Extending main-shaft bearing life in wind turbines

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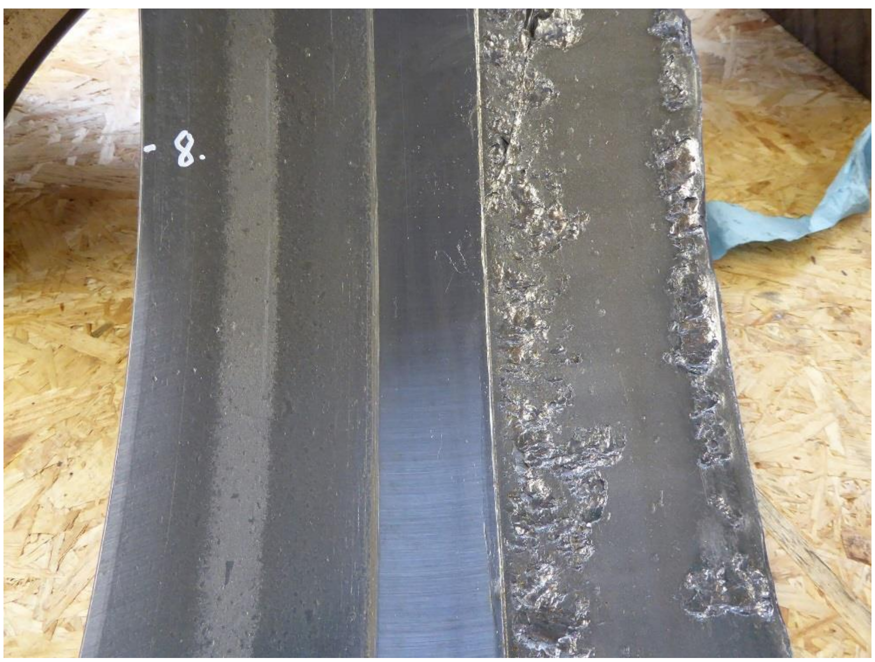
SKF

The renewable energy sector is being forced to reduce the levelized cost of electricity (LCoE). The wind energy industry is striving to match or exceed the LCoE of traditional energy sources. Due to the cost of the equipment combined with the lower relative operations and maintenance costs compared to traditional energy, the driving factors in reducing the LCoE in wind are the costs of the equipment and uptime.

Uptime in wind turbines is critical to the future of the energy source. In the past years, SKF scientists and research engineers conducted systematic investigation and verification tests on key parameters, which may have strong contribution to the main-shaft bearing performance.



Common main-shaft spherical roller bearing outer ring damage, upwind row left, downwind row

According to the investigation, following parameters have been identified:

- Lubrication starvation can be a direct cause of bearing failure, which will result in fast wear and surface distress (micropitting). This can lead to edge load on the wear grooves resulting to so-called spall bands in circumferential direction of the bearing raceways.
- Lubricant starvation is the result of the lack of grease in the contact and oil depletion in the grease.
- There are many parameters which have been identified to accelerate lubricant starvation, such as incorrect selection of lubricating greases, improper re-lubrication method, high friction, high sliding to rolling ratio, low lubrication film thickness, etc.

To reduce the risk of lubrication starvation, SKF NoWear surface coating has been selected and verified, which can not only increase the wear resistance on the raceway surfaces, but also reduce the friction and therefore prolong the grease life. NoWear testing has shown performance upgrades by reducing wear in the starved condition, and more critically to overall asset life, extending the time to starvation when compared to a non-coated roller bearing.

SKF NoWear is a wear resistant metal-containing hydrogenated amorphous carbon coating that is applied to the rolling elements of spherical roller main-shaft bearings. A physical vapor deposition process applies the wear-resistant, metal-doped, diamond-like-carbon coating. Thickness of the coating ranges from 0.6 to 6 µm, depending on the size and geometry of the bearing. The nano-indentation hardness of the coating is 12 GPa (~1,200 HV).

NoWear coated bearing surfaces retain the toughness of the underlying material while adopting the hardness, improved friction properties and wear-resistance of the coating. The dry sliding coefficient of NoWear against a steel counterpart is less than 0.2 while that of bearing steel is 0.6 – 1.0. As such, NoWear coated bearings can operate reliably even where adequate surface separation cannot be achieved. NoWear acts as a protective layer and may reduce the need for Extreme Pressure (EP) additives in the lubricant. This is beneficial in wind-turbine main-shaft applications, since EP additives should be avoided if possible as they can contribute to the generation of micropits.

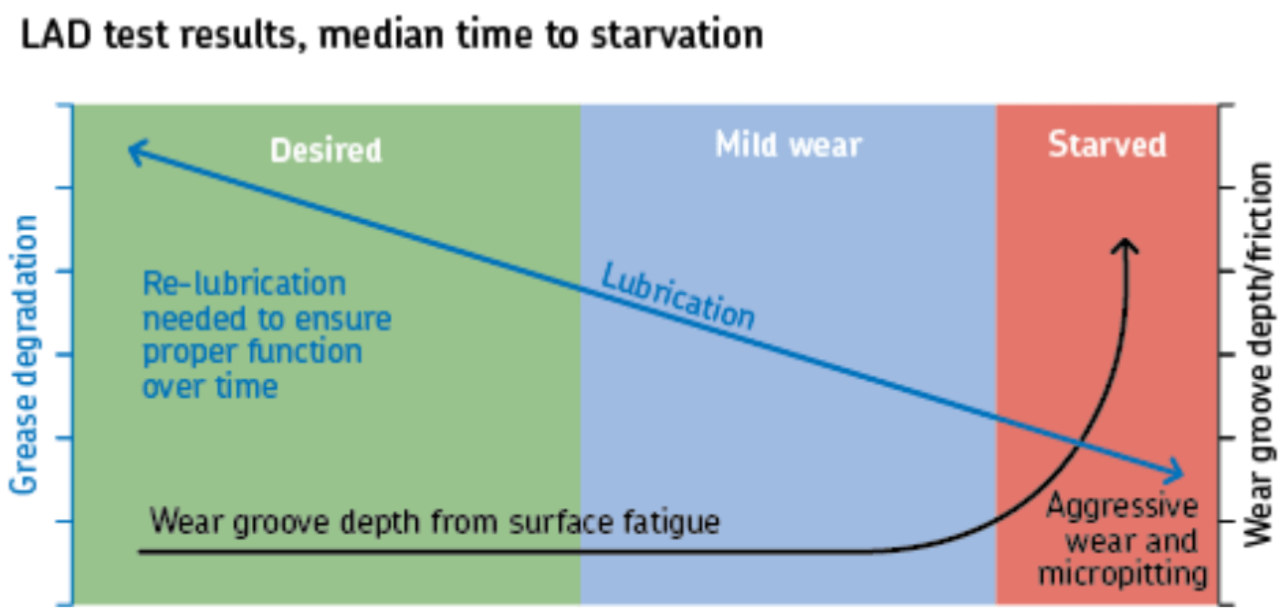
NoWear is a proprietary formulation patented by SKF and is constructed with three layers. The run-in layer at the surface, the functional layer in the middle and the adhesion layer attaching the coating onto the underlying steel component surface.

The adhesion layer is particularly important for bearing performance when compared to other coating formulations. The formulation allows for optimal adhesion and high elasticity, while maintaining high hardness for wear protection. This strong adhesion is fundamentally important in bearing applications to prevent coating material from becoming a contaminant in the system if it flakes from the substrate.

In addition, the NoWear coating achieves running in over a shorter period when compared to other coating formulations. The NoWear formulation is the preferred solution for surface fatigue or micropitting due to its low friction and running in which reduces the induced local Hertzian stress.

Before discussing the SKF NoWear testing and verification in the main-shaft applications, it's important to first understand the lubrication regimes the bearing operates to understand the resulting damage.

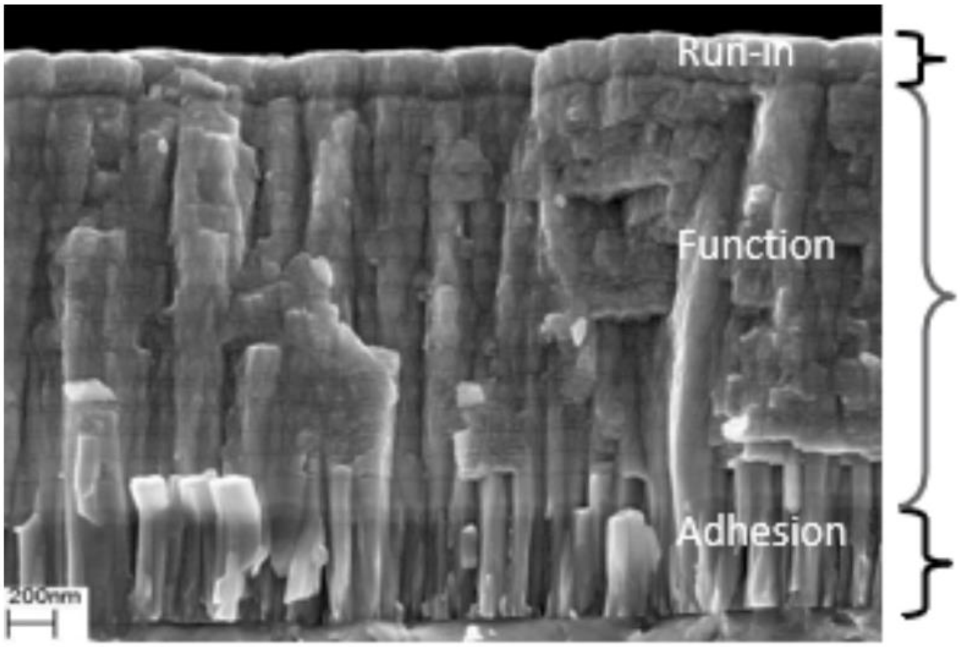
The following regimes are established.



Main-shaft bearing lubrication regimes

The green zone or desired operating regime occurs when lubricant is correctly selected and fresh grease is supplied to the contact. Little wear of the raceways is occurring, only smoothening on the micro level. The blue zone or mild wear regime occurs when lubricant is losing base oil content that is incorrectly selected, or insufficiently supplied to the contact. In this regime, mild wear or p*V (p: contact pressure and V: sliding velocity) like wear in the ~0-10 micron level occurs, where there is polishing but no surface distress.

The third regime is the red zone or starved regime. The red zone occurs when lubricant is below critical levels in the contact. Aggressive wear, surface distress (micropits) and high material removal are characteristics of the red zone regime. The time it takes to damage the surface in the starved regime is shorter when compared to bearing life and the typical maintenance intervals of six months.



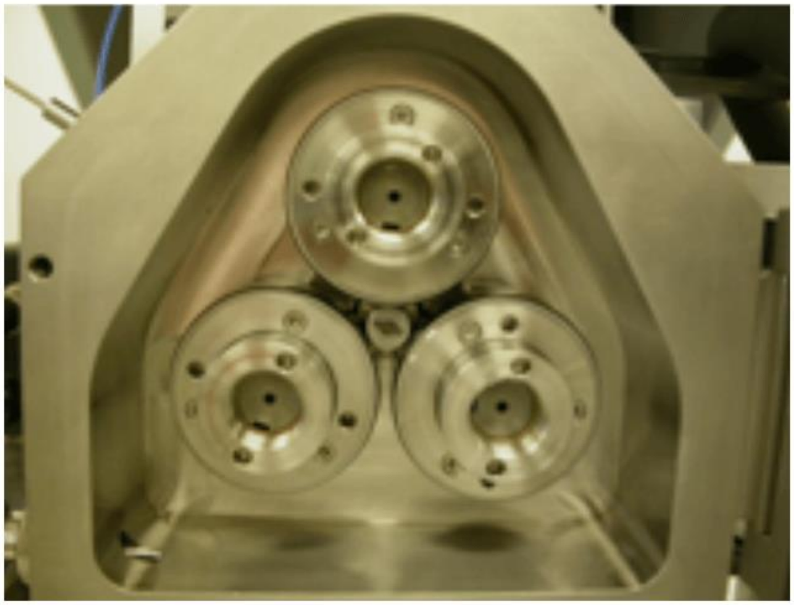
SKF NoWear coating layers

Therefore, if the red zone is reached in the application between maintenance intervals, surface damage is irreversible and the designed-for-load distribution across a rolling element can no longer be ensured and further damage may be accelerated due to the loss of geometry.

A common damage pattern of a spherical roller bearing (SRB) outer ring from the main bearing is shown in the following image. On the downwind row (right), a deep wear groove in the mid-raceway is observed and micropits fully covered the surface of the wear groove. Circumferential bands of spalling are presented on either side of the wear path, which is a result from the loss in profile and higher contact stresses at the edges.

These damages are seen primarily on the more heavily loaded downwind row.

Micropitting test results
The first set of application-specific SKF NoWear tests was a component level test. A small-scale experiment that could replicate the surface damage seen in the application. In a series of component level tests with a micropitting test rig (MPR) the objective of replicating the damage mechanism is possible.



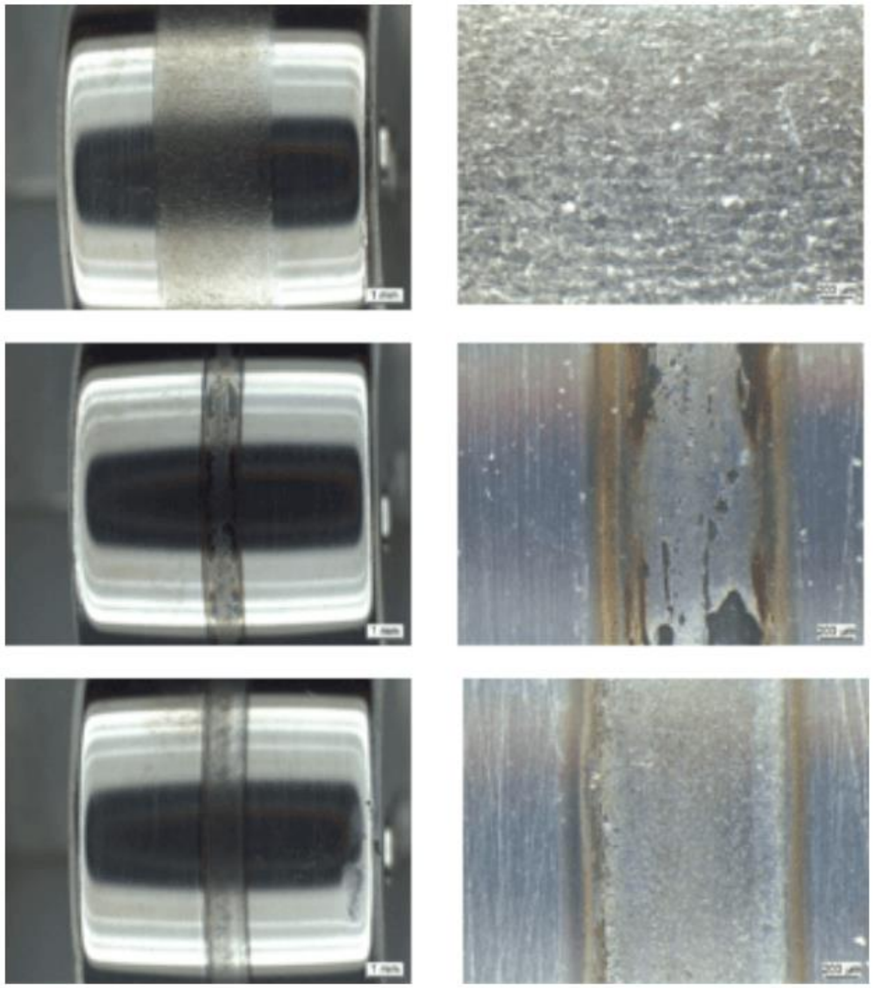
Micropitting test rig (MPR)

The MPR test rig is comprised of a single roller at the center with contact to three rings

Test conditions were set to maximize the damage within an acceptable time frame, while also maintaining application conditions. These tests would recreate the heavy damage period of the application where starvation has occurred in the contact. This would be considered “red zone” conditions. Tests measured both the time to starvation and the mass after test halt compared to pre-test weight to calculate wear. The test matrix included three samples of steel on steel and steel on NoWear coated surfaces.

The results indicate the SKF NoWear coated surface significantly limits the amount of wear once the starvation (red zone) conditions are reached. Based on this component level test, the time it takes to reach the red zone conditions are scattered across the samples and no correlation is noted.

Of the six samples, one steel on steel and two steel on NoWear samples operated for one hour after reaching the starved regime. The amount of wear during the hour after reaching the starved condition for the steel/steel contact was 22.02 mg, while the wear for the NoWear/steel contact resulted 0.77 and 0.18 mg, proving that NoWear coating reduces the damage after lubrication starvation occurs.



MPR test cases one hour of operation after starvation. Steel on steel (top row), SKF NoWear on steel (2nd and 3rd row).

However, since the duration of the red zone during the total life of the application is short or at the very least unknown, the next question to be answered is whether NoWear can prolong the time to lubrication starvation. As the MPR test rig was not suitable to answer the question, another test rig and matrix were established.

LAD testing results

The second level of testing was designed to answer the question of whether SKF NoWear coating can prolong the time to lubrication starvation. In other words, could NoWear delay the onset of the red zone in addition to the benefits shown once within the red zone. For these tests a full bearing was needed and a test rig known as an LAD was used.

The LAD tests measured the time to starvation or sharp increase in friction. The LAD test matrix includes both the all-steel bearings and SKF NoWear coated roller bearings. In addition, two types of greases were used for the LAD testing.

A recently developed main-shaft specific grease with base oil viscosity of 670 cSt and a common wind turbine main-shaft bearing grease with base oil viscosity of 460 cSt were chosen for these tests.

As done in the MPR testing, conditions for the LAD tests were set to replicate the application conditions. Producing a starved condition in the steel on steel samples within a time frame of approximately 100 hours was targeted in pre-tests. For all samples any test that had not failed at 480 hours were suspended.

The final results

The results of the LAD tests indicate the SKF NoWear significantly extends the time to starvation. Differences in the performance of the LAD test samples were noted between grease types, but the larger difference is noted between the steel and NoWear coated roller samples.

LAD test matrix

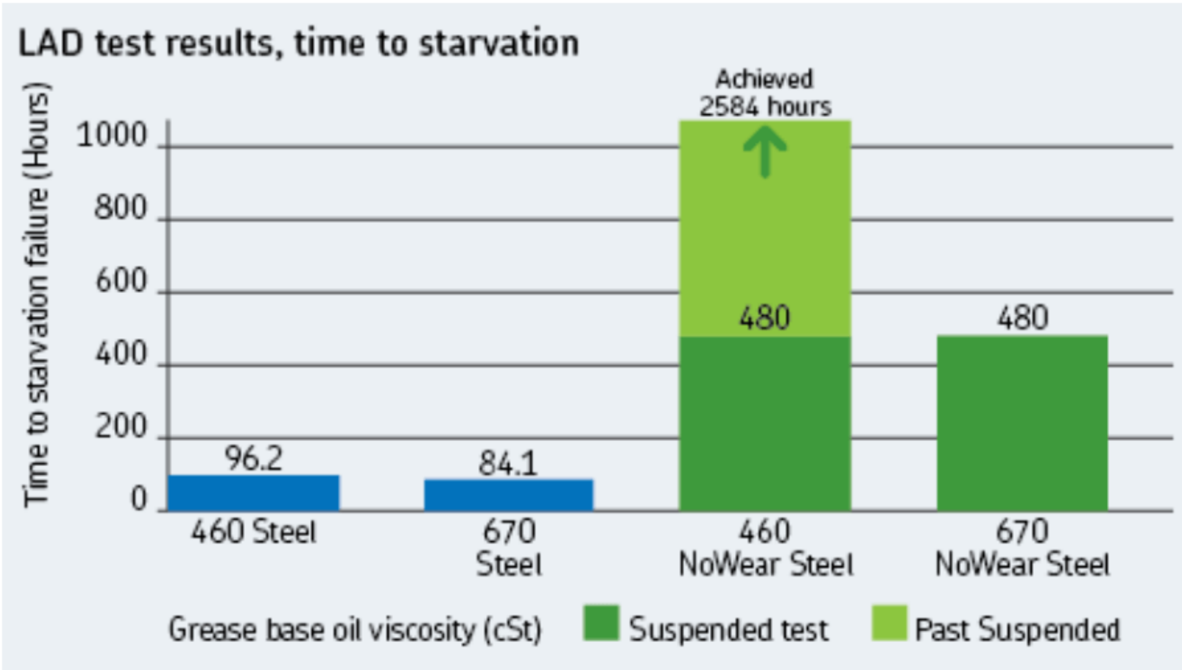
Contact	Grease base oil viscosity (cSt)	Samples
Steel/steel	670	3
Steel/steel	460	3
NoWear/steel	670	3
NoWear/steel	460	3

Considering the NoWear sample tests were suspended at 480 hours, the median time to starvation was more than 5x compared to the non-coated bearings.

In addition, a single data point was captured that was not suspended. A 460 cSt grease sample was allowed to run out and achieved 2,584 hrs. For this sample the time to starvation is greater than 26 times compared to the median non-coated sample with the same grease.

Testing and verification of SKF NoWear during development with the coating supplier shows the coating provides advanced wear protection in poor lubrication environments and reduces surface fatigue or micropitting. With the addition of SKF MPR testing, NoWear coating significantly reduces the amount of wear once the bearing contact is starved.

Furthermore, with the addition of the LAD testing, the reduced friction within the contact and improved run-in enables a NoWear coated roller bearing to significantly extend the time to starvation, which is critical to bearing service life.



LAD test results: Median time to starvation or suspension

SKF has been supplying NoWear coated bearings for applications including:

- Paper machines
- Marine and offshore
- Fans
- Compressors
- Hydraulic pumps gearboxes
- Hydraulic motors

The test results validate using SKF NoWear coating technology in rolling elements significantly increases main-shaft bearing reliability, with the goal of reducing LCoE in the wind energy segment.

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