Example 3.1 Effect of Interference Fitting on Free Contact Angle and Endplay in a Deep-Groove Ball Bearing

Problem Statement

The 209 DGBB of Example 2.1 is manufactured to ABEC 5 specifications and mounted on a solid steel shaft with a k5 fit and in a steel housing with a K6 fit.

- Inner ring bore diameter = 45 mm
- Outer ring outside diameter (OD) = 85 mm

Under light thrust load conditions find values for:

- Contact angle
- Endplay

Problem Solution

Table CD3.2: Shaft tolerance range = 0.0025 to 0.0127 mm

Mean shaft tolerance = 0.0076 mm

Table CD3.8: Bearing bore tolerance range = 0 to - 8 μm

Mean bore tolerance = -4 μm = -0.004 mm

I_s = mean interference between shaft OD and bearing bore = 0.0076 – (-0.004) = 0.0116 mm

Table 3.1: Assuming the bearing is mounted on a very accurately ground shaft, the reduction in interference due to surface finish smoothing is 0.0020 mm

I_s = 0.0116 – 0.002 = 0.0096 mm

Eq. (3.23) $$\Delta_s = I_s \frac{D_s}{D_i} = 0.0096 \cdot \frac{45}{52.3} = 0.0083 mm$$

Table CD3.4: Housing bore tolerance range = -0.018 to 0.004

Mean housing bore tolerance = -0.007 mm

Table CD3.8: Bearing O.D. tolerance range = 0 to - 10

Mean bore tolerance = -5 μm = -0.005 mm

I_h = mean interference between bearing OD and housing bore = 0.007 + (-0.005) = 0.002 mm

Table 3.1: Assuming the bearing is mounted in a very accurately ground housing, the reduction in interference due to surface finish smoothing is 0.0020 mm

$I_h = 0.002 - 0.002 = 0$ mm

Eq. (3.27) $\Delta P_d = \Delta_s + \Delta_h$

$$\Delta P_d = -0.0083 + 0 = -0.0083 mm$$

Eq. (2.10) $\alpha^0 = \cos^{-1}\left(1 - \frac{P_d + \Delta P_d}{2A}\right)$

$$\alpha^0 = \cos^{-1}\left(1 - \frac{0.015 - 0.0083}{2 \cdot 0.508}\right) = 6.584°$$

Eq. (2.12) $P_e = 2A \sin \alpha^0$

$$P_e = 2 \cdot 0.508 \cdot \sin 6.584^0 = 0.1165 mm$$

Example 3.2 Effect of Interference Fitting on Free Contact Angle in an Angular-Contact Ball Bearing

Problem Statement

The 218 ACBB of Example 2.3 has a 90 mm (3.5433 in.) bore, a 160 mm (6.2992 in.) O.D., and is manufactured to ABEC 7 specifications. The bearing is mounted on a hollow steel shaft of 63.5 mm (2.5 in.) bore with a k6 fit and in a titanium housing having an effective O.D. of 203.2 mm (8 in.) with an M6 fit. Under light thrust load conditions find the values for the contact angle.

Problem Solution

Table CD3.2: Shaft tolerance range = 0.0025 to 0.0254 mm (0.0001 – 0.0010 in.)

Mean shaft tolerance = 0.0140 mm (0.00055 in.)

Table CD3.9: Bearing bore tolerance range = -0.004 mm (-0.00016 in.)

Mean interference for the bearing bore and shaft

$$I = 0.0140 + 0.004 = 0.0180 \text{ mm } (0.00071 \text{ in.})$$

Table 3.1: **Assuming the bearing is mounted on a ground surface, the reduction in I due to surface finish .0.0020 mm (0.00008 in.)**

$$I = 0.0180 - 2 \times 0.0020 = 0.0140 \text{ mm } (0.00055 \text{ in.})$$

Ex. 2.3: $d_i = 102.8$ mm (4.047 in.)

$$D_1 = d_i$$

Eq. (3.22):

$$\Delta_s = I\left(\frac{D_1}{D_s}\right)\left[\frac{\left(D_S/D_2\right)^2 - 1}{\left(D_1/D_2\right)^2 - 1}\right] = 0.0140 \cdot \frac{102.8}{90} \cdot \left[\frac{(90/63.5)^2 - 1}{(102.8/63.5)^2 - 1}\right] = 0.00995 mm (0.00039 in.)$$

Table CD3.4: Housing bore tolerance range = -0.033 to –0.0076 mm (-0.0013 to – 0.0003 in.)

Table CD3.10: Bearing mean O.D. tolerance range = -0.005 mm (-0.0002 in.)

Mean interference for the housing bore and bearing O. D.

I = 0.0203 - 0.005 = 0.0153 mm (0.0006 in.)

Table 3.1: **Assuming the housing bore is a ground surface, the reduction in I due to surface finish .0.0020 mm (0.00008 in.)**

I = 0.0153 – 2 ×0.0020 = 0.0113 mm (0.00044 in.)

Ex. 2.3: **d_o = 147.7 mm (5.816 in.)**

$D_2 = d_o$

For steel: E = 206,900 MPa (30A10^6 psi) and ξ = 0.3

For titanium: E = 103,500 MPa (15A10^6 psi) and ξ = 0.33

Eq. (3.24):

$$\Delta_h = \frac{2I\left(D_h/D_2\right)}{\left[\left(D_h/D_2\right)^2 - 1\right]\left\{\left[\frac{\left(D_h/D_2\right)^2 + 1}{\left(D_h/D_2\right)^2 - 1} + \xi_b\right] + \frac{E_b}{E_h}\left[\frac{\left(D_1/D_h\right)^2 + 1}{\left(D_1/D_h\right)^2 - 1} - \xi_h\right]\right\}}$$

$$\Delta_h = \frac{2 \cdot 0.0113\left(160/147.7\right)}{\left[\left(160/147.7\right)^2 - 1\right]\left\{\left[\frac{\left(160/147.7\right)^2 + 1}{\left(160/147.7\right)^2 - 1} + 0.3\right] + \frac{206{,}900}{103{,}500}\left[\frac{\left(203.2/160\right)^2 + 1}{\left(203.2/160\right)^2 - 1} - 0.33\right]\right\}}$$

Δ_h = 0.0064 mm (0.00025 in.)

Eq. (3.27):

$$\Delta P_d = -\Delta_s - \Delta_h = 0.00995 - 0.0064 = -0.01635mm(-0.00064in.)$$

Ex. 2.3: P_d **= 0.483 mm (0.019 in.)**

Ex. 2.3: $A = BD$ **= 1.031 mm (0.0406 in.)**

Eq. (2.10):

$$\alpha^0 = \cos^{-1}\left(1 - \frac{P_d + \Delta P_d}{2A}\right) = \cos^{-1}\left(1 - \frac{0.483 - 0.01635}{2 \cdot 1.031}\right) = 39°19'$$

Example 3.3 Effect of Temperature Differential on the Free Contact Angle of a Press-Fitted Angular-Contact Ball Bearing

Problem Statement

The inner ring of a 218 ACBB operates at a mean temperature of 148.9°C (300°F) and the outer ring is at 121.1EC (250°F). Considering the bearing was assembled at 21.1°C (70°F) and considering the press fits of Ex. 3.2, what free contact angle will occur?

Problem Solution

Coefficient of thermal expansion

Steel: Γ = 11.7·10-6 mm/mm/°C (6.5·10-6 in./in./°F)

Titanium: Γ = 8.5·10-6 mm/mm/°C (4.7·10-6 in./in./°F)

Ex. 2.3: **d_i =102.8 mm (4.047 in.)**

Ex. 2.3: **d_0 =147.7 mm (5.816 in.)**

Eq. (3.35):

$$\Delta_T = \Gamma_b\left[d_o\left(T_o - T_a\right) - d_i\left(T_i - T_a\right)\right] = 11.7\cdot 10^{-6}\left[147.7\cdot 100 - 102.8\cdot 127.8\right] = 0.0191mm(0.00075in.)$$

The outer ring and housing have different rates of expansion!

Ex. 3.2: **D_h =160 mm (6.2992 in.)**

Eq. (3.36):

$$\Delta I = \left(\Gamma_b - \Gamma_h\right)D_h\left(T_o - T_a\right) = \left(11.7 - 8.5\right)\cdot 10^{-6}\cdot 160\cdot\left(121.1 - 21.1\right) = 0.0508mm(0.0020in.$$

Ex. 3.2: **Δ_h =0.0064 mm (0.00025 in.)**

Ex. 3.2: **I =0.0113 mm (0.00044 in.)**

$I = I + \Delta I$ = 0.0113 + 0.0508 = 0.062 mm (0.00244 in.)

$$\Delta_h = \frac{0.062}{0.0113}\cdot 0.00635 = 0.0348mm(0.00137in.)$$

Ex. 3.2: **Δ_s =0.00995 mm (0.00039 in.)**

Eq. (3.37):

$$\Delta P_d = \Delta_T - \Delta_s - \Delta_h = 0.0191 - 0.00995 - 0.0348 = -0.0257 mm (-0.00101 in.)$$

Ex. 2.3: **P_d =0.483 mm (0.019 in.)**

Ex. 2.3: **$A = BD$ = 1.031 mm (0.0406 in.)**

Eq. (2.10): $$\alpha^0 = \cos^{-1}\left(1 - \frac{P_d + \Delta P_d}{2A}\right) = \cos^{-1}\left(1 - \frac{0.483 - 0.0257}{2 \cdot 1.031}\right) = 38°54'$$

Example 3.4 Force Required to Accomplish a Press Fit on the Inner Ring of a Deep-Groove Ball Bearing

Problem Statement

The 209 DGBB of Example 3.1 has a nominal width of 19 mm (0.7480 in.). What force is required to accomplish the press fit of Example 3.1?

Problem Solution

Ex. 3.1: I **= 0.0076 mm (0.00030 in.)**

Ex. 3.1: D_s **= 45 mm (1.7717 in.)**

Ex. 3.1: D_1 **= 52.3 mm (2.0587in.)**

Eq. (3.29):

$$F_a = 47100BI\left[1-\left(D_s/D_1\right)^2\right] = 47100\cdot 19\cdot 0.0076\cdot\left[1-\left(45/52.3\right)^2\right] = 1766N\,(397lb)$$