

A Review on Optimizing Weight of Propeller Shaft using Composite Material

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ABSTRACT

Nowadays composite materials, as an alternative to conventional materials, are used in a variety of engineering applications such as spacecraft, automobiles, boats, sports equipment and structures. The automotive industry is exploiting composite material technology in order to obtain the reduction of weight, without the decrease in vehicle quality and reliability. The present study focuses on the composite propeller shaft. Using composite as a material can result in the weight reduction of the shaft without affecting any functional requirements. Literature review shows that proper design of composite propeller shaft could be achieved by selecting design variables such as layers thickness, number of layers, fibre orientation angle and layer stacking sequence, etc. This paper presents a review of information regarding the use of composite material to reduce weight of conventional steel propeller shaft.

Keywords: Composite materials, composite propeller shaft, functional requirements, stacking sequence.

I. INTRODUCTION

In recent years, engineers are trying to find an alternative solution for replacing the conventional materials. The focusing area of researchers is strength and reliability of material, which will fulfil the functional requirements. Nowadays composite materials, as an alternative to conventional materials, are used in a variety of engineering applications such as spacecraft, structures, boats, sports equipment and automobiles.

The automotive industry is exploiting composite material technology in order to obtain the reduction of weight, without the decrease in vehicle quality and reliability. While designing a vehicle, one of the most important objectives is the reduction of weight of the vehicle. There is almost a direct proportionality between the weight of the vehicle and its fuel consumption, particularly in city driving [1].

The composite material consists of fibres either continuous or non-continuous embedded in a matrix. The matrix works as a binding agent, which transfers load on the composite component to the fibres. Also, the

matrix helps to achieve the geometric arrangement of fibres. In this resulting composition, most of the load is carried out by the fibres, which result in achieving the necessary mechanical properties.

The advanced composite materials such as graphite, carbon, Kevlar and Glass with suitable resins are widely used because of their high specific modulus and high specific strength. Advanced composite materials seem ideally suited for long, power drive shaft (propeller shaft) applications [2]. There are many factors that affect the composite material properties such as fibres, materials for matrices and resins. Various manufacturing parameters such as stacking sequence, winding angle define properties that will be available with the composite material [3,4].

II. PROPELLER SHAFT

The Propeller shaft is a mechanical element, which is used to transmit torque and power. Most of the automotive vehicles consist of the arrangement in which engine is located at the front and the rear wheels of the vehicle are being driven. This results in the requirement of a longer propeller shaft. Due to this reason, in some arrangements, the propeller shaft is manufactured in two or three parts to transmit the power to the required distance.

In case of vehicles with rear wheel drive, engine torque is transmitted from engine to gearbox, through the propeller shaft to a differential, live axle and then finally to wheels. The propeller shaft is frequently incorporated with one or more universal joints to accommodate variations in the distance between driving and driven components and alignment of the shaft. In order to obtain the reduction of the weight of the vehicle without the decrease in strength and reliability, use of the composite material is an efficient alternative. Also, it is needed to optimise the composite propeller shaft so as to obtain the minimum mass along with enhanced mechanical properties by controlling the design parameters.

2.1 Demerits of Steel Propeller Shaft:

1. The conventional steel drive shaft has less strength and specific modulus. The strength of the shaft increases proportionately to the weight of the shaft.
2. Damping capacity of conventional steel drive shaft is less.
3. Corrosion resistance capacity of the conventional drive shaft is less as compared to the composite drive shaft.

III. LITERATURE REVIEW

Various authors carried out the study on design, optimization, analysis as well as experimentation in the development of composite propeller shafts. A brief review of the work carried by various researchers on the composite propeller shaft is presented as follows:

Kumar et al. [1] designed the propeller shaft assembly with the use of various materials in order to achieve the reduction in weight. The modelling of the propeller shaft assembly was done by using Catia V5 and analysis was carried out using ANSYS 10.0 Workbench for the five different materials. Comparing the factors such as

weight saving, deformation, shear stress induced and resonant frequencies, it was observed that boron is showing the most encouraging results.

Parashuram and Mangsetty [2] designed automotive drive shaft using different composite materials to reduce weight. The modelling of the propeller shaft was done by using Catia V5 and analysis was carried out using ANSYS. It was observed that there is a considerable amount of weight reduction in the range of 81% to 72% with the use of different composite materials when compared to conventional steel drive shaft. The results show that Kevlar/epoxy composite had the most encouraging properties.

Talib et al. [3] designed composite drive shafts incorporating carbon and glass fibers within an epoxy matrix. Configuration under study consists of one layer of carbon–epoxy and three layers of glass–epoxy with 0° , 45° and 90° . The results show that in changing carbon fibers winding angle from 0° to 90° , the loss in the natural frequency of the shaft was found to be 44.5%. Also, it was observed that shifting from the best to the worst stacking sequence, the propeller shaft caused a loss of 46.07% in its buckling strength, which represented the major concern over shear strength in the shaft design. On the other hand, stacking sequence has a significant effect on fatigue characteristics of the shaft.

Badie et al. [4] examined the effect of stacking sequence and fiber orientation angles on the torsional stiffness, fatigue life, buckling strength, natural frequency and failure modes of composite tubes. To predict the fatigue life of composite drive shaft (CDS) for different stacking sequence, finite element analysis (FEA) has been used. The condition of the CDS is assumed to be simply supported beam. It was observed that the natural frequency increases with decreasing fiber orientation angles as it depends on the modulus of elasticity in the longitudinal direction. The CDS has a reduction equal to 54.3% of its frequency when the orientation angle of carbon fibres at one layer, among other three glass ones, transformed from 0° to 90° . On the other hand, the critical buckling torque has a peak value at 90° and lowest at a range of 20° – 40° when the angle of one or two layers in a hybrid or all layers in non-hybrid changed similarly. Experimentally, composite tubes of fiber orientation angles of $\pm 45^\circ$ experience higher load carrying capacity and higher torsional stiffness. Specimens of carbon/epoxy or glass/epoxy composites with fiber orientation angles of $\pm 45^\circ$ show catastrophic failure mode. In a hybrid of both materials, $[\pm 45^\circ]$ configuration influenced the failure mode.

Khan et al. [5] developed a propeller shaft made of fibre reinforced plastic material (FRP). The study was carried out on various of fibre orientations with different angles as $[0^\circ, 90^\circ]_s$, $[\pm 45^\circ]_s$ and $[60^\circ]_s$ and better orientation among of the fibres was found by simulation results performed in ANSYS. After this, two propeller shafts were fabricated, one made of only glass/epoxy and the other hybrid shaft (glass/epoxy and aluminium) and performed the static test on the fabricated shafts. The results obtained show that orientation of $[\pm 45^\circ]_s$ was found to be better for the composite drive shaft when compared to conventional steel drive shaft

Bandgar and More [6] designed and built a single piece hybrid propeller shaft in order to replace two-piece conventional steel propeller shaft. They designed hybrid propeller shaft by using classical laminate theory. The study was carried out on the hybrid propeller shaft consisting of a composite of carbon fibre and epoxy resin and aluminium as the material. The hybrid propeller shaft was incorporated with four layers stalked as $[90^\circ/+45^\circ/-$

45°/20°]s and then aluminium is used on it. Finite element analysis was carried out to find static and modal analysis results. Modal analysis has been carried out for finding the natural frequency. Experimental set up was used to find static results, torsion behaviour and the natural frequency of hybrid drive shaft. The percentage of mass saving was 73.38 % by using hybrid drive shaft as compared to steel drive shaft.

Pallavi et al. [7] investigated the static and dynamic analysis of steel propeller shaft and composite propeller shaft made of glass fibre reinforced polymer. The Angle of twist and natural frequency were the design constraints. Finite element analysis of the composite propeller shaft was carried out by using finite element technique. Analytical results were compared with experimental results. The composite propeller shaft is found to have better torque carrying capacity and natural frequency when compared to steel propeller shaft with 37.9 % weight reduction.

Mutasher [8] designed and built the hybrid aluminum/composite shaft for different winding angle, number of layers and stacking sequences. The hybrid shaft consisting of aluminium tube wound outside by E-glass and carbon fibers/epoxy composite was analyzed for static torsion using ANSYS. A full-scale hybrid specimen was analyzed. It is concluded from the results that the static torque capacity had significantly affected by changing the winding angle, stacking sequences and number of layers. It was observed that shaft with 45° fibre orientation can withstand higher static torque compared to the 90° fibre orientation.

Gay D. [9] gives the information regarding the detailed study of composite materials and its properties. It provides properties of composite laminates for various types of fibre materials. It also provides information regarding basic design procedures for various applications.

Sino R. et al. [10] studied the dynamic instability of an internally damped rotating composite shaft. The author developed simplified homogenized beam theory (SHBT). This theory is then compared to the classical equivalent beam modulus theory (EMBT) as well as the layer-wise beam theory (LBT) and the modified equivalent beam modulus theory (modified EMBT). It was observed that the critical speeds obtained by the method developed are in good accord with those obtained by modified EMBT as well as the experimental one. The analysis shows that the first frequencies were not much influenced by the transverse shear but there is a significant effect on the following ones, thereby directly influencing instability thresholds.

Kaw A. K. [11] gives the information regarding the detailed study of composite materials, manufacturing of composite materials, failure theories as well as the design of laminated composites in various applications where composite material can be used as an alternative.

IV. CONCLUSION

The study and investigations carried out by various researchers provide the information on the composite materials, their properties as well as basic design procedure. It was noted that the theoretical, numerical as well as experimental investigation carried out by various authors provides insights into the effect of fibre orientation, the number of layers, stacking sequence and other design variables on torque transmission capacity, buckling, natural frequency, fatigue characteristics of the composite shaft. Practical strength or properties of composite material differs from theoretical one. So, prior to its use in further design or analysis, it is recommended to find

out properties of composite materials by performing standard testing methods. Buckling being dominating strength parameter, it is needed to find ways to enhance buckling strength as it adversely affects other parameters such as natural frequency, fatigue behaviour, etc.

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