Bearing clearance, operating clearance and preload

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Summary

- The internal mobility of the rolling elements and the rings in the axial and radial direction is referred to as *bearing clearance*
- *Bearing clearance* refers to an unmounted rolling bearing
- *Operating clearance* refers to a mounted rolling bearing in operation
- Typical bearing clearance classes (values for a deep groove ball bearing 6008): C2 (1->11µm) -> CN -> C3 -> C4 (28->46µm)
- Preload is defined as either a negative radial operating clearance or the axial preloading of a rolling bearing by means of a spring or a clamping system

Bearing clearance and operating clearance, isn't that the same thing? And preload, I've heard that before, but what is that supposed to be?! How do I calculate all these values and what criteria are important when choosing the right operating clearance? Perhaps you are confronted with such questions – you will find the answers and more detailed information in this article.

Definition of bearing clearance and operating clearance

The bearing clearance refers to an uninstalled rolling bearing and can be described as the internal mobility of the rolling elements and the rings in both axial and radial directions. The operating clearance can also be described as the internal mobility of the rolling elements and the rings in both directions, but it refers to an installed bearing in operation.

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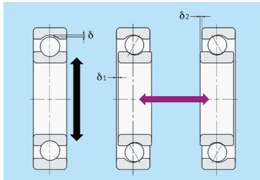
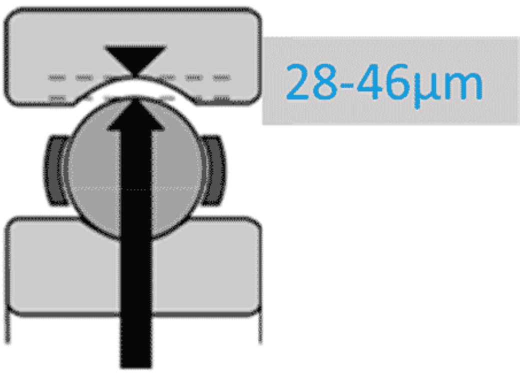
Internal clearance



The bearing clearance is characterised by displacements in both radial and axial directions.

The most practical way to explain internal clearance is to imagine a bearing (for example, a deep groove ball bearing) that you are holding in your hand. If you try to move the inner ring of this bearing up and down or to the left and right while holding the outer ring, you will notice a small displacement in the radial (black arrow) or axial direction (purple arrow). This displacement is called bearing clearance. Conversely, the inner ring can also be held and the outer ring moved up and down or to the left and right. This is also referred to as bearing clearance.



The bearing clearance of the deep groove ball bearing 6008C4, which uses the following example calculation, is shown here graphically.

But enough theory. What about the bearing clearance in a practical example? For a bearing 6008C4, for example, the radial internal clearance is 28-46µm (= C4). In the first step, bearing 6008C4 is mounted once on a steel shaft that has, for example, a k6 tolerance (+2 -> +18µm). Since bearing 6008C4 has a tolerance on the inner ring of 0/-12µm the resulting fit between the inner ring and the shaft gives 2 to 30 microns of interference. This value is obtained by looking at the tolerances on the bearing inner ring and the shaft.

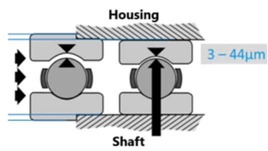
Only extreme values are taken into account, which cover the range when the “largest” bearing is mounted on the “smallest” shaft or the “smallest” bearing is mounted on the “largest” shaft. In this example, this would be the following cases:

- Shaft with 40.002 mm outside diameter (OD) and bearing with 40.000 mm inside diameter (ID) = 2 µm interference
- Shaft with 40.018 mm OD and bearing with 39.988 mm ID = 30 µm interference

Some force is needed to mount the 6008C4 on the shaft to overcome the interference. Due to this interference, the bearing clearance is reduced so that after mounting on the shaft it becomes +3µm -> +44µm. Now the shaft is mounted with the 6008C4 inside a steel housing. In this example, the housing has a H6 (0µm/+19µm) tolerance and the outer ring of the bearing has a tolerance of 0/-13µm.

Comparable to the shaft, the housing bearing fit and outer ring tolerance are considered. Here, the following applies:

- Housing with 68.000 mm inside diameter (ID) and bearing with 68.000 mm outer diameter (OD) = 0 µm
- Housing with 68.019 mm ID and bearing with 67.987 mm OD = 32 µm



Reduction of bearing clearance due to fits.

As you can see, the resulting fit between the outer ring and the housing is a clearance of 0µm – 32µm. This does not change the clearance in the bearing: +3 -> +44µm.

The shaft is then rotated at 8,000 rpm, for example. The bearing 6008C4 now has a

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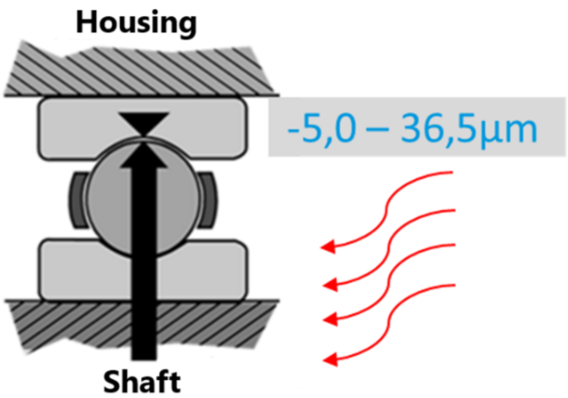
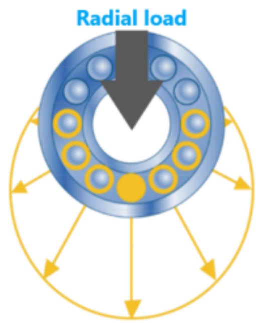


Due to the fact that the inner ring expands more than the outer ring, the bearing clearance is reduced.

temperature of 100°C on the inner ring and 90°C on the outer ring. But what is actually happening now? Well, the inner ring and the outer ring expand due to the heat, but the inner ring expands more than the outer ring due to the temperature difference. Because of this, the clearance in the bearing is reduced from +3 -> +44µm to -5.0 -> +36.5µm. This reduction of about 7.5µm is calculated with a computer programme or alternatively with the help of catalogue formulas.

If a radial force is now added, this increases the radial internal clearance again. The reason for this is that some of the rolling elements absorb the radial load while the other rolling elements are relieved. The rolling elements under load will deform slightly (elastic deformation). In the illustration of radial load, this is shown for a deep groove ball bearing. The length of the yellow arrows indicate the magnitude of the force acting on the rolling elements where the elastic deformation is proportional to the force.



In this illustration you can see the magnitude of the force acting on the rolling elements. In short: Small arrow = low load, large arrow = high load on the rolling element.

There are different groups of radial internal clearance for rolling bearings. These can be seen in the table. (Note: The axial internal clearance can be calculated from the radial clearance using formulae, for example for deep groove ball bearings).

Internal clearance	Meaning	Possible applications
C2	Bearing clearance is smaller than normal	• Small motors • Shaft journals of compressors
CN	Standard bearing clearance	• Most common applications
C3	Bearing clearance is larger than normal	• Axle bearings for rail vehicles • Paper machines and dryers
C4	Greater than C3	• Traction motor bearings for rail vehicles • Paper machines and dryers
C5	Greater than C4	• Special applications

You will certainly not come across CN, C3 and C4 for the last time. The other bearing clearance classes are only used under special operating conditions.

Operating clearance

We can now say that the bearing clearance in the operating state is -5.0µm to 36.5µm. This bearing clearance during operation is also called operating clearance. The corresponding changes to the bearing clearance depending on the assembly condition can be seen in the table.

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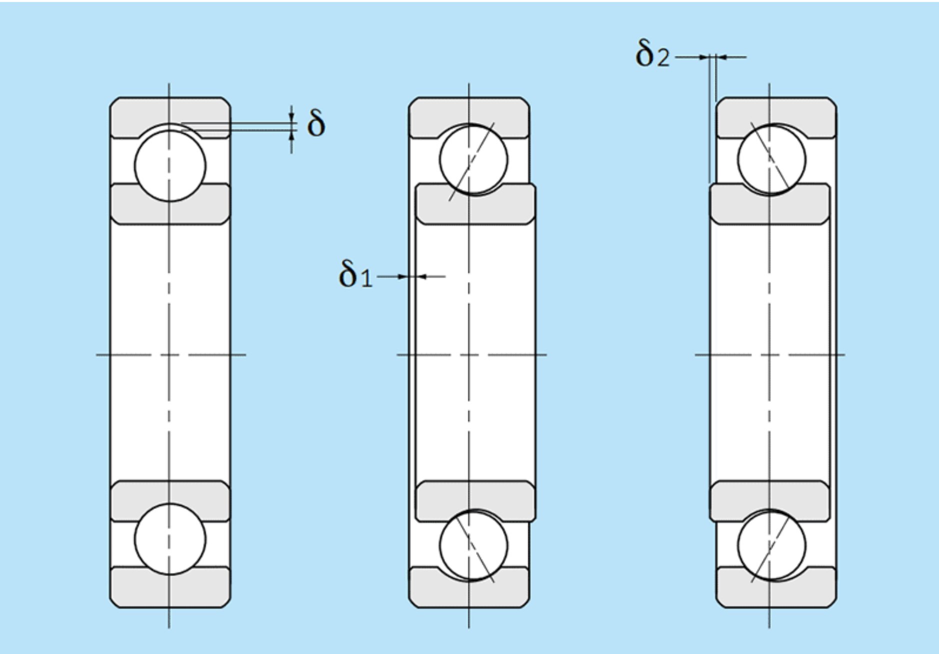
Summarised results		
Step	State	Radial internal clearance/operating clearance
1	**Before assembly**	28µm – 46µm
2	**After assembly on the shaft (k6 tolerance)**	3µm – 44µm
3	**After assembly into the housing (H6 tolerance)**	3µm – 44µm
4	**In operation, 8,000rpm, Inner ring temperature: 100°C, Outer ring temperature: 90°C**	-5.0µm – 36.5µm
5	**Radial force of 1,000 N**	+7,3µm -> +48,7µm

This table summarises the most important factors affecting radial clearance.

Formula 11
Radial clearance = δ
Axial clearance = $\delta_1+\delta_2$

The determination of

radial and axial clearance.



In the illustration you can see that the operating clearance is split into radial and axial clearance. Radial and axial clearance are determined differently.

Example: Relationship between operating clearance and service life

A targeted and careful selection of the bearing clearance is elementary, as the subsequent operating clearance has an effect on the service life (not the L_{10h} service life), the temperature curve, the bearing performance as well as the running noise. The effects of the operating clearance on the service life are shown in the graph.

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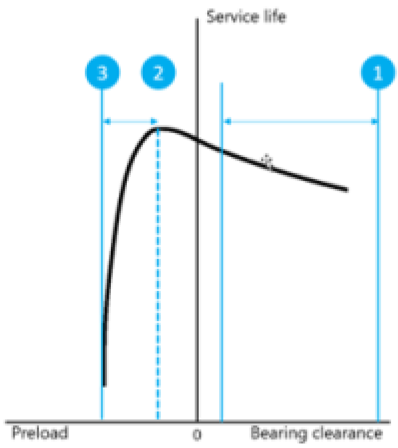
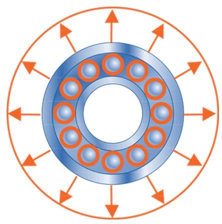
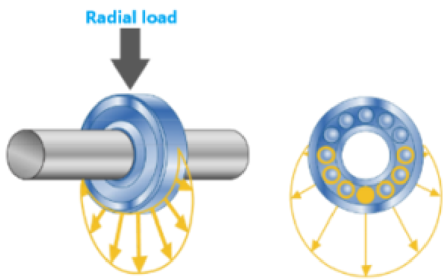


Lifetime depending on the operating clearance.

As you can see in the figure, the life span drops rapidly in areas 3 and 1. But why does the service life decrease so much? Let's assume that the bearing 6008C4 mentioned in the example above has 12 balls (rolling elements). However, if the temperature difference between the inner ring and the outer ring now always increases, the operating clearance will continue to decrease (range 3). As a result, all 12 rolling elements are now in contact, increasing resistance to rotation until eventually sliding occurs (rolling no longer takes place). This reduces the service life to the point of total failure!

If the table for the bearing clearance classes mentioned above is extended by a further column, the balls which "bear" the radial force (for example the weight of the shaft) are shown in the fourth column (load bearing).

Step	State	Bearing clearance/ Operating clearance	Load bearing balls	Service life area (see graph above)	Note
1	Before assembly	28µm – 46µm	–	–	–

2	After assembly on the shaft (k6 fit)	3µm – 44µm	3 – 12	1–2	–
3	After assembly into the housing (H6)	3µm – 44µm	3 – 12	1–2	–
4	In operation, 8,000rpm, Inner ring temperature: 100°C, outer ring temperature: 90°C	-5,0µm – 36,5µm	12 – 12	2–3	 The bearing 6008C4 has an inner ring temperature of 100°C and outer ring temperature of 90°C at n= 8,000rpm.
5	Radial force of 1,000 N	+7,3µm -> +48,7µm	7 – 12	2–1	 Bearing 6008C4 is in operation with a radial load of 1,000N.

This table shows how many balls or rolling elements bear the load depending on the operating clearance.

The calculation of the operating clearance

Even though the operating clearance should (theoretically) ideally be slightly negative in order to achieve maximum bearing life, in practical everyday life under normal operating conditions, operating clearance is usually targeted at just above zero. The reason for this is that this negative operating clearance (preload) could increase if a rolling bearing is exposed to changing operating conditions. This would in turn lead to the reduction in service life already described.

To calculate the operating clearance, factors such as fits as well as temperature differences that occur between the inner and outer ring must be taken into account.

Formula 12

$\delta_{eff} = \delta_o - (\delta_f + \delta_t)$

δ_{eff} = Effective interference (due to fits), mm

δ_o = Bearing clearance, mm

δ_f = Decrease in bearing clearance due to interference caused by fits, mm

δ_t = Decrease in bearing clearance due to temperature differences between inner and outer rings, mm

The calculation of the operating clearance δ_{eff} requires three variables.

The interference δ_f

The bearing clearance is reduced due to interference δ_f between the inner ring and shaft or outer ring and housing. Due to the interference δ_f between the inner ring and the shaft, the inner ring expands or the outer ring contracts (interference between the outer ring and the housing) during mounting.

Formula 13 can be used to calculate the reduction in bearing clearance. For the sake of simplicity, factors such as the shape of the bearing, shaft and housing as well as the materials used are taken into account by a numerical value of 70%-90%. In general, the larger the interference, the more the bearing clearance is reduced.

Formula 13

$\delta_f = (0{,}70 \sim 0{,}90)\ \Delta_{deff}$

Δ_{deff} denotes the effective interference in mm.

The temperature difference δ_t

The calculation of the value δ_f is not the whole picture. The next step is to calculate the variable δ_t which takes into account the reduction of the operating clearance due to a temperature difference in the bearing. An important piece of information: When the bearing is in operation, the outer ring is typically 5 to 10°C cooler than the inner ring, for example. Under certain conditions, such as above-average heat dissipation of the housing, this difference can be even greater.

Formula 14

$\delta_t = \propto \times \Delta T \times D_o$

$\propto$= Temperature coefficient of expansion of the bearing material, 12,5× ((10)*6/℃)

ΔT= Temperature difference (inner/outer ring) in °C

D_o= Outer ring raceway diameter, mm

When calculating the reduction in operating clearance due to a temperature difference, you must take several factors into account.

The raceway diameter of the outer ring D_o

In order to determine the raceway diameter of the outer ring again D_o (approximately), one must use formula 15 or formula 16, depending on the type of rolling bearing.

Formula 15
For ball bearings and spherical roller bearings:
$D_o = 0{,}20\ (d+4{,}0D)$

Formula 16
For roller bearings (except spherical roller bearings):
$D_o = 0{,}25\ (d+3{,}0D)$

The calculation of the raceway diameter of the outer ring D_o is different for ball bearings and roller bearings.

Preload

So far, this article has been about bearing clearance classes and how they change during operation. But depending on the application, it may be necessary to preload bearings axially.

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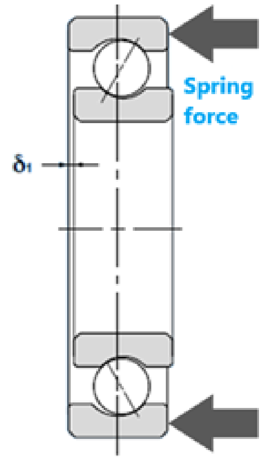
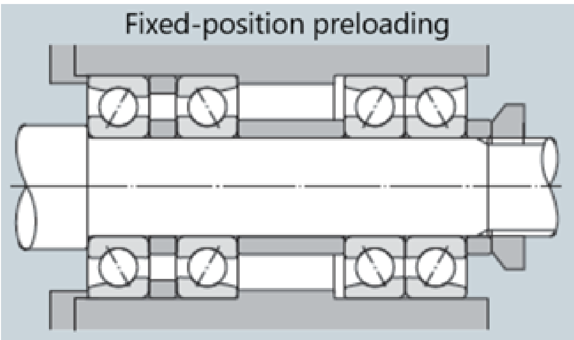
One possibility, which is often used in electric motors, for example, is axial preloading of the rolling bearings by means of a spring (preloading by means of a constant sprung preload force). This is shown symbolically in the illustration. The spring force acts around the entire circumference.



Spring force fixed-pressure preloading in a deep groove ball bearing.

Why is this done? The spring preload force causes all the balls to fit snugly against the raceways of the deep groove ball bearing (axial bearing clearance = 0µm). The preload thus causes a tension at the contact points of rolling elements and raceways. This reduces the operating noise and improves the vibration behaviour.



Spindle bearings are typically preloaded.

Another application is the bearings in a machine tool spindle (hence the name spindle bearing). Here, the spindle bearings are axially preloaded either by means of a spring, as with the electric motor, or alternatively via a fixed–position clamping system.

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Preload is most likely to occur in angular contact ball bearings and tapered roller bearings, and a slight preload also has a positive effect on the overall service life. In the context of preload, one should always consider the purpose and the goal, because preload also carries risks, especially if preload is excessive. Therefore, it shouldn't be overlooked that this can lead to increased surface pressure, extremely high heat generation and a shortening of the bearing service life.

Effects of preload:

- Increase in rigidity
- Only conditionally recommended for highest speeds (applies to fixed-position preload)
- Concentricity and positioning accuracy are improved
- Positive influence on vibrations and running noise
- Lower risk of skidding

- Forced guidance of rolling elements on the guide rib (for example with tapered roller bearings)

Preload has several effects.

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