LIFE & LOADS

When in service, even a bearing that is properly lubricated, properly installed, and adequately protected from abrasives, moisture, and corrosive reagents, can fail from material fatigue. Material fatigue is manifested as a flaking off of metallic particles from the surface of a raceway or rolling element. This flaking will eventually cause the bearings to fail. The effective life of a bearing is usually defined in terms of the total number of revolutions a bearing can undergo before flaking of either the raceway surface or the rolling element surfaces occurs.

● Machine applications and requisite life

The requisite life of the bearing is usually determined by the type of machine in which the bearing will be used, duration of service and operational reliability requirements. A general guide to these requisite life criteria is shown in the following table.

● Machine applications and requisite life

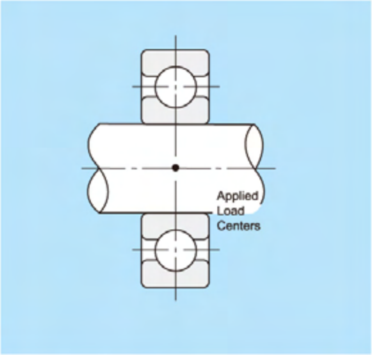
Operating condition	Application	Recommended service life
Short or intermittent operation	Household electric appliance, electric tools, agricultural equipment, heavy cargo hoisting equipment	4000 – 8000
Not extended duration, but stable operation required	Household air conditioner motors, construction equipment, conveyers, elevators	8000 – 12000
Intermittent but extended operation	Rolling mill roll necks, small motors, cranes	8000 – 12000
	Motors used in factories, general gears	12000 – 20000
	Machine tools, shaker screens, crushers	20000 – 30000
	Compressors, pumps, gears for essential use	40000 – 60000
Daily operation more than 8 hr.or continuous extended operation	Escalators	12000 – 20000
	Centrifugal separators, air conditioners, air blowers, woodworking equipment, passenger coach axle journals	20000 – 30000
	Large motors, mine hoists, locomotive axle journals, railway rolling stock traction motors	40000 – 60000
	Paper manufacturing equipment	100000 – 200000
24 hr.operation (no failure allowed)	Water supply facilities, power stations, mine water discharge facilities	100000 – 200000

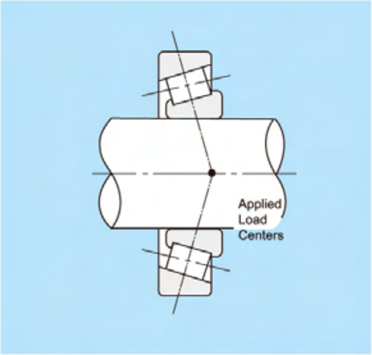
● Service life of bearing system comprising two or more bearings

Even for systems which comprise two or more bearings, if one bearing is damaged, the entire system malfunctions. Where all bearings used in an application are regarded as one system, the service life of the bearing system can be calculated using the following equation.

$$\frac{1}{L^e} = \frac{1}{L_1{}^e} + \frac{1}{L_2{}^e} + \frac{1}{L_3{}^e}$$

where:
L:rating life of system
L_1, L_2, L_3……: rating life of each bearing
e :constant
$e = 10/9$……ball bearing
$e = 9/8$……roller bearing
The mean value is for a system using both ball and roller bearings.



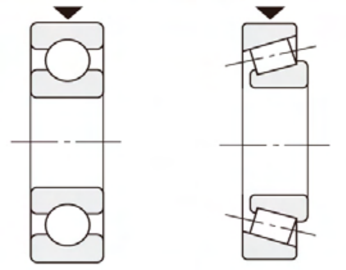
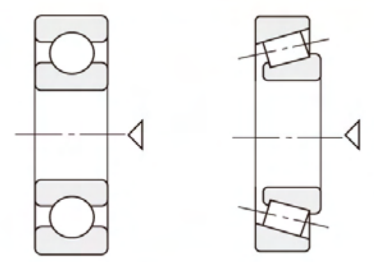
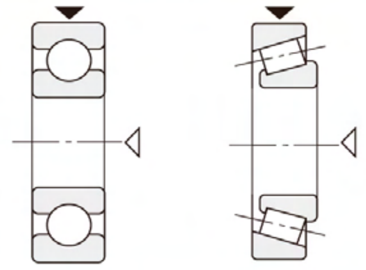


● Bearing loads

When calculating bearing load using the loads on a position on the shaft, it is necessary to calculate center distance between the load application points of the bearings. Deep groove ball bearings have load center points at the center line of the width. Single-row tapered roller bearings, have load center points off-center to the center line of the bearing width.

● Magnitude of load

The magnitude of the load is one of the factors that usually determine the size of the bearing. Generally, roller bearings are able to support heavier loads than similar sized ball bearings and bearings having a full complement of rolling elements can accommodate heavier loads than the corresponding caged bearings. Ball bearings are mostly used where loads are light or moderate. For heavy loads and where shaft diameters are large, roller bearings are usually the more appropriate choice.

Radial load	Axial load	Combined load
		
Bearings can only support pure radial loads.	Bearings are suitable for light or moderate loads that are purely axial.	A combined load comprises a radial and axial load acting simultaneously.

● Load acting on shafts

It is possible to calculate theoretical values for these loads. However, there are many instances where the actual operational shaft load is much greater than the theoretically calculated load, due to machine vibration and/or shock. This actual shaft load can be found by using formula

$$K = f_w \cdot K_c$$

where,
K : Actual shaft load {kgf}
f_w : Load factor
K_c: Theoretically calculated value {kgf}

● Load factor f_w

Amount of shock	f_w	Application
Heavy shock	1.0-1.2	Electric machines, machine tools, measuring instruments.
Light shock	1.2-1.5	Railway vehicles, automobiles, rolling mills, metal working machines, paper making machines, rubber mixing machines, printing machines, aircraft, textile machines, electrical units, office machines.
Very little or no shock	1.5-3.0	Crushers, agricultural equipment, construction equipment, cranes.

Basic rating life and basic dynamic load rating

The basic dynamic load rating is an expression of the load capacity of a bearing based on a constant load which the bearing can sustain for 1,000,000 revolutions (the basic rating life). For radial bearings this rating applies to pure radial loads. The common measurement is "L_{10}" life, defined as the number of revolutions before metal fatigue first appears on 10% of a large group of like bearings. This is referred to as basic rating life of fatigue life.The relationship between the basic rating life, the basic dynamic load rating and the bearing load is given in following formula:

$$L_{10} = \left(\frac{C_r}{P}\right)^p$$

where,

$p = 3$ for ball bearings

$p = 10/3$ for roller bearings

L_{10} : Basic rating life (at 90% reliability), millions of revolutions

C_r: Basic dynamic load rating, N or kgf

P: Equivalent dynamic load, N or kgf

If the speed is constant, the basic rating life can also be expressed in terms of hours of operation (revolution), and is calculated as shown in the formula below:

$$L_{10h} = \frac{10^6}{60n}\left(\frac{C_r}{P}\right)^p$$

where,

n: Rotational speed, rpm

The relationship between rotational speed "n" and speed factor as well as the relation between the basic rating life and the life factor is shown as following:

$$L_{10h} = 500 f_h^{\,p}$$

$$f_h = f_n \frac{C}{P}$$

$$f_n = \left(\frac{33.3}{n}\right)^{1/P}$$

where,

L_{10h} : Basic rating life

f_h : Life factor

f_n : Speed factor

Ball bearing	
L_{10h}	$\frac{10^6}{60n}\left(\frac{C_r}{P}\right)^3 = 500 f_h^{\,3}$
f_h	$f_n \frac{C}{P}$
f_n	$\left(\frac{33.3}{n}\right)^{1/3}$

Roller bearing	
L_{10h}	$\frac{10^6}{60n}\left(\frac{C_r}{P}\right)^{10/3} = 500 f_h^{\,10/3}$
f_h	$f_n \frac{C}{P}$
f_n	$\left(\frac{33.3}{n}\right)^{3/10}$

Example 1: What is the rating life in hours of operation (L10h) for deep groove ball bearing 6208 operating at 650 r/min, with a radial load Fr of 3.2 kN ?

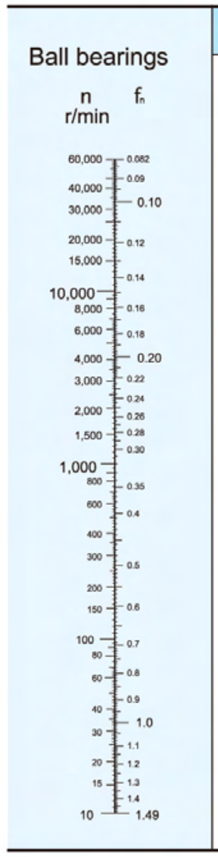
$P_r = F_r = 3.2\text{kN}\ \{326\text{kgf}\}$

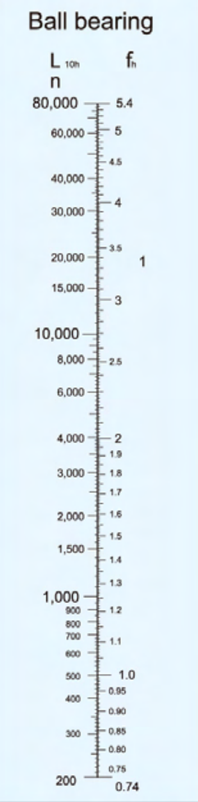
$f_h = f_n \frac{C_r}{P_r} = 0.37 \text{ X } \frac{29.52}{3.2} = 3.41$

The basic dynamic rated load for bearing 6208 (from bearing table) is 29.52 kN, and the speed factor (fn) for ball bearings at 650 r/min (n) from the table in the following page is 0.37. The life factor, fh, from formula is:

Therefore, with fh = 3.41 from the table in the following page, the rated life, L10h, is approximately 20,000 hours.

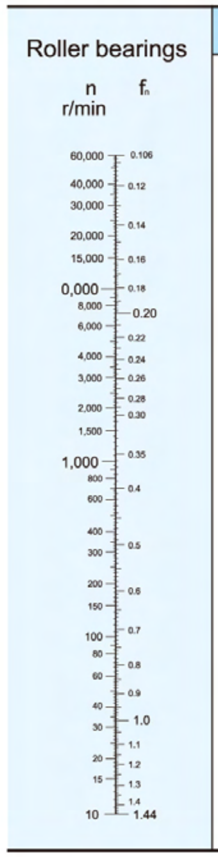
● Correlation of bearing basic rating life, life factor and speed factor (Ball bearing)

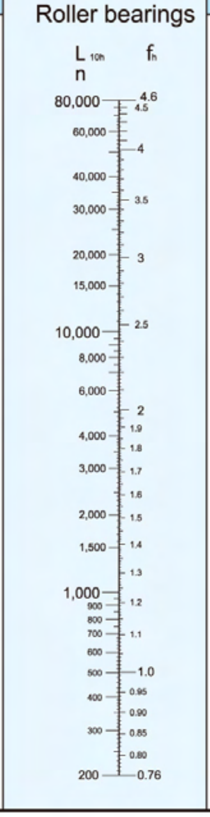




n	f_n	n	f_n	L_{10h}	f_h	L_{10h}	f_h
10	1.49	600	0.382	100	0.585	2800	1.78
12	1.41	700	0.362	120	0.621	3000	1.82
14	1.34	800	0.347	140	0.654	4000	2
16	1.28	900	0.333	160	0.684	5000	2.15
18	1.23	1000	0.322	180	0.711	6000	2.29
20	1.19	1200	0.303	200	0.737	7000	2.41
30	1.04	1400	0.288	220	0.761	8000	2.52
40	0.941	1600	0.275	240	0.783	9000	2.62
50	0.874	1800	0.265	260	0.804	10000	2.71
60	0.822	2000	0.255	280	0.824	12000	2.88
70	0.781	3000	0.223	300	0.843	14000	3.04
80	0.747	4000	0.203	400	0.928	16000	3.17
90	0.718	5000	0.188	500	1	18000	3.3
100	0.693	6000	0.177	600	1.06	20000	3.42
120	0.652	7000	0.168	700	1.12	22000	3.53
140	0.62	8000	0.161	800	1.17	24000	3.63
160	0.593	9000	0.155	900	1.22	26000	3.73
180	0.57	10000	0.149	1000	1.26	28000	3.83
200	0.55	12000	0.141	1200	1.34	30000	3.91
220	0.533	14000	0.134	1400	1.41	40000	4.31
240	0.518	16000	0.128	1600	1.47	50000	4.64
260	0.504	18000	0.123	1800	1.53	60000	4.93
280	0.492	20000	0.119	2000	1.59	70000	5.19
300	0.481	30000	0.104	2200	1.64	80000	5.43
400	0.437	40000	0.0941	2400	1.69	90000	5.65
500	0.405	50000	0.0874	2600	1.73	100000	5.85

● Correlation of bearing basic rating life, life factor and speed factor (Roller bearing)





n	f_n	n	f_n	L_{10h}	f_h	L_{10h}	f_h
10	1.44	600	0.42	100	0.617	2800	1.68
12	1.36	700	0.401	120	0.652	3000	1.71
14	1.3	800	0.385	140	0.683	4000	1.87
16	1.25	900	0.372	160	0.71	5000	2
18	1.2	1000	0.36	180	0.736	6000	2.11
20	1.17	1200	0.341	200	0.76	7000	2.21
30	1.03	1400	0.326	220	0.782	8000	2.3
40	0.947	1600	0.313	240	0.802	9000	2.38
50	0.885	1800	0.302	260	0.822	10000	2.46
60	0.838	2000	0.293	280	0.84	12000	2.59
70	0.8	3000	0.259	300	0.858	14000	2.72
80	0.769	4000	0.238	400	0.935	16000	2.83
90	0.742	5000	0.222	500	1	18000	2.93
100	0.719	6000	0.211	600	1.06	20000	3.02
120	0.681	7000	0.201	700	1.11	22000	3.11
140	0.65	8000	0.193	800	1.15	24000	3.19
160	0.625	9000	0.186	900	1.19	26000	3.27
180	0.603	10000	0.181	1000	1.23	28000	3.35
200	0.584	12000	0.171	1200	1.3	30000	3.42
220	0.568	14000	0.163	1400	1.36	40000	3.72
240	0.553	16000	0.157	1600	1.42	50000	3.98
260	0.54	18000	0.151	1800	1.47	60000	4.2
280	0.528	20000	0.147	2000	1.52	70000	4.4
300	0.517	30000	0.13	2200	1.56	80000	4.58
400	0.475	40000	0.119	2400	1.6	90000	4.75
500	0.444	50000	0.111	2600	1.64	100000	4.9

Correction of basic load rating

● Correction due to temperature

The operating temperature will significantly affect the fatigue life by altering the hardness of the bearing. Consequently, the basic load rating, which depends on the physical properties of the bearing material, will decrease with higher temperatures. Thus, the basic load rating must be corrected for higher temperatures using the equation:

$$C_t=f_t*C$$

where,
C_t: Basic load rating after temperature correction
f_t: Temperature factor (see following table)
C: Basic load rating, before application of temperature correction.

	Bearing Temperature (℃)			
	≤150℃	175℃	200℃	250℃
Temperature Factor f_t	1.00	0.95	0.90	0.75

● Adjustment to fatigue life rating

Some common applications require a bearing that can handle misalignment, loads in both directions, high speeds, etc., or a combination of two or more. These operating conditions will alter the bearing life and are accounted for by using correction factors for temperature, reliability, bearing material, and other operating conditions. The formula for adjusting life based on reliability, material, and operating conditions is:

$$L_{na}=a_1*a_2*a_3*L_{10}$$

Where,
L_{na}: Adjusted life rating
a_1: Life correction factor for reliability. This is determined from the reliability required of the bearing for its application (see table right).
a_2: Life correction factor for bearing material
a_3: Life correction factor for operating conditions

(1) Reliability coeffcient a1

The table on the right side describes reliability coefficient, a1, which is necessary to obtain the corrected rating life of reliability greater than 90%.

L_{10}: Life rating, adjusted for fatigue life for 90% reliability. This may not satisfy all applications. For higher reliability requirements, L_{10} must be adjusted.

Reliability coefficient

	Reliability		
	90%	95%	96%
a_1	1.00	0.62	0.53
	97%	98%	99%
a_1	0.44	0.33	0.21

(2) Bearing characteristic coefficient a2

The bearing characteristic in relation to bearing life may differ according to bearing materials(steel types and their quality), and may be altered by production process, design, etc. In such cases, the bearing life calculation can be corrected using the bearing characteristic coefficient a2.

HCH has employed vacuum-degassed bearing steel as HCH standard bearing material. It has a significant effect on bearing life extension which was verified through studies at HCH laboratory. The basic dynamic load rating of bearings made of vacuum-degassed bearing steel is specified in the bearing specification table, taking the bearing characteristic coefficient as a2=1. For bearings made of special materials to extend fatigue life, the bearing characteristic coefficient is treated as a2>1

(3) Operating condition coefficient a3

When bearings are used under operating conditions which directly affect their service life including improper lubrication, the service life calculation can be corrected by using a3. Under normal lubrication, the calculation can be performed with a3=1; and, under favorable lubrication,with a3>1. In the following cases, the operating condition coefficient is treated as a3<1

Operating lubricant of low kinematic viscosity (Ball bearing……13mm^2/s or less, Roller bearing……20 mm2^2/s or less)
Operation at very slow rotational speed (Product of rolling element pitch diameter and rotational speed is 10000 or less)
Contamination of lubricant is expected
Greater misalignment of inner and outer rings is present

Note: Since a2 and a3 are inter-dependent, some calculations treat them as one coefficient,a23. Due to difficult of value determination, for most applications, a23=1

● Factor η_c for contamination level

This factor was introduced to consider the contamination level of the lubricant in the bearing life calculation. The influence of contamination on bearing fatigue depends on a number of parameters including bearing size, relative lubricant film thickness, size and distribution of solid contaminant particles, types of contamination (soft, hard etc). The influence of these parameters on bearing life is complex and many of the parameters are difficult to quantify. It is therefore not possible to allocate precise values to η_c that would have general validity. However, some guideline values are provided in the following table.

Guideline values of factor η_c for different levels of contamination Condition	Facor η_c 1) for bearings with diameter d_m<100mm	 d_m ≥ 100mm
Extreme cleanliness Particle size of the order of the lubricant film thickness Laboratory conditions	1	1
High cleanliness Oil filtered through an extremely fine filter Conditions typical of bearings greased for life and sealed	0,8 ... 0,6	0,9 ... 0,8
Normal cleanliness Oil filtered through a fine filter Conditions typical of bearings greased for life and shielded	0,6 ... 0,5	0,8 ... 0,6
Slight contamination Slight contamination of the lubricant	0,5 ... 0,3	0,6 ... 0,4
Typical contamination Conditions typical of bearings without integral seals, coarse filtering, wear particles and ingress from surroundings	0,3 ... 0,1	0,4 ... 0,2
Severe contamination Bearing environment heavily contaminated Arrangement with inadequate sealing	0,1 ... 0	0,1 ... 0
Very severe contamination Under extreme contamination, values of η_c can be outside the scale resulting in a more severe reduction of life than predicte	0	0

ISO classification - allocation of scale number		
Number of particles per millilitre oil over	 incl.	Scale number
2 500 000		>28
1 300 000	2 500 000	28
640 000	1 300 000	27
320 000	640 000	26
160 000	320 000	25
80 000	160 000	24
40 000	80 000	23
20 000	40 000	22
10 000	20 000	21
5 000	10 000	20
2 500	5 000	19
1 300	2 500	18
640	1 300	17
320	640	16
160	32	15
80	160	14
40	80	13
20	40	12
10	20	11
5	10	10
2,5	5	9
1,3	2,5	8
0,64	1,3	7
0,32	0,64	6
0,16	0,32	5
0,08	0,16	4
0,04	0,08	3
0,02	0,04	2
0,01	0,02	1
0,00	0,01	0

Note:
1) This approach will probably indicate only an approximate value of the effective factor η_c for the contamination level of the application.
2) The scale for η_c refers only to typical solid contaminants, Contamination by water or other fluids detrimental to bearing life in not included. In case of very heavy contamination (η_c=0), failure will be caused by wear, the useful life of the bearing can be shorter than the rated life.

Dynamic equivalent load

When both dynamic radial loads and dynamic axial loads act on a bearing at the same time, the hypothetical load acting on the center of the bearing which gives the bearings the same life as if they had only a radial load or only an axial load is called the dynamic equivalent load. For radial bearings, this load is expressed as pure radial load and is called the dynamic equivalent radial load. The dynamic equivalent radial load is expressed by formula below:

$$P = XF_r + YF_a$$

where,
P : Equivalent dynamic radial load, N or kgf
F_r: Actual radial load, N or kgf
F_a: Actual axial load, N or kgf
X : Radial load factor
Y : Axial load factor

The values for X and Y are listed in the bearing tables

Equivalent dynamic P=XFr+YFa

$\frac{f_0 F_a}{C_{0r}}$	e	$\frac{F_a}{F_r} \le e$		$\frac{F_a}{F_r} > e$	
		X	Y	X	Y
0.172	0.19	1	0	0.56	2.30
0.345	0.22	1	0	0.56	1.99
0.689	0.26	1	0	0.56	1.71
1.03	0.28	1	0	0.56	1.55
1.38	0.30	1	0	0.56	1.45
2.07	0.37	1	0	0.56	1.31
3.45	0.38	1	0	0.56	1.15
5.14	0.42	1	0	0.56	1.04
6.89	0.44	1	1	0.56	1.00

In the table, the "e" value is definded as axial load influence factor. When $F_a/F_r > e$, it means that the axial load influences a lot, and the equivalent radial load P should be calculated by the formula $P=XFr+YFa$. Otherwise, when $F_a/F_r \le e$, the influence of the axial load can be ignored, here $P=Fr$. The "e" value is determined by multiplying the axial load applied to the bearing by the bearing coefficient factor "f_0", which is obtained from the bearing table above.

Example 2: What is the life rating L10h for the same bearing and conditions as in Example 1, but with an additional axial load Fa of 1.8 kN ?

To find the dynamic equivalent radial load value for Pr, the radial load factor X and axial load factor Y are used.The basic static load rating, Cor, for bearing 6208 is 18.14 from the bearing table.

$$\frac{f_0 F_a}{C_{or}} = \frac{14x1.8}{18.14} = 1.37$$

Therefore, from the bearing tables e= 0.29. For the operating radial load and axial load:

$$\frac{F_a}{F_r} = \frac{1.8}{3.2} = 0.56 > e = 0.29$$

From the bearing tables X = 0.56 and Y = 1.48, and from formula the equivalent radial load, Pr, is:

$$P_r = XF_r + YF_a = 0.56x3.2+1.48x1.8$$
$$= 4.46 \text{ kN } \{455 \text{kgf}\}$$

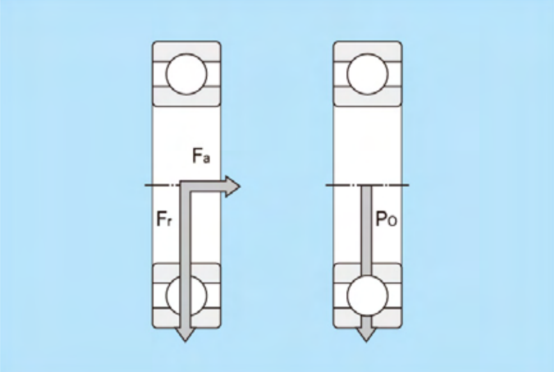
Therefore, with life factor fh = 2.45, from the table, the rated life, L10h, is approximately 7,500 hours.

$$F_h = F_h \frac{C_r}{P_r} = 0.37x\frac{29.52}{4.46} = 2.45$$

Static bearing load

The basic static load rating "C_o" is used in calculations when the bearings are to:
– rotate at very slow speeds (n < 10 r/min).
– perform very slow oscillating movements.
– be stationary under load for certain extended periods.

It is also most important to check the safety factor of short duration loads such as shock or heavy peak loads that act on a bearing, whether it is rotating (dynamically stressed) or at rest.



● Static equivalent load

The static equivalent load is a hypothetical load which would cause the same total permanent deformation at the most heavily stressed contact point between the rolling elements and the raceway under the actual load conditions where both static radial load and static axial load are simultaneously applied to a bearing. For a radial bearing, this hypothetical load refers to pure radial load. For radial bearings the static equivalent radial load can be found by using formula below. The greater of the two resultant values is always taken for "P_{or}".

$$P_{or}=X_oF_r+Y_aF_a$$

$$P_{or}=F_r$$

Where,
P_{or}: Static equivalent radial load, N or kgf
F_r : Actual radial load, N or kgf
F_a : Actual axial load, N or kgf
X_o : Static radial load factor
Y_o : Static axial load factor

● Required basic static load rating

The basic static load rating is considered as the limiting load for general applications. In terms of a safety factor, this means that, by definition, a safety factor "S_o" is set as a base of 1. An application may require a larger or allow a smaller safety factor provides a guide for selection of the safety factor "S_o", to be used with formula for calculation of the maximum (weighted) static equivalent load.

$$C_o=S_o \cdot P_o\text{max}$$

where,
C_o: Basic static load rating, KN
P_o: Equivalent static bearing load, KN
S_o: Static safety factor

Guideline values for the static safety factor S_o

Type of operation	Rotating bearing Requirements regarding quiet running						Non-rotating bearing	
	unimportant		normal		high			
	Ball bearing	Roller bearing	Ball bearing	Roller bearing	Ball bearing	Roller bearing	Ball bearing	Roller bearing
Smooth, vibration-free	0,5	1	1	1,5	2	3	0,4	0,8
Normal	0,5	1	1	1,5	2	3,5	0,5	1
Pronounced shock loads	≥1,5	≥2,5	≥1,5	≥3	≥2	≥4	≥1	≥2

Where the magnitude of the shock load is not known, values of "S_o" at least as large as those quoted above should be used. If the magnitude of the shock loads is exactly known, smaller values of "S_o" can be applied.