**Introduction**

Using sustainable and renewable energy resources becomes more and more important. One possibility is the use of the energy content of the wind. During the past 20 years the wind energy technology experienced a remarkable development. More than 50 countries worldwide are producing wind energy. The forecasts for 2005 are about 8,525 MW installations in Europe and 12,175 MW worldwide. The accumulated capacity at the end of 2005 will be in the order of magnitude of 65,000 MW (2). The main growth market is still Europe, followed by the USA and by Asia. In Europe the countries with the highest figures are Germany, Spain and Denmark. Until the end of 2005 in Germany an accumulated power output of about 18,000 MW will be installed (2).

Especially in Europe it becomes more and more difficult to find suitable onshore places for more wind parks. As a consequence, offshore places are defined as alternatives for wind power plants. The advantages of offshore parks are the higher energy potential due to the higher wind speeds. But some disadvantages have to be faced especially regarding economic aspects due to the much higher investment and maintenance cost. Therefore an optimized balance between the advantages and the disadvantages have to be found. As one of the consequences larger wind mills with rated power outputs of at least 5 MW are under development. Fig. 1 shows such an offshore wind park.

**Size and Dimensions**

Nowadays wind energy plants with a power output of 3 to 5 MW can be built. They need bearings with a diameter of more than 2 m (Fig. 2).

![Figure 2 Sizes and Dimensions](image)

The next table shows the rotor diameters depending on the power output:

<table>
<thead>
<tr>
<th>Power Output (kW)</th>
<th>Rotor Diameter (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>225</td>
<td>27</td>
</tr>
<tr>
<td>300</td>
<td>33</td>
</tr>
<tr>
<td>500</td>
<td>40</td>
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<tr>
<td>600</td>
<td>44</td>
</tr>
<tr>
<td>750</td>
<td>48</td>
</tr>
<tr>
<td>1000</td>
<td>54</td>
</tr>
<tr>
<td>1500</td>
<td>64</td>
</tr>
<tr>
<td>2000</td>
<td>72</td>
</tr>
<tr>
<td>2500</td>
<td>80</td>
</tr>
</tbody>
</table>

These large rotors with speeds of about 30 RPM need towers with a height of 100 m and more. The huge drive line equipments include all the gearings and control mechanisms necessary to operate the plant (Fig. 3).
These drive line equipments with all the other auxiliary parts are accommodated in gondolas or nacelles in which humans can stand and move in an upright position (Fig. 4).

**Tribological Contacts**

Wind energy plants consist of the following main components:

- Concrete fundament with fundament screws
- Steel tower of several elements bolted together
- Rotating track with large main bearings and open gears
- Gondola with shaft supports, gears and generator
- Rotor blades and rotor bearings

Frictional contacts are located in the following elements:

- Main bearings
- Shaft bearings
- Gear boxes with gears and bearings
- Hydraulic systems
- Yaw mechanisms
- Lubricating oil circuits

Fig. 5 shows schematically such a wind turbine.

In more detail the following machine elements have to be lubricated:

- Self-aligning radial roller bearings (steel and brass cages)
- Cylindrical roller bearings
- Tapered roller bearings
- Ball bearings
- Tooth gears
- Worm gears

**Main Components**

A total view of such a wind turbine with some more details of the different elements is shown in Fig. 6.

The tower of the wind plant carries the nacelle or gondola and the rotor. By the yaw mechanism the nacelle is turned to get the rotor blade always into the best relative position to the wind (only a few degrees at a time). Holding brakes have to stabilize the nacelle. Inside the nacelle the key components of the wind turbine are located—the gear boxes and the electrical generator. Outside the nacelle the wind rotor is located consisting of the blades and the hub. The rotor blades capture the wind and transfer its power to the rotor hub.
Rotor Details
High yield, high strength, weight optimised rotor blades
- Smooth rotor dynamics
- Generously designed motor hub with high connection rigidities

Rotor Blades
Number: Between 1 and 4, mostly 2 or 3
Attachment to the hub:
- Able to turn around its longitudinal axis (pitch)
- Bolted to the hub (stall)

Rotor Brakes
Powerful, full-scale twin calliper brakes
- „Soft-Brake“-function
- Low heating due to large brake liners

The hub of the rotor
is attached to the low speed shaft of the wind turbine

The low speed shaft connects the rotor hub to the gear box
Rotor rotation (low speed shaft): 19 to 30 RPM
High speed shaft: about 1,500 RPM

Drive train details
- Proven, reliable 3-point bearings
- Broad rotor bearings provide high stability
- High tensile, tough, heat-treated main drive shaft
- Planetary/spur gearbox with helical gears for quiet and efficient operation
- Efficient oil cooling and oil filter system

The high speed shaft drives the electrical generator
- 4/6 pole induction generator guarantees high yields
- Air cooling provides low operating temperature
- Large bearings ensure maximum reliability

Hydraulic System
- Intelligent hydraulic system for the control of the rotor blade tips and the breaking systems
- High quality proven components in redundant configuration provide excellent reliability

Lightning Protection
- Lightning protection zone concept
- Internal and external protection system

Operating conditions
The non-steady operating conditions for wind energy plants are characterized by the following effects:
- Vibrations of the plants resulting in eigenfrequencies and resonances
- Speed changes from slow to fast (multiplier)
- Extreme load ranges (very low to very high)

- Frequent load changes
- High sudden load peaks
- Emergency braking with additional wind forces
- Flow medium air with space orientated and stochastical loads
- Difficult maintenance procedures
- Extreme environmental conditions (temperature, humidity, salt, dust)

Needed Lubricants
To cover the requirements of wind energy plants the following basic lubricants have to be provided:
- Lubricating oils
- Lubricating greases
- Hydraulic oils

In more detail the following oil types have to be used:
- CLP Gear Oils (main gears, yaw drives, worm gears)
- HLP Hydraulic Oils (pitch, disc brakes)
- High Performance Multi-Purpose Greases (main bearings, blade bearings, cardan shafts, yaw bearings, plain bearings, generator bearings)
- Open Gear Lubricant (yaw gear).

Several high performance properties of these lubricants have to be tested. Among these are:
- Anti-Wear and Extreme-Pressure-Properties
- Viscosity Index
- Oxidation Stability
- Corrosion Protection
- Water and Air Release Properties

Unfortunately, up to now there do not exist complete specifications for all lubricants needed in a wind power plant. But, facing actual and future lubrication engineering difficulties, especially with the growing development of offshore wind parks, the wind mill manufacturers and the lubricant suppliers started closer co-operations in order to solve the tribological problems. The result of these co-operations is the definition of lubricant requirements, partly based on standardized minimum requirements.

Requirements for CLP Oil according to DIN 51517 (mineral oils)
- Viscosity ISO VG 230 or ISO VG 320
- Viscosity Index - 90
- Excellent copper compatibility - 2-100A 3DIN EN ISO 2160
- Excellent corrosion protection - O-A (DIN ISO 7120)
- Excellent wear protection in roller bearings - rolling element max. wear 30 mg (FE 8 Test)
- High load carrying, pitting & small pits capacity - Failure load 12/FZG
- High thermal and hydrolytic stability
- Good low temperature pumpability
- Compatibility with elastomers
- Good antifoaming properties
- Good air release properties

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High Performance Requirements for Gear Oils (3)

- In some cases of application the minimum requirements for CLP Gear Oils, according to DIN 51517, do not cover those of wind power plants.
- These high performance requirements are characterised by:
  - FZG Failure Load 14
  - FZG Small Pits Carrying Capacity >10 (high)
  - Viscosity Index VI>150
  - Pourpoint about -40 °C
  - FE8 Wear<30 mg

These requirements can be covered only by synthetic gear oils, e.g. based on polyalkylpolymers.

Open Gear Greases

The basic requirements can be defined as follows:
- Temperature range -30 to +100 °C
- NLGI 1
- Excellent wear protection
- High loading carrying capacity
- Adhesive
- Good pumpability

Necessary properties of semi-fluid greases (2)
- NLGI-Grade 1
- Base Oil Thickener synth./Li-spec. soap
- Viscosity DIN 51398
  - 2100 mPas @ +22 °C
  - 1200 mPas @ -55 °C
- Operating Temperature continuous range -55 °C
  - up to +140 °C
  - short term + 160 °C
- Corrosion Protection ISO 110007 0 / 0
- Copper Corrosion DIN 51811 1 - 120
- Water Resistance DIN 51807-1 1 - 90
- FZG-Test A 8.3/90 °C DIN 51354
  - damage load stage >14

Necessary properties of high performance multipurpose Greases (2)
The basic requirements can be defined as follows:
- NLGI 2
- Temperature range -30 to + 100 °C,
  - short term + 130 °C
- Excellent copper compatibility
- Excellent corrosion protection
- Excellent wear protection (cage / rolling element wear in FAG FE8 Test)
- Excellent false brinelling protection
- Long lifetime in FAG FE9 Test
- Controlled oil separation
- Very good suitability f. central lubrication systems
- (no separation, pumpability)
- Compatible with NBR seals
- nd, value ~ 350,000 (for the generator)
  - ~ 500,000 for large size generators

These requirements exceed the minimum requirements for lubricating greases according to DIN 51825.

Further necessary properties of high performance multipurpose Greases (2)
- Base Oil Thickener: synth./Ca spec. soap
- Consistency: DIN 51818, NLGI 2
- Operating Temperature: range -55 to +140°C, short term - 55 to + 160°C
- Corrosion Protection (EMCOR):
  - ISO 110007, 0/0
- Copper Corrosion: DIN 51811, 1 - 120
- Water Resistance: DIN 51807-1, 1 - 90
- Fafnir-Test: ASTM D 4170, < 0.5mg loss
- Flow Pressure: DIN 51805 < 1400 kPa @ -50°C
- Low Temperature Torque: ASTM 4170
  - @ -40 °C starting torque 200 Nmm
  - running torque 80 Nmm
  - @ -50 °C starting torque 900 Nmm
  - running torque 500 Nmm
- FE 9 Lifetime @ 100 °C, DIN 51821,
  - F50>500 h
- FE 8 DIN 51819
- Angular Contact Ball Bearing, steady state temp. 55 °C
  - Thrust Load: Fa = 80 kN, rolling element wear 15mg
  - Speed: n = 7.5 min⁻¹
  - 500 h Running Time
- Taper Roller Bearing 536048; steady state temp. 97 °C
  - Thrust Load: Fa = 10 kN, rolling element wear 11mg
  - Speed n = 3000 min⁻¹, cage wear 25mg
  - 500 h Running Time
  - Speed Index: 750000 min⁻¹ mm

HVL.P Hydraulic Oils according to DIN 51524 - Minimum requirements
- Viscosity: ISO VG32
- Viscosity Index: >140, DIN ISO 2909
- Pourpoint: < -30 °C, DIN ISO 3016
- Corrosion Protection Copper: 2-100 A3,
  - DIN 51759
  - Steel: 0-A, DIN 51858
- FZG Failure Load: >10, DIN 51354
- Vane Pump Test, DIN 51389
  - Ring Wear < 120 mg
  - Vane Wear < 30 mg

Oil Inspection and Maintenance

Regarding inspection and maintenance of wind power plants several aspects and problems have to be faced. They are characterized by the extremely high operating conditions and the very difficult access to the plants in offshore wind parks. In principle it has to be distinguished between condition monitoring of gears and bearings and condition monitoring of lubricants.
For the evaluation of the operating conditions the following parameters have to be measured:
- wind speeds
- power output
- temperature of bearings, gears and lubricants
- vibrations
These data should be recorded continuously and evaluated using special programs available from gear, bearing and lubricant suppliers. Remote control equipment is necessary for a long time trouble-free operation of wind power plants.

The oil condition monitoring is necessary for two reasons:
- Condition monitoring of machine elements
- Oil properties

By the measurement of the content of certain components of metals in the oil, e.g. Cu, Fe, Al, Cr, indications of wear in machine elements like bearings and gear wheels can be obtained.

By the periodical measurement of certain lubricant properties, property changes against the fresh oil data can be obtained. Often the following properties are measured:
- Total Acid Number (oxidation of the oil)
- Water Content (corrosion)
- Viscosity (oxidation)
- Additive Components (wear and scuffing)
- Air Release Capacity (oxidation)
- Water Release Capacity (oxidation, corrosion)
- Foaming (change of properties)
- IR-Spectra (change of properties and additive content)

The evaluation of the measured oil properties can help to define the necessary oil change period. Oil changes have to be performed if specific limiting data are reached. These limiting data are defined by the manufacturer and the operator of the wind power plant and by the lubricant supplier. Especially for offshore wind parks oil condition sensors are very helpful, which are under development.

Summary
This paper can be summarized as follows:

- Using sustainable and renewable energy resources becomes more and more important. One possibility is the use of the energy content of blowing winds

- Wind power plants with power output up to 5 MW can be built. They have rotor diameters of about 80 m and more, which are supported in roller bearings with diameters of 2 m and more, and need towers of 100 m height and more

- The main components of wind power plants are the fundament, the tower, the nacelle or gondola containing the wind turbine consisting of the rotor, the gears and the generator
- Frictional contacts are found in the gears and the bearings. There one can find ball, cylinder roller and tapered roller bearings, spur and worm gears

- The operating conditions are characterised by vibrations, extreme speed and load changes, frequent and sudden load peaks, extreme environmental conditions and difficult maintenance procedure

- The main lubricant types which are suitable are CLP Gear Oils, HLP Hydraulic Oils, High Performance Multi-Purpose Greases and Open Gear Lubricants

- By the monitoring process, the condition of the machine elements and the changing properties of the lubricants can be evaluated

- Online sensors for condition monitoring are helpful, if not necessary

Literature

2. Pohlen J.: Lubricants for Wind Power Plants NLGI Spokesman 67 (2003), 2, 8-16