Problems of Practices
Of
Mechanics of Solids
15- Members Subjected to Torsional Loads

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1. A torque transmitting solid steel shaft of 100 mm diameter is replaced by a hollow one of the same material having its outside diameter twice its inside diameter. Maximum stress in the hollow shaft remain same as that in the solid one. Compare torsional rigidity of the two shafts.

2. The pulley *A* excites a torque on the shaft *B* as shown in Fig. 4. The total vertical tension in both sides of the belt on each pulley is 400 kgf. The dia. of the shaft is 6 cm. If the tensile and shear stress intensities are not to exceed 3200 kgf/cm^2 and 1600 kgf/cm^2 respectively, what is the maximum power that can be transmitted by the shaft when running at 150 r.p.m.? The shaft may be assumed simply supported at the bearings.

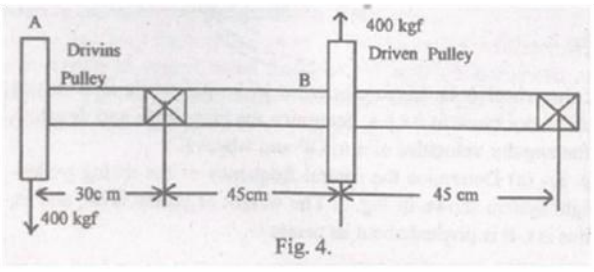


Fig. 4.

3. A brass tube fits closely over a steel shaft of 100 mm diameter. Find the thickness of the brass tube which would ensure that the torque applied to the assembly is shared equally by the two materials. Find maximum shear stress in each material and the angle of twist in a length of 3 m. The torque applied is equal to 20×10^4 kgf-cm. Assume modulus of rigidity (steel) = 8×10^5 kgf/cm^2 modulus of rigidity (brass) = 4×10^5 kgf/cm^2.

4. The steel shaft of Fig. 5 is in equilibrium under the torques shown.

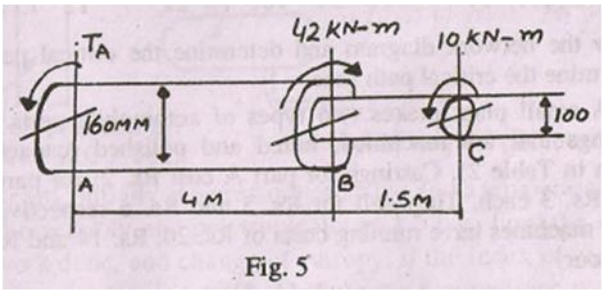


Fig. 5

Determine—

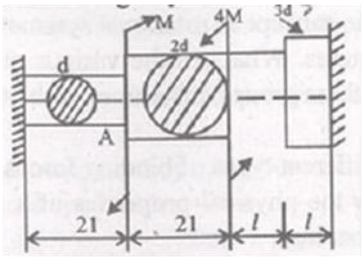
(i) the maximum shearing stress in the shaft;

(ii) the angle of twist of end *B* of the 160 mm segment with respect to end *A*;

(iii) the angle of twist of the end *C* with respect to end *A*.

The modulus of rigidity is 80 GPa.

5. For the shaft loaded as shown in Fig. 4, calculate the maximum shear stress induced and the angle of twist for cross-section *A*. Value of modulus of rigidity is *G*.



6. Obtain the angle of twist of one end relative to the other of a tapered shall having radii r_1 and r_2 at its ends and of length *l*. The shaft is subjected to equal and opposite torque *T* at its ends. Modulus of rigidity of the shaft material is *G*.

7. A solid circular uniformly tapered shaft of length *l*, with a small angle of taper is subjected to a torque *T*. The diameter at the two ends of the shaft are *d* and 1.2*d*. Determine the error introduced if the angular twist for a given length is determined on the basis of the uniform mean diameter of the shaft.

8. Determine the torsional stiffness of a hollow shaft of length *L* and having outside diameter equal to 1.5 times inside diameter *d*. The Shear modulus of the material is *G*.

9. A mild steel shaft of 200 mm diameter is to be replaced by a hollow shaft of alloy steel for which the allowable shear stress is 25% greater. If the power to be transmitted is to be increased by 20% and speed of rotation increased by 5%. Determine the maximum internal diameter of the hollow shaft taking its external diameter to be limited to 200 mm.

10. The ratio of inside to outside diameter of a hollow shaft is 0.6. If there is a solid shaft with same torsional strength, what is the ratio of the outside diameter of hollow shaft to the diameter of the equivalent solid shaft?

11. A hollow shaft with diameter ratio 0.7 is required to transmit 500 kW at 300 rpm with a uniform twisting moment. Allowable shear stress in the material is 65

N/mm² and the twist in a length of 2.4 m is not to exceed one degree. Calculate the minimum external diameter of the shaft satisfying these conditions. Modulus of rigidity = 8.2×10^4 N/mm².

12. A stepped shaft *ABC*, is 0.8 m long. For a length *AB* = 0.4 m, shaft diameter is 40 mm and for length *BC* = 0.4 m, shaft diameter is 20 mm. Shaft is fixed at both the ends *A* and *C*. At the Section *B*, a torque *T* is applied which causes a maximum shear stress of 100 MPa in stepped shaft. Determine the magnitude of torque *T*.

13. A hollow shaft of diameter ratio 3/8 is required to transmit 600 kW at 110 rpm, the maximum torque being 20% greater than the mean. The shear stress is not to exceed 63 MN/m² and the twist in a length off 3 m not to exceed 1.4 degrees. Determine the diameter of the shaft. Assume modulus of rigidity for the shaft material as 84 GN/m².

14. A solid phosphor bronze shaft 60 mm in diameter is rotating at 800 rpm and transmitting power. It is subjected to torsion only. An electrical resistance strain gauge mounted on the surface of the shaft with its axis at 45° to the shaft axis, gives the strain reading as 3.98×10^{-4}. If the modulus of elasticity for bronze is 10^5 GN/m² and Poisson's ratio is 0.3, find the power being transmitted by the shaft. Bending effect may be neglected.

15. A solid circular shaft running at 110 r.p.m. is used to transmit a power of 30 kW and produces safe stress of 80 N/mm². Find the diameter of shaft. If this shaft is replaced by a hollow shaft having ratio of external diameter to internal diameter of 2, what percentage saving of weight can be achieved, the length and material of the shafts remain same?

16. A hollow shaft has greater strength in bending and higher stiffness in torsion than a solid shaft of equal weight and same material. Discuss.

17. A hollow shaft having an inside diameter 60% of its outside diameter is to replace a solid shaft transmitting same power at same operating speed. Determine the percentage saving in material, if the material to be used for both the cases is also the same.

18. Two hollow shafts of same diameter are used to transmit same power. One shaft is rotating at 1000 rpm while the other at 1200 rpm. What will be the nature and magnitude of the stress on the surfaces of these shafts? Will it be the same in two cases or different? Justify your answer.

19. A solid circular steel shaft is encased in a hollow copper shaft so as to make a compound shaft. The diameter of the steel shaft is 8 cm and the outside diameter of the copper shaft is 11 cm. The compound shaft of length 2 m is subjected to an axial torque of 8 kNm.
Determine the maximum shear stress in steel and copper.
Given: $G_{steel} = 2\ G_{copper} = 80$ kN/mm².

20. A solid shaft is to transmit 300 kW at 120 r.p.m. If the shear stress is not to exceed 100 MPa, find the diameter of the shaft. What percent saving in weight would be obtained if this shaft were replaced by a hollow one whose internal diameter equals 0.6 of the external diameter, the length, material and maximum allowable shear stress being the same?

21. Compare the weights of equal lengths of hollow and solid shaft to transmit a given torque for the same maximum shear stress if the inside diameter is 2/3 of the outside.

22. A hollow shaft and a solid shaft constructed of the same material have the same length and the same outside radius. The inside radius of the hollow shaft is 0.6 times of the outside radius. Both the shafts are subjected to the same torque.

(i) What is the ratio of maximum shear stress in the hollow shaft to that of solid shaft?

(ii) What is the ratio of angle of twist in the hollow shaft to that of solid shaft?

23. In a torsion test, the specimen is a hollow shaft with 50 mm external and 30 mm internal diameter. An applied torque of 1.6 kN-m is found to produce an angular twist of 0.4° measured on a length of 0.2 m of the shaft. The Young's modulus of elasticity obtained from a tensile test has been found to be 200 GPa. Find the values of

(i) Modulus of rigidity,

(ii) Poisson's ratio.

24. Determine the ratio of the maximum shear stress in the hollow shaft to that in the solid shaft for the following data:

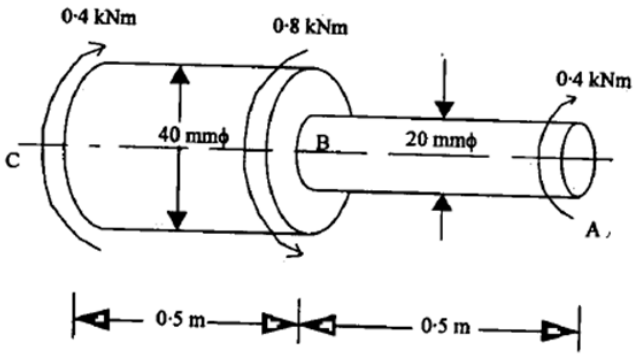
The two shafts are constructed of the same material and have the same length, and same outside radius r. The inside radius of the hollow shaft is $0.6r$. Assume that both shafts are subjected to the same torque.

25. A hollow shaft having an inside diameter 50% of its outer diameter is to replace a solid shaft transmitting the same power at the same speed. Calculate the percentage saving in material if the material to be used is also the same.

26. Compare the weights of equal lengths of hollow and solid shaft to transmit a given torque for the same maximum shear stress if the inside diameter is 2/3 of the outside diameter.

27. A stepped shaft ABC, 1 m long made of steel is of diameter 20 mm from A to B = 0.5 m, 40 mm from B to C = 0.5 m. It is subjected to twisting moments 0.4 kNm (cw) at A, 0.8 kNm (ccw) at B and 0.4 kNm (cw) at C.

If G = 84 kN/mm^2 determine angular twist between A to C.



28. A hollow cylindrical steel shaft is 1.5 m long and has inner and outer diameters equal to 40 mm and 60 mm respectively.

(i) What is the largest torque that can be applied to the shaft if the shearing stress is not to exceed 150 MPa?

(ii) What is the corresponding minimum value of the shearing stress in the shaft?

29. A hollow steel shaft 60 mm internal and 100 mm external diameter is to be replaced by a solid alloy shaft. If the polar modulus has the same value for both, calculate the diameter of the latter and the ratio of their torsional rigidities. Shear modulus G for steel = 2 times the G for the alloy.

30. A bar of steel is 50 mm in diameter and 600 mm long. A tensile load of 150 kN is found to stretch the bar by 0.23 mm. The same bar, when subjected to a torque of 1.4 kN-m is found to twist through 1°. Find the values of the four elastic constants.

31. What size of shaft should be used for the rotor of a 3.5 kW motor operating at 3600 rpm, if the shearing stress is not to exceed 58 MPa in the shaft?

32. A solid shaft of diameter d is used for power transmission. Due to modification of the existing transmission system, it is required to replace the solid shaft by a hollow shaft of the same material and equally strong in torsion. Further the weight of the hollow shaft per metre length should be half that of the solid shaft. Determine the outer and inner diameters of the hollow shaft if diameter of solid shaft, d = 40 mm.

33. A solid aluminium shaft 1 m long and 50 mm diameter is to be replaced by a tubular steel shaft of the length and the same outside diameter (i.e., 50 mm) such that each of the two shafts could have the same angle of twist per unit torsional moment over the total length. What must the inner diameter of the tubular steel shaft be? The modulus of rigidity of steel is three times that of aluminium.

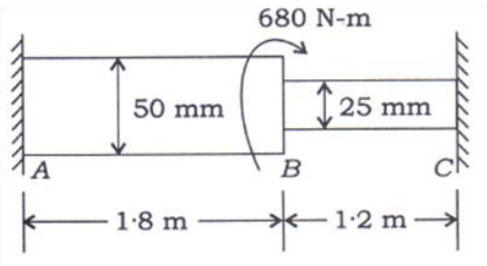
34. A shaft is required to transmit 40 kW at 300 r.p.m. The maximum torque may be 1.5 times the mean torque. The allowable twist is 1° per m length of the shaft. Determine the diameter of the solid shaft.

35. A steam turbine delivers 8200 kW of power at 1800 r.p.m. This power is received by a shaft coupled with the turbine. This shaft delivers this power to the other shaft through gear reduction unit at 90% efficiency. The other shaft rotates at 107 r.p.m. Determine the diameters of both the solid shafts. Take allowable shear stress as 3.45×10^8 N/m^2. Further, if these shafts are replaced by hollow shafts with internal diameters half of the outer diameter, determine the internal and external diameters of both the shafts.

36. A shaft is rotating at 150 rpm and it transmits power of 300 kW. The diameter of the shaft is 100 mm, What is the magnitude of torsional shear stress and the twist if the maximum torque is 25% more than the mean torque? The length of the shaft is 1.5 m. Given G = 85 GPa.

37. Two shafts of the material and of same lengths are subjected to same torque. If the first is of a solid circular section and the second shaft is of hollow circular section, whose internal diameter is 2/3 of the outside diameter and the maximum shear stress developed in each shaft is the same, compare weights of the shafts.

38. A circular bar *ABC*, 3 m long is rigidly fixed at its ends *A* and *C*. The portion *AB* is 1.8 m long and of 50 mm diameter and *BC* is 1.2 m long and of 25 mm diameter. If a twisting moment of 680 N-m is applied at *B*, determine the values of the resisting moments at *A* and *C*, and the maximum stress in each section of the shaft. What will be the angle of twist of each portion? Take the value of G for the shaft material as 80×10^9 N/m^2. The appearance of the shaft (bar) is shown in the figure below:



39. A solid shaft of diameter d is used in power transmission. Due to the modification of existing transmission system, the solid shaft is required to be replaced by a hollow shaft of the same material and equally strong in torsion. The weight of the hollow shaft per unit length is to be half of the solid shaft. Determine the outer diameter of the hollow shaft in terms of d.