

Multistage gearbox failure

Root cause analysis and recommendations for gearbox monitoring with HD technology

by

Göran Almqvist

SPM Instrument AB

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1 Introduction

This case study describes a failure in a gearbox driving a disc filter in a pulp mill. The installation was part of a gearbox monitoring project handled by the SPM Strategic Sales & Applications group. The measurements started when the gearbox was in healthy condition and continued throughout the period during which bearing and gear condition deteriorated, and continued after the gearbox had been repaired.

2 Summary

The root cause of this gearbox damage was that water had accidentally entered the gearbox during cleaning of the shaft.

The water adversely affected bearing lubrication, hence damaging the bearings. Consequently, the gears did not work properly and were also damaged.

It has been an instructive project where we have successfully detected gear damage in the gearbox. Among other things, the measurements from this and other gearboxes have resulted in recommendations regarding the most suitable measurement techniques for different gearbox problems.

3 Application description

The disc filter is a low-speed application driven by a four-stage gearbox and an electrical motor, see Figures 1, 2, and 3 (below).

The disc filter is an important part of the pulp process. If the disc filter stops, the production of pulp will stop immediately. The paper machine will also stop shortly after that due to lack of pulp.

Fig. 1 Disc filter.

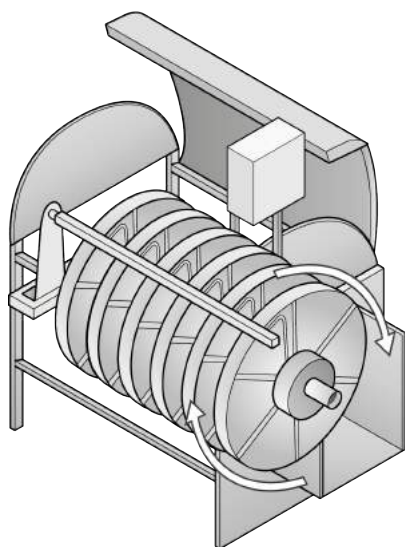


Fig. 2 The gearbox and motor driving the disc filter.

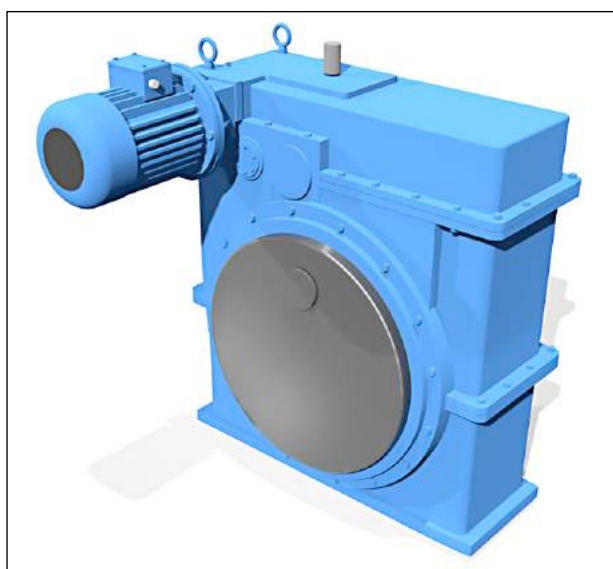
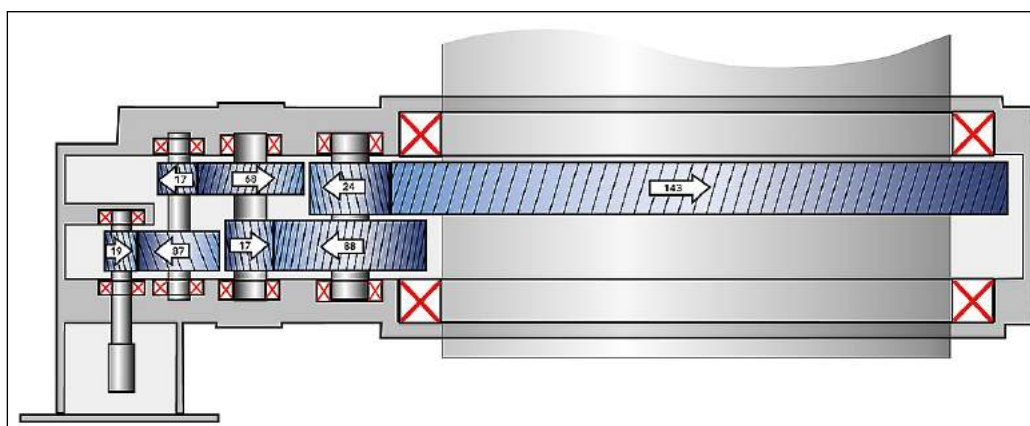


Fig. 3 Section from the gearbox.



4 Background

The Strategic Sales & Applications group runs a project involving gearbox monitoring, where the goal is to understand how gearboxes behave and how to best measure the mechanical and lubrication condition of a gearbox.

Several different test installations have been made in Sweden, one of which is on the gearbox in this case study. The reason for this installation was that the customer had experienced problems with this gearbox earlier.

5 System setup

5.1 Measuring equipment

The online system used was Intellinova Compact INS08V with eight DuoTech transducers and one RPM transducer.

5.2 Measuring techniques

The following measurement techniques were used on all sensors:

- SPM HD TSA
 - SPMHD and Time Synchronous Averaging (TSA)
- HD ENV3
 - HD ENV filter 500 – 10,000 Hz
- HD ENV3 TSA
 - HD ENV filter 500 – 10,000 Hz and Time Synchronous Averaging
- HD ENV4 TSA
 - HD ENV filter 5 000 – 40,000 Hz and Time Synchronous Averaging
- VEL TSA
 - Velocity and Time Synchronous Averaging

The reason for using mainly TSA measurements is that we were focusing on the gears, while the explanation for the relatively many measurement assignments is that we wanted to show how the different assignments respond if a gear problem were to occur.

To be able to do TSA measurements on intermediate shafts, we need to use the Pseudo Tach function. A normal TSA requires a trigger pulse from the very same shaft where the gears are mounted. By using Pseudo Tach, an artificial and VERY accurate trigger pulse is used to trigger measure-

ments. If, say 200 averages, is used and the artificial signal is not accurate enough, the fault will increase for every revolution and the result will be meaningless. By using HD Technology also for the Pseudo Tach, accuracy is ensured.

5.3 Condmaster setup

The following measurement setup was used.

Fig. 4 SPM HD TSA

Measuring point

- A-000.02 First Int. Shaft. Motor Side Horiz.
 - RPM (50 --> 800 RPM)
 - SPM (Online)
 - SPMHD TSA (Online)
 - VIBRATION
 - HDENV3 (Online)
 - HDENV3 TSA (Online)
 - HDENV4 TSA (Online)
 - VEL TSA (Online)

Techniques

- SPM HD
- Vibration
- HD ENV

SPMHD TSA (Settings | Online | Online Advanced)

General

Name: SPMHD TSA
 Bearing number: 22312 SKF

HDm/HDc measurement

Shaft diameter (d): 60 mm
 HDi: Calculated
 Measuring time: Same as FFT measurement

FFT measurement

Short time memory: Time signal and FFT
 Long time memory: Time signal and FFT
 Upper frequency: 1000 Orders
 Lines in spectrum: 6400
 Symptom enhancement factor: (Off)
 Time sync. averaging: 100 Average(s)

No. revolutions: 768

50 - 800 RPM (Max fluctuation: 20%)
 Upper frequency: 833,33 - 13333,33 Hz
 Resolution: 0,13 - 2,083 Hz (7,81 - 125 CPM)
 Acquisition time: 921,6 - 57,6 second(s)
 Calculation time: 3,6 second(s)

Fig. 5 HD ENV, Filter 3

Measuring point

- A-000.02 First Int. Shaft. Motor Side Horiz.
 - RPM (50 --> 800 RPM)
 - SPM
 - SPMHD TSA (Online)
 - VIBRATION
 - HD ENV3 (Online)
 - HDENV3 TSA (Online)
 - HDENV4 TSA (Online)
 - VEL TSA (Online)

Techniques ↑ Add

- SPM HD
- Vibration
- HD ENV

Techniques / References / History

✓ Save ✕

HD ENV HDENV3 Settings Online Online Advanced

General

Name: HDENV3
 Bearing number: 22312 SKF

Measurement

Short time memory: Time signal and FFT
 Long time memory: Time signal and FFT
 Upper frequency: 100 Orders
 Lines in spectrum: 3200
 Symptom enhancement factor: 3
 Envelope frequency: Filter 3 (500-10000 Hz)

Advanced

No. revolutions: 192

- 50 - 800 RPM (Max fluctuation: 20%)
 Upper frequency: 83,33 - 1333,33 Hz
 Resolution: 0,026 - 0,42 Hz (1,56 - 25 CPM)
 Acquisition time: 230,4 - 14,4 second(s)
 Calculation time: 133,1 second(s)

Fig. 6 HD ENV, Filter 3 with TSA

Measuring point

- A-000.02 First Int. Shaft. Motor Side Horiz.
 - RPM (50 -> 800 RPM)
 - SPM
 - SPMHD TSA (Online)
 - VIBRATION
 - HD ENV3 (Online)
 - HD ENV3 TSA (Online)**
 - HD ENV4 TSA (Online)
 - VEL TSA (Online)

Techniques ↑ Add

- SPM HD
- Vibration
- HD ENV

Techniques / References / History

✓ Save ✕

HD ENV3 TSA Settings Online Online Advanced

General

Name: HDENV3 TSA
 Bearing number: 22312 SKF

Measurement

Short time memory: Time signal and FFT
 Long time memory: Time signal and FFT
 Upper frequency: 1000 Orders
 Lines in spectrum: 6400
 Symptom enhancement factor: (Off)
 Envelope frequency: Filter 3 (500-10000 Hz)

Advanced

Time sync. averaging: 100 Average(s)

- Pseudo Tacho Activated
- No. revolutions: 768

50 - 800 RPM (Max fluctuation: 20%)
 Upper frequency: 833,33 - 13333,33 Hz
 Resolution: 0,13 - 2,083 Hz (7,81 - 125 CPM)
 Acquisition time: 921,6 - 57,6 second(s)
 Calculation time: 3,6 second(s)

Fig. 7 HD ENV, Filter 4 with TSA

The screenshot displays the SPM Instrument software interface for configuring a measuring point. The interface is divided into three main sections:

- Measuring point:** A tree view showing the hierarchy of the measuring point. The selected point is "A-000.02 First Int. Shaft, Motor Side Horiz.", which includes:
 - RPM (50 --> 800 RPM)
 - SPM
 - SPMHD TSA (Online)
 - VIBRATION
 - HD ENV3 (Online)
 - HD ENV3 TSA (Online)
 - HD ENV4 TSA (Online)** (Selected)
 - VEL TSA (Online)
- Techniques:** A list of techniques available for the measuring point:
 - SPM HD
 - Vibration
 - HD ENV
- HD ENV4 TSA Configuration Panel:**
 - General:**
 - Name: HDENV4 TSA
 - Bearing number: 22312 SKF
 - Measurement:**
 - Short time memory: Time signal and FFT
 - Long time memory: Time signal and FFT
 - Upper frequency: 1000 Orders
 - Lines in spectrum: 6400
 - Symptom enhancement factor: (Off)
 - Envelope frequency: Filter 4 (5000-40000 Hz)
 - Advanced:**
 - Time sync. averaging: 100 Average(s)
 - Status/Parameters:**
 - Pseudo Tacho Activated
 - No. revolutions: 768
 - 50 - 800 RPM (Max fluctuation: 20%)
 - Upper frequency: 833,33 - 13333,33 Hz
 - Resolution: 0,13 - 2,083 Hz (7,81 - 125 CPM)
 - Acquisition time: 921,6 - 57,6 second(s)
 - Calculation time: 3,6 second(s)

Fig. 8 VEL TSA

The screenshot displays the VEL TSA software interface. On the left, the 'Measuring point' section shows a tree view for 'A-000.02 First Int. Shaft. Motor Side Horiz.' with sub-items: RPM (50 -> 800 RPM), SPM, SPMHD TSA (Online), VIBRATION, HD ENV, HD ENV3 TSA (Online), HD ENV4 TSA (Online), and VEL TSA (Online). Below this is the 'Techniques' section with 'SPM HD', 'Vibration', and 'HD ENV'. At the bottom left are 'Techniques / References / History' tabs and 'Save' and 'X' buttons.

The main 'VEL TSA' panel has tabs for 'Settings', 'Online', and 'Online Advanced'. It is divided into three sections:

- General:**

Name	VEL TSA
Short time memory	Time signal and FFT
Long time memory	Time signal and FFT
Time signal unit	Vel
Spectrum unit	Vel
- Settings:**

Order tracking	Yes
Upper frequency, Orders	1000
Lower frequency, Hz	0,5
Window	Hanning
Lines in spectrum	6400
Envelope frequency	(None)
- Advanced settings:**

FFT type	Linear
Averaging type	Time synchronous
Averages	100
Average overlap	(None)
Zoom center	
Zoom factor	

On the right side, there are two performance summary boxes:

- Min RPM (Max fluctuation: 20%):** 50 RPM, 1000 Orders, 833,33 Hz, Resolution: 0,13 Hz 7,81 CPM, Acquisition time: 768 second(s), No. revolutions: 640
- Max RPM (Max fluctuation: 20%):** 800 RPM, 1000 Orders, 13333,33 Hz, Resolution: 2,083 Hz 125 CPM, Acquisition time: 48 second(s), No. revolutions: 640

A warning box at the bottom right states: **Warning! Resolution may be too low to get an accurate result. You are recommended to increase the number of spectrum lines, increase lower frequency or decrease frequency range.**

The reason for the high upper frequency – 1000 orders – of the TSA measurements is to visualize the gear in a circular plot with a high-resolution time signal.

6 Case descriptions

The root cause of this gearbox damage was that water accidentally entered the gearbox.

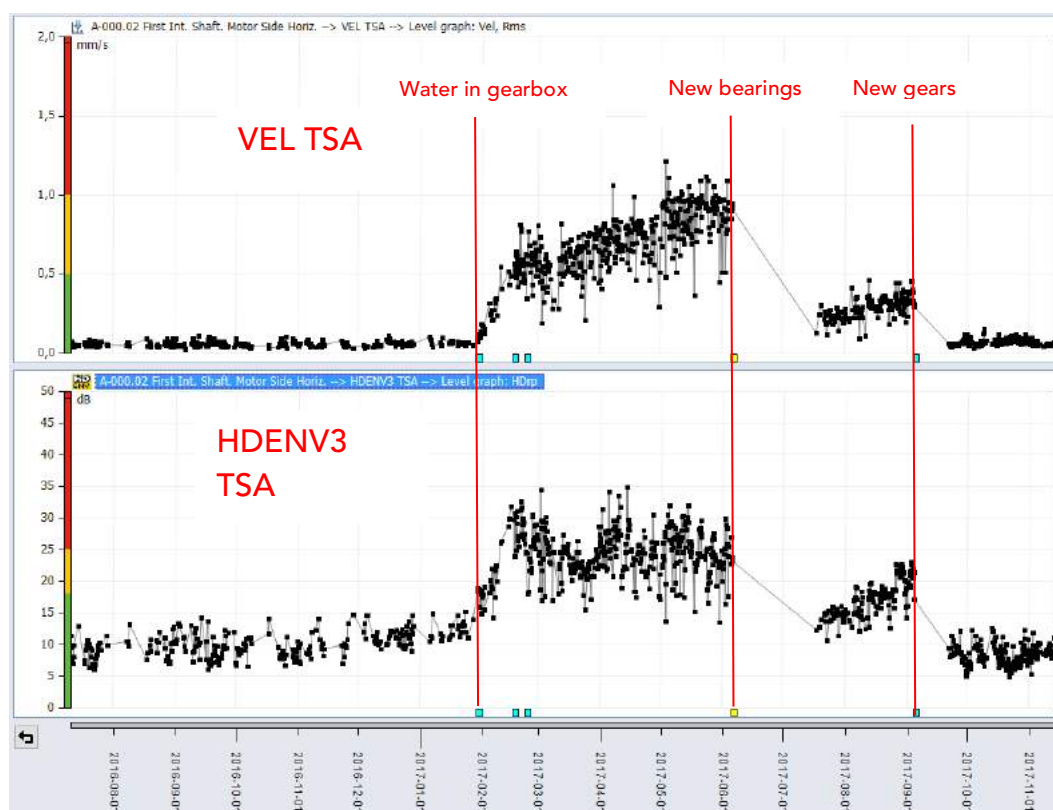
When the water came into the gearbox, the vibration levels increased very quickly and remained on a high level. During a planned machine stop, the gearbox was opened and inspected. There were clear damages on all gears, but due to a lack of spares, only the bearings could be replaced. After the bearing change, the vibration levels decreased but were still higher than normal.

In conjunction with another planned stop four months later, new gears were also mounted, after which the vibration readings dropped to a normal level.

6.1 Case #1: Intermediate shaft

The amplitude of the measurements from the intermediate shaft showed a clear increase, mainly in the VEL TSA (Time Synchronous Averaging) measurements. Because TSA measurements only measure gear condition, this is a clear indication that there was a gear problem.

Fig. 9 Trend graphs of VEL TSA and HD ENV, Filter 3 TSA measurements.



The reason for the gear damage was poor lubrication. Unfortunately, the only measuring assignment for bearing measurements that was activated was HD ENV, Filter 3, and in those measurements, we could not see any bearing frequencies.

The bearing damage is quite interesting. There are no spalls in the bearing surface, but the surface is very worn, see Images 1 and 2:

Img. 1 Damaged bearing from the 1st intermediate shaft.

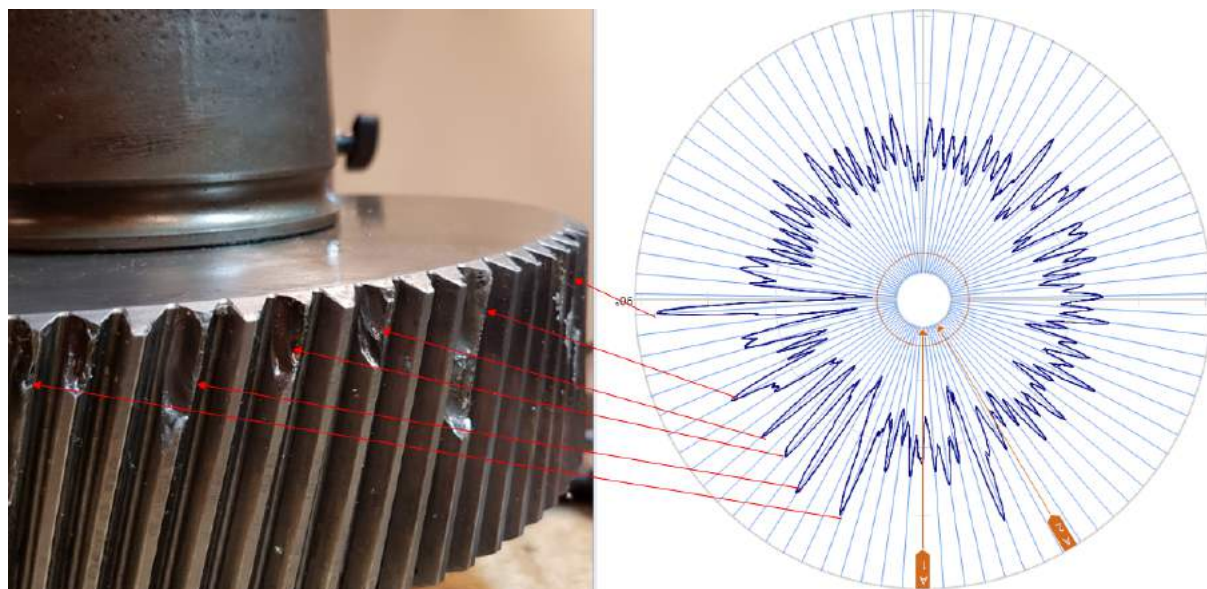


Img. 2 Damaged bearing from the 1st intermediate shaft.



As the bearings became worn out, the gears did not mesh as designed and were therefore damaged, see Images 3 and 4 below. In Image 3, it is possible to see the gear damages of the 1st intermediate shaft shown in the circular plot.

Img 3. Damaged 1st intermediate shaft and circular plot.



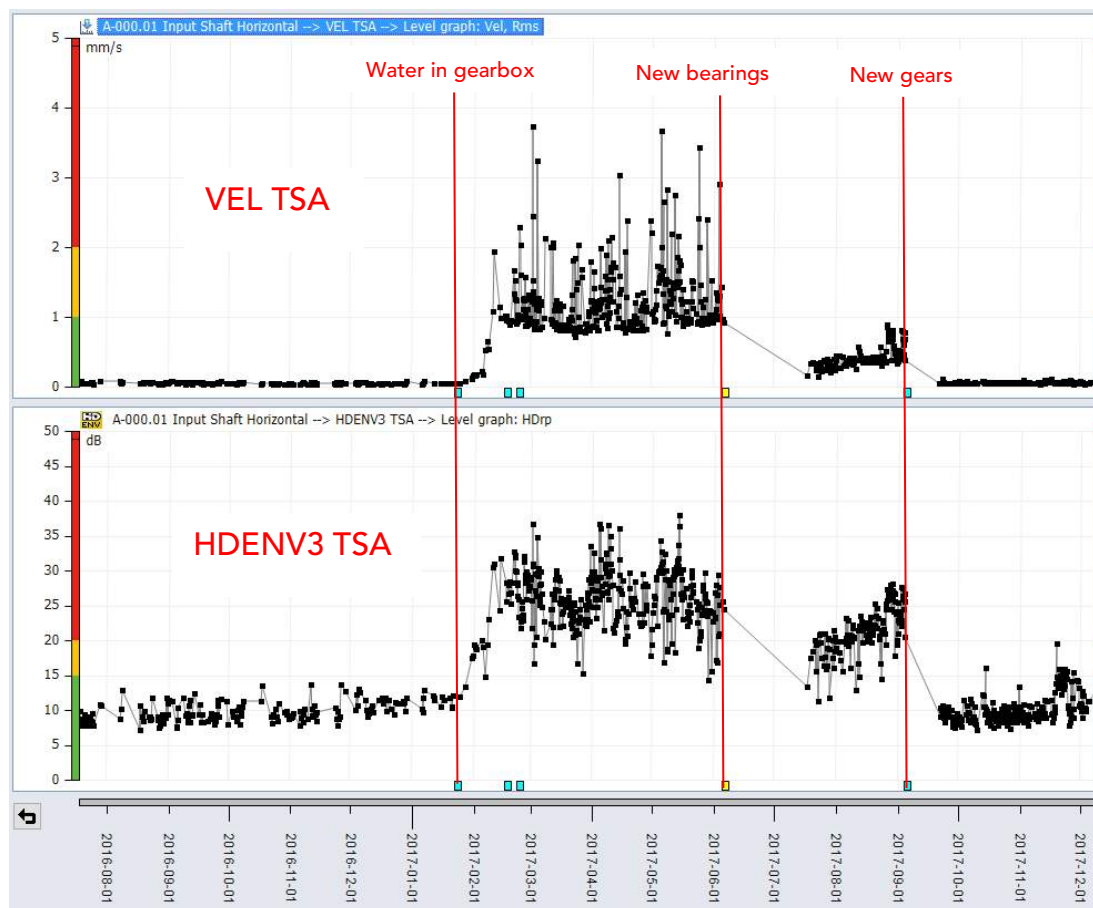
Img 4. Damaged 1st intermediate shaft.



6.2 Case #2: Input shaft

The measurements from the input shaft showed quite the same thing as those acquired from the intermediate shaft. The damaged gears are shown in Images 5 and 6.

Fig. 10 Measurements from the input shaft.



Img. 5 Damaged input shaft gear.

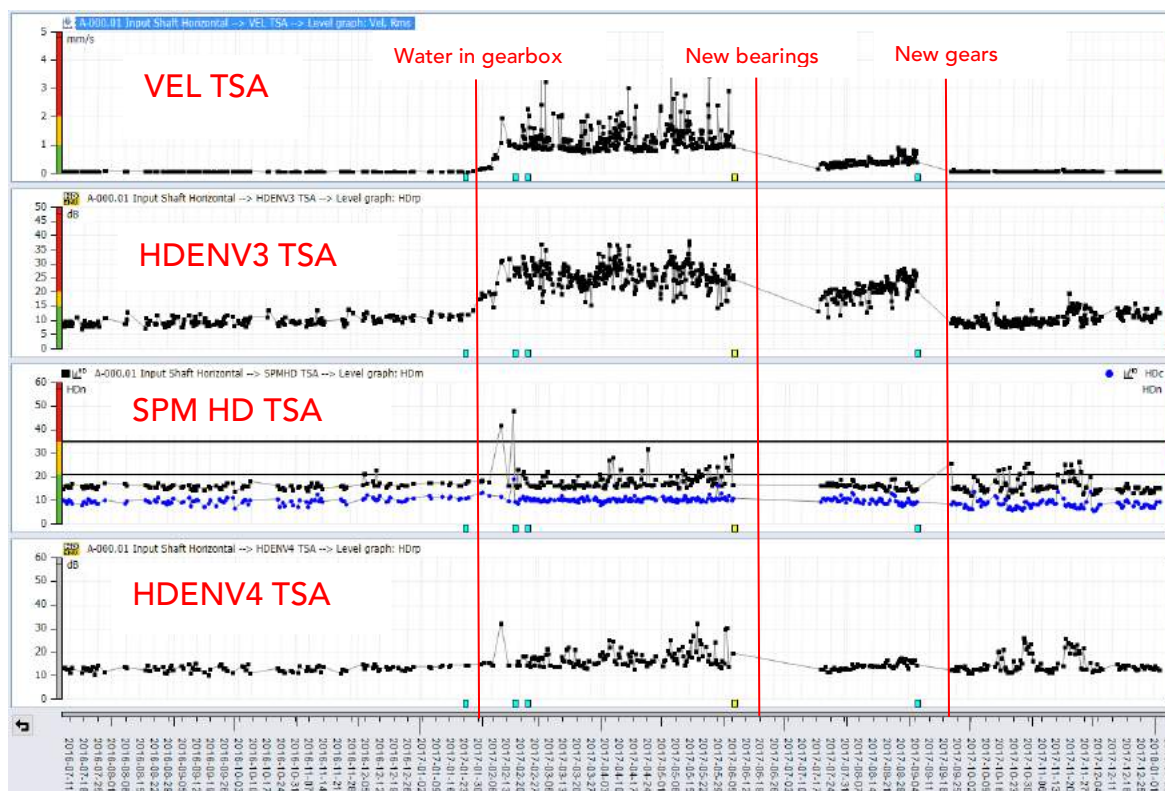


Img. 6 Damaged input shaft gear.



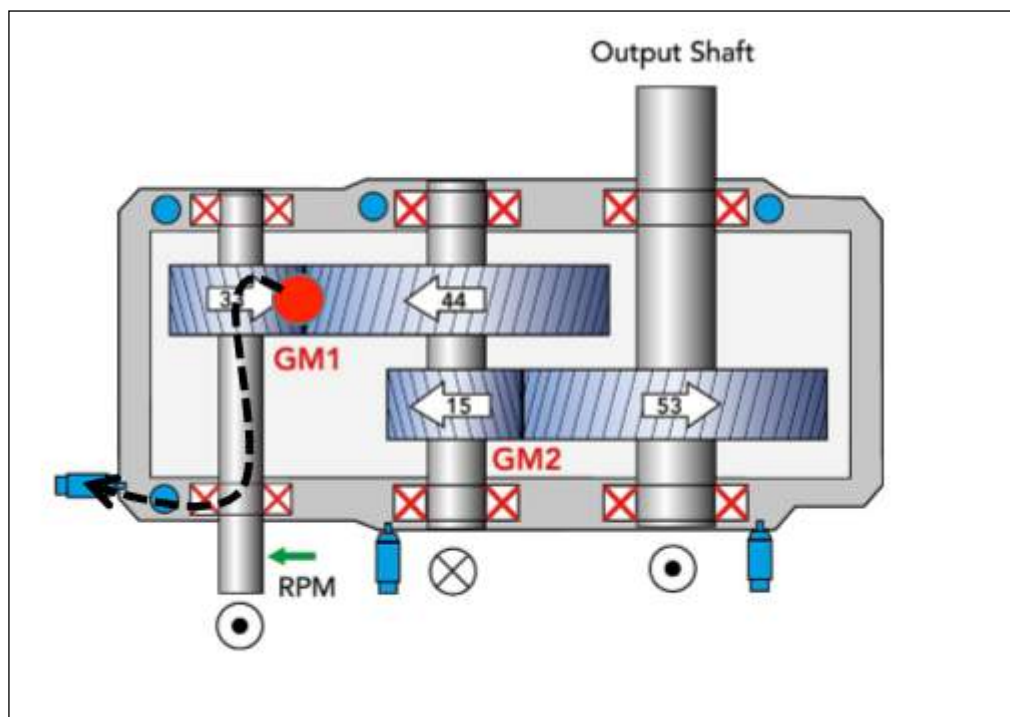
Comparing the different TSA assignments is interesting. In Figure 11 below, all TSA assignments from the input shaft are shown, and it is clear that only VEL TSA and HD ENV, Filter 3 with TSA measurement assignments react to this gear damage.

Fig. 11 Only VEL TSA and HD ENV, Filter 3 TSA indicate the gear damage.



The reason for this behavior can be seen in Figure 12. The high-frequency signals – originating from the gear damage and measured with SPM HD and HD ENV, Filter 4 – are damped at each of the material interfaces in the bearings.

Fig. 12 Only VEL TSA and HD ENV, Filter 3 with TSA indicate the gear damage.



7 Conclusion

The results in this case study show that HD ENV is ideal for detecting gear problems such as gear mesh, while SPM HD works very well for monitoring bearing and lubrication condition.

For successful gearbox monitoring, we recommend using one sensor per shaft, with the following measurement assignments set up on all sensors:

Bearing condition assignments

- *VEL*
- *HD ENV, Filter 3*
- *HD ENV, Filter 4, or SPM HD*

Gear condition assignments

- *VEL TSA*
- *HD ENV, Filter 3 with TSA*

Pseudo Tach will automatically be activated when using an RPM factor. To ensure the factor is accurate enough, enter the number of teeth on the gearwheels in the RPM factor settings.