Gearbox Monitoring using Dragonfly® Sensors

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Abstract Gearbox condition monitoring is critical for ensuring the reliability and availability of rotating machinery. Traditional accelerometer-based vibration analysis is widely used but has limitations, particularly in detecting early-stage faults and monitoring slow-rotating systems. This study explores the use of ultrasensitive piezoelectric strain sensors (Dragonfly® by Wormsensing) as an alternative for gearbox health assessment.

An ifm vibration test bench was used, featuring a gearbox with a missing tooth to simulate a defect. Both an industrial accelerometer and Dragonfly® were used to capture vibration and strain data, respectively. A synchronous averaging method was applied to analyze the signals at low and high rotation speed. Results showed that while the accelerometer primarily detected shocks from the missing tooth, the Dragonfly® sensor provided a tooth-by-tooth analysis, revealing variations in effort distribution across individual teeth and detecting abnormalities at an earlier stage.

Key Words
Piezoelectric, Strain gauge, Gearbox, Predictive Maintenance

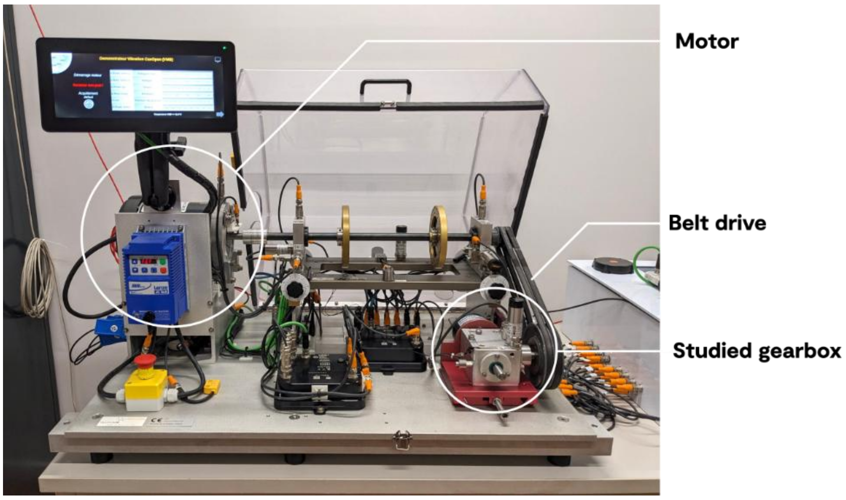

Figure 1: Picture of the vibration test bench used to study gearbox defects.

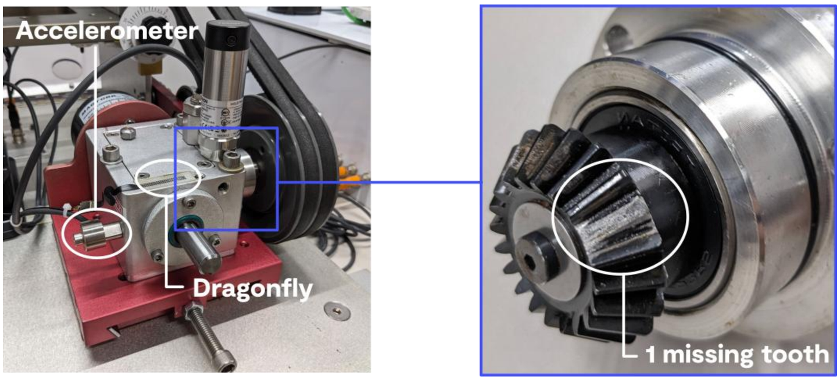

Figure 2: studied gearbox and picture of the faulty gear with one missing tooth. The position of the two installed sensors is shown (Dragonfly and accelerometer).

1 Introduction

Gearboxes are essential components in nearly all rotating machines, where they reduce the rotational speed of electric motors while increasing torque. Due to the high loads exerted on these systems, gear teeth can wear over time, potentially causing severe damage to the gearbox and, in some cases, the entire machine. Detecting early signs of wear is therefore crucial to replacing faulty gears before they lead to costly failures and long unplanned outages.

Traditionally, accelerometers used for this are limited to high frequencies (>10Hz, sometimes >2Hz generally to satisfy to ISO standards), meaning they primarily capture impacts between gears when a tooth is missing or when gear clearance is too high. As a result, many early signs of wear go undetected, and faults are only identified once it spreads to entire gear train.

This document presents an alternative approach to gearbox monitoring using ultrasensitive strain sensors. Wormsensing develops and manufactures Dragonfly®, ultrathin piezoelectric sensors capable of measuring strains as small as 5nm/m. Unlike accelerometers, strain sensors detect force variations within the gearbox, including those caused by the passage of individual gear teeth. This enables precise monitoring of each tooth and facilitates early defect detection, preventing further damage and reducing maintenance costs.

2 Test setup

To evaluate the effectiveness of the Dragonfly® sensor in detecting gearbox issues, a vibration test bench is used (see Figure 1). The setup includes an electric motor that drives a primary shaft equipped with two disks, where unbalance can be introduced. This shaft ends with a pulley that transmits power via a belt. On the driven side of the belt, a gearbox with conical gears is connected, with its output linked to a magnetic load.

To simulate a fault, one tooth of the gearbox's input gear has been milled to create a missing tooth (see Figure 2). The gearbox casing is equipped with two sensors: an industrial accelerometer from IFM (model VSA008) and a Dragonfly® sensor from Wormsensing. Both sensors are connected to a VSE150 acquisition device to capture raw vibration signals during the tests.

The motor speed is incrementally varied from 280 RPM to approximately 2930 RPM, with each speed level maintained for 10 seconds, as illustrated in Figure 3. The belt-drive system applies a reduction ratio of 2.5.

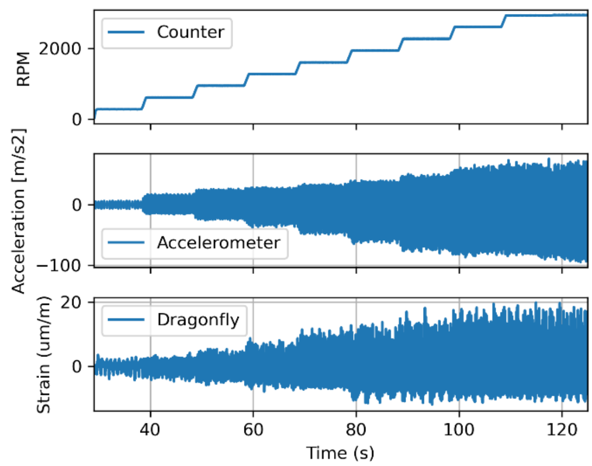

Figure 3: raw accelerometer and Dragonfly signals during the ramp up of the motor speed.

The analysis will focus on two specific rotational speeds:

- **280 RPM**: This corresponds to an input gear rotation speed of **112 RPM** (1.86 Hz), which represents the lowest operational speed of the tested machine.

- **2930 RPM**: This results in an input gear rotation speed of **1172 RPM** (20 Hz), representing the highest tested speed.

These two speeds will be examined in detail to assess the sensor performance in detecting gearbox issues across a wide operating range.

3 Results

3.1 Synchronous averaging method

To analyze gear defects, a synchronous averaging method will be applied [1]. The approach is first explained for the 112 RPM rotational speed and then extended to 1172 RPM.

At 112 RPM, the raw time signal from the accelerometer is plotted in Figure 5. The first step in the analysis involves generating a trigger signal that occurs once per revolution of the gear under study. In this case, the process is straightforward because the missing tooth introduces a distinct shock in the signal once per rotation, which serves as a natural trigger point.

Next, all rotation periods (measured between successive trigger points) are interpolated to ensure they contain the same number of bins. This step compensates for minor fluctuations in rotational speed.

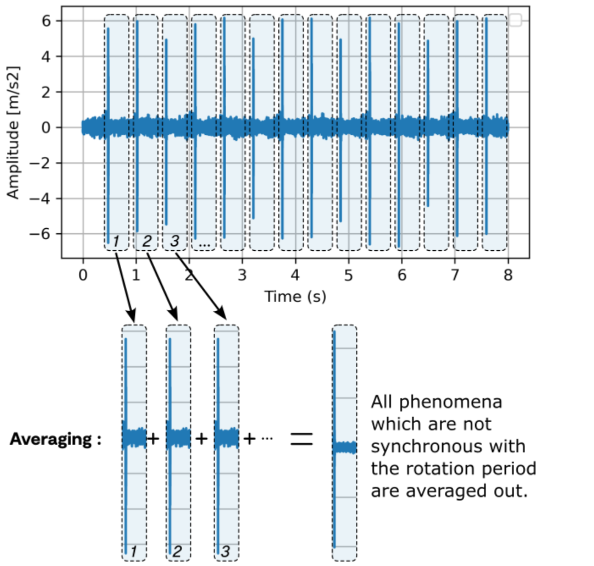

Figure 5: Principle of the time-synchronous averaging technique.

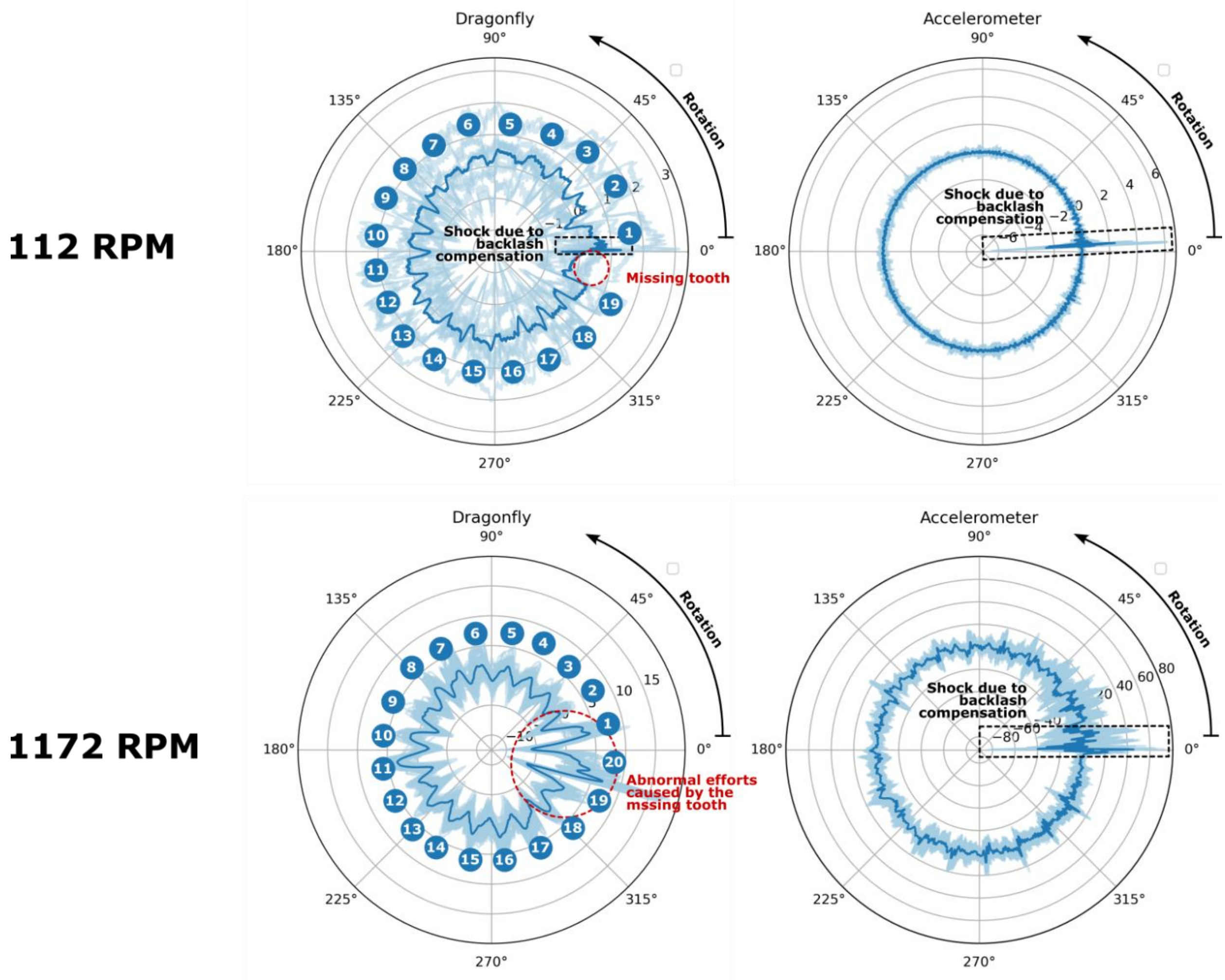

Figure 4: Polar plots of the synchronous average of the accelerometer and Dragonfly® signals at two rotation speed.

After interpolation, the average of all the interpolated signals is computed. This process effectively filters out any signal components that are not synchronous with the rotation of the studied gear. As a result, wide-band noise and vibrations caused by other gears or machine components are removed, isolating the relevant defect-related signal.

3.2 Polar plots

A convenient visualization technique for the averaged time signal is to use a polar plot, where one full rotation of the gear corresponds to 360°.

In this representation:

- The raw signals from all individual rotations are shown in light blue.
- The synchronous average of these signals is highlighted in darker blue.

Since the shock caused by the missing tooth occurs at the same position on the gear in every rotation, these shock signals align and reinforce each other in the plot.

The polar plots of the synchronous averages, computed from both the accelerometer and Dragonfly® sensor signals, are presented in Figure 4.

At **112 RPM**, the accelerometer signal clearly captures the shock caused by backlash compensation following the missing tooth. However, the Dragonfly® sensor provides significantly more detailed information:

- The effort applied by each tooth of the studied gear is distinctly visible, allowing for individual tooth monitoring—even before damage progresses enough to generate a shock.
- The missing tooth is clearly detected, as it does not produce the expected effort increase observed for the other teeth.
- The shock from backlash compensation is also present in the Dragonfly® data.

At **1172 RPM**, the overall observations remain similar:

- The accelerometer captures a single shock per revolution, corresponding to the missing tooth.
- The Dragonfly® sensor records the effort modulation for each tooth passage, making abnormal forces at the missing tooth location clearly identifiable.
- The averaged signal appears slightly smoother at this higher speed. This is likely due to gearbox casing deformations and vibrations at higher frequencies.

4 Conclusions

Monitoring gearboxes with ultrasensitive piezoelectric strain sensors in combination with traditional accelerometers offers several key advantages:

- **Direct Force Measurement**: Strain is directly proportional to the forces transmitted through gearbox components, which are present regardless of rotation speed. **This enables effective monitoring of very slow rotating machines**, where accelerometers struggle due to bandwidth and sensitivity limitations in detecting low-frequency accelerations.
- **Detailed Gearbox Health Analysis**: Unlike accelerometers, which primarily detect shocks from severe faults, strain sensors provide a **tooth-by-tooth analysis**, enabling early detection of wear or anomalies before they develop into major issues.

This enhanced capability makes piezoelectric strain sensors a powerful tool for proactive gearbox monitoring and predictive maintenance, paving the way for better Remaining Useful Life calculation and machine availability.

References

[1] E. Bechhoefer and M. Kingsley, "A Review of Time Synchronous Average Algorithms," 2009.