The Facts About Roller Bearing Life Calculations

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

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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; including, but not limited to: American National Standards Institute (ANSI), Deutsches Institut für Normung (DIN) & 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 L_{10} life of 100 km (10^5 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

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 L_{10} = 100 km, caution should be used when comparing load capacity or life values between suppliers. The most commonly used values are L_{10} = 50 km and L_{25} = 50 km. For comparison, at L_{10} = 100 km, an example bearing has a maximum static load of 1,000 N. That exact same bearing as an L_{10} = 50 km maximum static load of ≈2,300 N and an L_{25} = 50 km maximum static load of ≈4,600 N!

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 though ISO-Approved formulas. These formulas take into account several factors, including the design, internal geometry, material type, material quality and lubrication type.

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.

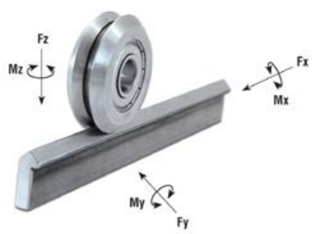
Operating Lifetime

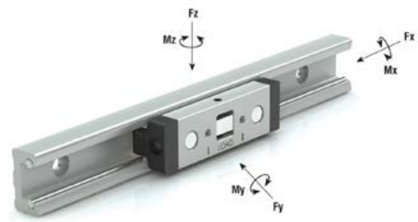
The "Operating Life" (or Operating Lifetime) is the actual life achieved by a rolling bearing. The actual lifetime typically varies from the calculated lifetime, sometimes significantly. It is not possible to accurately and reliably determine the actual Operating Life through calculations due to the 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:

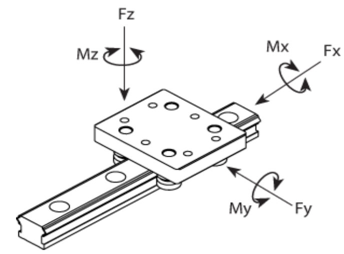
- Contamination within the application
- Inadequate or improper lubrication
- Operational conditions different from calculated values, including unexpected forces and moments
- Insufficient and/or excessive operating clearance between the roller & guideway
- Excessive interference between roller & guideway (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 PBC Linear rail)

Terms, Definitions and Symbols

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







$F_{y\_ap\ p}$ = 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, $N \cdot m$
M_{y_max} = Maximum allowable moment about the Y axis, $N \cdot m$
M_{z_max} = Maximum allowable moment about the Z axis, $N \cdot m$
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, $km\ (10^3 m)$
P_r = Equivalent radial (F_y) load, N
s.f = safety factor

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.

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.

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

$$L_{Distance}\,[1 * 10^5\, m] = L_{rev} \cdot (0.0314\, D_a) \quad \text{Eq. 2.}$$

$$L_{Distance}\,[km] = 100 \cdot L_{rev} \cdot (0.0314\, D_a) = 3.14 \cdot D_a \cdot L_{rev} \quad \text{Eq. 3.}$$

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.

$$L_{10}\,[km] = 3.14 \cdot D_a \cdot \left(f_L \cdot f_H \cdot f_{SS} \cdot \frac{\mathrm{F}_{\mathrm{y_{max}}}}{P_r}\right)^3 \cdot (\,f_R) \quad \text{Eq. 4.}$$

$$P_r = X \cdot \mathrm{F}_{\mathrm{y\_ap\,p}} + Y \cdot \mathrm{F}_{\mathrm{z\_app}} \quad \text{Eq. 5.}$$

The values for X & Y can be found using the table listed on the following page …

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

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	0	.41	.87	.68
Hardened Crown Rollers	1	0	.41	.87	.68
Integral-V (IVT) (Compact Linear Guides)	1	.78	.63	1.24	.8
Integral-V (IVT) (all other sizes & types)	1	.78	.63	1.24	.8
Redi-Rail (all sizes & types)	1	.78	.63	1.24	.8
Steel-Rail (all sizes & types)	1	.78	.63	1.24	.8
V-Rail (all sizes)	1	.78	.63	1.24	.8

Individual Rollers –*Hevi-Rail Rollers*

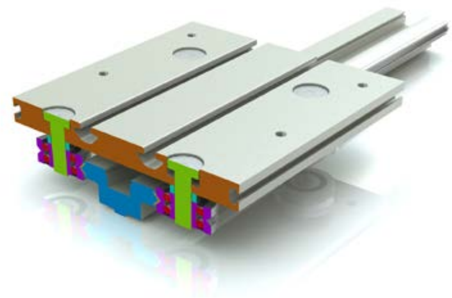
Hevi-Rail bearings are roller bearings, as opposed to radial ball bearings. The formulas are very similar to the formulas shown above, with only some minor changes.

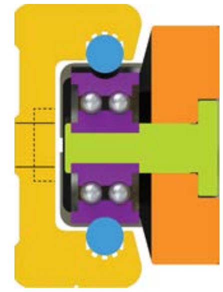
$$L_{r\_10}\,[km] = 3.14 \cdot D_a \cdot \left(f_L \cdot f_H \cdot f_{SS} \cdot \frac{F_{y_{max}}}{P_r}\right)^{\frac{10}{3}} \cdot (f_R) \qquad \text{Eq. 6.}$$

$$L_{a\_10}\,[km] = 3.14 \cdot D_a \cdot \left(f_L \cdot f_H \cdot f_{SS} \cdot \frac{F_{y_{max}}}{P_z}\right)^{\frac{10}{3}} \cdot (f_R) \qquad \text{Eq. 7.}$$

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).

$$L_{10}\,[km] = 100 \cdot \left(f_L \cdot f_H \cdot f_{SS} \cdot \frac{1}{\left(\frac{F_{y_{app}}}{F_{y\_max}} + \frac{F_{z_{app}}}{F_{z\_max}} + \frac{M_{x_{app}}}{M_{x\_max}} + \frac{M_{y_{app}}}{M_{y\_max}} + \frac{M_{z_{app}}}{M_{z\_max}} \right)} \right)^3 \cdot (f_R) \qquad \text{Eq. 8.}$$

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.

Carriages $$\frac{1}{s.f.} \geq \frac{F_{y\_app}}{F_{y\_max}} + \frac{F_{z\_app}}{F_{z\_max}} + \frac{M_{x\_app}}{M_{x\_max}} + \frac{M_{y\_app}}{M_{y\_max}} + \frac{M_{z\_app}}{M_{z\_max}} \qquad \text{Eq. 9.}$$

Individual Bearings $$\frac{1}{s.f.} \geq \frac{F_{y\_app}}{F_{y\_max}} + \frac{F_{z\_app}}{F_{z\_max}} \qquad \text{Eq. 10.}$$

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

Table 3. ***Recommendations for Safety Factor*** $(\boldsymbol{s.f.})$

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

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.

$$Minimum\ Dynamic\ Load\ \rightarrow\ \frac{F_{y\_app}}{F_{y\_max}} \leq\ 50 \qquad \text{Eq. 11.}$$

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.

$$Use\ Caution\ \rightarrow\ P_r\ > 0.5\ \cdot C_r \qquad \text{Eq. 12.}$$

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.

If the product under consideration is a carriage (slider) assembly and $P_r > 0.5 \cdot C_r$, then it 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 PBC Linear's CRT products; 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.

$$Dynamic \rightarrow F_{Y\_Eff} = F_Y \cdot f_H \quad \text{Eq. 13.}$$

$$Static \rightarrow F_{0Y\_Eff} = F_{0Y} \cdot f_H \quad \text{Eq. 14.}$$

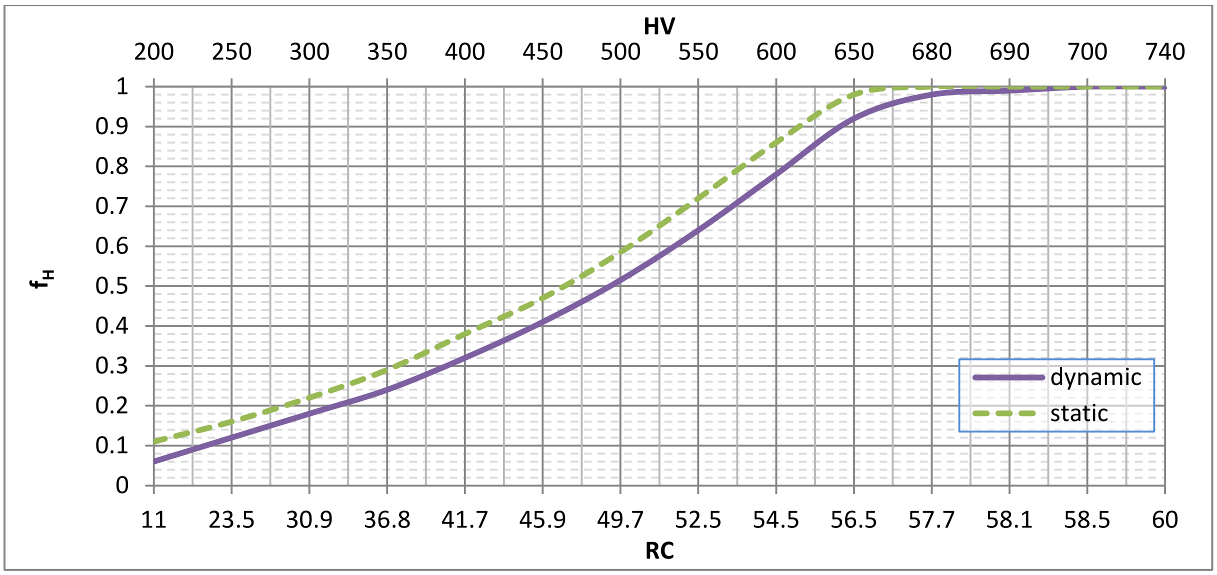


Figure #: Static & Dynamic Reduction Factors for Lower Raceway Hardness

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.

Table 4: Approximate Comparison of Common International Materials[1]

#	Type	EN Name	EN #	ASTM/AISI	Typical Hardness[2]	f_H
1	Steel	C60	1.0601	1060	60-62	1.0
2	Steel	52-3	1.0570	1024	19-22	0.1
3	Stainless Steel	X46 Cr13	1.4034	420	51-53	0.7
4	Stainless Steel	X90 CrMoV18	1.4112	440B	53-55	0.8
5	Stainless Steel	X105 CrMo17	1.4125	440C	59-61	0.95-1.0

Note: The values listed in the above 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 recommends using the "minimum hardness" when determining the reduction factor as this is the most conservative method.

[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.

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.

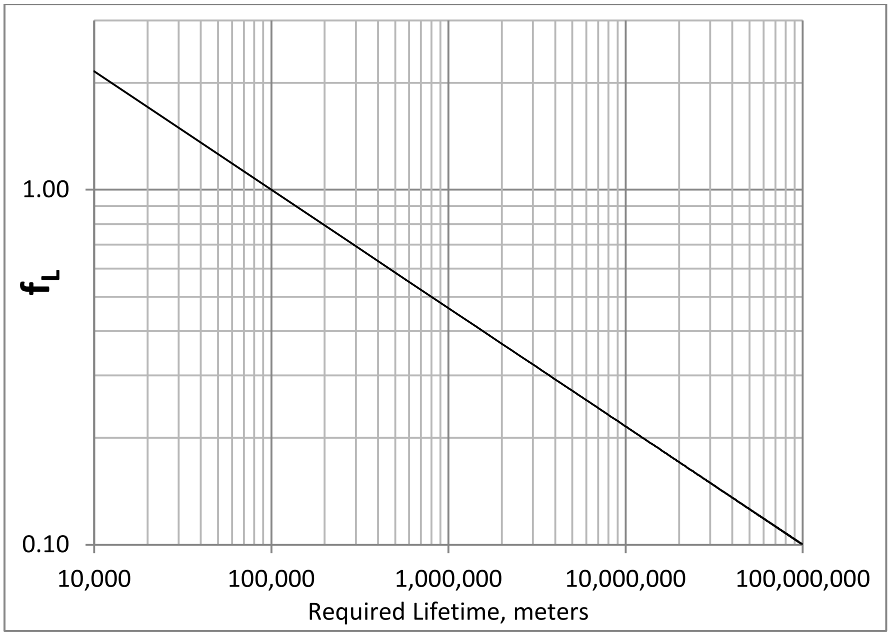


Figure #: Required Life Correction Factor

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.

Table 5: Reliability Factor

Reliability	L_n	f_R
50%	L_{50}	5.04
60%	L_{40}	3.83
70%	L_{30}	2.77
80%	L_{20}	1.82
90%	$\mathbf{L_{10}}$	**1.0**
95%	L_5	0.64
96%	L_4	0.55
97%	L_3	0.47
98%	L_2	0.37
99.0%	L_1	0.25
99.2%	$L_{0.8}$	0.22
99.4%	$L_{0.6}$	0.19
99.6%	$L_{0.4}$	0.16
99.8%	$L_{0.2}$	0.12
99.9%	$L_{0.1}$	0.093
99.92%	$L_{0.08}$	0.087
99.94%	$L_{0.06}$	0.080
99.95%	$L_{0.05}$	0.077

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.

$$Stroke\ Ratio, carraige\ (slider) = \frac{stroke\ [mm]}{carriage\ length\ [mm]} \qquad \text{Eq. 15.}$$

$$Stroke\ Ratio, individual\ bearing = \frac{stroke\ [mm]}{\pi\ D_p\ [mm]} \qquad \text{Eq. 16.}$$

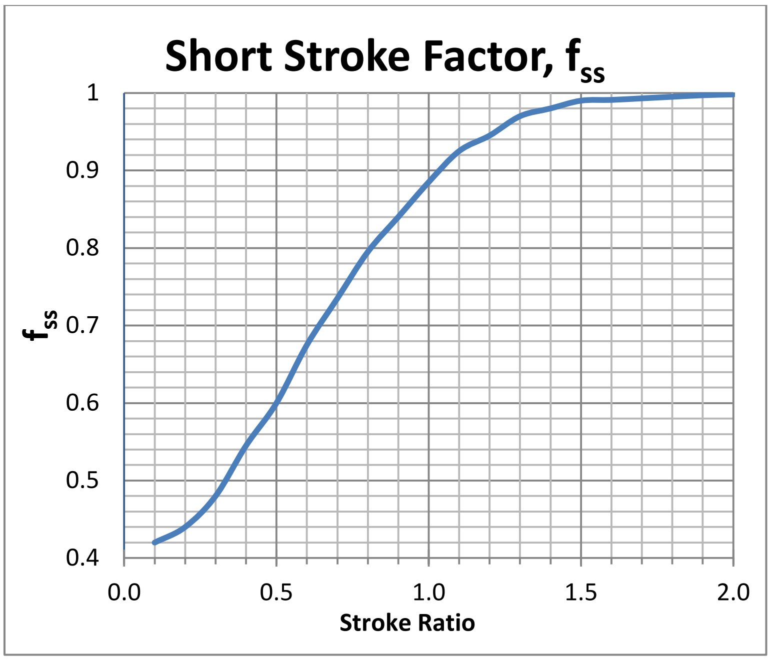


Figure #: Short Stroke Correction Factor

Contact an Application Engineer at PBC Linear to discuss your specific design challenge.

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WHITEPAPER: THE FACTS ABOUT ROLLER BEARING LIFE CALCULATIONS

HOW TO PROPERLY CALCULATE THE STATISTICAL PROBABILITY OF LIFETIME FOR LINEAR ROLLER BEARING APPLICATIONS

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