5.1 (S) A rectangular plate, 15 mm thick, made of a brittle material is shown in Fig. 5.58. Calculate the stresses at each of three holes of 3, 5 and 10 mm diameter. [LO 1]

[Ans. 161.82, 167.33 and 200 N/mm^2]

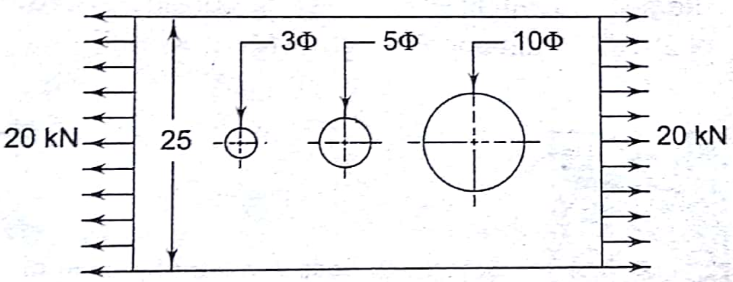

Fig. 5.58

5.2 (M) A round shaft made of a brittle material and subjected to a bending moment of 15 N-m is shown in Fig. 5.59. The stress concentration factor at the fillet is 1.5 and the ultimate tensile strength of the shaft material is 200 N/mm^2. Determine the diameter d, the magnitude of stress at the fillet and the factor of safety. [LO 1]

[Ans. 11.76 mm, 140.91 N/mm^2, and 1.42]

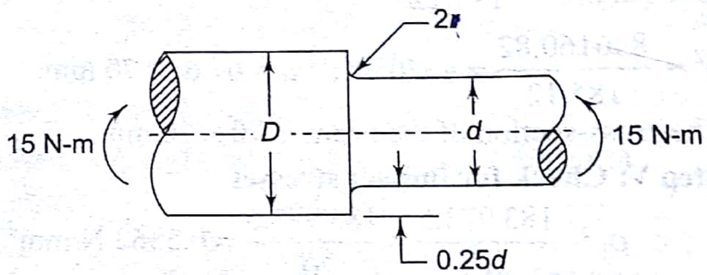

Fig. 5.59

5.3 (S) A shaft carrying a load of 5 kN midway between two bearings is shown in Fig. 5.60. Determine the maximum bending stress at the fillet section. Assume the shaft material to be brittle. [LO 1]

[Ans. 20.39 N/mm^2]

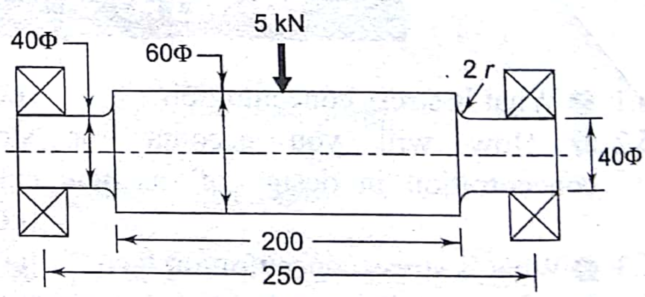

Fig. 5.60

M

5.4 (S) A plate, 10 mm thick, subjected to a tensile load of 20 kN is shown in Fig. 5.61. The plate is made of cast iron (S_{ut} = 350 N/mm^2) and the factor of safety is 2.5. Determine the fillet radius. **[LO 1]**

[Ans. 2.85 or 3 mm]

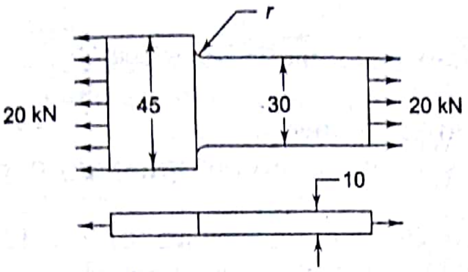

Fig. 5.61

5.5 (S) A 25 mm diameter shaft is made of forged steel 30C8 (S_{ut} = 600 N/mm^2). There is a step in the shaft and the theoretical stress concentration factor at the step is 2.1. The notch sensitivity factor is 0.84. Determine the endurance limit of the shaft if it is subjected to a reversed bending moment. **[LO 5]**

[Ans. 59.67 N/mm^2]

5.6 (S) A 40 mm diameter shaft is made of steel 50C4 (S_{ut} = 660 N/mm^2) and has a machined surface. The expected reliability is 99%. The theoretical stress concentration factor for the shape of the shaft is 1.6 and the notch sensitivity factor is 0.9. Determine the endurance limit of the shaft. **[LO 5]**

[Ans. 112.62 N/mm^2]

5.7 (M) A cantilever beam made of steel Fe 540 (S_{ut} = 540 N/mm^2 and S_{yt} = 320 N/mm^2) and subjected to a completely reversed load (P) of 5 kN is shown in Fig. 5.62. The beam is machined and the reliability is 50%. The factor of safety is 2 and the notch sensitivity factor is 0.9. Calculate: **[LO 6]**

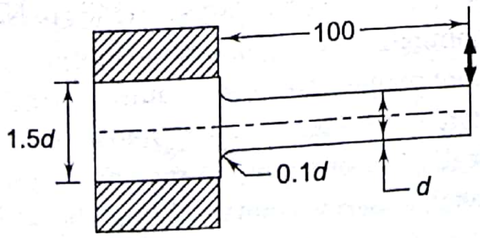

Fig. 5.62

(i) Endurance limit at the fillet section; and

(ii) Diameter 'd' of the beam for infinite life.

[Ans. (i) 109.20 N/mm^2 (ii) 45.35 mm]

5.8 (M) A solid circular shaft made of steel Fe 620 (S_{ut} = 620 N/mm^2 and S_{yt} = 380 N/mm^2) is subjected to an alternating torsional moment, which varies from – 200 N-m to + 400 N-m. The shaft is ground and the expected reliability is 90%. Neglecting stress concentration, calculate the shaft diameter for infinite life. The factor of safety is 2. Use the distortion-energy theory of failure. **[LO 6]**

[Ans. 29.31 mm]

5.9 (M) A solid circular shaft, 15 mm in diameter, is subjected to torsional shear stress, which varies from 0 to 35 N/mm^2 and at the same time, is subjected to an axial stress that varies from –15 to +30 N/mm^2. The frequency of variation of these stresses is equal to the shaft speed. The shaft is made of steel FeE 400 (S_{ut} = 540 N/mm^2 and S_{yt} = 400 N/mm^2) and the corrected endurance limit of the shaft is 200 N/mm^2. Determine the factor of safety. **[LO 11]**

[Ans. 4.05]

5.10 (M) A bar of steel has an ultimate tensile strength of 700 MPa, a yield point stress of 400 MPa and fully corrected endurance limit (S_e) of 220 MPa. The bar is subjected to a mean bending stress of 60 MPa and stress amplitude of 80 MPa. Superimposed on it is a mean torsional stress and torsional stress amplitude of 70 and 35 MPa respectively. Find the factor of safety. **[LO 11]**

[Ans. 1.54]

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(S), (M), (D) denotes Simple, Medium and Difficult Levels of complexity.

15.1 Ⓢ What are the functions of bearing? [LO 1]

15.2 Ⓢ What is a radial bearing? [LO 1]

15.3 Ⓢ What is a thrust bearing? [LO 1]

15.4 Ⓢ What is a sliding contact bearing? [LO 1]

15.5 Ⓢ What is a rolling contact bearing? [LO 1]

15.6 Ⓜ What are the applications of sliding contact bearing? [LO 1]

15.7 Ⓜ What are the applications of rolling contact bearing? [LO 1]

15.8 Ⓢ Why are ball and roller bearings called 'antifriction' bearings? [LO 1]

15.9 Ⓢ Name the various types of ball bearings. [LO 1]

15.10 Ⓢ Name the various types of roller bearings. [LO 1]

15.11 Ⓜ State any two advantages and two disadvantages of deep groove ball bearing. [LO 1]

15.12 Ⓜ State any two advantages and two disadvantages of cylindrical roller bearing. [LO 1]

15.13 Ⓜ State any two advantages and two disadvantages of angular contact bearing. [LO 1]

15.14 Ⓢ Where do you use self-aligning ball bearing and spherical roller bearing? [LO 1]

15.15 Ⓜ Why taper roller bearings are used in pairs? [LO 1]

15.16 Ⓜ State any two advantages and two disadvantages of taper roller bearing. [LO 1]

15.17 Ⓜ Enumerate any two advantages and disadvantages of rolling contact bearings over sliding contact bearings. **[LO 1]**

15.18 Ⓢ What is the criterion for static load carrying capacity of ball bearing? **[LO 3]**

15.19 Ⓢ Define static load carrying capacity of ball bearing. **[LO 3]**

15.20 Ⓢ Define rating life of bearing. **[LO 3]**

15.21 Ⓢ What is the criterion for dynamic load carrying capacity of ball bearing? **[LO 3]**

15.22 Ⓢ Define dynamic load carrying capacity of rolling contact bearing. **[LO 3]**

15.23 Ⓢ What is L_{10} life? **[LO 3]**

15.24 Ⓢ What is L_{50} life? **[LO 3]**

15.25 Ⓢ What is the reliability of rolling contact bearing selected from manufacturer's catalogue? **[LO 3]**

15.26 Ⓜ Enumerate any three advantages of needle roller bearings. **[LO 7]**

15.27 Ⓢ Where do you use needle roller bearings? **[LO 7]**

15.28 Ⓜ What is the objective of preloading of rolling contact bearings? **[LO 8]**

15.29 Ⓜ Where do you use preloaded rolling contact bearings? **[LO 8]**

PROBLEMS FOR PRACTICE

15.1 Ⓢ A ball bearing with a dynamic load capacity of 22.8 kN is subjected to a radial load of 10 kN. Calculate: **[LO 3]**

(i) the expected life in million revolutions that 90% of the bearings will reach,

(ii) the corresponding life in hours, if the shaft is rotating at 1450 rpm; and

(iii) the life that 50% of the bearings will complete or exceed before fatigue failure.

[Ans. (i) 11.85 (ii) 136.23 (iii) 681.17]

15.2 Ⓢ A cylindrical roller bearing with bore diameter of 40 mm is subjected to a radial force of 25 kN. The coefficient of friction is 0.0012 and the speed of rotation is 1440 rpm. Calculate the power lost in friction. **[LO 1]**

[Ans. 0.09 kW]

15.3 Ⓢ A ball bearing is subjected to a radial force of 2500 N and an axial force of 1000 N. The dynamic load carrying capacity of the bearing is 7350 N. The values of X and Y factors are 0.56 and 1.6; respectively. The shaft is rotating at 720 rpm. Calculate the life of the bearing. **[LO 3]**

[Ans. 340.42 hours]

15.4 Ⓜ A ball bearing operates on the following work cycle: **[LO 6]**

Element No.	*Radial load (N)*	*Speed (rpm)*	*Element time (%)*
1	3000	720	30
2	7000	1440	50
3	5000	900	20

The dynamic load capacity of the bearing is 16.6 kN. Calculate:

(i) the average speed of rotation,

(ii) the equivalent radial load; and

(iii) the bearing life.

[Ans. (i) 1116 rpm (ii) 6271.57 N (iii) 276.94 hr]

15.5 Ⓜ The radial load acting on a ball bearing is 2500 N for the first five revolutions and reduces to 1500 N for the next ten revolutions. The load variation then repeats itself. The expected life of the bearing is 20 million revolutions. Determine the dynamic load carrying capacity of the bearing **[LO 6]**

[Ans. 5303.43 N]

15.6 Ⓜ A ball bearing subjected to a radial load of 3000 N is expected to have a satisfactory life of 10000 hr at 720 rpm with a reliability of 95%. Calculate the dynamic load carrying capacity of the bearing, so that it can be selected from a manufacturer's catalogue based on 90% reliability. If there are four such bearings each with a reliability of 95% in a system, what is the reliability of the complete system? **[LO 6]**

[Ans. 27840.94 N and 81.45%]

15.7 Ⓓ A system involves four identical ball bearings each subjected to a radial load of 2500 N. The reliability of the system, i.e. one out of four bearings failing during the lifetime of five million revolutions, is 82%. Determine the dynamic load carrying capacity of the bearing, so as to select it from the manufacturer's catalogue based on 90% reliability. **[LO 6]**

[Ans. 5247.92 N]

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Ⓢ, Ⓜ, Ⓓ denote Simple, Medium and Difficult Levels of complexity.

16.1 Ⓜ What are the four objectives of lubrication? [LO 1]

16.2 Ⓢ What is thick film lubrication? [LO 1]

16.3 Ⓢ What is a zero film bearing? [LO 1]

16.4 Ⓢ What is hydrodynamic lubrication? [LO 1]

16.5 Ⓢ What is hydrostatic lubrication? [LO 1]

16.6 Ⓢ Why hydrodynamic journal bearing is called 'self--acting' bearing? [LO 1]

16.7 Ⓢ Why hydrostatic bearing is called 'externally pressurized' bearing? [LO 1]

16.8 Ⓢ Give two applications of hydrodynamic journal bearing. [LO 1]

16.9 Ⓢ Give two applications of hydrostatic bearing. [LO 1]

16.10 Ⓜ State any two advantages of hydrodynamic bearings over hydrostatic bearings. [LO 1]

16.11 Ⓜ State any two advantages of hydrostatic bearings over hydrodynamic bearings. [LO 1]

16.12 Ⓢ Give two examples of thin film bearings. [LO 1]

16.13 Ⓢ What is full journal bearing? [LO 1]

16.14 Ⓢ What is partial bearing? [LO 1]

16.15 Ⓢ Define viscosity. [LO 1]

16.16 Ⓢ State Newton's law of viscosity. [LO 1]

16.17 Ⓢ What are the units of absolute viscosity? [LO 1]

16.18 Ⓢ Define kinematic viscosity. [LO 1]

16.19 Ⓜ Why viscosity decreases with increasing temperature? [LO 1]

16.20 Ⓢ What is viscosity index? [LO 1]

16.21 Ⓢ Write down Petroff's equation. [LO 2]

16.22 Ⓢ Write down the expression for Sommerfeld's number. [LO 4]

16.23 Ⓢ What is bearing characteristic number as applied to the journal bearing? [LO 4]

16.24 Ⓢ What is bearing modulus as applied to the journal bearing? [LO 4]

16.25 Ⓢ What is meant by 'square' bearing? [LO 5]

16.26 Ⓜ What are the advantages and disadvantages of long bearings over short bearings? [LO 5]

16.27 Ⓜ What are the advantages and disadvantages of circumferential oil groove bearing over cylindrical oil groove bearing? [LO 6]

16.28 Ⓢ Give two applications of circumferential oil groove bearings. [LO 6]

16.29 Give two applications of cylindrical oil groove bearings. [LO 6]

16.30 State any four desirable properties of a good bearing material. [LO 6]

16.31 Define conformability. [LO 6]

16.32 Define embeddability. [LO 6]

16.33 What are the advantages and disadvantages of babbitt as bearing material? [LO 6]

16.34 Where do you use sintered metal bearings? [LO 6]

16.35 State any four desirable properties of a good lubricant. [LO 7]

16.36 What is S.A.E.? [LO 7]

16.37 Define 'additive' for mineral oil. [LO 7]

16.38 What is the purpose of additive? [LO 7]

16.39 What is 'doped' oil? [LO 7]

16.40 What are EP additives? Where do you use them? [LO 7]

16.41 What is 2T oil? What are its advantages? Where do you use 2T oil? [LO 7]

16.42 What is grease? State its applications. [LO 7]

16.43 Grease is 'thixotropic'. What does it mean? [LO 7]

PROBLEMS FOR PRACTICE

16.1 Following data is given for a hydrostatic thrust bearing: [LO 3]

shaft speed = 720 rpm
shaft diameter = 400 mm
recess diameter = 250 mm
film thickness = 0.15 mm
viscosity of lubricant = 30 cP
specific gravity = 0.86
specific heat = 1.75 kJ/kg°C
supply pressure = 5 MPa

Calculate:

(i) load carrying capacity of the bearing;
(ii) flow requirement;
(iii) pumping power loss;
(iv) frictional power loss; and
(v) temperature rise.

Assume that the total power loss in the bearing is converted into frictional heat.

[Ans. (i) 407.32 kN (ii) 37.6 litres/min (iii) 3.13 kW (iv) 2.42 kW (v) 5.88°C]

16.2 The developed view of a hydrostatic bearing is shown in Fig. 16.35 (a). Consider the flow in the direction shown by arrows and neglect the flow in the other direction and over corners. The pressure distribution is linear as shown in Fig. 16.35 (b). The thrust load is 500 kN and the film thickness is 0.2 mm. The viscosity of the lubricant is 500 cP. Calculate the supply pressure and flow requirement. [LO 3]

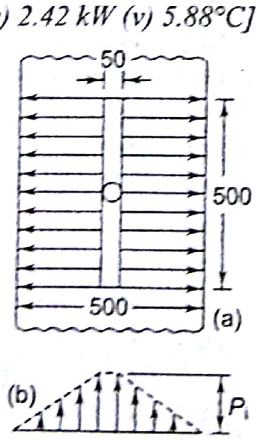

Fig. 16.35

[Ans. (i) 3.64 MPa (ii) 1.29 litres/min]

16.3 A hydrostatic thrust bearing consists of four pads as shown in Fig. 16.36(a). Neglecting the flow over corners, each pad can be approximated as a circular area of outer and inner diameters of 200 mm and 50 mm respectively, as shown in Fig. 16.36 (b). The thrust load is 300 kN and the film thickness 0.1 mm. The viscosity and specific gravity of the lubricating oil are 250 SUS and 0.88, respectively. Calculate the supply pressure and flow requirement. [LO 3]

[Ans. (i) 7.06 MPa (ii) 13.4 litres/min]

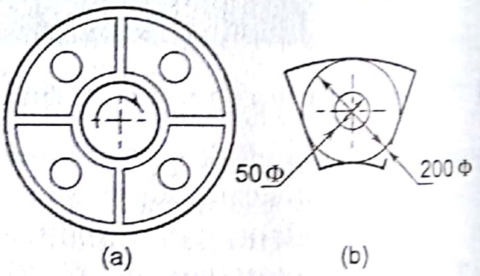

Fig. 16.36

16.4 A hydrostatic spherical step bearing is shown in Fig. 16.37. Show that the load carrying capacity of the bearing is given by [LO 3]

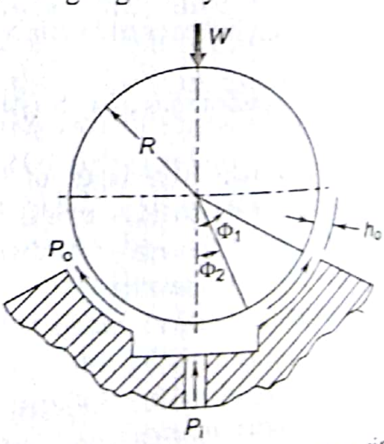

Fig. 16.37 Spherical step bearing

$$W = \frac{\pi P_i R^2 (\cos\phi_2 - \cos\phi_1)}{\log_e \left[\dfrac{\tan\left(\dfrac{\phi_1}{2}\right)}{\tan\left(\dfrac{\phi_2}{2}\right)} \right]}$$

and the flow requirement is given by,

$$Q = \frac{\pi P_i h_o^3}{6\mu \log_e \left[\dfrac{\tan\left(\dfrac{\phi_1}{2}\right)}{\tan\left(\dfrac{\phi_2}{2}\right)} \right]}$$

16.5 M A 360° hydrodynamic bearing operates under the following conditions: **[LO 4]**
radial load = 50 kN
journal diameter = 150 mm
bearing length = 150 mm
radial clearance = 0.15 mm
minimum film thickness = 0.03 mm
viscosity of lubricant = 8 cP
What is the minimum speed of operation for the journal to work under hydrodynamic conditions?
[Ans. 2973 r.p.m.]

16.6 M Following data is given for a 360° hydrodynamic bearing: **[LO 4]**
journal diameter = 100 mm
bearing length = 100 mm
radial load = 50 kN
journal speed = 1440 rpm
radial clearance = 0.12 mm
viscosity of lubricant = 16 cP
Calculate:
(i) minimum film thickness;
(ii) coefficient of friction; and
(iii) power lost in friction.
[Ans. (i) 0.0087 mm, (ii) 2.016 × 10^{-3} (iii) 0.76 kW]

16.7 M Following data is given for a full hydrodynamic bearing: **[LO 4]**
radial load = 25 kN
journal speed = 900 rpm
unit bearing pressure = 2.5 MPa
(l/d) ratio = 1
viscosity of lubricant = 20 cP
class of fit = H7e7
Calculate :
(i) dimensions of the bearing ,
(ii) minimum film thickness, and
(iii) requirement of oil flow.
[Ans. (i) 100 × 100 mm (ii) 0.0191 mm (iii) 1.057 litre/min]

16.8 M Following data is given for a 360° hydrodynamic bearing: **[LO 4]**
bearing diameter = 50.02 mm
journal diameter = 49.93 mm
bearing length = 50 mm
journal speed = 1440 rpm
radial load = 8 kN
viscosity of lubricant = 12 cP
The bearing is machined on the lathe from bronze casting, while the steel journal is hardened and ground. The surface roughness (c.l.a.) values for turning and grinding are 0.8 and 0.4 microns respectively. For thick film hydrodynamic lubrication, the minimum film thickness should be five times the sum of surface roughness values for the journal and bearing. Calculate:
(i) the permissible minimum film thickness;
(ii) the actual film thickness under operating conditions; and
(iii) power lost in friction.
[Ans. (i) 6 microns, (ii) 6.07 microns, (iii) 0.069 kW]

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17.1 Ⓢ State applications of gear drives. [LO 1]

17.2 Ⓜ State any four advantages of gear drive over other types of drives. [LO 1]

17.3 Ⓜ State any two disadvantages of gear drive over other types of drives. [LO 1]

17.4 Ⓜ In a gear speed reducer, why is the diameter of output shaft greater than input shaft? [LO 1]

17.5 Ⓢ In which gear drive, self-locking is possible? [LO 1]

17.6 Ⓢ What is Herringbone gear? [LO 1]

17.7 Ⓜ What are the advantages of cycloidal teeth gears? [LO 2]

17.8 Ⓜ What are the advantages of involute teeth gears? [LO 2]

17.9 Ⓜ State two important reasons for adopting involute curve for gear tooth profile? [LO 2]

17.10 Ⓜ What are the advantages of 14.5° full depth involute teeth gears? [LO 2]

17.11 Ⓜ What are the advantages of 20° full depth involute teeth gears? [LO 2]

17.12 Ⓜ What are the advantages of 20° stub involute teeth gears? [LO 2]

17.13 Ⓢ What is full depth involute gear tooth system? [LO 2]

17.14 Ⓢ What is stub involute gear tooth system? [LO 2]

17.15 Ⓢ Why tangential component of gear tooth force is called 'useful' component? [LO 4]

17.16 Ⓢ Why radial component of gear tooth force is called 'separating' component? [LO 4]

17.17 Ⓢ What is pitting? [LO 4]

17.18 Ⓢ What is scoring? [LO 4]

17.19 Ⓢ What is the minimum number of teeth on 20° pressure angle spur gear? Why? [LO 5]

17.20 Ⓢ What is a 'hunting' tooth? [LO 5]

17.21 Ⓜ Why pinion is weaker than the gear made of same material? [LO 6]

17.22 Ⓜ State two advantages of internal gear. [LO 8]

17.23 Ⓜ State two disadvantages of internal gear. [LO 8]

17.24 Ⓜ What are the advantages of planetary reduction gears as compared to ordinary gearboxes? [LO 8]

17.25 Ⓢ Where do you use grease as gear lubricant? [LO 8]

17.26 Ⓢ Where do you use oil as gear lubricant? [LO 8]

PROBLEMS FOR PRACTICE

17.1 Ⓢ In a pair of spur gears, the number of teeth on the pinion and the gear are 20 and 100 respectively. The module is 6 mm. Calculate: [LO 2]

(i) the centre distance;

(ii) the pitch circle diameters of the pinion and the gear,

(iii) addendum and dedendum;

(iv) tooth thickness and bottom clearance; and

(v) the gear ratio.

[Ans. (i) 360 mm, (ii) 120 and 600 mm, (iii) 6 and 7.5 mm, (iv) 9.4248 and 1.5 mm, (v) 5]

17.2 S A pinion with 25 teeth and rotating at 1200 rpm drives a gear which rotates at 200 rpm. The module is 4 mm. Calculate the centre distance between the gears. **[LO 2]**

[Ans. 350 mm]

17.3 S A pair of spur gears with a centre distance of 495 mm is used for a speed reduction of 4.5: 1. The module is 6 mm. Calculate the number of teeth on the pinion and the gear. **[LO 2]**

[Ans. 30 and 135]

17.4 M A train of spur gears is shown in Fig. 17.47. Gear 1 is the driving gear and transmits 5 kW power at 720 rpm. The number of teeth on gears 1, 2, 3 and 4 are 20, 50, 30 and 60 respectively. The module for all gears is 4 mm. The gears have a 20° full depth involute profile. Calculate the tangential and radial components of the tooth force between: **[LO 4]**

(i) Gears 1 and 2, and
(ii) Gears 3 and 4

[Ans. (i) 1657.86 and 603.41 N, (ii) 2763.11 and 1005.69 N]

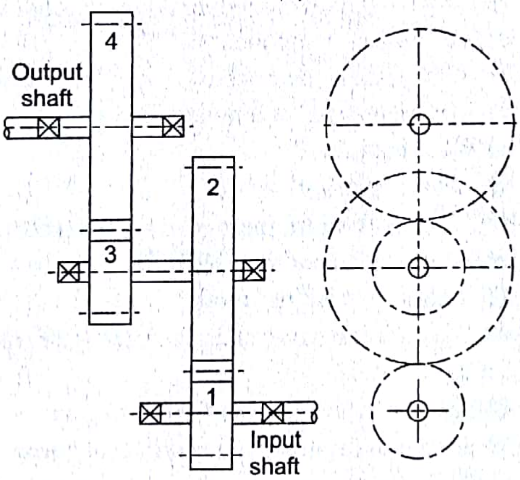

Fig. 17.47

17.5 D A train of gears transmitting power from a 10 kW, 1440 rpm motor to a rope drum is shown in Fig. 17.48. The number of teeth on the various gears is as follows, **[LO 4]**

$z_1 = 20 \quad z_2 = 100 \quad z_3 = 25$

$z_4 = 150 \quad z_5 = 25 \quad z_6 = 150$

The module of gears 1 and 2 is 5 mm, while that of all other gears is 6 mm. The pressure angle is 20°. Calculate:

(i) torques acting on shafts *A*, *B*, *C* and *D*;
(ii) tangential and radial components of tooth forces between gears 1 and 2, gears 3 and 4 and gears 5 and 6;

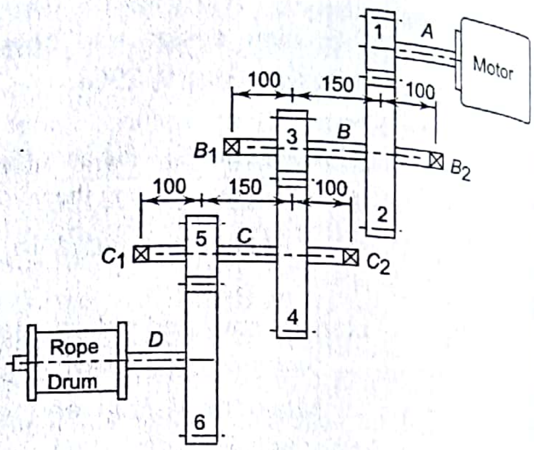

Fig. 17.48

(iii) resultant reactions at bearings B_1 and B_2, and
(iv) resultant reactions at bearings C_1 and C_2.

[Ans. (i) 66 314.56, 331 572.8, 1 989 436.79 and 11 936 620.73 N-mm, (ii) 1326.29 and 482.73 N, 4420.97 and 1609.1 N, 26 525.82 and 9654.61 N, (iii) 3678.56 and 2213.47 N, (iv) 21 210.32 and 10856.55 N]

17.6 D A train of spur gears with 20° full depth involute teeth is shown in Fig. 17.49. Gear 1 is the driving gear and transmits 50 kW power at 300 rpm to the gear train. The number of teeth on gears 1, 2, 3 and 4 are 30, 60, 25 and 50 respectively; while the module for all gears is 8 mm. Gears 2 and 3 are mounted on the same shaft. Gear 1 is rotating in clockwise direction when seen from the left side of the page. Calculate: **[LO 4]**

(i) tangential and radial components of tooth forces between gears 1 and 2 and gears 3 and 4; and
(ii) resultant reactions at bearing B_1 and B_2.

[Ans. (i) 13262.91 and 4827.31 N, 31830.99 and 11585.53 N, (ii) 43871.35 and 8693.44 N]

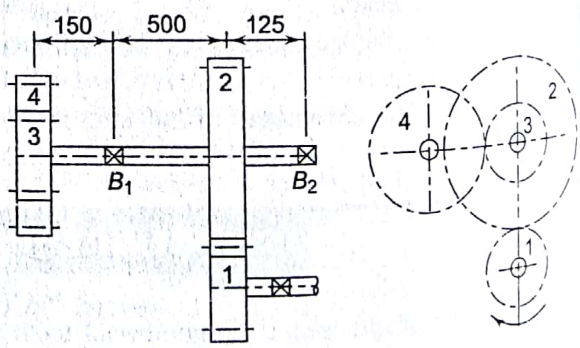

Fig. 17.49

17.7 M The following data is given for a pair of spur gears with 20° full depth involute teeth: **[LO 6]**

number of teeth on pinion = 24
number of teeth on gear = 56

speed of pinion = 1200 rpm
module = 3 mm
service factor = 1.5
face width = 30 mm

Both gears are made of steel with an ultimate tensile strength of. 600 N/mm^2. Using the velocity factor to account for the dynamic load, calculate:

(i) beam strength;
(ii) velocity factor; and
(iii) rated power that the gears can transmit without bending failure, if the factor of safety is 1.5.

[Ans. (i) 6066 N, (ii) 0.3987, (iii) 4.86 kW]

17.8 Ⓢ The pitch circle diameters of the pinion and gear are 100 and 300 mm respectively. The pinion is made of plain carbon steel 40C8 (S_{ut} = 600 N/mm^2) while the gear is made of grey cast iron FG 300 (S_{ut} = 300 N/mm^2). The pinion receives 5 kW power at 500 rpm through its shaft. The service factor and factor of safety can be taken as 1.5 each. The face width of the gear can be taken as ten times of the module. Assume that the velocity factor accounts for the dynamic load. Calculate: **[LO 6]**

(i) module; and
(ii) the number of teeth on the pinion and gear.

[Ans. (i) 5 mm, (ii) 20 and 60]

17.9 Ⓢ A steel pinion with 20° full depth involute teeth is transmitting 7.5 kW power at 1000 rpm from an electric motor. The starting torque of the motor is twice the rated torque. The number of teeth on the pinion is 25, while the module is 4 mm. The face width is 45 mm. Assuming that velocity factor accounts for the dynamic load, calculate: **[LO 6]**

(i) the effective load on the gear tooth; and
(ii) the bending stresses in the gear tooth.

[Ans. (i) 7863.79 N, (ii) 128.49 N/mm^2]

17.10 Ⓢ A pair of spur gears with 20° pressure angle, consists of a 25 teeth pinion meshing with a 60 teeth gear. The module is 5 mm, while the face width is 45 mm. The pinion rotates at 500 rpm. The gears are made of steel and heat treated to a surface hardness of 220 B.H.N. Assume that dynamic load is accounted by means of the velocity factor. The service factor and the factor of safety are 1.75 and 2 respectively. Calculate: **[LO 7]**

(i) wear strength of gears;
(ii) static load that the gears can transmit without pitting; and
(iii) rated power that can be transmitted by gears.

[Ans. (i) 6149.8 N, (ii) 840.41 N, (iii) 2.75 kW]

17.11 Ⓜ A pair of spur gears consists of a 24 teeth pinion, rotating at 1000 rpm and transmitting power to a 48 teeth gear. The module is 6 mm, while the face width is 60 mm. Both gears are made of steel with an ultimate tensile strength of 450 N/mm^2. They are heat treated to a surface hardness of 250 BHN. Assume that velocity factor accounts for the dynamic load. Calculate: **[LO 6, 7]**

(i) beam strength;
(ii) wear strength; and
(iii) the rated power that the gears can transmit, if service factor and the factor of safety are 1.5 and 2, respectively.

[Ans. (i) 18 198 N, (ii) 11 517.12 N, (iii) 8.24 kW]

17.12 Ⓓ It is required to design a pair of spur gears with 20° full-depth involute teeth. The input shaft rotates at 720 rpm and receives 5 kW power through a flexible coupling. The speed of the output shaft should be 144 rpm. The pinion as well as the gear are made of steel Fe 410 (S_{ut} = 410 N/mm^2). The service factor for the application is 1.25. The gears are machined to meet the specifications of Grade 6. **[LO 6, 7]**

(i) Assume suitable number of teeth for the pinion and the gear.
(ii) For preliminary calculations, assume the pitch line velocity as 5 m/s and the factor of safety as 2. Estimate the module and select the first preference value of the module.
(iii) Using this value of the module, calculate the pitch circle diameters of the pinion and gear and the face width.
(iv) Determine static load and the dynamic load by Buckingham's equation. Also calculate the beam strength and the correct value of factor of safety based on beam strength.
(v) Using a factor of safety of 2 for wear strength, specify the surface hardness for gears.

[Ans. (i) 18 and 90 teeth, (ii) 4.89 or 5 mm, (iii) 90, 450 and 50 mm, (iv) 1473.66, 5993 and 10523.33 N; (fs) = 1.34 (v) 361.33 or 370 BHN]

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Ⓢ,Ⓜ,Ⓓ denote Simple, Medium and Difficult Levels of complexity.

18.1 S Compare the contact between mating teeth of spur and helical gears. [LO 1]

18.2 S What are the advantages of helical gears over spur gears? [LO 1]

18.3 S Where do you use helical gears? [LO 1]

18.4 S What is a parallel helical gear? [LO 1]

18.5 S What is a crossed helical gear? [LO 1]

18.6 S What is virtual or formative helical gear? [LO 2]

18.7 S What is the relationship between actual and virtual number of teeth and the helix angle? [LO 2]

18.8 S What is the main disadvantage of a single helical gear? What is the remedy? [LO 8]

18.9 S What is a double helical gear? [LO 8]

18.10 S What is a herringbone helical gear? [LO 8]

18.11 S What is the difference between double and herringbone helical gears? [LO 8]

18.12 M State two advantages of herringbone and double helical gears? [LO 8]

18.13 M State two disadvantages of herringbone and double helical gears? [LO 8]

18.14 S Where do you use herringbone and double helical gears? [LO 8]

18.15 M What is the relationship between ψ_1, ψ_2 and Σ in crossed helical gear? [LO 8]

18.16 M Compare the contact between mating teeth of parallel and crossed helical gears. [LO 8]

18.17 M Why crossed helical gears are not used for high power transmission? [LO 8]

18.18 S State the applications of crossed helical gear? [LO 8]

PROBLEMS FOR PRACTICE

18.1 S A pair of helical gears consists of a 25 teeth pinion meshing with a 50 teeth gear. The normal module is 4 mm. Find the required value of the helix angle, if the centre distance is exactly 165 mm. [LO 1]

[Ans. 24.62°]

18.2 S A pair of parallel helical gears consists of a 20 teeth pinion and the velocity ratio is 3:1. The helix angle is 15° and the normal module is 5 mm. Calculate: [LO 1]

(i) pitch circle diameters of the pinion and the gear; and

(ii) centre distance.

[Ans. (i) 103.53 and 310.58 mm (ii) 207.06 mm]

18.3 S A pair of parallel helical gears consists of 18 teeth pinion meshing with a 63 teeth gear. The normal module is 3 mm. The helix angle is 23° while the normal pressure angle is 20°. Calculate: [LO 1]

(i) transverse module;

(ii) transverse pressure angle; and

(iii) axial pitch.

[Ans. (i) 3.26 mm (ii) 21.57° (iii) 24.13 mm]

18.4 M A pair of parallel helical gears consists of an 18 teeth pinion meshing with a 45 teeth gear. A 7.5 kW power at 2000 rpm is supplied to the pinion through its shaft The normal module is 6 mm, while the normal pressure angle is 20°. The helix angle is 23°. Determine the tangential, radial and axial components of the resultant tooth force between the meshing teeth. [LO 4]

[Ans. 610.41, 241.36 and 259.10 N]

18.5 M The following data is given for a pair of parallel helical gears made of steel: [LO 7]

power transmitted = 20 kW
speed of pinion = 720 rpm
number of teeth on pinion = 35
number of teeth on gear = 70
centre distance = 285 mm
normal module = 5 mm
face width = 50 mm
normal pressure angle = 20°

ultimate tensile strength = 600 N/mm^2
surface hardness = 300 BHN
grade of machining = Gr. 6
service factor = 1.25
Calculate:

(i) helix angle;
(ii) beam strength;
(iii) wear strength;
(iv) static load
(v) dynamic load by Buckingham's equation;
(vi) effective load;
(vii) effective factor of safety against bending failure; and
(viii) effective factor of safety against pitting failure.

[Ans. (i) 22.92°, (ii) 19 930 N, (iii) 21495.64 N, (iv) 2792.19 N (v) 8047.29 N, (vi) 11 537.53 N, (vii) 1.73, (viii) 1.86]

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is measured at the mean radius of the gear. In the figure, P is a point of the spiral tooth on the circle having mean radius. The line XY is drawn tangent to the tooth profile at point P. The inclination of line XY is the spiral angle (ψ). The salient features of the design of spiral bevel gears are as follows:

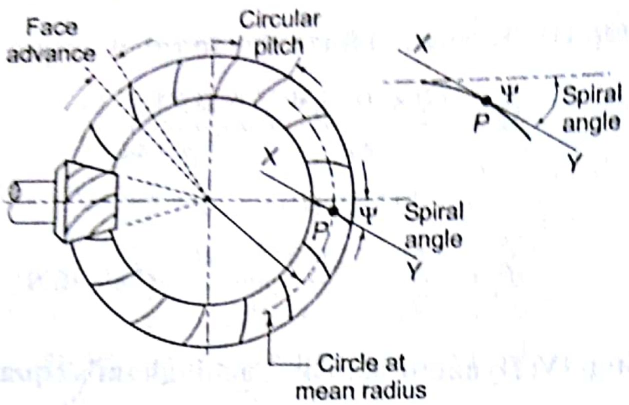

Fig. 19.18 Spiral Gear Terminology

(i) The spiral angle is usually 35°. The pressure angle varies from 14.5° to 20°.

(ii) In order to obtain smooth spiral tooth action, the face-contact ratio should be more than 1.25. The face-contact ratio is a ratio of face advance to circular pitch. Both these terms are illustrated in the figure.

(iii) The pinion should have minimum 12 teeth in general industrial applications. However, spiral bevel gears can be designed with pinion having as few as 6 teeth, provided the sum of number of teeth on pinion and the gear is more than 40.

(iv) The choice of hand for spiral is important in the design. Under certain conditions, the induced axial force, with one direction of rotation, draws the gears tightly together, whereas with opposite direction of rotation, the axial force pushes the gears apart. The hand of spiral should be selected in such a way so as to cause the gears to separate from each other.

ground.

The comparison between straight and spiral bevel gears is similar to the comparison between spur and helical gears. Spiral bevel gears offer following advantages over straight bevel gears:

(i) There is gradual contact between mating teeth. This results in smooth and quiet operation.

(ii) The spiral bevel gears have more load carrying capacity because more teeth are in contact simultaneously and there is greater arc of contact.

(iii) Spiral bevel gears permit higher operational speeds.

The spiral bevel gears are used for high speed applications.

The analysis of forces in spiral gears is difficult compared with straight tooth bevel gears because number of parameters are involved such as hand of spiral for pinion as well as for gear and direction of rotation for pinion.

Key Terms

Miter gear [LO 1]; Crown gear [LO 1]; Skew bevel gear [LO 1]; Hypoid gear [LO 1]; Zerol gear [LO 1]; Face gear [LO 1]; Pitch cone [LO 1]; Back cone [LO 1]; Cone distance [LO 1]; Pitch angle [LO 1]; Addendum angle [LO 1]; Dedendum angle [LO 1]; Back cone radius [LO 1]; Tredgold's approximation [LO 1]; Formative gear [LO 1]; Virtual number of teeth [LO 1]; Bevel factor [LO 3]; Spiral angle [LO 4]

End Notes

[1] Buckingham Earle – 'Analytical Mechanics of Gears' – McGraw Hill Inc

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QUESTIONS WITH SHORT ANSWERS

19.1 Ⓢ Where do you use bevel gear? [LO 1]

19.2 Ⓜ What are the advantages of straight bevel gears over spiral bevel gears? [LO 1]

19.3 Ⓜ What are the disadvantages of straight bevel gears over spiral bevel gears? [LO 1]

19.4 Ⓢ Where do you use spiral bevel gears? [LO 1]

19.5 Ⓢ What is zerol bevel gear? [LO 1]

19.6 Ⓢ What is the magnitude of spiral angle in zerol bevel gear? [LO 1]

19.7 Ⓜ What are skew gears? Where do you use them? [LO 1]

19.8 Ⓢ What is a crown gear? [LO 1]

19.9 Ⓢ What is miter gear? [LO 1]

19.10 Ⓜ What is hypoid gear? Why is it used in automobiles? [LO 1]

19.11 Ⓜ What is virtual or formative bevel gear? [LO 1]

19.12 Ⓢ What is the relationship between actual and virtual number of teeth and the pitch angle in bevel gears? [LO 1]

PROBLEMS FOR PRACTICE

19.1 Ⓢ A pair of bevel gears consists of a 30 teeth pinion meshing with a 48 teeth gear. The gears are mounted on shafts, which are intersecting at right angles. The module at the large end of the tooth is 4 mm. Calculate: [LO 1]

(i) the pitch circle diameters of the pinion and the gear;

(ii) the pitch angles for the pinion and gear; and

(iii) the cone distance.

[Ans. (i) 120 and 192 mm, (ii) 32° and 58°, (iii) 113.21 mm]

19.2 Ⓜ A pair of straight bevel gears has a velocity ratio of 2:1. The pitch circle diameter of the pinion is 80 mm at the large end of the tooth. 5 kW power is supplied to the pinion, which rotates at 800 rpm. The face width is 40 mm and the pressure angle is 20°. Calculate the tangential, radial, and axial components of the resultant tooth force acting on the pinion. [LO 2]

[Ans. 1921.79 N, 625.63 N and 312.81 N]

19.3 Ⓜ A pair of straight bevel gears consists of a 30-teeth pinion meshing with a 45-teeth gear. The module and the face width are 6 mm and 50 mm, respectively. The pinion as well as the gear is made of steel (S_{ut} = 600 N/mm^2). Calculate the beam strength of the tooth. [LO 3]

[Ans. 15 636.82 N]

19.4 Ⓜ A pair of straight bevel gears consists of a 24-teeth pinion meshing with a 48-teeth gear. The module at the outside diameter is 6 mm, while the face width is 50 mm. The gears are made of grey cast iron FG 220 (S_{ut} = 220 N/mm^2). The pressure angle is 20°. The teeth are generated and assume that velocity factor accounts for the dynamic load. The pinion rotates at 300 rpm and the service factor is 1.5. Calculate: [LO 3]

(i) the beam strength of the tooth;

(ii) the static load that the gears can transmit with a factor of safety of 2 for bending consideration; and

(iii) the rated power that the gears can transmit.

[Ans. (i) 5267.74 N (ii) 1384.19 N (iii) 3.13]

19.5 Ⓜ A pair of straight bevel gears is made of grey cast iron FG 200 (E = 114 000 N/mm^2). The surface endurance strength is 90 N/mm^2. The number of teeth on the pinion and gear are 30 and 40 respectively. The module and the face width are 6 mm and 50 mm, respectively. The pressure angle is 20°. Determine the wear strength of the tooth. [LO 3]

[Ans. 352.08 N]

19.6 Ⓜ A pair of straight bevel gears is mounted on shafts, which are intersecting at right angles. The gears are made of steel and the surface hardness is 300 BHN. The number of teeth on the pinion and gear are 40 and 65, respectively. The module at the outside diameter is 3 mm, while the face width of the tooth is 35 mm. Calculate the wear strength of the tooth. [LO 3]

[Ans. 7723.02 N]

19.7 Ⓜ A pair of straight bevel gears is mounted on shafts, which are intersecting at right angles. The number of teeth on the pinion and gear are 30 and 45 respectively. The pressure angle is 20°. The pinion shaft is connected to an electric motor developing 16.5 kW rated power at 500 rpm. The service factor can be taken as 1.5. The pinion and the gear are made of steel (S_{ut} = 570 N/mm^2) and heat-treated to a surface hardness of 350 BHN. The gears are manufactured in such a way that the error between two meshing teeth is limited to 20 μm. The module and face width are 6 mm and 50 mm, respectively. [LO 3]

Determine the factor of safety against bending as well as pitting failure.

[Ans. 1.25 and 1.85]

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Ⓢ, Ⓜ, Ⓓ denote Simple, Medium and Difficult Levels of complexity.

20.1 S Where do you use worm gear drive? [LO 1]

20.2 M What are the advantages of worm gear drives? [LO 1]

20.3 M What are the drawbacks of worm gear drives? [LO 1]

20.4 M What kind of contact occurs between worm and worm wheel? How does it differ from other types of gears? [LO 1]

20.5 S Why are worm gear reduction units not preferred over other types of gearboxes for transmitting large powers? [LO 1]

20.6 M What are single-enveloping and double-enveloping worm gear drives? Where do you use them? [LO 2]

20.7 M What are the advantages of double-enveloping worm gear drive over single-enveloping worm gear drives? [LO 2]

20.8 S What are the four important parameters that are required to specify the worm gear drive? [LO 2]

20.9 M What is the material for worm? Why? [LO 5]

20.10 M What is the material for worm wheel? Why? [LO 5]

20.11 S Why is the efficiency of worm gear drive low? [LO 4]

PROBLEMS FOR PRACTICE

20.1 S A pair of worm gears is designated as [LO 2]

2/54/10/5

Calculate:

(i) centre distance; (ii) speed reduction;
(iii) dimensions of the worm; and
(iv) dimensions of the worm wheel.

[Ans. (i) 160 mm, (ii) 27, (iii) $d_1 = 50$ mm; $d_{a1} = 60$ mm; $d_{f1} = 38.427$ mm; $p_x = 15.708$ mm, (iv) $d_2 = 270$ mm; $d_{a2} = 279.612$ mm; $d_{f2} = 258.039$ mm]

20.2 M A pair of worm and worm wheel is designated as [LO 3]

2/52/10/4

10 kW power at 720 rpm is supplied to the worm shaft. The coefficient of friction is 0.04 and the pressure angle is 20°. Calculate the tangential, axial and radial components of the resultant gear tooth force acting on the worm wheel.

[Ans. 27 105.78 N, 6631.46 N and 10 147.47 N]

20.3 M A pair of worm gears is designated as [LO 4]

1/52/10/8

The worm rotates at 1000 rpm and the normal pressure angle is 20°. Determine the coefficient of friction and the efficiency of the worm gears.

[Ans .0.027 and 77.45%]

20.4 M A pair of worm gears is designated as [LO 6]

1/40/10/4

The input speed of the worm shaft is 1000 rpm. The worm wheel is made of phosphor-bronze (sand cast), while the worm of case-hardened carbon steel 10C4. Determine the power transmitting capacity based on beam strength.

[Ans. 2.1 kW]

20.5 M Assume the data of Example 20.4 and determine the power transmitting capacity based on wear strength. [LO 6]

[Ans. 0.77 kW]

20.6 M The gear box for the worm gears of Examples 20.4 and 20.5 has an effective surface area of 0.25 m^2. A fan is mounted on the worm shaft to circulate air over the surface of the fins. The coefficient of heat transfer can be taken as 25 W/m^2°C. The permissible temperature rise of the lubricating oil above the atmospheric temperature is 45°C. The coefficient of friction is 0.035 and the normal pressure angle is 20°. Calculate the power transmitting capacity based on thermal considerations. [LO 6]

[Ans. 1.03 kW]

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S, M, D denote Simple, Medium and Difficult Levels of complexity.