Bearing Life Calculations / Selection

Bearing Life

Many different performance criteria exist that dictate how a bearing should be selected. These include bearing fatigue life, rotational precision, power requirements, temperature limits, speed capabilities, sound, etc. The life can also be limited by other system components such as the shaft, shaft interface and the housing. This publication deals primarily with bearing life as related to material associated fatigue. Bearing life is defined here as the length of time, or number of revolutions, until a fatigue spill of 6 mm² (0.01 in²) develops. Since metal fatigue is a statistical phenomenon, the life of an individual bearing is impossible to precisely predetermine. Bearings that may appear to be identical can exhibit considerable life scatter when tested under identical conditions. Thus it is necessary to base life predictions on a statistical evaluation of a large number of bearings operating under similar conditions. The Weibull distribution function is commonly used to predict the life of a population of bearings at any given reliability level.

Rating Life

Rating life, \( L_{10} \), is the life that 90 percent of a group of apparently identical bearings will complete or exceed before a fatigue spill of 6 mm² (0.01 in²) develops. The \( L_{10} \) life also is associated with 90 percent reliability for a single bearing under a certain load.

Bearing Life Equations

The \( L_{10} \) life has been calculated as follows for bearings under radial or combined loading where the dynamic equivalent radial load, \( P_r \), has been determined.

Tapered roller bearings often use a dynamic load rating \( (C_{90}) \) based on ninety million cycles, yielding the equations as follows:

\[
L_{10} = \left( \frac{C_{90}}{P_r} \right)^{1/3} \left( 90 \times 10^5 \right) \text{ revolutions}
\]

or based on shaft speed, \( n \) (RPM),

\[
L_{10} = \left( \frac{C_{90}}{P_r} \right)^{1/3} \left( 90 \times 10^5 \right) \text{ hours}
\]

Timken has expanded standard life equations to include certain additional variables that can affect bearing performance. The approach whereby these factors are considered in the bearing analysis and selection has been termed Bearing Systems Analysis (BSA).

The Timken expanded bearing life equation is:

\[
L_{10a} = a_1a_2a_3a_4a_5a_6a_{20} \left( \frac{C_{90}}{P_r} \right)^{1/3} \left( 90 \times 10^5 \right) \text{ hours}
\]

Where,

- \( a_1 \) = Reliability Life Factor
- \( a_2 \) = Material Life Factor
- \( a_3 \) = Debris Life Factor
- \( a_4 \) = Load Zone Life Factor
- \( a_5 \) = Lubrication Life Factor
- \( a_{20} \) = Misalignment Life Factor
- \( a_6 \) = Low Load Life Factor

More details on Life Adjustment Factors can be found in the Engineering Section of the Timken Product Catalog or by contacting a Timken technical sales representative. Other factors that can be taken into account within the simple bearing life equation are shock or vibration. These are known to occur in many industrial applications due to combined factors including unbalanced dynamic forces, abusive handling, equipment misuse or neglect. These are difficult to predict. When these conditions are known or suspected to occur, we suggest that equipment designers use a multiplication factor of \( (1.5 \times P_i) \) to estimate effects on housed unit selection and system reliability. Performance testing or advanced analysis is strongly suggested to validate final product selection.

Timken® Roller Housed Unit Selection

The Timken double extended tapered roller bearings used in the roller housed units in this catalog are suited for carrying radial, thrust or a combination of both types of loading. This section will describe the bearing selection process using different methods based on selection criteria and application details.

Method 1 – Selection table (radial loads only)

Note: Based on reference conditions with adequate lubrication.

1. Determine criteria for bearing selection
   - \( L_{10} \) life required.
   - Size of bearing based on shaft size (if known).
   - Loading conditions (radial and thrust) of the application.
   - Shaft speed (RPM).

2. Use Table 1: Timken® Type E Tapered Roller Bearing Load Rating Selection Table:
   - Find speed criteria on upper row.
   - Proceed in the column directly below that speed to the radial load \( (F_r) \) that is equal to or greater than that required.
   - Follow that row to the left to determine what the minimum shaft size should be for the required \( L_{10} \) life (hours). Many values are listed to help in selecting the proper bearing.
Bearing Life Calculations / Selection - continued

Method 2 – Using bearing life equation to select bearing for a different $L_{10}$ life (radial loads only)

If a different life is required than what is found in Table 1: Timken® Type E Tapered Roller Bearing Load Rating Selection Table, it can be calculated from the bearing life equation. Note that each value in the selection table was calculated using this equation. The equation can be re-written based on the unknown value.

Take the bearing life equation shown previously:

$$L_{10} = \left( \frac{C_{90}}{P_r} \right)^{0.3} \left( \frac{90 \times 10^6}{60 \cdot n} \right) \text{ hours}$$

Or re-written as:

$$L_{10} = \left( \frac{C_{90}}{P_r} \right)^{0.3} \left( \frac{1,500,000}{n} \right) \text{ hours}$$

Then to solve for $C_{90}$:

$$C_{90} = \left( \frac{L_{10} \cdot n}{1,500,000} \right)^{3.0} \left( P_r \right)$$

After calculating the $C_{90}$, check Table 1: Timken® Type E Tapered Roller Bearing Load Rating Selection Table to determine the shaft size needed. (Note: ensure that the application speed does not exceed the maximum RPM – found on that same table). Check the radial load as well with regards to the maximum allowable slip fit radial load ($F_{max}$, see Table 3: Tapered Roller Bearing - Radial and Thrust Factors, Speed and Slip-Fit Load Limits). If this value is exceeded, then a tighter line-to-line or press fit is required.

Timken Method 3a – Determine equivalent radial loads and use bearing life equation (for radial and thrust loaded applications)

For combined radial and thrust loaded applications, it is necessary to calculate an equivalent dynamic radial bearing load, designated by $P_e$, before applying the $L_{10}$ bearing life equation. The dynamic equivalent radial load is defined as a single radial load that, if applied to the bearing, will result in the same life as the combined loading under which the bearing operates.

Tapered roller bearings are ideally suited to carrying all types of loads - radial, thrust and any combination of both. Due to the tapered design of the bearing, a radial load will induce a thrust reaction that must be opposed by an equal or greater thrust load in order to keep the bearing cone and cup from separating. The ratio of the radial to the thrust load and the bearing included cup angle determine the load zone in a given bearing. The number of rollers in contact as a result of this ratio determines the load zone in the bearing. If all the rollers are in contact, the load zone is referred to as being 360 degrees. When only radial load is applied to a tapered roller bearing, for convenience it is assumed in using the traditional calculation method that half the rollers support the load – the load zone – is 180 degrees.

Note that the dynamic radial equivalent loads can be easily calculated using the Timken Bearing Selection Guide (TBGS) software. This is a simple program that calculates the bearing loads, catalog life and even BSA life.

If the TBGS is not used, then the subsequent procedure should be followed.

Table 4: Equivalent Radial Load Calculations

<table>
<thead>
<tr>
<th>Design</th>
<th>Thrust Condition</th>
<th>Dynamic Equivalent Radial Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_a$</td>
<td>$P_{IA} = 0.5F_r + 0.83K \cdot F_a$</td>
<td></td>
</tr>
<tr>
<td>$F_a$</td>
<td>$P_{IA} = 0.4F_r + K \cdot F_a$, $P_{IB} = 0$</td>
<td></td>
</tr>
</tbody>
</table>

![Diagram of bearing life calculations]
Bearing Life Calculations / Selection - continued

For Type-E roller housed units with no external thrust load ($F_x = 0$), the dynamic equivalent radial load ($P_r$) equals $F_r$. This $P_r$ value can then be used in the bearing life equation shown on page 16.

For Type-E units with thrust loading, Table 4: Equivalent Radial Load Calculations can be used. In this table, only bearing A has an applied thrust load. If bearing B has the applied thrust load, each A in the equations should be replaced by a B and vice versa.

The equations in the first row of Table 4 yield single row equivalent radial loads ($P_{1a}$ and $P_{1b}$). To find the two-row (Type-E housed unit) life, the following equations must be used to solve for $L_{10}$ life of each bearing row, and then combined for the system unit life:

$$L_{10A} = \left( \frac{C_{10}}{1.74 \times P_{1a}} \right)^{10/3} \left( \frac{1.500,000}{n} \right) \text{ hours}$$

and,

$$L_{10B} = \left( \frac{C_{10}}{1.74 \times P_{1b}} \right)^{10/3} \left( \frac{1.500,000}{n} \right) \text{ hours}$$

then,

$$L_{10} = \left[ \left( \frac{1}{L_{10A}} \right)^{2/3} + \left( \frac{1}{L_{10B}} \right)^{2/3} \right]^{-1/2} \text{ hours}$$

In the second row of Table 4: Equivalent Radial Load Calculations, $P_{1b} = 0$; therefore, $P_{1a} = P_r$ in the standard bearing life equation shown on page 16.

ISO Method 3b

The ISO Method uses the following equation to determine the equivalent dynamic radial load:

$$P_e = X F_r + Y F_x$$

Where,

- $P_e$ = Dynamic Equivalent Radial Load
- $F_r$ = Applied Radial Load
- $F_x$ = Applied Axial Load
- $X$ = Radial Load Factor
- $Y$ = Axial Load Factor

The values for $X$ and $Y$ are found in Table 3: Tapered Roller Bearing - Radial and Thrust Factors. In order to find these values, the value of $F_r / F_x$ must be compared to the "e" value. Determine if the value is greater than or less than the "e" and then use the corresponding $X$ and $Y$ values below that formula.

After the $P_e$ value is calculated, then use the bearing life equation as shown on page 16.

ISO Method 4 – (thrust only applications)

Use the equation $P_t = Y F_x$. Use $Y$ from Table 3: Tapered Roller Bearing - Radial and Thrust Factors for $F_r / F_x > e$. Then use this $P_t$ value for the equivalent radial load in the bearing life equation. This value can also be used as the radial load in the selection table.

After selection has been made, verify that the application does not exceed the maximum allowable speed, allowable thrust loads and allowable housing loads. Heavy loads should be directed through the base of the units. See Table 2: Housing Ratings for the uplift housing loads. The housings need to be bolted down with adequate strength.

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Installation / Lubrication

Installation

Proper installation of the housed unit is necessary. This includes the use of shafts that are clean, free from nicks and burrs, straight and of proper diameter. Follow Table 5: Recommended Shaft Tolerances. Do not mount the bearing on a worn section of the shaft. Use of shafts with hardness greater than Rc 45 will reduce effectiveness of locking devices. Also, it is necessary that the housed units and shafts are in alignment (Fig. 1). Verify that the mounting surfaces are in the same flat plane to help make sure good alignment is achieved. If shimming is required to minimize misalignment, use full shims across the entire housing base (Fig. 2). The bolts then need to be alternately torqued securely to their mounting supports. Flat washers should be used when installing any kind of housed unit (Fig. 2). Washers should be