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# Design and Analysis of Input Shaft of a Portal Axle

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***Abstract:***
*The input shaft of portal axle is used to recive the power from differential unit and sends it to portal axle unit and the output shaft transfer the power from portal axle unit to road wheels. The main objective of this project is design and analysis of input shaft of a portal axle unit with different thickness of hollow shafts. The portal axle input shaft models were modeled and analyzed using ANSYS software and validated through comparison of results with the analytical results. In the analysis of the input shafts of the portal axle, the hollow shaft with 3mm thickness is proposed and the final element model is built. The optimum set of parameters it is found that the hollow shaft thickness affects the shear strength of the hollow shaft compared to the solid shafts. The optimized shaft has an improvement in shear strength and the weight of the shafts shaft is will be reduced.*

***Keywords****: Shear strength; Maximum shear stress; hollow shaft thickness; weight reduction; Torque; Angle of twist*

## 1. Introduction

A portal axle unit is installed between the wheel and the axle shaft to give higher ground clearance to the vehicle. It allows driving on off-road so that the vehicle can go over high terrains and obstacles. Compared to normal axel, portal axles enable the vehicle to gain a higher ground clearance, as both axel tube and differential casing are tucked up higher under the vehicle. The difference between normal axel and portal axel are showed in the below figure 1.

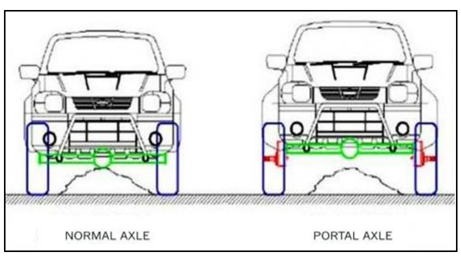


*Figure 1: Difference between normal axel and portal axel*

The input shaft of portal axle receives the power from differential unit and sends it to portal axle unit and the output shaft transfer the power from portal axle unit to road wheels. Shear strength is a material's ability to resist forces that can cause the internal structure of the material to slide against itself. Adhesives tend to have high shear strength. In engineering, shear strength is the strength of a material or component against the type of yield or structural failure where the material or component fails in shear. The shear strength is the load that an object is able to withstand in a direction parallel to the face of the material, as opposed to perpendicular to the surface. Shear strength can be determined in a torsion test where it is equal to torsional strength. It is reported in pounds per square inch, based on the area of the sheared edge. The shear strength of a structural adhesive is the maximum shear stress in the adhesive prior to failure under torsional loading. The shear strength of steel depends on the type of steel it is. In general, ductile materials (such as aluminum) fail in shear, whereas brittle materials (such as cast iron) fail in tension. It is important to understand the amount of weight (or load) that a structure can support. It is especially important to understand the forces that are applied to a structure in different directions. When a shaft is subjected to a torque or twisting, a shearing stress is produced in the shaft. The shear stress varies from zero in the axis to a maximum at the outside surface of the shaft.

**2. Literature Survey**

N. Lenin Rakesh [2] et al this project deals with the stress analysis of a shaft using Ansys. The shaft which is fixed at one end is selected and forces are given at particular points. The reactant forces acts in opposite directions. Torque acts at two points in opposite directions. The reactant forces and bending moments are initially calculated. Based on these parameters, the maximum shear stress, normal stresses are calculated. The same values are used then calculated by using ANSYS software. Finally the theoretical and analytical results are compared and verified.

Asmamaw Gebresilassie [3] in this project work an attempt is made to evaluate the suitability of composite material such as E-Glass/Epoxy for the purpose of automotive drive shaft application. A one-piece composite shaft is optimally analyzed using Finite Element Analysis Software for E-Glass/Epoxy composites with the objective of minimizing the weight of the shaft, which is subjected to the constraints such as torque transmission, critical buckling torque capacity and bending natural frequency.

Jong Boon Ooi [1] et al reviewed, a hollow shaft with a rib at both ends was proposed. The torsional stress of the three-dimensional shaft model was determined using finite element analysis (FEA) and validated by experimental testing.

The hollow shaft thickness, rib thickness, depth of spokes, rib fillet radius, and number of spokes are the five of parameters considered in the torsional strength analysis of the rib. A Taguchi orthogonal array (L25) was applied to determine the optimum set of parameters for the proposed shaft. The strength and weight of the optimized model were calculated and compared to the solid shaft, hollow shaft, and proposed model. The optimized model showed improvement in torsional strength with a slight increase in weight compared to the benchmark model.

**3. Scope**

In competitive world, light weight playing a major role in automotive industries to reduce the manufacturing cost of vehicle. By reducing weight of components in the vehicle the overall efficiency of the vehicle will be improved. When effectively used FEA can predict the results/behavior quite close to reality and can reduce the design lead times as well as number of prototypes to be tested

**4. Objective and Methodology**

- Design and analysis input and output shaft of a portal axle unit with different thickness to find the maximum shear stress.
- Analysis of shaft for shear strength by using ANSYS software. The optimized hollow shaft is compared with solid shaft with regard to the maximum shear stress and percentage of weight reduction.
- Analysis of shafts by using High modulus (HM) Carbon/Epoxy and High strength (HS) Carbon/epoxy composite material properties. Compare the results of composite shaft with steel shaft and recommend for alternative suited materials.

The below shows the points are methodology of present work

- Defining the objective of the work
- Literature review
- Design of Input shaft of Portal axle
- Finite element analysis of input shaft of portal axle with different thickness.
- Compare the FEA results with analytical results.

*4.1. Finite Element Analysis*

Finite Element Analysis (FEA) is numerical method for solving engineering problems and it is a type of computer program that uses the finite element method to analyze a material or object and find how applied stresses will affect the material or design. It shows the steps involved When effectively used FEA can predict the results/behavior quite close to reality and can reduce the design lead times as well as number of prototypes to be tested. Especially in situations like studying the behavior of a component by changing material, FEA can be highly handy as it is amounts to changing few numbers and re-running the analysis to know the component/system behavior.

*4.2. Design of Input Shaft*

The following Block dimensions and material properties are used for design of shaft.
Outer diameter = 37 mm
Inner diameter = 31mm
Length=490mm
Torque T=113Nm
Speed=1000rpm
Material Properties:
Material = Steel
Young's Modulus E = 207 GPa
Poisson Ratio = 0.3
Yield Strength = 370 Mpa
Shear modulus G = 80 Gpa
Density $\rho$ =7600 kg/$m^3$
The Torsional equation is given by:

$$\frac{T}{J}=\frac{\tau}{r}=\frac{G\theta}{L}$$

Design solid Shaft:

The maximum shear stress of solid shaft is $\tau=\frac{Tr}{J}=\frac{16TD}{\pi(D)^4}=\frac{16\times113\times0.037}{\pi\times(0.037)^4}=11.36Mpa$

Angle of twist $(\theta)=\frac{\tau L}{rG}=0.003$ Radians (0.171°)

Mass of the solid shaft:

m= $\rho AL=\frac{\rho\pi}{4}D^2\times L$

=7600*3.142/4*0.037²*0.49

m =4.004kg

Design hollow Shaft:

$$\tau=\frac{Tr}{J}=\frac{16TD}{\pi(D)^4}=\frac{16\times113\times0.037}{\pi\times(0.037-0.031)^4}=22.39Mpa$$

Angle of twist $(\theta)=\frac{\tau L}{rG}=0.007$ Radians (0.401°)

Mass of the hollow shaft

m= $\rho AL=\frac{\rho\pi}{4}(d_o^2-d_i^{2)})\times L$ =1.19kg

Percentage of mass reduction:

$$=\frac{(\text{mass of solid shaft - mass of hollow shaft})}{\text{mass of solid shaft}}==\frac{(4.004-1.19)}{4.004}*100$$

% of mass saving = 70.27%

*4.3. Boundary Condtions*

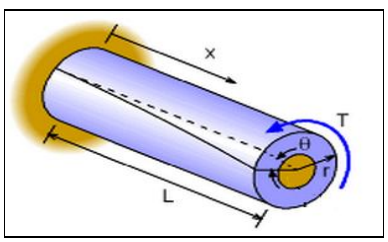


*Figure 2: Boundary condtions and torque applied for shaft*

The shaft is analyzed using ANSYS by giving the following boundary conditions. The left end of the shaft is restricted the motion in UX, UY, UZ, directions and the rotary motion restricted in ROTY, ROTZ directions. The torque T of 113 N-m is applied at the right end of the shaft. The model and boundary conditions are shown in the above Fig.2.

*4.4. Analysis of Input shaft*

4.4.1. Maximum Shear stress evaluation of solid input shaft:

Solid shaft of 37 mm of outer diameter and length of 490 mm is modeled and analyzed using ANSYS software determined the maximum shear stress of the solid shaft. The surface boundary conditions and material properties are applied to the shaft model. One end of the shaft is fixed and at the other end is applied with torque T.

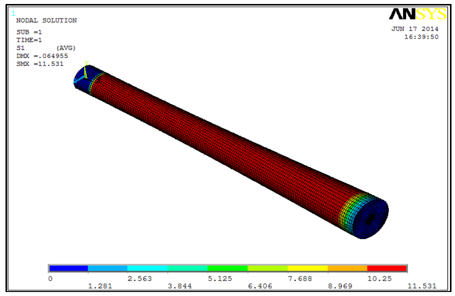

*Figure 3: Maximum shear stress of solid shaft*

Figure.3 shows the results obtained in the ansys software. Boundary conditions are one end is fixed and other end is applied with a torque of 113 Nm, material properties Young’s Modulus “E” and Poisson’s ratio of 0.3 are applied. The optimum element mesh size for the solid shaft model is 3 mm. The maximum shear stress is 11.531MPa. Obtained shear stress value is nearly equal to 11.36Mpa which is calculated from theoretical method. The stress values are with the permissible limit and the design is safe.

4.4.2. Maximum Shear stress evaluation of hollow input shaft

Solid shaft of 37 mm in outer diameter, 31 mm in inner diameter and length of 490 mm is modeled and analyzed by using ANSYS and determine the maximum shear stress of the hollow shaft. The surface boundary conditions and material properties are applied to the shaft model. One end of the shaft is fixed and at the other end is applied with a torque T.

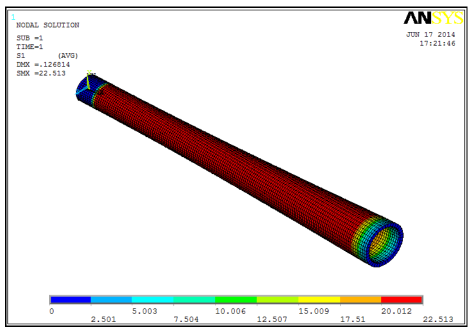

*Figure 4: Maximum shear stress of solid shaft*

Figure.4 shows the results obtained from the ansys software for hollow shaft of thickness 3mm. Boundary conditions applied are one end is fixed and other end is applied with a torque of 113Nm, material properties are Young’s Modulus “E” 200Gpa and Poisson’s ratio of 0.3 are applied. The optimum element mesh size for the hollow shaft model is 3 mm and the maximum shear stress is 22.513MPa. Obtained shear stress value is nearly equal to 22.39Mpa which is calculated from theoretical method. Therefore the stress values are with the permissible limit and the design is safe.

4.4.3. Effect of the hollow shaft thickness on Maximum shear stress

| Outer Diameter “D”mm | Inside Diameter “d”mm | Thickness mm | Max. Shear stress Mpa |
|---|---|---|---|
| 37 | 0 | 0 | 11.53 |
| 37 | 31 | 3 | 22.513 |
| 37 | 30 | 3.5 | 20.11 |
| 37 | 29 | 4 | 18.34 |
| 37 | 28 | 4.5 | 16.99 |
| 37 | 27 | 5 | 15.93 |
| 37 | 25 | 6 | 14.42 |
| 37 | 21 | 8 | 12.74 |

*Table 1*

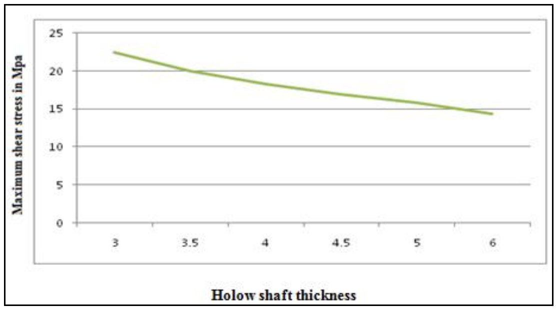

*Figure 5: Maximum shear stress versu(Mpa)s hollow shaft thickness (mm)*

The above table and graph shows an exponential correlation between the Maximum shear stress and the hollow shaft thickness. There is an improved in the shear strength when the hollow shaft thickness of 3 mm. This indicates that for 3mm in hollow shaft thickness contributes to the increase in shear strength of the hollow shaft. However, the shear strength decreases slightly when the hollow shaft thickness is increased from 3 mm to 8mm. mm. This indicates that the shear strength is converging when the hollow shaft thickness is increased beyond 4 mm.

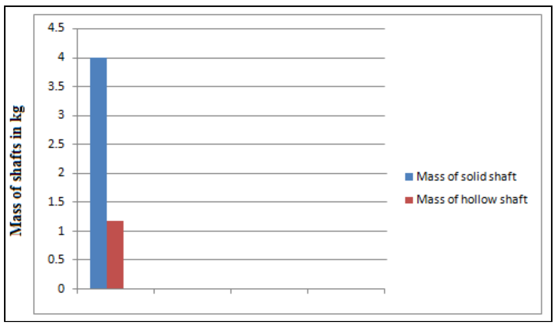

*Figure 6:Amount of mass save using hollow shaft*

**5. Conclusion**

The main objective of this project is Design analysis of the input shafts for its shear strength and weight reduction. The portal axle input shaft are modeled and analyzed using FEA software and validated through comparisons with the analytical results. In the analysis of the input shafts of the portal axle, the hollow shaft with 3mm thickness is proposed and the final element model is built. The optimum set of parameters it is found that the hollow shaft with 3mm thickness affects the maximum shear stress of the hollow shaft compared to the solid shafts. The optimized shaft has an improvement in shear strength and the weight of the shafts is reduced allot compare to solid shaft. The percentage of weight reduction from input shaft is 70%. The shear strength of hollow shaft is more compare to hollow and weight is less. Hence the hollow shaft can be replaced in the place of solid shaft.

**6. Scope of Future Work**

In competitive world, light weight playing a major role in automotive industries. So by using optimized design in different components of vehicle we can reduce the manufacturing cost and reducing in weight will also cause for improvement in efficiency of the vehicle. In future work different composite materials can be used for analysis of input and output shaft of portal axle unit.

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