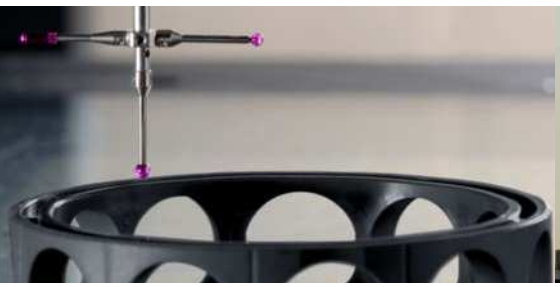
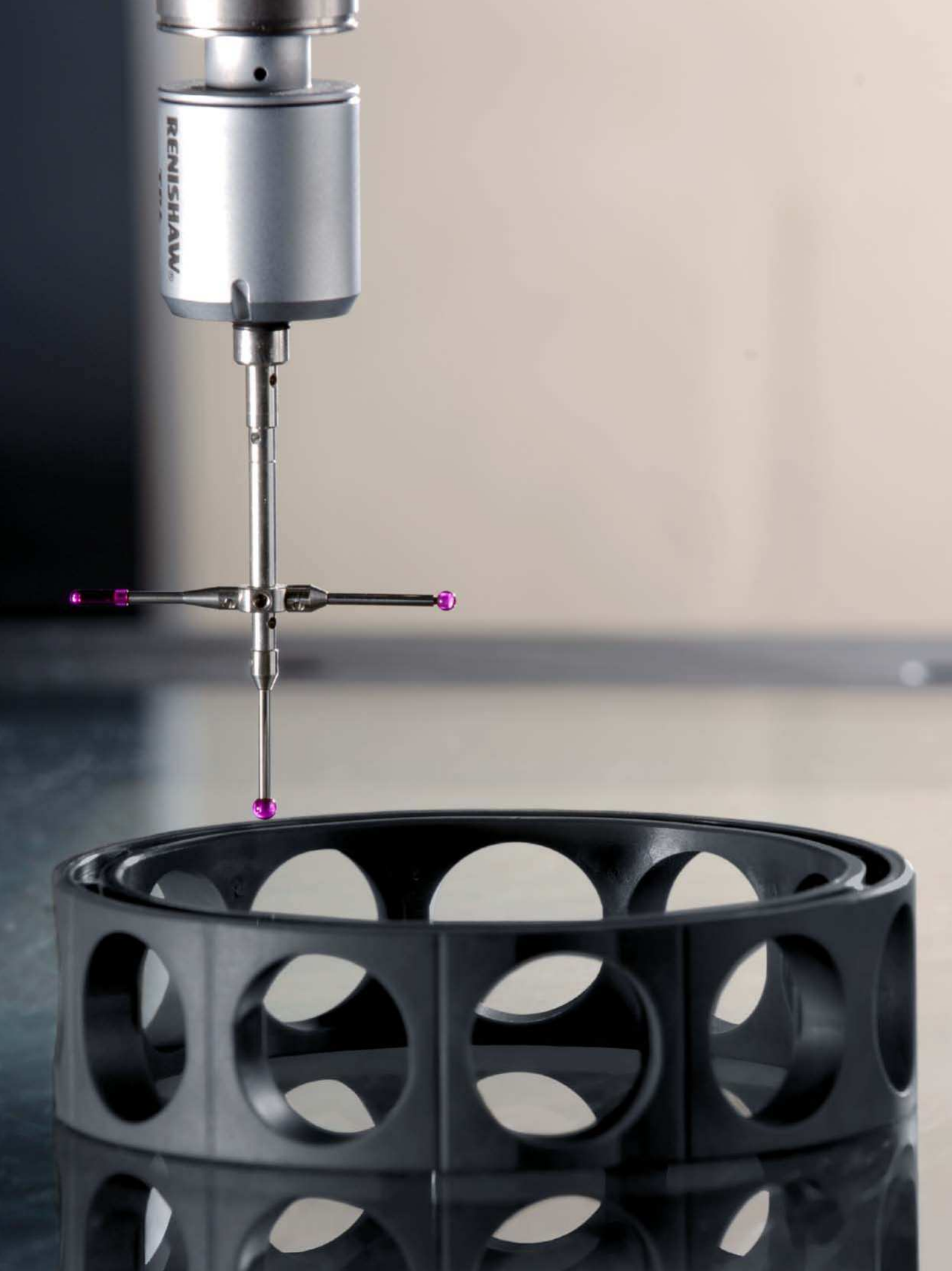
PEEK cages

for bearings in demanding applications




RENISHAW

PEEK – the high performance cage material

The use of PEEK (polyetheretherketone) as a cage material for ball and roller bearings is not new.

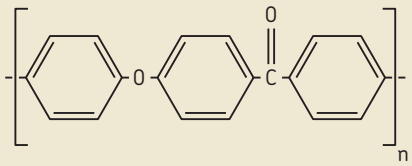
SKF first used PEEK, a partially-crystalline thermoplastic (→ **fig. 1**), to replace the brass cage in a ball bearing for a helicopter gearbox in the early 1980s. To prove PEEK's resistance to aging, tests were conducted in accordance with MIL spec 26399. The results showed that PEEK could accommodate high operating temperatures and lubricant starvation. In addition to its high performance characteristics, PEEK offered the benefit of reduced weight, making it even more attractive to the aerospace industry.

Since those early days, PEEK has been used successfully as a standard cage material for highly demanding applications in cylindrical roller bearings, angular contact ball bearings, deep groove ball bearings, four-point contact ball bearings and tapered roller bearings. PEEK cages can also be fitted to other bearing types to meet the needs of a specific application.

The success of PEEK is based mainly on its exceptional properties. Properties include but are not limited to:

- superior combination of high fatigue strength and flexibility
- almost constant mechanical properties through a wide range of temperatures
- high chemical resistance to all lubricants, additives and aggressive compressor media
- high resistance to aging
- promotes the formation of a hydrodynamic film
- high wear-resistance
- low coefficient of friction
- resists absorption of humidity
- accommodates higher temperatures than conventional polymers

Fig. 1



The chemical structure of PEEK makes it a partially-crystalline thermoplastic with a glass-transition point of 143 °C.

PEEK as a cage material provides the following benefits:

- accommodates high continuous operating temperatures (→ **table 1**)
- accommodates very high speeds
- reduces heat generated by the bearing
- reduces lubricant consumption
- reduces energy consumption
- accommodates shock loads and high centrifugal forces
- enables the bearing to survive longer under poor lubrication conditions
- extends bearing service life

PEEK – a cage material with many advantages

Thermal stability

Diagrams 1 and **2** compare the temperature limits of polyamide 6.6, the standard material for polymer cages in ball and roller bearings, to PEEK.

Depending on the design of the cage (window-type or snap-type), a PEEK cage will maintain its form far longer than polyamide, especially in applications where permanent operating temperatures exceed 120 °C.

PEEK has been used successfully in applications where peak temperatures were at or near -250 °C. However, when designing bearing arrangements below -70 °C, contact the SKF application engineering service.

Resistance to ageing

Extensive tests have been performed to compare the resistance to ageing of different polymer cage materials.

New material samples and samples that were aged in an aggressive oil with EP additives, were tested. The variables were time and temperature. **Diagram 3** shows when each material's properties fell below SKF's critical test values.

Based on these results, when PEEK is compared to polyamide 6.6, operating within the normal temperature range, PEEK does not show any significant signs of ageing.

Wear resistance

Tests have shown that PEEK cages have a very low coefficient of friction, making them extremely wear resistant. These tribological properties are not influenced by ageing.

Diagram 1
Cage materials ageing in an aggressive EP lubricant environment
Diagram 2
Comparison of temperature limits for different cage designs – Snap-type (ST) and Window-type (WT)
Diagram 3
Unlike polyamide 6.6, aged PEEK can accommodate the same high temperatures as unaged PEEK

Diagram 1

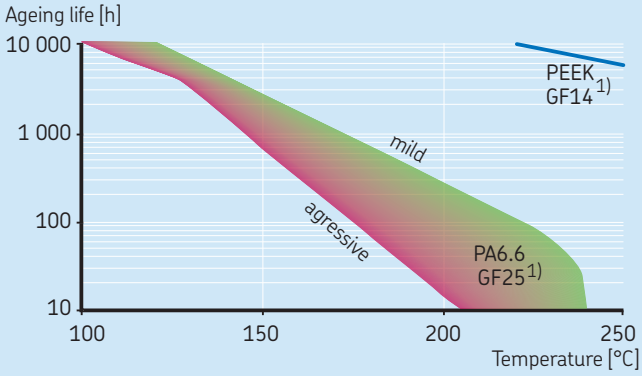


Diagram 3

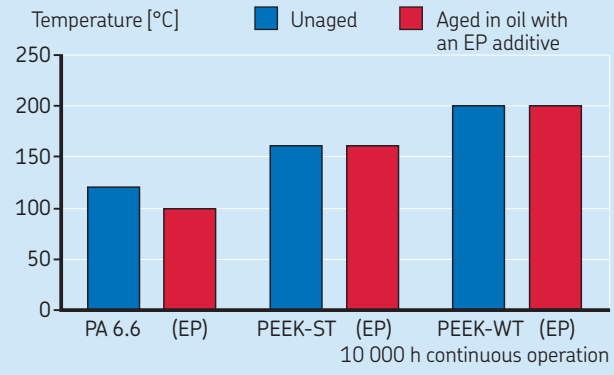


Diagram 2

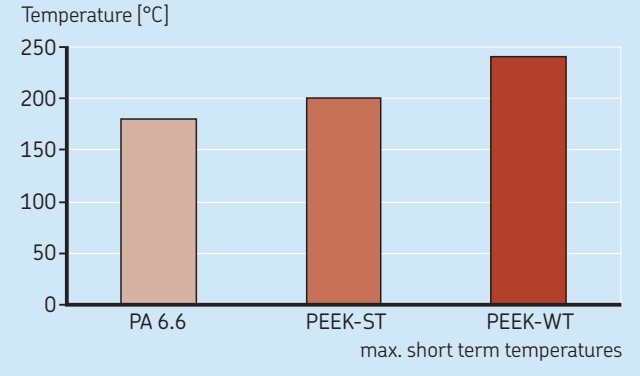


Table 1

Temperature limits for different PEEK cage designs

Temperature limit	Window-type	Snap-type
low	-70 °C [2]	-70 °C [2]
High (permanent operation)	200 °C	160 °C
High (peak temperatures)	240 °C	200 °C

[1] GFx ... x % glass fibre reinforcement
[2] Lower temperatures possible, SKF has some reference examples down to – 250 °C.

Compatibility with aggressive media

PEEK cages were exposed to compressor oils diluted with wet sour gas at 80 °C, ammonia at 120 °C and refrigerant R134 A at 120 °C. The results in **diagram 4** show that the flexural strength of PEEK remained virtually unchanged when exposed to sour gas and ammonia and that the loss of flexural strength when exposed to R-134 A was not substantial.

Diagram 5 shows that the reduction of impact toughness was consistent and relatively minor for all three media. This is significant, because as toughness decreases, brittleness increases.

Diagram 4

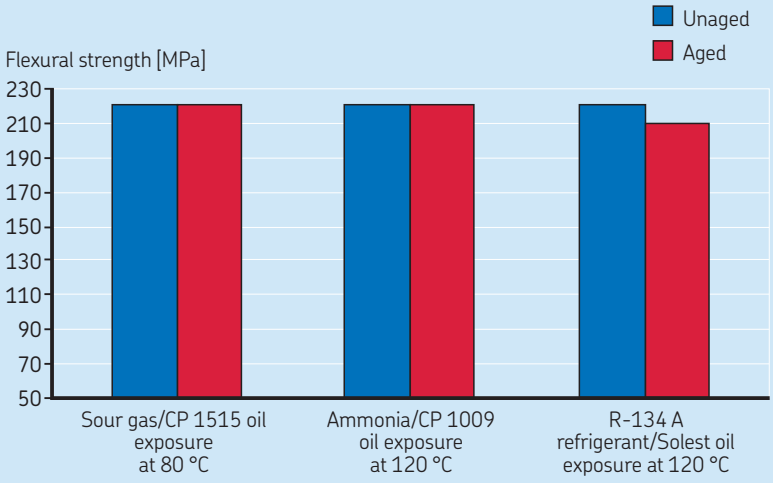


Diagram 5

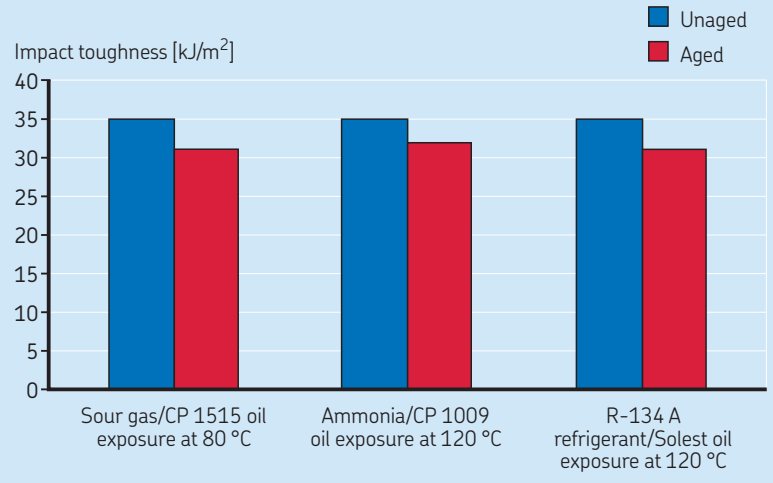
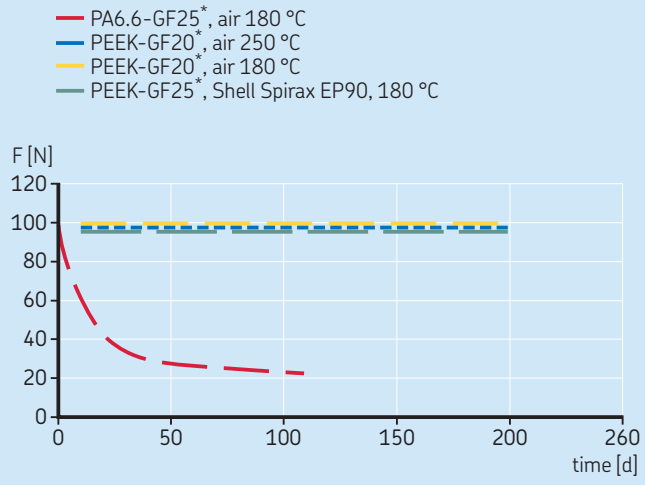


Diagram 4 & 5
After 1 000 hours of testing, the mechanical performance of PEEK did not show any significant signs of aging.

Fracture tests on aged needle roller bearing cages

In the early 1980s, SKF was performing fracture tests on aged PEEK and PA6.6 cages for needle roller bearings. The PEEK cages were aged in air at 180 °C and at 250 °C as well as in Shell Spirax, an EP-enriched oil at 180 °C. For comparative purposes, the PA6.6 cages were aged in air at 180 °C. The ageing time was between 10 and 200 days. **Diagram 6** shows the results of the fracture tests. When compared to PA 6.6, the fracture strength of PEEK was substantially higher and did not decrease as aging time increased.

Diagram 6



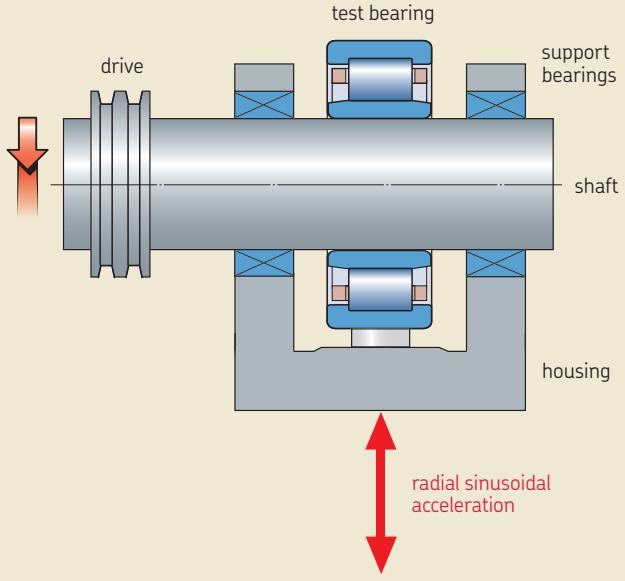
* GFx ... x % glass fibre reinforcement

Force fracture versus ageing time for differently aged needle roller bearing cages

Dynamic cage strength under extreme operating conditions

Recent dynamic tests, using fully assembled cylindrical roller bearings, were conducted to evaluate new cage materials. The test rig, designed to simulate very high accelerations or vibrations, rotated the bearings with a radial sinusoidal displacement in vertical direction and a frequency simulating very high accelerations or vibrations (→ **fig 2**). To date, of all the polymers tested, only PEEK and un-aged PA6.6 passed this test. Many other polymer compounds failed.

Fig. 2



Principle of test rig for dynamic cage strength testing

PEEK – a cage material for many applications

PEEK is an established material that is used in a variety of applications in a number of industries.

In many applications PEEK has replaced metals like aluminium and brass for cost and weight-saving reasons as well as "metallic reactions". It is also the one polymer that can meet the needs of more demanding applications where very high or low temperatures or chemical resistance are key operational parameters.

Screw compressors

Industrial refrigeration compressors often use ammonia as a refrigerant. In ammonia systems as well as in sour gas, chemical stress cracking is a concern when copper alloys are used. Machined brass cages made from centrifugally cast tubing are free from residual stress and are not susceptible to chemical stress cracking. SKF has successfully applied stress free machined brass cages in sour gas and ammonia compressors since the mid 1980s, however there are still requests not to apply any "yellow" metals in ammonia and sour gas applications. PEEK is resistant to ammonia and sour gas and is an excellent alternative cage material to brass in these applications.

Screw compressor usage in natural gas applications has risen steadily since the early 1990s and continues to grow. This is chiefly due to lower gas pressures in many older natural-gas fields, making reciprocating compressors uneconomical to install and operate.

For screw compressors in sour gas applications, PEEK cages have proven to be an important part of the solution, which in high concentration of sour gas also requires ceramic rolling elements and SKF super-tough (high nitrogen) stainless steel rings.

High speed applications

PEEK cages have been shown to perform well in tests with high speed centrifugal compressors, lubricated with refrigerant only.

More and more machine spindles are fitted with PEEK cages, as a replacement for PA6.6 or metallic cages. PEEK offers low weight, good tribological properties and high temperature resistance, enabling higher speeds and extended maintenance intervals.

Traction motors

In the early 1990s the first NU 324 cylindrical roller bearings with PEEK cages were delivered to railway customers and fitted to traction motors. Inspections after 10 years and a mileage of 1 000 000 km showed that the PEEK cages looked as good as new!

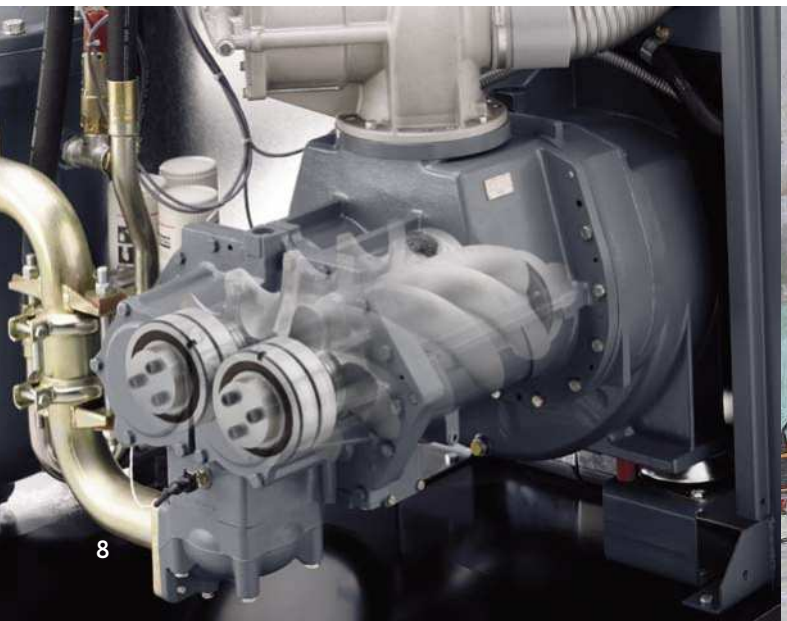
Construction equipment

Smaller cylindrical roller bearings (bore diameter ranging from 15 to 50 mm for bearings in the 200 and 2200 series) with PEEK cages are the standard solution for special kinds of construction equipment, such as concrete vibrators.

Special requirements on the cage material include: accommodate high speeds and high temperatures, high fatigue strength to withstand vibrations and shock loads. PEEK has replaced brass cages in most of these unbalanced applications.

Process pumps

Pumps that use process media to lubricate rolling bearings are becoming more common. These applications typically use bearings with PEEK cages and ceramic rolling elements, and in some cases, SKF super-tough stainless steel rings. These bearings, which can accommodate very high or low operating tempera-



tures, resist the damage caused by insufficient lubrication and exposure to chemicals. This enables very reliable, robust and low energy pump designs that are virtually leak-free. PEEK cages are currently used in pumps where the bearings are lubricated with light hydrocarbons, liquefied gases (cryogenic) and fire-safe hydraulic fluids.

Automotive applications

Bearings with PEEK cages can be found in truck transmissions. PEEK is also used for the thrust washer of large universal joints found on truck drivelines. PEEK is the standard material for the contained thrust washers due to its high temperature limits, resistance to creep and its excellent tribological properties.

Another example is the use of PEEK cages in ball bearings for liquid cooled car alternators. PEEK's advantages in this application include high resistance to ageing and creeping at high operating temperatures and high circumferential speeds.

Industrial transmissions

One of the key requirements for an elevator gearbox is that it must run quietly. To meet those noise level requirements, four-point contact ball bearings with PEEK cages frequently replace similar bearings with a brass cage. In addition to low noise levels, PEEK can accommodate the same high temperatures that make brass a popular cage material.

Formula 1

Low weight, high temperature limits and the excellent speed capability make PEEK the preferred cage material in Formula 1 applications. Reinforcing PEEK cages with carbon fibres also provides a very low coefficient of friction. Today, bearings with PEEK cages are used in Formula 1 car racing in applications such as the engine, gearbox, drive-train, suspension linkages and wheels.

Wind turbines

SKF has designed large diameter double row tapered roller bearings for the gearbox of wind turbines. This special bearing design called "Nautilus" is for a new concept of a wind turbine without a main shaft, which enables wind turbine designers to substantially reduce the weight and size of the nacelle and increase production without affecting reliability.

The new bearing is designed to accommodate heavy radial and axial loads and tilting moments and is equipped with a unique segmented PEEK cage which is resistant to the effects of ageing, and exposure to lubricant additives. When compared to a one-piece metal cage, the PEEK cage reduces friction, provides excellent performance under marginal lubrication conditions and provides better roller guidance.

PEEK – comparison to other cage materials

When compared to other cage materials, PEEK offers a number of advantages.

PEEK cages versus standard polymer cages (PA6.6)

- suitable for higher temperatures (permanent operation)
  - PEEK snap type: 160 °C
  - PEEK window type 200 °C (continuous operation)
    PA6.6 in non-aggressive media: 120 °C
    PA6.6 in media containing EP additives - 100 °C
- high chemical resistance, no noticeable ageing in oils containing EP additives, refrigerants, etc.
- higher wear resistance
- low absorption of humidity, thus no change of physical properties and dimensions

PEEK cages versus brass cages

- lower weight
- higher flexibility
- lower friction
- excellent emergency running properties, no sudden blocking of bearing
- for most types: more space for grease reservoir or oil flow

PEEK cages versus steel cages

- lower weight
- higher flexibility
- lower friction
- excellent emergency properties, no sudden blocking of bearing
- better tribological properties
- similar performance as PA 6.6 in grease lubricated bearings compared to sheet steel cages

Summary

PEEK offers a number of advantages when compared to "standard" cages made of polyamide, steel or brass.

Development goes on, but currently PEEK remains a superior polymer for ball and roller bearing cages. **Table 2** provides a rough overview of the different cage materials and their properties.

Table 2

	Temp	Chem. Resistance	Ductility	Tribology
PA6.6	–	–	+	+
Steel	+	+	0	–
Brass	+	0	0	+
PEEK	+	+	+	+

Comparison of different cage materials of single row bearings

Steel, brass, polyamide and PEEK cage for cylindrical roller bearings

PEEK – cages in different bearing types

Cage nomenclature

Cage design is very important for the performance of the cage as well as the operational reliability of the bearing.

As a result, SKF has developed a variety of cage designs in different materials depending on the bearing type.

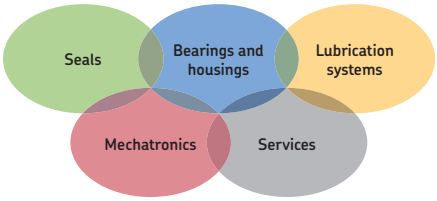
The use of glass fibre reinforced PEEK cages is becoming more common for demanding applications where there are high speeds, high temperatures or aggressive media.

Table 3 provides an overview of PEEK cages for different bearing types.

Table 3

Bearing type	**Suffix**	**Example of bearing designation**	**Guidance** rolling element	outer ring
Angular contact ball bearing	PH PHAS	7210 BEPH QJ 306 N2PHAS	X	 X
Cylindrical roller bearing	PH PHA	NU 312 ECPH NU 204 ECPHA	X	 X
Deep groove ball bearing	TNH	6205ETNH	X	

Nomenclature for different types of single row bearings



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These competence areas include bearings and units, seals, lubrication systems, mechatronics, and a wide range of services, from 3-D computer modelling to cloud-based condition monitoring and asset management services.

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