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Mechanical Design II Homework 08

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Mechanical Design 2

Class Section 01

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Use Manufacturer 1 for tapered roller bearings and Manufacturer 2 for all other bearings.

Manufacturer	Rating Life, Revolutions	Weibull Parameters Rating Lives x_0	θ	b
1	$90(10^6)$	0	4.48	1.5
2	$1(10^6)$	0.02	4.459	1.483

Problem 1

An 02-series single-row ball bearing is to be selected from Table 11–2 for the application conditions of

- Axial load = 3 kN
- Radial load = 8 kN
- Service Life = 10^8 revolutions
- Outer ring rotation
- Desired reliability = 90%

What size of bearing to use if choosing a deep-groove bearing versus choosing an angular-contact bearing? Discuss the considerations and decide your choice of bearing type for this application.

Solution:

$$F_a = 3 \text{ kN}$$

$$F_r = 8 \text{ kN}$$

$$L_D = 10^8$$

$$V = 1.2$$

$$R = 0.9$$

$$\frac{F_a}{VF_r} = \frac{3 \text{ kN}}{1.2 \times 8 \text{ kN}} = 0.3125$$

Guess $\frac{F_a}{VF_r} > e$ and $X_2 = 0.56,\ Y_2 = 1.63$.

$$F_e = X_2 VF_r + Y_2 F_a = 0.56 \times 1.2 \times 8 \text{ kN} + 1.63 \times 3 \text{ kN} = 10.2660 \text{ kN}$$

$$x_D = \frac{L_D}{L_R} = \frac{10^8}{10^6} = 100$$

$$C_{10} = F_e \left[\frac{x_D}{x_0 + (\theta - x_0)(1 - R_D)^{\frac{1}{b}}}\right]^{\frac{1}{a}} = (10.2660 \text{ kN}) \times \left[\frac{100}{0.02 + 4.439(1 - 0.90)^{0.674}}\right]^{\frac{1}{3}}$$
$$= 48.2977 \text{ kN}$$

For deep-groove bearing, from Table 11-2, we try 60 mm deep-groove bearing with $C_{10} = 47.5 \text{ kN}$, $C_0 = 28.0 \text{ kN}$.

$$\frac{F_a}{C_0} = \frac{3 \text{ kN}}{28.0 \text{ kN}} = 0.1071$$

In Table 11-1, $\frac{F_a}{C_0} = 0.1071$ is correspond to $e \in [0.28, 0.30]$. Therefore, our guess is correct.

$$\frac{F_a}{C_0} = 0.1071 \Rightarrow \begin{cases} X_2 = 0.56 \\ Y_2 = 1.4610 \end{cases}$$

$$F_e = X_2 VF_r + Y_2 F_a = 0.56 \times 1.2 \times 8 \text{ kN} + 1.4610 \times 3 \text{ kN} = 9.7590 \text{ kN}$$

$$C_{10} = F_e \left[\frac{x_D}{x_0 + (\theta - x_0)(1 - R_D)^{\frac{1}{b}}}\right]^{\frac{1}{a}} = (9.7590 \text{ kN}) \times \left[\frac{100}{0.02 + 4.439(1 - 0.90)^{0.674}}\right]^{\frac{1}{3}}$$
$$= 45.2971 \text{ kN} < 47.5 \text{ kN}$$

Therefore, 60 mm deep-groove bearing is suitable.

For deep-groove bearing, from Table 11-2, we try 55 mm angular-contact bearing with $C_{10} = 46.2 \text{ kN}$, $C_0 = 28.5 \text{ kN}$.

$$\frac{F_a}{C_0} = \frac{3 \text{ kN}}{28.5 \text{ kN}} = 0.1053$$

In Table 11-1, $\frac{F_a}{C_0} = 0.1053$ is correspond to $e \in [0.28, 0.30]$. Therefore, our guess is correct.

$$\frac{F_a}{C_0} = 0.1053 \Rightarrow \begin{cases} X_2 = 0.56 \\ Y_2 = 1.4682 \end{cases}$$

$$F_e = X_2 V F_r + Y_2 F_a = 0.56 \times 1.2 \times 8 \ \text{kN} + 1.4682 \times 3 \ \text{kN} = 9.7807 \ \text{kN}$$

$$C_{10} = F_e \left[\frac{x_D}{x_0 + (\theta - x_0)(1 - R_D)^{\frac{1}{b}}} \right]^{\frac{1}{a}} = (9.7807 \ \text{kN}) \times \left[\frac{100}{0.02 + 4.439(1 - 0.90)^{0.674}} \right]^{\frac{1}{3}}$$
$$= 45.3978 \ \text{kN} < 46.2 \ \text{kN}$$

Therefore, 55 mm angular-contact bearing is suitable.

From the analysis above, I can know that the diameter of angular-contact bearing needed to support the same load is smaller than that of deep-groove bearing. In daily use, we will consider the utilization of space, so we are more inclined to choose to use angular-contact bearing.

.Problem 2

A countershaft is supported by two tapered roller bearings using a direct mounting. The radial bearing loads are 560 lbf for the left-hand bearing and 1095 lbf for the right-hand bearing. An axial load of 200 lbf is pushed against the left bearing. The shaft rotates at 400 rev/min and is to have a desired life of 40 kh. Use an application factor of 1.4 and a combined reliability goal of 0.90. Using an initial K = 1.5, find the required radial rating for each bearing.

Select the bearings from Fig. 11–15.

Solution:

$$F_{rA} = 560 \ \text{lbf}$$

$$F_{rB} = 1095 \ \text{lbf}$$

$$F_{ae} = 200 \ \text{lbf}$$

$$K = 1.5$$

$$a_f = 1.4$$

$$x_D = \frac{L_D}{L_R} = \frac{(40 \ \text{kh}) \times (400 \ \text{rmp}) \times \left(\frac{60 \ \text{min}}{1 \ \text{h}}\right)}{90 \times 10^6} = 10.6667$$

$$R = \sqrt{0.90} = 0.9487$$

$$F_{iA} = \frac{0.47F_{rA}}{K} = \frac{0.47 \times 560\ \text{lbf}}{1.5} = 175.4667\ \text{lbf}$$

$$F_{iB} = \frac{0.47F_{rB}}{K} = \frac{0.47 \times 1095\ \text{lbf}}{1.5} = 343.1000\ \text{lbf}$$

Therefore, $F_{iA} < F_{iB} + F_{ae}$.

$$F_{eB} = F_{rB} = 1095\ \text{lbf}$$

$$C_{10} = a_f F_{eB}\left[\frac{x_D}{x_0 + (\theta - x_0)(1 - R_D)^{\frac{1}{b}}}\right]^{\frac{1}{a}}$$

$$= 1.4 \times (1095\ \text{lbf}) \times \left[\frac{10.6667}{0 + 4.48(1 - 0.9487)^{\frac{1}{1.5}}}\right]^{\frac{1}{\frac{10}{3}}} = 3601.8\ \text{lbf}$$

Select cone 32305, cup 32305, with 0.9843 in bore, and rated at $3910\ \text{lbf}$ with $K = 1.95$.

$$F_{iB} = \frac{0.47F_{rB}}{K} = \frac{0.47 \times 1095\ \text{lbf}}{1.95} = 263.9231\ \text{lbf}$$

$F_{iA} < F_{iB} + F_{ae}$ still exists.

Then,

$$F_{eA} = 0.4F_{rA} + K_A F_{iA} = 0.4 \times (560\ \text{lbf}) + 1.5 \times (263.9231\ \text{lbf} + 200\ \text{lbf}) = 919.8846\ \text{lbf}$$

$$C_{10} = a_f F_{eA}\left[\frac{x_D}{x_0 + (\theta - x_0)(1 - R_D)^{\frac{1}{b}}}\right]^{\frac{1}{a}}$$

$$= 1.4 \times (919.8846\ \text{lbf}) \times \left[\frac{10.6667}{0 + 4.48(1 - 0.9487)^{\frac{1}{1.5}}}\right]^{\frac{1}{\frac{10}{3}}} = 3025.8\ \text{lbf}$$

Select cone M84249, cup M84210, with 1.0000 in bore, and rated at $3140\ \text{lbf}$ with $K = 1.07$.

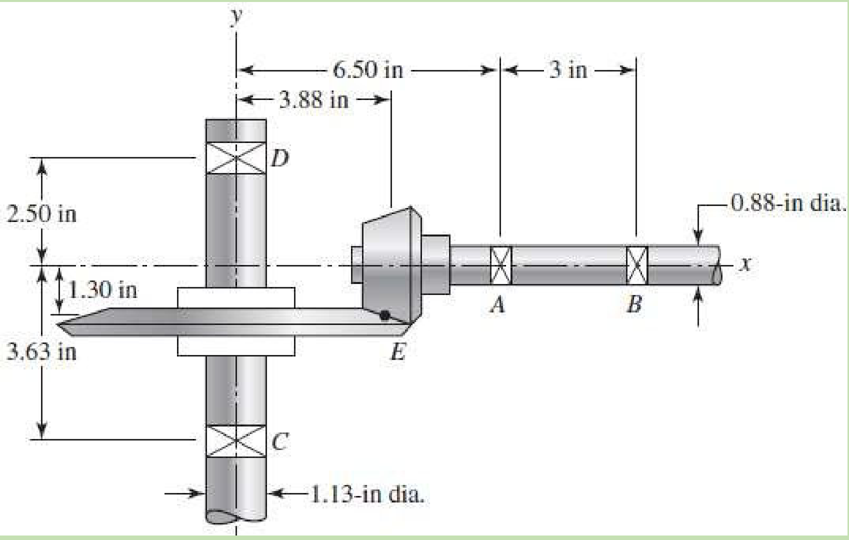
$$F_{iA} = \frac{0.47F_{rA}}{K} = \frac{0.47 \times 560\ \text{lbf}}{1.07} = 245.9813\ \text{lbf}$$

$F_{iA} < F_{iB} + F_{ae}$ still exists.

Problem 3

Statics analysis indicates the gear contact forces at point E are Fx = -92.8 lbf, Fy = -362.8 lbf, and Fz = +808 lbf. Tapered roller bearings are planned to be used at C and D. Should the bearings be oriented with direct mounting or indirect mounting for the axial thrust to be carried by the bearing at C?

Assuming bearings are available with K = 1.5 and an application factor of one. A bearing life of 10^8 revolutions is desired with a 90 percent combined reliability for the bearing set.



Solution:

Gear Load:

- tangential force of $+808$ lbf,
- radial force of -92.8 lbf, and
- thrust force of -362.8 lbf

$$L_D = 10^8$$

$$x_D = \frac{L_D}{L_R} = \frac{10^8}{90 \times 10^6} = 1.1111$$

$$R = \sqrt{0.90} = 0.9487$$

The reactions in the yz plane are

$$R_{zC} = \frac{808 \text{ lbf} \times (1.3 + 2.5)}{3.63 + 2.5} = 500.8809 \text{ lbf}$$

$$R_{zD} = \frac{808 \text{ lbf} \times (3.63 - 1.3)}{3.63 + 2.5} = 307.1191 \text{ lbf}$$

The reactions in the xy plane are

$$R_{xC} = \frac{(-92.8\ \text{lbf}) \times (1.3 + 2.5)}{3.63 + 2.5} + \frac{(-362.8\ \text{lbf}) \times 3.88}{3.63 + 2.5} = -287.1622\ \text{lbf}$$

$$R_{xD} = \frac{(-92.8\ \text{lbf}) \times (3.63 - 1.3)}{3.63 + 2.5} - \frac{(-362.8\ \text{lbf}) \times 3.88}{3.63 + 2.5} = 194.3622\ \text{lbf}$$

The radial loads F_{rC} and F_{rD} are the vector additions of R_{xC} and R_{zC}, and R_{xD} and R_{zD}, respectively:

$$F_{rC} = \sqrt{R_{xC}^2 + R_{zC}^2} = \sqrt{(500.8809\ \text{lbf})^2 + (-287.1622\ \text{lbf})^2} = 577.3593\ \text{lbf}$$

$$F_{rD} = \sqrt{R_{xD}^2 + R_{zD}^2} = \sqrt{(307.1191\ \text{lbf})^2 + (194.3622\ \text{lbf})^2} = 363.4540\ \text{lbf}$$

$$F_{iC} = \frac{0.47F_{rC}}{K} = \frac{0.47 \times 577.3593\ \text{lbf}}{1.5} = 180.9059\ \text{lbf}$$

$$F_{iD} = \frac{0.47F_{rD}}{K} = \frac{0.47 \times 363.4540\ \text{lbf}}{1.5} = 113.8822\ \text{lbf}$$

$$F_{ae} = 362.8\ \text{lbf}$$

Direct Mounting:

$$F_{iC} < F_{iD} + F_{ae}$$

Therefore, the axial thrust to be carried by the bearing at C.

Indirect Mounting:

$$F_{iC} > F_{iD} - F_{ae}$$

Therefore, the axial thrust to be carried by the bearing at D.

Will select direct mounting since it results in that the axial thrust to be carried by the bearing at C.

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