Ball and Roller Bearings

Theory, Design, and Application

Eschmann · Hasbargen · Weigand

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Second Edition, revised by L. Hasbargen and J. Brändlein

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Foreword

When, 30 years ago, the first edition of *Ball and Roller Bearings* was published, it soon became a sought-after reference book. In the meantime, decisive developments have taken place in the field of rolling bearings, as in all other fields of technology. The advancements made were not usually of a spectacular nature, but were mainly characterized by constant detailed exploration aimed at a higher degree of operational safety, higher load-carrying capacity, higher speeds and thus greater economic efficiency. Important criteria such as the calculation procedure for determining the dynamic and static load-carrying capacity, the quality specifications for rolling bearing steels etc., have meanwhile been standardized, and other bearing standards subjected to major changes. With the aid of modern computer methods, the calculation procedures were able to be improved and refined, and the knowledge of fatigue, friction, wear and lubrication considerably extended.

The continuous development in rolling bearing technology referred to above made it impractical for minor revisions to be made to the first edition, which had been out of print for a long time. The second edition, therefore, has been completely revised, maintaining, however, the established and successful principles on which the first edition was based. Great significance has been attached to the interests of practical operation, illustrated, for instance, by the attention given to the lubrication of rolling bearings. The examples described in the last chapter have been enlarged and rearranged.

Ludwig Hasbargen, to whom particular credit for the revision work is attributed, did not live to see the completion of the book. Johannes Brändlein took over the final revision of the manuscript. The book was published in Germany in 1978. The English edition incorporates the state of development of rolling bearing technology up to the end of the year 1982. The authors had at their disposal the experience of the engineering staff, and the facilities of FAG Kugelfischer Georg Schäfer KGaA.

Schweinfurt, 1984

The Editors

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1 Rolling Bearing Types and Dimension Tables

1.1 General Characteristics

Generally, rolling bearings consist of two rings with a set of rolling elements running in their tracks. Standard shapes of rolling elements include the ball, cylindrical roller, needle roller, tapered roller, symmetrical and unsymmetrical barrel roller (Fig. 1).

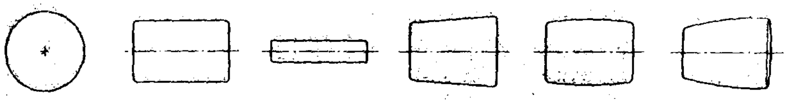


Fig. 1 Rolling elements for ball and roller bearings

As a rule, the rolling elements are guided in a cage that ensures uniform spacing and prevents mutual contact. In needle roller bearings and lipless spherical roller bearings the cage must additionally guide the rolling elements parallel to the axis. The cage of a separable bearing has the further function of holding together the rolling element set and thereby facilitating the bearing mounting.

Today, bearing rings and rolling elements are produced worldwide predominantly from the through-hardenable chromium steel, but casehardening steel is also used. Large-size rolling bearings such as slewing bearings are mainly made from heat treatable steel and have surface-hardened raceways. Special bearings designed for extreme operating conditions – load, speed, temperature, corrosion – are produced from tool steel, stainless steel, plastics, and from other materials.

The cage is either stamped from sheet metal or machined from tube or from cast, forged or injection moulded blanks. Stamped cages are nowadays almost exclusively made from sheet steel and sometimes from brass sheet. Machined cages are of brass, light alloys or steel, but sometimes of sintered iron or plastic material.

The numerous rolling bearing types are classified according to their design features and uses. While the main load direction creates the distinction between the radial and thrust bearings, the shapes of the rolling elements divides them into ball and roller bearings. Another important distinctive characteristic is the manner in which rolling bearings guide a shaft – whether, for example, they permit axial displacement, guide the shaft in one or both axial directions or permit angular movement and therefore misalignment.

1.1.1 Radial Ball Bearings

Deep groove ball bearings without filling slots

Both rings possess deep grooves with a radius only slightly exceeding the ball radius. Due to this curvature ratio the bearing can support high radial as well as axial forces (Fig. 2).

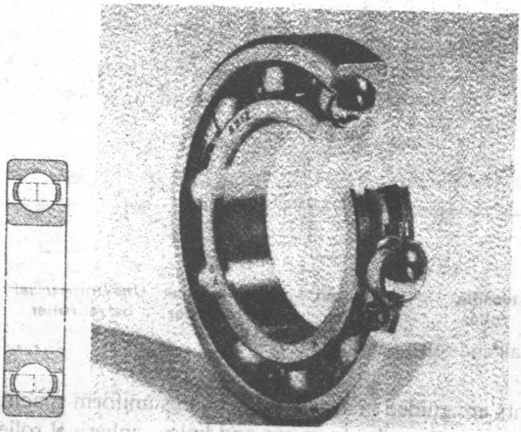


Fig. 2a and b Deep groove ball bearing without filling slot

Figure 3a–c shows the mode of installation of the balls between the rings. First the free space created by the eccentric positioning of the rings is filled with balls, whose size and number are so calculated that by utilizing the elasticity of the rings, the inner ring, located between the first and the last ball, can be displaced to a position concentric with the other ring. The balls are then distributed uniformly over the circumference and the cage can be inserted. Most frequently, two-piece stamped sheet steel cages are inserted from both sides of these bearings and then joined. Bearings for special operating conditions are provided with machined

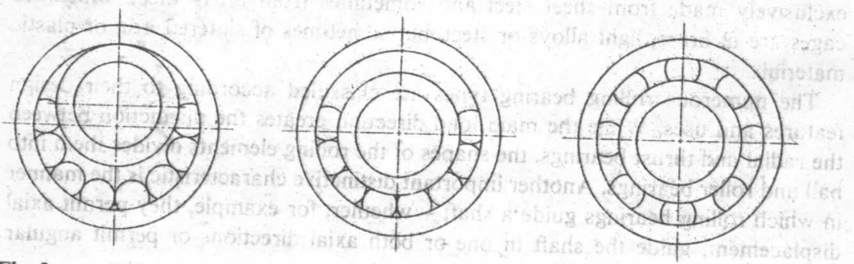


Fig. 3a–c Filling balls into a deep groove ball bearing without filling slot

cages guided, like sheet steel cages, on the balls. For extremely high speeds, the cage may be guided on the ground shoulders of the inner or outer ring.

Due to its ability to sustain forces in both the radial and axial directions, its low friction and its suitability for high speeds, the deep groove ball bearing finds many applications in all branches of industry.

For compact designs without space for a seal adjacent to the bearing, deep groove ball bearings with internal shields (Fig. 4) or seals (Fig. 5) have been developed.

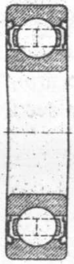


Fig. 4 Deep groove ball bearing with shields

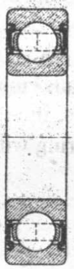


Fig. 5 Deep groove ball bearing with seals

The shields are profiled sheet steel discs pressed into the grooves of the outer ring and forming gap seals with the shoulders of the inner ring. The seals are discs of elastic rubber or plastic supported by a sheet metal insert. The inner edge of the seal has the shape of a lip sliding on the ground land of the inner ring shoulder. Bearings with either one or two seals or shields may be produced. The bearings sealed on both sides are grease-filled by the manufacturer and in normal working conditions the grease filling lasts the entire service life of the bearing.

S-bearing units

Deep groove ball bearings with extended inner rings, called S-bearing units, are manufactured in a number of designs. At one end of the inner ring the bearing is clamped to the shaft with an eccentric locking ring (Fig. 6) or with two setscrews (Fig. 7). On both sides, the bearings have rubbing contact seals and sometimes

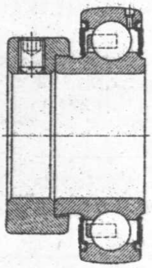


Fig. 6 S-bearing unit with eccentric self-locking collar

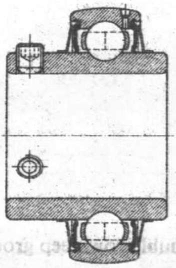


Fig. 7 S-bearing unit with two setscrews

flingers (Fig. 7) as added protection. The outer diameter of the outer ring is as a rule ground spherically, so that the ring can align itself in a suitably designed sheet steel or cast iron housing if the bearing locations are misaligned.

Deep groove ball bearings with filling slots

This bearing type is a predecessor of the deep groove ball bearing without filling slots and is shown in Figs. 8 and 9. Here, one ring shoulder is provided with a filling slot through which the balls are fed into the bearing. In this way, a larger number of balls can be filled into the bearing and the radial load carrying capacity can be increased. For axial loads, however, these bearings are less suitable, because under axial load the balls run over the filling slots. Since nearly all bearing applications involve axial loads, the type without filling slots has largely replaced, particularly in Europe, the bearing with filling slots.

Fig. 8 Deep groove ball bearing with filling slot

Fig. 9 Inner ring of a deep groove ball bearing with filling slot

Besides the single-row deep-groove ball bearing with filling slots there is the double row design shown in Fig. 10 in which both outside shoulders of the inner and outer rings contain filling slots. The filling slots also make this type suitable for mainly radial load. It has lost its importance due to the subsequently developed double-row angular contact ball bearing (see Fig. 16, page 7).

Fig. 10 Double-row deep groove ball bearing with filling slots

Magneto bearings

The magneto bearing (Fig. 11) is similar in its construction to the deep groove ball bearing without filling slots. The outer ring, however, has only one shoulder, so that the bearing can be taken apart. The circular profile of the outer ring raceway merges smoothly at its apex into a straight profile.

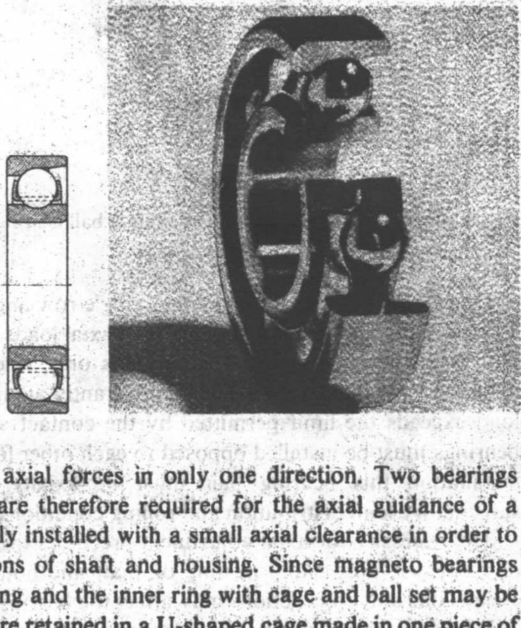


Fig. 11a and b Magneto bearing

Magneto bearings transmit axial forces in only one direction. Two bearings adjusted against one another are therefore required for the axial guidance of a shaft. The bearings are generally installed with a small axial clearance in order to compensate for length variations of shaft and housing. Since magneto bearings can be taken apart, the outer ring and the inner ring with cage and ball set may be installed separately. The balls are retained in a U-shaped cage made in one piece of brass or sheet steel. Cage, balls, and inner ring form a single constructional unit.

With regard to their tolerances, magneto bearings are non-standard: while the outside diameter of all other rolling bearings has a minus tolerance, for all magneto bearings the tolerance is +0.010/0 mm. The origin of this difference is historic.

Magneto bearings are installed in small electrical appliances, dynamos, car starter motors, vacuum cleaners, etc.

Single-row angular contact ball bearings

In single-row angular contact ball bearings, the raceways are so arranged that the forces are transmitted from one raceway to the other under a certain contact angle – that is the angle between the line of action of the force and the radial plane. The contact angle of the currently produced series is generally 40°, but there are bearings with contact angles of 15°, 25°, and 30°.

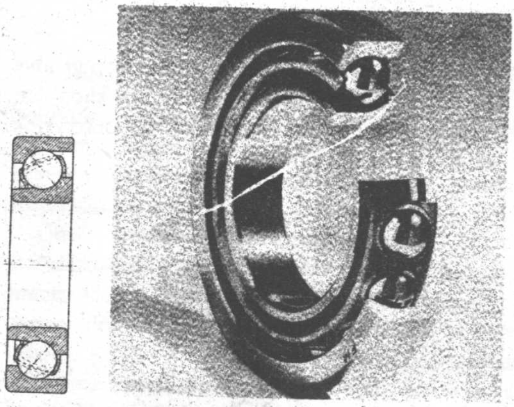
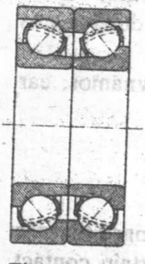


Fig. 12a and b Single-row angular contact ball bearing

Due to their larger contact angle, single-row angular contact ball bearings (Fig. 12) are better suited for sustaining high axial loads than deep groove ball bearings. However, they can sustain radial loads only when simultaneously subjected to axial loads. If the axial load is not constantly applied or if the ratio radial to axial load exceeds the limit permitted by the contact angle, two angular contact ball bearings must be installed opposed to each other for mutual axial support. During installation this bearing pair must be axially adjusted in order to obtain satisfactory load distribution and rolling conditions.

The necessity for axial adjustment precludes the wide separation of the bearing pair because differential heating of shaft and housing, and the consequent axial expansions and contractions may affect the bearing running clearance.

Formerly, single-row angular contact ball bearings designed for installation in O-, X- or tandem arrangements (Figs. 13–15) were matched in pairs, but modern



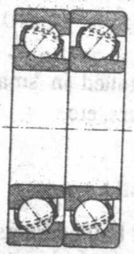


Fig. 13 O-arrangement of two angular contact ball bearings of universal design
Fig. 14 X-arrangement of two angular contact ball bearings of universal design
Fig. 15 Tandem arrangement of two angular contact ball bearings of universal design

designs are of the so-called 'universal' or U-type. They may be paired in any required arrangement without adjusting shims.

Single-row angular contact ball bearings are applied mainly where, besides radial loads, large axial loads must be sustained. They are also suitable for carrying axial loads at high speeds. Machine tool spindles operating at high speeds under zero clearance conditions and with a minimum of radial and axial runout are often supported by so-called spindle bearings, that is, high-precision single-row angular contact ball bearings with small contact angles.

The current production series of single-row angular contact ball bearings are self-retaining in that the ring shoulders are so designed that the bearings are non-separable. Single-row angular contact ball bearings are generally provided with a sheet steel cage, but machined cages of brass, light alloys or plastics are employed where there are increased demands for high speed and low running noise.

Double-row angular contact ball bearings

The design of double-row angular contact ball bearings corresponds to a ready-to-mount pair of single-row angular contact ball bearings in O-arrangement (Fig. 16a). Double-row angular contact ball bearings are capable of sustaining large radial and axial forces. They are particularly suitable for applications demanding rigid axial guidance. Generally, each ball set has a pressed sheet sheel waved ribbon cage.

Double-row angular contact ball bearings with non-split rings have filling slots on one side (Fig. 16). For combined radial and axial loading, the bearing must be installed so that the axial load is carried by the ball set without the filling slot. A special design of double-row angular contact ball bearing with split inner ring

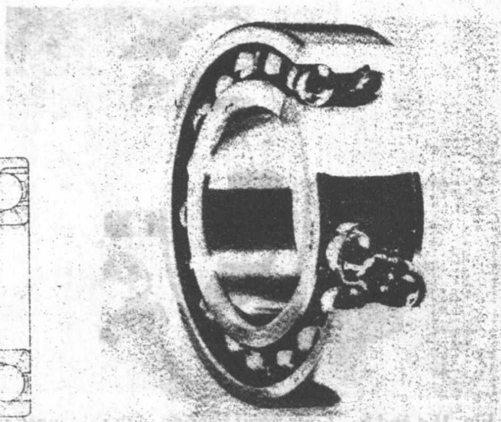


Fig. 16a and b Double-row angular contact ball bearing with filling slots

Fig. 17 Double-row angular contact ball bearing with split inner ring

(Fig. 17) serves for carrying high and frequently reversing axial loads. These bearings have a larger contact angle but no filling slots. The inner ring halves may be withdrawn and separately fitted.

Four-point bearings

Four-point bearings have on both the outer and the inner rings two circular arc-shaped raceways whose centres of curvature are offset in such a manner that during radial loading the balls contact the raceways at four points (Fig. 18). For inserting the balls, one of the rings, preferably the inner ring, is split. If possible, these bearings are to be used for exclusively or predominantly axial loads only, in which case the balls contact the inner and the outer rings only at one point, as in an axially loaded single-row angular contact ball bearing.

The two equal contact angles of four-point bearings are large and therefore capable of carrying axial forces in both directions. The main application of these bearings lies in the field of power transmission where axial loading in both direc-

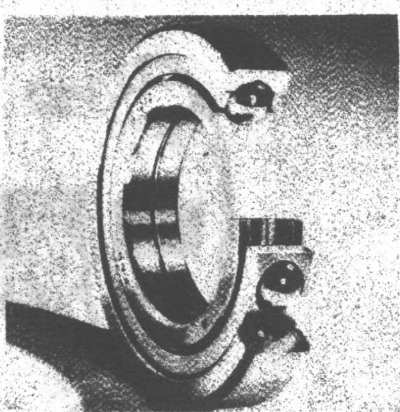


Fig. 18a and b Four-point bearing with split inner ring