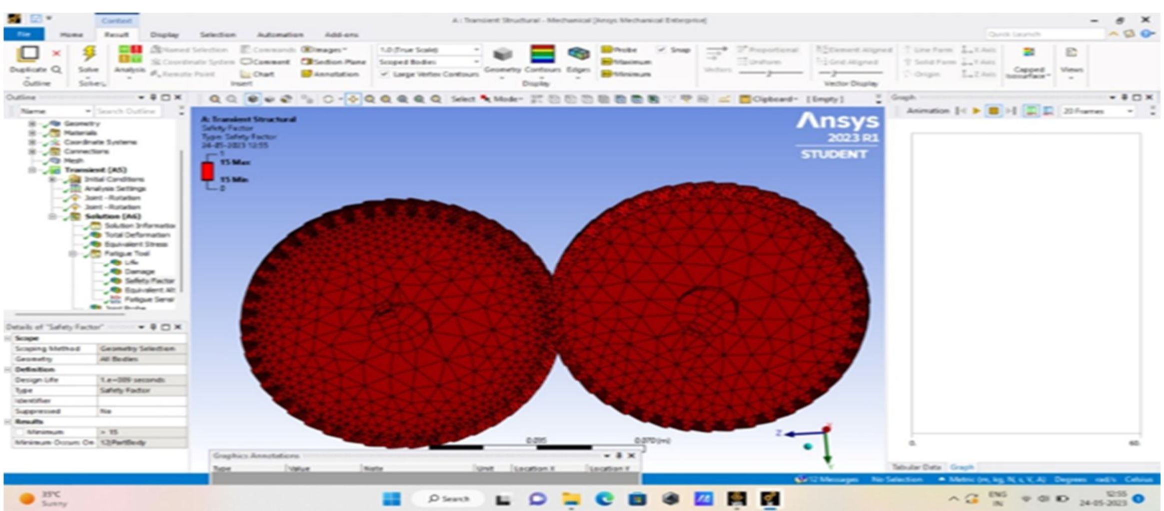

Fig 5 Safety Factor

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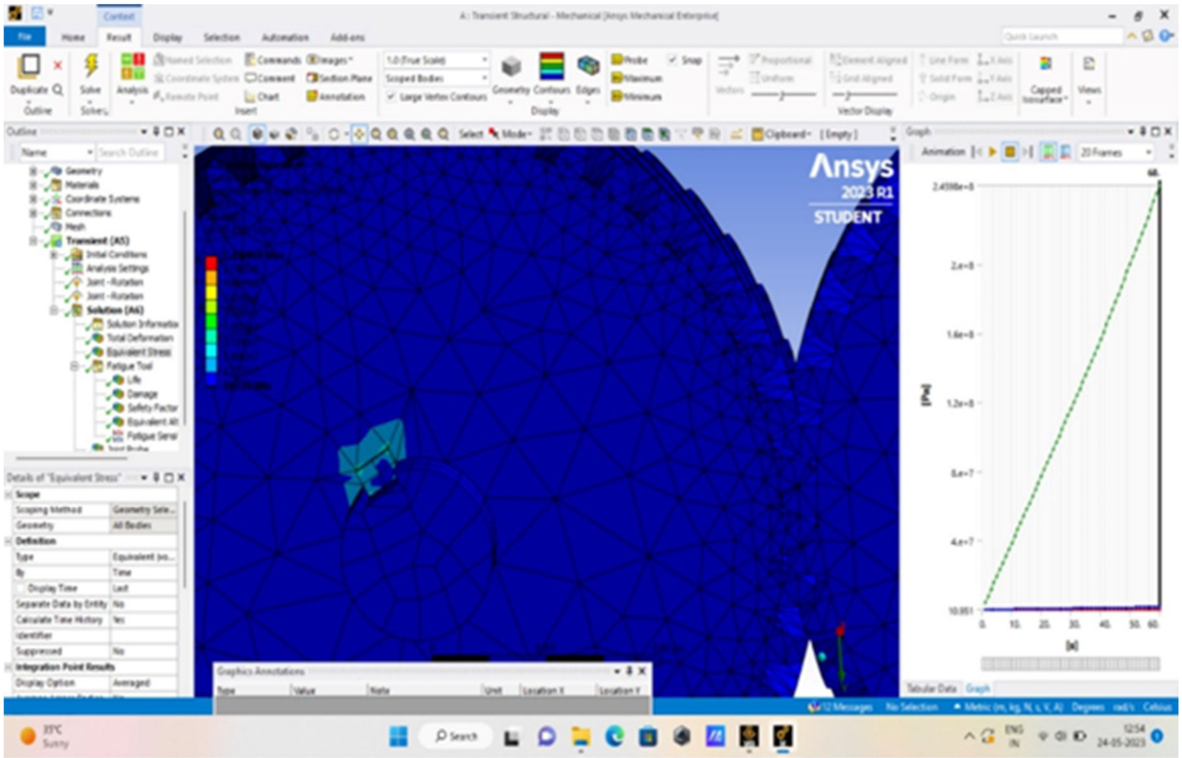

Fig 6 Equivalent Stress (Von Mises)

As per the above analysis which is made in ANSYS the following results are obtained:

1) Safety factor: The safety factor is greater than 1.5.
2) Maximum shear stress:
3) Minimum value = 391.84 Pa
a) Maximum value = 1.382×10^{8} Pa
4) Equivalent stress (Von Mises):
a) Minimum value = 682.09 Pa
b) Maximum value = 2.459×10^{8} Pa
5) Total deformation:
a) Minimum value = 0.00076 m
b) Maximum value = 0.05203 m

Therefore, the correlation between the theoretical and analytical results are compared in the following table shown below:

Table 2 Correlation table

SL NO	Details	Theoretical value	Analytical value
1	Safety Factor	2	Greater than 1.5
2	Maximum Shear Stress	251.5×10^{3} Pa	Min = 391.84 Pa Max = 1.382×10^{8} Pa
3	Equivalent Stress (Von Mises)	1.33×10^{6} Pa	Min = 682.09 Pa Max = 2.459×10^{8} Pa

VII. CONCLUSION

Firstly, Al 7075 alloy is a high-strength material known for its excellent mechanical properties, including high tensile and yield strength, which make it suitable for demanding applications like gearbox gears. This alloy's superior strength-to-weight ratio contributes to the overall efficiency and performance of the gearbox.

Secondly, the six-speed configuration provides a wide range of gear ratios, allowing for optimal power transfer and torque distribution across various driving conditions. This versatility enhances the vehicle's performance, responsiveness, and fuel efficiency. Moreover, the constant mesh design ensures smoother gear shifting operations, reducing the likelihood of gear grinding and damage. This promotes driver comfort and prolongs the lifespan of the gearbox. Additionally, Al 7075 alloy exhibits good wear resistance and fatigue strength, essential qualities for a gear material subjected to repetitive loads and contact stresses during operation. These characteristics enhance the durability and reliability of the gearbox, reducing the likelihood of gear failure and maintenance requirements. However, it is worth noting that Al 7075 alloy may have some limitations. While it offers excellent strength properties, it may not possess the same level of toughness and ductility as some other gear materials. Therefore, proper design considerations, such as adequate tooth profiles and load distribution, should be taken into account to mitigate potential stress concentrations and prevent premature failure.

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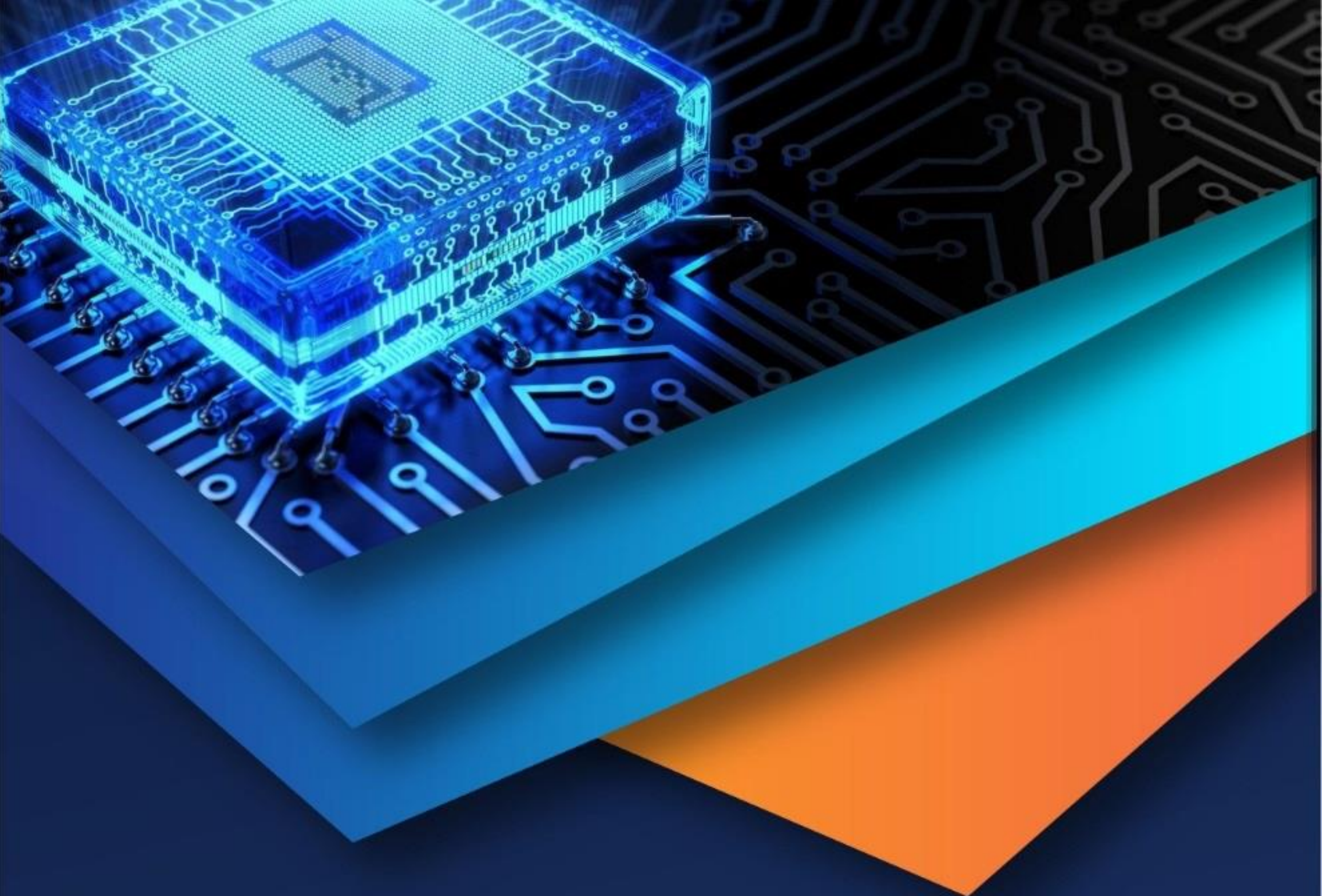

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