Condition Monitoring Selection: Matching Technique to Failure Mode

Condition-Based Maintenance / PdM - Rotating Equipment in Minerals Processing and Water Utilities

Abstract. *The selection of a condition monitoring technique should begin with the failure mode and its physics, not with the technology catalogue. This Technical Note sets out a structured decision framework anchored in the P–F interval: the conditions under which vibration analysis, thermography, oil analysis, acoustic emission, and process parameter surveillance are and are not appropriate; the layered tactics that critical rotating assets typically require; and the circumstances in which no available technique provides reliable advance warning, making designed replacement, redundancy, or failure-finding the correct response. Case material is drawn from rotating equipment in minerals processing and water utility contexts.*

1. Start with the Failure Mode, Anchored by the P–F Interval

Condition monitoring exists to provide warning between the onset of a detectable failure condition (the **P point**) and the point of functional failure (the **F point**). The interval between them, the P–F interval, is a property of the *failure mode,* not of the asset. A technique is viable for a given failure mode only if it detects that mode's specific precursor and does so sufficiently early within the P–F interval to enable economic intervention.

Two practical corollaries follow:

- The monitoring interval must be shorter than the P–F interval by a safety margin. A common rule is that the monitoring interval should be **no greater than one-third of the P–F interval**, so that two sequential inspections have a reasonable probability of detecting the progression before functional failure occurs.
- Detection capability and detection lead time are not the same thing. A technique whose detection threshold falls near the end of the P–F interval, when failure is imminent, adds no useful decision time and is effectively no better than run-to-failure.

The selection question, therefore, is not "what techniques do we have?" but "what precursor does this failure mode produce, when in the P–F interval does it become detectable, and by what technique?"

2. Matching Technique to Failure Physics

Each condition monitoring technique detects a specific physical signature. A technique is appropriate only when the failure mode produces that signature, within detectable range, at sufficient lead time. The table below summarises the primary capabilities and limitations of the five techniques most commonly deployed on industrial rotating equipment.

Technique	Detects	Strong for	Poor for / Limitation
Vibration analysis	Mechanical dynamics: imbalance, misalignment, bearing defects, gear mesh, looseness	Rolling-element bearings, couplings, pinion / gear mesh, structural integrity, motor/pump trains	Process related faults; very slow speed assets (< ~120 rpm); highly intermittent duty; submerged or inaccessible measurement points
Thermography (IR)	Surface temperature anomalies	Electrical connections, switchgear, motor terminations, blocked cooling, insulation defects, steam-trap leakage	Internal mechanical faults without surface signature; hot ambient environments that mask anomalies; line of sight required
Oil analysis	Wear debris, particle count, contamination, additive depletion, viscosity drift, water content	Gearboxes, large plain bearing systems, hydraulic systems, engines, circulating oil lube systems	Assets without a circulating oil system; small oil volumes where debris flushes through rapidly; sampling discipline is critical
Acoustic emission	High frequency stress waves from crack propagation, cavitation, gas tight leaks	Early stage bearing defects; structural crack growth; pump cavitation; high pressure leak detection	Noisy industrial environments; precursors attenuate rapidly with distance; requires careful sensor placement and baselining

Technique	Detects	Strong for	Poor for / Limitation
Process parameter surveillance	Whole asset performance drift: pressure, flow, motor current, temperature, differential pressure	Pumps (head/flow curve drift), motors (current signature), heat exchangers (ΔT), fans, filters (ΔP)	Localised component faults without a whole asset signature; assets without adequate instrumentation; operating point variation masks trends

3. When No Technique Works

Three categories of failure mode defeat condition monitoring entirely, and the correct response is to stop trying:

- **Hidden failures.** Protective or standby functions (relief valves, trip systems, standby pumps, check valves) fail undetectably in normal operation. The correct tactic is **scheduled failure finding**, deliberate demand at a defined interval.
- **Failures without useful precursors.** Electronic component failure, sudden ductile overload, and brittle fracture at a material flaw present no practical P–F interval. The correct response is redesign, redundancy, or scheduled replacement at a demonstrated life.
- **P–F interval too short for economic monitoring.** Some precursors exist but develop so rapidly that the required monitoring interval is uneconomic, for example, continuous real time instrumentation on a low criticality asset. Scheduled replacement or redundant design is typically the rational choice.

Naming these cases explicitly rather than defaulting to a token “quarterly inspection” that cannot detect what it looks for is what separates a credible condition monitoring programme from a performative one.

4. Worked Example A - Vertical Turbine Pump (Water Utility)

A single duty vertical turbine pump delivers water from a bore to a service reservoir, operating continuously at constant speed. The dominant technique allocation is **vibration plus process parameter surveillance**. Thermography is a useful supplement, not a primary. Several important failure modes, bowl wear, check-valve failure, have no vibration signature at all; recognising this is more important than applying vibration as a default:

Failure mode	Precursor	Technique(s) and rationale
Upper (thrust) bearing wear	Vibration energy at bearing fault frequencies; surface temperature rise	Vibration analysis (primary); thermography (backup). Standard fault signatures; typical P–F 2 to 8 weeks.
Line-shaft bearing wear (below floor)	Subtle vibration at surface; bowl performance drift	Process parameter surveillance (primary). Submerged bearings are not accessible for direct vibration measurement; performance trend is the viable signal.
Bowl / impeller wear	Reduced head at duty point; motor-current and power drift	Performance-curve tracking via periodic pump test (6 to 12 months). No local vibration signature; process parameter is the only viable technique.
Motor winding insulation	Insulation resistance decline; partial-discharge activity	Periodic IR / PI testing; thermography on terminal box and starter. Slow degradation mode, long P–F interval.
Check valve failure (hidden)	None in normal operation	Scheduled failure finding actuation test (annual or bi-annual). Valve state undetectable without deliberate demand.

5. Worked Example B - Ball Mill Pinion Drive (Minerals Processing)

A ball mill is driven through a pinion & girth gear pair with a pressurised oil spray lubrication system. The asset is a single train bottleneck; planned shutdown for pinion replacement is a multi-day event. No single technique is sufficient, so the correct programme is layered, with each failure mode addressed by its dominant precursor and a secondary confirmation where available:

Failure mode	Precursor	Technique(s) and rationale
Pinion tooth wear / pitting	Spectral energy at tooth mesh frequency and sidebands; wear debris in oil	Vibration analysis (primary); oil analysis (confirmation)

Failure mode	Precursor	Technique(s) and rationale
Pinion tooth crack (sudden)	Acoustic bursts at crack initiation; step change in vibration amplitude	Acoustic emission (if instrumented) for earliest warning; vibration trend as backup
Lubrication oil contamination	Wear debris count, ISO cleanliness code, water content	Oil analysis (primary); routine oil return visual check
Pinion / trunnion bearing wear	Vibration envelope; temperature rise; wear metals in oil	Vibration analysis (primary); thermography and oil analysis (secondary)
Lube oil pump / pressure failure (protection)	Loss of supply pressure	Process parameter surveillance (oil pressure alarm / trip); scheduled pump swap over test

This pattern, vibration as primary, oil analysis as confirmation, acoustic emission reserved for sudden crack modes, process parameters for protection functions, is characteristic of high-criticality rotating assets. The right answer is a suite, not a single technique; and each element of the suite must be tied to a specific failure mode with a demonstrated P–F interval.

6. Key Takeaways

- Start with the **failure mode and its P–F interval**, not the technology catalogue. The selection question is “what precursor does this mode produce, and when?”
- Monitoring interval should be **no more than one third of the P–F interval**. Detection capability and detection lead time are not the same thing.
- Match technique to physics. Each technique detects a specific signature; **no technique is universal**.
- For critical rotating assets, expect **layered tactics**, vibration as primary, oil analysis or thermography as confirmation, process parameter surveillance as an asset level check.
- Name the undetectable modes explicitly. Hidden failures, sudden failures, and modes with impractically short P–F intervals should be addressed by failure finding, redundancy, or scheduled replacement and **not by token inspection tasks**.

References and Further Reading

ISO 17359:2018 Condition monitoring and diagnostics of machines - General guidelines. International Organization for Standardization.

ISO 13374 Condition monitoring and diagnostics of machines - data processing, communication and presentation (series).

ISO 13381-1:2015 Condition monitoring and diagnostics of machines - prognostics - Part 1: General guidelines.

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Moubray, J. Reliability-centred Maintenance (2nd ed.), Industrial Press.

SEAMPAS TN01 A Practitioner’s Guide to FMEA in Mining Environments.

SEAMPAS TN03 Maintenance Criticality Frameworks: Beyond the 2×2 Matrix.

About this Technical Note

SEAMPAS Technical Notes are short, focused treatments of specific problems in physical asset management and reliability engineering, drawn from field application in mining, minerals processing, oil and gas, utilities, and heavy rail. They are intended for practising engineers, maintenance managers, and asset management leaders responsible for translating principle into practice.

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