The sphere roller –

Less is more!

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Introduction

It started with the point, then along came the circle and in 1883 the ball was born.

It has always the rolling elements – whether they were balls or rollers – that decisively influence the design, types and ultimately the performance capability of rolling bearings. The basic designs of almost all rolling bearings were developed to a level ready for volume production around 1900, when it became possible to harden reliably and grind precisely (Figure 1).

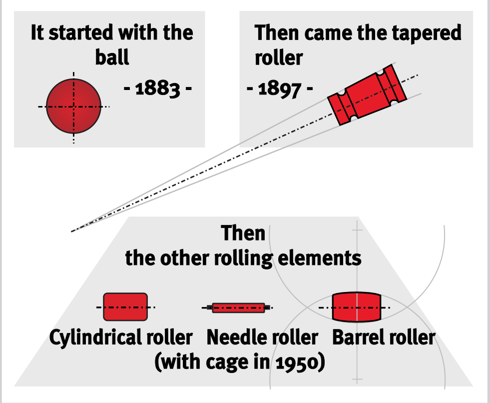

Figure 1 History of rolling bearing types

It was the new vehicles – whether they were pedal cycles or motor vehicles – that were most notably dependent on low friction, namely on rolling friction. The level of torque that could be applied to the pedal crank of a cycle, or could be supplied by the earliest engines, was still too small.

The low rolling friction between a wheel and a solid road had been known and exploited for millennia; with the invention of the ball bearing and tapered roller bearing, this was transferred to the centre of the wheel. The balls or rollers act as numerous small low-friction wheels between the wheel axle and the hub.

From a very early stage, the shafts in the early gearboxes were supported in order to give precise, low-wear guidance of the gears (Figure 2).

Although now more than 100 years old, the ball bearing is still the world champion of ball bear-

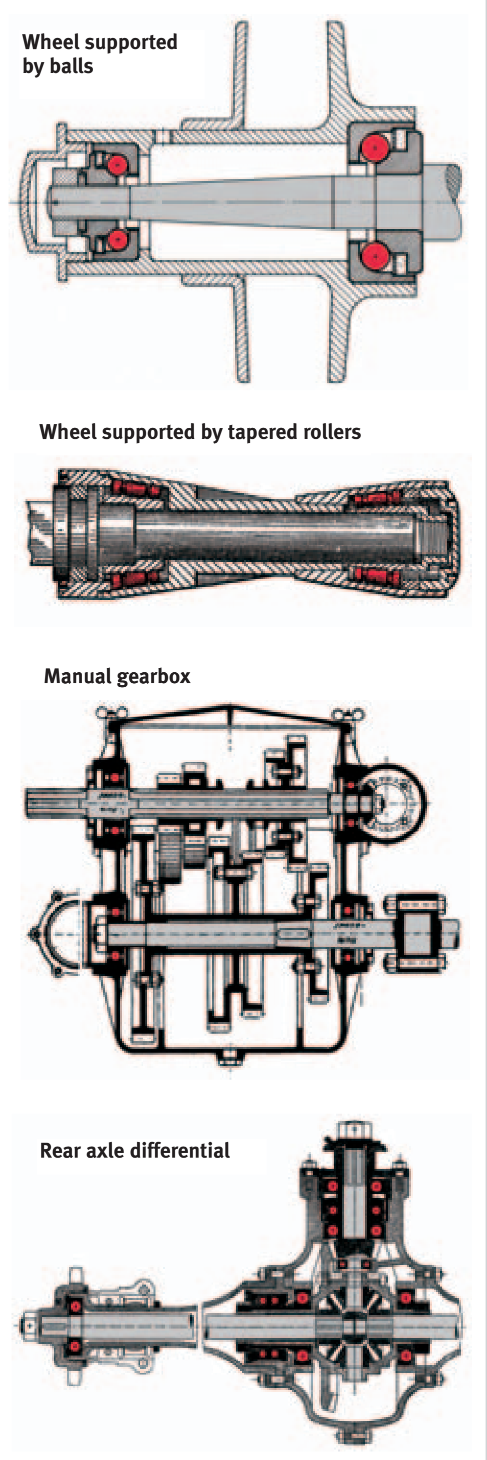

Figure 2 Wheel and gearbox bearing arrangements around 1900

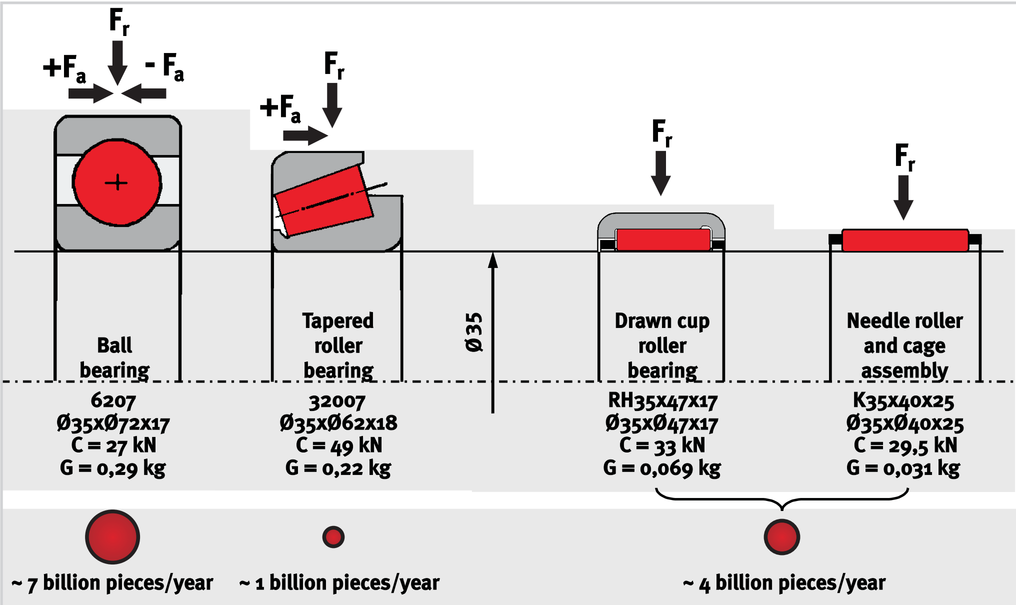

Figure 3 Comparison of types

ing series in terms of quantity. Almost 7 billion pieces are now produced worldwide each year.

Tapered roller bearings – also developed around the turn of the century – are now number 3, with a quantity of almost 1 billion produced each year.

It took the 50 years from 1900 to 1950 until the needle bearing became the third major series ready for volume production. The technology required to produce the thin cross-sections for cages and formed bearing rings was not ready for volume usage until about 1950. In terms of quantities – with production of 4 billion pieces per year – the needle roller bearing family is number 2 worldwide.

The scale illustration with a constant bore size of 35 mm – arranged in order of outside diameter – shows considerable differences in size, load rating and mass (Figure 3).

All other rolling bearing series fitted with cylindrical rollers and barrel rollers are produced in quantities that are smaller by several powers of ten than the three series mentioned.

Differences between series with balls, tapered rollers and needle rollers

A comparison of the power-to-weight ratio, i.e. the load carrying capacity in kN divided by the bearing mass in kg, clearly shows the differences.

In order to highlight the differences between the series when mounted, a virtual twin-shaft gearbox was designed.

Shaft 1 is supported as a locating/non-locating bearing arrangement in a ball bearing and a drawn cup roller bearing.

Shaft 2 is designed as a semi-locating bearing arrangement in two identical tapered roller bearings. The tapered roller bearings are axially abutted against each other. This is also described as an adjusted bearing arrangement, since the axial clearance is adjusted to ensure optimum function (Figure 4).

In the semi-locating bearing design, it is clear that the inner ring rib of the tapered roller bearing takes up axial space. This rib is necessary in order to guide the end face of the tapered roller. In addition to rolling friction on the outside surface of the roller, there is therefore sliding friction at the rib. In terms of friction, the tapered roller bearing is therefore a so-called hybrid bearing. The load carrying capacity is high in both the radial and axial directions. The power-to-weight ratio for the example bearing 32007 is at a respectable level of 223 kN/Kg.

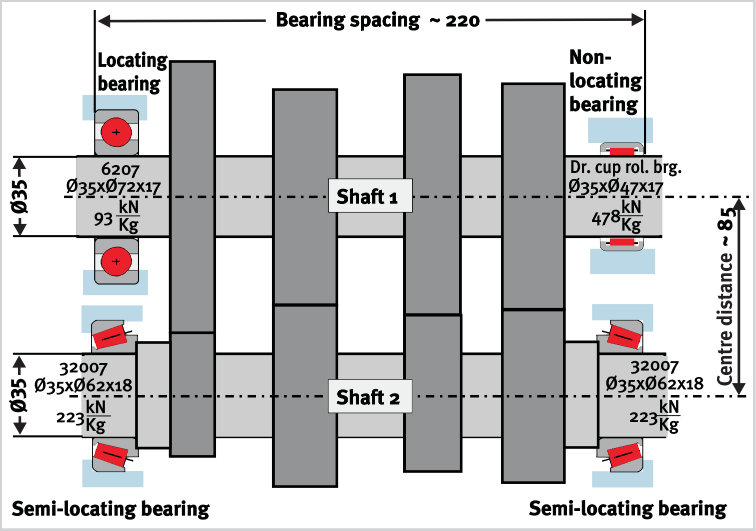

Figure 4 Twin-shaft gearbox, current level of technology

With an outside diameter of 62 mm, the tapered roller bearing does not require much radial space.

The weakpoints of the tapered roller bearing are therefore the section width and the friction.

In the non-locating/locating bearing design of shaft 1, it is noticeable that the drawn cup roller bearing as a non-locating bearing requires little radial space. This is possible due to the integration in the shaft of the inner ring raceway and the thin-walled formed outer ring.

The power-to-weight ratio is very high at 478 kN/kg. The drawn cup roller bearing, however, can only support radial loads.

The drawn cup roller bearing, a relative of the needle roller, is a technically sophisticated and cost-effective solution for a purely radial bearing arrangement!

The ball bearing 6207 as a locating bearing has the largest section size with an outside diameter of 72 mm and has the lowest-power-to-weight ratio of 93 kN/kg. However, it can support radial as well as axial loads.

The ball bearing, from today's perspective, is a successful misdesign from 1900.

Weakpoints of the ball bearing

Ball filling capacity

On the one hand, the eccentric assembly allows single-piece rings without weakpoints such as filling slots. The deep grooves increase the axial load carrying capacity. In the USA, the ball bearing is therefore described as a “deep groove ball bearing”.

For reasons of assembly, the ball filling capacity is limited by the sickle-shaped space between the bearing rings or, in other words, there is “lots of air but not many balls” around the pitch circle after ball distribution. For example, the ball bearing 6207 can only be fitted with 9 balls.

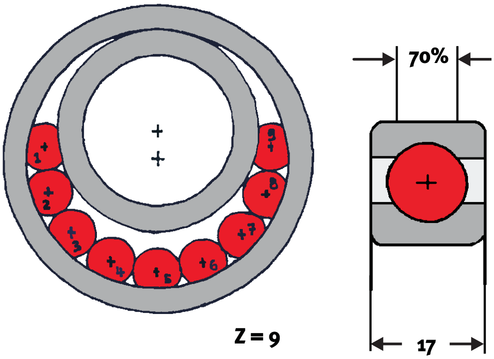

Figure 5 Ball filling capacity/Width utilisation

Width utilisation

Only 70 % of the ball width is used, i.e. 30 % of the ball width wastes space and increases mass.

Contact pressure

Under small loads, the contact zone is only "punctiform", i.e. due to the poor osculation, the pressure ellipse is small and the contact pressure high. The contact pressure is therefore larger than in roller bearings with line contact.

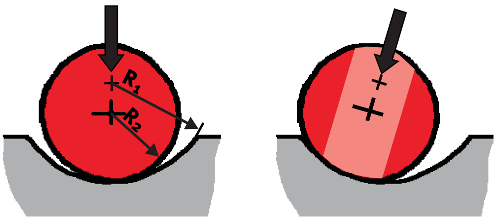

Figure 6 Contact angle and osculation

Under purely axial load – see Figure 6 – a circumferential wear track is found on the ball equator and increases in width with increasing load.

Solutions

The answer is the sphere roller bearing! The thick ball is slimmed down and becomes a lean sphere roller (KXR) in the sphere roller bearing!

Under load, the rotational axis of the ball does not change. If, however, a load-free zone occurs in the bearing, for example under radial load, the rotational axis of the ball changes chaotically with every revolution.

In other words, the "lazy" part of the ball each 15 % to the left and right of the ball diameter that does not support load is cut away. The bearing rings are therefore narrower by 30 % of the ball diameter.

In the design of KXR bearings, a new guidance mechanism for the rolling elements using the cage and end of the sphere roller was developed.

Under zero load and zero speed, this guidance mechanism allows alignment of the rolling elements in start-up operation.

The pocket bases of the cage are designed such that the sphere roller under load can align itself freely as a function of the contact angle.

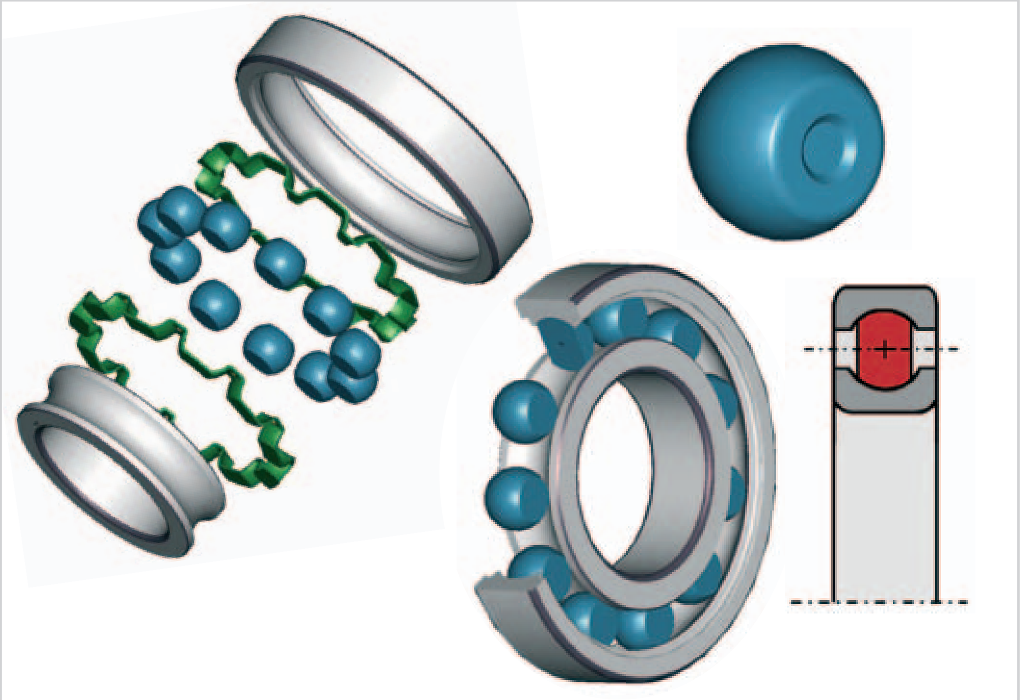

Figure 7 Sphere roller bearing

Advantages of the "lean" sphere roller bearing

Filling capacity

The ball filling capacity is increased, i.e. the basic bearing 6207 can accommodate eleven rolling elements instead of nine.

Since the width of the sphere roller is only 70 % of the ball diameter, more rolling elements can be fitted by means of eccentric assembly in a position rotated by 90 degrees (Figure 8).

More rolling elements means higher load carrying capacity.

Width utilisation

If the full width of the sphere roller is utilised, the bearing width is reduced. In the case under consideration, this is a decrease from 17 mm to 13,5, i.e. a reduction of 20 %. Due to the reduced width, the bearing mass is reduced by 20 %.

In the case of the sphere roller: Less is more, since despite the smaller width, more rolling elements can be fitted.

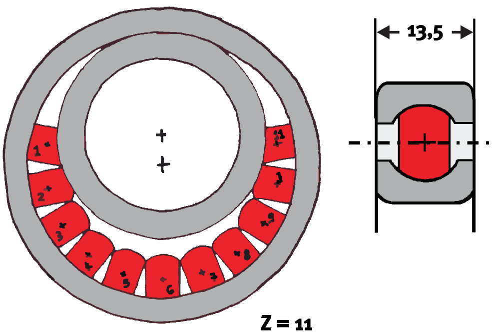

Figure 8 Filling capacity/Width utilisation

Contact pressure

It is known that the point contact in the case of balls leads to higher contact pressure. The change in osculation to a logarithmic profile on the sphere roller further increases the basic load rating. The logarithmic profile of the sphere roller outside surface prevents edge pressure in the axial boundary areas of the sphere roller

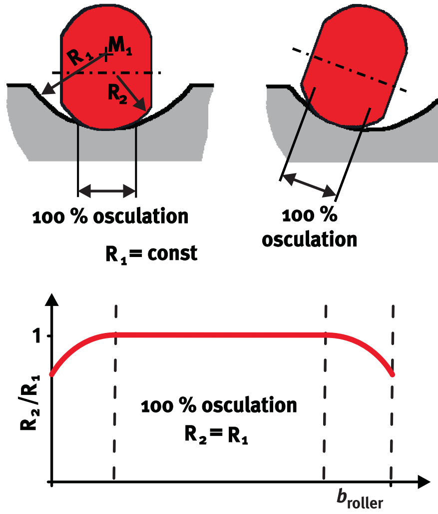

Figure 9 Contact angle and osculation

(small radius) with very narrow osculation in the contact area (large radius). Even under smaller and moderate loads, there is a wide pressure ellipse with low contact pressure.

The sphere roller can be designed with a logarithmic profile since the rotational axis is always perpendicular to the variable contact angle. The osculation conditions therefore do not change if the load ratio changes from axial to radial and the contact angle changes as a result. The osculation "creeps" in an optimum manner with the change in load.

All computer simulations and running tests demonstrate: "Yes it does rotate" about the intended rotational axis!

The sphere roller rotates in an optimum manner about its axis due to the special mass distribution, this means that it follows the gyroscopic laws.

Note: The KXR bearing retains the deep grooves of the ball bearing and thus the high axial load carrying capacity. The sphere rollers are wider than the distance between the ring ribs. With eccentric assembly, however, numerous sphere rollers can be fitted.

Areas of application of sphere roller bearings

A distinction is drawn between single row locating bearing applications and double row semi-

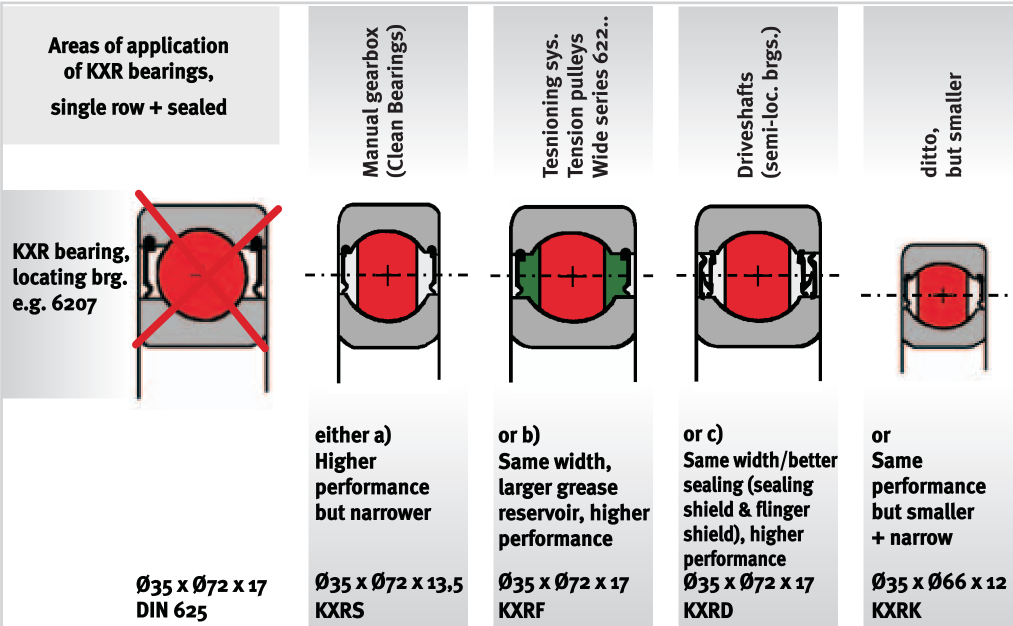

Figure 10 Applications of KXR bearings

locating bearing arrangements (adjusted bearing arrangements).

The single row KXR bearing, e.g. 6207KXR supplements the ball bearing to DIN dimensions and is:

- either higher performance but narrower with the same outside diameter and the same bore
- or higher performance with the same width but with an increased grease reservoir or improved sealing
- or equal performance but smaller radially and even narrower than the standard ball bearing.

The double row KXR bearing = KXRT (tandem arrangement) can replace the tapered roller bearing and multi-row ball bearings, since 2 sphere rollers can replace one tapered roller.

The KXRT bearing has the same performance but lower friction and is narrower than the tapered roller bearing.

The KXRT bearing is the logical development of the tandem ball bearing (used, for example, in pinion bearing arrangements) with 2 rows of balls.

The four-row KXR4 bearing replaces double row tapered roller bearings and four-row ball bear-

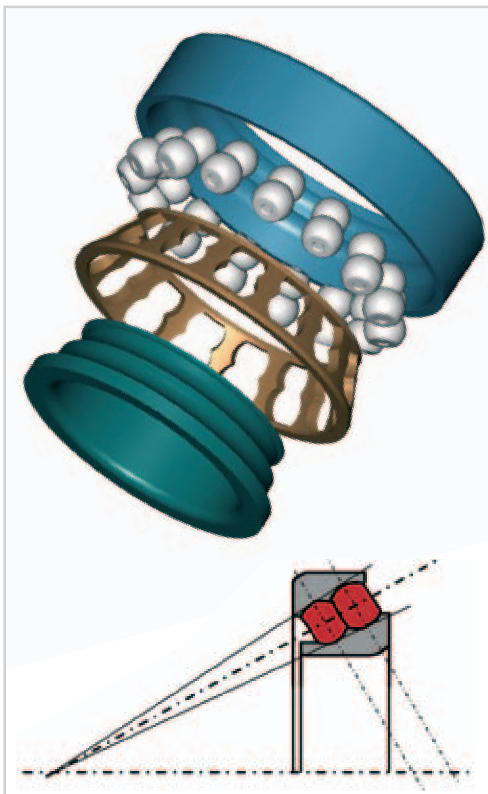

Figure 11 KXRT bearing (double row)

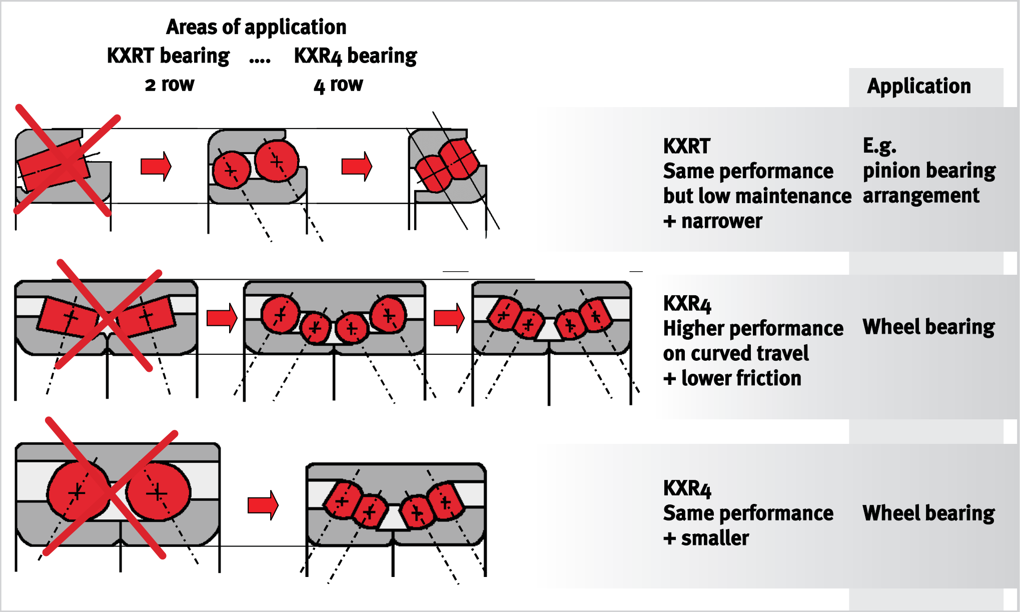

Figure 12 Applications of KXRT/KXR4 bearings

ings of the same bore and outside diameter. The KXR4 bearing can also replace double row ball bearings using smaller sphere rollers with a reduced outside diameter.

For the virtual shaft arrangement in a gearbox as described in Figure 4, there are advantages in using the new KXR designs (Figure 11).

The locating bearing on shaft 1 is replaced by a single row KXR bearing of equal performance but of smaller dimensions and narrower section size.

The two semi-locating bearings on shaft 2 are substituted by double row KXRT bearings.

Design envelopes – centre distance and bearing spacing – can be reduced!

It is well known that vehicles with front wheel drive and transverse engines require manual gearboxes with short mounting dimensions.

It is also a fact that the friction of the KXRT bearings is smaller than that of the tapered roller bearing since there is no sliding friction on ribs.

Bearing adjustment and lubrication is simpler and more robust for the KXRT semi-locating bearings.

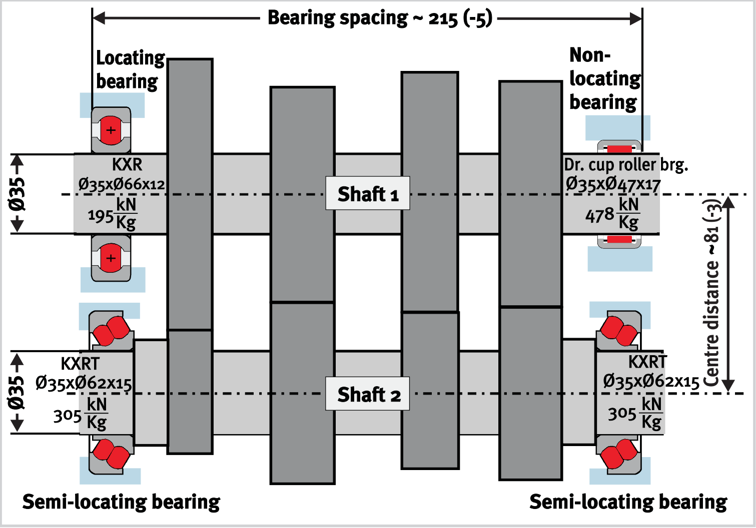

Figure 13 Twin-shaft gearbox with KXR/KXRT bearings

Verification

The following investigations were carried out in order to demonstrate the performance of the KXR designs.

Computer simulation of the kinematics

Due to its moment of inertia, the KXR is more quickly stabilised than the "fully round ball". It is known, for example, that a pedal cycle runs with greater stability as the speed increases. This can be explained by the gyroscopic forces.

Tests under load and speed

- Testing under moment load
- In this challenging test, the contact angle changes from plus to minus for each sphere roller on each revolution. It is found that the sphere rollers "creep" with the contact angle in accordance with the theory.
- Dynamic tests under axial and radial load
- The KXR bearings fulfil the theoretically anticipated life.
- Drive tests

Correct function in the manual gearbox is assured in jump starting and "drive and coast".

Summary and outlook

The sphere roller is a new rolling element leading to a new series of rolling bearings with a wide range of possible applications in the automotive and industrial sectors.

The KXR and KXRT bearings are highly suitable for applications in gearboxes.

Perhaps this is a law similar to that in the IT sector according to which product performance is increased according to a rhythm which may differ for electronics or mechanical engineering (source: G. E. Moore, co-founder of Intel)

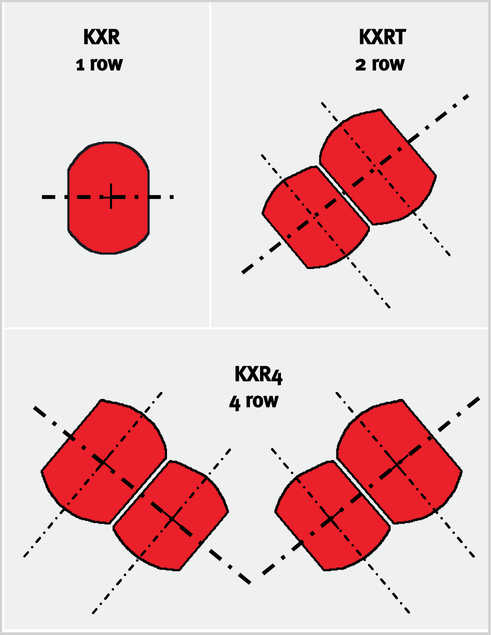

Figure 14 Summary/advantages

Advantages of the sphere roller family

For an unchanged load case

- Less space required
- Lower mass
- Lower friction, reduced energy consumption

For the same design envelope

- Higher performance (load carrying capacity)
- Larger grease reservoir
- More space for improved sealing

The KXR family is a solution with high performance density!

100 years after the ball bearing was invented, and 50 years after the needle roller bearing could be put into production, a new series of rolling bearings has been born!