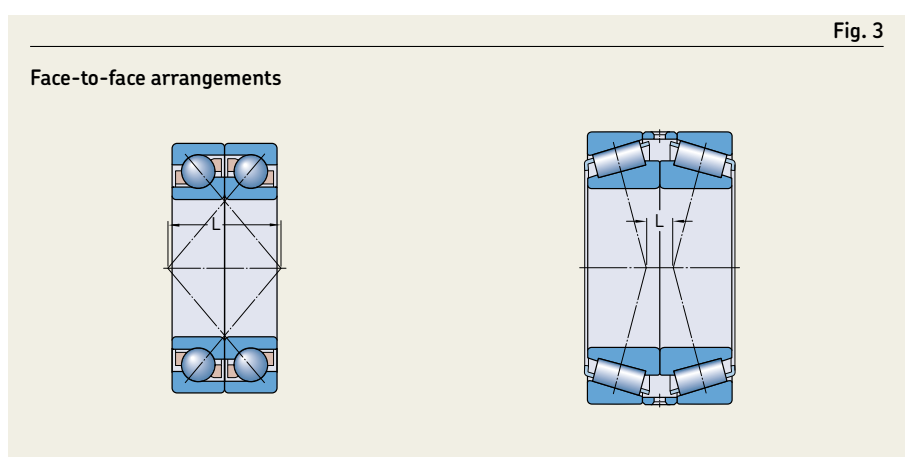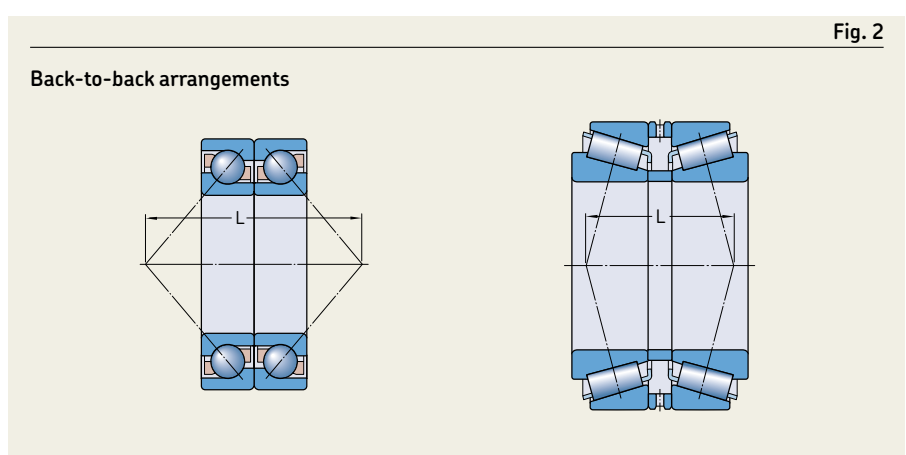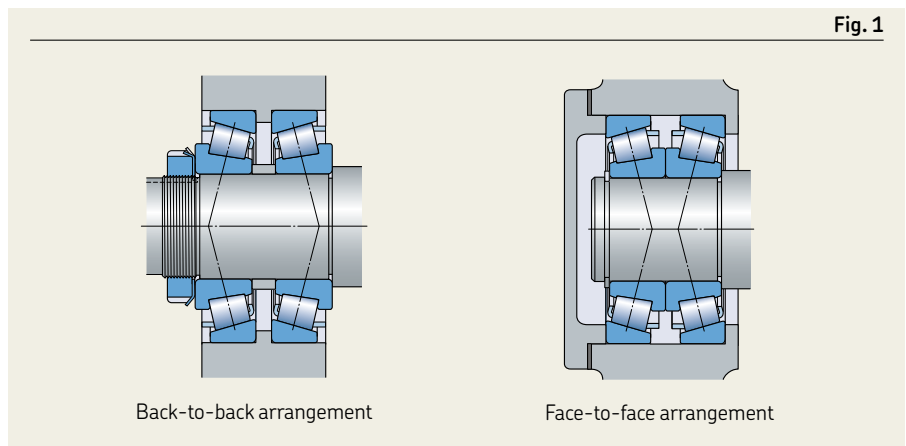# Bearing preload

There may be some applications where the bearing arrangement needs to be preloaded – i.e. requires a negative operating clearance. In applications such as machine tool spindles, automotive differentials and electric motors, preload enhances stiffness or precise shaft positioning. Preload can be obtained with a spring or by adjustment (e.g. by a nut). Springs are also used to provide a minimum load on lightly loaded bearings.

Preload is typically expressed as a force, but can also be expressed as a distance (path).

Empirical preload values can be obtained from proven designs and then applied to similar designs. For new designs, SKF recommends calculating the preload force and checking if its appropriate by testing the application. Generally, it is not always possible to identify all influencing factors in operation fully during the design stage and adjustments may be necessary. The accuracy of the calculated results depends on how closely the estimated operating temperature and elastic behaviour of the associated components – most importantly the housing – match the actual operating conditions.

Preload considerations

Depending on the bearing type, preload may be either radial or axial. Cylindrical roller bearings, for example, can be preloaded radially only, because of their design, while thrust ball and cylindrical roller thrust bearings can be preloaded axially only. Single row angular contact ball bearings and tapered roller bearings (**fig. 1**) are generally preloaded axially by mounting them against a second bearing of the same type and size in a back-to-back (load lines diverge) or face-to-face (load lines converge) arrangement. Deep groove ball bearings can also be

Fig. 1

Back-to-back arrangement   Face-to-face arrangement

Fig. 2

Back-to-back arrangements

Fig. 3

Face-to-face arrangements

preloaded axially – in this case, the bearings have a greater radial internal clearance (C3 or C4) so that a contact angle is obtained.

For both tapered roller and angular contact ball bearings, the distance L between the pressure centres is longer when the bearings are arranged back-to-back (**fig. 2**) compared with bearings arranged face-to-face (**fig. 3**). This means that bearings arranged back-to-back can accommodate relatively large tilting moments even if the dis tance between the bearing centres is relatively short. The radial loads and bearing elastic displacements resulting from a moment load are smaller for bearings arranged back-to-back than when arranged face-to-face.

If during operation the shaft temperature is higher than the housing temperature, the preload, which was adjusted at ambient temperature during mounting, will change.

Depending on the distance between the bearings and the type of arrangement (face-to-face or back-to-back) the preload may increase or decrease. In any case, thermal expansion of the inner ring in the radial direction leads to increase of the preload. Thermal expansion in the axial direction increases the preload when the bearings are face-to-face, but is reduced for back-to-back arrangements.

Depending on the distance between the bearings, and provided the coefficient of thermal expansion is the same for the bearings and associated components, thermal expansion in both the radial and axial directions can cancel each other out so that preload remains unchanged for back-to-back arrangements independent of operating temperature.

Effects of bearing preload

The primary benefits resulting from preload include but are not limited to:

- enhanced stiffness
- reduced noise levels
- improved shaft guidance
- compensation for wear and settling
- extended bearing service life

Enhanced stiffness

Bearing stiffness [kN/mm] is defined as the ratio of the force acting on the bearing to the elastic deformation in the bearing. The elastic deformation caused by a load in preloaded bearings is smaller for a given load range than for bearings that are not preloaded.

Reduced noise levels

As operating clearance in a bearing decreases, rolling elements in the unloaded zone become loaded, which reduces noise levels in operation.

Improved shaft guidance

Preloaded bearings provide more accurate shaft guidance because preload provides a higher degree of stiffness, which limits the ability of the shaft to deflect under load. For example, preloading the bearings in a differential results in increased stiffness, which limits gear mesh variation. This minimizes dynamic forces and reduces noise levels, which can extend the service life of the gears.

Compensation for wear and settling

Wear and settling between mating surfaces in an adjusted bearing arrangement during running-in leads to clearance. This can be compensated for with preload.

Extended bearing service life

Provided the preload is properly set in an adjusted bearing arrangement, the operational reliability can be enhanced, because of a more favourable load distribution in the bearings, which can extend bearing service life. Setting the preload too high will overload the bearing, lead to higher friction and nega-tively influence bearing life.

Preload in adjusted bearing arrangements with single row angular contact ball or tapered roller bearings

When determining preload, the preload force required to provide an optimum combination of stiffness, bearing service life and operational reliability should be calculated first. Then calculate the preload force to be used when adjusting the bearings during mounting; the bearings should be at ambient temperature and should not be subjected to any other load.

The appropriate preload at normal operating temperature depends on the bearing load. A single row angular contact ball bearing or a tapered roller bearing can accommodate radial and axial loads simultaneously. Under radial load, these bearings produce an internal axial load which must be accommodated by a second bearing facing the opposite direction. Purely radial displacement of one bearing ring relative to the other means that half of the rolling elements are under load. The internal axial load produced in the bearing can be determined by:

- for single row angular contact ball bearings $F_a = R\,F_r$
- for single row tapered roller bearings $F_a = 0,5\,F_r/Y$

where

F_a = axial bearing load (**fig. 4**) F_r = radial bearing load (**fig. 4**)

R = variable depending on the contact angle:
  - 20° contact angle (suffix AB) → R = 0,50
  - 25° contact angle (suffix AC) → R = 0,57
  - 30° contact angle (suffix A) → R = 0,66
  - 40° contact angle (suffix B) → R = 0,88

Y = calculation factor (→ product table *Tapered roller bearings, single row*)

When a single bearing is subjected to a radial load F_r, an axial load F_a (external) of the same magnitude as the internal axial load must be applied to the bearing if the basic load rating is to be fully exploited. If the applied external load is lighter, fewer rolling elements will be supporting the load and the load carrying capacity of the bearing is correspondingly reduced. In an adjusted bearing arrangement consisting of two single row angular contact ball bearings or two tapered roller bearings arranged back-to-back or face-to-face, each bearing must accommodate the axial load in one direction. When these bearing arrangements are adjusted to near-zero clearance, a radial load acting at a location centrally between the two bearings, is shared equally between them and half the number of rolling elements in each bearing are loaded.

In other cases, particularly where there is an external axial load, it may be necessary to preload the bearings to compensate for the clearance that can occur when the axially loaded bearing deforms elastically and to obtain a more favourable load distribution in the axially unloaded bearing.

Preload also increases the stiffness of a bearing arrangement. However, bear in mind that stiffness is also influenced by the elasticity of the shaft and housing, the shaft and housing fits, and the elastic deformation of all other components adjacent to the bearings, including abutments. Each of these factors has a considerable impact on the resilience of the total bearing system. The axial and radial resiliencies of a bearing depend on its internal design, contact conditions (point or line contact), the number and diameter of rolling elements and the contact angle. The greater the contact angle, the higher the degree of stiffness in the axial direction.
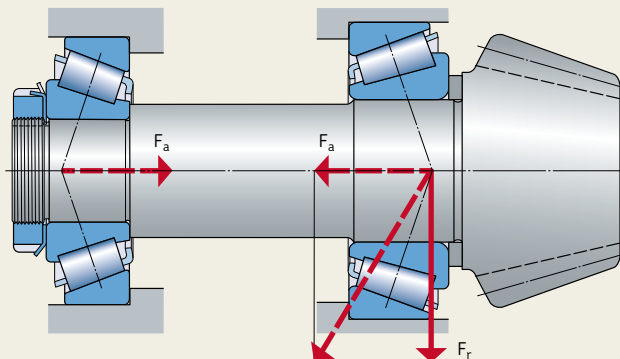
If, as a first approximation, a linear dependence of the resilience on the load is assumed, such as a constant spring ratio, a comparison shows that the axial displacement arrangement under preload is smaller than for a bearing arrangement without preload for the same external axial force K_a (**diagram 1**). A pinion arrangement design (**figs. 6 and 7**, **page 6**) typically consists of two different size tapered roller bearings, A and B, with different spring constants c_A and c_B. Both are subjected to a preload force F_0. If an external axial force K_a acts on bearing A, bearing B becomes unloaded, and the additional load acting on bearing A results in an axial displacement δ_a that is smaller than it would be if the bearings had not been preloaded. However, bearing B is relieved of the axial preload force, and the axial displacement under additional load is the same as it is for a bearing system without preload, that means it is determined solely by the spring constant c_A, if the external axial force exceeds the value

$$K_a = F_0\left(1 + \frac{c_A}{c_B}\right)$$

To prevent bearing B from becoming unloaded when bearing A is subjected to an axial force Ka, the following preload force is required

$$F_0 = K_a\left(\frac{cB}{c_A + c_B}\right)$$

Fig. 4

SKF

Loads and elastic displacements in a preloaded bearing arrangement, and the effects of a change in preload, are easily understood from a preload force / axial displacement diagram (**diagram 1**). This consists of the spring curves of the components that are adjusted against each other to apply preload and enables the following.

- the relationship of the preload force and axial displacement within the preloaded bearing arrangement
- the relationship between an externally
- applied axial force K_a and the bearing load for a preloaded bearing arrangement, and the elastic deformation produced by an external load

In **diagram 2**, all the components subjected to external loads in operation are represented by the curves that increase from left to right, and all the unloaded components by the curves that increase from right to left. Curves

1, 2 and 3 are for different preload forces (F_{01}, $F_{02} < F_{01}$ and $F_{03} = 0$). The broken lines repre sent individual bearings, while the solid lines represent the total bearing system (bearing(s) and associated components) for different preload forces.

From **diagram 2**, it is also possible to explain the relationship between components, for example in a pinion arrangement design (**fig. 5**, **page 6**), where bearing A is located adjacent to a gear and is adjusted against bearing B to provide preload. The external axial force K_a (axial component of tooth forces) is superimposed on the preload force F_{01} (curve 1) in such a way that bearing A is subjected to additional load while bearing B is less loaded. The axial load on bearing A is designated F_{aA} and on bearing B it is designated F_{aB}. Under the influence of the axial force K_a, the pinion shaft is axially displaced by the amount δ_{a1}.

The smaller preload force F_{02} (curve 2) has been chosen so that bearing B is just unloaded by the axial force K_a, which means $F_{aB} = 0$ and $F_{aA} = K_a$. The pinion shaft is displaced in this case by the amount $\delta_{a2} > \delta_{a1}$.

When the arrangement is not preloaded (curve 3), the axial displacement of the pinion shaft is greatest ($\delta_{a3} > \delta_{a2}$).

Diagram 1

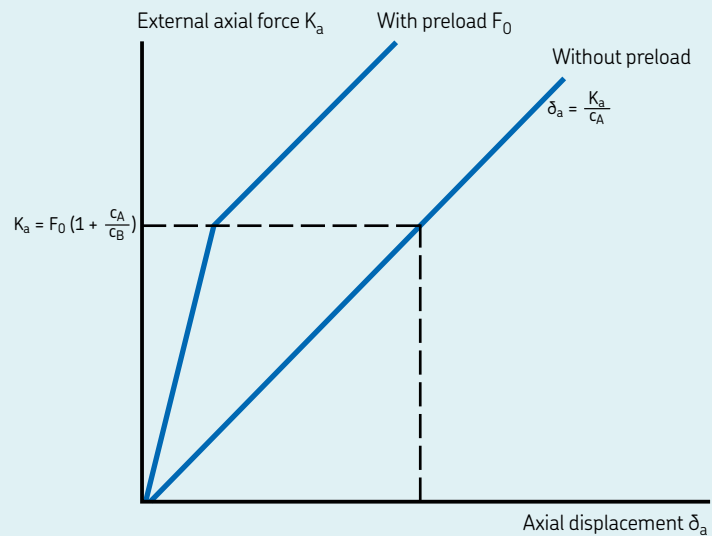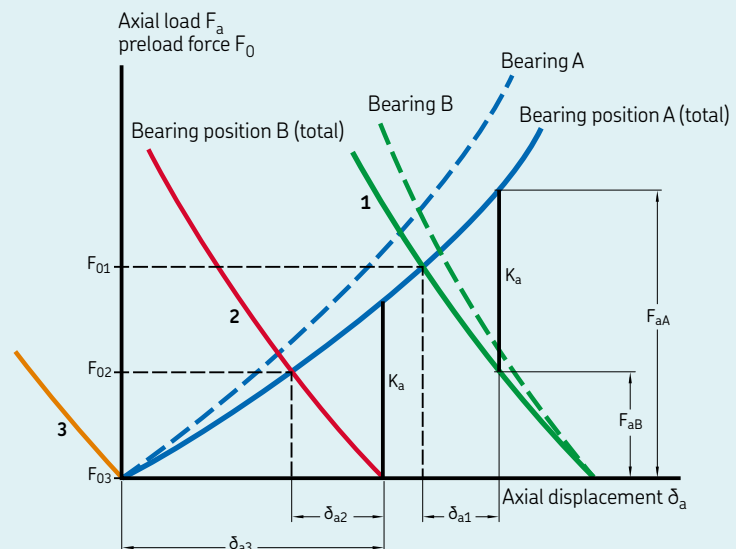**Axial displacement in bearing arrangements with and without preload**

External axial force K_a With preload F_0

Without preload

$\delta_a = \dfrac{K_a}{c_A}$

$K_a = F_0 \left(1 + \dfrac{c_A}{c_B}\right)$

Axial displacement δ_a

Diagram 2

Influence of preload and axial load on axial displacement in adjusted bearing arrangements

Axial load F_a
preload force F_0

Bearing A

Bearing B

Bearing position B (total)

Bearing position A (total)

1

F_{01}

K_a

2

F_{aA}

K_a

3

F_{02}

K_a

F_{aB}

F_{03}

Axial displacement δ_a

δ_{a2} δ_{a1}

δ_{a3}

Adjustment procedures

Adjustment means setting the internal clearance or preload in an adjusted bearing arrangement during assembly. In operation a certain clearance/preload, or only preload, range then arises.

Axial preload in an adjusted bearing arrangement with single row angular contact ball bearings, tapered roller bearings and deep groove ball bearings, is produced by displacing one bearing ring axially, relative to the other, by an amount corresponding to the desired preload force.

There are basically two principal methods to adjust preload: individual adjustment and collective adjustment.

Individual adjustment

With individual adjustment, each bearing arrangement is adjusted separately using nuts, shims, spacer sleeves, crush sleeves, etc. Measuring and inspection procedures are used to ensure that the established nominal preload is obtained with the least possible deviation. There are various methods to obtain the required preload:

- axial displacement method
- frictional moment method
- direct force method

The method used depends on, among other things, the application design and the number of bearings to be mounted. Individual adjust0ment can accommodate enough tolerance stackup so that if individual components are produced to Normal tolerances, the desired preload can be achieved with a relatively high degree of accuracy.

Axial displacement method

The axial displacement method is based on the relationship between the preload force and the elastic deformations within the bearing arrangement. The requisite preload can be determined from a preload force / axial displacement diagram (**diagram 3**).

This method of adjustment is frequently used when the components of a bearing arrangement are preassembled. The required preload, which is expressed as a negative distance, requires measuring total axial positive displacement (end play) of the shaft relative to a fixed surface. This is typically done with a dial indicator.

Shims, intermediate rings or spacers can then be used to adjust axial displacement to the correct negative distance. The preload is achieved, for example, for pinion arrangement designs by:

- fitting intermediate rings between the inner and outer rings of the two bearings (**fig. 5**)
- inserting shims between the housing shoulder and the bearing outer ring or between the cartridge and the housing (**fig. 6**), where the cartridge in this case is the flanged angled insert
- fitting a spacer between a shaft shoulder and one of the bearing inner rings
- (**fig. 7**) or between the inner rings of both bearings

The width of the shims, intermediate rings or spacers is determined by:

- the distance between the shaft and housing shoulders
- the total width of both bearings
- the axial displacement corresponding to the desired preload force
- a correction factor for the axial displacement to account for thermal expansion in operation the manufacturing tolerances of all related components, established by measuring the actual dimensions before mounting
- a correction factor to account for a certain loss of preload as a result of settling and wear

Frictional moment method

This method is common in large series production because it is fast and can be automated. Since there is a relationship between bearing preload and the frictional moment in the bearings, it is possible to stop adjustment when a frictional moment corresponding to the desired preload has been reached. This can be done if the frictional moment is continuously monitored while setting preload. However, the frictional mo ment can vary from bearing to bearing, and it also depends on the preservative, the lubri cant and the sealing method.

Direct force method

As the purpose of bearing adjustment is to ob tain a specific preload, it would seem sensible to use a method either to produce or to meas ure the force directly. However, in practice, the indirect methods of adjustment by axial dis placement or frictional moment are preferred, because they are simple and can be achieved easily and more costeffectively.

Diagram 3

Relationship between the preload force and the axial displacements within a bearing arrangement, for example in a pinion arrangement design
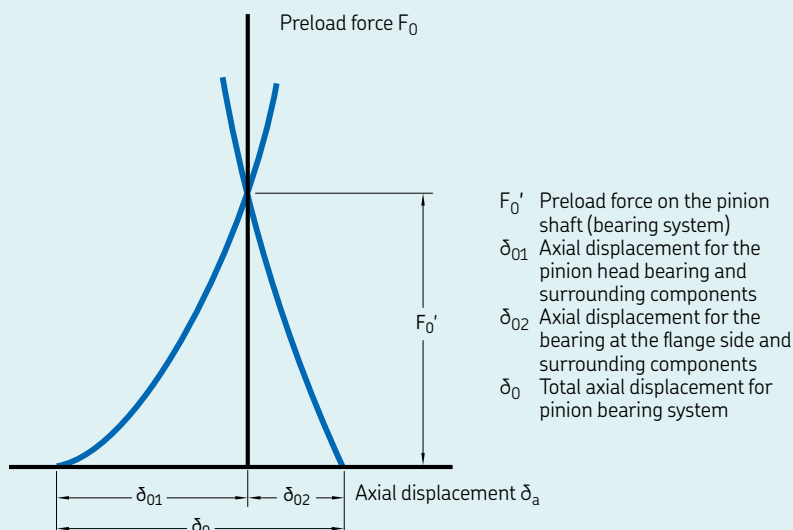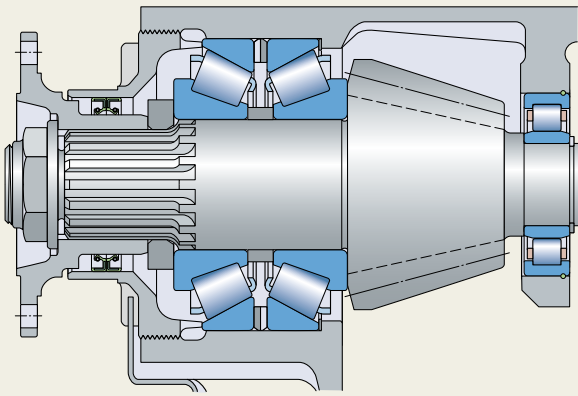

F_0' Preload force on the pinion shaft (bearing system)
δ_{01} Axial displacement for the pinion head bearing and surrounding components
δ_{02} Axial displacement for the bearing at the flange side and surrounding components
δ_0 Total axial displacement for pinion bearing system
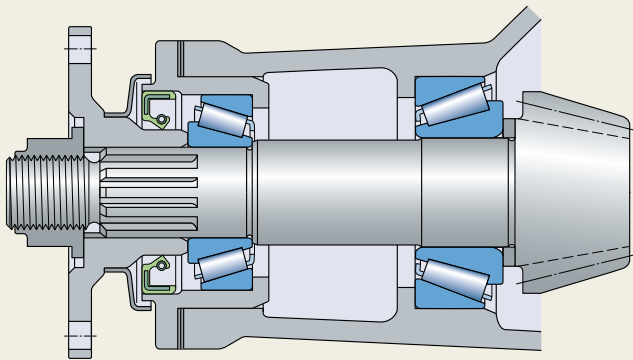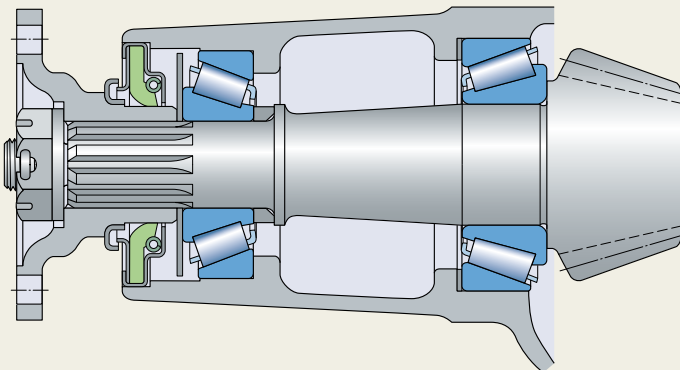
Fig. 5

Fig. 6

Fig. 7

Collective adjustment

This method can also be referred to as "random statistical adjustment". Using this method, the bearings, shaft, housing, and any other components are manufactured to Normal tolerances. The components, which are considered fully interchangeable, are assembled randomly. For tapered roller bearings, this interchangeability also extends to the inner ring assemblies and outer rings. To avoid high machining costs and the use of precision bearings, it is assumed that given the limiting values of the tolerances, it is statistically improbable that the extremes of the tolerance stackup occurs. If, however, accurate preload is to be obtained with as little scatter as possible, manufacturing tolerances must be narrowed. The advantage of collective adjustment is that no inspection is necessary and no extra equipment is needed when mounting the bearings.

Selecting the correct preload

When selecting the preload for a bearing arrangement, the degree of stiffness increases marginally once preload exceeds a given optimum value. When exceeding this optimum value, friction and the resulting increase in heat can substantially reduce bearing service life. Excessive preload includes a risk that the operational reliability of a bearing arrangement is compromised. Because of the risk and complexity normally required to calculate an appropriate preload, SKF strongly recommends using our most modern engineering software tools, such as SKF SimPro Quick and SKF SimPro Expert or contacting the SKF application engineering service.

When adjusting preload in a bearing system, it is also important that the established preload value, determined either by calculation or from experience, is attained with the least possible variation. To reduce variation when mounting tapered roller bearings, for example, the shaft must be turned several times so that the rollers are not skewed and the roller ends are in contact with the guide flange of the inner ring. When the rollers are not fully settled into position, a much smaller preload than the requisite value results.

Bearings for preloaded bearing arrangements

For certain applications, SKF supplies single bearings or matched bearings, which are specifically made to enable simple and reliable adjustment, or which are matched during manufacture so that after mounting a predetermined preload is obtained. These include:

- tapered roller bearings to CL7C specifications for higher running accuracy, such as automotive differentials (→ *Tapered roller bearings*)
- universally matchable single row angular contact ball bearings (→ *Angular contact ball bearings*)
- matched single row tapered roller bearings (→ *Tapered roller bearings*)
- matched single row deep groove ball bearings (→ *Deep groove ball bearings*)