Root Cause Analysis

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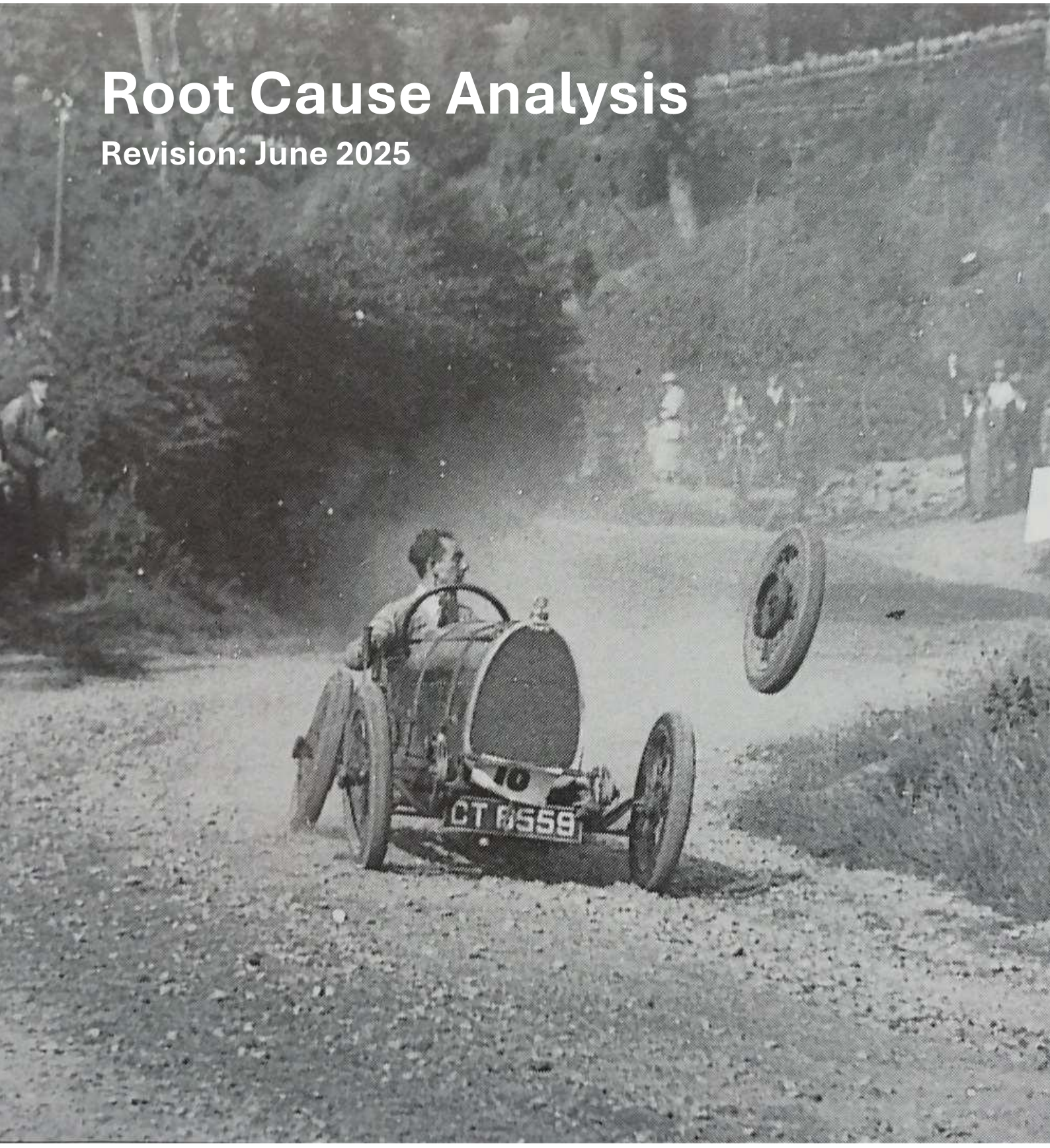

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Unbalance

Rotor Mass Unbalance

All rotating machinery inherently experiences some degree of **mass unbalance** within the rotor, wherein the **center of mass is not aligned** with the **center of rotation**.

This misalignment generates a **centrifugal force**, potentially leading to **undesired vibration** during operation.

Common Causes of Rotor Unbalance:

- Uneven load distribution (e.g., accumulation of foreign matter on the impeller, bent rotor shaft after e.g. stone impact, etc)
- Eccentric wear or mechanical damage
- Improper assembly or installation
- Thermal expansion or mechanical distortion
- Misaligned couplings, wear of elastomeric shaft coupling or damaged drive belts

The **unbalance parameter** is defined as vibration **energy at rotational frequency**, and is used to monitor and assess the condition of the rotating system.

Unbalance Warning Condition – Elevated Level Detected

If the measured unbalance level exceeds **2× the baseline** for more than **30 seconds**, the sensor will issue a **warning**. This may be due to a **temporary overload** or indicate a **developing mechanical issue, or damaging impact.**

Verification Procedure:

1. **Assess Load Condition**:
   Verify that the motor is operating within its intended load range.
2. **Inspect Driven Equipment**:
   Check for signs of wear or mechanical damage in the connected equipment.
3. **Trend Analysis**:
   Monitor vibration RMS levels and unbalance data over time to detect progressive changes.
4. **Temperature Check**:
   Measure skin temperature while the machine is running to identify abnormal heat development.

Follow-up Action:

Based on the findings, use the next scheduled machine stop to perform a detailed inspection and, if necessary, plan for rotor balancing or place damaged parts.

Unbalance Alarm Condition – High Level Detected

If the measured unbalance level exceeds **3× the baseline** for more than **30 seconds**, the sensor will trigger an **alarm**. This indicates a **significant change over time** and requires **immediate attention**.

While the condition may result from a **temporary overload**, it could also signify a **persistent mechanical issue**.

Recommended Actions:

- **Immediate Inspection**: If operationally feasible, stop the machine to conduct a rapid balancing/failure inspection.
- **Planned Maintenance**: If immediate inspection is not possible, plan for a balancing intervention or replace of damaged parts during the next scheduled machine stop.

Troubleshooting Steps:

1. **Impeller Contamination**:
   In pumps and blowers, a sharp increase in unbalance is often caused by the accumulation of foreign matter on all impellers. If debris from one impeller breaks off, a significant unbalance can occur. Cleaning all impellers may restore balance.
2. **Mechanical Wear or Damage**:
   Unbalance resulting from wear or damage to rotating components typically requires a **full balancing procedure or place of damaged parts**. This should be **scheduled as part of planned maintenance**.

Wear of damaging of coupling:
Skewed assembly of parts, with rigid coupling, will lead to increased wear and tear, premature failure of components, and even damage to the coupling itself. Alignment is recommended.

Cavitation

Cavitation (in pumps)

Cavitation is a common issue in pump systems, caused by the formation of **vapor bubbles** within a liquid in **low-pressure regions**. This phenomenon is undesirable as it leads to:

- **Severe erosion** of rotating blades
- **Increased noise**, due to knocking and vibration
- **Significant loss of efficiency**, resulting from distorted flow patterns and speed fluctuations
- **Loss of head pressure**

Although a minimal, non-damaging level of cavitation is often present, **measurable cavitation** detected through **vibration analysis** typically indicates **blade erosion** and requires **maintenance intervention**.

Common Causes of Cavitation

- Too low water level on pump inlet side (open systems).
- Inlet restrictions or blockages affecting flow or pressure
- Clogged filters or strainers
- Excessively long inlet piping
- Collapsed or restricted inlet hoses
- Improper pump specification or pimp operating in very left or right part of the performance curve.
- Unsuitable operating conditions (e.g., machine speed, system pressure, fluid temperature, and ambient temperature)

Detection and Measurement

Cavitation can often be recognized audibly as **random bursts of high-frequency sound**. The **cavitation parameter** quantifies the **energy** of these acoustic bursts. For ease of monitoring, both the parameter and its baseline are **normalized** to the reference level established at installation.

A **cavitation level of 2** indicates that the current cavitation-related vibration energy has **doubled** compared to the initial baseline.

Cavitation Warning Condition – Elevated Level Detected

In the measured **cavitation level exceeds 2× the baseline** for more than **30 seconds**, the sensor will issue a **warning**. This may indicate a **temporary overload** but could also signal a **persistent problem** requiring corrective action.

Verification Procedure:

- **Inspect inlet conditions** to ensure there are no blockages or restrictions.
- **Confirm adequate fluid supply** to the pump, without interruptions.
- **Compare temperature conditions** during periods with and without cavitation to identify contributing factors.
- **Monitor skin temperature** while the machine is operating to detect any abnormal increases, like over-pumping, right side on the pump performance curve.

Based on these observations, consider **adjusting machine speed** or **modifying discharge pressure** to evaluate the impact on cavitation behavior.

Cavitation Alarm Condition – High Level Detected

If the measured **cavitation level exceeds 3× the baseline** for more than **30 seconds**, the sensor will trigger an **alarm**. This represents a **significant increase** over time and requires **immediate attention**.

While it may be caused by a **temporary overload**, it could also indicate a **persistent system issue**.

Recommended Operational Adjustments:

- **Temporarily reduce impeller rotation speed** to move the pump out of cavitation while investigating the installation.
- **Increase the available Net Positive Suction Head (NPSHa)** to improve suction conditions and reduce vapor bubble formation.

Vibration RMS

Vibration Measurement – RMS Value

Vibration Measurement – RMS Value

A classical and widely used vibration metric is the **Root Mean Square (RMS)** value. This parameter measures the **overall vibration energy** within a **low-frequency band (10–1000 Hz)**. While easy to interpret, the RMS value provides **limited diagnostic insight**, as it does not distinguish between different vibration sources and is **insensitive to high-frequency faults**.

Due to its broad sensitivity, the RMS value reflects the combined influence of various fault types and operational variations, including:

- Unbalance
- Misalignment
- Looseness
- Cavitation (characterized by broadband vibration)
- Resonance

Standard References:

- **ISO 20816-3** provides fixed warning and alarm thresholds for medium and large rotating machines.
- **ANSI/HI 11.6-2017** covers vibration evaluation for **submerged wastewater pumps**.

Vibration RMS Warning Condition – Elevated Level Detected

If the **vibration RMS level exceeds 2× the baseline** for more than **30 seconds**, the sensor will issue a **warning**. This may be due to a **temporary overload** but could also indicate a **persistent mechanical issue**. Given that RMS is highly sensitive to a wide range of vibration sources, troubleshooting should begin with the most common causes:

Verification Procedure:

- Is the machine experiencing **abnormally high load**?
  (e.g., seasonal demand changes, machine clogging)
- Could the elevated vibration be due to **rotor unbalance due to damaged/warn parts**?
- Is the increase related to **resonance**?
  (Try adjusting the RPM slightly to evaluate the effect.)
- Has there been **an alignment drift** between the motor and driven machine?
- Are there signs of **looseness, soft foot**, or other **mechanical defects**?

Recommended Action:

Based on the findings, schedule appropriate **repairs or adjustments** during the **next planned machine stop**.

Vibration RMS Alarm Condition – High Level Detected

If the **vibration RMS level exceeds 3× the baseline** for more than **30 seconds**, the sensor will trigger an **alarm**. This indicates a **significant and sustained change** in vibration and requires **immediate attention**. While it may result from a **temporary overload**, it could also signify a **serious and persistent fault**.

Recommended Immediate Actions:

- **Temporarily reduce the impeller rotation speed** to decrease mechanical load while troubleshooting the system.

If the vibration level does not improve after following the **Vibration RMS Warning Verification Procedure**, **plan to stop the machine as soon as possible** to perform a detailed investigation.

Bearing Fault Detection

Bearing Condition Monitoring

Bearings are critical components in all rotating machinery. Under normal operating conditions, they produce **low-level, random vibration signals**.

However, when a **defect begins to develop**, the vibration pattern changes to a **higher-level, periodic signal**. Each time a rolling element passes over a crack or defect, a high-frequency impact occurs. The frequency of each of these impacts is directly related to the shaft RPM and the specific location of the fault - outer race, inner race, balls or the cage.

Under normal conditions, **none of these characteristic frequencies** should be present in the vibration spectrum. The detection of any such frequency is a **strong indicator of a developing bearing fault**. Because a bearing defect will not self-heal, it will typically **worsen over time**, and the **periodic vibration energy** will continue to increase as the crack propagates.

The **bearing monitoring algorithm** measures this periodic energy and **normalizes it relative to the baseline** recorded at the time of installation. A **normalized level above 1** signifies an **increasing severity level**.

Bearing Warning Conditions – Elevated Level Detected

If the **bearing vibration level exceeds 2× the baseline** for more than **30 seconds**, the sensor will issue a **warning**. This condition may be attributed to one of two scenarios:

- **Extraordinary load on the bearings** – a **reversible** condition
- **Accelerated bearing wear** – an **irreversible** condition

Recommended Action for Reversible Conditions:

If the increased level is due to extraordinary loading, take immediate steps to **reduce the operational load** on the bearings (e.g., by lowering **RPM**, **torque**, or **mechanical load**). This can help **extend or maintain the remaining bearing life**.

Bearing Alarm Condition – High Level Detected

If the **bearing vibration level exceeds 3× the baseline** for more than **30 seconds**, the sensor will trigger an **alarm**. This condition may indicate:

- **Extraordinary load on the bearings** – a **reversible** condition
- **Accelerated bearing wear** – an **irreversible** condition

Recommended Actions:

- If the alarm is due to **extraordinary loading**, immediately **reduce the operational load** on the bearings (e.g., by lowering **RPM**, **torque**, or **mechanical weight**) to help **preserve bearing life**.

Regardless of the cause, it is **strongly recommended to replace the bearing as soon as possible**, and **no later than the next scheduled maintenance stop**, to avoid unplanned downtime or secondary damage.

Temperature

Temperature Monitoring Considerations

Temperature is a fundamental parameter in monitoring the condition of machinery and processes. While conceptually straightforward, practical factors often influence its interpretation.

In this case, the temperature sensor is housed within a **stainless-steel capsule**, which leads to:

- **Attenuation** of the actual motor/machine surface temperature due to thermal insulation
- **Offset readings** caused by internal heat generation from the **microcontroller**, typically adding **15–20°C**

As a result, **absolute temperature values may not be reliable**, but **relative temperature trends** remain highly valuable in a **condition monitoring context**. By comparing current readings to the **initial baseline**, deviations can signal early signs of abnormal operating conditions.

Common Causes of Elevated Temperature Readings:

- Mechanical **wear or damage**
- **Excessive machine loading**
- **Seasonal temperature variations**
- **Increased fluid temperature** in the system
- **Clogging**

Action Thresholds:

Default **warning and alarm thresholds** (gains) are set to **2.0** and **3.0**, respectively, across all parameters. However, for **temperature**, it may be beneficial to **manually adjust these thresholds** to lower values to better suit specific applications and equipment sensitivity.

Temperature Warning Condition – Elevated Level Detected

If the **temperature level exceeds 2× the baseline** for more than **30 seconds**, the sensor will issue a **warning**. This may be due to a **temporary increase** or the onset of a **persistent temperature issue**.

Recommended Response:

- Inspect the machine and process conditions.
- Identify potential causes of the temperature rise (e.g., load changes, ambient conditions, wear).

Determine if **intervention is needed** to stabilize or reduce temperature.

Temperature Alarm Condition – High Level Detected

If the **temperature level exceeds 3× the baseline** for more than **30 seconds**, the sensor will issue an **alarm**. A temperature alarm must be **treated as a priority**, as it is often a **secondary effect of a more serious underlying issue**.

Excessive heat may result from **mechanical wear, overloading, or other faults**, indicating that the problem has likely **progressed to an advanced stage**.

Recommended Response:

- **Immediately reduce motor RPM**, if possible, or **shut down the machine** to prevent further thermal buildup.
- **Identify the root cause** of the elevated temperature to mitigate **collateral damage** and address the primary fault.

Do not resume operation until corrective actions have been implemented and the temperature has stabilized.

Gear Mesh Frequency

Gear Mesh Frequency (GMF) Monitoring

Gears come in various designs, but a key performance indicator is the **vibration level associated with gear tooth engagement**. This is measured at the **Gear Mesh Frequency (GMF)**, which is calculated as:

GMF = Shaft RPM × Number of Gear Teeth

For standard spur gears, this results in an **integer multiple** of the shaft speed. For **planetary gears**, the mesh frequency may be a **non-integer multiple**, depending on the configuration.

Indicators of Gear Faults

Under **normal operating conditions**, gears produce a **low-level vibration signal** at the GMF. However, **wear or damage** will cause an increase in vibration at the GMF and its harmonics. In some failure modes, **sidebands** around the GMF may also appear.

Common causes of elevated GMF vibration levels include:

- Normal gear wear
- Premature gear wear
- Damaged gear teeth
- Gear misalignment
- Improper or insufficient lubrication
- Excessive gear loading
- Bearing fault => high tooth clearance

Measurement and Interpretation

Absolute GMF vibration levels are difficult to assess in isolation due to influencing factors such as **sensor placement**, **gear size**, and **operational context**. A more reliable method involves **normalizing both the vibration readings and the baseline** to the **initial value recorded at installation**.

Using this approach, a **normalized GMF vibration level of 2** indicates that the current vibration energy has **doubled relative to the original baseline**, providing a **clear indicator of condition change** over time.

GMF Warning Condition – Elevated Level Detected

If the **Gear Mesh Frequency (GMF) level exceeds 2× the baseline** for more than **30 seconds**, the sensor will issue a **warning**. Troubleshooting elevated GMF levels can be **complex**, as gear systems involve multiple **interconnected components**. The issue may originate from **internal faults** within the gear assembly or **external influences**.

Initial Troubleshooting Checklist:

- **Improper attachment** of the gearbox or drive components
- **Incorrect or insufficient oil levels** affecting lubrication and cooling
- **Premature gear wear** or degradation
- **Bent or undersized shaft** (not within specified tolerances)
- **Overhung load** creating uneven stress on gears and bearings

Noise or vibration originating from connected equipment (e.g., misalignment or resonance in driven machinery).

GMF Alarm Condition – High Level Detected

If the **Gear Mesh Frequency (GMF) vibration level exceeds 3× the baseline** for more than **30 seconds**, the sensor will trigger an **alarm**. This condition indicates a **serious fault** within the gear system that requires **immediate attention**.

A GMF alarm typically signals **advanced gear wear**, **tooth damage**, or a **critical alignment or load issue**. It is essential to follow up **promptly**, building on the initial steps from the **GMF warning-level troubleshooting**.

Recommended Action:

- Review all previously identified potential causes (attachment, lubrication, shaft condition, load, and connections).
- If the source cannot be corrected through operational adjustments, **schedule a shutdown as soon as possible** for in-depth inspection and repair.

Do not continue operation under alarm conditions to avoid secondary damage or catastrophic failure.

Machine Looseness

Machine Looseness Monitoring

Looseness in machinery can generally be categorized into two types:

- **Rotating Looseness**: Caused by **excessive movement in rotating components** such as shafts, couplings, or bearings. It typically results from **excessive clearance** between rotating and stationary parts.
- **Structural Looseness**: Occurs when the **machine or its components are not securely fastened** to the base or foundation. In such cases, components may exhibit erratic motion - **not a smooth sinusoidal pattern**, but rather a **truncated or distorted motion**, often likened to a "chopped" sine wave due to the impact of a loose bolt shifting within its mounting hole.

Measurement Principle

Both types of looseness are assessed using the **Machine Looseness parameter**, which measures the **purity of mechanical motion** through a **Total Harmonic Distortion (THD)** approach. Specifically, it evaluates the **relationship between total harmonic energy and the unbalance level**.

Because every machine has a unique vibration signature, the looseness parameter will differ **in absolute terms** from one machine to another. However, a **rising trend in this parameter** is a reliable indicator that **some component has become loose** within the system.

Note: The Machine Looseness parameter is currently **not baselined** and is **not integrated** into the overall Machine Health index.

Warning action – Elevated Level Detected

Not active.

Alarm action – High Level Detected

Not active.

False Brinelling

False Brinelling Monitoring

While **operating machinery** naturally produces some level of vibration, this is generally **not harmful to bearings and gearboxes**.

In motion, the load is **evenly distributed** across the inner and outer races of the bearing via the rotating balls or rollers. However, when a machine is **not in operation**, and it is subjected to **external vibrations** from nearby equipment or long truck transportation, the **stationary bearing elements** can suffer **localized loading**. Over time, this leads to **wear marks** on the races—commonly referred to as **False Brinelling**.

Key Risk Indicator

- A **vibration level of 2 mm/s**, though acceptable for an **operating bearing**, can be **harmful to a non-operating bearing** over a short period due to localized impact forces.

Measurement Method

The **False Brinelling parameter** calculates the **ratio of vibration energy received while the machine is not operating**, compared to the **total vibration energy received**, then multiplies this by 100% to express it as a percentage:

False Brinelling Level (%) = (Idle Vibration Energy / Total Vibration Energy) × 100

Interpretation Guidelines

False Brinelling Level (%)	
0–20%	Normal range
21–40%	Elevated concern – monitoring recommended
41–60%	Severe concern – damaging mechanical coupling between machines

Application and Benefits

Unlike standard bearing diagnostics, which detect faults **after damage has occurred**, the False Brinelling algorithm allows for **early identification of installation issues**, even from the **first day of operation**. This enables proactive intervention and can prevent premature bearing failure.

Additionally, it serves as a **quality metric** for installation practices and is a valuable tool for **root cause analysis** in **warranty cases involving premature bearing or gearbox failure**.

Note: The False Brinelling parameter is currently **not baselined** and is **not part of the overall Machine Health**

Warning action – Elevated Level Detected

Not active.

Alarm action – High Level Detected

Not active.


1
2
2


Vibration RPM
Unbalance
Gear Mesh Frequency
Cepstral Analysis
Slip Speed
Cavitation
Magnetic RPM
Rotation Direction
Vibration STD
Motor Pole Pairs
False Brinelling
Envelope Analysis
Operation Time
Kurtosis
Start Stop Counter
Bearing Fault Detection
Crest Factor
Duty Cycle
Skewness
Baseline
Magnetic Strengt
Temperature
Vibration RMS
Machine Health
Raw Data