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A member of the NSK Group

Case study – Outer race bearing creep detected on intermediate shaft of wind turbine gearbox

Application Note

Wind Energy

ABSTRACT

Bearing looseness, also called bearing creep, can occur between the outer race and the housing, as described in this Application Note, or between the inner race and shaft. Detection and diagnostics of either condition requires specialized condition monitoring techniques and diagnostic expertise. In the case of the outer race bearing creep, the consequences of not correcting the fault in good time can lead to shaft replacement and the entire gearbox.

Introduction

This application note deals with the rotor end bearing on the intermediate speed shaft (IMS), as shown in Figure 1, which is mounted between the bearing housing of the gearbox and the IMS. It is a single row roller bearing. The looseness detected in this case study is between the outer race of the bearing and the bearing housing of the gearbox.

This case study focuses on a bearing on the IMS, but it could have also occurred on the low speed or high speed shafts also.

Monitoring strategy – Sensors

The sensor configuration shown in Figure 2 is typical for a three stage wind turbine gearbox. As can be seen in the figure, there is no sensor mounted close to the rotor end bearing on the IMS, so the signals used for the detection and diagnostics of the bearing looseness were taken from a combination of sensors, namely sensors 1, 2 and 4. This was considered satisfactory with regards to the vibration transmission path from the bearing to the sensors, which can vary a lot from one gearbox model to the next.

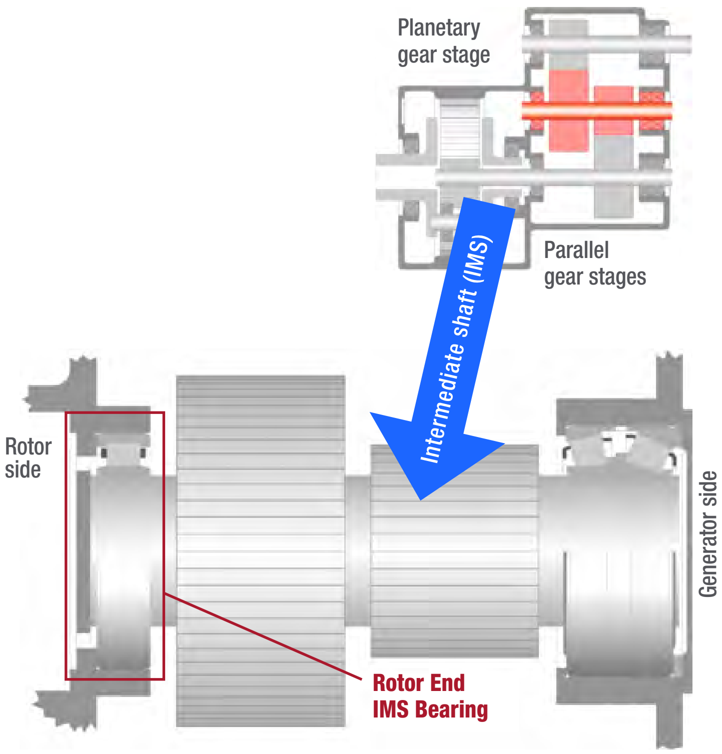

Figure 1. The wind turbine gearbox (top) showing the intermediate shaft (IMS) highlighted in red, and a zoom of the IMS (bottom), showing the location of the rotor end bearing.

Monitoring strategy – Techniques

There are two primary types of measurement techniques used in machine condition monitoring:

- Detection
- Diagnostics

Detection techniques for wind turbine monitoring include a wide range of narrowband and broadband vibration measurements for picking up a developing fault as early as possible under all operating conditions. Many of these measurements were designed for detecting specific failure modes of a specific component, and are continuously refined over the years as experience is gained. All the detection measurements are monitored to five specific power classes to increase reliability and repeatability of fault detection.

Two detection measurements highlighted in this case study include:

- **Residual value (RV)** – Root mean square of tooth meshing frequency sidebands
- **2xTMF** – 2nd harmonic of the tooth meshing frequency (TMF)

The diagnostic measurements are used to identify the type and severity of the fault, so the proper service action can be planned. These primarily include frequency spectra, envelope spectra and the time waveform signal, but there are other diagnostic tools also used where required. The diagnostic measurements require expertise from a specialist to properly analyze the developing fault and evaluate the lead-time to service.

The **frequency spectrum** is used as a diagnostic measurement in this case study.

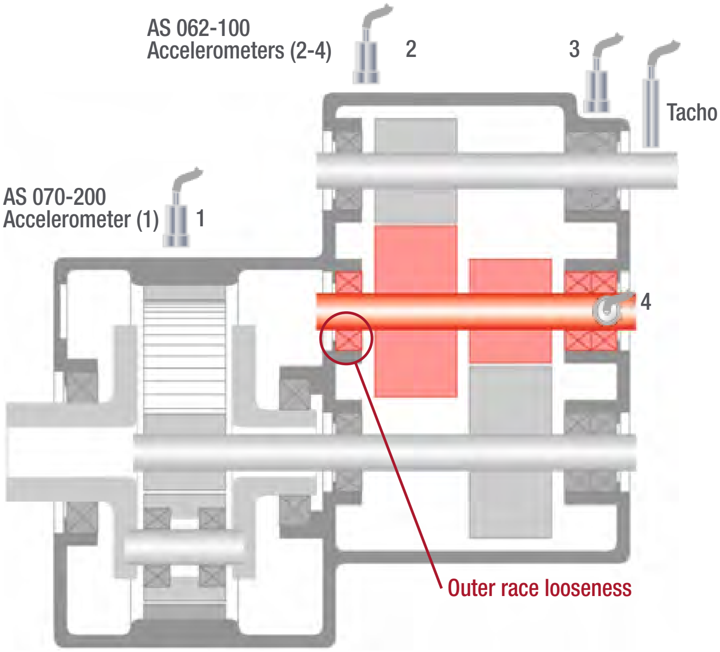

Figure 2. Sensor installation on the gearbox. Sensor 4 is shown mounted horizontally on the generator end (right side) of the IMS (shown in red).

Detection and diagnostics of the fault

Figure 3 shows two detection measurements, indicating the date of detection, trend and shutdown for service. In this particular case there are two symptoms occurring at the initial stages of the fault development:

- **Gear shaft misalignment** – Seen by TMF harmonics
- **Modulation of TMF** – Due to load variations

Figure 4 on the top shows the 2nd and 3rd harmonics of the TMF, greater than the first harmonic in amplitude, thus indicating gear misalignment. The bottom plot in Figure 4 shows bearing fault frequencies for the ball passing frequency (BPFO) of the generator end of the inboard bearing on the IMS. This is a strong indication that the rotor end bearing looseness (discussed later) has changed the shaft dynamics and increased the loading on the generator end bearing.

Results and Feedback

It has been determined that the outer race of the IMS rotor side bearing has been wearing the gearbox housing bore hole over time. This cannot be repaired up-tower and therefore will require a crane to remove the gearbox. The excess clearance of the bearing consequently results in excess misalignment of the shafts for the parallel stage gears. If the excessive clearance is not detected in time, misalignment of the parallel stage shafts causes tooth damage to the IMS gear and the high speed shaft (HSS) pinion plus damage to the IMS Generator side bearings. Even the mechanical oil pump operation can be affected since it is quite often coupled directly to the HSS.

Without proper monitoring, replacement of only the damaged bearings and gears will not solve the problem and they will eventually be damaged again. Therefore the gearbox will have to be replaced to avoid this.

Bearing looseness can be detected by several measurements, including TMF and harmonics, RV, and shaft speed orders. Oil analysis, incidentally, gave no indication of gearbox housing wear.

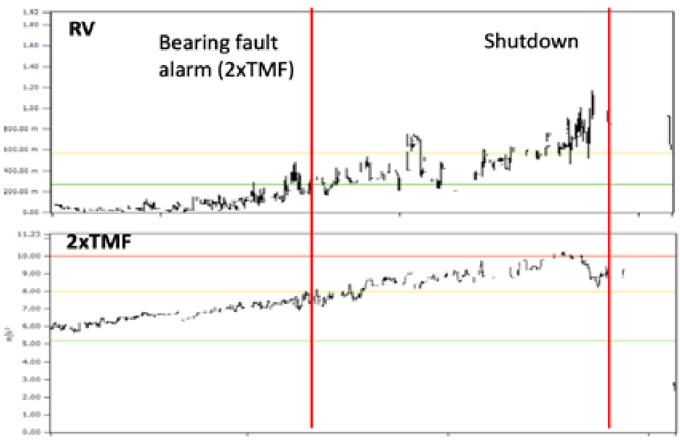

Figure 3. Residual value plot (top) and 2xTMF plot (bottom).

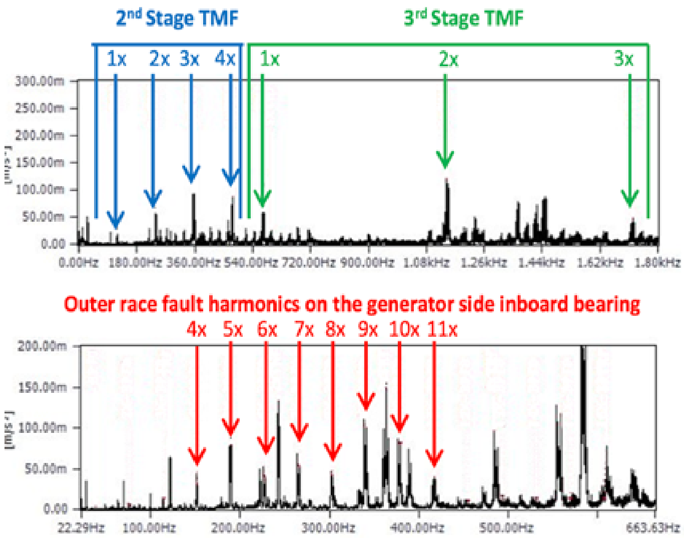

Figure 4. FFT plots for second and third stage gears (top) and generator side inboard bearing (bottom).

Benefits

There are two maintenance scenarios,
but it is the first scenario that gives savings:

1. Early bearing looseness detection
2. IMS gear problem observed but bearing looseness not detected

In the first scenario, as the clearance is minimal, the wind turbine can run until gearbox replacement. At maintenance time, assuming four days downtime at $2120/day plus $244,000 for a crane and a new gearbox, this amounts to a total of **$252,480.**

In the second scenario, the IMS shaft, gears and bearings will be damaged and have to be replaced. This results in six days downtime at a cost of $44,520. Over time a new gear fault will be detected on the recently replaced IMS. The wind turbine will be stopped and investigated to determine the cause, resulting in 21 days downtime plus the need for a crane and a new gearbox. This total cost is **$333,040**, which is **$80,560** more expensive than the first maintenance scenario.

Figure 6. Endoscope camera pictures of the parallel gears and bearings: IMS gear (top), IMS-NRE bearing (middle), IMS rotor side bearing (bottom).

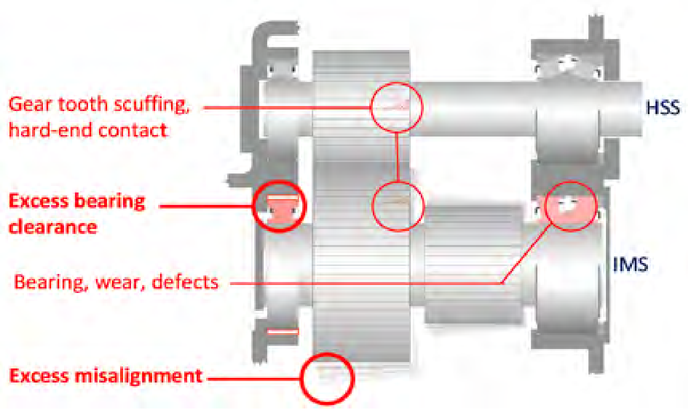

Figure 5. Results of excess clearance in the IMS rotor side bearing leads to damage of other components.

Conclusion

If bearing looseness is detected, this is considered as a high severity alarm situation and requires immediate action to avoid catastrophic failure of the gearbox, and to be pro-active in planning service.

For proper fault detection and diagnostics for this type of fault, it is important to use specialized filtered measurements to detect bearing looseness early to avoid the problem of excess clearance due to wear. The measurements needed include:

- Shaft running speed orders
- HFCF
- TMF
- RV

Another important requirement for the proper detection and diagnostics of this fault is diagnostic expertise and machine knowledge. This is needed to distinguish between bearing faults and bearing looseness to avoid unnecessary costly service.

Finally, site communication is very important between the owner and operator, the manufacturer, the service provider and condition monitoring system supplier to optimize the entire process of the fault detection and diagnosis.

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