Optimization and FEA Analysis of Centrifugal Pump Shaft

Amolkumar D. Lonkar[1] Prof. Anurag V. Karande[2]
[1]M.E. Student [2]M.Tech. Student
[1,2]Department of Mechanical Engineering
[1,2]DGOIFOE, Swami-Chincholi, Pune

Abstract— This paper deals with the optimization and FEA analysis of centrifugal pump shaft using structural steel and composite material. Nowadays composite materials are gaining worldwide attention due to its low cost and high reliability. The weight optimization of the shaft is carried out. Deflection in shaft, natural frequency and life of both materials calculated. The von misses' stresses are also calculated in the shaft for both the materials and the best suitable material is selected for centrifugal pump shaft.

Key words: FEA Analysis, Centrifugal Pump Shaft

I. Introduction

Nowadays composite materials are gaining worldwide attention due to its low cost and high reliability. Shaft is the rotating member of the centrifugal pump which is driven by the motor. The impeller and bearing are the mounted on the Shaft. Due to this shaft is subjected to both torsion and bending. Due to repetitive loading there are chances of failure of the shaft. Hence shaft is the primary component of centrifugal pump which transmits power. The FEA analysis of the shaft is done using structural steel and composite material considering all the important factors.

The objective of our project is to optimization of centrifugal pump drive shaft. The weight reduction of the drive shaft can be achieved using composite material without increase in cost and decrease in quality and reliability. It is possible to achieve design of composite shaft with less weight to increase the first natural frequency of the shaft.

II. Material selection & properties

A. *Material of Shaft – Structural Steel:*

Mechanical properties	Steel	Units
Young's Modulus	207	GPa
Shear modulus	80	GPa
Poisson's ratio	0.3	-
Density	7600	Kg/m3
Yield Strength	370	MPa

Table 1: Material Properties of Structural steel

B. *Specification of Composite Material:*

The specification of composite drive shaft for an automobile is same as of steel drive shaft for an optimum design. Classical lamination theory was used for design of composite drive shaft.

1) Selection of Material:

Carbon Fiber (Panex 35):

A carbon fiber is a long, thin strand of material about 0.0002-0.0004 in (0.005-0.010 mm) in diameter and composed mostly of carbon atoms. The carbon atoms are bonded together in microscopic crystals that are more or less aligned parallel to the long axis of the fiber. The crystal alignment makes the fiber incredibly strong for its size. Several thousand carbon fibers are twisted together to form a yarn, which may be used by itself or woven into a fabric. The yarn or fabric is combined with epoxy and wound or molded into shape to form various composite materials. Carbon fiber and matrix is used in this case in the proportion of 60:40 volume fraction.

Panex® 35 continuous carbon fiber is manufactured from polyacrylonitrile (PAN) precursor. The consistency in yield and mechanical properties that are provided by large filament count strands gives the user the ability to design and manufacture composite materials with greater confidence and allows for efficient and fast buildup of carbon fiber reinforced composite structures. Material properties of Carbon fiber (Panex 35) are as follows.

Mechanical properties	Value	Units
Tensile Strength	4137	MPa
Tensile Modulus	242	GPa
Electrical conductivity	0.00155	ohm-cm
Density	1.81	g/cc
Fiber Diameter	7.2	microns
Carbon content	95	%
Yield	270	m/kg
Spool weight	5.5 / 11	kg
Spool Length	1500 /3000	m

Table 2: Material Properties of Carbon Fiber. (Panex 35)

Epoxy resin

Epoxy resins are polyether resins containing more than one epoxy group capable of being converted into the thermoset form. These resins, on curing, do not create volatile products in spite of the presence of a volatile solvent. Different classes of epoxy resin are available such as Bisphenol A epoxy resin, Bisphenol F epoxy resin, Novolac epoxy resin, aliphatic epoxy resin, curing epoxy resin.

Mechanical Property	Value	Units
Tensile Strength	81	MPa
Tensile Modulus	3.45	GPa
Specific Gravity	1.34	g/cc
Poisson's ratio	0.3	-
Shear Strength	1.34	MPa
Shear Modulus	1.3269	GPa

Table 3: Material Properties of Epoxy Resin (Hexcel Hexply EH04 Epoxy Resin)

2) Mechanical Analysis of Lamina:

1) Volume fraction of fibre – 0.7 (60%)
2) Volume fraction of matrix – 0.3 (40%)
3) Volume of composites – 1 (100%)

Using the formula of micromechanical analysis of lamina following properties are calculated

Density of composite

$$\rho_c = \rho_f V_f + \rho_m V_m$$

From above table, we know

ρ_f = 1810 kg/m^3, ρ_m =1340 kg/m^3

$$\rho_c = 1810 \times 0.6 + 1340 \times 0.4$$
$$\rho_c = 1622 kg / m^3$$

III. ANALYTICAL RESULTS

A. Deflection of Shaft Due to Self-Weight (Δ1):

Deflection due to self-weight is given by,

$$\delta_1 = \frac{5WL^4}{384EI}$$
$$\delta_1 = \frac{5*1068.837115*1507.093^4}{384*210*10^9*1.5558*10^{-5}}$$
$$\delta_1 = 2.1974*10^{-5} m$$

B. Deflection of Shaft Due To Impeller Weight (Δ2):

Deflection due to self-weight is given by,

$$\delta_2 = \frac{WL^3}{48EI}$$

$= (1610.833728*1507.093^3) / (48*210*10^9*1.5558*10^{-5})$

$$\delta_2 = 1.2847*10^{-5} m$$

C. Total Deflection (Δ):

$$\delta = 3.4822*10^{-5} m$$

D. Mass of Steel Drive Shaft:

$$m = \rho AL$$
$$m = \rho \times \frac{\pi}{4}(d_o^2 - d_i^2) \times L$$
$$m = 7600 \times \frac{\pi}{4}(0.075^2 - 0.06912^2) \times 1.3$$
$$m = 6.575 kg$$

E. Mass of Composite Drive Shaft:

$$m = \Pi (r_0^2 - r_i^2) L \rho$$
$$m = \Pi (0.0375^2 - 0.0360^2)(1.3)(1622)$$
$$m = 0.7303 Kg$$

Percentage of mass saving over steel is

$$= \frac{6.575 - 0.7303}{6.575} \times 100$$
$$= 88.89\%$$

IV. NUMERICAL RESULT (FEA ANALYSIS)

A. Composite Material:

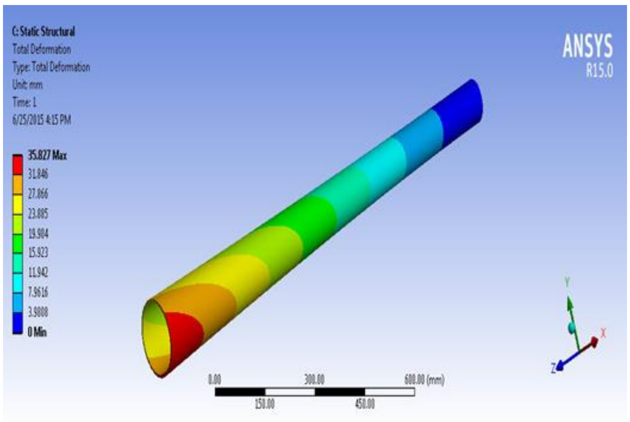

Fig. 1: Total Deformation in shaft for composite material

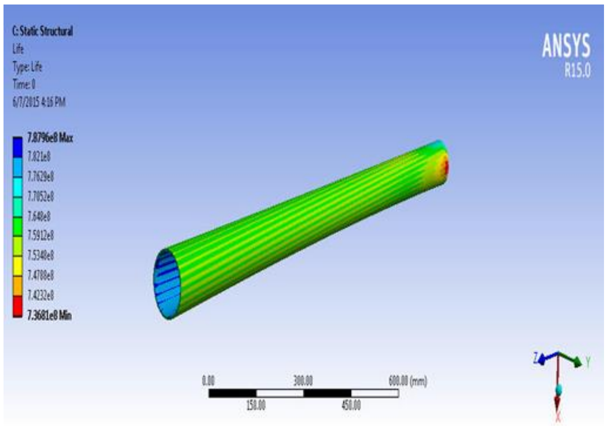

Fig. 2: Von-Mises stresses in shaft for composite material

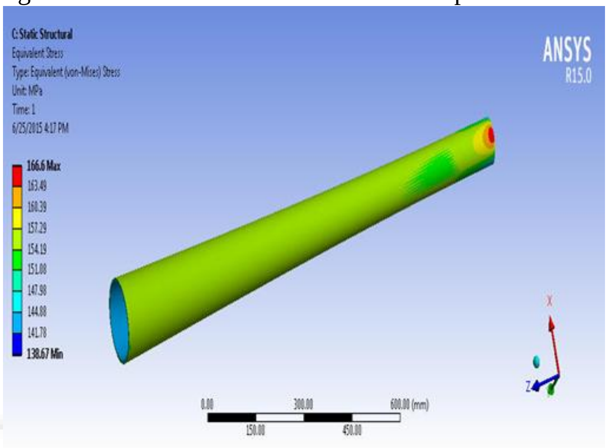

Fig. 3: Life of Shaft for composite material

V. CONCLUSION

We can conclude that the deflection occurred in the shaft for composite material is less as compared to stainless steel. The life of the shaft is more for composite material than for structural steel. Weight of composite shaft is much lesser than structural steel shaft. We can choose composite material over stainless steel due to its low cost and better results compared to stainless steel.

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