

The Facts About Roller Bearing Life Calculations

How to Properly Calculate the Statistical Probability of Lifetime for Linear Roller Bearing Applications

Introduction: Important Notice about Lifetime Calculations

There is no known formula for accurately and reliably calculating the *actual* lifetime of a linear or rotary bearing system. The formulas within this section are solely based upon the statistical probability of success. It is important to recognize and distinguish between formulas of absolute certainty and probability.

Even though these formulas are not absolutely certain, they have been generally accepted as the best available method for determining bearing lifetime by the International Organization for Standardization (ISO), as well as its membership bodies. They include, but not limited to: American National Standards Institute (ANSI); Deutsches Institut für Normung (DIN); and Japanese Industrial Standards Committee (JISC).

Static & Dynamic Load Ratings

PBC Linear uses the two internationally accepted methods for calculating the Rated Lifetime, Static and Dynamic Capacities. Per the international standard, all lifetimes are calculated to an L10 life of 100 km (105 meters or ≈ 3.94 million inches). The two standards used are:

- ISO76 Rolling Bearings – Static Load Ratings
- ISO281 Rolling Bearings – Dynamic Load Ratings & Rating Life

In summary, the static load ratings are defined as the maximum applied load (or moment) which will result in the permanent deformation which does not exceed $1/10,000$ of the diameter of the rolling element (ball or rod) within the bearing. The basic dynamic load rating, C, is the load of a constant magnitude and direction which a sufficiently large number of apparently identical bearings can endure for a basic rating life of one million revolutions. It's important to note that both the static and dynamic values are determined through ISO-Approved formulas. These formulas take into account several factors, including the design, internal geometry, material type, material quality and lubrication type.

Operating Lifetime

The "Operating Life" (or Operating Lifetime) is the actual life achieved by a rolling bearing. The actual lifetime typically varies from the calculated lifetime, sometimes significantly. It is not possible to accurately and reliably determine the actual Operating Life through calculations due to the large variety of operating and installation conditions. The most reliable method to achieve an approximation is by comparing the current application to similar applications. Primary factors which can negatively affect the life and are generally not included in calculations are:

- Contamination within the application
- Inadequate or improper lubrication
- Operational conditions different from calculated values, including unexpected forces and moments
- Insufficient and/or excessive operating clearance between the roller and guideway
- Excessive interference between roller & guideway (typically due to misalignment or excessive preload)
- Temperature out of range
- High shock loads (exceeding static load capacity)
- Vibration (which causes False Brinelling resulting from Fretting)
- Short stroke reciprocating motion (also causes False Brinelling)
- Damage caused during installation or from improper handling
- Improper mating surface hardness (when not used with a rail from PBC Linear)

◀ **NOTE:** Some suppliers may choose to rate their bearings based upon a useful life of less than 100 km or a probability of success less than 90%. This causes their bearings to falsely appear to have a higher static and dynamic load capacity. If a catalog does not specifically note L10 = 100 km, caution should be used when comparing load capacity or life values between suppliers. The most commonly used values are L10 = 50 km and L25 = 50 km. For comparison, at L10 = 100 km, an example bearing has a maximum static load of 1,000 N. That exact same bearing as an L10 = 50 km maximum static load of $\approx 2,300$ N and an L25 = 50 km maximum static load of $\approx 4,600$ N!

◀ **NOTE:** Additional factors are provided so that the estimated lifetime (default = 100 km) and/or the probability of success (default = 90%) can be changed from their default value to any desired value

The actual operating lifetime typically varies from the calculated lifetime, sometimes significantly.

Terms, Definitions and Symbols

The following variables are used within the equations listed on the following pages.

- F_{y_app} = Force applied in the Y direction (*radial force*), *N*
- F_{z_app} = Force applied in the Z direction (*axial force*), *N*
- M_{x_app} = Moment applied about the X axis, *N*
- M_{y_app} = Moment applied about the Y axis, *N*
- M_{z_app} = Moment applied about the Z axis, *N*
- F_{y_max} = Maximum allowable force in the Y direction (*radial force*), *N*
- F_{z_max} = Maximum allowable force in the Z direction (*axial force*), *N*
- M_{x_max} = Maximum allowable moment about the X axis, *N · m*
- M_{y_max} = Maximum allowable moment about the Y axis, *N · m*
- M_{z_max} = Maximum allowable moment about the Z axis, *N · m*
- D_a = rolling contact diameter, from product tables, *mm*
- f_H = Shaft (rail) hardness reduction factor
- f_L = Required Lifetime (km) reduction factor
- f_R = Reliability reduction factor
- f_{SS} = Short stroke reduction factor
- L_{10} = Basic rating life, *km* (10^3m)
- P_r = Equivalent radial (F_y) load, *N*
- s.f** = safety factor

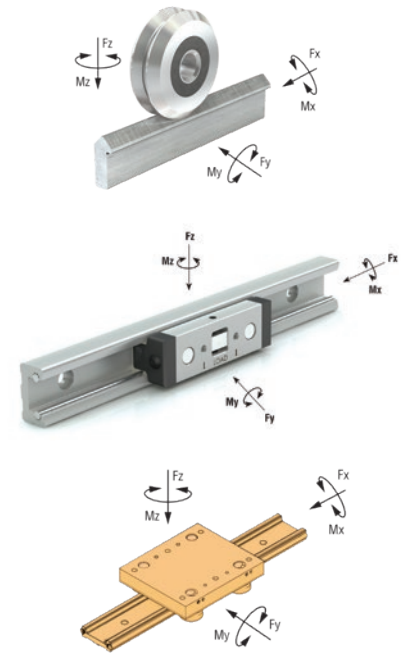
Derivation

The lifetime formula within ISO 281 gives the life in millions of revolutions. The conversion from rotary life to linear life is done using the conversion factors listed in the following three equations. This derivation applies to both individual rollers and carriages. L_{rev} and $L_{distance}$ represent the lifetime of the bearing in revolutions and linear distance, respectively.

$$L_{Distance}[1 * 10^5 m] = L_{rev} [1,000,000 rev] \cdot (3.14 D_a [\frac{mm}{rev}]) \cdot (\frac{1 * 10^5 m}{100,000,000} [\frac{m}{mm}])$$

$$L_{Distance}[1 * 10^5 m] = L_{rev} \cdot (0.0314 D_a)$$

$$L_{Distance}[km] = 100 \cdot L_{rev} \cdot (0.0314 D_a) = 3.14 \cdot D_a \cdot L_{rev}$$



◀NOTE: PBC has chosen to depart from the nomenclature standards used by ISO. Instead, PBC has chosen to use a convention which is more in line with other PBC products. This ensures that all PBC products use the same naming conventions, making it easier to compare multiple products from different product families.

◀Equation 1

◀Equation 2

◀Equation 3

NOTE: Attention must be paid to units of measure, especially when considering products from different manufacturers. All of the lifetime formulas within this section yield results in kilometers; however, not all companies follow the same standard. Some companies may express life in meters or 100's of kilometers.

Individual Rollers – All products except Hevi-Rail Rollers (see next section for Hevi-Rail Rollers)

Most of the individual rollers within this catalog are Radial Ball Bearings. The following formulas should be used for all individual bearings **except Hevi-Rail** bearings (which are roller bearings). This formula calculates the basic rating life (L_{10} life), which does not take into account any reduction factors based upon the application.

$$L_{10}[km] = 3.14 D_a (f_L \cdot f_H \cdot f_{SS} \cdot \frac{F_{Ymax}}{P_r}) \cdot (f_R)$$

$$P_r = X \cdot F_{y_app} + Y \cdot F_{z_app}$$

The values for X & Y can be found using the table listed below:

Product	$\frac{F_{z_app}}{F_{y_app}} \leq \epsilon$		$\frac{F_{z_app}}{F_{y_app}} > \epsilon$		ϵ
	X	Y	X	Y	
Commercial Rail (all sizes)	1.00	0	.41	.87	.68
Hardened Crown Rollers	1.00	0	.41	.87	.68
Integral-V (IVT) (Compact Linear Guides)	1.00	.78	.63	1.24	.80
Integral-V (IVT) (all other sizes & types)	1.00	.78	.63	1.24	.80
Redi-Rail (all sizes & types)	1.00	.78	.63	1.24	.80
Steel-Rail (all sizes & types)	1.00	.78	.63	1.24	.80
V-Rail	1.00	.78	.63	1.24	.80

Individual Rollers–Hevi-Rail Rollers

Hevi-Rail bearings are roller bearings, as opposed to radial ball bearings. The formulas are very similar to the formulas shown above, with only some minor changes.

$$L_{r-10}[km] = 3.14 \cdot D_a \cdot (f_L \cdot f_H \cdot f_{SS} \cdot \frac{F_{Ymax}}{P_r})^{\frac{10}{3}} \cdot (f_R)$$

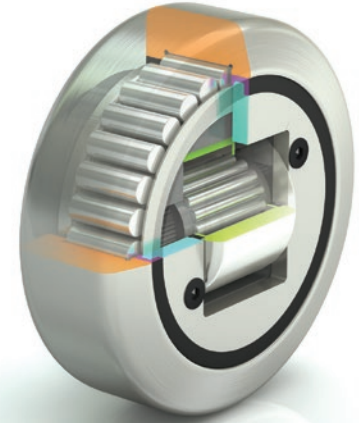
$$L_{a-10}[km] = 3.14 \cdot D_a \cdot (f_L \cdot f_H \cdot f_{SS} \cdot \frac{F_{Ymax}}{P_z})^{\frac{10}{3}} \cdot (f_R)$$



◀ Equation 4

◀ Equation 5

◀ Table 1: Values of X & Y for Radial Ball Bearing Life Formula



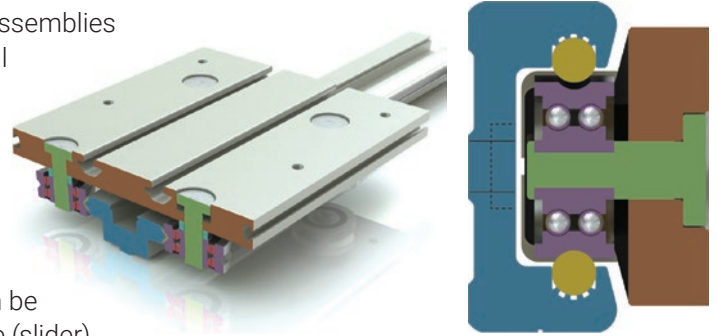
◀ Equation 6

◀ Equation 7

NOTE: Hevi-Rail rollers are combined bearings. Essentially there are two bearings combined into one. Life calculations should be performed for both the radial **and** the axial bearing.

Carriage (Slider) Assemblies

Formulas for calculating the estimated lifetime for carriage assemblies are fundamentally similar to the calculations for the individual rollers. The most accurate method for determining the life of a carriage (slider) assembly is to create a free body diagram for the carriage and determine the axial, radial and moment load applied to each individual roller. This method is cumbersome and is usually only required in the most severe of circumstances. In most cases, the carriage (slider) assembly can be treated as a rigid body and calculations can be completed based upon the load ratings for the entire carriage (slider).



$$L_{r-10}[km] = 100 \cdot (f_L \cdot f_H \cdot f_{SS} \cdot \frac{1}{\frac{F_{y_app}}{F_{y_max}} + \frac{F_{z_app}}{F_{z_max}} + \frac{F_{x_app}}{F_{x_max}} + \frac{F_{y_app}}{F_{y_max}} + \frac{F_{z_app}}{F_{z_max}}}})^3 \cdot (f_R)$$

◀ Equation 8

Safety Factor

All individual rollers and carriages are subject to use a balancing formula which ensures an adequate product life. The following formulas should be used for all CRT Products.

$$\text{Carriages: } \frac{1}{s.f.} \geq \frac{F_{y_app}}{F_{y_max}} + \frac{F_{z_app}}{F_{z_max}} + \frac{F_{x_app}}{F_{x_max}} + \frac{F_{y_app}}{F_{y_max}} + \frac{F_{z_app}}{F_{z_max}}$$

◀ Equation 9

$$\text{Individual Bearings: } \frac{1}{s.f.} \geq \frac{F_{y_app}}{F_{y_max}} + \frac{F_{z_app}}{F_{z_max}}$$

◀ Equation 10

Where the safety factor value can be determined using the following table.

Duty	Shock/ Vibration	Reverse frequency	Contamination	s.f.
Very Light	None	Smooth & Low	None	1.0 – 1.2
Light	Light	Light	Light	1.2 – 1.5
Medium	Medium	Medium	Medium	1.5 – 2.0
Heavy	Heavy	High & Fast	Heavy	2.0 – 3.5

◀ **Table 2:** Recommendations for Safety Factor (s.f.)

Note: The table above contains suggested safety factors based upon the most commonly encountered adjustment criteria. Additional criteria may require raising the safety factor.

Minimum Load Notice

It is possible to apply too small of a load to a bearing/carriage. In this case, there is a possibility of the outer ring slipping or the roller lifting off the track. This can cause unexpected vibration or skidding which will reduce the life of the bearing. Therefore, the following condition should be met under **dynamic** load conditions.

$$\text{Minimum Dynamic Load: } \frac{F_{y_app}}{F_{y_max}} \leq 50$$

◀ Equation 11

There is no minimum load requirement under **static** conditions.

Heavy Load Notice

It is also possible to over load the bearings. Extra-heavy loads can cause unexpected stress concentrations in the bearing or railway which reduce the actual lifetime below the minimally acceptable level. These stress concentrations typically come from unexpected vibration within the application or unexpectedly high preload forces caused by misalignment, damage or thermal expansion. In these cases, a larger safety factor should be used.

Use Caution: $P_r > 0.5 \cdot C_r$

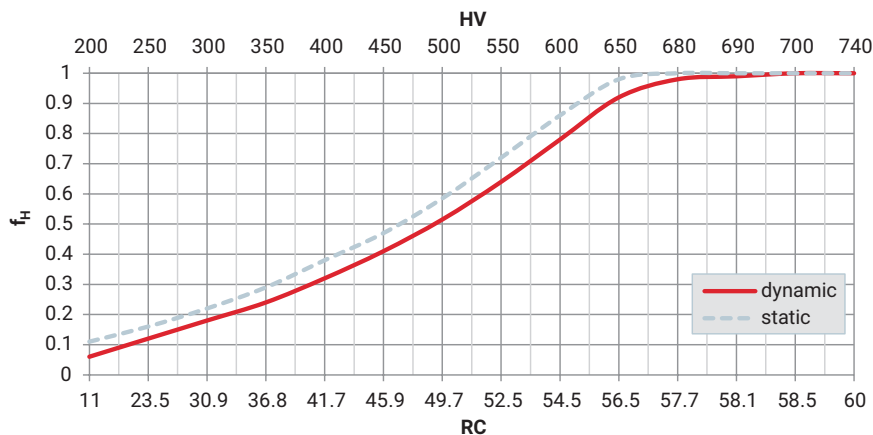
If the product under consideration is a carriage (slider) assembly and $P_r > 0.5 \cdot C_r$, then it is recommended to consider the axial, radial and moment load applied to each individual roller to ensure each roller still has an adequate safety factor.

Shaft/Rail Hardness Factor, f_H

It is possible to use a softer rail material in combination with CRT products from PBC Linear; however, it is necessary to reduce the static and dynamic load capacities of each product. The reduced load capacity is known as the "Effective Load Capacity". This value can be calculated using the formula below. The reduction factor, f_H , can be determined using the figure below.

Dynamic: $F_{Y, Eff} = F_Y \cdot f_H$

Static: $F_{OY, Eff} = F_{OY} \cdot f_H$



For easy reference, some of the most common materials have been plotted on the on the chart above. The circled numbers correspond to material types listed in the table below. Other material types can be used.

#	Type	EN Name	EN #	ASTM/AISI	Typical Hardness ²	f_H
1	Steel	C60	1.0601	1060	60-62	1.00
2	Steel	52-3	1.0570	1024	19-22	0.10
3	Stainless Steel	X46 Cr13	1.4034	420	51-53	0.70
4	Stainless Steel	X90 CrMoV18	1.4112	440B	53-55	0.80
5	Stainless Steel	X105 CrMo17	1.4125	440C	59-61	0.95-1.00

It is possible to over load the bearings.

◀ Equation 12

Note: Although typically applying to linear motion rolling bearings, ISO 14728-1 states that the above equation should be followed. It should be treated as a rule as opposed to a guideline.

◀ Equation 13

◀ Equation 14

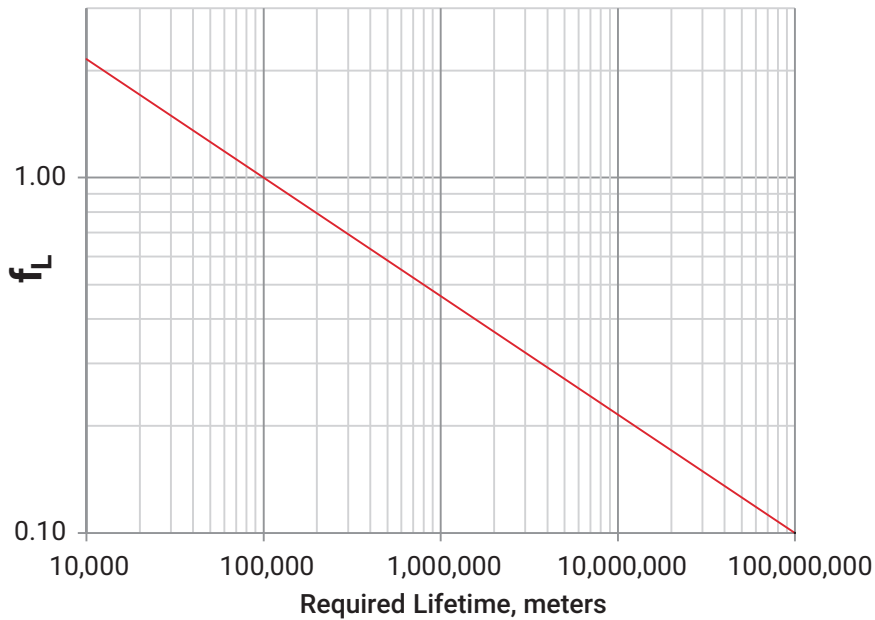
◀ Chart 1: Static & Dynamic Reduction Factors for Lower Raceway Hardness

◀ Table 4: Approximate Comparison of Common International Materials¹

Note: The values listed in the table should be considered **for reference only**. It is critical that individual suppliers are contacted to ensure an accurate hardness rating. Depending upon the supplier, "hardness" can actually be the *minimum*, *maximum*, or *average* value. The wrong interpretation can have unexpected consequences for the application. When given the choice, PBC Linear recommends using the "minimum hardness" when determining the reduction factor as this is the most conservative method.

Required Lifetime (km) Factor, f_L

The standard lifetime formulas listed within this catalog describe an L_{10} life based upon 100 km, in accordance to the applicable ISO standards. Sometimes 100 km is either excessive or shy of the target life of a machine and the required lifetime needs to be adjusted. An appropriate adjustment factor can be found using the chart, below.



Reliability Factor, f_R

The L_{10} Life Formulas are a statistical probability formula with a success rate of 90%. Sometimes an L_{10} life (90% success) is just not good enough and the formulas need to be modified in order to have a higher probability of success. In this case, choose the desired reliability rate and insert the f_R value into the life equation.

Reliability	L_n	f_R	Reliability	L_n	f_R
50%	L50	5.04	99.0%	L1	0.250
60%	L40	3.83	99.2%	L0.8	0.220
70%	L30	2.77	99.4%	L0.6	0.190
80%	L20	1.82	99.6%	L0.4	0.160
90%	L10	1.00	99.8%	L0.2	0.120
95%	L5	0.64	99.9%	L0.1	0.093
96%	L4	0.55	99.92%	L0.08	0.087
97%	L3	0.47	99.94%	L0.06	0.080
98%	L2	0.37	99.95%	L0.05	0.077

¹ Material Types may not be an exact match. PBC Linear has carefully reviewed the material standards and has determined that if there is not an exact match; the listed materials are the closest approximation. A material specialist should be consulted before translating one material type to another.

² Different suppliers may have alternate ranges for material hardness, depending upon their heat treating process. Consult manufacturer's specifications for a more exact number/range.

◀ **Chart 2:** Required Life Correction Factor

The L_{10} Life Formulas are a statistical probability formula with a success rate of 90%.

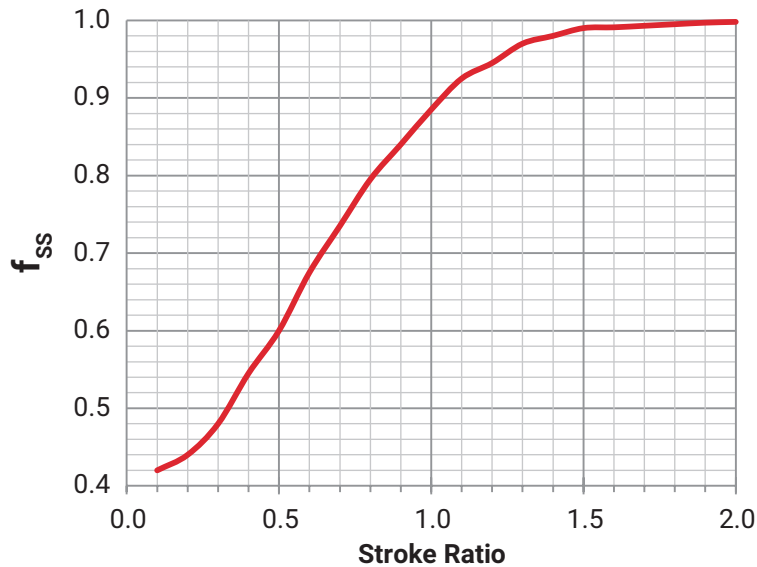
◀ **Table 5:** Reliability Factor

Short Stroke Factor, f_{ss}

In the case that the travel distance is low, a short stroke reduction factor must be included. In general, this factor only applies when the stroke is less than 2x the carriage length. In the case of individual bearings, use 2 full revolutions of the bearing.

$$\text{Stroke Ratio, carriage (slider)} = \frac{\text{Stroke [mm]}}{\text{carriage length [mm]}}$$

$$\text{Stroke Ratio, individual bearing} = \frac{\text{Stroke [mm]}}{\pi D_p \text{ [mm]}}$$



◀ Equation 15

◀ Equation 16

◀ Chart 3: Short Stroke Correction Factor

Further Information

If you're still having difficulties, contact a PBC Linear Application Engineer to discuss your application. You can contact an engineer directly by calling 1.800.962.8979 (from within the USA) or +1.815.389.5600 (from outside the USA). If you prefer, e-mail an engineer at: appeng@pbclinear.com

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