SKF hybrid bearings for extreme application conditions

High nitrogen stainless steel bearings for special applications

Pure refrigerant lubricated bearings

Sour gas bearings

Sour gas bearings

Cryogenic bearings

Longer bearing service life reduces cost of ownership

In extremely demanding applications, as in the oil & gas industry where specialized pumps and compressors are used, bearings are often subjected to one or a combination of the following operating conditions:

- High/Low temperatures
- Contaminated and/or corrosive environments
- High or very low loads
- Thin-film lubrication
- Frequent, rapid starts and stops
- Media lubrication

Under any of these conditions, bearings can fail prematurely from either surface or subsurface initiated fatigue on rings. The result: machine downtime, lost productivity and increased maintenance costs.

To enable longer bearing service life and reduce the costs associated with downtime, SKF has developed hybrid bearings with two variants of high nitrogen stainless steel. One variant, VC444 (martensitic) is most suitable for corrosive and wet environments; VC4444 (secondary hardened) is most suitable for a very wide operating temperature range.

Both variants show enhanced fatigue strength and a high degree of impact toughness. Compared to standard carbon chromium bearing steels, this ultra clean high nitrogen stainless steel can extend bearing service life in applications under thin-film lubrication conditions. Under full-film lubrication conditions, this life extending effect is even more significant.

Another benefit of SKF high nitrogen stainless steels is that they have a low coefficient of thermal expansion. This means they are less sensitive to temperature differences between inner and outer rings. As a consequence, preload or internal clearance remains much more stable over the extremes of operating temperatures compared to standard steel.

VERY HIGH ROLLING CONTACT FATIGUE STRENGTH

Features and properties of high nitrogen stainless steels

- High corrosion resistance
- High wear resistance
- Very high rolling contact fatigue strength
- High impact toughness
- Superior thermal dimensional stability[1)]
- Low coefficient of thermal expansion
- Ultra clean steel with a fine and uniform microstructure

1) VC4444

Features and properties of silicon nitride rolling elements

- Low density
- High hardness
- Low coefficient of thermal expansion
- Electric resistivity (insulator)

Features and properties of glass fibre reinforced PEEK cage material

- High chemical resistance to lubricants and aggressive media
- Wide range of operating temperatures
- High resistance to aging
- Low absorption of humidity
- Unique cage design

The SKF solution for extreme application conditions

SKF high nitrogen stainless steel hybrid bearings have rolling elements made from bearing grade silicon nitride and a glass fibre reinforced PEEK cage as standard. The combined properties of the components greatly improve bearing performance, enabling these bearings to run significantly longer than conventional hybrid bearings especially in harsh conditions.

Benefits of hybrid bearings for extreme application conditions compared to standard hybrid bearings:

Longer bearing service life

The high rolling contact fatigue strength of high nitrogen stainless steel in combination with ceramic rolling elements leads to significantly longer bearings service life, especially under harsh conditions.

Fatigue life tests were conducted on hybrid bearings made from 100Cr6 (carbon chromium) steel and high nitrogen stainless steel (VC444 and VC4444).

The superior performance of bearings made from high nitrogen stainless steel is demonstrated by the test result.

Depending on the bearing arrangement and operating conditions, the bearings lasted up to two times longer than bearings made from conventional bearing steel under thin-film and more than three times under full-film lubrication conditions (→ **diagram 1**)

Corrosion resistance

This stainless steel material has a very high nitrogen content and a very clean microstructure. Bearings equipped with glass fibre reinforced PEEK cages are able to operate in aggressive media, like sour- and/or acid gases. This enables these bearings to operate under extremely corrosive operating conditions.

High wear resistance

The hardness of ceramic rolling elements in combination with this high nitrogen stainless steel provides a high degree of wear resistance.

Clearance and preload

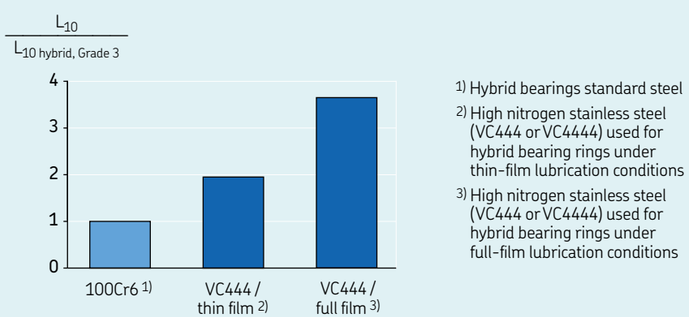
Compared to conventional all-steel bearings, the rolling elements of hybrid bearings have a much lower coefficient of thermal expansion. This means that at increasing temperatures, the bearing clearance remains almost constant. If the temperature reaches very low levels, a larger clearance class may be required.

Thermal dimensional stability

The enhanced performance of bearings made from stainless steel rings (VC444) means that bearings can be used in operations where temperature limits reach 200 °C (*392 °F*); VC4444 can even be used in operations where operating temperatures exceed 350 °C (*662 °F*).

Diagram 1

Fatigue life tests under thin-film and full-film lubrication conditions



High nitrogen stainless steels – a unique bearing material for superior bearing performance

This high nitrogen stainless steel is a very clean steel. Compared to standard carbon chromium bearing steel (→ **fig 1**), the following advantages are provided:

Enhanced fatigue strength

The enhanced fatigue strength of high nitrogen stainless steel is associated with the coherent nature and fine distribution of the chromium nitride precipitates.

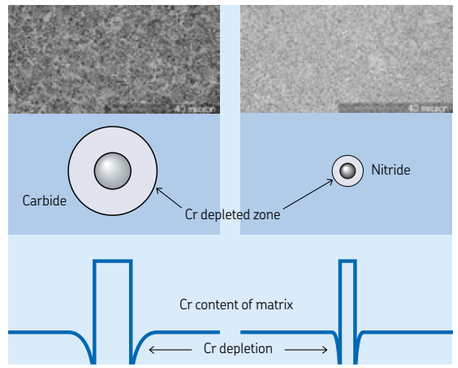
High degree of fracture toughness

High impact toughness, dimensional stability and hardness (>58 HRC) result from the final quenching and tempering stages of the heat treatment process.

Wide operating temperature

SKF high nitrogen stainless steel VC444 is suitable for operating temperatures up to 200 °C (*392 °F*). For the extremes of operating conditions, SKF high nitrogen stainless steel VC4444 has slightly less corrosion resistance but otherwise similar properties and is suitable for operating temperatures ranging from very low (cryogenic) up to 350 °C (*662 °F*).

Fig. 1



The microstructures of high nitrogen stainless steels VC444 and VC4444 (right) consist of a fine distribution of chromium nitrides, compared to that of conventional corrosion resistant bearing steels (left) with larger brittle carbides and surrounding chromium depleted zones.

Superior corrosion resistance

When this steel is heat treated, the process produces large, brittle chromium and chromium-molybdenum carbides that deplete the surrounding steel matrix of chromium and molybdenum, reducing its corrosion and pitting resistance. On the other hand, when high nitrogen stainless steel is hardened and tempered, fine chromium nitrides are formed. This occurs because nitrogen partly replaces carbon in the steel alloy, enabling a much higher content of chromium to be dissolved in the steel matrix. The resulting, smaller chromium-depleted zones around the nitrides make the high nitrogen stainless steel much more corrosion resistant.

Salt spray test

The salt spray test is a standardized test that assesses the corrosion resistance of materials. The test was conducted, in accordance with ISO 9227, on specimens of AISI 440C stainless steel and high nitrogen stainless steel VC444. The steels were subjected to corrosive attack for 100 hours, after which the samples were evaluated for the presence of oxides (→ **fig. 2**).

The results of the salt spray test confirmed that VC444 has far superior corrosion resistant properties (→ **table 1**).

Fig. 2

AISI 440C VC444

Table 1

Comparison of the properties of various bearing steels

Bearing steel	Property Corrosion resistance	Fatigue strength	Wear resistance	Thermal dimensional stability
100Cr6 (carbon chromium steel)	–	+	+	++
AISI 440C (corrosion resistant steel)	+	+	+++	++
VC444 high nitrogen stainless steel	+++	++	++	++
VC4444 high nitrogen stainless steel	++	+++	++	+++

– low + medium ++ high +++ very high

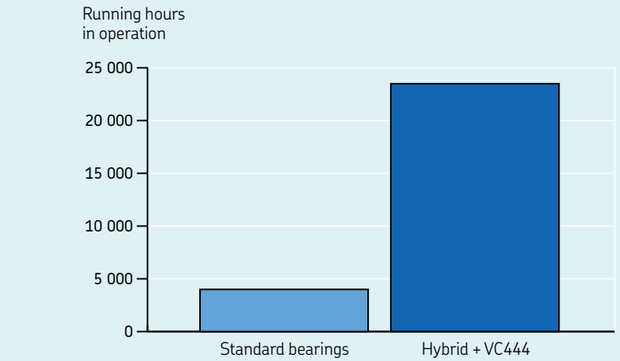
Outstanding performance under harsh conditions

Field test results

In one refinery, a vapor recovery unit was equipped with an oil flooded screw compressor with conventional all-steel bearings. The unit was handling a mix of 30–40% sour gas and 35% acid gas. A statistical analysis showed a mean time between failure (MTBF) of the bearings of only 3 800 hours. The failures were characterized by stress cracks in the raceways and split rolling elements. The compressor was retro-fitted with high nitrogen stainless steel hybrid bearings VC444. These sour gas bearings ran for 23 300 hours before the compressor was taken out of service for maintenance of a valve (→ **diagram 2**). The bearing assessment hardly showed any wear or corrosion. It was replaced by another compressor equipped with similar high nitrogen stainless steel hybrid bearings VC444.

Diagram 2

Comparison of service life



Application recommendations

Sour gas compressors:

In gas plants, offshore platforms, oil field separators and refineries the use of oil-flooded screw compressors for vapor recovery units (VRU) is on the rise. Their relative low cost, small footprint and performance flexibility make them a good fit for the application.

In cases where the lubricating oil is contaminated by sour gas, the mean time between failure (MTBF) of standard bearings can be very short. The result: lost productivity and high repair costs. And when the compressor is at a remote location, these costs can increase significantly.

SKF high nitrogen stainless steel hybrid bearings are a robust and field proven alternative to conventional steel bearings with brass or steel cages for sour gas compressors.

The combination of high nitrogen stainless steel rings (VC444), glass fibre reinforced PEEK cage and silicon nitride rolling elements provides superior resistance to

- sulfide- and hydrogen-related stress cracks
- poor lubrication conditions
- corrosion
- electrical arcing from variable frequency drives

The ultimate result:

SKF high nitrogen stainless steel hybrid bearings can provide 6–10 times the service life of conventional bearings in oil-flooded screw compressors used on sour gas applications. This SKF solution enables significant reductions in compressor maintenance and operating costs.

Sour gas bearings

Sour gas bearings

Table 2

Sour gas applications

Applications	Challenges	Engineered solution
Gas gathering, pipeline boosting	Sour and acid process gases	SKF high nitrogen stainless steel hybrid bearings VC444
Gas well boosting	Hydrogen-rich process gases	
Off-gas units, refineries	Water condensation	
Recip boosting e.g. EOR (CO_2 injection); sour and acid gas re-injection etc.	Dilution of lube oil by low viscosity hydrocarbons	
VRUs	Ingress of particles	
Hydrogen-rich gases e.g. distillate unifiers; hydrogen plants; sulfur reductions etc.		

Cryogenic pumps:

Cryogenic submersible pumps that transport liquefied gases need to withstand temperatures that range from –74 °C (101 °F) for liquefied petroleum gas to –253 °C (–423 °F) for liquefied hydrogen gas. As a result of these cold temperatures, conventional petroleum-based lubricants cannot be used. Instead, the bearings are lubricated by the media being pumped.

To withstand these harsh temperatures and operating conditions, SKF engineers designed a robust bearing solution specifically for cryogenic applications. The bearing is a hybrid deep groove ball bearing with a specially heat-treated variant of high nitrogen stainless steel rings (VC4444), ceramic rolling elements and a flexible single piece glass fibre reinforced PEEK cage These bearings resist damage from each of the following conditions:

- Cavitation
- External vibrations
- Contamination
- Thin hydrodynamic film

The ceramic rolling elements can also protect these bearings from damage caused by stray electric currents created by using variable frequency motor speed control.

Cryogenic bearings

Table 3

SKF cryogenic bearings

Applications	Challenges	Engineered solution
Submerged cryogenic pumps: LNG; LEG; LPG etc.	Media lubrication	SKF high nitrogen stainless steel hybrid bearings VC4444 with specially designed single-piece glass fibre reinforced PEEK cage
Cryogenic seal support bearings	Cavitation	
LNG loading arms	Low viscosity process fluids	
	Cryogenic temperatures	
	Ingress of contaminants	
	Electrical erosion from variable frequency drives	

Pure refrigerant lubricated centrifugal compressors:

Large capacity chillers use a refrigerant to cool water that is then circulated throughout a building to provide air conditioning or to cool an industrial process. Typically, these chillers are equipped with centrifugal compressors that rely on hydrodynamic bearings lubricated with a mix of oil and refrigerant.

To avoid diluting the refrigerant and its effectiveness, while still maintaining an oil rich mixture to lubricate the hydrodynamic bearings, these centrifugal compressors use oil injection and separation systems before and after the bearings. If, however, oil is not needed to lubricate the bearings, the oil injection and separation systems can be eliminated and the overall compressor efficiency improved because the refrigerant will not be diluted. Also if oil is eliminated, the heat transfer efficiency of the evaporator and condenser will improve. The efficiency also improves since the oil circulation in the system is displacing refrigerant that could be used for cooling.

For pure refrigerant lubricated centrifugal compressors SKF high nitrogen stainless steel hybrid bearings were further developed. These pure refrigerant lubricated (PRL) bearings offer a reliable solution and enable compressor designs that reduce system complexity and cost while improving reliability and energy efficiency.

Pure refrigerant lubricated bearings

Table 4

SKF pure refrigerant lubricated bearings (PRL)

Applications	Challenges	Engineered solution
Centrifugal compressors, chillers	Media lubrication	SKF high nitrogen stainless steel hybrid bearings VC444
Other refrigerant pumps and compressors at higher speeds	Low viscosity process fluids	Specially designed and quality assured features
	Liquid cavitation	
	Corrosion	
	Electrical erosion from variable frequency drives	
	Extreme service life requirements	

Additional application examples:

Table 5

SKF high nitrogen stainless steel hybrid bearings: Engineered bearing designs

Applications	Challenges	Engineered solution
Hydraulic pumps, HFC[1] fire-resistant fluids	• Water-glycol fluids as lubricants • Ingress of corrosive fluids	• SKF high nitrogen stainless steel hybrid bearings VC444 • Cages according to the specific application
Polyethylene reactors	• Lubrication by ethylene gas and polyethylene • Corrosive catalyzers • Special requirements	• SKF high nitrogen stainless steel hybrid bearings VC444 • Cages according to the specific application
Process lubricated or gas running electrical drives	• Low viscosity and corrosive process fluids • Ingress of particles electrical erosion from variable frequency drives	• SKF high nitrogen stainless steel hybrid bearings VC444 • Cages according to the specific application
F1 racing	• High loads • High speeds • High accelerations	• SKF high nitrogen stainless steel hybrid bearings VC4444
Screw pumps	• High radial shaft loads causing misalignment high contact and edge stresses • Ingress of fluids and particles	• SKF CARB toroidal roller and angular contact ball bearings with high nitrogen stainless steel rings VC444 • Ceramic or high nitrogen stainless steel VC444 rolling elements and cage according to specific application

1) HFC - ISO 12922:1999 and ISO 6743-4: 1999 (min 35% water)

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