DESIGN OPTIMIZATION OF UNIVERSAL JOINTS FOR ALL-TERRAIN VEHICLES

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Abstract. Universal joint mechanism widely used in the automobile power transmission systems. This joint mechanism desired to permit some angular deviations along the axis of rotation. The cardan joint comprises of the three main parts including the input drive shaft, the output drive shaft and the cross like piece. Two points of the cross piece connect to the input drive shaft and two other points connect to the output drive shaft. Connections are provided by the needle bearings. It is an important aspect of these bearings that while in action they never go through complete cycles. In other words, each of these bearings revolves only a few degrees around its axis before returning to its original position. The paper aims to develop a UV joint that is suitable for All-Terrain Vehicles (ATVs). These types of vehicles have to traverse rough terrain and hence require taller suspension set up. Conventional universal joints limit this ability as the allowable articulation angle is very less. Due to this, they are prone to wear and malfunction and need to be replaced in comparatively short intervals of time. Naturally, it means that such parts have limited life span. We have hence developed a UV joint design which allows for better articulation angle while maintaining strength and reducing weight at the same time. Keywords: Universal joint, All-Terrain Vehicles, Computer Aided Design, Ansys.

1. INTRODUCTION

The idea of a mechanism that can provide slight inclination to the direction of the rotating shafts has long been thought of by the engineers. Failure of the universal joints can end up with serious consequences and it can be very costly. It causes sudden disruption in the supply of power between its source and the consumer device. Therefore, many studies are performed in order to recognize the nature of the corresponding forces and the failure within these mechanisms. All such studies concentrated on the failure in the universal joints or its connecting rods, in a general sense. There is hardly any research report specifically concerned with the optimization of the design of a universal joint to prevent failure while improving the articulation angle and the weight.

Sheikh, S. M used Pro/E software for the design and HyperMesh for analysis of UV joints. Basically the author focused on modification of UV joint geometry using topology optimization concept and free size optimization concept to reduce the mass of UV [1]. Neve et al. [2] uses different epoxy materials of composites for driving shaft. Out of those, Kevlar/Epoxy composite has given maximum strength compared to the others composite materials. During the study, 90° fibre angle is giving better fundamental frequency compared to other angles. Vasekar et al. [3] is concerned with the failure analysis and weight optimization of a universal joint yoke of an automobile power transmission. The weight optimization has been carried out with help of hyper mesh to reduce the weight from 1.11 kg to 0.967kg (12.8% reduction in weight).
Gagandeep Singh & Rajbir Singh [4] have proposed optimised universal joint using two materials to reduce the stress and mass of UV joint. The author has done failure analysis also to know at portion the UV joint fails. Vesali, Farzad et.al. [5] have analysed the dynamics of universal joint and failures for the improvement of the UV joint. This is achieved by the deriving the different motions associated with the UV joint.

Kang, and Weidan Wang [6] investigated faults associated with the double cross universal joint, including looseness, wear, and intermediate shaft torsional deformation. First, the authors propose a transmission model and a new fault model for this joint. Then, the model parameters of the optimal transmission performance are analyzed. Finally, the main contribution of this article is in discussing the transmission performance as related to looseness, wear, and the intermediate shaft torsional deformation.

The paper is organised as follows: section-1 deals with introduction and literature of the ASP problem. Section-2 explains about the improvement made for the fruit fly algorithm and how it is implemented to solve ASP problem. Section-3 deals with the results obtained from the proposed methodology. Section-4 explains about conclusion made from the proposed method in the paper.

2. METHODOLOGY

In this section, testing of universal joints made by AISI4340 and Al7075 for factor of safety, minimum deformation, stress analysis and weight optimization. Finite element analysis method is used for stress analysis to determine the stress condition at failed section. The main aim is to design a universal joint that provides maximum articulation angle while maintaining strength of the joint and also reducing the weight. The cup was designed keeping in mind an Original Equipment Manufacturer (OEM) part by DANA SPICER used for TATA Ace vehicle. This helped us to arrive at a baseline for designing the part. After performing many iteration and were analyzed at each stage to arrive at the final part.

After obtaining the basic final design, different parts of the driveshaft such as the spindle and flange were created. The shaft was designed to be a hollow shaft as it provides much better torsional rigidity as compared to a solid shaft.

The designs were analyzed for both aluminum 7075 and steel 4340. Aluminum is a lighter metal and proves to be more weight effective. But at the same time, it compromises on strength. Due to this, certain sections need to be made thicker in order to preserve the strength of the joint.

Aluminum is a very desirable metal because it is more malleable and elastic than steel. Aluminum can go places and create shapes that steel cannot, often forming deeper or more intricate spinning’s. Especially for parts with deep and straight walls, aluminum is the material of choice. Steel is a very tough and resilient metal but cannot generally be pushed to the same extreme dimensional limits as aluminum without cracking or ripping during the spinning process.

While malleability is very important for manufacturing, aluminum’s greatest attribute is that it is corrosion resistant without any further treatment after it is spun. Aluminum doesn’t rust. With aluminum there is no paint or coating to wear or scratch off. Steel or “carbon steel” in the metals world usually needs painted or treated after spinning to protect it from rust and corrosion, especially if the steel part will be at work in a moist, damp or abrasive environment.

Even with the possibility of corrosion, steel is harder than aluminum. Most spinnable tempers and alloys of aluminum dent ding or scratch more easily as compared to steel. Steel is strong and less likely to warp, deform or bend underweight, force or heat. Nevertheless the strength of steel’s tradeoff is that steel is much heavier /much denser than aluminum. Steel is typically 2.5 times denser than aluminum.

Thus, aluminum is a more suitable material as compared to steel as we get weight reduction along with good strength.
2.1 Modeling

Figure 1. Existing Design (based on the Polaris RANGER)

Figure -1 represents the existing model of UV joint used in ALL-Terrain Vehicles (Polar Ranger) designed in Solid Works. Keeping in mind the inherent design inconsistencies of the conventional design used in ATVs, which were discussed in introduction section, a new designed is proposed by changing the articulation angle. The modified design with exploded view is shown in Figure 2 designed in Solid Works.

Figure 2. Represents the exploded assembly view

All these parts of the back transmission were created keeping in mind the primary goal of increasing the ride height of the ATV while reducing weight and preserving the strength of the joint. The detail specification about all the parts is shown in the table-1.

| Specification   | Old design | Optimized design |
|-----------------|------------|------------------|
| Shape           | Straight cup | Tapered cup      |
| Shaft OD        | 30mm       | 35mm             |
| Flange thickness | 4mm       | 6mm              |
| Cup diameter    | 65mm       | 67mm             |

2.1 Simulation in ANSYS
Finite Element Analysis (FEA) was carried out on the individual modules of the joint in ANSYS Structural. Using these simulations, we optimized the individual modules for stress, deformation and FOS. Simulation was conducted for both steel and aluminum joints.

The reason for analyzing individual modules instead of the entire assembly was that it helps to reduce the computation time required and also helps to reinstate that each part will be able to suffice to the requirement.

The parts were meshed with a 1mm mesh in automatic mode to uniformly mesh the entire part. The torque was applied to either the “ears” of the yoke or the internal region of the yoke depending on its position in the assembly. The torque was applied to either the “ears” of the yoke or the internal region of the yoke depending on its position in the assembly.

The torque was calculated as follows from the previous literature data:

Engine Torque =19 Nm

CVT reduction ratio= 3.9:1

Gearbox reduction ratio=7.2:1

Overall reduction ratio= CVT reduction ratio x Gearbox reduction ratio

=28.08

Driveshaft Torque=Overall ratio x Engine Torque

=533.33 Nm ~600 Nm (approx.)

These values were taken into account while designing the joint and analyzing it. These values represent the maximum possible value of torque that may be experienced by the joint at any given point of time.

Steel AISI 4340

In Figures 3, 4 & 5 represents the deformation of yoke, flange and shaft of back transmission system made of steel AISI 4340 for ALL-Terrain Vehicle.
In Figures 6, 7 & 8 represents the stress of yoke, flange and shaft of back transmission system made of steel AISI 4340 for ALL-Terrain Vehicle.

**Aluminum 7075 (T6)**

In Figures 9, 10 & 11 represents the deformation of yoke, flange and shaft of back transmission system made of aluminum 7075 for ALL-Terrain Vehicle.
In Figures 12, 13 & 14 represents the stress of yoke, flange and shaft of back transmission system made of aluminum 7075 for ALL-Terrain Vehicle.

![Figure 12. Represents the stress of yoke](image1)

![Figure 13. Represents the stress of flange](image2)

![Figure 14. Represents the stress of shaft](image3)

3. **RESULTS AND DISCUSSION**

From the results obtained from the analysis, AISI 4340 steel UV and Al 7075 UV have close resemblances in their respective results. This shows that both the materials will be suitable for the universal joint. But, Aluminum will be preferred over Steel as it is much lighter and is providing us with similar results in both cases. As can be seen, the values of stress and deformation are well in the acceptable limits of both the materials. The Factor of Safety is satisfactory for the required application of off-roading.

Our primary motive of increasing the ride height of the vehicle has been achieved as the max permissible angle is 65 degrees (approx.) as compared to 37.45 degrees for the conventional design. We also see a 78% reduction in weight for the Aluminum design as compared to the conventional design.

| Type of analysis | Steel UV | Aluminum UV |
|------------------|----------|-------------|
| **Yoke**         |          |             |
| Deformation      | 0.36mm   | 0.29mm      |
| Stress           | 403 MPa  | 224 MPa     |
| **Shaft**        |          |             |
| Deformation      | 0.53mm   | 0.77mm      |
| Stress           | 231 MPa  | 210 MPa     |
| **Flange**       |          |             |
| Deformation      | 0.23mm   | 0.17mm      |
| Stress           | 192 MPa  | 201 MPa     |
Table-2 represents the various analysis values of steel and aluminum material of UV joint used in ALL-Terrain Vehicles. Form the table Al is having better results than the Steel.

Figure 15. Angle before Optimization (37.45°)
Figure 16. Angle after Optimization (58.65°)

Figure 17. Weight of original design (490.44 grams)
Figure 18. Weight of optimized design (259.34 grams)

Figures 15, 16, 17 &18 represents the original and modified articulation angle of UV joint and weight reduction of yoke respectively.

4. CONCLUSION

In this paper, optimization of UV joint design by changing the articulated angle is carried out for use in higher ride height vehicles such as ATVs. The weight has also been lowered while maintaining strength of the joint. This can help to improve the fuel efficiency of the vehicle in the long run. To optimize the articulated angle, two types of materials has been considered: steel and aluminum and different analysis like deformation, stress and FOS has been done to generate modified shape of UV joint with reduction in weight.

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