RBC BEARINGS

TECHNICAL DATA

Cam Followers, Yoke, and Track Rollers

Introduction to Cam Follower Technology

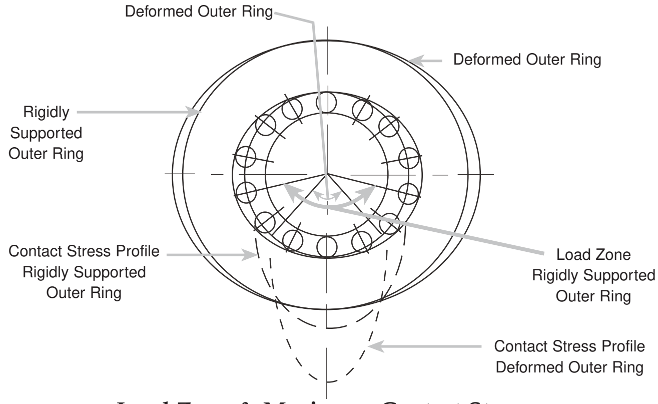
Safety Precaution

In rare cases a bearing failure may cause great mechanical damage or even lead to personal injury. To help prevent such losses, you may contact RBC's engineering staff to review your application details. The engineering staff's review will assist you in identifying potential problem areas and suggest modifications to improve bearing performance in your application. The engineering staff at RBC has many years of experience with a large variety of applications and operating conditions. If you have a safety related application and would like an evaluation by RBC's engineering department, please submit your application details in confidence.

1. Difference from Standard Bearings

The outer rings of regular ball and roller bearings are typically mounted in rigid housings providing support around the entire circumference. Individual roller forces are transmitted through the outer ring directly into the housing with no major deformations.

By contrast, cam followers and yoke rollers are supported at a single point on their circumference. Individual roller forces produce bending moments on



Load Zone & Maximum Contact Stress

Fig. 1

the outer ring around the point of contact. The effects are outer ring deformation with reversed bending stresses in dynamic applications, a reduced load zone, and a higher maximum roller load (see Fig. 1.).

To keep deformation to a minimum, the outer ring of a cam follower must have a considerably heavier cross section than a standard bearing. This requirement conflicts with the desire for maximum dynamic bearing capacity which needs as large a roller diameter as possible. RBC cam followers and yoke rollers provide an optimum compromise between outer ring strength and theoretical bearing capacity.

2. Capacity and Load Limits

Evaluation of the expected service life and limit loads of cam followers is more complex than with housed bearings. In addition to the static and dynamic capacity of the rolling elements, outer ring deformation, track capacity, and cam follower stud bending stress must be considered. In yoke rollers, the pin shear stress must be considered.

RBC lists the static bearing capacity for reference purposes only. Typically, the maximum allowable load is a function of the maximum permissible bending stress of the stud or the outer ring. For best results, the operating loads should not exceed the lower of track capacity or 50% of the dynamic capacity.

2.1 Capacity of Rolling Element Bearing

Equations for static and dynamic capacities of roller bearings are given in ANSI/ABMA Standard 11. The more recent revisions leave it up to the manufacturer to introduce factors which account for internal design features and operating conditions. For cam followers and yoke rollers RBC has chosen to apply a conservative rating system, so a direct comparison with capacity figures of competitive products may not be possible.

2.2 Track Capacity

Track capacity is that load which a track subject to a uniform contact stress can withstand without excessive plastic deformation. It is directly related to track hardness. The published track capacity is based on a hardness of HRc 40. For other track hardness values the track capacity must be modified with factors from Table 1.

RBC BEARINGS

Track Hardness [HRc]	Material Strength [psi]	Modification Factor
26	128,000	.45
32	146,000	.61
36	165,000	.79
40	182,000	1.00
44	204,000	1.24
47	229,000	1.50
50	247,000	1.78
53	266,000	2.09
56	281,000	2.42
58	298,000	2.78

Table 1. Track Capacity Adjustment Factors.

Alternatively, contact stress can be easily calculated and compared directly to the strength of material. The equation for the Hertz contact stress between a cylindrical cam follower outer ring and a flat steel track is given by “Roark, Formulas for Stress and Strain” as:

$$\sigma_{C\,max} = 3{,}237 * \sqrt{\frac{F}{l_{eff} * D}} \qquad \text{[psi]} \qquad (1)$$

where

F = radial load [lbf]
l_{eff} = length of outer ring contact [in]
D = outer ring diameter [in]

It can be shown that for infinite life the ultimate tensile strength of track and roller must be at least equal to the maximum contact stress $\sigma_{C\,max}$

Example 1:

Determine the required minimum track hardness for an RBC cam follower S 56 L operating under a 3000 lbf radial load.

Solution:

$$\sigma_{C\,max} = 3{,}237 * \sqrt{\frac{3{,}000\ \text{lbf}}{0.8\ \text{in} * 1.75\ \text{in}}} = 149{,}800\ \text{psi}$$

Referring to *Table 1*, 149,800 psi is between 146,000 psi (HRc32) and 165,000 (HRc 36). Interpolation yields a minimum track hardness of HRc 33.

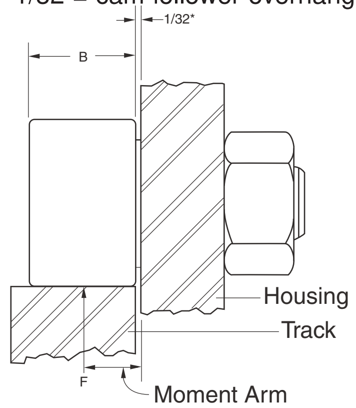
2.3. Bending and Shear Stresses

2.3.1 Cam Follower Stud Bending Stress

If the load over the width of the outer ring is evenly distributed, it may be replaced by a single concentrated force F [lbf] acting at the center of the cam follower (see Fig.2). Assuming that the cam follower stud has been tightly mounted in a housing bore flush with the end plate, this concentrated force generates a bending moment M_b.

$$M_b = F * \left(\frac{B}{2} + \frac{1}{32}\right) \qquad \text{[in * lbf]} \qquad (2)$$

where B = outer ring width [in]
1/32 = cam follower overhang [in]



Theoretical Moment Arm without stud deflection

*sizes 160 and above = 1/16

Fig. 2

The bending moment generates a bending stress in the cam follower stud of approximate magnitude

$$\sigma_b = 10 * \frac{M_b}{SD^3} \qquad \text{[psi]} \qquad (3)$$

where SD=Stud Diameter [in]

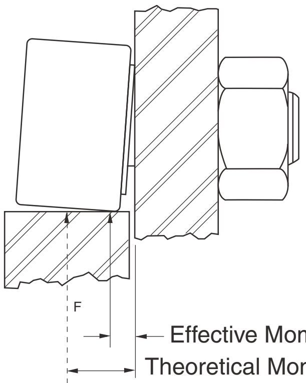
Standard cam follower studs are heat treated to a hardness of HRc 58 min in the raceway area only.

RBC BEARINGS

The hardness in other areas of the stud is typically in a range of HRc 20 -22 with an ultimate strength of material of 110,000 -120,000 psi. RBC bases the maximum allowable load of stud type cam followers on a theoretical stud bending stress of 100,000 psi. Standard stud cam followers and heavy stud cam followers differ in stud diameter, which permits higher operating loads and more resistance to impact loading for the heavy stud version. High stud strength cam followers are available by special order.

In most applications the stud will deflect away from the load, which causes the point of attack to shift toward the support, shortening the moment arm and reducing the effective bending moment (see Fig. 3). Tests show that this deflection yields a safety factor of at least 2 over RBC's maximum allowable load. However, this effect may not be sufficient to avoid damage in severely misaligned applications where the load is applied at the very extreme outboard edge of the cam follower outer ring.

Where misalignment is a problem, RBC recommends crowned cam followers.



Effective Moment Arm
with stud deflection

Fig. 3

Example 2
Cam follower S 64 L supports a load of 6,000 lbf. The stud diameter is .875", the outer ring width 1.25". Determine the theoretical bending stress at the stud housing interface.

Solution:

$$M_b = 6{,}000\ \text{lbf} * \left(\frac{1.25\ \text{in}}{2} + \frac{1}{32}\ \text{in}\right) = 3{,}938\ \text{in} * \text{lbf}$$

$$\sigma_b = 10 * \frac{3{,}938\ \text{in} * \text{lbf}}{(.875\ \text{in})^3} = 58{,}776\ \text{psi}$$

2.3.2 Yoke Roller Pin Shear Stress

Yoke rollers are mounted with a pin in a yoke. Under load the pin is subject to shear and bending stresses. RBC recommends that the yoke arms are located as close to the yoke roller as possible, so that bending stress can be ignored. In case of widely spaced pin supports, the resulting pin deflection may cause yoke roller damage.

The pin shear stress can be calculated with

$$\sigma_s = 2 * \frac{F}{\pi * d^2} \quad \textbf{[psi]} \qquad \textbf{(4)}$$

where d=pin diameter

The permissible stress depends on the pin material selection.

Example 3
Determine the shear stress of the .375 in. diameter pin for yoke roller Y 40 L, loaded radially with 3,200 lbf.

Solution:

$$\sigma_s = 2 * \frac{3{,}200\ \text{lbf}}{\pi * (.375\ \text{in})^2} = 14{,}487\ \text{psi}$$

2.4 Outer Ring Stress and Deformation

The exact calculation of these values is beyond the scope of this introduction. The following method may be used for a (high) first estimate of the outer ring tensile stress at the inside diameter opposite the contact point of a single row cam or roller follower. The assumption is that the entire load is supported by only 2 rollers straddling the point of contact:

$$\sigma_{b\,max} = \frac{6 * F * D_i * \pi}{z * b * (D - D_i)^2} \quad \textbf{[psi]} \qquad \textbf{(5)}$$

where
F = cam follower load [lbf]
D_i = outer ring raceway diameter [in]
D = outer ring outside diameter [in]
z = number of rollers per row
b = idealized outer ring width [in]

Example 4
Estimate the outer ring tensile stress of yoke roller Y 56 L subject to a load of 6,000 lbf. The yoke roller has 25 rollers, the outer ring outside diameter = 1.750 in., the outer ring raceway diameter =1.125 in., the idealized outer ring width = .690 in.

Solution:

$$\sigma_{b\,max} = \frac{6 * 6{,}000\ \text{lbf} * 1.125 * \pi}{25 * .690\ \text{in} * (1.75\ \text{in} - 1.125\ \text{in})^2} = 18{,}880\ \text{psi}$$

3. Fatigue Life

Fatigue life, L_{10} [rev, hrs], is a statistical measure of the life which 90% of a large group of apparently identical rolling element bearings will complete or exceed. For a single bearing, L_{10} also refers to the life associated with 90% reliability.

The relationship between fatigue or rating life, capacity and load is:

$$L_{10\,rev} = \left(\frac{C}{P_e}\right)^{\frac{10}{3}} \quad \textbf{(6)}$$

where $L_{10\,rev}$ = Rating life [10^6 rev]
C = Dynamic capacity [lbf]
P_e = Equivalent radial load

To obtain the rating life in hours, use

$$L_{10\,hrs} = \frac{16{,}667}{n_e} * \left(\frac{C}{P_e}\right)^{\frac{10}{3}} \quad \textbf{(7)}$$

where $L_{10\,hrs}$ = Rating life [hours]
n_e = equivalent speed [rpm]

In case of constant speed, the equivalent speed equals the constant bearing speed. In all other cases the equivalent speed is the weighted average of all individual speed components.

$$n_e = \sum\left(\frac{n_i * t_i}{100}\right) = \frac{n_1 * t_1}{100} + \frac{n_2 * t_2}{100} + \ldots \quad \textbf{(8)}$$

where n_i = individual speed component [rpm]
t_i = time interval in percent of total time

In case of constant load, the equivalent radial load equals the constant load. To compute the equivalent load for all other cases, use:

$$P_e = \sqrt[q]{\sum\left(\frac{F_i^q * n_i * t_i}{n_e * 100}\right)} = \sqrt[q]{\frac{F_1^q * n_1 * t_1}{n_e * 100} + \frac{F_2^q * n_2 * t_2}{n_e * 100} + \ldots} \quad \textbf{(9)}$$

where q = 10/3 for roller bearings
F_t = individual radial load [lbf]

4. Speed Limit and Maximum Acceleration

4.1 Speed Limit

The limiting speed of rolling element bearings is primarily a function of size and internal design. The speed limits given in this catalog should not be exceeded on a continuous basis to prevent premature failure due to excessive temperature. Contact RBC for solutions to high speed applications.

4.2 Maximum Acceleration (Deceleration)

A sufficiently large tangential friction force F_t , acting between outside diameter and track is needed to change the rotational speed of cam follower and yoke roller outer rings.

$$F_t = F * \mu \ \text{[lbf]} \quad \textbf{(10)}$$

where = coefficient of friction (outer ring to track)

The force F_t produces a moment M_t, which must accelerate the masses of outer ring and rollers around the bearing axis, plus the rollers in the load zone around their own axes.

RBC BEARINGS

The moment M_t can be calculated using:

$$M_t = \frac{D * F_t}{2} \quad [in * lbf] \qquad \textbf{(11)}$$

Accelerating the mass of the outer ring normally requires the largest part of moment M_t. Assuming a coefficient of friction of = 0.10 and a typical cam follower design, the following equation may be used for an estimate of the permissible angular acceleration α:

$$\alpha_{perm} = \frac{6000 * M_t}{B * D^4} \quad [rad/sec^2] \qquad \textbf{(12)}$$

Excessive acceleration causes sliding of the outer ring on the track. The effects range from minor uniform wear on cam follower and track to flat spots on the cam follower with subsequent failure.

5. Mounting

5.1 Cam Followers

For greatest rigidity and strength, the end plate should be drawn up snugly against a boss or other flat surface of the housing. The tables on pages 8 throughout 23 list the maximum recommended clamping torque for lubricated threads, which is the normal condition. Use up to twice the listed torque for completely dry threads.

The housing bore should be drilled and reamed to the recommended tolerance. If a greater tolerance is needed, it should be added to the plus side to prevent cam follower damage during assembly. If the cam follower stud fits tightly into the housing bore, use an arbor press and apply pressure against the central portion of the flange. Never press against the rim of the flange or the outer ring.

Although wide blade screwdrivers may be used to hold slotted head cam followers during assembly, rounded tools conforming to the slot are preferable to avoid plastic deformation in the slot area.

RBC offers a convenient socket (W suffix) for hex wrenches to provide a more substantial grip, especially for 'blind hole' applications.

5.2 Eccentric Cam Followers

Eccentric cam followers are used when there is a need to make height adjustments between the cam follower and the track. By simply turning the entire cam follower inside the housing it is possible to adjust the distance between the cam follower and the track by twice the eccentricity. However, due to the mechanical advantage that the eccentricity provides, it is inadvisable that the cam follower be adjusted over this entire range.

A very large force can be exerted on the track for a small applied adjusting torque as the eccentricity of the cam follower approaches ±90 degrees from a starting position parallel to the track, in the housing. Adjustments should be limited to ±45 degrees and the resulting preload should not exceed 10% of the cam follower's capacity.

The following equation can be used to find an appropriate adjusting torque.

$$T = 0.1 * C * e * \cos 45° \quad [in * lbf] \qquad \textbf{(13)}$$

where T = appropriate adjusting torque [lbf]
C = cam followers dynamic capacity [lbf]
e = eccentricity of cam follower [in]

Example 5
CamCentric cam follower S48LWX has a dynamic capacity of 4,600 lb, and an eccentricity of 0.03 in. Determine the appropriate adjusting torque.

Solution: **(14)**

$$T = 4{,}600\ lbf * 0.03\ in * 0.070711 = 9.76\ in * lbf$$

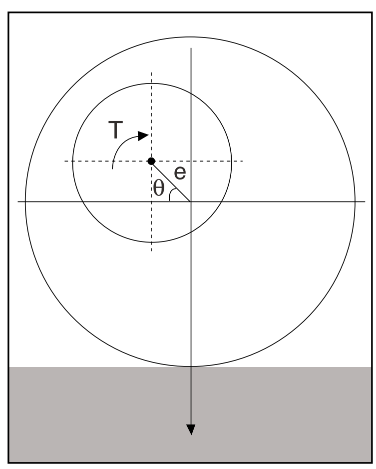


Fig. 4

RBC BEARINGS

5.3 Yoke Rollers

RBC yoke rollers correspond in many respects to the same size cam follower, except they are mounted on a pin for use in yoke type applications for greater shock resistance.

Yoke rollers should be clamped axially or mounted within closely fitting side rails to prevent displacement of the end plates. For applications with heavy loads, it is recommended to heat treat the pin and use a press fit for the inner ring. A soft pin and light press or push fit are sufficient for lightly loaded applications. When press fitting a yoke roller, pressure should be applied centrally and uniformly against the end plate, never against the outer ring.

The pin should have a suitable lead-in chamfer or radius to prevent scoring and to hold the mounting force to a minimum.

5.4 Caged Roller Followers

Caged roller followers can operate directly on a hardened and ground shaft (HRc 58 min, 16 rms min surface finish) or can be used with matching inner rings. Operating without an inner ring yields the largest possible shaft diameter with greatest strength and rigidity. Axial guidance must be provided by the application. It is recommended to use hardened steel or bronze thrust washers with radial lubricating grooves as needed.

6.1 Track Lubrication

In most applications it is difficult to eliminate *all* cam follower misalignment. Misalignment causes the outer ring to thrust, which in needle bearing cam followers, produces wear of the seal followed by wear of the outer ring face and the stud flange or the end plate. In RBC Rollers® the wear is generallly limited to the center thrust ring. Misalignment where the axis of the cam follower is not perpendicular to the direction of rolling, typically produces the most severe thrust and also causes wear on the cam follower outside diameter, and the track. To reduce these symptoms as much as possible, the track must be lubricated. Lubrication also reduces wear stemming from excessive acceleration. Oil and grease are acceptable lubricants.

If the track cannot be lubricated, contact RBC Engineering for a review of the operating parameters to ensure that they do not exceed the limits of the bearing selected.

6.2 Bearing Lubrication

Cam followers and yoke rollers are pre-lubricated with an NLGI grade 2, lithium soap, mineral oil based grease with EP additives. RBC Roller® type cam followers and yoke rollers are normally lubricated for life and have no provisions for relubrication. Needle roller type cam followers require relubrication depending on operating speed, duty cycle, operating environment, desired service life, etc.

For relubrication in service, mineral oil, or any good roller bearing grease on mineral oil basis may be used. Inquire about compatibility of greases with different base oil and thickener.

Except for the very small sizes (see tables), cam followers with screwdriver slots can be relubricated from both ends of the stud and through the housing. *Table 2* lists suitable drive fit Alemite fittings. Plugs are furnished by RBC to close off unused passages.

Size	Bearing P/N	Fitting P/N
1/2" - 11/16"	-16 to -22	3019
3/4" - 2 3/4"	-24 to -88	1728-B, 1646-B, 1992-B
3" - 4"	-96 to -128	1743, 1743-B
5" - up	-160	any 1/4" NPT fitting

Table 2. Alemite fittings.

Cam followers of the HexLube® series are supplied with a grease fitting at the bottom of the hex hole. Yoke rollers and sealed roller followers must be relubricated through the shaft.

7. Misalignment

Initial misalignment should not exceed .001 in./in. Any misalignment generates thrust forces between outer ring and flange or end plate. Excessive thrusting can lead to increased operating temperature and destruction of the seal in standard cam followers and yoke rollers. Where misalignment and outer ring thrusting cannot be avoided, RBC recommends crowned outer rings or the RBC Roller® design which is more capable of withstanding thrust loads. Contact RBC engineers about thrust and load limits.

8. Operating Temperature

The temperature limits of all standard cam followers and yoke rollers in this catalog, except airframe bearings, are determined by the temperature limits of the seals and the lubricant. With lower temperatures, grease gradually becomes stiffer, increasing the rolling resistance of the cam follower. Any application with the cam follower operating continuously below 0° F (-18° C), consult with RBC Engineering for a specific low temperature grease. The maximum continuous operating temperature is +250° F (120° C), and for short periods, the maximum temperature may rise to +300° F (150° C). For continuous operation above +250° F (120° C), consult with RBC Engineering to determine the need for special high temperature grease and seal material.

RBC can provide special solutions for applications outside the normal operating temperature range.