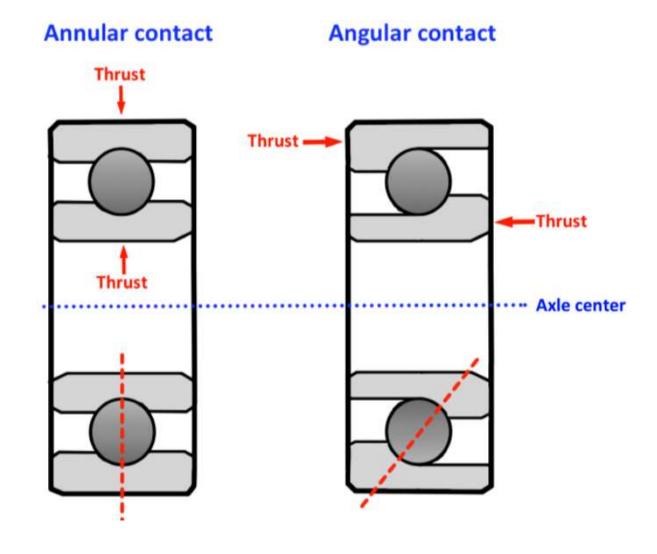
Bearing Mounting Issues

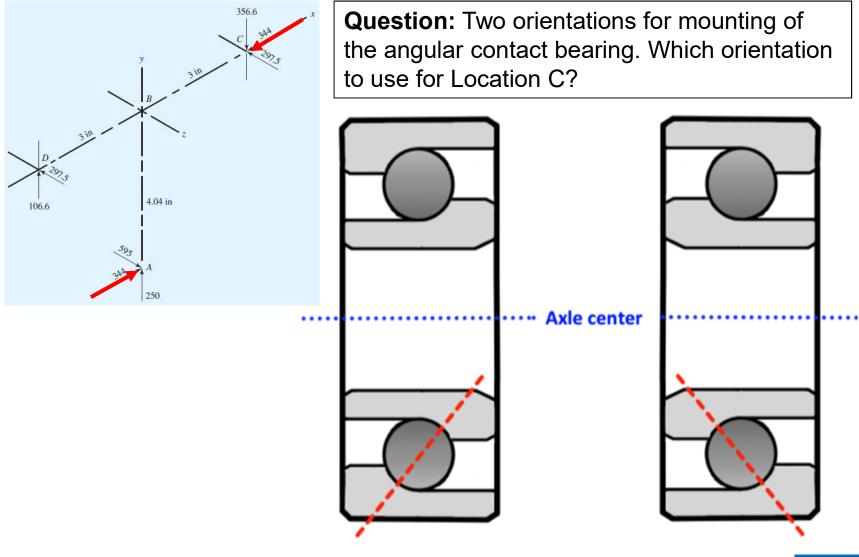


Deep Groove vs. Angular Contact Ball Bearing

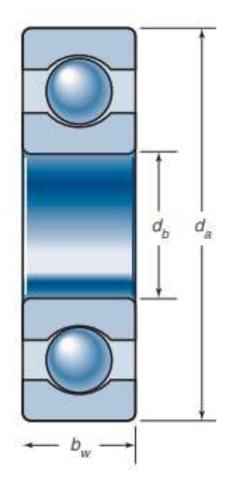




Mounting of Angular Contact Ball Bearings



Critical Bearing Design Parameters



| | | | Fillet | Shou | lder | | Load Ra | tings, kN | |
|-------|-----|--------|---------|--------|----------------|-----------------|----------------|-----------|----------------|
| Bore, | OD, | Width, | Radius, | Diamet | er, mm | Deep G | roove | Angular | Contact |
| mm | mm | mm | mm | ds | d _H | C ₁₀ | C ₀ | C10 | C _o |
| 10 | 30 | 9 | 0.6 | 12.5 | 27 | 5.07 | 2.24 | 4.94 | 2.12 |
| 12 | 32 | 10 | 0.6 | 14.5 | 28 | 6.89 | 3.10 | 7.02 | 3.05 |
| 15 | 35 | 11 | 0.6 | 17.5 | 31 | 7.80 | 3.55 | 8.06 | 3.65 |
| 17 | 40 | 12 | 0.6 | 19.5 | 34 | 9.56 | 4.50 | 9.95 | 4.75 |

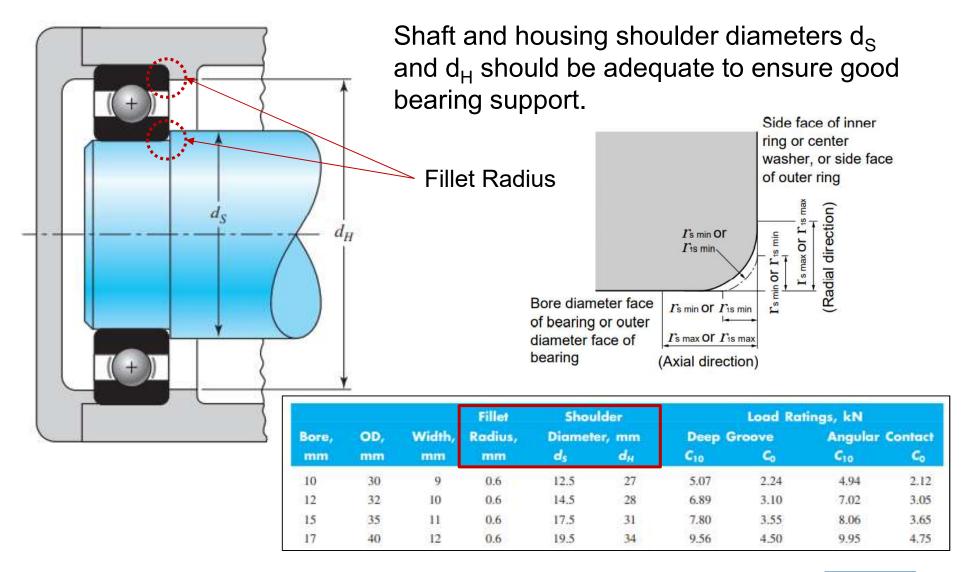
d_b: Bore

d_a: Outer Diameter

b_w: Width

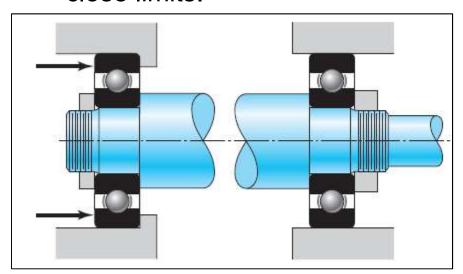


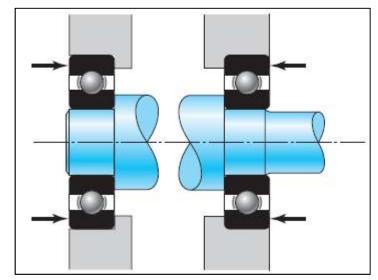
Critical Bearing Design Parameters



Typical Bearing Mounting

- One ball bearing at each end,
- One tapered roller bearing at each end, or
- A ball bearing at one end and a straight roller bearing at the other.
- One of the bearings usually has the added function of positioning or axially locating the shaft.
- The housing bore and shaft outside diameter must be held to very close limits.





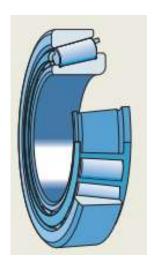


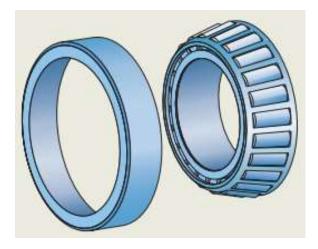


Instructor: Ping C. Sui, Ph.D. ME 1029 Machine Design 2

Fall 2021

11–9 Selection of Tapered Roller Bearings







Tapered Roller Bearings

Tapered roller bearings are more complicated than ball/cylindrical roller bearings.

Four components of a tapered roller bearing assembly:

- Cone (inner ring)
- Cup (outer ring)
- Tapered rollers
- Cage (spacer-retainer)

Advantages over Ball Bearing:

- Greater load-carrying capacity
- Carrying both <u>radial</u> and <u>thrust</u> (axial) loads, or any combination of the two, at the same time.

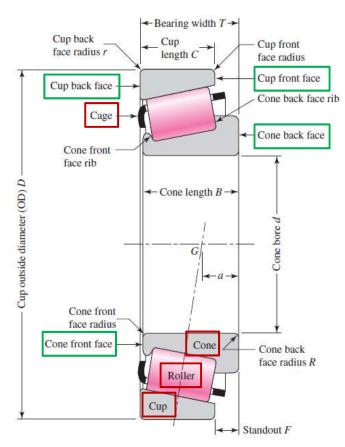


Figure 11-13



Bearing Preload, Mounting, Alignment, and Fit



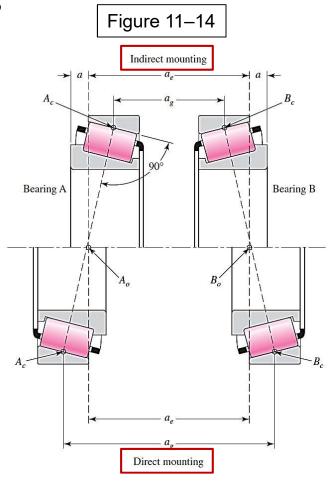
Mounting of Tapered Roller Bearings

Even when an external thrust load is not present, the <u>radial load will induce a thrust reaction</u> within the bearing because of the taper.

To avoid the separation of the races and the rollers, it is common to use at least two tapered roller bearings on a shaft.

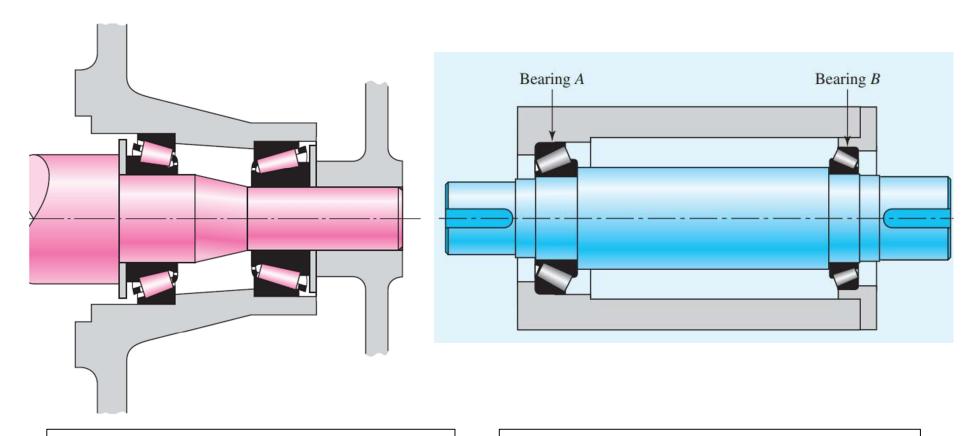
<u>Direct mounting</u>: two bearings mounted with the cone backs facing each other

<u>Indirect mounting</u>: with the cone fronts facing each other





Load Transmission of Tapered Roller Bearings



Indirect Mounting

- Cone fronts facing each other
- Applied preload from ID side

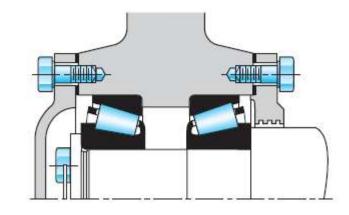
Direct mounting:

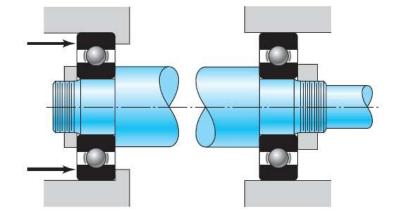
- Cone backs facing each other
- Applied preload from ID side



Bearing Preload

- Objective of preloading is to remove the internal clearance to increase the fatigue life, and to decrease the shaft slope at the bearing.
- Preloading of straight roller bearings may be obtained by using an interference fit for the outer ring.
- Ball bearings are usually preloaded by the axial load built in during assembly by the differences in widths of the inner and outer rings.
- It is always good practice to follow manufacturers' recommendations in determining preload, since too much will lead to early failure.



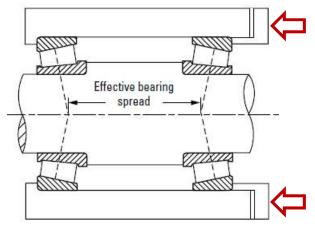




Preload Setting - Direct vs. Indirect Mounting

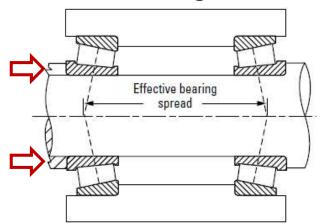
Tapered roller bearings are designed to take both radial and thrust loading. Under radial loads, a force is generated in the axial direction that must be counteracted. As a result, tapered roller bearings are normally adjusted against a second bearing.

Direct Mounting



- The outer ring is used to adjust the bearing setting
- The outer ring is usually set in position by an outer-ring follower or mounted in an outer-ring carrier.

Indirect Mounting



 Bearing setting is typically achieved by clamping against one of the inner rings.



Tapered Roller Bearing Equivalent Loading



Induced Radial Load on Tapered Roller Bearing

A radial load on a tapered roller bearing will induce a thrust reaction. Loading zone includes about half the rollers (approximately 180°).

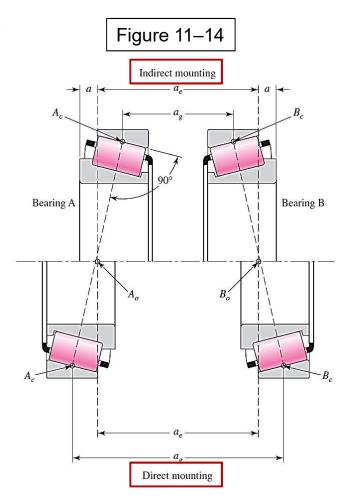
F_i: <u>induced thrust load</u> from a radial load with a 180° load zone, Timken provides the equation

$$F_i = \frac{0.47F_r}{K}$$

where the K factor is geometry-specific, and is the ratio of the radial load rating to the thrust load rating.

Recommended K factor in the preliminary selection process:

- K=1.5 for a radial bearing
- K=0.75 for a steep angle bearing





Timken Taper Roller Bearing Catalogue

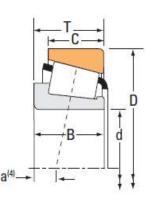
TAPERED ROLLER BEARINGS

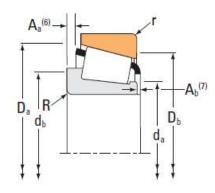
SINGLE-ROW • TYPE TS

TYPE TS

Fig. 11-15 in the textbook is an example table for singlerow tapered roller bearings







| Bea | aring Dimensi | ions | | | | | | | | Part Number | | |
|-------------------------|----------------------|----------------------|--|-----------|-------------------------|-------------------------|--|-----------------------------|--------------------------|-------------|---------|--|
| | | | | | | Load Ratings | | | | | | |
| Bore d | 0.D. D | Width T | Dynamic ⁽¹⁾ C ₁ | Fact e | ors ⁽²⁾ Y | Dyna C ₉₀ | mic ⁽³⁾ C _{a90} | Factors ⁽²⁾ K | Static C ₀ | Inner | Outer | |
| mm in. | mm in. | mm in. | N Ibf | | | N lbf | N Ibf | | N lbf | | | |
| 19.050 0.7500 | 56.896 2.2400 | 19.368 0.7625 | 45400 10200 | 0.31 | 1.95 | 11800 2650 | 6200 1390 | 1.90 | 45300 10200 | 1775 | 1729 | |
| 19.987 0.7869 | 46.982 1.8497 | 14.381 0.5662 | 26700 6010 | 0.36 | 1.68 | 6930 1560 | 4230 952 | 1.64 | 25400 5720 | 05079 | 05185/ | |
| 19.987 0.7869 | 46.990 1.8500 | 15.250 0.6004 | 26700 6010 | 0.36 | 1.68 | 6930 1560 | 4230 952 | 1.64 | 25400 5720 | 05079 | 05186 | |
| 19.987 0.7869 | 47.000 1.8504 | 14.381 0.5662 | 26700 6010 | 0.36 | 1.68 | 6930 1560 | 4230 952 | 1.64 | 25400 5720 | 05079 | 05185 | |
| 19.987 0.7869 | 47.000 1.8504 | 14.381 0.5662 | 26700 6010 | 0.36 | 1.68 | 6930 1560 | 4230 952 | 1.64 | 25400 5720 | 05079 | 05185-3 | |

SINGLE-ROW STRAIGHT BORE

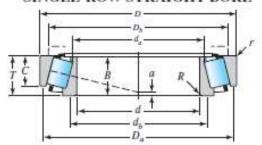


Figure 11-15

| | | 000 | 9 | | | | | | co | ne | 36 | | cu | p | | |
|------------------|----------------------|------------------|---------------------|---|------|----------------|-------------------------|----------------|------------------|------------------|--------------|---------------|------------------|------------------|----------------|-----------------|
| F1000 | outside | Total delica | 500 n | ng at pm for ours L ₁₀ | fac- | eff. | part n | umbers | max shaft | Section 4. | abou | king ilder | max hous- | width | sho | cking sulder |
| bons | diameter | width | row radial | thrust | tor | load center | cone | cup | fillet radius | width | dum | eten | fillet radius | width | dis | noters : |
| d | D | T | N lbf | N lbf | K | a© | | - | R® | В | db | da | гO | С | D _b | D _a |
| 25,000 0.9843 | 52,000 2.0472 | 16.250 0.6398 | 8190 1840 | 5260 1180 | 1.56 | -3.6 -0.14 | ♦ 30205 | ♦ 30205 | 1.0 | 15,000 0.5906 | 38.5 1.20 | 29.0 1.14 | 1.0 0.04 | 13,000 0,5118 | 46,0 1.81 | 48.5 1.91 |
| 25.000 0.9843 | 52,000 2.0472 | 19.250 0.7579 | 9520 2140 | 9510 2140 | E.00 | -3.0 -0.12 | ◆32205-B | ◆32205-B | 1.0 0.04 | 18,000 0.7087 | 34.0 1.34 | 31.0 1.22 | 0.04 | 15,000 0,5906 | 43.5 1.71 | 49.5 1.95 |
| 25,000 0.9843 | 52,000 2,0472 | 22,000 0.8661 | 13200 2980 | 7960 1790 | 1.66 | -7.6 -0.30 | 33205 | ♦ 33205 | 1.0 0.04 | 22.000 0.8661 | 34.0 1.34 | 30.5 1.20 | 1.0 0.04 | 18.900 0.7087 | 44.5 1.75 | 49.0 1.93 |
| 25.000 0.9843 | 62,000 2,4409 | 18.250 0.7185 | 13000 2930 | 6680 1500 | 1.95 | -5.1 -0.20 | ◆ 30305 | ◆38305 | 1.5 0.06 | 17,000 0.6693 | 32.5 1.28 | 30.0 1.18 | 1.5 0.06 | 15.000 0.5906 | 55.0 2.17 | 57.8 2.24 |
| 25.000 0.9843 | 62.000 2.4409 | 25.250 0.9941 | 17400 3910 | 8930 2010 | 1.95 | -9,7 -0.38 | + 32305 | ◆32305 | 1.5 0.06 | 24.900 0.9449 | 35.0 1.38 | 31.5 1.24 | 1.5 | 20,000 0,7874 | 54.0 2.13 | 57.0 2.24 |
| 25.159 0.9905 | 50.005 1.9687 | 13.495 0.5313 | 6990 1570 | 4810 1080 | 1,45 | -2,8 -0.11 | 07096 | 07196 | 1,5 0.06 | 14.260 0.5614 | 31.5 1.24 | 29.5 1.16 | 1.0 0.04 | 9.525 0.3750 | 44.5 1.75 | 47.0 1.85 |
| 25,400 1,0000 | 50.005 1.9687 | 13.495 0.5313 | 6990 1570 | 4810 1080 | 1.45 | -2.8 -0.11 | 07100 | 07196 | 1.0 0.04 | 14.260 0.5614 | 30.5 1.20 | 29.5 1.16 | 1.0 | 9.525 0.3750 | 44.5 1.75 | 47.0 1.85 |
| 25,400 1,0000 | 50.005 1.9687 | 13.495 0.5313 | 6990 1570 | 4810 1080 | 1.45 | -2.8 -0.11 | 07100-S | 07196 | 1.5 0.06 | 14.260 0.5614 | 31.5 1.24 | 29.5 1.16 | 1.0 0.04 | 9.525 0.3750 | 44.5 1.75 | 47,0 1.85 |
| 25,400 1,0000 | 50,292 1,9800 | 14.224 0.5600 | 7210 1620 | 4629 1040 | 1,56 | -3.3 -0.13 | 1.44642 | L44610 | 3.5 0.14 | 14.732 0.5800 | 36.6 1.42 | 29.5 1.16 | 1.3 0.05 | 10.668 0.4200 | 44.5 1.75 | 47.0 1.85 |
| 25.400 1.0000 | 50,292 1.5800 | 14.224 0.5600 | 7210 1620 | 4620 1040 | 1.56 | -3.3 -0.13 | L44643 | L44610 | 1.3 | 14.732 0.5800 | 31.5 1.24 | 29.5 1.16 | 1.3 0.05 | 10.668 0.4200 | 44.5 1.75 | 47.0 1.85 |
| 25,400 1,0000 | 51.994 2.0470 | 15.011 0.5910 | 6990 1570 | 4810 1080 | 1.45 | -2.8 -0.11 | 07100 | 07204 | 1.0 0.04 | 14.268 0.5614 | 30.5 1.20 | 29.5 1.16 | 1.3 0.05 | 12,700 0.5000 | 45.0 1.77 | 48.0 1.89 |

Tapered Roller Bearing Equivalent Load Calculation

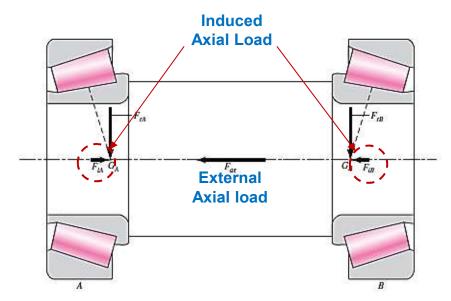
Equivalent load of ball bearings with combined radial and axial loading,

$$F_e = X_i V F_r + Y_i F_a$$

For <u>tapered roller bearings</u>, Timken recommends using X=0.4 and V=1 for all cases, and using the K factor for the specific bearing for Y:

$$F_e = 0.4F_r + KF_a$$

F_a is the net axial load including induced axial load and external axial load.



<u>Direct-mounted</u> Tapered Roller Bearings

Question:

One out of the two paired tapered roller bearings carries majority of the net axial load. But which one though?



Tapered Roller Bearing Equivalent Load Calculation Case: Direct-Mounting

Default Inducted Axial Force

$$F_{iA} = \frac{0.47F_{rA}}{K_A}; \quad F_{iB} = \frac{0.47F_{rB}}{K_B}$$

If
$$F_{iA} \le (F_{iB} + F_{ae})$$

$$F_{iB} = \frac{0.47F_{rB}}{K_B}$$

$$F_{iA} = \frac{0.47F_{rB}}{K_B} + F_{ae} = F_{iB} + F_{ae}$$

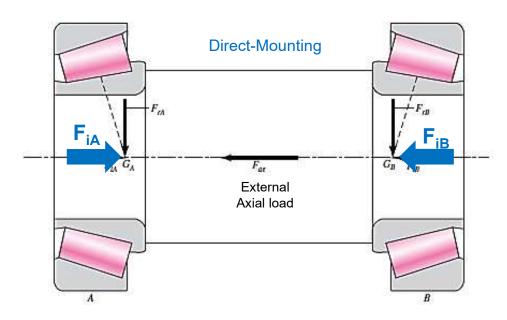
$$F_{eA} = 0.4F_{rA} + K_A F_{iA} \qquad F_{eB} = F_{rB}$$

If
$$F_{iA} > (F_{iB} + F_{ae})$$

$$F_{iA} = \frac{0.47F_{rA}}{K_A}$$

$$F_{iB} = \frac{0.47F_{rA}}{K_A} - F_{ae} = F_{iA} - F_{ae}$$

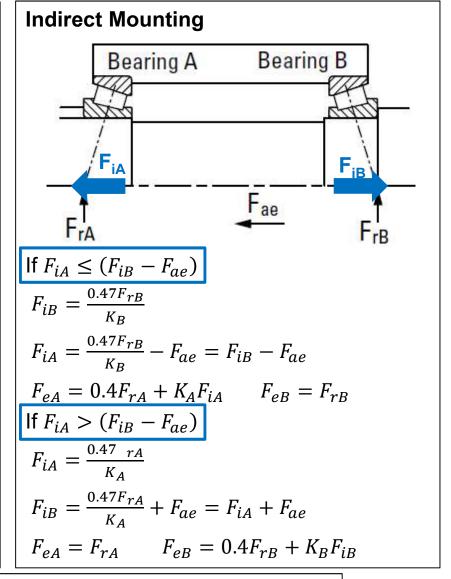
$$F_{eA} = F_{rA} \qquad F_{eB} = 0.4F_{rB} + K_B F_{iB}$$



Majority of the external axial load is carried by one out of the two bearings.

Tapered Roller Bearing Equivalent Load Calculation

Direct Mounting Bearing A Bearing B F_{iA} F_{ae} If $F_{iA} \leq (F_{iB} + F_{ae})$ $F_{iB} = \frac{0.47F_{rB}}{K_{P}}$ $F_{iA} = \frac{0.47F_{rB}}{K_{R}} + F_{ae} = F_{iB} + F_{ae}$ $F_{eA} = 0.4F_{rA} + K_A F_{iA} \qquad F_{eB} = F_{rB}$ If $F_{iA} > (F_{iB} + F_{ae})$ $F_{iA} = \frac{0.47F_{rA}}{K_A}$



* If calculated equivalent load is less than radial load, then use radial load instead. TechRef: TIMKEN ENGINEERING MANUAL, p.43



 $F_{iB} = \frac{0.47F_{rA}}{K_A} - F_{ae} = F_{iA} - F_{ae}$

 $F_{eA} = F_{rA} \qquad F_{eB} = 0.4F_{rB} + K_B F_{iB}$



Load-Life-Reliability Relation (Tapered Roller Bearing)

For <u>ball and cylindrical roller bearings</u>, the load-life-reliability relationship using three-parameter Weibull distribution:

$$R = exp\left\{ -\left[\frac{x_D \left(\frac{a_f F_D}{C_{10}}\right)^a - x_0}{\theta - x_0} \right]^b \right\} \qquad R \approx 1 - \left[\frac{x_D \left(\frac{a_f F_D}{C_{10}}\right)^a - x_0}{\theta - x_0} \right]^b \qquad R \ge 0.90$$

For <u>tapered roller bearings</u>, using Timken's two-parameter Weibull distribution (x_0 = 0, θ =4.48, and b=1.5), above equation can be reduced to

$$R = exp\left\{-\left[\frac{x_D\left(\frac{a_f F_D}{C_{10}}\right)^a - x_0}{\theta - x_0}\right]^b\right\} = exp\left\{-\left[\frac{x_D\left(\frac{a_f F_D}{C_{10}}\right)^a\right]^b\right\}$$

$$R_D \approx 1 - \left[\frac{x_D}{\theta} \left(\frac{a_f F_D}{C_{10}} \right)^a \right]^b$$

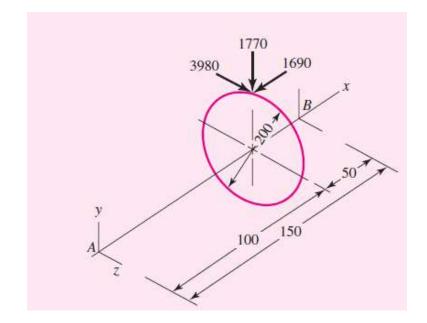
The shaft carries a helical gear with a tangential force of 3980 N, a radial force of 1770 N, and a thrust force of 1690 N at the pitch cylinder with directions shown. The pitch diameter of the gear is 200 mm. The shaft runs at a speed of 800 rev/min, and the span (effective spread) between the direct-mount bearings is 150 mm. The design life is to be 5000 h and an application factor of 1 is appropriate.

If the reliability of the bearing set is to be 0.99, select suitable single-row

tapered roller Timken bearings.

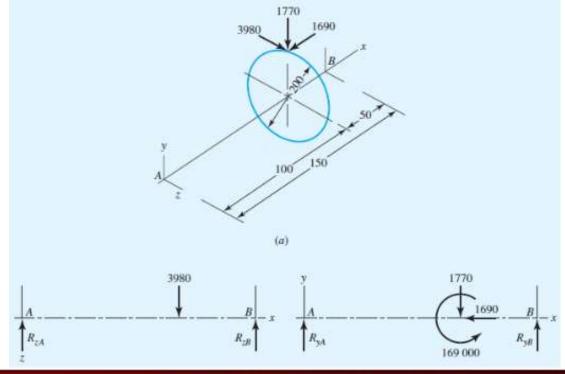
External axial load is in –X direction. Assign left-side bearing as bearing A, right-side bearing as bearing B

Assume direct mounting





- Gear Load:
 - tangential force of 3980 N,
 - radial force of 1770 N, and
 - thrust force of 1690 N
- Pitch Dia=200mm
- Location A: single-row tapered-roller Timken bearings
- Location B: single-row tapered-roller Timken bearings
- Design life is 5000h
- Bearing set reliability 0.99
- Application factor is to be 1.
- Direct mounting



| $F_t = 3980 \cdot N$ | $F_r = 1770 \cdot N$ | $F_a = 1690 \cdot N$ |
|---|--|--|
| $Trq := F_t \cdot \frac{200}{2}$ | mm=398 N·m | |
| $n_D = 800 \cdot \frac{1}{min}$ | | |
| $HP \coloneqq Trq \cdot 2 \cdot \pi$ | $\cdot n_D = 44.713 \ hp$ | |
| NB := 2 | Bearing Set Reliability | $R_s = 0.99$ |
| $R := \left(R_s\right)^{\left(\frac{1}{NB}\right)} =$ | 0.995 | 70 1690 |
| $L_{hr} \coloneqq 5000 \cdot hr$ | | 50 |
| $L_D := L_{hr} \cdot n_D = 2$ | 2.4 • 108 | 150 |
| $x_D := \frac{L_D}{L_{10}} = 2.66$ | 3980 (a) | y 1770 A 1690 |
| | $n_D \coloneqq 800 \cdot \frac{1}{min}$ $HP \coloneqq Trq \cdot 2 \cdot \pi$ $NB \coloneqq 2$ $R \coloneqq \left(R_s\right)^{\left(\frac{1}{NB}\right)} =$ $L_{hr} \coloneqq 5000 \cdot hr$ $L_D \coloneqq L_{hr} \cdot n_D = 2$ | $R := (R_s)^{\left(\frac{1}{NB}\right)} = 0.995$ |

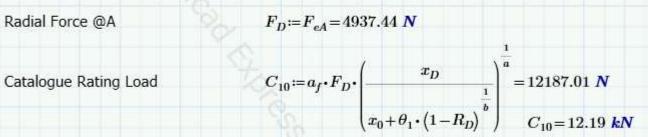
| Bearing Type | e: Tapered Roller Beari | ng | $a = \frac{10}{3}$ | $R_D = R$ | | |
|----------------------|---------------------------|--|--|---|-----------------------------|-------|
| Iterate on | K Factor | | 13 | | 1770 3980 1690 x | |
| Iteration 1, | Assume K Factor | $K_A = 1.5$ | $K_B := 1.5$ | | 50 | |
| Induced Thr | ust Load | $F_{iA} := \frac{0.47 \cdot F_{iA}}{K_{A}}$ | rA = 679.795 N | y A | 100 150 | |
| | | $F_{iB} := \frac{0.47 \cdot F_{iB}}{K_B}$ $F_{iB} + F_{ae} = 25$ | $\frac{rB}{}$ = 831.546 N | $ \begin{array}{c c} & & & & \\ \hline A & & & & \\ \hline R_{ZA} & & & & \\ \end{array} $ | (a) R_{zB} A R_{yA} | 16900 |
| Eq. 11-19 (P.589) | If $F_{iA} \leq (F_{iB})$ | $(+F_{ae})$ | $F_{eA} = 0.4F_{rA} + F_{eB} = F_{rB}$ | $K_A(F_{iB}+F_{iB})$ | ae) | |
| | If $F_{iA} > (F_{iB})$ | $(r + F_{ae})$ | $F_{eB} = 0.4F_{rB} + F_{eA} = F_{rA}$ | $K_B(F_{iA}-F_{iA})$ | ae) | |
| FiA < (FiB+F | ae) | $F_{eA} = 0.4 \cdot F_{rA}$ | $+K_A \cdot (F_{iB} + F_{ae})$ | =4650.14 N | | |

 $F_{eB} := F_{rB} = 2653.87 \ N$

| Application Factor | $a_f = 1.0$ | | EXAMPLE | E 11-8 |
|--|---|--|-------------------------------------|------------------------|
| Radial Force @A | $F_D := F_{eA} = 4650.$ | 14 N | | ` |
| Catalogue Rating Load | $C_{10} := a_f \cdot F_D \cdot \left(- \right)$ | x_D $\frac{1}{a}$ | =11477.88 N | |
| | | $+\theta_1 \cdot (1-R_D)$ | | |
| | $C_{10} = 11.48 \text{ kN}$ | | | |
| Use Fig. 11.15 (P.586) to pick at 15.400 62.000 19.050 12100 7280 1.0000 2.4409 0.7500 2730 1640 | 1.67 -5.8 15100 1524 | | 31.5 1.3 14.288 1.24 0.05 0.5625 | 55.0 58.0 2.17 2.28 |
| From Fig. 11–15, tentatively se = 12100 N. | elect type TS 15100 cone | and 15245 cup, wh | nich will work: KA =1 | l.67, <i>C</i> 10 |
| Radial Force @B | $F_D = F_{eB} = 2653.$ | 87 N | | |
| Catalogue Rating Load | $C_{10} \coloneqq a_f \cdot F_D \cdot \left(\begin{array}{c} \\ x_0 \end{array} \right)$ | $\left. \begin{array}{c} x_D \\ \hline + 	heta_1 \cdot \left(1 - R_D \right)^{rac{1}{b}} \end{array} \right)^{rac{1}{a}}$ | =6550.5 N | |
| Tentatively select the bearing i | dentical to bearing A | | | |

58.0 2.28

Induced Thrust Load $F_{iA}\coloneqq 1.67 \qquad K_{B}\coloneqq 1.67$ Induced Thrust Load $F_{iA}\coloneqq \frac{0.47\cdot F_{rA}}{K_{A}}=610.59\ N$ $F_{iB}\coloneqq \frac{0.47\cdot F_{rB}}{K_{B}}=746.9\ N$ $F_{iB}+F_{ae}=2436.9\ N$ FiA < (FiB+Fae) $F_{eA}\coloneqq 0.4\cdot F_{rA}+K_{A}\cdot \left(F_{iB}+F_{ae}\right)=4937.44\ N$ $F_{eB}\coloneqq F_{rB}=2653.87\ N$ Application Factor $a_{f}\coloneqq 1.0$

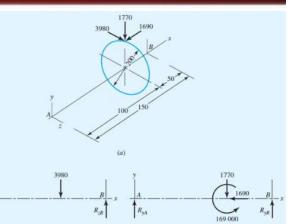


Although this catalog entry exceeds slightly the tentative selection for bearing A, we will keep it since the reliability of bearing B exceeds 0.995.

Radial Force @B
$$F_D \coloneqq F_{eB} = 2653.87 \ N$$

Catalogue Rating Load
$$C_{10}\!\coloneqq\!a_f\!\cdot\!F_D\!\cdot\!\left(\!\frac{x_D}{x_0\!+\!\theta_1\!\cdot\!\left(1\!-\!R_D\!\right)^{\frac{1}{b}}}\!\right)^{\!\frac{1}{a}}\!=\!6550.5\,\textit{N}$$

Select cone and cup 15100 and 15245, respectively, for both bearing A and B.





In Ex. 11-8 bearings A and B (cone 15100 and cup 15245) have C_{10} = 12100 N. What is the reliability of the pair of bearings A and B?

Solution:

Desired life
$$x_D = \frac{L_D}{L_R} = \frac{60 \ L_D n_D}{90 \ 6} = \frac{60.5000 \cdot 80}{90 \cdot 10^6} = 2.67$$

For bearing A, $F_D = F_{eA} = 4938$ N, and $a_f = 1$:

$$R_{DA} = 1 - \left[\frac{x_D}{\theta} \left(\frac{a_f F_D}{C_{10}}\right)^a\right]^b = 1 - \left[\frac{2.67}{4.48} \left(\frac{1.493}{12100}\right)^{\frac{10}{3}}\right]^{1.5} = 0.99479$$

For bearing B, $F_D = F_{eB} = 2654$ N, and $a_f = 1$:

$$R_{DB} = 1 - \left[\frac{x_D}{\theta} \left(\frac{a_f F_D}{C_{10}} \right)^a \right]^b = 1 - \left[\frac{2.67}{4.48} \left(\frac{1 \cdot 2654}{12100} \right)^{\frac{10}{3}} \right]^{1.5} = 0.99977$$

Reliability of the bearing pair is

$$R = R_{DA}R_{DB} = 0.99479 \cdot 0.99977 = 0.99456$$

For the shaft AB, perform a preliminary specification for tapered roller bearings at A and B. A bearing life of 500 million revolutions is desired with a 90 percent combined reliability for the bearing set, assuming distribution data from manufacturer 1 in Table 11–6.

Should the bearings be oriented with direct mounting or indirect mounting for the axial thrust to be carried by the bearing at A?

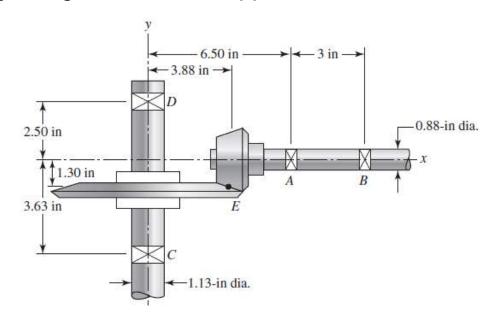
Assuming bearings are available with K=1.5, find the required radial rating for each bearing. For this preliminary design, assume an application factor of one.

Given:

 $F_{rA} = 1643 \text{ lbf}$

 F_{rB} =758 lbf

 $F_{ae} = 92.8 \text{ lbf}$



EXAMPLE 11-42 (Cont'd)

$$F_{iA} = \frac{0.47F_{rA}}{K_A} = \frac{0.47 \cdot 1643}{1.5} = 515 \ lbf$$

$$F_{iB} = \frac{0.47F_{rB}}{K_B} = \frac{0.47 \cdot 758}{1.5} = 238 \ lbf$$

f 3.63 in $F_{iB} = 238 \text{ } lbf$ $F_{iB} = 238 \text{ } lbf$

3.88 in ->

Direct Mounting: $F_{iA} < F_{iB} - F_{ae}$

$$F_{iA} + F_{ae} = 515 + 93 = 608 \, lbf$$
 $F_{iB} = 238 \, lbf^{-1}$

Bearing B carries the axial thrust.

$$F_{eA} = F_{rA} = 1643 \ lbf$$

 $F_{eB} = 0.4F_{rB} + K(F_{iA} + F_{ae}) = 0.4 \cdot 758 + 1.5 \cdot 608 = 1215 \ lbf$

Indirect Mounting:

$$F_{iA} = 515 \ lbf$$
 $F_{iB} + F_{ae} = 238 + 93 = 331 \ lbf$

 $F_{iA} > F_{iB} + F_{ae}$ Bearing B carries the axial thrust.

$$F_{eA} = F_{rA} = 1643 \ lbf$$

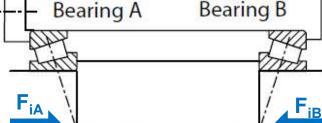
$$F_{eB} = 0.4F_{rB} + K(F_{iA} - F_{ae}) = 0.4 \cdot 758 + 1.5 \cdot (515 - 93) = 936 \ lbf$$

Will select indirect mounting since it results in lower F_{eB}.

0.88-in dia.

Tapered Roller Bearing Equivalent Load Calculation

Direct Mounting



 F_{ae}

If
$$F_{iA} \leq (F_{iB} + F_{ae})$$

$$F_{iB} = \frac{0.47 r_B}{K_B}$$

$$F_{iA} = \frac{0.47F_{rB}}{K_B} + F_{ae} = F_{iB} + F_{ae}$$

$$F_{eA} = 0.4F_{rA} + K_A F_{iA} \qquad F_{eB} = F_{rB}$$

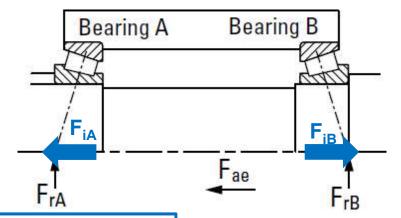
If
$$F_{iA} > (F_{iB} + F_{ae})$$

$$F_{iA} = \frac{0.47 r_A}{K_A}$$

$$F_{iB} = \frac{0.47F_{rA}}{K_A} - F_{ae} = F_{iA} - F_{ae}$$

$$F_{eA} = F_{rA} \qquad F_{eB} = 0.4F_{rB} + K_B F_{iB}$$

Indirect Mounting



If
$$F_{iA} \leq (F_{iB} - F_{ae})$$

$$F_{iB} = \frac{0.47F_{rB}}{K_B}$$

$$F_{iA} = \frac{0.47F_{rB}}{K_B} - F_{ae} = F_{iB} - F_{ae}$$

$$F_{eA} = 0.4F_{rA} + K_A F_{iA} \qquad F_{eB} = F_{rB}$$

If
$$F_{iA} > (F_{iB} - F_{ae})$$

$$F_{iA} = \frac{0.47F_{rA}}{K_A}$$

$$F_{iB} = \frac{0.47 r_A}{K_A} + F_{ae} = F_{iA} + F_{ae}$$

$$F_{eA} = F_{rA} \qquad F_{eB} = 0.4F_{rB} + K_B F_{iB}$$

* If calculated equivalent load is less than radial load, then use radial load instead. TechRef: TIMKEN ENGINEERING MANUAL, p.43



Tapered Roller Bering Frictional Torque Calculation

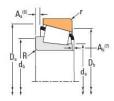


Running Torque

Assume the bearing running torque has stabilized after an initial period referred to as running-in.







| $Trq = k_1 G_1(n\mu)^{0.62} \left(\frac{f_3 F_r}{K}\right)^{0.3}$ | |
|--|--|
| $n_{min} = \frac{k_2}{\mu G_2} \left(\frac{f_2 F_r}{K}\right)^{2/3}$ | |

n = shaft speed (rpm)

 $k_1 = 2.56x10^{-6}$ (N-m); or

 $k_1 = 3.54 \times 10^{-5} \text{ (in-lbf)}$

 $k_2 = 625$ (metric) or 1700 (inch)

 μ = lubricant dynamic viscosity at operating temperature (centipoise)

 f_3 = combined load factor

 f_2 = combined load factor

| | | | | Bea | ring Dime | nsions | | | | | 0.0 | | *2009000000 | |
|-------------------------|----------------------|-----------------------|------------------------------------|---------------------|------------------------|------------------------------|---------------------|------------------------|--------------------------|--------------------------|----------------|----------------|-------------|---------------------|
| | | | | Shaft | | H | ousing | | | | 960 | metry f | actors | Bearin |
| Width B | Width C | Eff. Ctr. | Max Shaft Fillet Radius R(5) | | king ler Dia. ds | Max Housing Fillet Radius | | king der Dia. Ds | Ca A _a (6) | ge Α _h (7) | G ₁ | G ₂ | Cg | Weigh |
| mm | mm | mm | mm | mm | mm | nm | mm | mm du | mm | mm | | | | kg |
| in. | in. | in. | in. | in. | in. | in | in. | in. | in. | in. | | | | lbs. |
| 10.785 0.4246 | 7.938 0.3125 | -3.0 -0.12 | 0.5 0.02 | 12.5 0.49 | 13.0 0.51 | 1.3 0.05 | 29.0 1.14 | 26.0 1.02 | - 0.3 -0.01 | 1.5 0.06 | 1.7 | 3.2 | 0.0308 | 0.05 0.10 |
| 10.785 0.4246 | 7.938 0.3125 | -3.0 -0.12 | 1.3 0.05 | 13.5 0.53 | 15.0 0.59 | 1.3 0.05 | 29.0 1.14 | 26.0 1.02 | - 0.3 -0.01 | 1.5 0.06 | 1.7 | 3.2 | 0.0308 | 0.05 0.10 |
| 10.988 0.4326 | 8.730 0.3437 | -2.5 -0.10 | 1.3 0.05 | 15.5 0.61 | 17.5 0.69 | 1.3 0.05 | 32.0 1.26 | 29.0 1.14 | 0.1 0.00 | 1.2 0.05 | 2.3 | 4.1 | 0.0355 | 0.05 0.13 |
| 10.785 0.4246 | 7.938 0.3125 | -3.0 -0.12 | 0.8 0.03 | 15.5 0.61 | 16.5 0.65 | 1.3 0.05 | 29.0 1.14 | 26.0 1.02 | - 0.3 -0.01 | 1.5 0.06 | 1.7 | 3.2 | 0.0308 | 0.04 |
| 10.988 0.4326 | 8.730 0.3437 | -2.5 -0.10 | 0.8 0.03 | 17.5 0.69 | 17.5 0.69 | 1.3 0.05 | 32.0 1.26 | 29.0 1.14 | 0.1 0.00 | 1.2 0.05 | 2.3 | 4.1 | 0.0355 | 0.05 0.12 |
| 10.988 0.4326 | 8.730 0.3437 | -2.5 -0.10 | 1.3 0.05 | 17.0 0.67 | 18.5 0.73 | 1.3 0.05 | 32.0 1.26 | 29.0 1.14 | 0.1 0.00 | 1.2 0.05 | 2.3 | 4.1 | 0.0355 | 0.05 0.12 |
| 14.072 0.5540 | 11.112 0.4375 | -5.1 -0.20 | 1.5 0.06 | 16.5 0.65 | 19.0 0.75 | 0.8 0.03 | 34.0 1.34 | 33.0 1.30 | -0.4 -0.02 | 1.3 0.06 | 3.1 | 2.9 | 0.0329 | 0.08 0.18 |
| 10.988 0.4326 | 8.730 0.3437 | -2.5 -0.10 | 0.8 0.03 | 19.0 0.75 | 19.5 0.77 | 1.3 0.05 | 32.0 1.26 | 29.0 1.14 | 0.1 0.00 | 1.2 0.05 | 2.3 | 4.1 | 0.0355 | 0.04 0.11 |
| 10.998 0.4330 | 8.712 0.3430 | - 3.3 -0.13 | 1.3 0.05 | 19.5 0.77 | 21.5 0.85 | 1.3 0.05 | 32.5 1.28 | 29.0 1.14 | - 0.3 -0.02 | 1.4 0.06 | 3.0 | 5.4 | 0.0348 | 0.06 0.11 |
| 11.153 0.4391 | 9.525 0.3750 | -1.5 -0.06 | 1.3 0.05 | 20.5 0.81 | 22.0 0.87 | 1.3 0.05 | 37.0 1.46 | 34.0 1.34 | 0.5 0.02 | 1.6 0.07 | 2.9 | 5.6 | 0.0404 | 0.08 0.16 |
| 14.681 0.5780 | 11.112 0.4375 | -5.1 -0.20 | 1.3 0.05 | 20.0 0.79 | 21.5 0.85 | 2.0 0.08 | 37.5 1.48 | 34.0 1.34 | 0,3 0.01 | 1.4 0.06 | 4.2 | 4.0 | 0.0384 | 0.09 |
| 14.288 0.5625 | 9.525 0.3750 | -1.3 -0.05 | 1.5 0.06 | 22.5 0.89 | 24.5 0.96 | 1.5 0.06 | 39.5 1.56 | 34.5 1.36 | 1.5 0.05 | 0.7 0.03 | 3.4 | 4.6 | 0.0465 | 0.10 0.22 |
| 16.670 0.6563 | 13.495 0.5313 | -5.8 -0.23 | 1.5 0.06 | 21.0 0.83 | 23.0 0.91 | 1.5 0.06 | 39.0 1.54 | 36.5 1.44 | 0.4 0.01 | 1.9 0.08 | 5.3 | 4.5 | 0.0423 | 0.12 0.27 |
| 14.381 0.5662 | 11.112 0.4375 | -4.1 -0.16 | 1.5 0.06 | 21.0 0.83 | 23.5 0.93 | 1.3 0.05 | 42.5 1.67 | 40.5 1.59 | 0.2 0.00 | 1.3 0.05 | 5.8 | 5.5 | 0.0448 | 0.14 0.29 |
| 21.539 0.8480 | 14.288 0.5625 | -9.1 -0.36 | 0.8 0.03 | 21.5 0.85 | 22.0 0.87 | 1.3 0.05 | 44.5 1.75 | 42.0 1.65 | 2.2 0.09 | 0.7 0.03 | 8.0 | 4.0 | 0.0452 | 0.19 0.44 |
| 21.539 0.8480 | 17.462 0.6875 | -9.1 -0.36 | 0.8 0.03 | 21.5 0.85 | 22.0 0.87 | 3.5 0.14 | 44.5 1.75 | 39.0 1.54 | 2.2 0.09 | 0.7 0.03 | 8.0 | 4.0 | 0.0452 | 0.21 0.47 |
| 21.839 0.8598 | 15.875 0.6250 | - 5.8 -0.23 | 0.8 0.03 | 26.4 1.03 | 29.0 1.14 | 2.3 0.09 | 50.0 1.97 | 43.0 1.69 | 1.3 0.05 | 2.0 0.08 | 7.0 | 4.1 | 0.0558 | 0.25 0.57 |

TechRef: TIMKEN Tapered Roller Bearing Catalogue, p.51



Running Torque

Assume the bearing running torque has stabilized after an initial period referred to ²⁸ as running-in.

$$Trq = k_1 G_1 (n\mu)^{0.62} \left(\frac{f_3 F_r}{K}\right)^{0.3}$$

$$n_{min} = \frac{k_2}{\mu G_2} \left(\frac{f_2 F_r}{K}\right)^{2/3}$$

n = shaft speed (rpm)

 $k_1 = 2.56 \times 10^{-6} \text{ (N-m)}$; or

 $k_1 = 3.54 \times 10^{-5}$ (in-lbf)

 $k_2 = 625$ (metric) or 1700 (inch)

 μ = lubricant dynamic viscosity at operating temperature (centipoise)

 f_3 = combined load factor

 f_2 = combined load factor

The torque equations will be underestimated if n is less than n_{min} .

Load Condition f3 and f2 $KF_a/F_r > 2.0$ f3 = KFa/Fr $f_2 = f_3 + 0.8$ $0.47 \le KF_a/F_r \le 2.0$ Use graph above $f_3 = 0.06$ $KF_a/F_r < 0.47$ $f_3 = 1.78$ 2.6 2.4 2.2 2.0 Combined load factors, f₁ and f₂ 1.8 1.0 0.8 0.6 0.4 0.2 0.2 1.0 1.4 KFa/Fr

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Example

Calculate the running torque of a Timken TS 05075X tapered roller bearing with shaft speed of 4000rpm and lubricated with SAE 30 oil operated at 65°C.

$$F_r$$
=3000 N, F_a =1500 N
K=1.64, $\frac{KF_a}{F_r}$ = 0.82

f₃=0.6 (from chart)

Viscosity @65°C=25cP

| Bea | ring Dimensi | ions | | | Part Number | | | | | | |
|--------------------------|------------------|------------------|--|--------------|-------------------------|-------------------------|--|------------------------|--------------------------|--------|---------|
| Bore O.D | | | | Load Ratings | | | | | | | |
| | 0.D. D | Width T | Dynamic ⁽¹⁾ C ₁ | Fact e | ors ⁽²⁾ Y | Dyna C ₉₀ | mic ⁽³⁾ C _{a90} | Factors ⁽²⁾ | Static C ₀ | Inner | Outer |
| mm in. | mm in. | mm in. | N lbf | | | N lbf | N lbf | | N Ibf | | |
| 1 9.050 0.7500 | 47.000 1.8504 | 14.381 0.5662 | 26700 6010 | 0.36 | 1.68 | 6930 1560 | 4230 952 | 1.64 | 25400 5720 | 05075X | 05185-S |

| | Bearing Dimensions | | | | | | | | | | | | antore | |
|------------------|--------------------|---------------|--|--------------|------------------------------------|--|------------------|------------------------------------|-------------------------------------|-------------------------------------|------------------|----------------|--------|--------------|
| Width B | | | | Shaft | | Housing | | | | | Geometry Factors | | | Bearing |
| | Width C | Eff. Ctr. | Max Shaft Fillet Radius R ⁽⁵⁾ | | king Ier Dia. d _b | Max Housing Fillet Radius r ⁽⁵⁾ | | king der Dia. D _b | Ca A _a ⁽⁶⁾ | ge A _b ⁽⁷⁾ | G ₁ | G ₂ | Cg | Weight |
| mm in. | mm in. | mm in. | mm in. | mm in. | mm in. | mm in. | mm in. | mm in. | mm in. | mm in. | | | | kg lbs. |
| 21.000 0.8268 | 16.000 0.6299 | -6.1 -0.24 | 1.0 0.04 | 23.0 0.90 | 27.5 1.08 | 2.0 0.08 | 43.0 1.69 | 37.5 1.48 | 1.4 0.05 | 1.4 0.06 | 6.1 | 4.6 | 0.0526 | 0.20 0.42 |

Torque =
$$k_1 G_1(n\mu)^{0.62} \left(\frac{f_3 F_r}{K}\right)^{0.3}$$

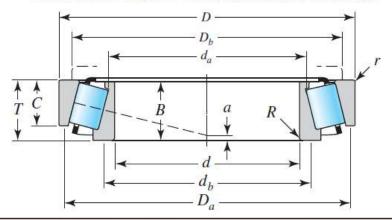
= $2.56 \cdot 10^{-6} \cdot 6.1 \cdot (4000 \cdot 25)^{0.62} \left(\frac{0.6 \cdot 3000}{1.64}\right)^{0.3} = 0.161 N \cdot m$



Selection of Tapered Roller Bearing

| 4 | outside | 525 | 500 m | ng at pm for ours L 10 | fac- | eff. | part nu | imbers | max shaft fillet | +44 | shot | cing ilder | max hous- | | sho | cking ulder |
|------------------|----------------------|------------------|-----------------------|------------------------------|------|------------------------|--------------|---------|------------------------|------------------|--------------|----------------|------------------|------------------|------------------|----------------------|
| bore | diameter | width | one- row radial | thrust | tor | load center | cone | cup | fillet radius | width | diam | eters | fillet radius | width | diar | neters |
| d | D | Т | N Ibf | N Ibf | K | a ^② | | | R® | В | d_{b} | d _a | r® | C | D _b | D _a |
| 25.400 1.0000 | 66.421 2.6150 | 23.812 0.9375 | 18400 4140 | 8000 1800 | 2.30 | - 9.4 -0.37 | 2687 | 2631 | 1.3 0.05 | 25.433 1.0013 | 33.5 1.32 | 31.5 1.24 | 1.3 0.05 | 19.050 0.7500 | 58.0 2.28 | 60.0 2.36 |
| 25.400 1.0000 | 68.262 2.6875 | 22,225 0.8750 | 15300 3440 | 10900 2450 | 1.40 | -5.1 -0.20 | 02473 | 02420 | 0.8 0.03 | 22.225 0.8750 | 34.5 1.36 | 33.5 1.32 | 1.5 0.06 | 17.462 0.6875 | 59.0 2.32 | 63.0 2.48 |
| 25.400 1.0000 | 72.233 2.8438 | 25.400 1.0000 | 18400 4140 | 17200 3870 | 1.07 | - 4.6 -0.18 | HM88630 | HM88610 | 0.8 0.03 | 25.400 1.0000 | 39.5 1.56 | 39.5 1.56 | 2.3 0.09 | 19.842 0.7812 | 60.0 2.36 | 69.6 2.72 |
| 25,400 1.0000 | 72.626 2.8593 | 30.162 1.1875 | 22700 5110 | 13000 2910 | 1.76 | - 10.2 -0.40 | 3189 | 3120 | 0.8 0.03 | 29.997 1.1810 | 35.5 1.40 | 35,0 1.38 | 3.3 0.13 | 23.812 0.9375 | 61.0 2.40 | 67. 0 2.64 |
| 26.157 1.0298 | 62.000 2.4409 | 19.050 0.7500 | 12100 2730 | 7280 1640 | 1.67 | - 5.8 -0.23 | 15103 | 15245 | 0.8 0.03 | 20.638 0.8125 | 33.0 1.30 | 32.5 1.28 | 1.3 0.05 | 14.288 0.5625 | 55.0 2.17 | 58.0 2.28 |
| 26.162 1.0300 | 63.100 2.4843 | 23.812 0.9375 | 18400 4140 | 8000 1800 | 2.30 | - 9.4 -0.37 | 2682 | 2630 | 1.5 0.06 | 25.433 1.0013 | 34.5 1.36 | 32.0 1.26 | 0.8 | 19.050 0.7500 | 57.0 2.24 | 59.0 2.32 |
| 26.162 1.0300 | 66.421 2.6150 | 23.812 0.9375 | 18400 4140 | 8000 1800 | 2.30 | - 0.4 | 2682 CINI | GLE-R | OW | 25.433 C/T/D | A I C | 32.6 | 13 | 10.050 | 58.0 2.28 | 60. 6 |





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