WEIGHT REDUCTION OF PLANETARY GEARBOX PEDESTAL USING FINITE ELEMENT ANALYSIS

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Abstract

Planetary gearboxes are widely used in machineries and machine tools to obtain high speed reduction. In this project the planetary gearbox used in winch application is analysed for weight reduction using finite element analysis. The analysis for weight reduction is carried out on two major components of the assembly, pedestal and planet carrier. As the manufacturers focused on weight reduction in the components without affecting the performance in the products in order to reduce cost and sustain in the market.

In this analysis the assembly of gearbox is constructed as solid model, the forces and torques are found using hand calculations and verified using Adams results. The model is meshed and finite element model is generated initially. The FE model is imported to Ansys and FE analysis is conducted by providing the forces and boundary conditions to the pedestal. The results of von-Mises stress and deflections are obtained for existing model, based on the results with size modifications three different models were developed and analysis is conducted without changing the loads and boundary conditions using the design constrains the results were refined. The material used is IS:2062 Gr-A and compared its yield strength with the induced von-Mises stress and identified that the modified design is safe.

Based on the results of static analysis, a new model with the change of geometry without affecting the performance is developed with weight reduction. It was found that the proposed design of pedestal gives sufficient improvement over existing designs. The recommended weight reduction in pedestal is 40.8kg with 13.1% weight reduction.

Keywords*:Planetary Gear Box, Winch, Pedestal, Planet Carrier, Weight reduction*

Nomenclature

F	Force
T	Torque
Zs	Number of teeth in gear
Ns	rpm of gear
f	Frequency
ω	Angular velocity
θ	Angle
g	Acceleration due to gravity
P	Pressure
A	Angular acceleration
E	Young's modulus
S	Factor of safety
σ	Stress
δ	Deflection

Abbreviations

3D	Three-Dimensional
AGMA	American Gear Manufacturer Association
CAD	Computer Aided Design
CG	Centre of Gravity
CPM	Cycles per minute
FE	Finite Element
FEM	Finite Element Modeling
FEA	Finite Element Analysis
FOS	Factor of Safety
DOF	Degrees of freedom
PCD	Pitch Circle Diameter
RPM	Revolution Per Minute

1 INTRODUCTION

Planetary gearbox is used in machineries and machine tools to obtain speed reduction, which in turn increases the torque. These gearboxes are used in many applications such as automatic automobile transmissions and hybrid transmission systems. The construction of planetary gearbox is such that, it has the sun gear in the middle and it is meshed with one or more planet gears. The planet gear is in turn meshed with the ring gear. The sun gear and planet gears are together placed inside the carrier. Of late, to sustain in the market, the manufacturer has to produce their products in less weight.

The recent advances in mechanics and computational techniques have provided the capabilities of reducing the weight of the product using finite element analysis [1, 2]. In this paper, weight reduction in the pedestal and planet carrier of planetary gearbox has been carried out using finite element analysis. The gearbox is used in winch application. Winch is a mechanical device powered by planetary gear reduction system for hauling or pulling. The exploded view of the gearbox assembly is shown in Figure 1. Manufacturers focus is on weight reduction along with the high performance in the products. Finite element (FE) analysis provides the most effective solution [3, 4]. In this analysis, the assembly of gearbox is constructed as solid model and the model is meshed for FE analysis. FE analysis was carried out by providing the forces and boundary conditions. The stress distribution and deflection plots obtained from FE analysis are described in this paper. The new model with the change of geometry were developed and validated by comparing and verifying the results.

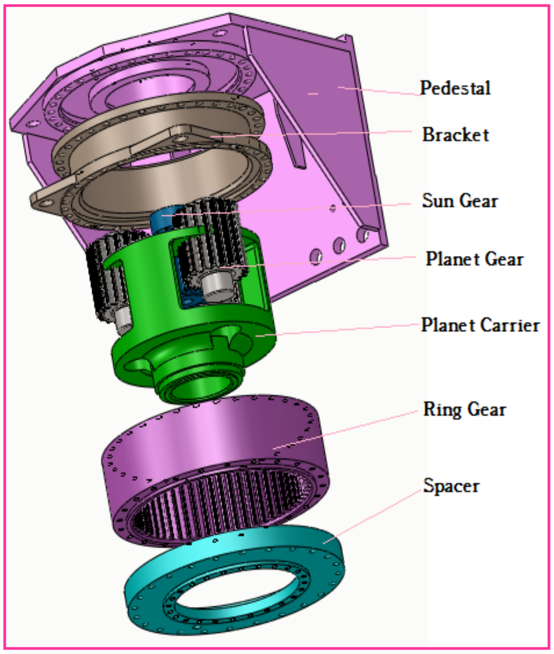

Fig. 1 Exploded View of Gearbox Assembly

2. PROBLEM DEFINITION

The traditional method of designing involves over design of components in order to reduce the risk of failure of component during its function. This results in design of component with heavier weight and high factor of safety, which in turn results in high production cost. The advances in FE techniques help to design the component with appropriate weight by reducing the material and manufacturing cost without affecting the function. In this paper, FE analysis is conducted for the planetary gearbox used in winch application, manufactured at Magtorq Private Limited, Hosur. The static analysis has been carried out on pedestal and planet carrier.

3. PLANET CARRIER AND PEDESTAL

3.1 Planet Carrier

The function of the planet carrier is to hold one or more peripheral planet gears of the same size, meshed with the sun gear and ring gear. The weight reduction is focused on the planer carrier (Figure 2) as the raw material cost is 1.5 % of overall raw material cost of gearbox [5].

Fig. 2 Planet Carrier of the Gear Box

3.2 Pedestal

The pedestal is the static member used to hold and support the entire gearbox assembly. The gearbox assembly is fixed to the pedestal using clamping bolts and the pedestal is fixed on to the winch using the clamping bolts. The Figure 3 shows the pedestal used in gearbox.

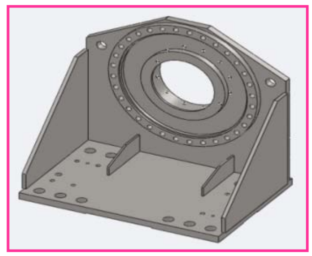

Fig. 3 Pedestal used in Gearbox

4. MATHEMATICAL MODELLING

The planetary gearbox comprises of sun gear, planet gear and ring gear. The gears [6] used in the assembly is manufactured with the following technical specifications and overall operating condition of gearbox is shown in Table 1.

Table 1. Technical Specification of Gearbox

Gear / Parameter	Sun	Planet	Ring
Number of teeth	17	19	55
Pitch circle diameter	153	171	495
Root diameter	137.7	156.6	540.9
Module	9	9	9
Pressure angle	20°	20°	20°
Face width	180	186	180
Addendum modification	0.40	0.45	-1.3
Gear material	: 18CrNiMo7 – 6		

Rated power	: 22kw
Gear ratio	: 452:1
Pinion torque	: 123000Nm
Driving rpm	: 988

From the data obtained from the technical specification of gear box as shown in the Table 1, the rpm of the sun gear can be found out by finding the gear ratio for the particular or present stage (P_r) as given in equation 1.

$$\text{Ratio } (P_r) = \frac{Nr}{Ns} + 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where, Nr = Number of teeth in ring gear

Ns = Number of teeth in sun gear

From equation 1, the gear ratio of present stage was calculated to be 4.23.

The difference in the gear ratio (R_d) is given by

$$\text{Ratio difference}(R_d) = \frac{F_r}{P_r} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where, F_r = Final gear ratio

P_r = Present gear ratio

From equation 2, the ratio difference was found to be 106.85.

Also, the rpm of sun gear can be found by the equation

$$\text{Sun gear rpm} = \frac{I_{rpm}}{R_d} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where, I_{rpm} = Input rpm

R_d = Ratio difference

The sun gear rpm was calculated to be 9.24 rpm from equation 3.

The torque generated by the sun gear is given by

$$\text{Torque in sun gear} = P / \omega \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where, P = Output power

ω= Angular velocity

Calculate torque generated by the sun gear was 22736.42 Nm

5. FINITE ELEMENT MODELLING

The finite element model for the analysis was generated using Hypermesh. 3D element used for the analysis is Solid 92. The details of the element are shown in Table 2. The other element used in finite element modeling is Mass 21 and rigid elements.

Table 2. Property of 3D element used in FEM

Element Type	Solid92-3-D 10-Node Tetrahedral structural
Behavior	Quadratic displacement behavior
Element definition	Ten nodes having three degrees of freedom at each node
Element capabilities	The element also has plasticity, creep, swelling, stress stiffening, large deflection and large strain capabilities

The meshed model of the pedestal and planet carrier is shown in Figure 4 and Figure 5 respectively.

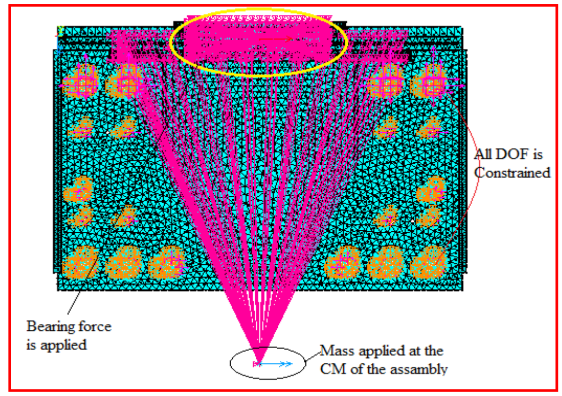

Fig. 4 Meshed Model of Pedestal

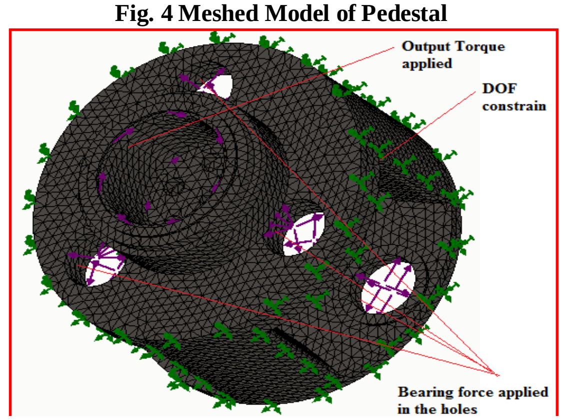

Fig. 5 Meshed Model of Planet Carrier

6. RESULTS AND DISCUSSIONS

Static analysis was carried out for the weight reduction. Initially, the analysis was carried out for the existing model of the pedestal. von-Mises stress plot observed for the existing model as shown in Figure 6. The maximum von-Mises stress was found to be 125.82MPa and the deflection at the region of bearing fixed was observed to be 0.07mm (Figure 7).

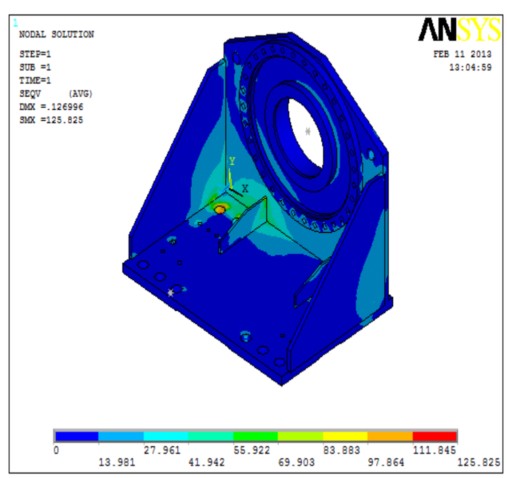

Fig. 6 von-Mises Stress in Pedestal Existing Design

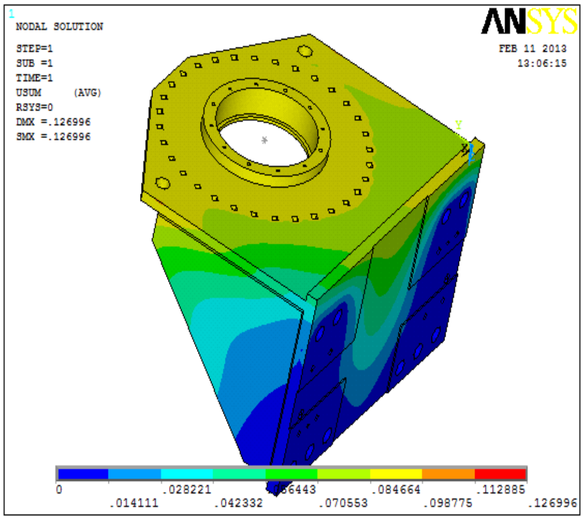

Fig. 7 Deflection in Pedestal Existing Design

Three different iterations were carried out for pedestal in static analysis. The size has been varied by keeping loads and boundary conditions constant. The results obtained using these conditions are shown in Figure 8 and Figure 9 respectively.

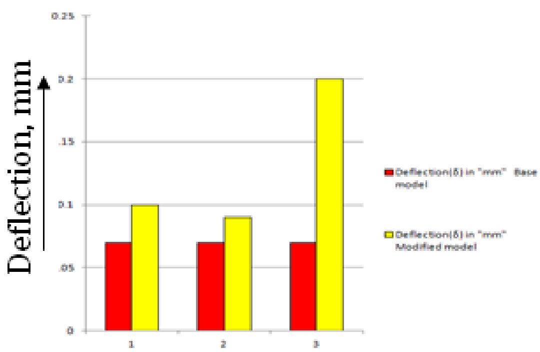

Fig. 8 Deflection Result Comparison

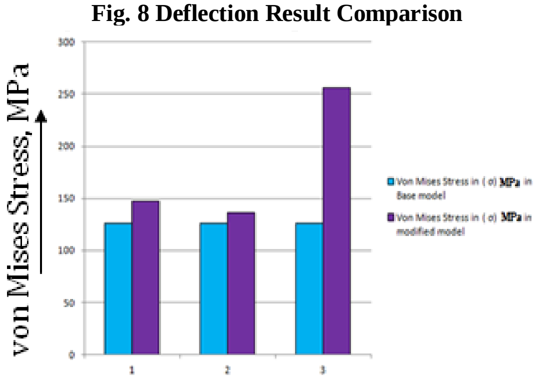

Fig. 9 von-Mises Stress Result Comparison

Table 3 gives the comparision of stress, deflection and weight obtained in existing model and three different modified model.

Table 3. Comparison of Static Analysis Result

Parameters	Existing	Modified-1	Modified-2	Modified-3
Deflection	0.07	0.13	0.09	0.2
Stress	125.82	147.58	136.54	256.65
Weight	304	254.83	270.18	209.24

7. CONCLUSIONS

By comparing the results obtained from the finite element analysis, the modified model 2 showed good results with von-Mises stress of 136.54MPa, deflection of 0.09mm and with factor of safety 2 compared to other modified models. The percentage of the weight reduced by this modification was found to be 11% that is 40.8 kg.

8. SCOPE FOR FURTHER WORK

The overall weight of the gearbox can be reduced by performing modal and harmonic analysis [7] of the pedestal carrier by accounting pulsating coefficient. This in turn helps to further reduction in the weight of the assembly.

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