NEON Vibration Sensor Use Case

Bearing Fault Detection

For Industry White Paper

How To Detect Hazardous And Costly Bearing Faults In Industry

1. Introduction

Rolling element bearings play a pivotal role in the industrial landscape. Their malfunction can spell not just financial loss but also potential hazards. Predictive maintenance, enabled by sensor technology, can pinpoint issues in advance, allowing optimal utilization of bearing lifespan - ensuring cost savings and safety.

A prevalent challenge is that most predictive algorithms require extensive data on the asset. Such data is scarce for older machinery (often a decade or two old). Manual analysis by vibration experts, though effective, is time-consuming. Our solution uses the NEON vibration sensor paired with the SolidRed analytics platform. The combination enables swift, automated detection of bearing anomalies, regardless of prior asset knowledge.

This paper describes the automation of this process, overcoming the lack of historical data and the time-consuming nature of manual analysis.

2. Decoding Bearing Failures

2.1 Bearing Failure and Vibration Signatures

Bearing failure is a multifaceted issue that can appear in multiple dimensions. Bearings play a crucial role in many mechanical systems, and their health is vital for proper functioning and longevity.

2.1.1 Vibration in Healthy Bearings

In a pristine condition, bearings are not devoid of vibrations. They inherently produce vibration signals due to two primary reasons:

Radial Clearance: The free space between the inner and outer races allows for slight movement. This is an intentional feature in many bearing designs to accommodate thermal expansion and other operational parameters.

Contact Deformation of Rolling Elements: As the rolling elements travel through the load zone, they undergo slight deformations due to the forces exerted upon them. This change in shape, though minuscule, results in a unique vibration signature.

This deterministic, repetitive signal acts as the base or carrier wave upon which anomalies, due to failures, will later be superimposed. The visualization of these dynamics is aptly depicted in Figure 1.

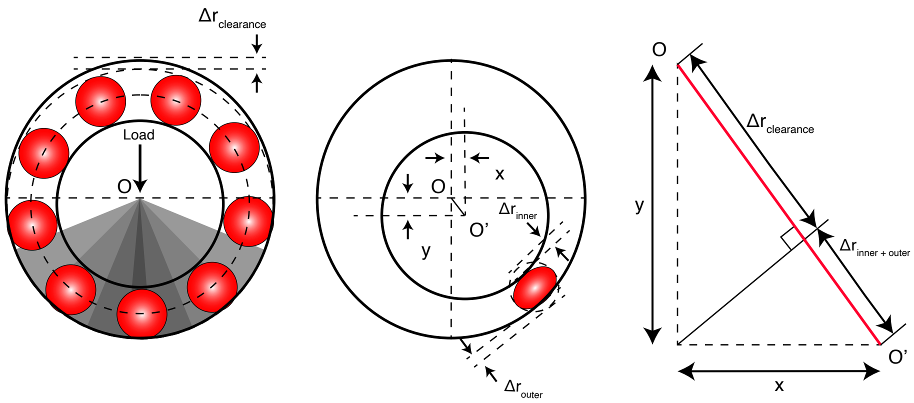


Figure 1. Radial deflection of the inner race in relation to the outer race in a healthy roller bearing.

a) Deflection due to radial clearance. b) Deflection due to contact deformation of rolling elements.

c) Geometric view of total deflection.

2.1.2 Defect Vibration Signatures

Certain anomalies in bearing operations, like pits, cracks, and spalls, generate distinct impulse response signals. These imperfections can emerge on any part of the bearing – the races, the rolling elements, or even the cage. When the rolling element interacts with these defects, a characteristic signature arises. This interaction is a multi-stage process:

Initial Contact with Defect: The rolling element first meets the defect's edge.

Impact with the Second Edge: As the rolling element traverses the defect, the impact effectively reduces the diameter. This means its contact profile changes momentarily as it interacts with the defect's depth.

Exiting the Defect Zone: Once past the defect, the rolling element's effective diameter returns to its original form, signaling the end of the defect interaction.

These phases are captured in Figure 2.

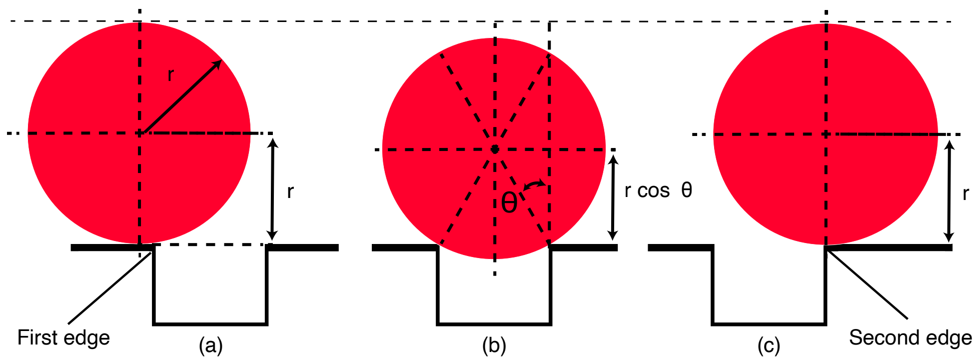


Figure 2. NEON vibration sensor on site; providing real-time monitoring of acceleration and RMS velocity.

The vibration signal generated due to the interaction with defects, especially the impact with the second edge, is of significant interest. This impulse not only alters the native vibration signature of the bearing but also resonates through the entire bearing assembly, echoing at its natural resonance frequency, which usually lies in the 4-6 kHz range. These impulse responses subtly modulate the amplitude of the bearing's vibration signals.
Moreover, if a bearing operates at a constant speed, these impulse responses will manifest at consistent intervals, leading to a persistent fault frequency distinct from the resonance frequency.

2.1.3 Progression of Bearing Fault

It's worth noting that bearing faults aren't static. Over operational time, the continuous interaction with a fault exacerbates its severity. As the defect grows, so does the energy of its vibration signature. If these warning signs are overlooked or left unattended, the defect can grow to a point where the bearing and the entire mechanical system can face catastrophic failure.

Maintaining a keen observation of these vibration signatures, understanding their cause, and implementing timely maintenance strategies can ensure the prolonged life of bearings and the machinery they support.

2.2. Identifying the Challenge in Traditional Vibration Analysis

Traditional vibration analysis uses Fourier analysis, which transforms the vibration signal into its frequency spectrum. An analysis is then carried out in the frequency domain. However, doing so would only show the modulating (resonance) frequency, not the fault frequency. To detect bearing faults, the frequency of repetition of the modulating signal, fault frequency, must be detected.

With a prior understanding of the machine generating the vibration, pinpointing the fault frequency becomes straightforward. Bearing irregularities give rise to distinct frequencies, influenced by the bearing's design and the shaft's rotational speed. Using this insight, merely matching observed frequencies to known characteristic ones suffices to ascertain the presence of a bearing malfunction.

However, this information is only sometimes available. To automatically detect bearing faults, specific frequencies should be confidently designatable as defect

Figure 3. Rolling element bearings play a pivotal role in the industrial landscape. Their malfunction can spell not just financial loss but also potential hazards.

frequencies. Automatic detection also means that no person should be involved in monitoring the asset when nothing is out of the ordinary. Additionally, the detection should not be limited to only one asset. Thousands of assets should be automatically monitorable at once.

3. Developing an Innovative Approach for Bearing Fault Detection

Our solution employs advanced analytical techniques to accurately identify bearing faults. The approach is distinctive in its ability to detect anomalies within the vibration signals, a key indicator of potential bearing issues.

3.1 Signal Component Analysis

The core of our solution lies in the sophisticated analysis of vibration signals. Each signal comprises various components, and our focus is on isolating the one indicative of a bearing fault. This precise identification is crucial for effective fault detection.

3.2 Utilizing Gradual Fault Development

One characteristic of bearing faults is their incremental development over time. This gradual progression results in a steady increase in the energy signature of the fault within the vibration profile. By monitoring these subtle energy escalations, our system proactively identifies potential bearing issues at their nascent stage.

3.3 Proactive Fault Identification Strategy

Our proactive approach is centered around continuous monitoring and analysis of the energy levels in each vibration profile. This method allows us to detect early signs of bearing faults, long before they evolve into serious mechanical failures. By implementing this strategy, we ensure a higher level of precision in predictive maintenance, averting costly machinery downtimes and ensuring operational efficiency.

4. Integration of Advanced Diagnostic Tools

Our solution is distinguished by the seamless integration of our NEON vibration sensor with a comprehensive asset management system. This synergy employs advanced digital signal processing techniques, guaranteeing precise identification of bearing anomalies.

4.1 Measuring the Signal

Our NEON vibration sensor specializes in continuous monitoring, making it the optimal tool for tracking the energy contained in vibration profiles. As it continuously gauges the asset's vibrations, the sensor performs preliminary analyses and transmits the results to our asset management platform via LoRaWAN.

4.2 Extracting the Envelope Spectrum

The extraction of the signal envelope is executed through the Hilbert Transform, a mathematical maneuver that produces an analytical counterpart when applied to a real signal. This analytical signal's imaginary component is the original signal, only phase-shifted by 90 degrees. By determining the analytical signal's absolute value, we can isolate the real signal's envelope. Our approach employs Fourier analysis to determine the envelope spectrum, with all processes being autonomously performed by the NEON vibration sensor.

4.3 Extracting the Vibration Profiles

Drawing from our deep-rooted understanding of bearing fault nuances, we've designed a tailored algorithm for vibration profile extraction. Such an extraction is another milestone the NEON vibration sensor achieves, following envelope calculation. This way, only the most relevant profiles get relayed to our SolidRed asset management system via LoRaWAN.

Figure 4. NEON Vibration Sensor: ATEX / IECEx certified, wireless, battery-powered and retrofittable.

4.4 Tracking the Vibration Profiles

SolidRed meticulously monitors every received vibration profile. Detecting nuanced alterations posed a significant hurdle. We aimed to pinpoint the lowest anomaly threshold that would avoid false positives. This precision is achieved using the Cumulative Sum (CUSUM) algorithm, a statistical method that identifies shifts in sequential data over a period. By maintaining an ongoing tally of deviations from a predetermined reference value, CUSUM excels in discerning subtle changes in vibration profile energy without false alarms.

4.5 Putting it all together

All components of this solution are seamlessly integrated, offering a scalable and autonomous system. Installation is straightforward: users need only affix the NEON vibration sensors to their assets. These sensors will then continuously process data as outlined, alerting users if any asset shows indications of a budding bearing fault. The alerts are comprehensive, equipping engineers with tangible evidence like graphs delineating the bearing fault.

5. Validation and Efficacy of the Solution

5.1 CWRU Dataset

The dataset from Case Western Reserve University, a popular benchmark in predictive maintenance research, was extensively discussed in the paper: “Rolling element bearing diagnostics using the Case Western Reserve University data: a benchmark study” by Wade A. Smith and Robert B. Randall.

This influential study benchmarked the datasets created by the Bearing Center of the Case Western Reserve University. These datasets have become a staple in vibration-based predictive maintenance academic research. Notably, our tests yielded a 98% success rate for the inner and outer race faults measured at 48 kHz and an 86% success rate for those measured at 12 kHz.

While the benchmarking in the referenced study was conducted through manual evaluation by experts analyzing each dataset individually, our methodology, in contrast, capitalizes on the capabilities of the NEON vibration sensor and the SolidRed platform. Our fully automated system ensures real-time, precise insights without human oversight.

5.2 NASA's Run-to-Failure Tests

In addition to our tests using the CWRU dataset, we utilized the University of Cincinnati's NASA Bearing Database to test our solution further.

The entire dataset was run through our algorithms to see how early we could detect the bearing fault. Our solution was able to detect all bearing faults before failure. The results for the second dataset are illustrated in Figure 5, where we were able to detect the bearing fault at a very early stage. Figure 6 shows the comparison of the early state bearing fault, at 89 hours, with the same fault at failure, after 164 hours.

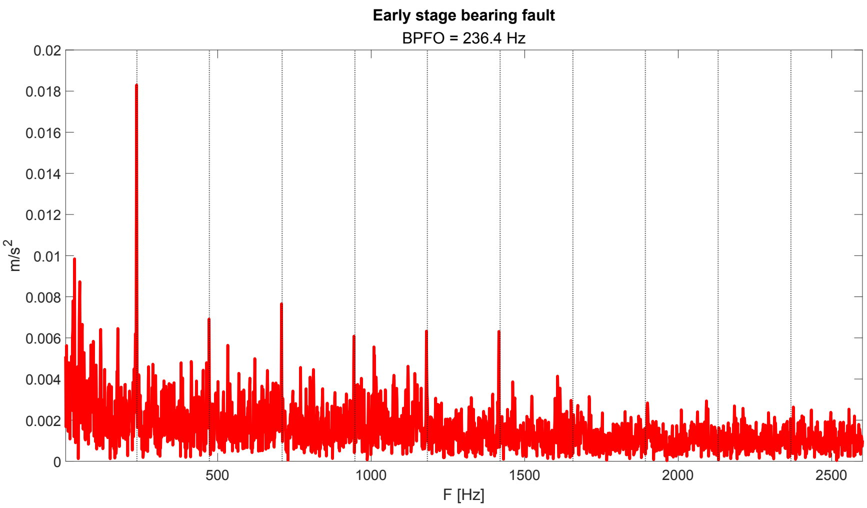


Figure 5. In the NASA dataset 2, fault detection was achieved at 89 hours.

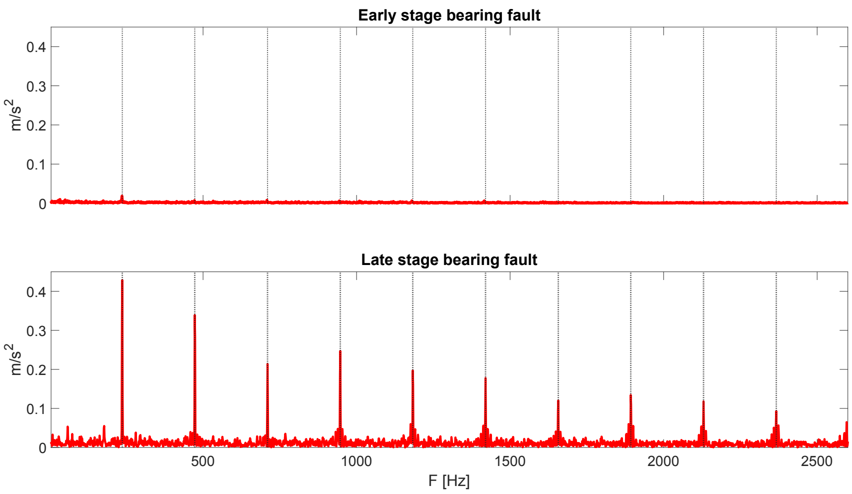


Figure 6. Comparison of early stage of Figure 5 to late stage bearing fault, clearly showing how early the failure was detected.

6. Implications and Future Directions

The landscape of industrial maintenance is rapidly evolving, driven by the ever-increasing demand for efficient, cost-effective, and scalable solutions. The goal is to ensure optimal machine health, minimize unscheduled downtimes, and amplify productivity.

Our study has underlined the viability of an innovative solution that addresses these demands: a bearing fault detection mechanism that synergizes the capabilities of the NEON vibration sensor with the SolidRed asset management platform. In our analysis, several key takeaways emerged:

6.1 Pioneering the Predictive Maintenance Revolution

Traditional preventive maintenance methodologies, mainly driven by predetermined schedules, are fast becoming obsolete. In their place, predictive maintenance, underpinned by data analytics, is coming to the fore.

6.2 Unmatched Scalability and Reliability

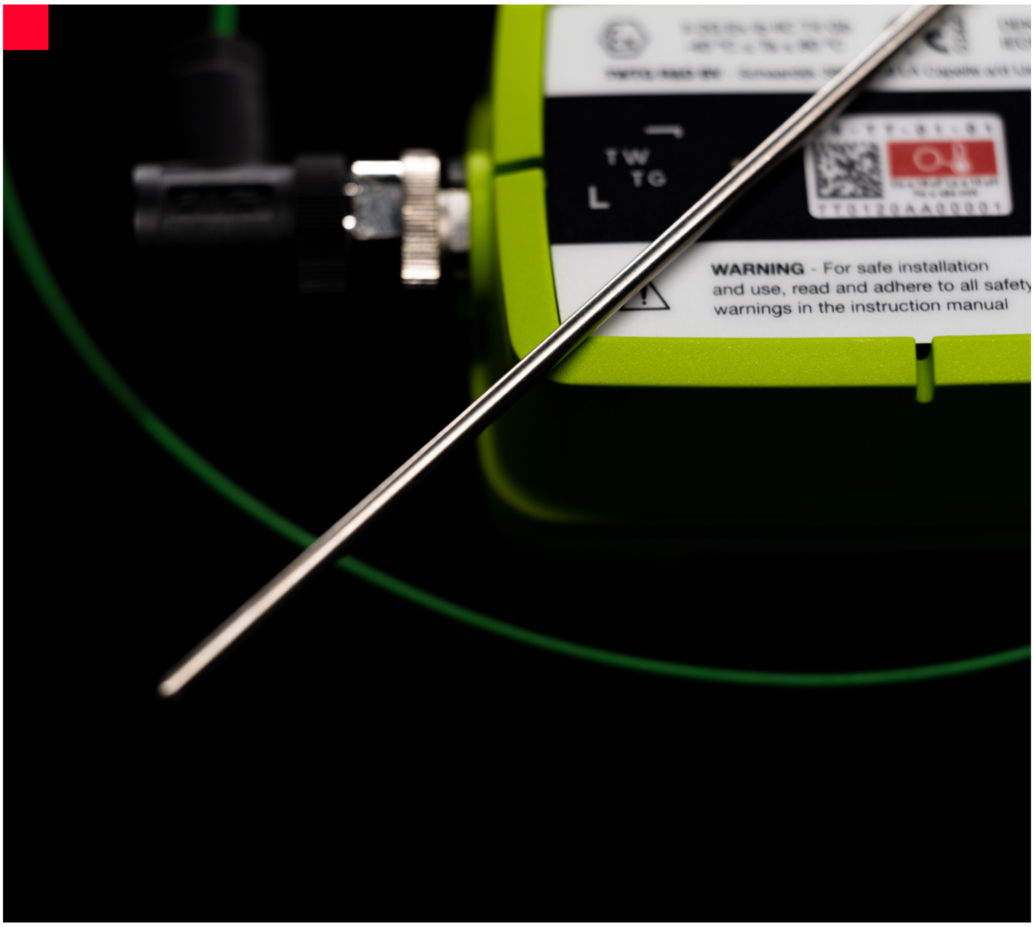
With the integration of NEON and SolidRed, we are not merely presenting a solution but a paradigm shift in how industries view fault detection. The self-reliant data processing capability of the NEON sensor, combined with the advanced analytics of SolidRed, ensures that large-scale deployments become feasible without compromising precision or incurring significant infrastructure costs.

6.3 Empowering End-Users

Beyond the technological marvels, our solution's heart is a commitment to user-friendliness. With most automated processes, engineers aren't inundated with constant data streams but are provided with actionable insights only when anomalies arise or when they choose to examine the data. These insights come bundled with comprehensive diagnostic reports, empowering users to make informed decisions promptly.

6.4 Future Prospects and Enhancements

Innovation is an ongoing process, and as such, we aim to regularly improve our algorithms, broaden our fault detection capabilities, and adapt our system to the changing needs of industries.



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