Design and Analysis of a Solid and Hollow Unibody Driveshaft of an ATV

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Abstract - *This paper presents the characteristic details of both hollow and solid driveshafts for an ATV having a unibody design to reduce the number of assemblies and ease of assembling which can be connected to a universal joint. What could be better a hollow or a solid shaft is analysed by calculating and comparing the stress & deformation. SolidWorks is used for the CAD modelling and assembly of the design and finite element analysis has been performed on ANSYS by considering static structural to estimate deformation, stress under given loads and fatigue analysis for the life and number of cycles. The main objective of this paper is to reduce weight of the drivetrain and reducing assemblies by using a unibody design of the driveshaft.*

***Key Words*: Hollow Driveshaft, Unibody Shaft, Finite Element Analysis, ANSYS, Solidworks, Universal Joints, FEA**

1. INTRODUCTION

A drive shaft is a mechanical component of the powertrain of a vehicle and is used to transmit torque and rotation to the wheels of a vehicle. It is also used to connect the gearbox with the wheel as they cannot be connected directly because of the distance and the possibly the height difference between them. As they carry variable torque, torsional and shear forces are acted upon the driveshaft, which could be calculated with the input torque and the load. To bear this stress with a reduced weight, a hollow shaft is used instead of a solid shaft because with the same weight, radius of the hollow shaft could be increased and hence, more polar moment of inertia and so it will be able endure more torque transferring through it. The walls of the shaft shouldn't be too thin or else it will get unstable and might break. The optimal thickness of the driveshaft is decided after iterating with different diameters and checking for stress and deformation.

Here, a unibody driveshaft is being used which shall be connected to the gearbox at one side and the wheel hub to the other side with the help of a flange and spindle. The flange and spindle are connected to the shaft at either side with the help of a cross/spider. Yokes gathering are constantly subjected to torsion and shear [1]. A universal joint is used in the ATV as it provides with greater articulation angle than a constant velocity joint and has more rigidity which helps in driving through rough terrains.

Hollow shafts have some downsides too, like they require more space as they have a greater radius, and they are weaker than solid shafts when bending force is applied. Hollow shafts show better stress distribution and can also resist rotational imbalance because of lower weight and also high temperatures because of low specific mass. Weight reduction will help in better acceleration and deceleration as less energy will be required to rotate them.

The unibody shaft could be connected to a gearbox and spindle with 2 yokes which will provide 2 degrees of freedom for the movement of shaft while moving. A unibody driveshaft when connected to the wheel hub also prevents wobbling of the wheel. Material selection plays an important role while designing any part, here after comparing many materials for the shaft, choosing the right material is very important. We have chosen AISI 4340 (normalized) for its analysis after comparing it with other materials as we needed minimum weight with maximum strength for our part.

This study provides you with the analysis of both types of shafts and the benefits of substituting the conventional solid shafts to hollow shafts as they have many advantages over solid shafts.

2. MATERIALS AND METHODS

The calculation of the torque, forces and its validation are a vital step while designing a custom driveshaft. While designing the shaft, the goal is to make such a design which can withstand high torque with minimum weight and also endure the rough terrain.

2.1 Methodology Flowchart

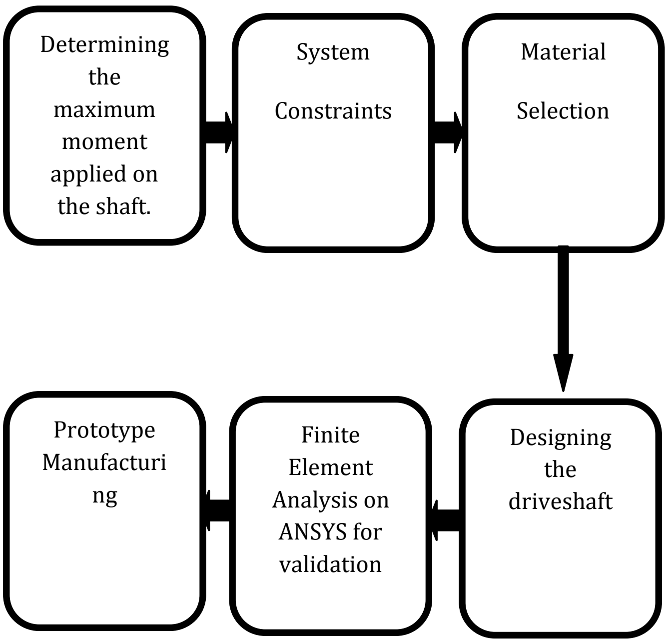

Figure 1. The flowchart shows the method of how the final prototype of the unibody driveshaft has been designed.

Choosing an appropriate material for your driveshaft is a very important part while designing a driveshaft. The shaft material is chosen after a comprehensive analysis of various steel alloys, such as AISI 4130 and AISI 4340. Since the driveshaft has to withstand all the forces acting upon it, it mandated the shaft material to be of high bending strength and less weight. The weight of the shaft is dependent on the material you choose for the shaft, lower the weight, greater would be the acceleration of the vehicle

In the table below, there is a comparison between various materials and their properties after which we have chosen AISI 4340 as a suitable material for the driveshaft. The material has a good yield strength and fatigue strength which can also be heat treated. The unibody shaft can be manufactured using CNC machining to achieve highest level of precision.

Table -1: Material Comparison

Material Comparison			
Parameters	Al 7075 T6	AISI 4340	Ti6Al4V
Yield Strength, Tensile	503 MPa	470 MPa	880 MPa
Yield Strength, Ultimate	572 MPa	745 MPa	950 MPa
Density	2.81 g/cc	7.85 g/cc	4.43 g/cc
Machinability (out of10)	8	8	4

Engine Specifications:

Model- Briggs and Stratton Model 19L-232-0054-G1
Displacement- 305 cc
Power- 10 HP

CVT:
Model- Custom Gaged GX9 CVT
Low Ratio- 3.9:1
High Ratio- 0.9:1
Engagement Speed- 2100 RPM

Gearbox here is a custom-made gearbox with overall gear ratio 9.

Maximum torque produced by the engine = 19.5 Nm
CVT Ratio = 3.9
Gear Ratio = 9

Coming to the calculations, the diameter of a solid shaft is first identified whose weight is equal to the weight of the hollow shaft. Then using the equation, the shear stress of both shafts is calculated due to the maximum moment acting on the shaft.

Maximum moment produced = (Maximum Torque x CVT Ratio x Gear Ratio)
= 19.5 x 3.5 x 9
= 684 N
Length of Shaft = 280 mm = 0.28 m
Outer Diameter of Shaft = 32 mm = 0.032 m
Inner Diameter of Shaft = 27 mm = 0.027 m

If,
Weight of solid shaft is equal to the weight of the hollow shaft, diameter for the solid shaft would come out to be 8 mm or 0.008 m.
Here,

$$\frac{T}{J}=\frac{\tau}{R}=\frac{G\theta}{l} \quad \ldots\ldots (1)$$

For solid shaft, the polar moment of inertia is,

$$J=\frac{\pi D^{\wedge}4}{32} \quad \ldots\ldots (2)$$

Using this which will come out to be, **4 x 10^(-4) m^4**.
By putting (2) in (1), the stress (τ) comes out to be **3420 MPa**.

For hollow shaft, the polar moment of inertia is,

$$J=\frac{\pi(OD^{\wedge}4-ID^{\wedge}4)}{32} \quad \ldots\ldots (3)$$

Similarly, polar moment of inertia is found to be **5.07 x 10^-8 m^4** and using the relation (1), the stress is found to be as **215 MPa** which is significantly lower than that of a solid shaft of equal weight. This proves that a hollow shaft is a better option than a solid shaft for any chosen material.

3. DESIGN AND ANALYSIS

3.1 Design and Assembly

The driveshaft has been designed on SolidWorks 2018 and the Finite Element Analysis has been done on ANSYS v18. The element size for meshing has been taken as 0.5 mm to get as accurate result as possible. The other mesh details are given in Figure 6 below.

Fig- 3: CAD Model of Unibody Hollow Driveshaft with 32 mm Diameter

Fig- 4: CAD Model of Unibody Solid Driveshaft with 8 mm Diameter

Fig- 5: Assembly of Shaft with Flange and Spindle

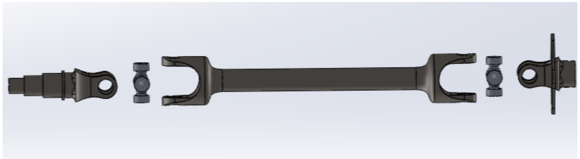

Fig- 6: Exploded view of Driveshaft Assembly

3.2 Analysis

3.2.1 The moment of 686 Nm is applied on the shaft acting on the 2 holes of the yoke of one side while the two holes of the other side will act as fixed support for the shaft. By fixing one side and twisting the other side, we can check the torsional rigidity for the shaft. The torsional rigidity not only depends on the global cross-sectional geometry, but also on the properties and configurations of each constituent [3]. The final moment, which is 686 Nm is the total moment produced from the output shaft of the gearbox and 343 Nm will be distributed to either side of the rear, but here, the worst-case scenario is taken, when only one wheel is in contact with the ground. Hence, the analysis is being done with 686 Nm rather than 343 Nm.

Object Name	*Mesh*
State	Solved
Display	
Display Style	Body Color
Defaults	
Physics Preference	Mechanical
Relevance	0
Element Order	Program Controlled
Sizing	
Size Function	Adaptive
Relevance Center	Coarse
Element Size	0.50 mm
Initial Size Seed	Assembly
Transition	Fast
Span Angle Center	Coarse
Automatic Mesh Based Defeaturing	On
Defeature Size	0.5 mm
Minimum Edge Length	1.0 mm
Quality	
Check Mesh Quality	Yes, Errors
Error Limits	Standard Mechanical
Target Quality	Default (0.050000)
Smoothing	Medium
Mesh Metric	None
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No

Fig- 7: Mesh Details for FEA

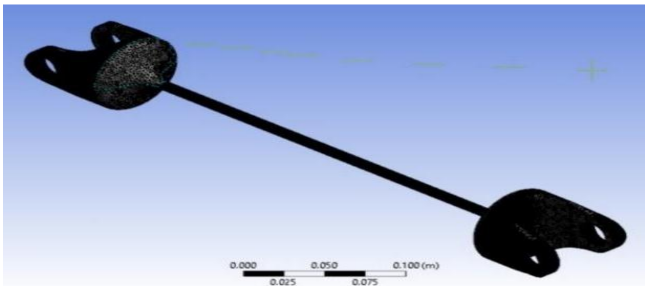

Fig- 8: Meshed Model of Solid Driveshaft

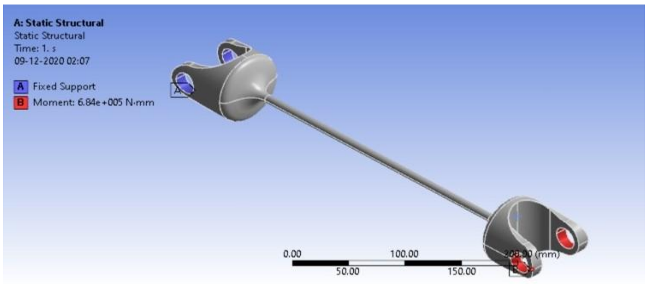

Fig- 9: Boundary conditions for the Analysis

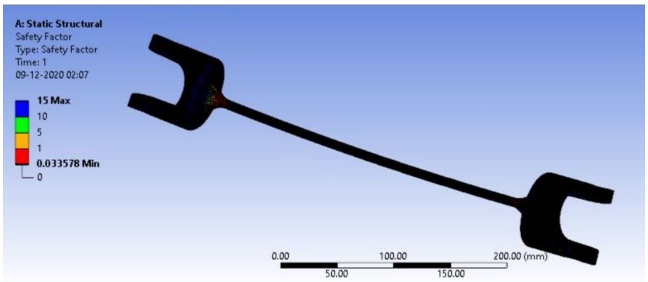

Fig- 10: Factor of Safety for Solid Shaft = 0.033578

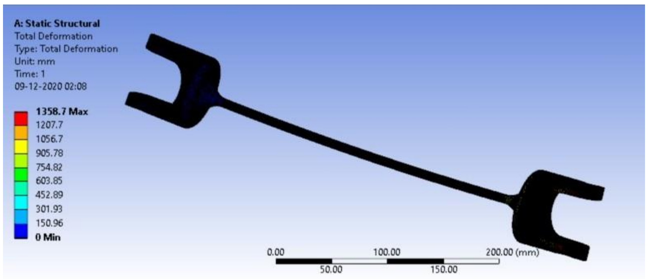

Fig- 11: Deformation = 1358.7 mm

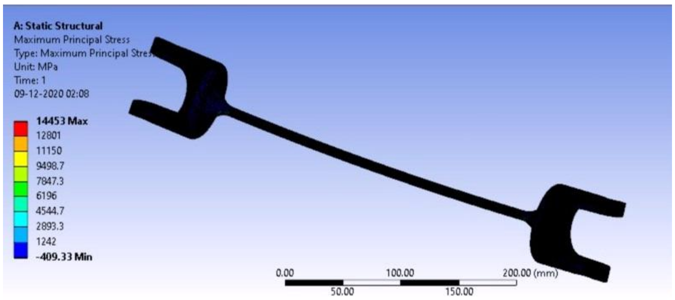

Fig- 12: Stress = 14453 MPa

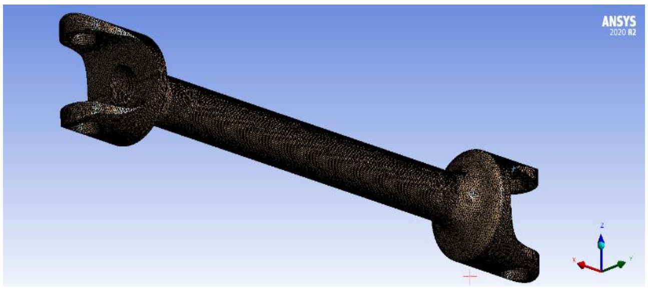

Fig- 13: Meshed Model of Hollow Driveshaft

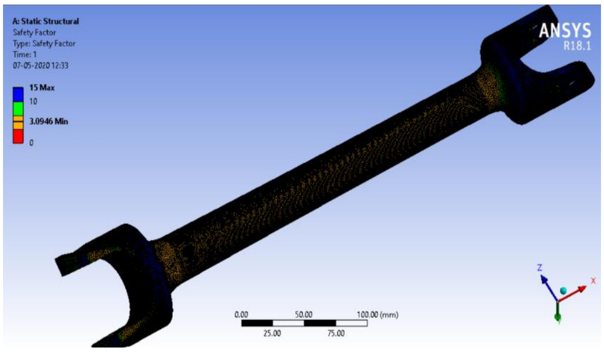

Fig- 14: Factor of Safety = 3.0945

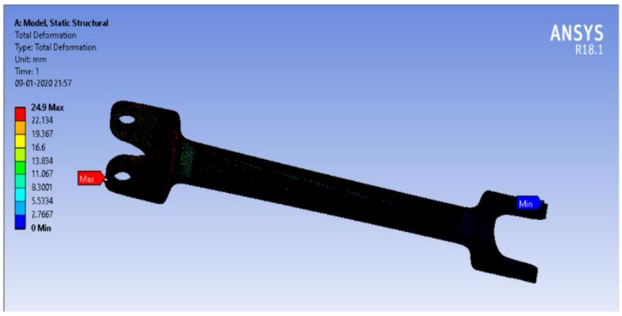

Fig- 15: Deformation = 24.9 mm

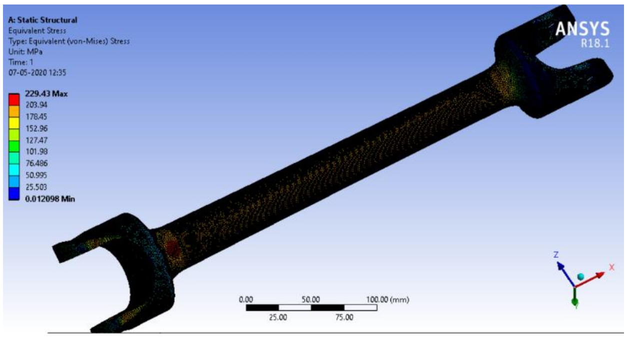

Figure 16. Stress = 229 MPa

The boundary conditions (Figure 8) and the mesh properties (Figure 6) are taken the same for both hollow and solid shaft.

4. CONCLUSIONS

On comparing the results of both hollow and solid unibody shafts, it is finalized to manufacture the prototype of the hollow driveshaft due to its high factor of safety, low deformation and stress.

The maximum stress is found out to be on the connection of the yoke and shaft which is till in an acceptable range. The deformation is highest at the upper edge of the yoke because of the high twisting moment acting on it as the worst-case scenario is taken.

Weight reduction can be achieved by replacing conventional driveshafts with hollow driveshafts for same strength and rigidity.

This paper provides a detailed study on designing and analyzing a hollow as well as solid unibody driveshaft which is lightweight yet providing with great enduring limit. This study has provided with a scope of future work. Unibody designs are still not used commercially as well as in student teams.

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