Gear box damages - why?

In 2000 I wrote this in german for the journal Vindögat, who translated it to swedish and finnish. After 9 years I had it now translated to english and changed some items to avoid misunderstandings. GBö

Between the years 1997 - 99, blade damages occurred due to the leadlag stall instability. From the year 2000 on, there were more gear box damages, of which NEG/MICON-FLENDER had the worst luck [1 - 9].

Here I would like to explain seven reasons why the gearbox may brake down earlier than would be normal. I myself have seen almost all of these cases during the last 16 years.

1. Underestimated loads in stalling

If the blades are adjusted for approximately the default angle when they are clean, rated power is not reached, as the blade accumulates dirt with time. That is why the blades are adjusted for a slightly more positive angle, taking into account the future dirt accretion of the blades, and the newly erected power plant produced too much power in strong wind in the first time. On the partial load area, a slightly too positive angle (+ = nosedown, - = noseup) is not harmful.

In addition, there is the summer/winter problem; in winter, an area of high pressure will produce 20 % more power than low pressure in summer.

Sometimes adjustments were made for a definitely too high maximum power on purpose. I know certain cases in which the customers were even promised overpower in a verbal agreement! In addition to the overpower, there will be natural variation in power on the stalling area: +-20 % is quite normal.

As the overpower in power often correlates with high oil temperature, and the lubrication properties of the oil diminish, overpower is especially harmful to the gearbox.

Now that wind power plants with passive stalling are hardly manufactured any more, the damages due to this problem are more or less a thing of the past. Adding an oil cooler and a filter will not of course do any harm, but it does not have any effect on the cause of the problem.

Measures: Suitable adjustment of blade angle (may have to change later), a realistic specification of loads, a solution to the possible temperature problems.

2. Vibration in the transmission system

This applies only to a couple of power plants that are not dynamically sound. There are cases in which there will be classical torsion vibration in addition to the average power. As the loads have a non-linear effect on the lifetime, there is a difference whether the power plant operates evenly with 600 kW +- 20 % or whether the power oscillates in a sinusoidal fashion between 300 kW and 900 kW.

Solution: Unfortunately, an exhaustive one. The whole gearbox has to be re-engineered for a different distribution of rigidity, and the point of resonance has to be removed.

A well-known 600 kW plant was such a problem. All kind of tricks were used. Flywheels on the generator side, a hydrodynamic coupling, different generator slip ratios. Now these machines are no more operative, as they have been sold to Kannabistan or even further eastwards in course of the so-called Repowering. (Replacing old small turbines with new large ones, has nothing to do with the company Repower).

3. Braking dynamics

Emergency stop braking requires a 2 - 2.5 -fold rated torque from power plants with passive stalling to cover the load case "all three tip brakes fail". In 1988 - 1993, the brake was planned for the above mentioned torques, and the operating life of the brake in the hydraulics system was ca. 0.2 s. The generator is always disconnected.

The system consisting of rotor, gearbox, brake disc and generator is a classical spring-mass oscillating system. A sudden braking causes a step response, an internal vibration in an only slightly dampened system. A disconnected generator is merely a flywheel. The transmission system is thus oscillating, and in the gearbox, the maximum torque is equal to twice the braking torque, which comes to be a 4-5 -fold rated torque! This hits the static load limits of the gearbox and causes immediate damage.

It was the cause of, amongst others, a bearing damage (1000 kW power plant, 1996, Germany), and the sliding of a shrink fit inside the gearbox (600 kW power plant, 1997, Germany).

Measures:

* A choke added to the brake pressure hose, the brake activation time was made longer, some 0.6 - 0.8 s. In fact, this is not allowed for security reasons, if the loads are calculated with 0.2 seconds only. The step response is modified to a ramp response and the peaks are lowered.

* A controllable brake, such as Svendborg-Sobo (1000kW plant 1996), or a corresponding self-made hydraulic system (100 kW power plant, 1994, Germany).

* A hydraulic system with tip brake cylinders that will be approved by Germanischer Lloyd as a fail-safe system. The load case "all tip brakes fail" will be left out, and the load calculation will be performed with failing of one tip brake as the worst case. The needed braking torque decreases to circa the rated torque. This concept was used successfully in a 750 kW power plant that was designed in my then engineering office. It is the best solution. In addition, a choke can be installed to the brake pressure hose if the load calculation show that this delay is permittable.

4. Idling and partial load

Idling is often recommended in weak wind. Firstly, for the reason that in case of immersion lubrication, the bearings and teeth will remain lubricated. Secondly, for the reason that the owner will be able to say with pride, "The wind is almost still and in spite of that, my power plant is operating".

The rotor goes through varying torques in turbulence and distribution of wind, and the generator is just a flywheel. Because of that, the gearbox reverses in the turbulent low windspeeds. The reversing torque results in "hacking", dynamic load peaks on the whole drive train. Also in the simple fact that the bearing loads fall under the minimum loads for some seconds. These load cases cause gliding of the rolling elements and subsequent damage.

The toothing does not generally suffer, but helical teeth cause axial forces to all the bearings. If the bearings are not playfree and prestressed, they will suffer from small movements and shocks.

Measures: No idling, but instead a waiting position with brakes on. The power plant is not started until there is enough wind, so that the generator will produce a continuous power output without idling. Disconnect when too much negative torques occur. Additionally many gearbox manufacturer have redesigned the planet bearings. The commonly used roller bearings were replaced with tapered roller bearings, which were slightly prestressed. This allowed some slight reversal from the viewpoint of the planet bearings, but still leaves the issue of the helical gear and axial play of the sunwheel open.

An other reversing load situation arises, when the turbine is stopped only by pitchback, but without the brake. In this case, a remarkable reversing torque stresses the gearbox, as the rotor slows down the generator, which acts as a pure flywheel if electrically disconnected. Such a shutdown action has to be avoided.

5. Stillstand situation

When the machine is braked on the fast side, the gearbox moves internally because it is flexible and it has a clearance. If the gearbox has immersion lubrication only, the teeth above will get dry gradually. If the machine stands still during maintenance for example for a month, and during that time there is a storm that lasts for a couple of days, this will cause a wear mark on the dry gearing. Damage may start spreading as a consequence.

Measures: Circulated oil lubrication, lubrication in phases, or continuously in a strong wind. In case the network is not connected, lubrication must be done manually.

Also: Open and close the brake from time to time if possible and let the gear run into a different tooth contact.

6. Problems of three-point bearing

Three-point bearing is nowadays generally in use (see the draft). The rotor's bending torques go in part via the gearbox frame and through its rubber bush bearing to the main frame.

In addition to the usual, known loads there are loads that often have not been taken into consideration as carefully as they should have been.

The most important of these is the axial flexibility of the main bearing. Because the drive train makes slight angular movements, a spherical roller bearing is generally used. A bearing of this type is soft axially, which can be seen immediately from the small thrust angle. In addition, the bearing housing bends. In the partial load area, changes in wind pressure and tower dynamics cause an axial movement of 1 - 1.5 mm; and during pitch control this is even higher.

The whole shaft moves axially and takes the gearbox along. The axial movement causes reacting forces to the rubber bushing and thus an additional load to the bearing of the gearbox main shaft. Even if this bearing succeeds in resisting the load, it nevertheless gives way, causing axial movements inside the toothing. This changes the axial movement through the helix angle to cyclical torque variation. The phenomenon is complex. What happens in reality must be investigated case by case. In all cases, unwanted internal and additional loads occur.

Measures:

* A more rigid bearing housing, if possible, and in addition:
* Axially soft rubber bushes, radial rigidity may remain the same.
* If this is not enough, the torque suspension arms have to be supported by elements which give axial motion freedom.

7. Connection stiffness

The softness of the roller bearing increases with the size of the bearing. Roller bearings require a housing that is rigid enough and well-machined. [11, 12]. If the bearing's support structure is flexible, the shape of the bearing will be deformed and its lifetime decreases radically. This has been underestimated for many years. Together with a tight dimensioning because of cost and competition, the bearings failed often quite naturally [10].
Measure: FEM calculation of the whole gear including the bearings.

8. Other cases

This section handles the more rare cases.

8.1 Electric currents through the bearing
One 1.5 MW machine was equipped with a generator with a rotor fed from the converter. A generator of this type tends to cause especially high bearing currents. The bearings were insulated and the shaft had an earthing slip ring. In spite of that, the current went through the coupling into the gearbox and caused a bearing damage there.
Measure: an insulated coupling.

8.2 Special sites
One wind power plant was erected by a steep shore in Greece. The wind contained vortices caused by the cliff. These vortices hit the turbine and resulted in a strong dynamic load. Along with other problems, gearbox damages occurred.
Measures: Checking the site for special conditions (for example also sand dust in desert areas - filter!)

8.3 Motor start
A smaller wind power plant was equipped afterwards with control software that connects the generator directly to the network, permitting the generator to start rotating earlier on a small wind. The result: the generator/motor screamed loudly, the lights went dark and the turbine was shaking.
Measure: Lay off the man who gave this order.

8.4 Tilt and leakage of oil
An immersion-lubricated gearbox was tested on a horizontal platform and approved. In real application, it was assembled under a 5 degree inclination. In this position the oil did not circulate as it should have done, and one bearing went dry and was damaged.
Measure: Test in the position of use. In all other cases as well, circulation lubrication is better than immersion lubrication (see section 5).

8.5 Storage
A used wind power plant was erected anew. Unfortunately the gearbox had been subjected to internal corrosion damage due to exposure to water vapour during storage. Especially the roller bearings were damaged and made noise. The owner added lots of graphite to the oil, and the power plant has been in operation for years, which is nevertheless due to good luck.
Measures: If the gearbox stands still for a long time, it must be rotated and lubricated regularly. Alternatively the gearbox can be filled entirely with oil or protective dry-gas, or anti-corrosive wax applied to all places, or all of the above measures can be performed.

8.6 Damage during transport (I did not see this case myself but was told about it by a workmate) The gearbox was transported on a truck with rigid suspension on a long, bumpy road. Vibration caused small damages to the roller bearings; an as a result, the gearbox broke down soon.
Measures: Transport using an air spring suspension vehicle, the whole cargo placed on rubber plates, prestressing of the generator bearings.

8.7 Problems in lubrication
The oil pump was sucking in air along with the oil, causing foam. The system was changed, no damages.
Another power plant: The use of two incompatible oils (PG / PAO) caused a deposit that clogged the filter instantly. There was an electric feedback to the control computer. The problem was noticed immediately and there were no damages.

8.8 Technical problems in production, such as local overheating by too fast grinding, or bearing damage due to too rough assembly.

Nearly all of the damages that have occurred during the recent years could have been avoided with careful thinking and a normal manufacturing quality system.

The fact that the world is full of gearboxes, but only the windpower gearboxes broke down in thousands of numbers, reveals a branch-specific problem.

This was:

* The windpower branch is by nature a poor one, the sales margins are extremely small, and this problem is passed on to the component manufacturers. These compromise quality in order to get the price down.

* Being a poor branch, the windpower gearboxes have not been analyzed using FEM and whatsoever analysis tools as well as ship or car gearboxes.

* The development went too fast in 1992- 2000 and too irregularly. Typical thinking in 1991 was: "let us quickly put a 600kW machine on the market, our competition has only 450, has to be ready this autumn. Teething troubles we cure later". Under such circumstances there was no time for test runs or prototype machines.

* The gearbox manufacturer had experience with their traditional branches and customers. But they did not yet have a notable windpower-specific knowledge and had to rely on the wind turbine manufacturers. These, in turn, were too hectic and too much willing to take risk, often in chaotic circumstances. From 1980 to 2000 the lifetime of a windpower company was typically 2-3 years, followed by bancruptcy or closedown.

Now, in 2009 the majority of the problems has been solved. There are still some old turbines under service, which cause trouble, or there are some very special effects, or there are the normal small amount of manufacturing quality problems. But in general the gearbox is no longer an especially risky component.

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