

# Lubrication of Rotor Bearings in Wind Turbines

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# SCHAEFFLER



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# 1. Lubrication of Wind Energy Turbines

## 1.1. General

The lubrication of rolling bearings mainly serves one purpose: To avoid or at least reduce metal-to-metal contact between the rolling and sliding contact surfaces, i.e. to reduce friction and wear in the bearing.

Therefore it is also a part of FAG's application consulting service, to recommend a suitable and sufficient lubrication (e.g. type, viscosity, temperature,) for FAG main bearings in wind turbines. The given recommendations have to be checked during the prototype testing of the wind turbine. Due to the actual operational conditions of the wind turbine being beyond Schaeffler's knowledge and sphere of influence, Schaeffler will neither take any responsibility nor warranty for the function and the suitability of the lubrication system (among others: especially lubricant supply, sealing) during customer's operation.

### **An insufficient lubrication means seldom a lack of lubricant but often:**

- an unsuitable oil viscosity in operating condition
- insufficient additive properties
- unacceptable cleanliness

The typical conditions for a WET rotor bearing and its lubrication are among other things high loads, slow rotation speeds, axial sliding and vibrations. Local mixed friction could occur. A standstill has to be avoided, because the oil film will then be pushed out of the contact areas. In that case, the idle rotation of the rotor has favorable effects on the distribution of the lubricant within the bearing.

The bearings shall be lubricated with oil or grease, containing effective anti wear additives. The operating viscosity must have a "not-too-soft" consistency with a minimum viscosity class of ISO VG 320 in order to ensure good lubricating conditions.

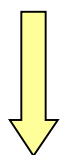
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There are different common types of lubricating systems and the following table shows some of their advantages and disadvantages:

	Oil sump lubrication	Oil circulating lubrication	Grease lubrication
<b>Advantage</b>	<ul style="list-style-type: none"> <li>• moderate costs</li> <li>• complete renewal of lubricant possible</li> <li>• increased lifetime by good conditions</li> <li>• monitoring of temperature possible</li> </ul>	<ul style="list-style-type: none"> <li>• safe solution</li> <li>• adaptable for Condition Monitoring (amount, temperature, etc.)</li> <li>• complete renewal of lubricant possible</li> <li>• filter segregates wear particles</li> <li>• increased lifetime due to good conditions</li> <li>• the lubricant could be sprayed to all locations where it is required</li> <li>• monitoring of temperature possible</li> </ul>	<ul style="list-style-type: none"> <li>• simplified design of seals and housing</li> <li>• lower costs for sealing, construction and design</li> <li>• good emergency running property in the event of lubrication failure (e.g. caused by power failure)</li> </ul>

	Oil sump lubrication	Oil circulating lubrication	Grease lubrication
<b>Disadvantage</b>	<ul style="list-style-type: none"> <li>• higher costs for seal system, etc.</li> <li>• control more difficult (e. g. oil level and quality)</li> <li>• segregating of wear particles more difficult (e. g. through magnetic system)</li> <li>• bad emergency running property in the event of lubrication failure if rotor doesn't turn</li> </ul>	<ul style="list-style-type: none"> <li>• higher costs for seal system, oil pump, filters, pipes, etc.</li> <li>• bad emergency running property in the event of lubrication failure (e.g. caused by power failure)</li> </ul>	<ul style="list-style-type: none"> <li>• impossible to segregate wear particles</li> <li>• grease could become soft due to vibrations</li> <li>• frequent maintenances</li> <li>• the lubricant has to be changed completely after three to five years</li> </ul>

The different lubrication possibilities are listed in the following. Starting with the today's customary way, followed by further steps towards a better lubrication system.



- Grease lubrication, semi-annually re-lubrication interval**
- Grease lubrication, with higher frequency of re-lubrication**
- Oil sump lubrication**
- Oil circulation system**

For more detailed information, please refer to our publication [TPI 176 "Lubrication of Rolling Bearings"](#).

**1.2. Lubrication at extreme weather conditions**

When a lubricant has to be chosen for usage at very low temperature conditions, an important issue is the starting frictional moment of the bearing. The magnitude of the frictional moment depends on the loads, the speed and the lubricant viscosity.

At oil lubrication, this effect could be minimized easily by heating the oil before the turbine starts. But if grease lubrication is used, the type of the grease has to be suitable for the expected temperatures.

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1.3. Life reduction due to water content in the lubricant

The effects of liquid contaminants in lubricants are still widely underestimated. Even pure water without any additional aggressive agents has considerable potential for causing damage in rolling bearings. This potential can be categorized as follows:

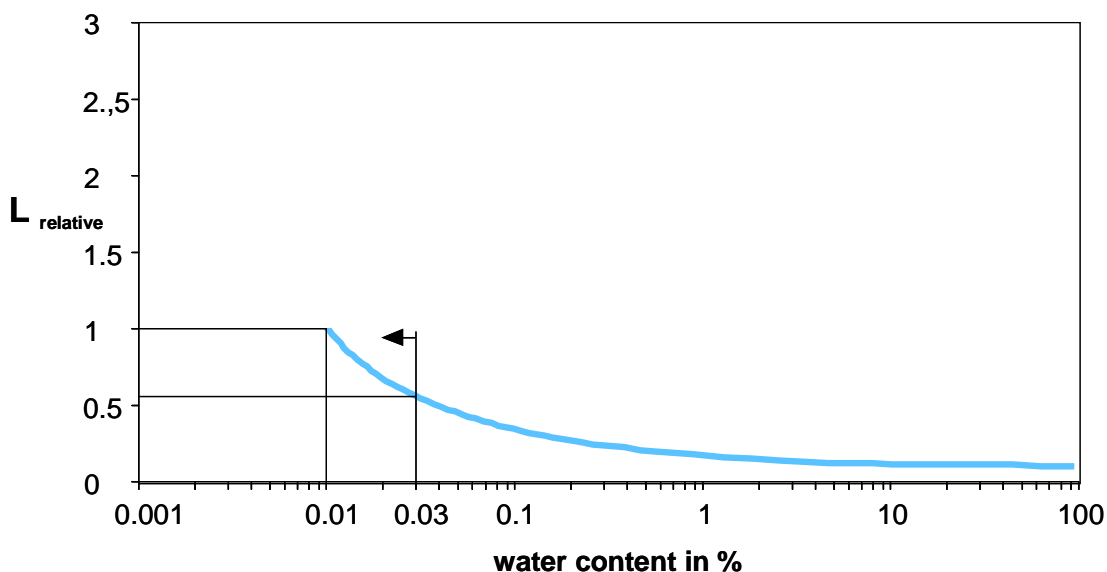
- Fatigue life reduction
- Wear
- Acceleration of the aging process and of the formation of lubricant residues
- Destructive corrosion

Depending on the amount of water in the lubricant, and depending on the type of lubricant and bearing material, one or several of these damage causes can take effect, resulting in inoperativeness or destruction of the bearings.

The reasons for water ingression could be:

- Poor housekeeping of new lubricants (e.g. upright stocking of barrels in the open air)
- Leakage in water coolers or heaters (e.g. through cracks or faulty seals)
- Condensation of moisture due to temperature changes

For oil lubrication the following graphs shows the reduction of the life time depending on the amount of water in the oil:



1.4. The influence of temperature to lubrication regimes

The friction and lubrication behavior and the achievable life of the rolling bearing are dependent on the lubrication regimes:

- Full lubrication: The surfaces moving relative to each other are separated completely or almost completely by a lubricant film.
- Mixed lubrication: If the lubricant film thickness is too small, solid body contact occurs partially. As a result, so-called mixed friction is present.
- Boundary lubrication: Fluid friction is present only partially. Predominantly, solid body contact occurs. If the lubricant contains suitable additives, reactions occur between the additives and the metallic surfaces in the solid body contacts under conditions of high pressure and high temperature.

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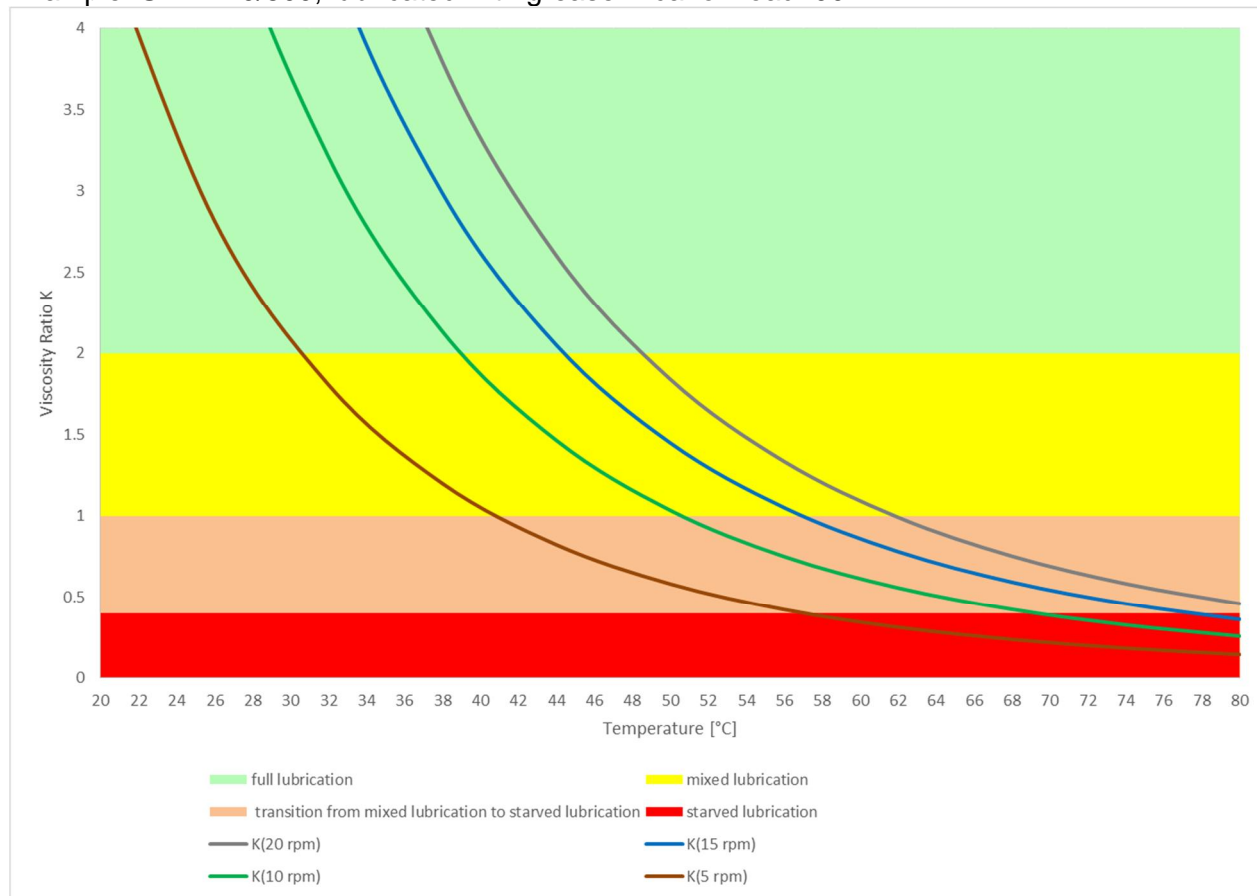
The viscosity ratio  $\kappa = v / v_1$  is an indication of the quality of lubricant film formation:

- $v$ : kinematic viscosity of the lubricant at operating temperature
- $v_1$ : Reference viscosity of the lubricant at operating temperature

Lubrication regimes depending on the viscosity ratio  $\kappa$ :

- $\kappa \geq 2$ : full lubrication
- $\kappa \geq 1$ : mixed lubrication
- $1 \geq \kappa \geq 0,4$ : transition from mixed lubrication to starved lubrication
- $0,4 \geq \kappa$ : starved lubrication

Example: SRB 240/800, lubricated with grease Arcanol Load400



### 1.5. Sealing

The choice of a suitable sealing arrangement is of special importance for a successful lubrication. On one hand it has to prevent external particles from contaminating the lubricant and on the other hand it has to ensure that the lubricant is available where it is required and cannot leak from the system.

Depending on the operating conditions contact sealings, contact-free sealings and combinations of these are available. If the housing is a part of FAG’s supply, FAG develops also suitable sealing arrangements.

The reaction of sealing materials with lubricants differs widely. They can swell, shrink, embrittle or even dissolve. Operating temperatures, lubricant composition, additives and duration of exposure can play a major role here. Seal and lubricant manufacturers should therefore be consulted for seal compatibility.

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## 2. Oil (circulating) lubrication

### 2.1. In general

Oil circulation lubrication with filtering has a lot of advantages as already mentioned in chapter 1.1. Especially if machine components close-by (e.g. the gearbox) are supplied with oil as well. If heat must be dissipated by the lubricant, oil lubrication offers the best prospects.

As lubricant, we suggest an (mineral) oil with a viscosity class of at least VG 320 and with additives, which are suitable for bearings. Further important characteristics of the oil:

- Passed 4-step-test
- Wetting capability over time (please see chapter 2.4)

We strongly recommend to inquire these test results at the oil manufacturer.

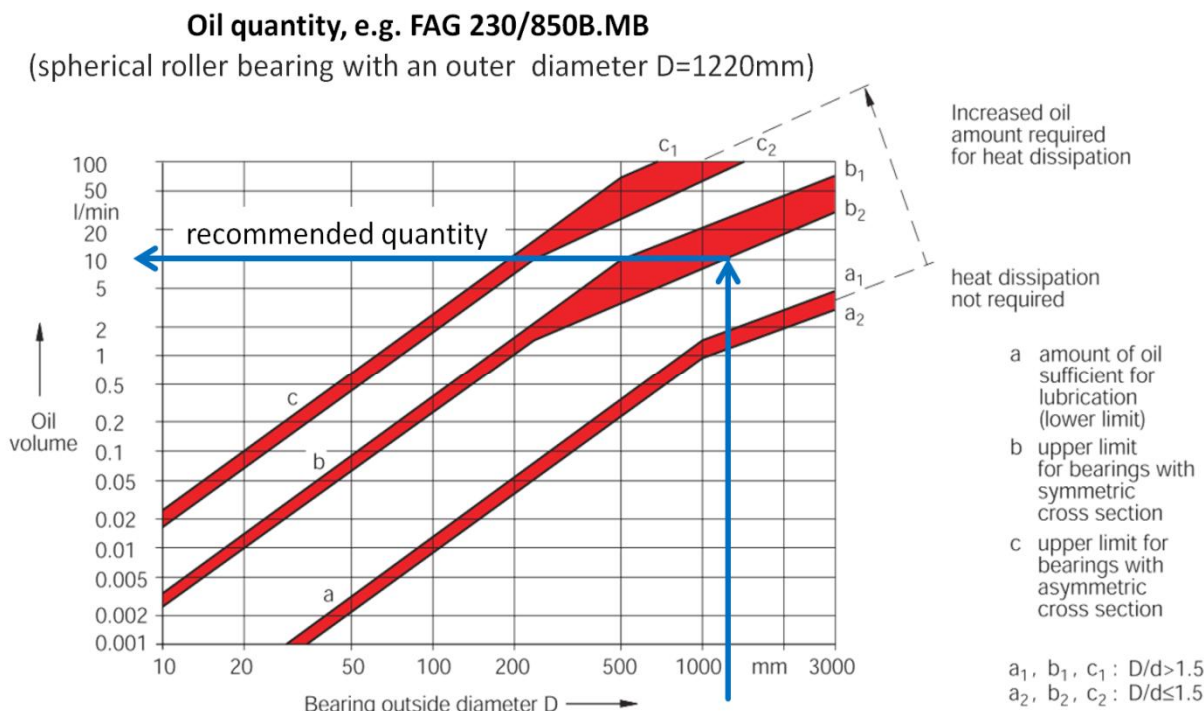
The period for oil changes should be scheduled by means of bearing inspection, operation data and oil inspections/analyses (once per year at minimum).

Rolling bearings have to be lubricated before turbine start. At a circulating oil lubrication, this is achieved by starting the oil pump before the wind energy turbine is put into operation.

For recommendations regarding the supply of lubricant to the bearings, please see our brochure [TPI 176 "Lubrication of Rolling Bearings"](#).

### 2.2. Amount of oil

The oil volume required depends on several conditions. The following graph gives a first estimation of the necessary quantities, depending on the outer ring diameter and the bearing type. (From FAG publication WL 81115/4EA, "Rolling Bearing Lubrication", page 44). But this estimation cannot substitute a more detailed heat balance calculation.



For example the oil quantity recommended for the bearing FAG 230/850B.MB (spherical roller bearing with an outer diameter  $D=1220\text{ mm}$ ) should be approximately 10 litres per minute at minimum (please see graph "b" above; graph "c" can be used for tapered roller bearings, if the

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oil flows from the small inner ring lip to the large inner ring lip). However the optimum amount of oil should be revealed during tests.

### 2.3. Filtering

Modern filtering elements retain a wide spectrum of particles every time the oil volume passes through them. The filtration ratio is indicated by the value  $\beta_x$  and shows the ability of the filter to retain particles of certain sizes (ISO4572).

The oil has to be filtered according to ISO 4406 to an oil cleanliness class of at least 18/16/13 (requiring a filter mesh size of  $\beta_{25} \geq 75$ ), before it is sprayed into the main bearing. For very large bearings (bore diameter larger 1000mm) a cleanliness class of 19/17/14 is sufficient. The filter unit and the oil flow have to be monitored continuously.

### 2.4. Lubrication supply during special conditions

During idling and turbine failures (e.g. with possible grid losses), the minimum lubricant quantity to the bearing has to be guaranteed. Additionally a good wetting capability of the oil is needed to protect all functional surfaces against metal-metal contact.

Especially during standstill, fretting corrosion and still stand marks may occur. Therefore a minimum oil quantity (depending on the regular oil amount) has to be pumped through the lubrication system in certain intervals and for a certain duration. Please see the following chart for further details:

Working condition		Normal production	Tailspin	Failure	
				rotating	stopped
Wind speed	[m/s]	3 - 25	< 3; > 25	-	-
Rotor speed	[1/min]	> 2; < 30	> 0; < 2	> 0; < 2	0
Pump interval	[h]	-	0.25	0.5	0.5
Pump duration	[min]	permanent	5	5	5
Oil quantity	[%]	100	75	75	75
Maximum acceptable duration	[days]	-	-	6	3

For longer standstills and unpredictable events (e.g. caused by power failure) which could occur especially in offshore applications an oil with a sufficient wetting capability is recommended.



### 3. Grease lubrication

Grease lubrication is used for approx. 90 % of all rolling bearings, among other things because of its simple and cost effective design and simple components. Re-lubrication at appropriate intervals has to be planned and grease supply, discharge drain holes and a grease collecting container for the used grease must be provided.

#### 3.1. ARCANOL – Tested Grease

In many years cooperation with several established lubricant manufacturers, FAG has developed lubricating greases that are particularly suitable for bearings. The constant high quality of these ARCANOL greases is ensured by testing every single batch according to strict guidelines and with special tests.

For main bearings in wind energy turbines, our recommendation is to use FAG Arcanol LOAD400. This grease shows even at a starting temperature of -40 °C a low starting frictional moment. Therefore this grease combines an acceptable starting torque with a good base oil viscosity, necessary for this kind of application.

By the end of March 2009 another grease FAG Arcanol LOAD460 was released. We recommend the usage of this grease in combination with bolted cages and if an improved behavior against false brinelling is required. This grease has a NLGI class of 1 and it is applicable in a lower temperature range.

If the starting temperature is often below -50° C, we recommend to use the grease ARCANOL MULTITOP, due to its even lower starting frictional moment. Also in cases, where the isothermal operational temperature is about 5° C (or below), ARCANOL MULTITOP should be used.

	<b>Lower operation temperature</b> (acc. to FE8 low temperature torque test)	<b>Maximum continuous operation temperature</b> (without usage reduction)	<b>Upper operation temperature</b> (acc. to DIN51821)
FAG Arcanol LOAD400	-40 °C	+80 °C	+130 °C
FAG Arcanol LOAD 460	-40 °C	+80 °C	+130 °C
FAG Arcanol MULTITOP	-50 °C	+80 °C	+140 °C

In addition to the suitability of the relevant greases for low temperature applications, the feeding of the grease at low temperatures has to be considered.

The excellent performances of those FAG greases have been proven in many cases by wind turbine manufacturers and operators.

Please refer to our brochure [TPI 176 “Lubrication of Rolling Bearings”](#) for more details.

#### 3.2. Greases of other manufacturers

In few cases FAG tested the suitability of greases from other manufacturers. In most cases, these greases have been found to be equally rated to FAG products (referring to typical mechanical and chemical properties of the grease).

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But those test results have just a temporary significance, as they are based on samples of single batches. As there are no continuous tests, changes and variations of those Non-FAG products may not be detected.

Even if the main properties of the chosen grease fulfils the requirements and are comparable to the respective FAG grease mentioned, its usability with FAG main rotor bearings in wind turbines is not guaranteed. Differences in additives and quality variations in manufacturing are possible. Deviations and poor performance regarding low temperature torque, anti-wear properties or poor mechanical stability of the grease could be the result. Due to this, FAG cannot assume any responsibility for performance, properties, quality and serviceability of non FAG lubricants.

### 3.3. Miscibility and compatibility of greases

Generally drastically changes of the grease structure and softening (in rare cases also hardening) may occur by mixing different greases. Also WEC-critical additive-combinations could arise. Even with mixtures with base oil and thickener types which seem to be compatible in the past those effects can not be excluded. If mixtures of grease can not be avoided, FAG generally recommends to check the compatibility in specific tests before.

Those tests may be performed by FAG on customer order and for payment. Again this will lead to momentary results, as the mixture grade in reality may not be covered, the blending of more than two greases might occur and the composition of the respective greases might change.

Nevertheless, even if the compatibility of a grease mixture (with respect to base oil and thickener) had been proved in specific tests, a reduction of the performance can not definitely be excluded, due to the additive interaction.

Therefore: If (especially in cases of re-lubrication) the grease type is changed, the old grease has to be flushed out with a large amount of new grease. Provided this can be done with respect to the existing design of the bearing location. A certain amount of new grease should be pressed in after a relatively short period of time.

### 3.4. Initial fill

To grant grease supply to all contact areas (inner ring, rolling elements and outer ring), it is necessary to fill the bearing cavity, the housing cavity and the labyrinth gaps completely with grease.

A large quantity of the bearing grease will be pushed into the housing during operation. This volume has to be taken into account for the determination of the initial grease amount for housing and bearing cavities. Following quantities are recommended for initial fills (the amounts should be adapted by the customers and users, depending on their experiences):

- Bearing cavity: 100 %
- Labyrinth gaps: 100 % <sup>1)</sup>
- Housing cavity: 50 %

These considerations prevent from having too much grease, which escapes from the housing during operation. Exact values are given in the wind energy turbine specific "Mounting and Maintenance Instruction", or can be supplied by the Application Engineering of FAG.

## Lubrication of Rotor Bearings in Wind Turbines

Depending on the temperature level and the environmental temperature, small amounts of the initial greasing will escape through the drain hole during start up phase. Nevertheless Schaeffler recommends to use this amount of grease to ensure the lubrication of all contact surfaces during the start of operation.

<sup>1)</sup> During assembly all contact surfaces of sealings (V-Ring or radial seal ring) should be moistened with grease. This can be done by using a brush or grease pump. Labyrinth gaps (if existing) should be filled through grease nipples 100 %. To ensure this, filling of labyrinth gaps or housing cavity respectively should be done until the grease is escaping through the sealing contact equally around the circumference.

### 3.5. Re-lubrication

The following re-lubrication intervals and quantities are minimum recommendations. The actual required demands depend on various conditions like vibrations, temperatures, humidity, etc. These conditions could require higher quantities and/or frequencies.

#### 3.5.1. Before putting into operation

The time period between initial greasing and putting into operation should not be longer than one month. Of course this limit does also depend on actual temperatures, vibrations, packaging, etc. during this time. If this period is exceeded, fresh grease has to be added to the bearing, right before the wind energy turbine is put into operation. The amount should be approx. 5 – 10 % of the bearing cavity (i.e. of the initial 100%-filling of the bearing).

#### 3.5.2. Replenishment intervals

In most cases it is difficult to remove the used grease entirely from the bearing when re-lubricating it. Consequently, the re-lubrication quantities have to be larger. A weekly or monthly replenishment should be preferred (e.g. by means of an automatic central lubricating system). A continuous greasing is the optimum.

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3.5.3. Replenishment quantity for bearing and housing cavity

The appropriate amounts of grease for replenishment can be calculated for different intervals:

$$m_R = x \cdot D \cdot B \quad [g]$$

$m_R$  = replenishment amount per interval (e.g. per day, week)

$D$  = bearing outer-Ø [mm]

$B$  = bearing width [mm]

$x$  = re-lubrication intervals factor

continuously / daily:	0,00006	...	0,00008
weekly:	0,00040	...	0,00054
monthly :	0,0015	...	0,0021

The replenishment frequency and quantities are minimum recommendations. Vibrations, humidity, etc. could demand higher quantities and/or frequencies. The optimum settings should be identified during operation and due to field experiences.

3.5.4. Replenishment quantity for labyrinth cavity

The appropriate amounts of grease for replenishment can be calculated for different intervals:

$$m_R = x \cdot D \cdot B \quad [g]$$

$m_R$  = replenishment amount per interval (e.g. per day, week)

$D$  = circa Ø of labyrinth [mm]

$B$  = labyrinth width [mm]

$x$  = re-lubrication intervals factor

continuously / daily:	0,00006	...	0,00008
weekly:	0,00040	...	0,00054
monthly :	0,0015	...	0,0021

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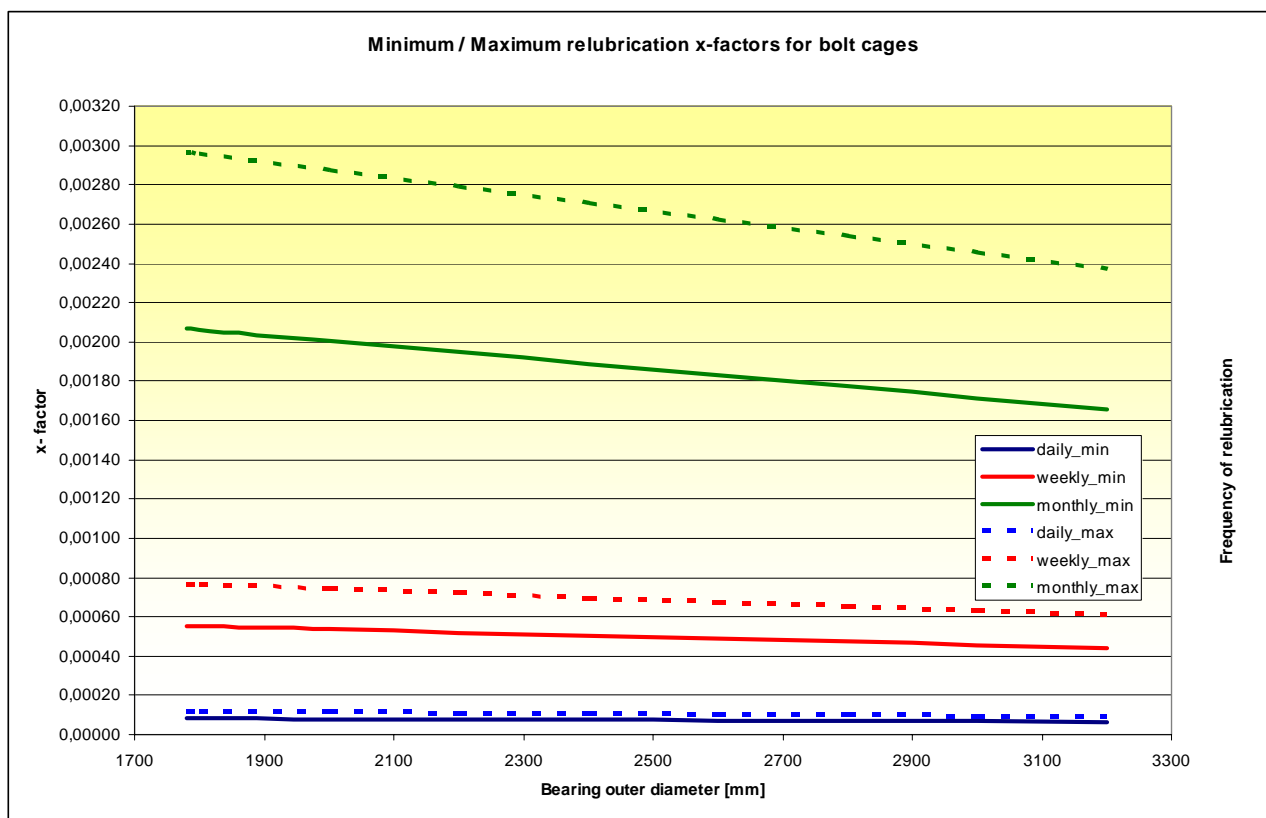
3.5.5. Replenishment quantities for bearings with bolt cage

Replenishment quantities for bearings with bolt cage are higher to ensure the appropriate lubrication of the bolt – roller bore contact. Also a short term frequency for re-lubrication is recommended (daily or weekly). Therefore Schaeffler recommends to use the following re-lubrication interval factors for the calculation of the replenishment amounts:

Values for bearing outer diameter ≤ 1800 mm:

continuously/ daily:	0,000083 ...	0,000113
weekly:	0,00055 ...	0,00076
monthly:	0,00207 ...	0,00296

Values for bearing outer diameter > 1800 mm ≤ 3200 mm:



Exact values can be provided through Schaeffler application engineering department for wind energy turbines.

The replenishment frequency and quantities are minimum recommendations. Vibrations, humidity, etc. could demand higher quantities and/or frequencies. The optimum settings should be identified during operation and due to field experiences.

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### 3.5.6. Schaeffler warranty for the grease

#### Grease filling of bearing by Schaeffler

- Grease not recommended by Schaeffler  
The bearing will, at the customer's explicit request, be greased with grease not recommended by Schaeffler. Schaeffler usually recommends a different kind of grease and does neither have relevant field nor other relevant experience with the grease requested by the customer. The functionality and suitability of the requested grease for the application of the bearing intended by the customer or the operating conditions (e. g. speed range, temperature, etc.) is therefore subject to the customer's sole responsibility. Schaeffler does not take any warranty in this regard.
- Grease recommended by Schaeffler  
According to Schaeffler's recommendation the bearing will be greased with Arcanol grease. In correspondence with our test results and field experience this grease seems to be suitable for usual applications and the operation conditions (e. g. speed range, temperature) prevailing in such cases. Due to the actual operational conditions being beyond Schaeffler's knowledge and sphere of influence, Schaeffler will neither take any responsibility nor warranty for the function and the suitability of the grease during customer's operation.

#### Grease filling of bearing by customer

In the event the customer itself greases the bearing, it is customer's sole and exclusive responsibility to choose the used grease as well as to duly perform the greasing. Schaeffler bears no warranty in this regard.

- Grease not recommended by Schaeffler  
According to Schaeffler's information, the bearing will be greased with grease not recommended by Schaeffler. Schaeffler usually recommends a different kind of grease and does neither have relevant field nor other relevant experience with the grease potentially used by the customer. The functionality and suitability of the aforementioned grease for the application of the bearing intended by the customer or the operating conditions (e. g. speed range, temperature, etc.) as well as the filling of the bearing with grease is therefore subject to the customer's sole responsibility. Schaeffler does not take any warranty in this regard.
- Grease recommended by Schaeffler  
According to Schaeffler's information, the bearing will be greased with the recommended Arcanol grease. In correspondence with our test results and field experience this grease seems to be suitable for the usual application and the operation conditions (e. g. speed range, temperature) prevailing in such cases. Due to the actual operational conditions being beyond Schaeffler's knowledge and sphere of influence, Schaeffler will neither take any responsibility nor any warranty for the functionality and suitability of the grease during customer's operation and the filling of the bearing with grease by the customer.

## 4. Maintenance

Maintenance of wind turbine bearings shall be carried out regularly and in proper time. Concerning the main bearing and its lubrication, the basic maintenance operations are re-lubrication, evaluation of lubricant (quantity and quality), seals check (aging), inspection for damages (housing and bearings), inspection for leakages and inspection/replacement of the components in the oil lubrication systems.

Also check the cleanliness of the seal contact area and the presence of grease.

During maintenances, the raceway surfaces (inner ring and outer ring) and rolling elements should be inspected and lubricant samples at different bearing locations should be examined.

### 4.1. Exchange of lubricant

The exchange of the lubricant should be done during turbine standstill (rotor shaft secured against movement) and calm or low wind. Please see also the turbine specific security instructions.

#### 4.1.1 Exchange of Oil

Usually after two to five years (depending on oil analyses and operation experiences for the specific wind turbine and its site), the oil has to be exchanged completely. At this occasion, the surfaces of the raceways and the rolling elements should be inspected.

Furthermore it is important to clean or renew the filter, to clean drain plugs, tank and housing. In cases of serious contamination, the system has to be cleaned by flushing with fresh oil. The old seals have to be checked for damages and if necessary new seals have to be installed (if specified in the Mounting and Maintenance instruction, the rubber seals have to be greased.)

#### 4.1.2 Exchange of Grease

Because the old grease is pushed to the cavity of the bearing surroundings during the replenishment, an exchange of the complete grease is necessary after approx. 3–5 years. The appropriate time depends on the grease condition. Furthermore this is the only way to remove wear particles and to create free space for new grease.

The old grease can be removed with a suitable (plastic) tool or exhausted with a pump. In cases of serious contamination, the system has to be cleaned by flushing with fresh grease (flushing with oil is not recommended due to the risk of grease dilution → please see also chapter 3.3.).

The old seals have to be checked for damages and if necessary new seals have to be installed. After that they should be moistened with grease and the labyrinth seals filled with grease (see chapter “initial fill”).

Finally the bearing cavity has to be filled with grease, as described in item “initial fill“. While the shaft is turning slowly more grease shall be pressed through the lubrication channels until small amounts of grease are pushed out of the seals.

## 4.2. Examination of Lubricants

On request, FAG performs a qualified lubricant analysis. For this purpose, a sufficient amount of lubricant has to be filled in clean containers. They have to be sealed and marked carefully (to make it possible to relate them to the original sample location). For a grease analysis, there should be always at least two samples been taken: One from a location near the rolling contact and one from a housing part which is far away from the bearing as reference. A sample of new and unused grease, which is used for re-lubrication, should also be delivered to FAG as reference.

## Schaeffler Technologies GmbH and Co. KG.

Wind Energy