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FACT-SHEET AED-RB-17(EN)

THE GEARBOX PROBLEM REVISITED

by

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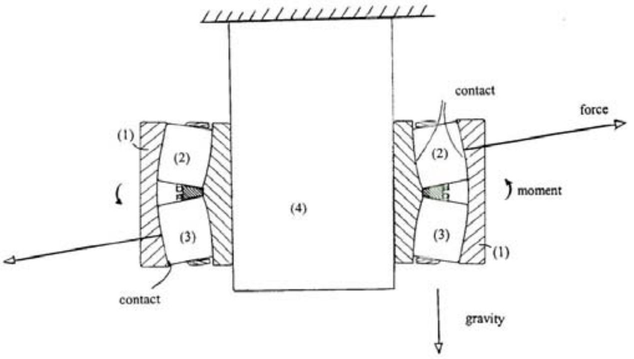

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The gearbox problem revisited

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Review

Strange Skriver, The Association of Danish Wind Turbine Owners
Christer Eriksson, Det Norske Veritas (DNV)

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Abstract

The gearbox problem that was experienced a few years ago is probably related to a special wedging or locking phenomenon for the rollers in a spherical roller bearing. This prevents the ability of the bearing to angular compensate for misalignment, and converts actual misalignment to high additional roller bearing loads.

The wedging of the unloaded row of rollers between the inner and outer ring is likely to happen during low rotational speeds, and with the shaft tilted relative to horizontal, which is the condition for large wind turbines where also gravity plays an increasingly important role. This characteristic or problem for spherical roller bearings is a new discovery that is mainly related to the “new” designs introduced 6-8 years ago, and which in principle is a very simple phenomenon.

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Main results

In this Fact-sheet we present a hypothesis of a special locking mechanism, which can occur in spherical roller bearings under certain conditions. The locking prevents the bearing from the ability to angular compensate for misalignment, and can locally increase the bearing loads to a degree that causes failure.

The phenomenon is caused by wedging of the unloaded row of rollers between the inner and outer ring and is most likely to happen during low rotational speeds, and with the shaft tilted relative to horizontal, which is the condition for large wind turbines where also gravity plays an increasingly important role. This characteristic or problem for spherical roller bearings is a new discovery that is mainly related to the “new” designs introduced 6-8 years ago, and which in principle is a very simple phenomenon.

1. Simplified description of the phenomenon

In order to describe the phenomenon in a simplified manner, consider a spherical roller bearing positioned with the shaft vertical and suspended in a shaft through the inner ring, and with only gravity acting on the bearing.

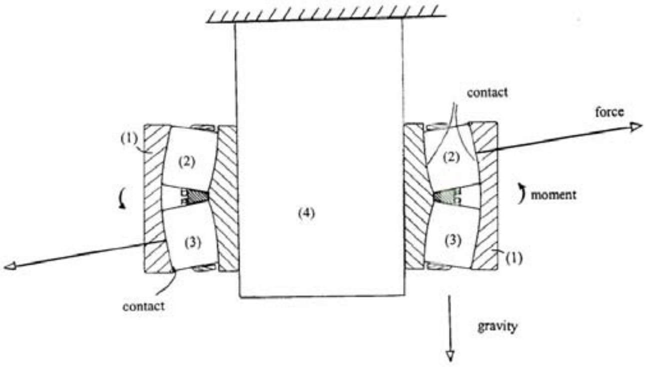

Figure 1: Bearing mounted on a vertical shaft

In this condition gravity forces the outer ring (1) downwards until contact is established between the upper row of rollers (2) and the inner and outer ring. However, important for the wedging phenomenon is that the lower row of rollers (3) is “falling” down unrestricted until contact is established at the edge of the rollers. In this position the bearing can be “locked “ for angular compensation of misalignment, even though the bearing is perfectly free to rotate around the shaft (4). If a shaft misalignment occurs in this condition, it creates a shaft bending moment that is counter-reacted by a pair of normal forces between the two rows of rollers. This creates the additional normal (radial) forces and corresponding pressures in the raceway that can overload the bearing. The degree of wedging depends upon the geometry of the bearing, in particular the diameter to widths ratio and the lubrication. The locking can be unlocked by rotating the shaft at a certain minimum rotational speed, depending upon the same parameters.

2. Operational condition

The operation and loading of the bearing in a wind turbine and in particular as part of a wind turbine gearbox is much more complicated, however, the principle of shaft bending moments (due to deformations) being converted to high radial bearing loads is the same.

In order to illustrate this for a wind turbine gearbox, consider the bearings supporting the planetary wheels, Fig. 2.

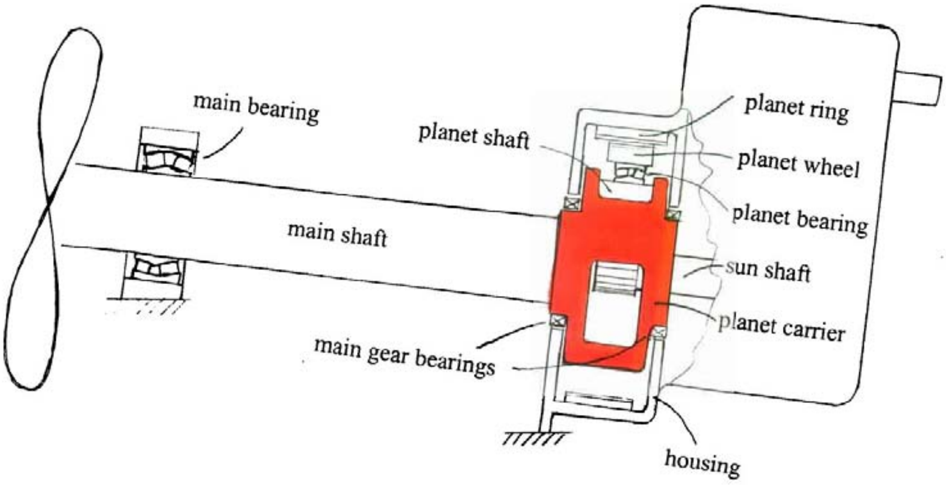

Figure 2: Illustration of drive train with one planetary bearing for each planet wheel.

This bearing is subject to all misalignments between the shaft and the planetary wheel, which is in contact with the gearbox housing that incorporates the planetary ring. All vibrations and inertia forces originating from wind turbine dynamics are affecting the gearbox housing and thus transmitted through misalignment in the planetary bearing.
These vibrating forces and misalignment e.g. due to the overhanging moment from the gearbox housing means that the bearing is performing a wobbling movement during rotation. These wobbling movements combined with the inertia forces from vibrations and gravity due to tilt (of normally 6 deg.) causes the rollers now and then to move or roll themselves into the wedged position, where the bearing is locked with respect to the ability to adjust itself for misalignment.

A finite element model of the planetary carrier is illustrated in Figure 3, as well as simulation results illustrating the deformation due to the overhanging moment from weight. The holes for the shafts supporting the bearings are visible and so is the corresponding misalignment.

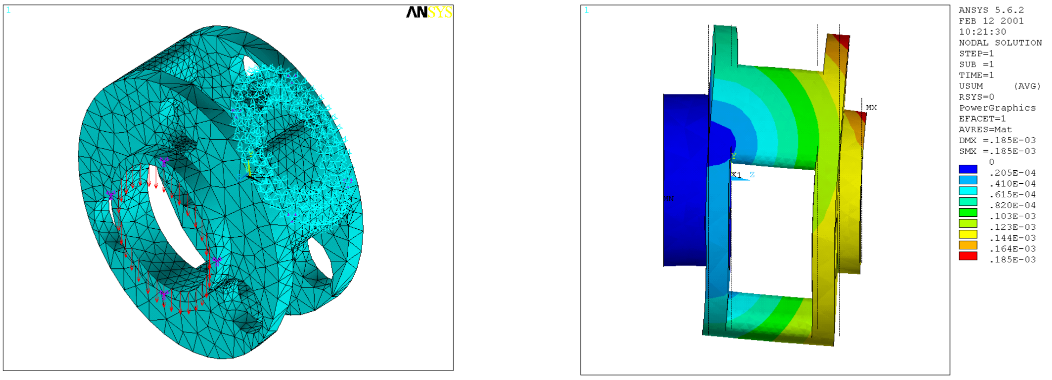

Figure 3: FEM model and bearing shaft misalignment due to carrier deformation from weight.

3. Torque fluctuations

The operational condition of a wind turbine is characterised by an ever fluctuating torque with the turbulent wind. For large turbines this variation is relatively fast compared to the rotational speed. The torque causes deformations of the carrier including the planetary shafts as illustrated in Figure 4. This means that the bearing will be subject to the corresponding misalignment several times during a revolution. So just in order to transfer the varying torque, the bearing will perform the wobbling motion.

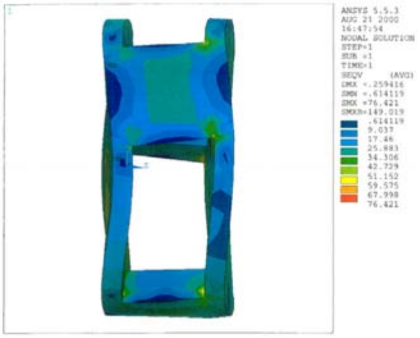

Figure 4: Carrier deformation (bearing shaft misalignment) due to torque.

3. Braking sequence

For a simpler example consider the braking sequence of a wind turbine, Fig. 5.

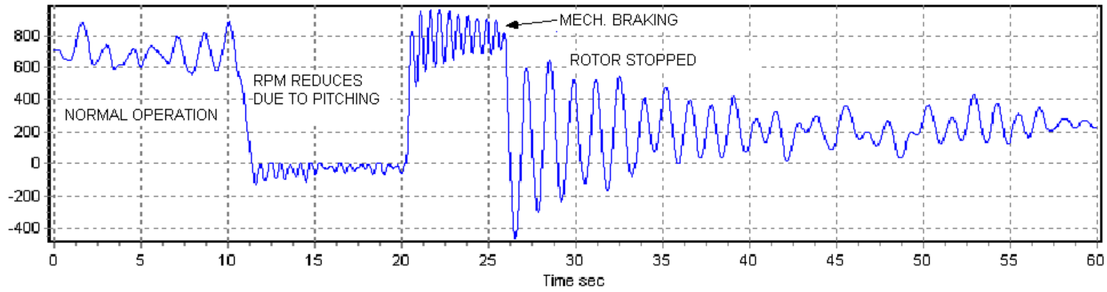

Figure 5:Shaft torque during braking sequence.

After the generator has come to a stopped position (at 27 sec.), the rotor still oscillates back and forth reaching nearly nominal torque in both directions. In this condition the bearing undergoes several load cycles from unloaded to loaded condition (in both directions) as illustrated in Fig 6.

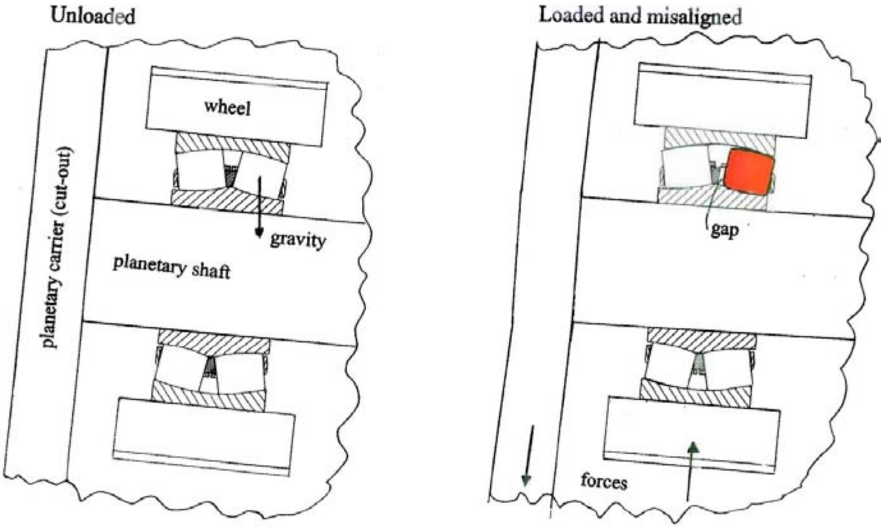

Figure 6: Load cycles with corresponding varying misalignment

The important phenomenon here is that due to the main shaft tilt, gravity causes the right hand unloaded roller at the upper position to move to the right into the wedged position. At a subsequent part of the cycle during load reversal, this roller is loaded with the nominal load and in addition the load from the bending moment due to the wedging.

A lot of parameters are determining whether the (one) roller under this condition is fixed in the wedged position and thus much overloaded from the bending moment. Some of these are the geometry of the bearing (diameter to width ratio), lubrication/friction, deformation of the planetary wheel including the outer ring and the small rotation of the rollers back and forth during the rotor oscillating motion due to flexibility of the drive train.

All together the braking sequence, on the precondition of tilt and some flexibility of the planetary carrier (or shaft) is enough in some cases to cause the wedging of the rollers with subsequent locking and overloading of the bearing. The small damages introduced during this sequence will gradually develop with time.

4. Main shaft bearing

For the typical drive train illustrated in Figure 2, also the main shaft front bearing is of the spherical roller type. When considering the gravity force due to tilt of the shaft and thrust from the rotor, this bearing arrangement is in principle different from that one in Figure 1, in that the bearing is supported at the outer ring and affected by gravity forces on the shaft through the inner ring as shown in Figure 7.

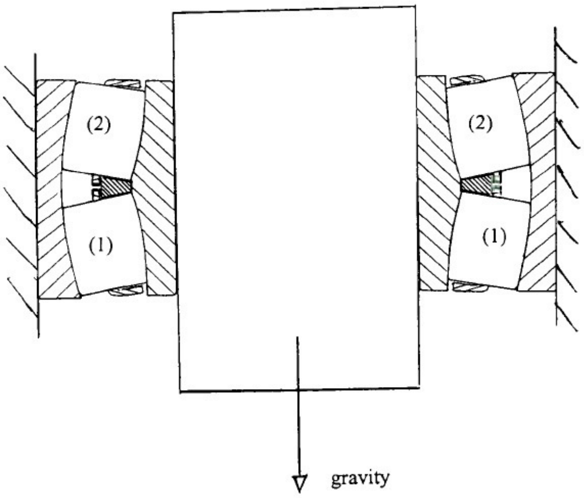

Figure 7: Bearing fixed on the outer ring and mounted vertically.

This represents the important difference from Figure 1, that roller contact is on the lower row of rollers (1) and gravity forces the upper (unloaded) row of rollers (2) downwards. This means that the two rows of rollers are forced in a direction towards each other, in which case a separation ring restricts the displacement. This will prevent the upper rollers to come to a wedged position. Thus one would expect this bearing to be less critical, which is also the experience from operation. However, the already described wedged or locked condition might happen occasionally, if the thrust becomes sufficiently negative to overcome the gravity force in the direction of the shaft. This is normally not the case during operation, however braking sequences, where blades are being pitched to feather very fast, could create this situation. In the same way, vibrations exceeding the gravity force in the tilted shaft direction on the first row of rollers might create this situation. All together the unfavourable condition is much less frequent for the main shaft bearing, as tilt has a favourable influence.

5. Discussion

It should be emphasized that the argumentation in this article is rather a hypothesis than a proven theory. The operational environment for the planetary bearings in a wind turbine gearbox is influenced by so many parameters, that a real experimental “proof” would be very comprehensive, and it might be that the phenomenon only has a catalysing effect when combined with other effects.

The research programme Aeroelastic Design entered this field of research from the point of view that the gearbox loading is an integral part of the whole wind turbine aeroelastic response and not isolated only to the drive train torque. We developed dynamic models for this interaction including the detailed dynamics and finite element modelling of flexibility of the planetary stage. Such a modelling is illustrated in Figure 8 (from Ref 1).

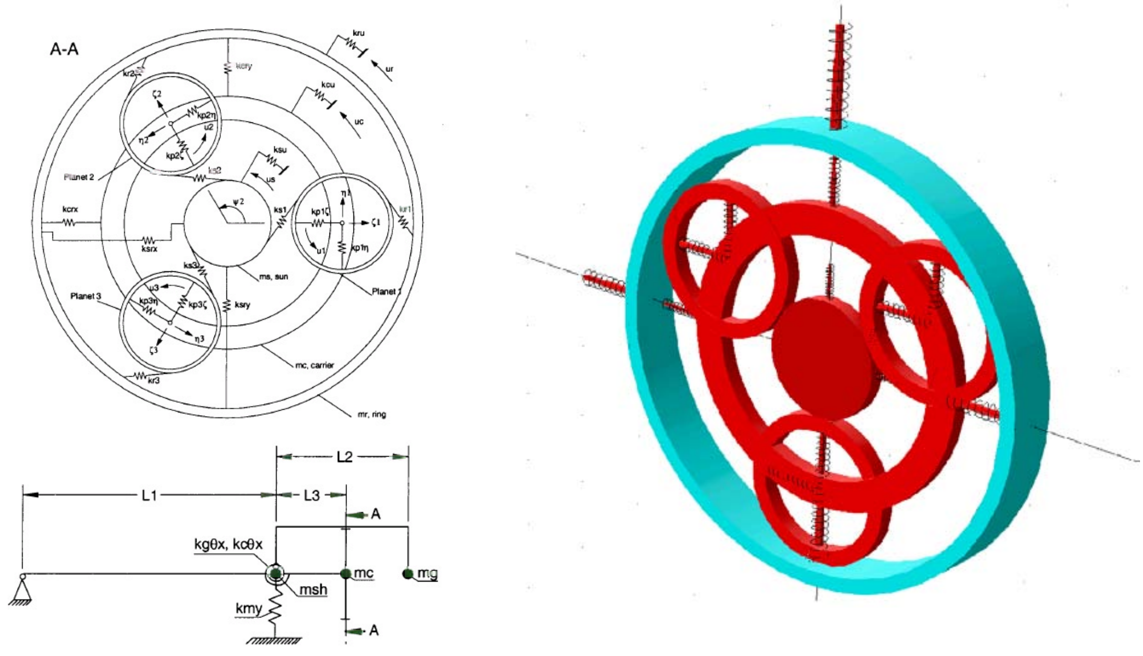

Figure 8: Dynamic model of planetary stage.

Furthermore dynamic measurements including accelerations of the gearbox were recorded and analysed for a 500 kW wind turbine (Ref. 2). The conclusion from this study was that dynamics and thus inertia forces does play a role as input to the loading and behaviour of the gearbox, as pointed out earlier in this article. However, the planetary stage is very efficient in balancing unequal loading of the three planetary wheels and bearings when exposed to external loads. Thus the observed gearbox problems should be related to the internal environment. Wobbling of the bearing e.g. due to flexibility was the characteristic that we investigated in more detail. Several experiments related to the locking effect were conducted in the laboratory with smaller types of spherical roller bearings of different radius to width ratio. It was only possible to establish a simplified loading condition and sequence of combined radial loads, varying misalignment and rotational speed, but it was very clear that the narrower types of bearings were very likely to lock completely with respect to the ability to compensate for angular misalignment even up to around 100 rpm (for a 100mm outer diameter bearing). The wide bearing did not lock completely under the simplified loading conditions, but would unlock itself at a certain bending moment even during no rotation.

With the reservations taken in the preceding paragraphs, the authors want to emphasise the reality of the locking phenomenon discovered for many series of spherical roller bearings of present day design, which anyone can convince himself about by doing the very simple experiment illustrated in Figure 1.

The reason for this locking tendency to occur at low rotational speeds, at which condition the rollers ability to adjust itself into the raceway is overtaken by gravity, is simply due to the fact that the rollers are not restricted in their movement away from each other. It seems very easy to remedy this unfavourable characteristic of the spherical roller bearing by introducing a simple restriction to the rollers relative movement in this direction. An example is given in the patent application Ref. 3.

Tendencies in today's design moves towards using different types of bearings (e.g. cylindrical roller bearings) instead of the spherical roller bearings even though this calls for more conservatism with respect to the design requirements for the wheels. However, if the wedging phenomenon presented here is the primary cause for the failures, the advantage of the spherical roller bearing with respect to compensation for misalignment could be exploited in the future.

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[3] Rasmussen, F., Thomsen, K., Larsen, T.J. Patent application PA 2002 01969 "A spherical roller bearing having a holding structure for controlling axial displacement of two rows of rollers in a direction away from each other".