SKF hybrid bearings for extreme application conditions
High nitrogen stainless steel bearings for special applications

Pure refrigerant lubricated bearings

Sour gas bearings

Cryogenic bearings
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 full-film lubrication conditions. Under thin-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.

### Features and properties of high nitrogen stainless steels
- Highly corrosion resistance
- High wear resistance
- Very high rolling contact fatigue strength
- High impact toughness
- Superior thermal dimensional stability
- 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
- Electrically 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 up to four times under full-film lubrication conditions (→ diagram 1).

Corrosion resistance
This new generation of stainless steel has a very high nitrogen content and an ultra clean microstructure compared to conventional stainless steels. 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, it needs to be considered, that 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 150 °C (302 °F); VC4444 can even be used in operations where operating temperatures exceed 150 °C (302 °F).

![Diagram 1: Fatigue life tests under thin-film and full-film lubrication conditions](attachment:diagram.png)

Diagram 1

| Fatigue life tests under thin-film and full-film lubrication conditions |
|------------------------|---------------------------|
| \( L_{10} \) hybrid, Grade 3 |
| 100Cr6 1) | VC444 / thin film 2) | VC444 / full film 3) |
| 0 | 1 | 2 |

1) Hybrid bearings standard steel
2) High nitrogen stainless steel (VC444 or VC4444) used for hybrid bearing rings under thin-film lubrication conditions
3) High nitrogen stainless steel (VC444 or VC4444) used for hybrid bearing rings under full-film lubrication conditions
High nitrogen stainless steel is a new generation of ultra clean steel. When compared to standard carbon chromium bearing steel (→ fig 1), this steel provides the following:

**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 150 °C (302 °F). For the extremes of operating conditions, SKF high nitrogen stainless steel VC444 has slightly less corrosion resistance but otherwise similar properties and is suitable for operating temperature ranges from very low (cryogenic) to very high.

**Superior corrosion resistance**
When carbon chromium 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, which enables 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.

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.
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).

<table>
<thead>
<tr>
<th>Bearing steel</th>
<th>Property</th>
<th>Corrosion resistance</th>
<th>Fatigue strength</th>
<th>Wear resistance</th>
<th>Thermal dimensional stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>100Cr6 (carbon chromium steel)</td>
<td>–</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>AISI 440C (corrosion resistant steel)</td>
<td>+</td>
<td>+</td>
<td>+++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>VC444 high nitrogen stainless steel</td>
<td>+++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>VC4444 high nitrogen stainless steel</td>
<td>++</td>
<td>+++</td>
<td>++</td>
<td>+++</td>
<td></td>
</tr>
</tbody>
</table>

– low  + medium  ++ high  +++ very high

Fig. 2

Table 1
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 for the bearings (MTBF) of only 3800 hours. The failures were characterized by stress cracks in the raceways and split rolling elements. The compressor was retrofitted with high nitrogen stainless steel hybrid bearings VC444. These sour gas bearings ran for 23300 hours before the compressor was taken out of service for maintenance of a valve (→ diagram 1). 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](image)

- **Running hours in operation**
  - Standard bearings
  - Hybrid + VC444

- **Comparison of service life**
  - Standard bearings
  - Hybrid + VC444
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. Along with significant reductions in CO₂ emissions, this SKF solution enables significant reductions in compressor maintenance and operating costs.

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<table>
<thead>
<tr>
<th>Applications</th>
<th>Challenges</th>
<th>Engineered solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas gathering, pipeline boosting</td>
<td>Sour and acid process gases</td>
<td>SKF high nitrogen stainless steel hybrid bearings VC444</td>
</tr>
<tr>
<td>Gas well boosting</td>
<td>Hydrogen-rich process gases</td>
<td></td>
</tr>
<tr>
<td>Off-gas units, refineries</td>
<td>Water condensation</td>
<td></td>
</tr>
<tr>
<td>Recip boosting e.g. EOR (CO₂ injection); sour and acid gas re-injection etc.</td>
<td>Dilution of lube oil by low viscosity hydrocarbons</td>
<td></td>
</tr>
<tr>
<td>VRUs</td>
<td>Ingress of particles</td>
<td></td>
</tr>
<tr>
<td>Hydrogen-rich gases e.g. distillate unifiers; hydrogen plants; sulfur reductions etc.</td>
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</tr>
</tbody>
</table>

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Table 2

Sour gas applications

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Sour gas bearings

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Sour gas bearings
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.

Table 3

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

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

Table 4
## Additional application examples:

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

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