[Intelligent early warning platform for mobile equipment]

Glossary of Terms

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Contents

I. Rotor Alignment Status

1.1 Definitions

Rotor Alignment (Rotor Alignment) refers to whether the geometrical positional relationship between the connected rotor shafts in rotating machinery (e.g., motors, pumps, fans, turbines, etc.) is in a desired state of alignment. The purpose of alignment is to ensure that the centerlines of the rotor shafts remain continuous and co-linear during rotation to avoid vibration, wear or energy loss due to deviation.

Ideal for the center:

The centerlines of each rotor shaft are perfectly coincident (aligned under both static and dynamic conditions).

Transmits torque without additional bending stresses or alternating loads.

Not right in the middle:

When there is a deviation from the centerline of a shaft, it is called shaft misalignment (Misalignment) and is one of the common sources of vibration in rotating machinery.

Misalignment can lead to additional cyclical forces that trigger vibration, bearing wear, seal failure and other problems.

1.2 Types of misalignment

typology	clarification	Vibration characteristics
parallel misalignment (Offset Misalignment)	The axes of the two axes are parallel but there is a horizontal or vertical offset	Radial vibration is predominant, and the spectrum may show 1-octave (1×RPM) and 2-octave (2×RPM) components.
Angle misalignment (Angular Misalignment)	The axes of the two axes form an angle	Significant axial vibration, with 1x frequency dominating the spectrum, accompanied by high harmonics.
Compound misalignment (Combined Misalignment)	In practice, it is mostly a combination of parallel and angular misalignment.	

1.3 Effect of poor alignment on vibration:

Increase in vibration amplitude: misalignment generates alternating forces, leading to increased vibration in bearings, couplings and other components.

1.4 means of detection:

Vibration analysis: Determine the type of misalignment by spectrum, phase, and axis trajectory.

Spectral characteristics: 1x frequency (related to RPM) and 2x frequency components are prominent. Abnormally elevated axial vibration (especially in case of angular misalignment).

Phase analysis: The vibration phase difference between the two sides of the coupling is close to 180° (parallel misalignment) or varies asymmetrically (angular misalignment).

1.5 Adjustment measures:

Readjust the coupling or base to ensure cold and hot alignment (taking into account the effects of thermal expansion).

Use flexible couplings to compensate for slight misalignments.

Regular monitoring and maintenance to avoid deviations triggered by foundation settlement or component deformation.

1.6 Summary

The state of rotor alignment is a critical factor in the healthy operation of rotating machinery. Misalignment significantly increases vibration energy and accelerates component fatigue failure. By identifying misalignment characteristics through vibration analysis and combining them with precision adjustment technology, failure rates can be effectively reduced and equipment life extended.

II. Rotor Balance Status

2.1 Definitions

Rotor balance state (Rotor Balance) refers to the rotating machinery rotor mass distribution is uniform state. If the rotor mass distribution symmetrical to the axis of rotation, rotation will not produce centrifugal force imbalance, known as the **state of balance**; on the contrary, it is known as the **state of imbalance**, which will lead to increased vibration, component fatigue and even equipment damage.

ideal balance

The center of mass (center of mass) of the rotor is perfectly coincident with the geometric center (axis of rotation).

The centrifugal forces cancel each other out during rotation and no additional periodic excitation forces are generated.

disequilibrium

The center of mass deviates from the axis of rotation, creating a centrifugal force (unbalance force) that causes the vibration energy to be concentrated at a frequency related to the rotational speed (1 octave, i.e., 1 x RPM).

It is one of the most common sources of vibration failure in rotating machinery (accounting for about 80% of vibration problems).

2.2 Types of Imbalance

☆ **Static Unbalance (Static Unbalance)**

The center of mass of the rotor is off-axis, but there is no deflection moment (mass deviation in a single plane).

Characteristics: The center of gravity of the rotor is naturally shifted to the lowest position at rest (similar to the absence of wheel counterweight).

Calibration method: adding or removing counterweights in a single plane.

☆ **Dynamic Unbalance (DU)**

The center of mass is off-axis and there is a deflection moment (mass deviation is distributed over multiple planes).

Commonly used for rotors with relatively large length and diameter (e.g. multi-stage fans, turbine rotors).

Calibration method: Counterweights need to be adjusted in two or more planes.

☆ **Couple Unbalance (CU)**

Two unbalanced forces of equal size and opposite direction are distributed in different axial planes, forming a force couple.

Vibration characteristics: significant axial vibration, phase difference close to 180°.

2.3 Effect of unbalance on vibration

Vibration frequency: dominated by 1x frequency (synchronized with RPM), possibly accompanied by harmonics (2×, 3×RPM).

Direction of vibration: radial vibration is dominant (static unbalance), or accompanied by axial vibration (dynamic unbalance).

Amplitude change: amplitude increases with the square of the rotational speed (centrifugal force is proportional to the square of the rotational speed).

Phase characteristics: The phase difference between horizontal and vertical vibrations in the same housing is close to 90° (typical unbalance characteristics).

2.4 Means of detection

Spectral analysis: 1x frequency amplitude in the vibration spectrum is significantly higher, and the phase is stable.

2.5 Common Causes of Imbalance

Manufacturing defects (casting porosity, machining errors)

Component dislodgement or corrosion (e.g., dust buildup on fan blades, impeller wear)

Assembly errors (keyway offset, coupling mounting deviation)

Thermal deformation (change in mass distribution due to uneven heating of the rotor).

2.6 Difference between balancing and centering

特征	平衡状态	对中状态
核心问题	转子自身质量分布均匀性	多转子间的轴线几何对齐
振动频率	1×RPM主导	1×RPM、2×RPM
振动方向	径向为主	径向或轴向（角度不对中时）
校正方法	配重调整	调整联轴器或底座位置

2.7 Summary

The state of rotor balance is the basis for the stable operation of rotating machinery. Unbalance will directly lead to excessive vibration, shortened bearing life and energy loss. By locking the 1x frequency characteristics through the vibration spectrum, combined with dynamic balance correction technology (such as test weight method or influence coefficient method), rotor balance can be quickly restored to ensure the safe and efficient operation of equipment.

III. Fit Condition

3.1 Definitions

Fit Condition (Fit Condition) refers to the mechanical components (such as shafts and bearings, gears and shafts, couplings and shafts, etc.) of the assembly fit to meet the design requirements, including fit tolerance, clearance or surplus and other parameters. The fit condition directly affects the contact stiffness, friction characteristics and dynamic response of the components, which is one of the important factors leading to vibration abnormalities.

Ideal fit:

The dimensional tolerances between components are in accordance with the design criteria (e.g. clearance fits, transition fits or interference fits).

Under static and dynamic conditions, the contact surface is uniformly stressed without localized stress concentration or loosening.

Bad fit:

Excessive looseness (excessive clearance): causes relative movement of components (e.g. sliding of the shaft against the inner ring of the bearing), triggering shocks, friction and random vibrations.

Over-tightening (excessive overload): Increases assembly stresses, which may cause deformation, heat generation or sudden changes in stiffness of the component, resulting in vibration energy concentrated in the high frequency band.

3.2 Types of mating states and vibration characteristics

☆ **Clearance Fit**

Typical scenarios: plain bearings, gear mesh clearance.

Vibration issues:

Too large a gap can cause nonlinear vibrations (e.g., crossover frequency, high frequency noise).

Sub-synchronous frequencies (e.g., 0.5 × RPM) or broadband energy may be present in the spectrum.

Loose parts (e.g., untightened bolts) can generate random shock signals with "burr" characteristics in the time domain waveform.

☆ **Interference Fit**

Typical scenarios: cold press assembly of bearing inner rings to shafts, tight fit of couplings to shafts.

Vibration issues:

Excessive overfill can lead to localized stress concentrations, triggering fatigue cracks or high-frequency resonance.

The intrinsic frequency component of the rotor (excited by stiffness changes) may appear in the spectrum.

☆ **Wear-induced fit deterioration**

Typical scenario: Wear of bearings, gear teeth or keyways after long periods of operation.

Vibration characteristics:

A gradual increase in vibration amplitude, accompanied by an increase in harmonics (e.g., sideband broadening when gears are worn).

Modulation phenomena may be triggered (e.g. load modulation effects when the bearing outer ring is worn).

3.3 Effect of poor fit on vibration

☆ **Vibration frequency:**

Loose gaps: sub-synchronous frequencies, high-frequency noise.

Overshoot fits: high frequency resonance or stiffness related octave components.

☆ **Vibration direction:**

Radial vibration is predominant (e.g. shaft and bearing fit problems).

Axial vibration may be elevated by tilted components or uneven forces (e.g. over-tightened couplings).

☆ **Phase Characterization:**

The phase is unstable and fluctuates randomly when loose.

Overfitting can lead to sudden phase changes (due to stiffness nonlinearity).

3.4 Detection and diagnostic methods

☆ **Vibration spectrum analysis:**

Identifies sub-synchronous frequencies, high-frequency resonances, or modulated side frequencies (e.g., gear mesh frequencies± shaft frequencies).

Shock signal features are extracted using **envelope demodulation techniques** (suitable for loose or worn diagnosis).

☆ **Time domain analysis:**

Observe whether the waveform contains random shocks or periodic pulses (e.g., transient impacts from loosening bolts).

Elevated kurtosis is often indicative of shock vibration.

☆ **Phase and coherence analysis:**

The correlation of vibration phases between different measurement points is reduced when the fit is poor.

Loose parts may cause **non-smoothness** of the vibration signal.

☆ **Temperature and noise monitoring**:

When the interference fit is too tight, the local friction heating is significant.

Excessive clearance can be accompanied by abnormal mechanical noise (e.g., "clicking").

3.5 Adjustment and maintenance measures

☆ **Assembly control:**

Select fit tolerances according to design requirements (e.g. H7/g6 clearance fit, H7/s6 interference fit).

Use hydraulic assembly or heating to avoid stress concentrations in interference fits.

☆ **Wear and tear repair:**

Regularly check the amount of wear on bearings and gear teeth and replace or repair them in time.

Worn journals can be restored to size using processes such as spraying and plating.

☆ **Dynamic compensation:**

For components sensitive to thermal expansion (e.g., turbine rotors), design to allow for thermal fit clearance.

Use flexible couplings or flexible supports to compensate for slight fit deviations.

3.6 Correlation of fit status with other faults

- ☆ Interaction with unbalance: Loose fits may amplify vibrations caused by unbalance (due to reduced support stiffness).
- ☆ Superposition with poor alignment: Improper coupling interference fits can exacerbate the effects of alignment errors.
- ☆ Relationship to resonance: Overfitting changes the stiffness of the component and may shift the system intrinsic frequency to near the operating speed.

3.7 Summary

The state of fit is a hidden factor in vibration analysis that cannot be ignored. Abnormalities can significantly affect the vibration characteristics of equipment by altering contact stiffness, friction characteristics, or inducing shocks. Mating problems can be effectively diagnosed through subsynchronous components in the frequency spectrum, modulated side frequencies or high-frequency resonance features, combined with time-domain shock signals and temperature variations. Maintenance requires strict control of the assembly process and dynamic adjustment of the fit parameters to the operating environment (e.g., temperature, load) to ensure stable operation of the equipment.

IV. Rolling Bearing Lubrication Condition

4.1 Definitions

Rolling bearing lubrication condition refers to the bearing internal lubricant (grease) distribution, oil film thickness, the degree of contamination and lubrication effectiveness and other comprehensive state. Lubrication state directly affects the bearing friction, wear, temperature rise and vibration characteristics, is one of the core factors of healthy bearing operation. Poor lubrication will significantly change the dynamic behavior of the bearing, and trigger high-frequency vibration, noise or early failure.

☆ **Ideal lubrication:**

The lubricant film completely covers the contact area between the rolling element and the raceway, forming elastohydrodynamic lubrication (EHL).

Minimal friction, low vibration energy and smooth frequency spectrum, no abnormal impact or high frequency noise.

☆ **Poor lubrication:**

Insufficient lubrication: rupture of the oil film leads to direct metal-to-metal contact, triggering dry friction, localized high temperatures and wear.

Lubrication contamination: particulate matter (such as dust, metal shavings) mixed into the lubricant, exacerbating the rolling body surface scratches.

Excessive lubrication: Excessive grease leads to increased mixing resistance and abnormal temperature rise.

4.2 Influence of lubrication state on vibration

☆ **High-frequency noise with broadband energy:**

When lubrication is inadequate, intermetallic microconvex body collisions produce broadband random vibrations (typically in the frequency range of several kHz to tens of kHz).

The spectrum shows **a "burr" of high-frequency energy**, which may be accompanied by resonance peaks (e.g., the intrinsic frequency of the outer ring of the bearing is excited).

☆ **Shock signals:**

After the lubrication failure, the rolling body and raceway contact instantly generates transient impact, and the time domain waveform appears as a **short-time spike pulse**.

Modulated shock eigenfrequencies (e.g. bearing failure frequencies) can be extracted using **envelope demodulation analysis**.

☆ **Vibration amplitude fluctuations:**

When the lubrication state is unstable, the vibration amplitude shows non-periodic fluctuation with time, especially under variable speed or variable load conditions.

☆ **Temperature correlation:**

Poor lubrication is often accompanied by increased bearing temperatures, and vibration energy (especially in the high frequency band) is positively correlated with temperature.

4.3 Classification and diagnosis of poor lubrication

☆ **Insufficient lubrication**

Diagnostic Markers:

The energy in the high frequency band (2~10 kHz) of the spectrum is significantly elevated, which may be accompanied by a bearing intrinsic frequency component.

An increase in the kurtosis value of the time-domain signal reflects an increase in shock vibration.

Acoustic emission (AE) signals sensitively capture microscopic friction events.

☆ **Lubrication contamination**

Diagnostic Markers:

Broadband random shocks associated with contaminant size appear in the vibration signal.

Oil analysis detects metal wear particles or foreign matter (e.g. iron spectrum analysis, PQ index).

☆ **Aging or deterioration of grease**

Diagnostic Markers:

A decrease in lubricant viscosity leads to a reduction in the oil film's load-bearing capacity and a shift of vibration energy to lower frequencies.

Abnormal vibration accompanying the outer ring or cage of the bearing (e.g. cage failure frequency components).

4.4 Detection and analysis methods

☆ **High frequency vibration analysis:**

Use accelerometers (frequency response range ≥ 10 kHz) to capture high frequency signatures of poor lubrication.

Spectral analysis: Observe the energy distribution in the 2~20 kHz band, the energy is significantly higher when there is insufficient lubrication.

☆ **Envelope demodulation techniques:**

Extract the modulation frequency of high-frequency shock signals to identify bearing failure frequencies (e.g. BPFO, BPFI, FTF).

Example: Insufficient lubrication leads to dry friction between the rolling elements and the raceways, which may show up in the envelope spectrum as bearing periphery failure frequency (BPFO).

☆ **Time domain indicator monitoring:**

RMS (RMS): Reflects the overall energy of the vibration but is not sensitive to high frequency lubrication problems.

Peak, kurtosis: more effective identification of transient shocks (kurtosis >5 in case of poor lubrication).

☆ **Multi-sensor fusion:**

Combine vibration, temperature and acoustic emission signals to comprehensively determine the lubrication status.

Sudden rise in temperature+ Increased high frequency vibration energy→ Strong indication of lubrication failure.

4.5 Lubrication state optimization measures

☆ **Lubricant selection and management:**

Select a lubricant or grease (e.g. ISO VG 32 or NLGI grade 2 grease) with the appropriate viscosity for the operating conditions (speed, load, temperature).

Regularly test the lubricant for contamination (e.g. ISO 4406 standard) and replace or filter it in time.

☆ **Lubrication improvement:**

High-speed bearings are lubricated with oil mist or oil-air lubrication to ensure even distribution of the oil film.

Control the amount of grease injection when grease lubrication (generally fill 1/3~1/2 of the bearing cavity).

☆ **Condition monitoring and maintenance:**

Establish a vibration baseline and monitor changes in energy trends in the high frequency band.

For bearings with frequent lubrication problems, check the sealing performance (to prevent the intrusion of contaminants).

4.6 Correlation of poor lubrication with other failures

Inadequate lubrication→ Wear→ Spalling: Chronic poor lubrication accelerates bearing surface fatigue, eventually leading to pitting or spalling (a clear failure frequency in the vibration spectrum).

Contamination→ Micromotor Wear→ Looseness: Particle contamination triggers micromotor wear, which may lead to widening of the fit gap and superimposed loosening characteristics (e.g. subharmonics) in the vibration.

Grease Aging→ Cage Wear: Deteriorated grease increases the friction between the cage and the rolling elements, which may stimulate the frequency of cage failures (FTF).

4.7 Summary

Rolling bearing lubrication is a "hidden health indicator" that cannot be ignored in vibration analysis. Although poor lubrication is not directly manifested in the classical failure frequency, it will expose the problem through high-frequency noise, random impact and temperature abnormality. Through high-frequency vibration analysis, envelope demodulation and multi-parameter fusion diagnosis, lubrication failure risk can be warned in advance. Maintenance needs to be combined with lubricant performance monitoring and vibration trend analysis to achieve "precision lubrication", thereby extending bearing life and avoiding sudden failure.

V. Component Rubbing Condition

5.1 Definitions

Component Rubbing Condition refers to the rotor (or impeller, blades, etc.) in rotating machinery and stationary housing, seals, bulkheads and other fixed parts of the unintended contact or friction phenomenon. This kind of contact will cause transient impact, nonlinear vibration and energy dissipation, is one of the common causes of abnormal vibration and failure of equipment.

☆ **Ideal state:**

Design clearances (e.g. air seal clearances, labyrinth seal clearances) are maintained between rotating and stationary parts without any contact.

Dynamic rotor displacement is always within safe limits to avoid friction interference.

☆ **Bumper-to-bumper occurrences:**

When the gap is breached due to vibration, deformation or assembly error, the rotor comes into contact with the stator, generating friction, localized high temperatures and wear.

Bumping may be **transient** (e.g., startup/shutdown process) or **continuous** (e.g., severe misalignment or thermal deformation resulting in loss of clearance).

5.2 Types of Bumping and Vibration Characteristics

☆ **radial contact**

Cause: Excessive radial displacement of the rotor (e.g. unbalance, misalignment, shaft bending).

Vibration characteristics:

High-frequency vibration: A broadband shock is generated at the moment of contact, with a significant increase in energy in the high-frequency band of the spectrum (1~10 kHz).

Crossover and octave: there may be crossover components such as 1/2 x RPM, 1/3 x RPM, or octave components such as 2 x RPM, 3 x RPM (due to nonlinear friction excitation).

Sudden phase change: the vibration phase jumps with the change of friction position, showing instability.

☆ **axial contact**

Cause: Abnormal axial thrust (e.g. thrust bearing failure, uneven thermal expansion).

Vibration characteristics:

Sudden increase in axial vibration: significant increase in axial 1×RPM amplitude in the spectrum.

Shock modulation: the time-domain waveform shows periodic shocks (related to the rotor rotation period).

☆ **touch briefly**

Cause: Eccentricity of rotor or local deformation of stator (e.g. tilted seal installation).

Vibration characteristics:

Sub-synchronous vibration: may excite the rotor system intrinsic frequency (e.g. 0.4×RPM~0.8×RPM).

Chaotic properties: the vibration signal shows non-periodic fluctuations (recognizable by Lyapunov exponential analysis).

5.3 Typical triggers for touching

☆ **Gaps are not properly designed:**

Installation clearance is too small or thermal expansion is not compensated.

☆ **Abnormal rotor dynamics:**

Unbalance, misalignment, and shaft bending result in rotor trajectories outside the safe range.

Resonance amplification displacement near critical speed.

☆ **External interference:**

Fluid excitation (e.g., wheezing, vortexing), loose foundations, or external shock loads.

☆ **Thermal deformation:**

The difference in thermal expansion rates between the rotor and stator during startup and shutdown results in a loss of clearance.

5.4 Vibration Diagnostic Methods for Touch and Go

☆ **spectral analysis**

High-frequency energy surge: Significantly elevated energy in the 2 to 10 kHz band (contact shock).

Crossover frequencies and harmonics: components such as 1/2 x RPM, 2 x RPM, etc. appear in the spectrum (nonlinear friction excitation).

Side-frequency modulation: If the touching occurs periodically, side frequencies (e.g., 1 × RPM) may occur on both sides of the fundamental frequency (e.g., 1 × RPM ± intrinsic frequency).

☆ **Time domain waveform analysis**

Waveform clipping: The top or bottom of the waveform is "cut off" due to frictional resistance limiting the displacement amplitude (Figure 1).

Shock pulse: Periodic or random spikes in the time domain signal (corresponding to the contact instant).

☆ **Phase and Trajectory Analysis**

Phase instability: the vibration phase fluctuates randomly with the friction position.

Axial trajectory distortion: normal elliptical trajectory becomes "8" or polygonal (non-linear motion due to frictional interference).

☆ **envelope demodulation technique (computing)**

Extract the modulation frequency of the high-frequency shock signal and identify the characteristic frequency (e.g. rotor rotation frequency or intrinsic frequency) associated with the touch cycle.

5.5 Accompanying phenomena of touching

☆ Elevated temperature: friction localized heat, infrared thermography can locate hot spots.

☆ Abnormal noise: high-frequency rubbing or periodic "scraping" sounds.

☆ Wear marks: Visual inspection reveals scratches and discoloration on the rotor or stator surface (downtime verification required).

5.6 Handling and preventive measures for bumping

☆ **Adjust the clearance**:

Redesign of moving and static component clearances according to thermal conditions (e.g. compensation for thermal expansion during start-up and shutdown of the turbine).

Use adjustable seals (e.g. honeycomb seals, brush seals) to absorb displacement fluctuations.

☆ **Eliminate sources of motivation:**

Calibrate the rotor dynamic balance and alignment status to avoid vibration amplitude exceeding the standard.

Optimize the operating process to avoid prolonged operation in the critical speed range.

☆ **Enhanced monitoring:**

Install eddy current sensors to monitor rotor displacement in real time and set alarm thresholds.

Combined vibration, temperature and acoustic emission multi-parameter integrated diagnosis.

☆ **Materials & Coatings:**

Use of wear-resistant coatings (e.g. tungsten carbide, ceramic coatings) in areas prone to friction to minimize damage.

Static components are cushioned against impacts by flexible materials such as graphite seals.

5.7 Evolution and Consequences of Touching the Moor

- ☆ **Initial stage**: transient slight touching, vibration amplitude fluctuation, high frequency energy briefly elevated.
- ☆ **Continuous phase**: Friction leading to localized high temperatures→ Thermal buckling→ Increased vibration→ Wider bumping (vicious circle).
- ☆ **Final failure**: severe wear, rotor cracks or damage to the static sub-structure, triggering a shutdown.

5.8 Summary

Component friction is a typical nonlinear fault in rotating machinery, and its vibration characteristics are complex (high-frequency shock, crossover components, phase instability), which need to be combined with spectral, time-domain, phase and multi-physical field data for comprehensive diagnosis. Early contact can be repaired by gap adjustment and vibration control, while continuous contact may lead to catastrophic consequences. Maintenance needs to focus on the start-stop process, thermal gap changes and rotor dynamics stability, to avoid the coupled failure mode of "vibration to promote the motor, motor to increase the vibration".

VI. Electromagnetic Condition

6.1 Definitions

Electromagnetic Condition (Electromagnetic Condition) refers to the phenomenon of mechanical vibration caused by uneven electromagnetic field, abnormal current or imbalance of magnetic field in equipment related to electromagnetic force (such as motors, generators, transformers, etc.). Electromagnetic condition anomalies can lead to periodic or non-periodic fluctuations in electromagnetic force, and through the mechanical structure is transferred into vibration energy, its frequency characteristics are usually directly related to the power supply frequency, the number of poles or electromagnetic harmonics.

☆ **Ideal electromagnetic state:**

Uniform magnetic field distribution, balanced three-phase current, symmetrical air gap (motor-type equipment).

The electromagnetic force is constant in amplitude and symmetrical in direction, and does not generate alternating mechanical excitation forces.

☆ **Electromagnetic anomaly state:**

Magnetic field asymmetry (e.g. rotor eccentricity, stator winding short circuit).

Current imbalance (e.g., supply voltage fluctuations, phase loss operation).

Harmonic interference (e.g., high-frequency harmonic currents from inverter output).

These anomalies generate periodically varying electromagnetic forces that trigger characteristic vibrations associated with electromagnetic parameters.

6.2 Main types and characteristics of electromagnetic vibration

☆ **Power Frequency Related Vibrations**

Typical frequency:

2 x power supply frequency (2 x f): For example, for a 50 Hz grid-supplied motor, the vibration mains frequency is 100 Hz (due to the electromagnetic force pulsation frequency of 2 times the power supply frequency).

Pole Pass Frequency (Pole Pass Frequency): fpp= Npoles× Rotation rate × f2fpp = 2Npoles × Rotation rate × f. Commonly found in induction motor rotor eccentricity faults.

Vibration direction: radial vibration is dominant (electromagnetic force perpendicular to the rotor axis).

Spectral characterization: the 2×f component of the spectrum is prominent and may be accompanied by side bands (e.g.,± transitions).

☆ **Air Gap Eccentricity Vibration**

Static eccentricity: Fixed offset of stator and rotor axes (e.g. assembly error).

Dynamic eccentricity: the rotor axis shifts periodically with rotation (e.g. shaft bending, bearing wear).

Vibration characteristics:

The vibration frequency is the power supply frequency (ff) and its harmonics (e.g. 2f,3f2f,3f).

Dynamic eccentricity may excite the combined frequency of the rotational frequency (RPM) and the power supply frequency (e.g., f±RPMf±RPM).

☆ **Rotor broken bars or winding failure**

Induction motor rotor broken bars:

In the vibration spectrum, side frequencies appear on both sides of the power supply frequency (f±2sff±2sf, ss is the slew rate).

(1±2s)f(1±2s)f component in the concomitant current spectrum (can be diagnosed by joint vibration and current analysis).

Stator winding short circuit:

The vibration energy is concentrated at odd multiples of the power supply frequency (e.g., 3f, 5f) and may be accompanied by localized overheating.

☆ **Vibration caused by variable frequency drives (VFD)**

High-frequency harmonic vibration: The high-frequency switching frequency (e.g., 2 to 20 kHz) output from the inverter is transmitted to the mechanical structure through electromagnetic force.

Low-frequency beat vibration: Resonance may be triggered when the carrier frequency is close to the intrinsic frequency of the machinery.

6.3 Diagnostic methods for electromagnetic vibration

☆ **Spectral analysis:**

Identifies the power supply frequency multiplier (2f, 3f), pole pass frequency, or combination of frequencies (e.g., f±RPMf±RPM).

Compare the spectral difference between no-load and loaded conditions (electromagnetic vibration amplitude often rises with increasing load).

☆ **Current-vibration correlation analysis:**

Simultaneous acquisition of current and vibration signals and analysis of the correlation of the frequency components (e.g., current harmonics are synchronized with vibration harmonics in case of stator winding faults).

☆ **Phase Analysis:**

Electromagnetic vibration phases may show specific patterns between different measurement points (e.g., when the stator is eccentric, the vibration phase is related to the rotor position).

☆ **Air gap detection:**

Measurement of stator-rotor air gap uniformity using a plug gauge or eddy current sensor aids in determining static/dynamic eccentricity.

6.4 Typical Sources of Failure in Electromagnetic Vibration

故障类型	振动频率特征	伴随现象
转子断条	$f \pm 2sf$（边频）	电流波动、效率下降
定子绕组短路	$3f, 5f$（奇次谐波）	局部过热、三相电流不平衡
气隙偏心	$f, 2f, f \pm \mathrm{RPM}$	电磁噪声、转矩脉动
电压不平衡	$2f$幅值升高	温升异常、振动幅值随负载变化
变频器谐波	高频开关频率及其边带	高频噪声、轴承电流导致电蚀

6.5 Distinction between electromagnetic and mechanical vibrations

特征	电磁振动	机械振动
频率来源	电源频率、极数、谐波	转速、部件固有频率、故障频率
负载相关性	幅值随负载增加显著升高	可能受负载影响较小
相位稳定性	相位与电源同步，相对稳定	相位可能随机波动（如碰摩）
消除方法	调整电气参数（如平衡电压）	机械校正（平衡、对中）

6.6 Measures to address electromagnetic vibration

☆ **Optimization of electrical parameters:**

Balance three-phase voltages/currents and reduce harmonics (e.g., add filters).

Adjust the inverter carrier frequency to avoid mechanical resonance points.

☆ **Mechanical correction:**

Repair rotor eccentricity (dynamic balancing, adjust bearing clearance).

Check stator winding insulation and replace damaged coils.

☆ **Air Gap Adjustment:**

Re-center the stator rotor to ensure an even air gap (static eccentricity).

Replace worn bearings to eliminate dynamic eccentricity.

☆ **Condition monitoring upgrade:**

A vibration+ current+ temperature multiparameter fusion monitoring system was used.

Perform regular motor current signature analysis (MCSA).

6.7 Summary

The electromagnetic state is the key bridge connecting electrical and mechanical systems in vibration analysis. Its vibration characteristics (e.g., 2× power supply frequency, side frequency modulation) have clear electrical properties, which need to be combined with current analysis and mechanical diagnosis to make a comprehensive judgment. Through the spectrum locking electromagnetic related frequency, it can quickly locate faults such as rotor broken bar, winding short circuit or air gap eccentricity. In maintenance, it is necessary to focus on the synergistic optimization of electrical and mechanical, to avoid the vicious cycle of "electric excitation, vibration loss of electricity", and to ensure the efficient and reliable operation of the equipment.

VII. RMS of Vibration Velocity

7.1 Definitions

Velocity RMS (Root Mean Square) is a key parameter for measuring the intensity of vibration energy, which represents the RMS value of the vibration velocity signal (i.e., the average energy in a statistical sense). It is one of the most commonly used vibration evaluation indexes in equipment condition monitoring and fault diagnosis, and is especially valuable in analyzing the mid-frequency bands of rotating machinery (e.g., bearing and gear failures).

7.2 Definition and Calculation of Velocity Root Mean Square (VRMS)

☆ **Mathematical expressions:**

$$V_{\mathrm{RMS}} = \sqrt{\frac{1}{T}\int_0^T v(t)^2 dt}$$

v(t): instantaneous vibration velocity signal (unit: mm/s or in/s);

T: Sampling time window (need to cover multiple vibration cycles).

☆ **Physical Significance:**

Reflects the time-averaged intensity of vibration energy, which is directly related to equipment fatigue damage (the higher the vibration energy, the faster the life loss of components).

RMS values are more stable and less disturbed by transient shocks than Peak or Peak-to-Peak.

7.3 Application Scenarios for Speed RMS

☆ Condition monitoring baseline:

Determine equipment health status (e.g., bearing wear, increased imbalance) by monitoring trend changes in VRMS over time.

Standards such as ISO 10816 classify vibration on the basis of velocity RMS (e.g., ≤1.8 mm/s is "good" and ≥4.5 mm/s is "hazardous").

☆ **Fault severity assessment**:

Low-frequency faults (e.g. misalignment, unbalance): VRMS value increases significantly with speed.

Medium to high frequency failures (e.g. early bearing damage): VRMS may be less variable and need to be combined with acceleration or envelope analysis.

☆ **Vibration standard compliance:**

The VRMS is often used as a direct indication of compliance with vibration limits in the acceptance or maintenance of industrial equipment (e.g. vibration acceptance criteria for fans and pumps).

7.4 Advantages and Disadvantages of Speed RMS

优点	局限性
反映长期振动能量，稳定性高	无法区分振动频率成分
与设备疲劳寿命相关性好	对瞬态冲击（如松动）不敏感
国际标准广泛采用（如ISO 10816）	需结合频谱分析定位故障类型

7.5 Relationship to other vibration parameters

☆ **Comparison with acceleration RMS:**

Speed RMS: Mainly in the mid-frequency band (10~1000 Hz), suitable for monitoring bearings, gears and other medium-speed parts.

Acceleration RMS: Mainly in the high frequency band (>1 kHz), suitable for capturing impact faults (e.g. early pitting).

☆ **Comparison with displaced peak values:**

Displacement Peak-to-peak: Reflects low-frequency vibration amplitude (e.g., shaft bending, critical speed resonance).

Speed RMS: More concerned with cumulative energy effects, suitable for long-term trend analysis.

7.6 Typical Application Examples

☆ **Motor vibration evaluation (ISO 10816-3 standard):**

Power ≤15 kW: VRMS ≤1.8 mm/s (Class A, excellent)

Power > 15 kW: VRMS ≤ 2.8 mm/s (Class A)

VRMS >7.1 mm/s (Class D, requires immediate shutdown for service).

☆ **Bearing life prediction:**

Empirical formula: Bearing life∝ (CVRMS)3(VRMSC)3 (CC is a design constant).

Double the VRMS value→ Theoretical life is reduced to 1/8th.

7.7 How do you interpret speed RMS values?

☆ **Absolute value judgment:**

Refer to equipment manufacturer's standards or industry specifications such as ISO 10816/API 610.

Example: A centrifugal pump has a vibration limit of 4.5 mm/s (ISO 10816-3 Class II).

☆ **Relative value trends:**

Flat rise: May be a progressive failure due to wear, lubrication deterioration, etc.

Sudden elevation: Indicates a sudden malfunction (e.g., dislodged component, severe misalignment).

☆ **Band correlation:**

If the total VRMS is normal, but there is a sudden increase in vibration energy in a certain frequency band (e.g. bearing failure frequency), further diagnosis is still required.

7.8 Summary

Velocity Root Mean Square (VRMS) is the "energy scale" of vibration analysis, quantifying the average energy of vibration to provide a visual judgment of equipment health. Its core value is:

Standardized evaluation: Relying on international standards, it enables comparison of vibration levels across equipment and industries;

Trend Alert: Capture progressive deterioration signals of early failures through long-term monitoring;

Maintenance Decision Making: In conjunction with threshold setting, guides downtime for service or replacement of parts.

In practical application, it is necessary to combine the speed RMS with spectrum analysis, time domain waveform, phase diagnosis and other means to form a multi-dimensional fault diagnosis system to avoid misjudgment of a single parameter.

VIII. Steady-State Impact Severity

8.1 Definitions

Steady-State Impact Severity is a quantitative assessment parameter of the shock energy caused by periodic or repetitive shock events (e.g., gear meshing, bearing rolling element impact defects, etc.) during continuous operation (steady state) of the equipment. It is used to measure the cumulative damage risk or failure severity of a mechanical system due to shock events under steady state conditions.

☆ **Steady-State:**

It means that the equipment is in a stable operating state (constant speed and load), and the frequency and intensity of shock events remain relatively stable statistically, rather than transient (e.g., startup, shutdown) or random sudden shocks.

For example, periodic shocks in gearboxes due to pitting of tooth surfaces.

☆ **Shock Severity:**

Characterizes the ability of a single or multiple impact events to damage a mechanical system, usually based on a combination of parameters such as impact acceleration, energy or duration.

Smooth shock intensity emphasizes the long-term cumulative effects of repetitive shocks (e.g., fatigue crack extension, bearing spalling) in steady-state operation.

8.2 Measurement and calculation methods

☆ **Time domain parameters:**

Peak acceleration (Peak g): the maximum acceleration value of a single impact, reflecting the instantaneous impact strength.

Shock Energy: Calculated by integrating the acceleration signal, it reflects the total energy of a single shock.

☆ **Frequency domain analysis:**

Shock Response Spectrum (SRS): analyzes the maximum response of a shock signal to a structure at different frequencies and is used to assess the risk of system resonance.

☆ **Statistical indicators:**

Shock Severity Index (SSI):

$$SSI = \frac{1}{T}\sum_{i=1}^{N}(A_i^2 \cdot D_i)$$

Ai: peak acceleration of the iind shock;

Di: Duration of impact;

T: Total monitoring time.

8.3 Application Scenarios

☆ **Gear Troubleshooting:**

Periodic shocks are triggered by flank spalling or broken teeth, and an increase in the intensity of smooth shocks indicates a worsening of the failure.

The increased amplitude of the gear meshing frequency and its side bands in the spectrum, combined with the time-domain shock intensity metrics, quantifies the extent of damage.

☆ **Bearing health monitoring:**

The rolling body passes over defects (e.g., spalling pits) with repetitive impacts, and the smooth impact intensity is positively related to the defect size.

The envelope demodulation technique extracts the shock eigenfrequencies (e.g., BPFO, BPFI), and the intensity values are used to assess the remaining lifetime.

☆ **Reciprocating Machinery Assessment:**

Steady state shocks such as internal combustion engine piston knocking, compressor valve plate impact, etc., with intensity indicators reflecting mechanical wear or clearance abnormalities.

8.4 Relationship to other vibration parameters

参数	描述	与平稳冲击烈度的关联
加速度峰值	单次冲击的最大瞬时强度	直接影响冲击烈度的瞬时破坏力评估
速度RMS	振动能量平均水平	平稳冲击烈度侧重冲击事件，RMS侧重整体
峭度（Kurtosis）	信号峰度的统计量，反映冲击信号的尖锐程度	峭度高通常伴随冲击烈度升高
包络能量	高频冲击信号的调制能量	用于计算冲击烈度的频域分量

8.5 Diagnostic and Maintenance Strategies

☆ **Threshold setting:**

Set shock intensity alarm thresholds based on historical data or industry standards such as ISO 13373-3, for example:

Normal: SSI ≤ 5

Early warning: 5 < SSI ≤ 10

Hazard: SSI > 10

☆ **Trend Analysis:**

Long-term trends in shock intensity are monitored, and if they continue to rise (e.g., 20% increase per month), this suggests that the fault is progressing and requires intervention.

☆ **Root cause localization:**

Combined with spectral analysis to determine the source of the impact (e.g., frequency of bearing outer ring defects) and guide targeted repairs.

8.6 Case Study: Elevated Shock Intensity in Wind Turbine Gearboxes

Phenomenon: In the gearbox vibration acceleration signal during steady state operation, a periodic shock occurs at the meshing frequency (1 kHz) and the SSI rises from 3 to 8.

Diagnosis:

The envelope spectrum shows side frequency intervals at shaft frequencies (30 Hz), suggesting gear eccentricity or tooth damage.

Disassembly and inspection revealed cracks in the root of the active gear teeth, which coincided with the elevated impact intensity.

Measures:

Replacing the gears and adjusting the mesh clearance restored the SSI to 2.5.

8.7 Summary

Smooth shock intensity is a key metric for assessing the risk of damage to a mechanical system from repetitive shock events during steady state operation. By quantifying shock intensity, frequency and energy, it is able to:

Early Warning: Capturing shock energy changes at the budding stage of a fault;

Damage quantification: Combining historical data to predict the remaining life of a component;

Maintenance optimization: guides precise repairs (e.g. replacement of specific bearings or gears).

In practical application, it is necessary to synthesize the time-domain impact parameters, frequency-domain characteristics and working condition information to avoid misjudgment of a single index, and at the same time pay attention to the multi-dimensional correlation of impact intensity with temperature and noise.

IX. Optimized Kurtosis

9.1 Definitions

In vibration analysis, Kurtosis Optimization refers to the adjustment of signal processing parameters (such as filtering band, time window length or envelope demodulation method), so that the Kurtosis as a statistical indicator can be more sensitive to capture the characteristics of mechanical failure (especially early impact damage), thereby improving the accuracy and reliability of fault detection. The kurtosis reflects the "sharp peaks and thick tails" characteristic of the signal distribution, and optimizing its calculation method can significantly enhance the identification of transient shocks.

9.2 Definition and meaning of crags

☆ **Math formula:**

$$K = \frac{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^4}{\sigma^4}$$

xi: vibration signal sample;

x¯: signal mean;

σ: standard deviation;

Cliff of normal distribution: k=3k=3; k>3k>3 indicates the presence of a significant shock component in the signal.

☆ **Physical Significance:**

High crag (e.g. K>5K>5): Transient shocks (e.g. spalled bearings, broken gears) are present in the vibration signal.

Low crag (e.g., K ≈ 3K ≈ 3): the signal is close to a Gaussian distribution with no obvious shock characteristics.

9.3 Why do I need to optimize the crag?

☆ **Limitations of the original crag:**

Noise interference: background noise reduces the sensitivity of the crag to real impacts.

Band-independence: full-band calculations may mask band-specific fault characteristics.

Condition dependent: Load or speed changes may cause fluctuations in the crag value, requiring dynamic adjustment.

☆ **The goal of optimization:**

Enhanced sensitivity of crags to early failures (e.g., weak shock recognition);

Improved robustness of crags to noise (reduced false alarms);

Adaptive adjustment of frequency bands for different fault types (e.g. optimization of high frequency bands for bearing faults).

9.4 Common methods for optimizing crags

☆ **Band Selection Optimization**

Principle: The impact signal energy is concentrated in a specific frequency band (e.g. high frequency resonance region of bearing failure), the target frequency band signal is extracted by band-pass filtering, and then the crag is calculated.

Steps:

Analyze the spectrum of the vibration signal to determine the resonance band (e.g., 5 to 20 kHz) in which the fault may be excited;

Design bandpass filters to preserve the target frequency band;

Calculate the cliffiness of the filtered signal (called **spectral cliffiness, Spectral Kurtosis**).

Advantage: Suppresses extraneous band noise and highlights fault impact characteristics.

Tool: Fast Kurtogram algorithm automatically selects the optimal frequency band.

☆ **Envelope demodulation optimization**

Principle: Envelope demodulation of high-frequency shock signals, extraction of low-frequency modulation components (e.g., bearing fault eigenfrequency), and then calculation of the cliff of the envelope signal.

Steps:

The Hilbert transform is applied to the original signal to extract the envelope;

Calculate the cliffiness (called the **envelope cliffiness**) for the envelope signal;

Combined with envelope spectrum analysis, the frequency of faults is verified.

Strengths: Separate the periodic characteristics of shock events and improve the correlation between crags and failures.

☆ **Time Window Segmentation Optimization**

Principle: Adjust the length of the time window according to the periodicity of the shock event to avoid signal averaging that leads to lower crag values.

Steps:

Determine the shock period (e.g., time between bearing failures);

Segmentation of the signal into multiple sub-segments containing complete shock cycles;

Cliff is calculated for each sub-segment and the maximum or mean value is taken as the optimization index.

Advantage: avoids dilution of the crag value by signals from non-impact segments.

☆ **Multi-indicator fusion optimization**

Principle: Combine crag with other metrics (e.g., peak, impulse factor, RMS) to construct a comprehensive assessment model.

Example:

$$\text{优化指标} = K \times \text{Peak} \times \frac{1}{\text{RMS}}$$

Advantage: Comprehensive impact strength, energy distribution and noise level, reducing misjudgment of a single indicator.

9.5 Practical Application of Optimized Cliffs

☆ **Case 1: Bearing early pitting detection**

Problem: The original crag of a fan bearing vibration signal, K=4.2K=4.2, does not exceed the threshold, but there is an intermittent noise.

Optimization Steps:

Determine the optimal frequency band (12 to 18 kHz) using fast spectral crag;

Calculate the filtered crag K=8.5K=8.5 for this band;

Envelope spectra show the frequency of outer ring failures (BPFO), confirming early pitting.

RESULTS: Optimized crag sensitivity increased, warning of failures 2 weeks in advance.

☆ **Case 2: Diagnosis of broken teeth in a gearbox**

Problem: The gearbox vibration signal is noisy, the original crag K = 3.8K = 3.8, it is difficult to determine the fault.

Optimization Steps:

The split signal is a sub-segment of the engagement cycle length;

Calculate the crag of each sub-section with a maximum value of K=7.1K=7.1;

The time-domain waveform shows periodic shocks, corresponding to the location of the broken tooth.

RESULTS: Through the time window optimization, the noise interference is effectively suppressed and the broken teeth are accurately located.

9.6 Engineering Implications of Cliff Optimization

Early Failure Warning: Optimized crags detect weak shocks (e.g., early stages of bearing spalling) that are difficult to identify with traditional RMS or peaks.

Reduced false alarm rate: Avoid interference from ambient noise or normal mechanical shocks through band/time window selection.

Adaptive Diagnostics: Dynamically adjusts optimization strategies for different equipment types (motors, gearboxes, pumps) to enhance ubiquity.

9.7 Summary

Optimizing Cliff is to enhance the fault sensitivity of Cliff indicators through signal processing techniques, the core of which is to **focus on the frequency band, time period or modulation form where the impact characteristics are located**. In practice, it is necessary to combine the characteristics of the equipment and fault mechanisms, and flexibly choose band filtering, envelope demodulation or multi-indicator fusion methods, so as to upgrade the crag from a "statistical parameter" to an "engineering diagnostic tool". Maintenance personnel can practice through the following steps:

Data Acquisition: High sampling rate to acquire raw vibration signals (≥50 kHz recommended);

Band exploration: locating faulty resonance bands using the spectral crag tool;

Algorithm optimization: choose envelope, time window segmentation, or multi-indicator fusion based on fault type;

Threshold Setting: Develop optimized crag alarm rules based on historical data or industry standards.

By optimizing crags, "hidden shock signals" can be captured at the budding stage of a fault, gaining a critical time window for predictive maintenance.

X. RMS (1–10 kHz Band)

10.1 Definitions

In vibration analysis, the **1K to 10K Hz Root** Mean **Square (RMS)** refers to the calculation and evaluation of the effective value (Root Mean Square) of a vibration signal in the **1,000 Hz to 10,000 Hz frequency band**. This parameter is used to quantify the intensity of **vibration energy** at **high frequencies**, and is particularly useful for detecting mechanical faults associated with shock, high-frequency vibration (e.g., early damage to bearings, pitting of gears, poor lubrication, etc.). The following is an explanation of its core meaning and application:

10.2 Significance of high-frequency vibrational energy

☆ **Fault Characterization Correlation:**

The 1K to 10K Hz band often contains the characteristic frequencies or resonance bands of the following faults:

Rolling bearings: High frequency resonance of impacts triggered by defects such as early spalling and cracks (e.g. inherent frequency of the outer ring or rolling element of the bearing).

Gearboxes: meshing high-frequency harmonics or side bands due to localized damage such as pitting of tooth surfaces and broken teeth.

Poor lubrication: high-frequency random noise from dry friction between metals (broadband energy).

☆ **Early failure sensitivity:**

High-frequency vibration energy tends to be significantly elevated at the beginning of a failure (e.g., minor spalling), providing earlier warning than low-frequency vibration parameters (e.g., velocity RMS).

10.3 Calculation of the Root Mean Square of 1K to 10K Hz

☆ **Signal Preprocessing:**

The original vibration signal (usually acceleration signal) is **band-pass filtered** (1K~10K Hz) to filter out low-frequency noise and ultra-high-frequency interference.

The filtered signal retains the vibrational component of the target frequency band.

☆ **RMS Calculation Formula:**

$$\mathrm{RMS}_{1K-10K} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} x_i^2}$$

xi: the ith sampling point of the filtered signal;

N: number of sampling points.

Units: usually units of acceleration (e.g., m/s2 or g)

10.4 Application scenarios and diagnostic value

☆ **Early Bearing Damage Detection**

Phenomenon: Small spalls or cracks in the bearing trigger periodic shocks that excite the inherent frequency of the bearing element (e.g., 2 to 8 kHz).

Diagnosis:

The sudden increase in RMS values from 1K to 10K Hz may precede the conventional velocity RMS (low frequency band) anomaly.

Combined with envelope demodulation techniques, bearing fault characteristic frequencies (e.g. BPFO, BPFI) can be extracted.

☆ **Identification of localized defects in gears**

Phenomenon: Gear tooth pitting or broken teeth lead to meshing high-frequency harmonics (e.g., the octave of the meshing frequency into 1K~10K Hz).

Diagnosis: High-frequency RMS values increase significantly with increasing load, and side bands are visible in the spectrum (engagement frequency± axial frequency).

☆ **Lubrication condition monitoring**

Phenomenon: poor lubrication, rolling body and raceway direct contact to produce broadband random vibration (1K ~ 10K Hz energy diffusion).

Diagnosis: High-frequency RMS continues to rise, accompanied by a rise in temperature, and the spectrum shows "burr"-like high-frequency noise.

10.5 Advantages and Disadvantages of High Frequency RMS

优点	局限性
对早期冲击性故障敏感	易受环境噪声干扰（需滤波优化）
可量化高频能量累积趋势	无法直接定位故障类型（需频谱分析辅助）
适用于滚动轴承、齿轮等高频故障	需高采样率传感器（≥20 kHz）

10.6 Comparison of HF RMS with other parameters

参数	频段	适用场景
速度RMS（整体）	10~1,000 Hz	不平衡、不对中、轴弯曲等低频故障
加速度RMS（高频）	1K~10K Hz	轴承损伤、齿轮点蚀、润滑不良
包络解调能量	调制低频	提取冲击周期性特征（如轴承故障频率）

10.7 Examples of practical applications

☆ **Case: Vibration monitoring of a wind turbine bearing**

Background: The regular speed RMS (10~1,000 Hz) is 2.1 mm/s (normal), but the device has a strange noise.

Analysis:

The 1K to 10K Hz acceleration RMS was calculated and the value was found to increase from 0.5 g to 3.2 g (exceeding the standard).

Envelope spectra show bearing outer ring failure frequency (BPFO), confirming early spalling.

TREATMENT: After replacing the bearing, the HF RMS was restored to 0.6 g and the noise disappeared.

10.8 Engineering Recommendations

Sensor Selection:

Uses a broadband accelerometer (frequency response range ≥ 10 kHz) to ensure high-frequency signal fidelity.

Signal processing optimization:

Combines **bandpass filtering** with **anti-alias processing** to reduce noise interference.

The signal-to-noise ratio is boosted using **time-domain synchronized averaging** (for gears) or **peak-holding algorithms** (for random shocks).

Alarm threshold setting:

Set dynamic thresholds based on historical data or industry standards such as ISO 13373-3.

Example: A device with a 1K~10K Hz acceleration RMS baseline of 0.8 g, set the alarm threshold to 2 times the baseline value (1.6 g).

Multi-parameter fusion diagnostics:

Combining high-frequency RMS, crag (Kurtosis), envelope spectrum and other indicators to improve diagnostic reliability.

10.9 Summary

1K~10K Hz rms is a core parameter in vibration analysis focusing on high-frequency fault energy. By quantifying the rms value of impact vibration, it provides a sensitive early warning of early damage to bearings, gears, and other components. Its value is:

Earliness: Capture fault signals before conventional low-frequency parameters become abnormal;

Targeted: direct hit on high-frequency mechanical defects (e.g. flaking, pitting);

Quantitative: Provides traceable energy trend data for maintenance decisions.

Practical applications need to be combined with spectral analysis, envelope demodulation and other technologies to avoid single parameter misjudgment, while focusing on the optimization of sensor performance and signal processing methods to ensure the accurate extraction of high-frequency vibration information.

XI. RMS (10–25.6 kHz Band)

11.1 Definitions

In vibration analysis, **the Root** Mean **Square (RMS)** of **10K to 25.6K Hz** is a calculation of the Root Mean Square (RMS) of a vibration signal in the **10,000 Hz to 25,600 Hz (25.6 kHz) frequency band**, which is used to quantify the intensity of vibration energy of a device in **the ultra-high frequency band**. This parameter is often used for **very early failure detection** or analysis of **special high frequency phenomena** (e.g., galvanic corrosion, micromotor wear, ultrasonic noise), and has the following core significance and application scenarios:

11.2 Physical significance of the 10K to 25.6K Hz band

☆ **UHF vibration source:**

Microshock: Transient high-frequency resonance triggered by micron-sized defects (e.g., early spalling, microcracks) in bearings or gears.

Galvanic corrosion phenomenon: electric spark impact caused by bearing current discharge in motor or inverter-driven equipment (commonly found in high-frequency switching equipment).

Friction noise: High frequency friction between metals or cavitation when lubrication fails (e.g., hydraulic pump cavitation).

Ultrasonic signals: structural resonance or high-frequency electromagnetic interference (e.g., loose transformer core).

☆ **Band specificity:**

Far beyond the conventional mechanical failure frequency: common bearing failure frequency, gear meshing frequency is usually below 10 kHz, this band reflects more high-frequency resonance or non-mechanical source noise.

Sensor and Sampling Requirements: High frequency sensor (≥50 kHz) and high sampling rate (≥100 kHz) are required to ensure signal fidelity.

11.3 Calculation of the root mean square of 10K to 25.6K Hz

☆ **Signal Acquisition:**

Use of high-frequency accelerometers (e.g. piezoelectric, frequency response range 10 Hz to 30 kHz).

Sampling rate ≥ 51.2 kHz (satisfies Nyquist's theorem and covers the upper limit of 25.6 kHz).

☆ **Signal Processing:**

Band-pass filtering: 10K~25.6K Hz components are retained, and low-frequency and ultra-high-frequency noise are filtered out.

RMS calculations:

$$\mathrm{RMS}_{10K-25.6K} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} x_i^2}$$

xi: the ith sampling point of the filtered signal;

N: number of sampling points (need to cover multiple shock cycles).

Units: usually units of acceleration (m/s2 or g).

11.4 Typical application scenarios

☆ **Electrical Erosion Inspection of Bearings**

Phenomenon: High frequency shaft current in inverter motor discharges through the bearings, resulting in "rolling board-like" galvanic corrosion patterns on the raceway surface.

Vibration characteristics:

Significantly higher RMS values from 10K to 25.6K Hz accompanied by random broadband shocks.

Current analysis can be synchronized to detect abnormal shaft currents.

☆ **Gear Micropitting Monitoring**

Phenomenon: UHF vibration energy from microscopic fatigue cracks on tooth surfaces.

Diagnosis:

The high-frequency RMS value grows exponentially with increasing load, and diffuse broadband noise is visible in the spectrum.

☆ **Lubrication film rupture detection**

Phenomenon: High-frequency friction noise at the moment of metal contact when the very thin oil film ruptures.

Characteristics:

Sudden increase in RMS values from 10K to 25.6K Hz, synchronized with the sudden rise in temperature.

☆ **Ultrasonic leakage or cavitation**

Phenomenon: Ultrasonic vibration (20K~25K Hz) generated by pipeline leakage or cavitation of hydraulic pump.

Diagnosis:

High-frequency RMS combined with acoustic emission (AE) signals can pinpoint leaks.

11.5 Advantages and Disadvantages of High Frequency RMS

优点	局限性
对极早期故障敏感（微米级缺陷）	需专用高频传感器与高采样设备
可捕捉非机械源故障（如电蚀）	易受电磁干扰或环境噪声影响
适用于特殊工况（如高频变频器）	数据量大，分析复杂度高

11.6 vs. other parameters

参数	频段	适用场景
速度RMS（整体）	10~1,000 Hz	常规机械故障（不平衡、不对中）
1K~10K Hz RMS	1K~10K Hz	轴承/齿轮早期损伤、润滑不良
10K~25.6K Hz RMS	10K~25.6K Hz	电蚀、微点蚀、超声波现象

11.7 Recommendations for Engineering Practice

☆ Sensor Selection**:**

Select an accelerometer with a frequency response range covering 25.6 kHz (e.g. PCB 352C33).

Ensure mounting stiffness (e.g. magnetic mounts or adhesive) to avoid resonance interference.

☆ **Anti-jamming measures**:

Shielded cables reduce electromagnetic interference (especially near inverters).

Grounding is optimized to avoid common mode noise affecting high frequency signals.

☆ **Signal processing optimization:**

Wavelet analysis: decomposition of high-frequency signals to extract transient shock features.

Probability density function (PDF): distinguishing random noise from fault shocks.

☆ **Threshold setting:**

Establishment of baseline: 10K~25.6K Hz RMS values under normal operating conditions (e.g. 0.2~0.5 g).

Alarm rule: 3 consecutive measurements exceeding the baseline by a factor of 3→ triggers a warning.

11.8 Practical cases

Case: a frequency conversion motor bearing galvanic corrosion diagnosis

Background: The motor vibration speed RMS is normal (1.5 mm/s), but the bearings are making strange noises.

Analysis:

10K~25.6K Hz acceleration RMS up to 4.8 g (baseline 0.3 g).

Current detection found shaft current overruns and no bearing failure frequency in the envelope spectrum.

Disassembly and inspection of the bearing revealed raceway galvanic corrosion lines.

Measure: Add insulated bearings with shaft grounding device, HF RMS restored to 0.4 g.

11.9 Summary

10K~25.6K Hz rms is a "precision probe" for UHF energy monitoring in vibration analysis, and its core value is:

Over-warning: Capturing fault signals before microscopic defects have triggered low-frequency vibration anomalies;

Specialized Fault Coverage: Diagnose problems such as galvanic corrosion, micropitting, and other problems that are difficult to detect with traditional methods;

Multidisciplinary intersection: connecting mechanical vibration with fault characterization in electrical and ultrasonic fields.

Practical applications need to weigh the costs and benefits of high-frequency vibration monitoring of the necessary equipment (sensors, acquisition systems) to invest, and with signal processing algorithms (such as wavelet, envelope analysis) and multi-parameter fusion (current, temperature), in order to accurately lock the root cause of the fault in complex working conditions.