Journal of Mechanical Engineering Research and Developments
ISSN: 1024-1752
CODEN: JERDFO
Vol. 44, No. 6, pp. 169-176
Published Year 2021

Effect of diameter on the critical speed of a composite shaft under dynamic load

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ABSTRACT

The effect of changing the shaft diameter on the dynamic load of the response system was investigated in this paper. Composite material columns (high polyester and fiberglass type) with a volume fraction of Vf = 40% was used in this work. Three composite samples are produced using a glass mold and a capillary tube using the injection process, with diameters of 6 mm, 9 mm, and 14 mm with constant length. The device used to measure critical speed was (TQTM1 system) with different boundary conditions. The results show that, first and second mode shape for all specimens except specimen (6 mm) diameter appearance third mode shape in value (106.63) Hz. The value of critical speed increase when transmission from first mode to second mode. appearance differed between experimental and theoretical values of critical speed. The critical speed depends on the state of fixed.

KEYWORDS

dynamic load, Composite material, boundary, transmission

INTRODUCTION

Since the dawn of civilization, composite materials have been regarded as the perfect materials for use as a good replacement for other materials (metals, polymers, ceramics).[1] As a result, several studies have been conducted to strengthen it. The composite driveshaft, which replaces the traditional steel driveshaft in an automobile power train, has been studied in an attempt to optimize the design parameter. The parameter such as ply thickness is calculated using the Genetic Algorithm (GA). The number of plies and stacking sequence for E-glass/ epoxy and boron/epoxy shafts using (GA) were optimized with the aim of reducing the weight of the composite shaft that is being tested. As a result, they conclude (Drive shafts made of E-Glass/ Epoxy and Boron/Epoxy multilayered composites have been designed, and the designed drive shafts have been optimized using GA for better torque transmission capability and bending vibration characteristics. As compared to a steel shaft, the use of composite materials and optimization techniques resulted in a significant weight savings of 48 percent to 86 percent, and the stresses and strains along the thickness of the shaft were found to be within the permissible limit [2].

Studying the whirling speed of the shaft of the ship where in the paper the Power generated from the engine was transmitted to the propeller with two way directly/indirectly by used gearbox. degree of freedom on this study was considered including engine, propeller, gearbox, flywheel and etc. connecting by using the shaft. Whiling speeds of the shaft were determined at different conditions as the effect of the shaft diameter and the shaft torsional stiffness were presented and discussed.[3] presented a vibration analysis and a design method of a (carbon/epoxy) composite drive shaft. several parameters were studied as critical speed, fibre orientation, static torque and adhesive joints the modal analysis and critical speed analysis were carried out used ANSYS. The results showed the significant points about design of composite drive shafts. The used of composite drive shaft has resulted in redused weight reduction about (72%) compared when used conventional steel shaft.[4] to sum up the number of carbons fiber layers had an impact on the value of fundamental natural frequencies of the shaft obtained by combining aluminium and composite material, and the fundamental natural frequencies had a significant value if the orientation angle of the carbon fibers was 0.

The benefit of composite over classical metal shaft is a biased limit for the critical value of fundamental natural frequencies and the critical speed, according to a comparison of the critical speed of steel, aluminium, and hybrid aluminium/carbon fibers/epoxy composite shaft. This means that, as opposed to steel shafts, composite shafts can work at higher speeds and frequencies.[5] formulated the analytical expression is based on the modified laminated plate theory, which takes into account the laminate's tubular wall curvature. It is discovered that the existing method's axial deformation and twisting angle calculations agree well with the finite element method's results. Finally, he says the analytical model's results are compared to those obtained using the finite element form. The following conclusions can be drawn from this study. The axial stresses and shear stresses for each ply are also very similar to the results obtained using the finite element process. Angle of twist can be reduced by using 45° plies. By integrating near 0° plies, axial deformation of composite tubes can be reduced, and tubes with a lower taper angle can be used to reduce deformations in structural applications.

EXPERIMENTAL WORK

Glass fibre in the form of filaments was used in this study, as shown in FIGURE(1-a). Polyester resins are low-cost, quick-processing resins that are commonly used in low-coast applications. The glass pipes that are used as mold castings and to achieve a good surface finish, as shown in FIGURE (1-b), have a length of 780 mm and an inside diameter range of (6, 9, 14) mm. The injection is used to inject the Resin inside the glass pipe through elastic pipe Figure (1-c)[6,7,8].

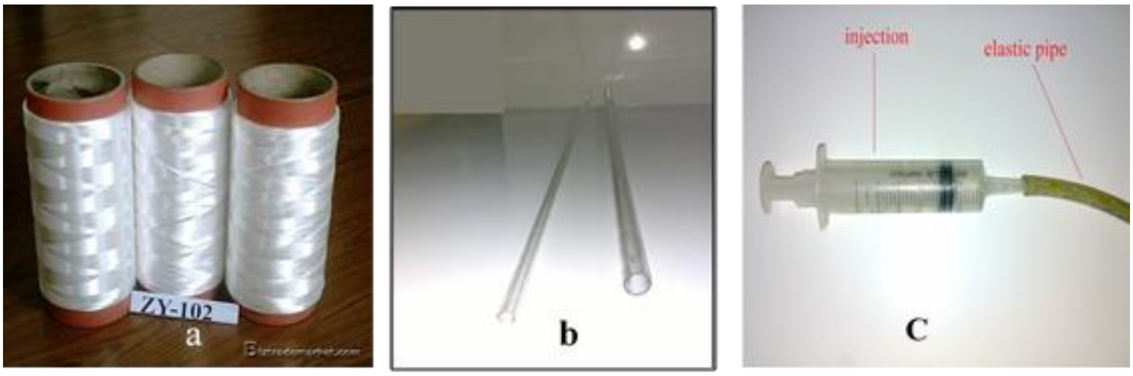

Figure 1. (a) Fibre glass (b) glass pipe (c) Big injection

The first step in the casting process is to apply an insulating material to the pipe's inner wall. The steps outlined below were used to create the assignments [8,9,10].

Insert the fibre as a longitudinal system inside the pipe, attempting to tighten it to the pipe's centre Figure(2)[11 ,12,13]

Figure 2. A fiber and glass pipe

Place the glass pipe in a vertical position and slowly inject the resin into the glass pipe from the lower end until the glass pipe is fully filled with resin as shown in the Figure(3). After that, seal both ends of the glass pipe. After two days, break the glass pipe and get the composite material shaft.[14,115,16]

Figure 3. The injection processes

The adapters are rotating, and they link the device's motor shaft to the composite shaft, as seen in the Figure 4.

Figure 4. The adapters

The turner fabricates the adapters with his machine. The measurements of the adapters are determined by the fixtures of the device's stander shaft. Around 15mm from both ends of the shaft to the catcher.

Investigation results

Calculate the Young's Modulus of Elasticity (E) of a composite shaft using static deflection of a simple support beam. This approach involves mounting the shaft on two supports, exposing it to various weights at its center, and measuring the deflection with a dial gauge. Shows in Figure(5)

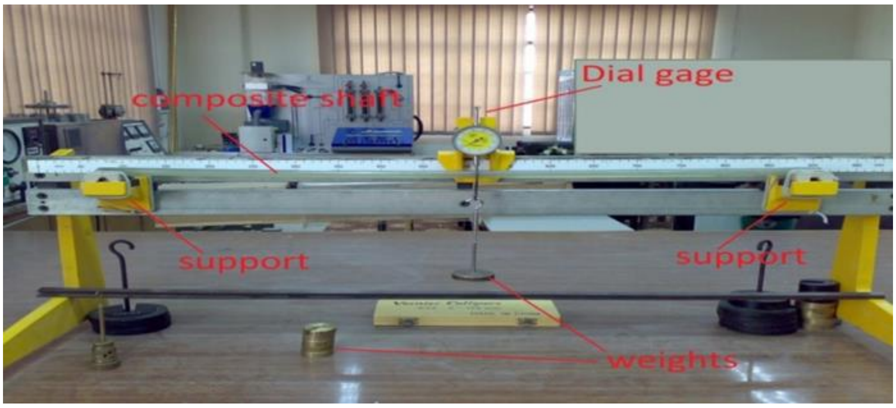

Figure 5. Simply support beam.

After take the values of the deflection, take its mean rang then have mean deflection (δ mean) and then apply equation 1:

$$\delta = \frac{PL^3}{48EI} \tag{1}$$

The system is a TQ TM1 whirling of shafts as shown in Figure(6), which helps elastic theory to predict the actual whirling configuration. [17] Which is intended to prevent the motor from transmitting any restraining force to the shaft.

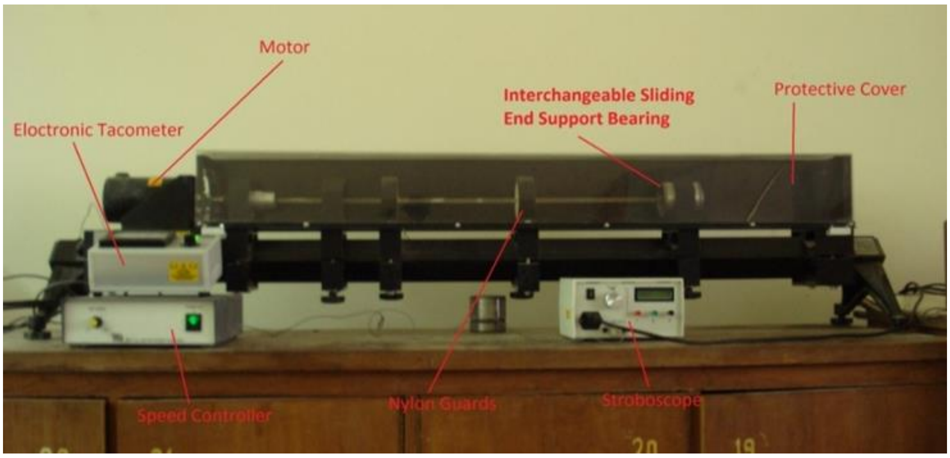

Figure 6. Whirling of shaft device.

Two nylon guards are provided and adjustable along the length of the system due to the risk of excessive amplitudes and potential shaft failure. The sliding end bearing support can be rotated to accommodate different shaft lengths. There are additional parts to the unit.

1- **Stroboscope:** The TQ stroboscope is a transistorized device that is completely portable. The TQ TM1 has an output plug that provides the signal needed to activate the stroboscope. as seen in the Figure(7).

2- **Tachometer Output Socket:** The TQ TM1 has a tachometer output socket that, when connected to TQ's E64 Electronic Tachometer, provides a direct readout of the shaft's rotational speed.

3- **Motor speed controller:** The TQ TM1 has a motor speed controller output socket where the motor speed can be adjusted by increasing or decreasing the speed.

Figure 7. Device unit

The shafts are about 78cm long and have diameters of (6, 9, 14) mm. According to the tests, first run the shaft through the nylon guards, then through the catchers that run through the center hole of the bearing assembly, and then locked at both ends, then close the protective cover. The speed controller should then be turned on and the control knob slowly rotated clockwise. The shaft speed will increase until it reaches a point where instability appears, indicating that the critical speed is approaching. The tachometer is used to calculate the shaft's rotational speed, and the stroboscope should be turned on and set to internal mode. The value of frequency at which the excessive amplitudes begin and then fade away, i.e. the limits of the band of frequencies containing the critical speed, is one method of determining the critical speed. Shows in Figure(7). After determining the first whirling speed, raise the speed to see the amplitude fade away and the shaft's stability return. When the speed is increased, a double bow appears, indicating that the second mode shape has been reached, as shown in FIGURE (7). The above method can be repeated to determine the critical speed of the second mode shape.[18].

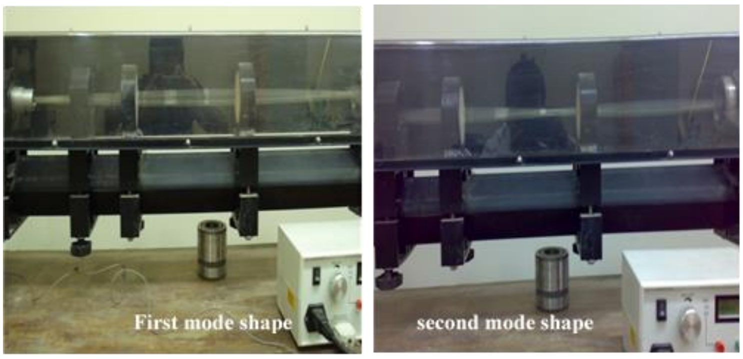

Figure 7. Mode shape

RESULTS AND DISCUSSIONS

Deflection result

Every shaft a tempt to three type of experiments (fixed-fixed at both ends, fixed-free at ends and free-free at both ends). The values that take out from static deflection on simply support beam are there:

Table 1. Result of static deflection.

Run	Weight g	δ mm
1	200	0.15
2	300	0.81
3	400	1.31
4	500	1.95
5	600	2.65
6	700	3.26

The above table shows the deflection of the shaft (diameter 14 mm) with a series of weight apply on the shaft's center, and the same procedure apply with the shaft about 6 mm and 9 mm.

Young's Modula's results

applied equation (1) to determined young modules E, taken, Diameter 14 mm, Mean weight=450 g ,δ mean=1.688 m

$$\delta = \frac{PL^3}{48EI}$$ *Then* *E*=13.7 G P

the same procedure to calculate *E* done with shafts 9 mm and 6 mm , Table (2) shows value of Young's Modula's of Elasticity (E) for the three shafts.

Table 2. Values of *E*.

Shaft Diameter mm	*E* GPa
14	13.7
9	14.5
6	15.3

The equation (1) has a constant value there are (P&L) there for the equation can be written as:

$$\mathrm{E}\alpha\frac{1}{\delta I} \tag{2}$$

When value of δ or I increase then E decreasing therefore the relation shape is reversible shape as can see in equation (2). But the value of Young's Modula's of Elasticity is property of the material don't change with changing the engineering dimension of the piece, the value of Young's Modula's of Elasticity that take out from static deflection is changing with diameter change, that change is because of many reasons there are presence many bubbles inside the shaft, and the fiber is not arrange fully inside the shaft and may be reading of Dial gage is not exactly. That reasons are effect on deflection value then effect in equation (2), there for the value of Young's Modula's of Elasticity is changing.

There for in this test will take the mean value of Young's Modula's of Elasticity of the three shafts to reduce the error.

$$E_{mean} = \frac{15.3+14.5+13.7}{3} \quad , \quad E_{mean}=14.5 \text{ G pa}$$

Natural Frequency

Dunkerley deduced that the whirling speed were equal to the natural frequencies of transverse vibration, there being the same number of whirling speeds as natural frequencies for a given system. thus, a theoretical value for the critical speed may be obtained from the formula for the fundamental frequency of transverse vibrations.[19,20,21]

$$f = \sqrt{\frac{EIg}{wL^4}} * C \tag{3}$$

The value of C is that resultant from various end condition, the values are shown in table (3).

Table 3. Values of C1&C2

Case	**Ends**	**C1**	**C2**
1	Free-fixed	2.459	7.96
2	Fixed-fixed	3.75	8.82
3	Free-free	1.572	6.3

The value C_1 is the constant for use in calculating the first natural frequency and C_2 is that necessary for the second mode, for <u>Case 1 end condition (free-fixed):</u>

$$f_1 = \sqrt{\frac{14.5*10^9*3.14*(0.006)^4*9.18}{0.363*64*(0.78)^4}} * 2.459$$

f_1=20.17 Hz =1210.2 rpm

similarly to find the second critical speed, f_2 the same formula is used, but with C_2=7.96 thus: f_2=65.3 Hz =3918 rpm

When operating the specimen under dynamic load, see appearance first mode through the test until appearance second mode shape, except specimen (6 mm) diameter see appearance third mode shape in frequency (106.63) Hz in (Free-Fixed) end state, that is due to high flexibility compared to other specimens. Reading the experimental results for the values of frequency for the first and second modes for the shaft around (6) mm for (free-fixed) state fixture, it was discovered that the value of frequency in the first mode (20.17) Hz, which increased with an increase in the angular velocity of the shaft until it reached (65.3) Hz in the second mode, as shown in the table (3), for all specimens, increasing the angular velocity leads to an increase in the critical speed, and for all specimens, the value of stiffness relative to the mass leads to an increase in the critical speed, which leads to an increase in the amplitude.

When compared the experimental values and the theoretical values that take out from equation (2) in chapter four noted differed between there in the values of critical speed as it can see in table (3), the differed because of main reasons there is presence many bubbles inside the shaft, and the fiber is not arranged fully inside the shaft and the of the fixture is not conformant on the centre line of the shaft that led to unbalance happened in the shaft when it rotates. By compared the cases of fixes for all shafts that used in the test see that values of frequency appearance in largest value in case (fixed-fixed) and it decrease in case (free-fixed) and then decrease more in case (free-free), it means the critical speed happened faster in the third case where the shaft was free to take the shape of the wave in low speed this state happened in both first and second mode. The speed controller has a maximum value (10000) rpm and when arrived at this value the specimen's dose not fails, which means the speed can be increased more than (10000) rpm, and the shafts still durable.

CONCLUSIONS

1. Appearance first and second mode shape for all specimens except specimen (6 mm) diameter appearance third mode shape in value (106.63) Hz.
2. The value of critical speed increase when transmission from first mode to second mode.
3. Appearance differed between experimental and theoretical values of critical speed.
4. The critical speed depends on the state of fixed.

ACKNOWLEDGMENTS

The authors (Adil Abed Nayeeif, Hyder Abdual khaliq ali,Fadhel Abbas Abdulla and Zahra Khalid Hamdan,) would like to thank Mustansiriyah University (www.uomustansiriyah.edu.iq) Baghdad-Iraq for its support in the present work.

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