DRIVE SHAFT DESIGN AND ANALYSIS FOR MINI BAJA

Gowtham S 1, Raaghul V 2, Sreeharan B N 3, Praveen Kumar R A 4, Mohamed Kasim S 5

1 UG Scholar of Third Year Mechanical Engineering, Department of Mechanical Engineering, Kumaraguru College of Technology, Coimbatore, Tamil Nadu, India.
2 UG Scholar of Third Year Mechanical Engineering, Department of Mechanical Engineering, Kumaraguru College of Technology, Coimbatore, Tamil Nadu, India.
3 Assistant Professor of Mechanical Engineering, Department of Mechanical Engineering, Kumaraguru College of Technology, Coimbatore, Tamil Nadu, India.
4, 5 Alumni, Department of Mechanical Engineering, Kumaraguru College of Technology, Coimbatore, Tamil Nadu, India.

Abstract. A wide variety of automobile design and racing events happening across the country to encourage the student community in the design of automobile vehicles. In this regard, the Society of Automotive Engineers (SAE) enables a student to gain real world experience in the fields of design, analysis and manufacturing of the all-terrain vehicle by conducting such events. This paper describes about the design and analysis of drive shaft for mini BAJA vehicle that has participated in one of the national level competitions conducted by SAE. Drive shaft is one of the major components used in BAJA. The drive shaft discussed here is used to transmit the required torque from the differential to the wheels. All the components of the drive shaft were designed analytically, modeled in SolidWorks and analyzed using Ansys software to ensure its safety. The main objective is to fabricate more reliable and eco-friendly drive shaft by minimizing the cost and increasing the overall performance. Keywords: Design and analysis, Drive shaft, Terrain vehicle, Torque transmission, Safety

1. INTRODUCTION

Half Axle is a device used to transfer the power by means of rotational motion from the differential gearbox to the wheel. One end is engaged with the differential gearbox while another to the wheel hub assembly. The suspension system used in this work is a double-wishbone which is used to make the full-floating axle. The load that came on axle is the only torsional or driving force. From the viewpoint of functionality, the axle should have the rigidity at the lower weight. This work was focused on the BAJA SAE INDIA event as the ATVs must have less weight at the same rigidity is also required. By optimizing the design and upgrading the material it can be achieved. The design is validated on the Ansys software to ensure the safety and it has been used in the BAJA vehicle in the competition.

2. TERRAIN VEHICLE

2.1 Identification of problem

MINI BAJA events are intercollegiate events involving purely students. Their budget is limited that they must build the entire vehicle within the given budget. Having a tight budget must not affect vehicle performance (in this paper the design quality of the driveshaft). A lot of teams use drive shafts from OEMs. Which might help them clear the event but will not gain scores in the design event thus affecting their overall score.
2.2 Objective of the paper
The primary objective of the project is not to use composite materials since they cost much more than typical steel or aluminum alloy drive shafts. Further, no compromises should be made on the build quality of the drive shaft. The project focuses on reducing as much weight possible yet not failing the ATV to satisfy the judges in every way and to survive all road conditions and toughest of tracks.

2.3 All terrain vehicles
An all-terrain vehicle (ATV), additionally referred to as a quad, three-wheeler, four-track, hackney carriage, or curve cycle, as outlined by the Yankee National Standards Institute (ANSI) could be a vehicle that travels on unaggressive tires, with a seat that's straddled by the operator, alongside handlebars for steering management. As the name implies, it's designed to handle a wider kind of piece of ground than most different vehicles. Though it's a street-legal vehicle in some countries, it's not street-legal inside most states and provinces of Australia, the US or Canada.

2.4 Purpose of drive shaft
The torque that is produced from the engine and transmission must be transferred to the rear wheels to push the vehicle forward and reverse. The drive shaft must provide a smooth, uninterrupted flow of power to the wheels. The drive shaft is used to transfer this torque.

2.5 Functions of drive shaft
❖ The primary work is to transmit torque from the transmission to the rear wheels. During the operation, it is necessary to transmit maximum low gear torque developed by the engine.
❖ The drive shaft must be capable of rotating at very fast speeds required by the vehicle
❖ The drive shaft must also operate through at constantly varying angles.
❖ The suspension of the ATV determines the angle through which the drive shaft has to vary.
❖ This change in the angle determines the significance of the need of face width of the spline in the drive shaft.
❖ The input velocity must equal the output velocity to get the maximum performance of the drive shaft. Single cardan drive shafts usually fail to produce that, causing failure of the drive train. Double cardan or CV joint drive shafts overcome this drawback.

2.6 Design considerations
➢ Handling of high torques which is required by the ATV must be taken care.
➢ The diameter and the length of the drive shaft being fixed, the material must be selected.
➢ The shaft is subjected to shear loads and fatigue loads. Hence a highly durable design is needed to sustain all the driving conditions.

2.7 Drive shaft arrangement in ATV
Generally, drive shafts in automobiles are considered as the propeller shaft which transfers power from transmission in front wheel drive car to differential at the back. The shaft which transmits torque from differential to the rear wheels are known as rear axles. In the design of ATV for BAJA the drive axles are known as drive shafts since it is the only component to transmit power from transmission or differential to rear wheels.

3. LITERATURE REVIEW
[1] Jasim M. Salman et. al. [2013] studied to improve properties of 7075-T6 such as impact toughness, thermal age hardening behavior and corrosion resistance in 3.5% NaCl solution by using quenching in 30% polyethylene glycol and addition alloying elements, i.e. boron (B) to this alloy. Results showed improved impact toughness by (30%) when quenching in water, and by (50 %) when quenching in 30% PAG corresponding to the base alloy at aging temperature 150°C.
[2] BHIRUPANKAJPRAKHET al. [2014] The graphite/carbon/ fiberglass/aluminum driveshaft tube was developed as a direct response to industry demand for greater performance and efficiency in light trucks, vans and high performance automobiles. The main reason for this was significant saving in weight of drive shaft; the results showed that the final composite drive shaft has a mass of about 2.7 kg, while this amount for steel drive shaft is about 10 kg.

[3] P.N. SHARMA et. al. [2016] The common normal at the action between two teeth must always pass through a pitch point in such a way that it divides line joining the centers of the mating gears in the reverse ratio of angular velocity. Increasing pressure angle increases the width of the base of the gear tooth, leading to greater strength and load carrying capacity.

[4] L. VALTIER et. al. [2002] Spline couplings have a reputation of being able to accommodate some angular misalignment, the dangers of tooth fracture, fatigue, and wear that may result should be recognized. Unfortunately, it is exceedingly difficult to achieve perfect alignment in practice; thus, the design process should prudent allow for some minimum misalignment attainable and accept a reasonable penalty.

[5] BASKAR et. al. [2013] Due manufacturing and design fault, raw material faults, maintains faults, material processing faults, to avoid this problem various techniques such as either, modify material or geometry and conduct analysis on the same and finally implemented in the solution or used to find out the best design of Joint with considering the all the factor such as weight, cost, Fatigue life, stress distribution, stiffness.

4. DESIGN CALCULATIONS

4.1 Strength: Maximum shear stress theory

\[
\tau_{\text{max}} = \frac{16}{\pi d^2} \sqrt{M_b^2 + M_t^2}
\]

where,
- \(M_b\) = maximum bending moment in Nm
- \(M_t\) = maximum twisting moment in Nm
- \(d\) = diameter of the shaft in m
- \(\tau_{\text{max}}\) = maximum shear stress in N/mm²

Considering bending moment will be maximum at the center since the shaft is symmetric,

\[
M_b = \frac{W L^2}{24} = \frac{0.086 \times 0.394^2}{24} = 0.55 \text{ Nm}
\]

Where,
- \(W\) = load per unit length, which is 0.086 kN/m
- \(L\) = length of the complete drive shaft from support to support

Thus

\[
\tau_{\text{max}} = \frac{16}{\pi \times 0.038^2} \sqrt{0.55^2 + 700^2} = 83150354.6 \text{ N/m}^2
\]

\[
\tau_{\text{max}} = 83.2 \text{ N/mm}^2
\]

Figure 1. Drive shaft
Shear strength for Al7075T6 is 331 N/mm$^2$, and the fatigue strength being 159 N/mm$^2$ which is greater than the actual shear stress of 83.2 N/mm$^2$. Therefore, the design is safe.

4.2 Strength: Angle of twist

$$\theta = \frac{180}{\pi} \frac{M_t l}{J G}$$

Where,

- $M_t$: maximum twisting moment in N.mm
- $l$: length of the center shaft in mm
- $J$: polar moment of inertia = 1.47*10$^{-7}$ N/mm$^2$
- $G$: modulus of rigidity = 25.8*10$^9$ N/mm$^2$
- $\theta$: angle of twist in degrees

$$\theta = \frac{180 \times 620 \times 10^9}{1.47 \times 25.8 \times 10^9} = 8.5^\circ$$

$\theta$ is minimum and even decreases when the wheel starts to spin. Therefore, the design is safe.

4.3 Whirling of shaft

$$f_n = 3.562 \sqrt{\frac{GEI}{WL^4}}$$

Where,

- $G$: Acceleration due to gravity.
- $E$: young’s modulus = 71.7*10$^9$ N/mm$^2$
- $I$: Area of moment of inertia = 73.7*10$^{-9}$ mm$^4$
- Density of AL7075T6 = 2.81 g/cm$^3$ = 2.81*10$^3$ kg/m$^3$
- Volume per unit length = $A \times L$ = 96.2*10$^4$ mm$^3$
- Mass per unit length = Density*volume = 2.7 kg

Bending Natural Frequency,

$$f_n (\text{rev/sec}) = 3.562 \sqrt{\frac{GEI}{WL^4}}$$

$$= 3.562 \sqrt{\frac{71.7 \times 73.7 \times 10^9 \times 2.81 \times 10^3}{2.7 \times 96.2 \times 10^4}}$$

$$= 3.562 \sqrt{4333243.1073}$$

$$= 7290 \text{ rev/sec}$$

From Engine specifications and transmissions design, the maximum speed at which the shaft rotates is 560 rev/sec.

So, the design is safe.

4.4 Spline strength: Lewis factor equation

$$\sigma = \frac{W_t p}{f_y}$$
Where,

\[ W_t = \text{tangential tooth load}, \ F = \text{face width of tooth}, \ Y = \text{Lewis form fraction}, \ P = \text{diametrical pitch}. \]

Maximum Torque, \( T = 700 \text{ Nm} \)
Pitch circle Radius, \( R = 14.5 \text{ mm} \)
Total load, \( F = 48275.86 \text{ N} \)
No. of teeth = 29

Load shared by each tooth,

\[ W_L = \frac{48275.86}{29} = 1664.69 \text{ N} \]

Lewis factor equation,

\[ \sigma = \frac{W_L P}{fY} = \frac{1664 \times 1}{25 \times 0.42} = 154.8 \frac{N}{mm^2} < 680 \frac{N}{mm^2} \]

In general, the yield strength for EN24 is 680 N/mm².

From Lewis factor equation, the stress is 154.8 N/mm² < 680 N/mm². Thus, the design is safe.

5. ANALYSIS AND TESTING

5.1 Static structural analysis

Static structural analysis helps in determining the displacements, stresses, strains, and forces in any structures or components. Here, the structures response to change in the loads expected to happen slowly. Types of loading that can be applied in static structural analysis include:

- Externally applied pressures and forces
- Steady state inertial forces
- Imposed displacements
- Temperatures for thermal strain

This type of analysis can either be linear or non-linear. All types of nonlinearities are allowed - large deformations, stress stiffening, plasticity, contact (gap) elements, hyper elasticity and so on.

5.2 Safety factor

Safety factor (SF) is the ratio of absolute strength of structures to the actual load applied. Reliability of a particular design can be measured using safety factor. It expresses stronger a system needs to be for intended load. Safety factors are often calculated using detailed analysis because comprehensive testing is impractical on many projects. Many systems are intentionally built much stronger than needed for normal usage to allow for emergency situations, unexpected loads, misuse, or degradation.

5.3 Modal analysis

A good solution can be delivered only after the function of the modal being tested modal analysis is performed by using ANSYS software. The figures of the results are shown below:
6. FABRICATION PROCESS

6.1 Lathe

Lathe is a rotating machine which rotates about an axis to perform various operations such as cutting, knurling, sanding, drilling, deformation, facing, and turning. The drive shaft material is purchased around billet. The round billet is then produced to the lathe. The round billet is then turned to the desired diameter and cut at the edges.

6.2 CNC machine

CNC machining is the short for “computer numerical control” machining is a manufacturing process in which computer software is pre-programmed to decide the movement of the machining tool or component in order to achieve the desired output. The process can be used to control a range of complex machinery, from grinders and lathes to mills and routers. With CNC, three dimensional tasks can be achieved in minutes. The components called cups which hold the cross carrying a roller bearing is machined using CNC machine.

The versatility of the CNC machine makes it easy to manufacture the cup within minutes. By importing the model data to CNC, codes are generated to make precise cuts and then the machining takes place. Finally, the desired component that is required for this project work is fabricated.

6.3 Electric discharge machine

Electrical discharge machining (EDM), also known as spark machining, spark eroding, burning, die sinking, wire burning or wire erosion, is a manufacturing process whereby a desired shape is obtained by using electrical discharges (sparks). Material is removed from the work piece by a series of rapidly recurring current discharges between two electrodes, separated by a dielectric liquid and subject to an electric voltage. One of the electrodes is called the tool-electrode, or simply the "tool" or "electrode;" while the other is called the work piece-electrode, or "work piece." The process depends upon the tool and work piece not making actual contact. The sparks generated make the cut on the subjected shaft carrying cup at the end. The precision of the cut produced by EDM is unmatched by even many of the current technologies. Spline in the male cup is machined with the help of EDM.

7. MATERIAL SELECTION

The materials have been analyzed in static and structural analysis using ANSYS software and the data have been tabulated below:

Figure 2. Structural analysis of aluminium 7075T6
Figure 3. Structural analysis of EN24
Figure 4. Structural analysis of grade 1 titanium
Figure 5. Structural analysis of 304 stainless steel
Table 1. Numerical simulation results

| Material               | Safety factor |
|------------------------|---------------|
| EN24                   | 1.9563        |
| Aluminium 7075T6       | 2.0937        |
| Aluminium 6061T6       | 1.1488        |
| Stainless Steel 304    | 0.8862        |
| Titanium Grade 1       | 1.0159        |

From the above table 1, Aluminium 7075T6 is the best chosen option to manufacture the drive shaft which meets all the design criteria and the project objectives.

8. RESULTS AND DISCUSSION
The design is focused on factors like strength, fatigue and whirling of the solid drive shaft. Primarily a set of materials are taken into consideration which are widely used in the field of automobile industries to manufacture drive shaft.

A SOLIDWORKS model is created with the length and diameter constraints set by design of other components of the ATV. The maximum amount of stress the shaft has to withstand is calculated as well. With these in hand, all the above-mentioned materials are put to test both analytically and theoretically.

9. ACKNOWLEDGEMENTS
We would like to thank all the people who made their role unavoidable. Without their contribution this paper would have not been come true. Also, we thank our Institution head and Department head for providing facilities without which this paper would not be possible. We would also like to thank the industry for giving the constant support to carryout experimental work in real time practices.

10. CONCLUSION
With the completion of the project, the primary objectives of the project are met with maximum efficiency. Even at high speeds, the drive shaft maintained not to whirl. This contributed highly to the overall performance of the ATV. The selection of material resulted in much lesser manufacturing cost when compared to reinforced composite drive shafts and meeting the other
objective of designing and fabricating a budget drive shaft favoring the enthusiastic students to participate in all the ATV design and racing events across the country.

REFERENCES

[1] Sivakandhan C and SureshPrabhu P 2012 CompositeDrive Shaft is a Good Strength and Weight Saving toCompare Conventional Materials Design and Analysis of EGlass/Epoxy Composite Drive Shaft for Automotive Applications European J. of scientific Research Vol 76 No 4 2012 pp.595-600.

[2] Rangaswamy T, Vijayarangan S, and Chandrashekar, R.A.&Venkatesh 2002 Optimal design and analysis of automotive composite driveshaft Int. Symp. of Research Students on Materials Sci. and Engg, pp 1-9.

[3] Mohammad Reza Khoshravan, AminPaykani and AidinAkbarzadeh 2011 Design and modal analysis of composite drive shaft for automotive application IJEST 11, Vol.3 No 4

[4] Mouritz A P and Thomson R S 1999 Compression, flexure and shear properties of a sandwich composite containing defects Composite structures pp 263-278

[5] Pratap, P., Kusak E and Reddy T Y 2003 Novel stitch bonded sandwich composite structures”, Composite structures pp 251-259.

[6] Jung-Seok Kim, Hyuk-Jin Yoon and Kwang-Bok Shin 2011 A study on crushing behaviors of composite circular tubes with different reinforcing dibres Int. J. of Impact Engg Vol 38 pp 198-207

[7] Davoodi M.M, Sapuan S M, Ahmad D, Aidy A, Khalina A and Mehdi Jonoobi 2011 Concept selection of car bumper beam with developed hybrid bio-composite material Materials and Design Vol 32 pp 4857-4865.

[8] Kedar S Pandya, Ch.Veeraraju and Naik N K 2011 Hybrid composites made of carbon and glasswoven fabrics under quasi static loading Materials and Design Vol 32 pp 4094-4099.

[9] Thimmegowda Rangasamy and Sabapathy Vijayarangan 2005 Optimal sizing and stacking sequence of composite drive shafts Materials Science (Medziagotyra) Vol 11 No 2 pp 133-139.

[10] Dudley Bukey D 1899 Horse-Power U.S. Patent 631,198.