Design And Analysis Of 9 Speed Gearbox

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Abstract- To transmit torque from rotating power source to another device gears or gear trains are used. There are different types of gears such as spur gear, helical gear, double helical gear, bevel gear, crown gear, hypoid gear, worm gear, rack and pinion, epicyclical gear, etc.[4]Designing of gear is such a vast and critical process that whole research coverage in such work is very difficult. To provide speed and torque conversion to output shaft from rotating source, the gearbox is used. Multispeed gearboxes are used in the applications where frequent changes in speed or torque at the output shaft are required. The transmission of motion and power from the input source to output is possible due to the meshing of teeth of the gears. This paper consists of designing of 9 speed gearbox and the procedure for calculating the number of teeth on gear including structure and ray diagram. [3]For analysis, the gearbox assembly is created in CATIA and the .igs file is exported to ANSYS. Also deformation is attained as the gear efficiency depends on the deformation. The result shows that the deformation and maximum stresses are under safe limits.

Index terms: 9 speed, gearbox, speed variation, spur gear, methodology

I. INTRODUCTION

In mechanical Engineering applications, mostly the power is transmitted with the help of gears. There is a wide range of gears for various applications such as very minute gears for wristwatches and there are also very large gears that are used in ships, trucks, and the equipment used for mining. In many pieces of machinery such as automobiles, washing machines, blenders, construction equipment, fuel pump, mills, mining engines, etc.; gears are a vital element of mechanism. Toothed headgears are used to change the direction, speed, and power between input and output shaft.

When you see the inner construction of the gearbox, you will observe that it is very simple. It consists of two gears coupled with each other mounted on two different shafts. The gear may be spur, bevel, worm or helical. For gear reduction the diameter of input gear must be smaller than the diameter of the output gear. If an only change in direction is required then the size of the gear may be the same. Spur gears are used for heavy load applications, but they are noisy in operation. Due to gradual engagement, helical gears are used silent in operation. Hence they are used for light-load applications. If a change of plane of rotation is required then hypoid gears are used. [3]

In the power transmission system, the controlled application of power is provided by the transmission mechanism. Transmission refers to the gearbox, which is used to provide speed and torque conversion from a rotating power source to another device with the help of gear and gear trains. In automobiles the output of the internal combustion engine is provided to the drive wheel with the help of a transmission mechanism. Such an engine needs to operate at relatively high speed which is not appropriate for starting, stopping, and slow travel. By increasing the torque, the gearbox reduces the higher engine speed to lower engine wheel speed. Also on pedal bicycles, large machines, and where different speed and torque are required, transmissions are used. [3]

The source of rotary motion having higher angular momentum and lower torque is converted into higher torque with the help of gears. This high torque is necessary for the performance of the work. This phenomenon of increasing torque is called gear reduction which is brought by coupling of large gear called gear with small gear called the pinion. This means, the speed of output shaft of the gearbox is less than the speed of input shaft of the gearbox, and this reduction results in mechanical advantage i.e. increase in torque, which results in a reduction of torque at the cost of angular momentum. This type of gearbox is called a reducer. The gearbox can be structure to act as the exact opposite such as to give a large speed with a decrease of torque. Some of the simplest gearboxes merely change the physical rotational direction of power transmission. Another use of gearbox is to change the axis of the rotary motion of a plane with or without gear reduction. [4]

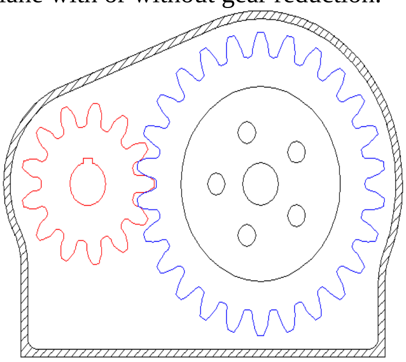


Fig. 1 Gear Arrangement

The gearbox has variously used in agricultural, industrial, constructional, mining, and automotive equipment, etc. and to maximize its efficiency gearbox with 8-speed variation is used. The highly effective 9-speed gearbox has many benefits. The most important benefit is an increase in fuel efficiency. Another benefit is a fast locking torque converter that allows for quick engagement and limited-slip. This results in less wear and tear on the clutches inside the unit and longer life. An additional benefit is that it provides smooth shifts that happen so quickly that they often sensed by the driver. In Automobiles, the gearbox is mainly used to supply the power to wheels from the engine through the differential. The differential is also a combination of gears. [3]

II. PROBLEM DEFINITION

It is being observed that all the hype in the automobile industry is about the huge improvement in the efficiency of the vehicles being produced. You can see that the companies have been spending so much time and money on developing the transmission that maximizes efficiency because customers have fuel economy at the top in their checklist.

The 9-speed transmission system helps to improve the efficiency of the transmission as compared to the 5-speed transmission system and 6-speed transmission systems. It also gives 9 different speed variations. The advancement in the transmission system of modern-day cars being produced is a major benefit to car enthusiasts of all types. This can handle a significant amount of torque and power and offer an unparalleled fuel economy. These are certainly a small step in the direction for increasing the efficiency of the transmission.

III. CALCULATIONS

For Design of gearbox between the speeds range 110 RPM to 1120 RPM with 9 numbers of steps for 15 KW power, the methodology [5] is,

STEP – 1: Material Selection:

Some factors are to be considered while choosing the gear material. The main three factors are strength, durability, and cost. The cost includes the cost of the material and the cost of manufacturing. The importance of these factors is different for different projects. The main factor of material selection for gear is getting the correct combination of physical properties that fulfill the requirements of the gearbox at a low cost. [1]

Gears can be manufactured of various materials used for gear making, some of them are steel, brass, bronze, cast iron, ductile iron, aluminum, powdered metals, and plastics. But the Steel is the most commonly used material for gearbox manufacturing. [2] Mostly steel is used for making gear because of advantages such as high resistance to wear and the ability to increase the physical properties by the use of various heat treatment.

Material for pinion:

‘15 Ni 2 Cr 1 Mo 15’

Bending stress = 3200 kgf/cm^2

Crushing stress = 9500 kgf/cm^2

Material for gear:

‘15 Ni 2 Cr 1 Mo 15'

Bending stress = 1400 kgf/cm^2

Crushing stress = 5000 kgf/cm^2

STEP – 2: Calculation of Step ratio or speed progression ratio:

$$(N_{max} / N_{min}) = \phi^{n-1}$$

$$\Phi = 1.34$$

Since it is not standard value, we have to find out the multiple standard values which come close to the calculated step ratio.

1.6 – cannot be used
1.25 – cannot be used
1.12 – 1.12 * 1.12 = 1.254
1.06 – 1.06 * 1.06 * 1.06 * 1.06 = 1.338

Multiple of 1.06 gives nearest value of 1.34. As 1.06 is multiplied 4 times we skip 4 speeds. Hence standard ϕ value is 1.06 and R40 series is selected.

STEP – 3: Selection of speeds in RPM:

N_1	110
N_2	200
N_3	355
N_4	630
N_5	150
N_6	265
N_7	475
N_8	850
N_9	1120

Table No. 1 Selection of speeds

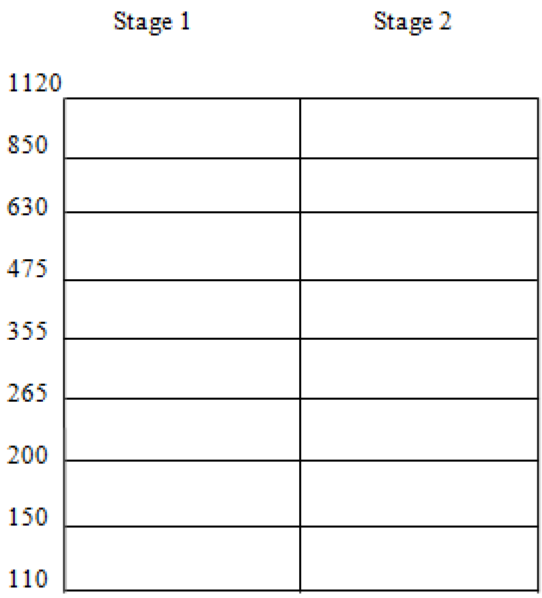
STEP – 4: Structural formula and Ray Diagram:

Structural Formula: The structural formula for the 9-speed gearbox is,

3 (1) 3 (3)

Stage 1: Single input speed is divided into three different speeds according to user requirements.
Stage 2- 3 input is split into 9 speeds i.e. each input is split into 3 speeds.

Ray Diagram: This diagram is used to represent the structural formula. It gives information like the speed of gear in each stage, transmission ratio for each stage, and the total number of speeds.
The ray diagram is drawn as,



Selected speeds are 110, 150, 200, 265, 355, 475, 630, 850, and 1120. Let us group the output speeds into 3 since the structural formula is,

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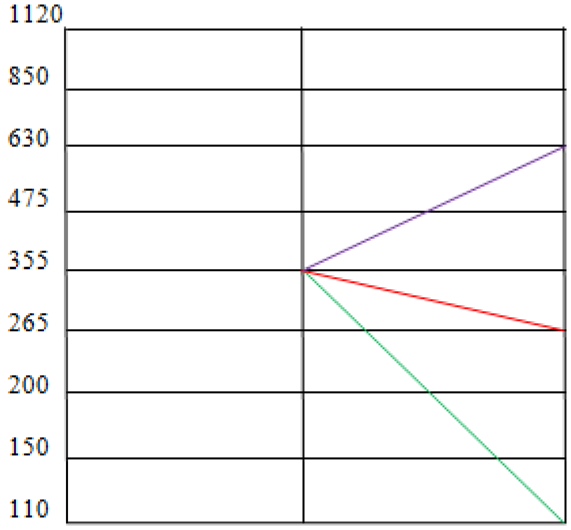
[3 (1) 3 (3)]

Now let's select the input speed of stage 2. Two following condition should be satisfied for that input speed.

$(N_{min} / N_{input}) > 0.25$

$(N_{max} / N_{input}) < 2$

Stage- 2

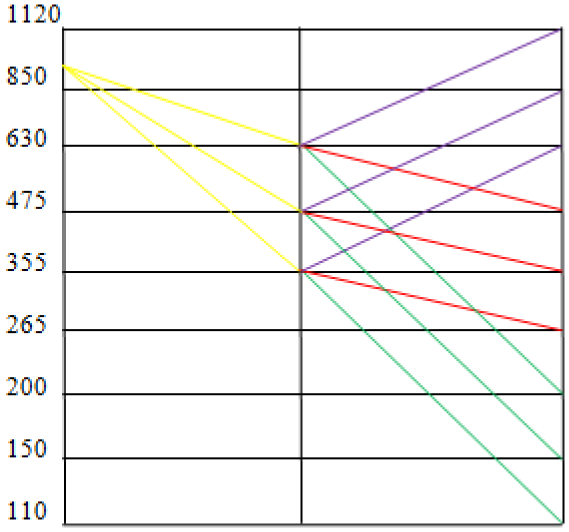


$(N_{min} / N_{input}) = 110 / 355 = 0.30 > 0.25$

$(N_{max} / N_{input}) = 630 / 355 = 1.77 < 2$

The Conditions are satisfied.

Stage- 2



$(N_{min} / N_{input}) = 355 / 1000 = 0.355 > 0.25$

$(N_{max} / N_{input}) = 630 /1000 = 0.63 < 2$

The Conditions are satisfied.

STEP – 5: Kinematic Arrangement:

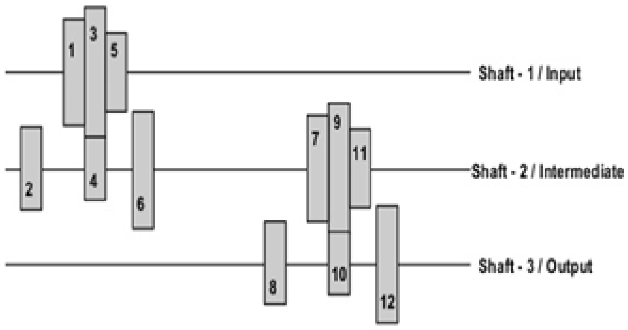


Fig. 2 kinematic arrangement

Step – 6: Calculation of the number of teeth:

For calculating the number of teeth on gear pair we assume that the number of teeth on driver gear is 22. We used formulas as follows,

1. $(N_{pinion} / N_{gear}) = (Z_{gear} / Z_{pinion})$
2. $Z_5 + Z_6 = Z_3 + Z_4 = Z_3 + Z_4$
3. $Z_7 + Z_8 = Z_9 + Z_{10} = Z_{11} + Z_{12}$

Gears	Teeth's
1	28
2	56
3	40
4	44
5	22
6	62
7	42
8	52
9	62
10	32
11	22
12	72

Table No. 2 Number of teeth's

Step 7: Calculation of Diameter:

The diameters of gears are found out by using the relation,

$$d = m * Z$$

Where,

d = diameter of gear
m = module (4 mm)……from calculation
Z = number of teeth

Gears	Diameter in mm
1	112
2	224
3	160
4	176
5	220
6	248
7	168
8	208
9	248
10	128
11	88
12	288

Table No. 3 Diameter of gears

Step 7: Diameter of shaft:

From the calculation, we have found diameters of shafts are,

Shaft	Diameter in mm
1	30
2	40
3	60

Table No. 4 Diameter of Shaft's

IV. IMPLEMENTATION

Certain parameters must be considered for selecting the gearbox for different applications in the industry. Some of them are [1],

- Gear ratio
- Output torque
- Maximum input power
- Maximum input speed
- Gearing arrangement
- Reducer output
- Shaft Alignment

Standard Spur Gear: The Fig. 3 shows the meshing of standard spur gears. The meshing of standard spur gears means the reference circles of each gear come in contact and roll with each other. Below formula for the calculation is shown in table no.5

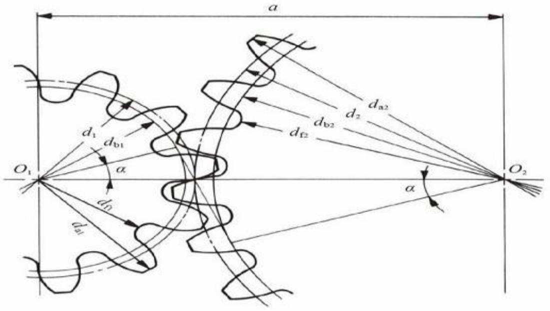


Fig. 3 Meshing of spur gears

No.	Item	Symbol	Formula	Example	
				Pinion (1)	Gear (2)
1	Module	m	Set Value	4 mm	
2	Pressure Angle	ϕ		20^0	
3	Number of Teeth	Z		28	56
4	Center Distance	CD	(z1 + z2) m / 2	168 mm	
5	Reference Diameter	d	Z * m	112 mm	224 mm
7	Addendum	a	1.00m	4 mm	4 mm
8	Tooth Depth	H	2.25m	9 mm	9 mm
9	Tip Diameter	d_a	d + 2m	120 mm	232 mm
10	Root Diameter	d_f	d – 2.5m	102 mm	214 mm

Table No. 5 Calculation for standard spur gear

V. METHODOLOGY

Step 1: Assembly Creation - First of all we created our gearbox assembly in CATIA and saved the file in .igs format, to export it into ANSYS workbench environment.

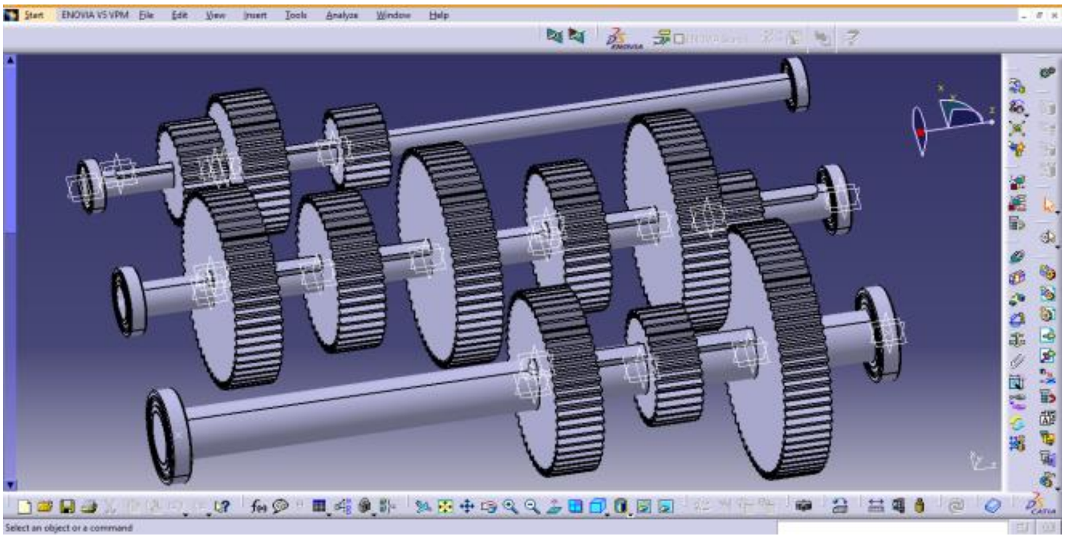


Fig. 4 Design of Gearbox

Step 2: Meshing - Meshing is applied to the assembly to get accurate results.

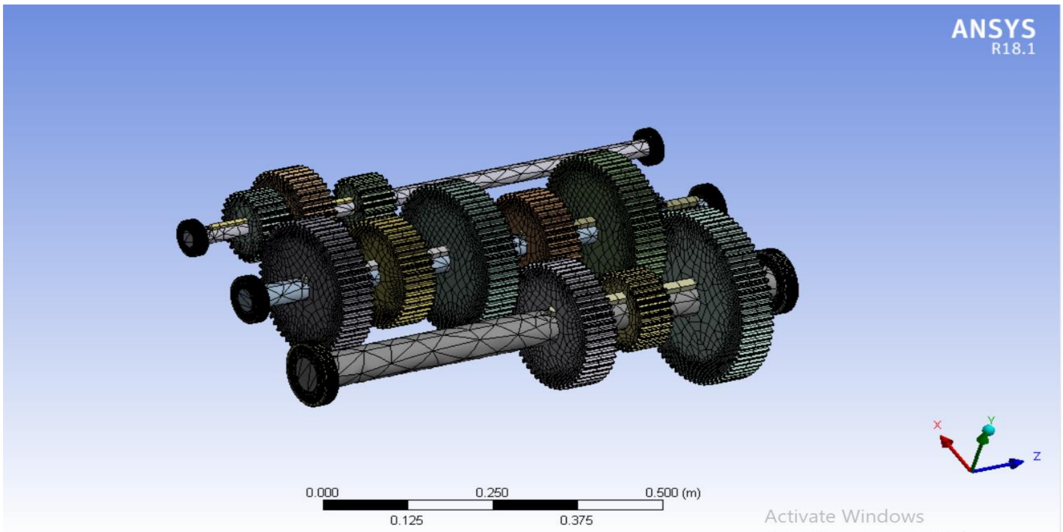


Fig. 5 Meshing

Step 3: Boundary Conditions - Boundary conditions are a necessary part of finite element analysis. So here the moment of 206.65 Nm is applied as driving torque.

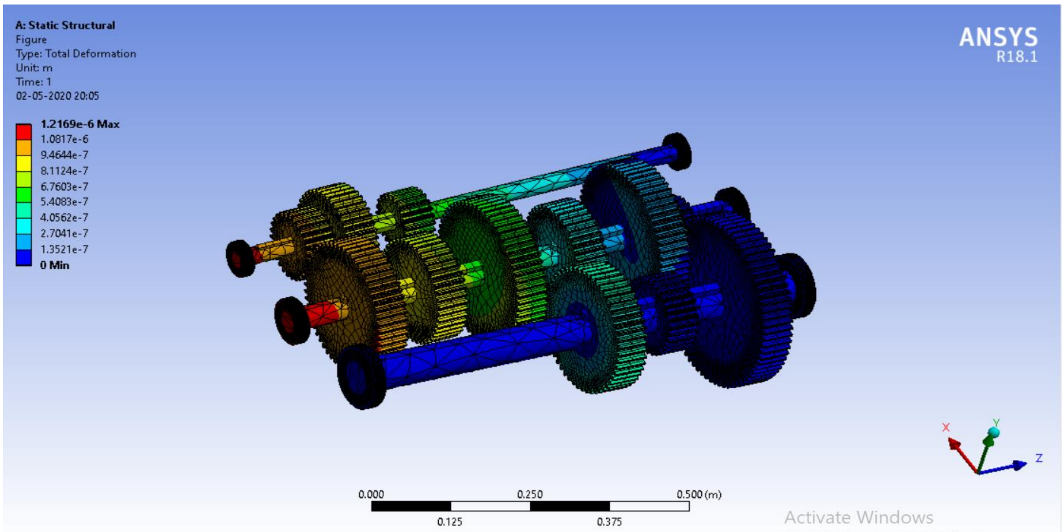


Fig. 6 Total Deformation

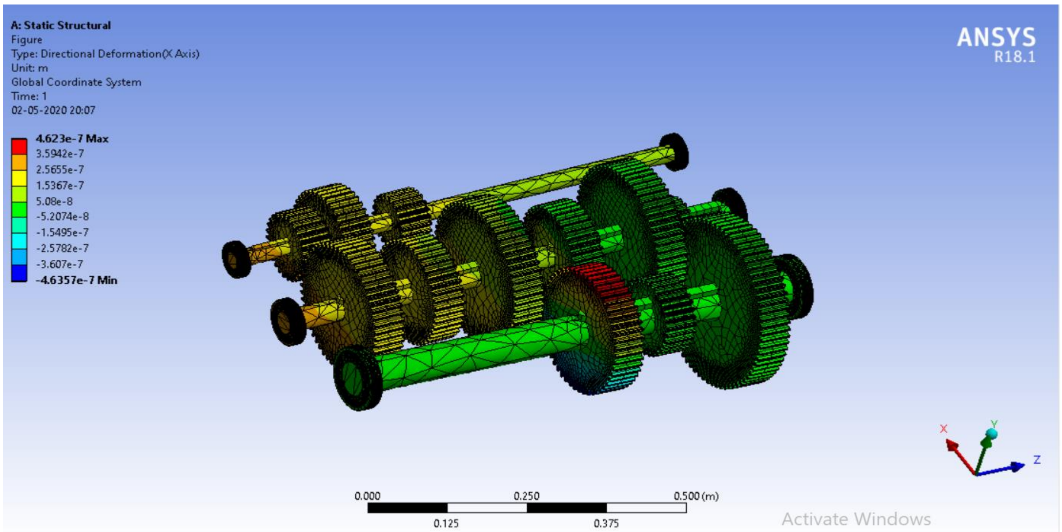


Fig. 7 Directional Deformation

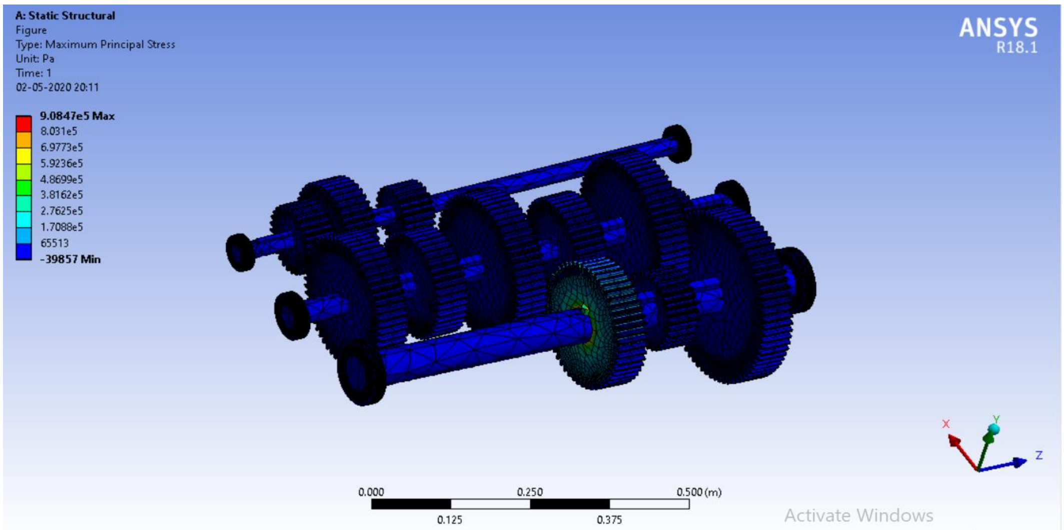


Fig. 8 Maximum principle stress

VI. RESULTS

Results	Total Deformation	Directional Deformation	Max. Principle Stress
Maximum value	1.2169e-6 m	4.623e-7 m	9.0847e5 Pa
Minimum value	0	-4.6357e-7 m	-39857

Table No. 6 Results

VII. CONCLUSION

Lastly, we concluded that as per the design criteria, we have designed the gearbox and the design made by us is safe and satisfactory and can be proceeded with the production process. Also the stepwise solution of the present work would be beneficial as per an aspect of time and reducing complexity for designing the gearbox. The ray diagrams are used to make the design more feasible concerning the number of teeth used in gearbox and transmission ratio.

The analysis shows that the gearbox can carry maximum stresses and deformation under the safety zone. Based on the results, spur gear with a higher module is preferred if a large amount of power is required to transmit.

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