Machine Vibration

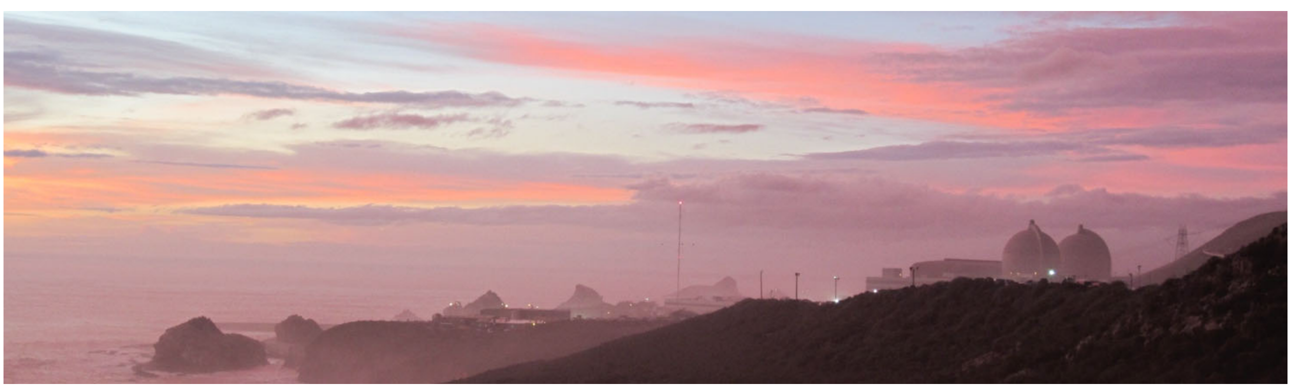
Initial Onsite Assessment Guideline

2025

Force Response Equation

$$X = \frac{\frac{F_0}{k}}{\sqrt{\left[1 - \left(\frac{\omega}{\omega_n}\right)^2\right]^2 + \left[2\zeta\frac{\omega}{\omega_n}\right]^2}}$$

Where:
X = mass motion, inches-peak
F_0 = exciting force, lbf
k = spring stiffness, lbf/in
ω = forcing frequency, rad/s
ω_n = natural frequency, rad/s
ζ = damping ratio = C/C_c



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Initial Onsite Assessment Guideline

Use of This Guideline

This guideline is a structured assembly of notes and learnings an onsite vibration analyst might reference when asked to provide an initial evaluation of a machine exhibiting abnormal vibration. It is sourced largely from experiences and learnings at a large U.S. nuclear facility, but may likely be applied to other industrial settings. It supports a methodical investigation that, for me, calms urgency; and commonly yields sufficient insight to write a timely initial assessment before going home that day. The goal of this assessment, while not necessarily final or perfect, is to serve the immediate needs of the station and provide sufficient insight to move forward.

Step One – Perform individual Machine Assessments:

An evaluation of a machine's vibration condition normally requires a review of diagnostic elements beyond just vibration. This guideline incorporates five individual Machine Assessments:

1. Vibration Assessment
2. Field Assessment
3. Operational Assessment
4. Maintenance Assessment
5. Predictive Maintenance Assessment

These assessments identify data to collect, inspections to perform, and questions to ask regarding a machine's state of operation. Use of this guideline begins by performing the five individual assessments cited above. These assessments are more thoroughly described on a later page, under the heading *Machine Assessments*.

Step Two – Review Assessment results against a Machine Vibration Matrix:

Use of this guideline continues by taking the results of the Machine Assessments mentioned above, and reviewing them against a Machine Vibration Matrix. This matrix displays potential sources of vibration in vertical columns, and associated symptoms in horizontal rows. Potential sources of vibration are divided into three groupings:

- **Generic Vibration Sources**
- **Component Related Vibration Sources**
- **Machine Related Vibration Sources**

Use of the matrix begins by reviewing the top two rows of symptoms, backlit in **Yellow**, for each potential source of vibration. The first row prompts the analyst to compare observed *frequencies* of offending vibration against possible sources. The second row prompts the analyst to evaluate whether offending vibration is:

- "*Isotropic*" (evidenced in all radial directions) or:
- "*Anisotropic*" (dominant in a single radial direction)

Unlikely sources of offending vibration are quickly eliminated, allowing the analyst to more efficiently continue his/her evaluation. Continued review of the matrix will, hopefully, identify resolutions or prompt additional investigations that will eventually lead to a final disposition of a machine's condition.

Initial Onsite Assessment Guideline

Hint to Users…

Successful use of this guideline does not demand all assessment elements be completed. You may not have enough time to get to it all. In my experience, however, the tactile activity of just trying to perform these assessments yields results. Once you begin, you realize you are making progress. By the end of the time you have available, you discover you have enough to write an initial evaluation.

Some versions of this guideline are printed on laminated paper. The intent is to allow an analyst to use it, consume it, then reuse it again. Erasable board markers may be used to strike steps off as they are performed, and to circle information to be remembered and used later when writing your report.

Safety

Nothing presented in this guideline should cause an analyst to exceed or violate an established industrial or site-specific safety requirement. Every industry and site has their own specific safety hazards that must be uniquely addressed. Every analyst is accountable for awareness of these, and for implementing the rules and standards that protect themselves and coworkers from danger.

It is an ironic coincidence that our attempt to protect against risk of machine failure often leads to an increased safety risk to people collecting additional surveys. If you find yourself there, position yourself to remain safe. The machine you are dealing with, inherent to the fact you are even there, is potentially compromised. Be especially watchful during starts or transients. Avoid areas of close proximity, areas with no escape, areas radial or axial from rotating elements, areas close to leakage paths or gasketed flanges, etc. Be vigilant to protect yourself and the people around you. Speak up, take action, back away if you have a suspicion or an intuition that something may not be safe.

George D'Entremont, 2025

Initial Onsite Assessment Guideline

Machine Assessments

1. Vibration Assessment

Perform a Confirmatory Vibration Survey. Note the following:

a. Frequencies of offending vibration (e.g. 1X, 2X, et al)
b. If offending vibration is synchronous to shaft speed, evaluate whether it is:
   - Isotropic – Distributed in all radial directions, or
   - Anisotropic – Dominant in a single radial direction.

2. Field Assessment

Inspect equipment for the following:

a. Sound anomalies. Try to identify specific source locations of suspected sound anomalies.
b. Radiometer gun temperature anomalies. Focus on bearing housing temperatures and motor stator temperatures. Reference hot spots for personal safety and diagnostics.
c. **Caution! Observe safety protocols!** Any relative motion, sensed by touch at either grouted or jointed interfaces, should be noted.
d. Degraded pedestal or grout. Visible evidence of fracture or degradation. Rigid pedestal base vibration >0.03-0.05 ips-p. Machine foot vibration >30% of bearing vibration.
e. Excessive (> 4), corroded, or displaced shims.
f. Lubrication anomalies; level, flow, temperature, expelled, misdirected.
g. Inspect visible portions of rotating element for seal leakage, visible runout, shaft shuttling, etc.
h. Strobe tach anomalies, speed vs historical speed, speed vs motor rated speed, speed modulation, condition of rotating components, etc.
i. Valve or damper mispositioning.
j. Environmental anomalies; temperature, moisture, ventilation, corrosive liquids or atmosphere, etc.

3. Operational Assessment

Evaluate the operational history of the machine for:

a. Anomalies noted during operation, startup, or shutdown.
b. Anomalies noted in operating or process parameters (e.g. load, pressure, temperature, etc.).
c. Different operating condition, lineup, or procedure, “are you running equipment differently now that in the past?”

4. Maintenance Assessment

Evaluate the maintenance history of the machine for:

a. Details related to recent maintenance outages, repeated failures, etc.
b. Anomalies noted during recent inspections (unusual as-found conditions, out-of-tolerance conditions, etc.).
c. New or different procedures, parts, or components used during recent maintenance.
d. Anomalies observed during recent maintenance (e.g. difficulty in assembling or aligning, “did it seem to go together right?”).

5. Predictive Maintenance (PdM) Assessment

Perform a review of:

a. The station’s Vibration Database for previous similar occurrences and/or assessments.
b. The station’s PdM Databases for corroborating evidence of anomalies or degradation.

Machine Vibration Matrix

Common Sources and Symptoms of Machine Related Vibration

	Generic Vibration Sources		
	Unbalance	**Resonance**	**Softfoot / Distortion**
Vibration Frequency Domain	**1X**	**1X** of rotor speed most common. **1X Harmonic.** **2XLF** or **RBPF** (motor), **Vane Pass** (may excite piping or ducting resonance; not likely rotor or brg resonance). **Any Forcing Frequency.**	**1X.** **2XLF or RBPF** (Motor).
Vibration Direction / Amplitude	**Isotropic** High Radial. Possible high axial with couple unbalance. Rigid Shaft: Force ∝ Speed Squared.	**Anisotropic** - Structural. High in direction of resonance mode. **Isotropic** - Shaft Critical (Except Split Critical, which may be anisotropic)	**Any direction.**
Vibration Time Domain	Sinusoidal	Sinusoidal in the direction of greatest response.	
Vibration Phase	Stable.	Large phase changes w/ speed change.	
Vibration Orbit	Circle / Open Ellipse. Normally forward precession. Possible reverse precession if overhung.	Elongated ellipse along axis of resonant response. Normally forward precession (Reverse precession if between split criticals)	
Field / Operation Assessment	Step change - possible material loss. Gradual change - Possible erosion or oxide accumulation on rotating element.	Large amplitude changes with speed changes. Sole plate "Hammer test" may ID new grout voids that have allowed F*n* to approach excitation frequencies.	Observed cracked pedestal grout. Displaced or excessive # of shims (> 4) that result in springy support.
Maintenance Assessment	Inspect for damaged or corroded rotating element. If recently installed or balanced, review applicable documents for acceptable residual balance condition and balancing procedure.	Structural changes w/ recent maintenance which may have altered mass or stiffness? Recommend quieting resonance before attempting to correct balance. Use of Belleville washer may detune structural resonance.	Alignment or softfoot recently adjusted? Inspect for loose or corroded shims. Eval whether recent maintenance caused pipe strain or distortion?
PdM Assessment	Large 1X shaft displacement at slow-roll speed indicates a condition other than unbalance (e.g. runout, bowed rotor, coupling crank, etc.). Large change following start/stop cycle - possible loose rotating part, fluid or debris in rotor, or coupling lock.	Verified with impact test, modal analysis, runup/coastdown Bode plot. Inverted "V" at the foot of a spectral peak (displayed log-scale amplitude) corroborates resonance. May require "running" impact test to determine shaft resonant freqs.	
Notes	Balancing References: Rigid rotors ref ISO 21940-11 and IRD "Balance Rqmts Rigid Rotors". Flexible rotors ref ISO 21940-12. In-situ balance ref ISO 21940-13. Pumps ref API 610-2021, 6.9.3.	May quiet resonance by varying mass, stiffness, damping or speed. Torsional resonance normally undetected?... but generates high radial in gear units. When machine placed in service - shaft Fn increases, struct Fn may decrease.	2XLF or RBPF on motor result of distortion causing uneven motor air-gap. Avoid softfoot correction if pedestal is degraded or soleplate delaminated.

Machine Vibration Matrix

Common Sources and Symptoms of Machine Related Vibration

	Generic Vibration Sources		
	Misalignment	**Looseness / Impacting**	**External Force**
Vibration Frequency Domain	**1X and/or 2X, Possible low-order harmonics** (dependent on coupling type). Note: Symptoms may occur in pairs, affecting bearings adjacent to one another..	**1X w/ multiple harmonics. Fractional harms (1/2X, 1/3X etc.)** if condition is severe or coincident with resonant frequencies.	**Any Frequency.** Frequency peaks generated by adjacent machinery. May be due to operating frequency of a sub-component (e.g. gear-driven oil pump)
Vibration Direction / Amplitude	**Anisotropic. Isotropic** if causing fluid-film bearing to become unloaded. Note: Causes changing static radial load, which *may or may not* affect vibration, and may result in either *increasing or decreasing* vibration.	**Anisotropic** Amplitude difference across loose interfaces.	**Any direction. Possible long period "beat"** from interaction between machine freqs and closely matched external freqs.
Vibration Time Domain	Possible "W" or "M" shape, or double step in sinusoid.	Not sinusoidal. Sharp peaks or truncation	
Vibration Phase	May not rotate with transducer. Possible approx 180 deg phase shift across coupling… axial or radial.	Unstable. Phase difference across loose structural joints.	
Vibration Orbit	Possible pinched, peanut shaped, or figure 8 orbits; w/ possible exterior loops. Enlarged orbit if result of shaft position moving toward center of unloaded fluid-film brg.		
Field / Operation Assessment	May result in adjacent bearings becoming alternately loaded or unloaded, corroborated by changing bearing temps.	**Caution! Observe safety protocols!** Any relative motion, sensed by touch at either grouted or jointed interfaces, is evidence of looseness. Observed gaps at structural interfaces.	Assess likely external sources and compare frequencies.
Maintenance Assessment	Newly Installed or aligned? Confirm appropriate "cold-offsets". Allowable misalignment ref Piotrowski "Basic Shaft Alignment Workbook".	Undertorqued fasteners, fractured weldments, damaged grout. Visible fretting or denting at loose contact surfaces.	
PdM Assessment	Thermography - changing brg temps if bearing becomes loaded/unloaded due to misalignment. Fluid-film brg - Shaft centerline position shows evidence of changing bearing loads due to misalignment, resulting in lower eccentricity ratio for unloaded bearings, and higher eccentricity ratio for loaded bearings.	NDE evidence. ODS. Video amplification. Wear particles in oil if looseness occurring within lube boundary.	
Notes	Ref. Piotrowski "Shaft Alignment Handbook". May require "Off-line to Running" alignment survey to correct. Avoid attempt to correct shaft alignment if pedestal is degraded or soleplate delaminated. Fluid-film brg - Reduced eccentricity ratio may lead to instability.		Use "time synch avg" when balancing around external forces.

Machine Vibration Matrix

Common Sources and Symptoms of Machine Related Vibration

	Generic Vibration Sources		
	Rub	**Thermal Variability**	**Self-Excitation**
Vibration Frequency Domain	**1X** - Most common. **1X Harmonics.** **Fractional Subharms (1/2X, 1/3X, etc.)** - when such frequencies are coincident with rub-modified natural frequencies.	**1X** - Rub or Distortion. **1X & Harms w/ Pole Pass S/Bs** (motor rotor fault).	**Approx 0.35X - 0.48X** - Whirl instability. **Sub-Synch** - Shaft whip, or brg degradation on deep-draft vert pump. **Approx 0.6X - 0.95X** - Trapped fluid within hollow shaft or coupling: **Non-Synch** -- Vortex shedding, deep-cavity standing wave.
Vibration Direction / Amplitude	**Any direction.** **Long period 1X amplitude oscillation.** from partial rub or viscous heating resulting in a long period 1X amplitude oscillation, period from several minutes to hours (Newkirk Effect).	**Any direction.** Vibration amplitude change occurs during warm-up following cold start.	**Any Direction**
Vibration Time Domain	Non-sinusoidal. Truncation.		
Vibration Phase	1X may create circular pattern on polar plot, normally progressing against shaft rotation over time (Newkirk Effect).	Phase may vary during warm-up, which may warrant caution if performing balancing.	
Vibration Orbit	Truncation. Reverse precession exterior loops. "Rebounding" pattern.		Whirl instability or whip - forward precession, circular or nearly circular, keyphaser dot moving.
Field / Operation Assessment	Noise or visible indication near area of rub, may be more obvious during coastdown. Reversing any speed or load change may quiet effects of rub.	Vibration change occurs during warmup to equilibrium conditions; with change in machine or process fluid temperatures, change in ventilation or ambient conditions, or the result of thermal distortion or localized rotor heating due to rub or motor rotor fault.	Change in speed or load may quiet self-excitation. *With caution!* ... adding small amounts of misalignment, unbalance, or changing oil temperature may quiet whirl instability. Throttling fan suction damper <30% may initiate vortex shedding.
Maintenance Assessment	Damaged or discolored seals, babbitt, turbine blades, pump impellers, etc.		Risk of whirl decreases with opening bearing clearances (ref Sommerfeld equation). Deep-draft vert pumps - inspect for opening pump bearing clearances.
PdM Assessment	Thermography - Evidence of high temperature at contact point. Wear particles in oil if rub occurring within lube boundary.	Thermography - Evidence of temp anomalies. MCSA - Pole Pass S/Bs possible motor rotor fault.	Fluid film bearing - Shaft C/L approaching lower eccentricity ratio may trigger instability.
Notes	May result in "transient" condition, wiping away interference, restoring normal vibration. Gap Voltage may show evidence of change in shaft centerline position. Thermal bow may be caused by rub-induced localized rotor heating.	Thermal bow may be caused by localized rotor heating (e.g. rub, viscous heating, motor rotor fault, etc.),	Ref. Fundamentals of Rotating Machine Diagnostics, 2002, Bently, Chpt 22. Source of whirl instability may be at bearings, seals, pump impellers, etc. Vane pass freq may excite standing wave, affecting piping or ducting, not likely rotor.

Machine Vibration Matrix

Common Sources and Symptoms of Machine Related Vibration

	Component Related Vibration Sources	
	Rolling Element Bearing Degradation	**Rolling Elem Bearing Poor Fit / Distortion**
Vibration Frequency Domain	**Stage 1 Fatigue Degradation / or under lubrication** Elevated hi-frequency acceleration (>5K Hz), HFD, or Spike Energy. Defect frequencies in demod spectra. Excites transducer mounted F*n* . **Stage 2 Fatigue Degradation** Elevated acceleration (0.5K – 6K Hz) – Defect frequencies in demod spectra. Excites Brg F*n* . **Stage 3 Fatigue Degradation** Defect frequencies in velocity spectra (<1K Hz) – w/ harmonics and/or sidebands. **Stage 4 Fatigue Degradation** Increasing 1X and defect frequencies in velocity spectra.	**1X** - Cocked bearing. **Defect freqs in Velocity Spectra w/o corroborating high freq precursor** - pinched, distorted, or pre-loaded bearing.
Vibration Direction / Amplitude	**Any Direction**, radial or axial. Evident closest to energy source.	**Any Direction** Evident closest to energy source. **Axial** - Cocked bearing.
Vibration Time Domain	Increasing or elevated true-peak acceleration (ref freq band 10 Hz - 6K Hz): Ball Bearing True-Peak acceleration >8g-p Roller Bearing True-Peak acceleration >12g-p	
Vibration Phase		
Vibration Orbit		
Field / Operation Assessment	Noise may accompany ball-sliding, under-lube, over-lube, early degradation, or false brinelling. If squeal is due to ball-sliding, it is likely intermittent, and may be accompanied by elevated housing temperature (increase approx. 20 degF?).	Elevated housing temperatures due to pre-load from poor fit or distortion.
Maintenance Assessment	Observe damaged ball paths due to fatigue failure, overload, false brinelling, contamination, or fluting. Confirm damage cause via ISO 15243. Ball-sliding - may be due to under-loaded bearing, possibly corrected with wavy-washer.	Poorly fitted inner ring to shaft (<80% contact), may result in bore fretting.
PdM Assessment	High Fe in oil may confirm bearing damage. High Fe in oil w/o defect frequencies, possible Inner Ring/Shaft fretting. Black oil possibly due to poor oil delivery or level, or ball sliding. High bearing housing temp may be due to overpacked lubricant, or excessive pre-load due to poor alignment.	Thermography - Elevated housing temperatures due to pre-load.
Notes	Recommend replacement @ Stage 3 (damage visible at contact surface of rolling elements). Diagnosis of rolling element bearings, ref ISO 13373-3, Annex D. Inadequate or contaminated lubrication may result in elevated noise floor of the spectra, broadband haystacking, or BSFs. Ball-sliding: Haystacking near bearing natural frequency w/ BPFO sidebands.	Inner ring fretting may cascade quickly to failure; causing heat, expanding inner ring, squeezing bearing clearance, and loss of oil film.

Machine Vibration Matrix

Common Sources and Symptoms of Machine Related Vibration

	Component Related Vibration Sources	
	Sleeve Bearing Degradation / Condition	**Coupling Degradation / Condition**
Vibration Frequency Domain	**1X** - Opening internal clearance, change in shaft centerline position w/ decreased eccentricity ratio (possibly due to an underloaded bearing), internal misalignment, shaft scratch, mechanical or electrical runout. **Sub-synch** - Whirl: Approx 0.35X - 0.48X. Whip: Sub-synch locked on shaft resonance. Trapped fluid within hollow shaft or coupling: Approx 0.6X - 0.95X. **Sub-synch on long vert shaft** - Opening or worn bearing clearances.	**1X, and/or 2X** **Possible low-order harmonics** (dependent on coupling type). **Fractional Orders** - Severe wear or inadequate lube of geared coupling.
Vibration Direction / Amplitude	**Isotropic** - Opening internal clearance (opening all radial directions), change in shaft centerline position w/ decreased eccentricity ratio, mechanical or electrical runout. **Anisotropic** - Opening internal clearance (dependent on axis of opening), Internal misalignment, improper twist / tilt.	**Anisotropic** - Degradation, changing axial or radial. Presence may *increase or decrease* vibe amplitude. **Isotropic** - Hub runout, face or rim, coupling lock.
Vibration Time Domain	1X spikes (Prox Probe) - Shaft scratch Random spikes (Prox Probe) - Electro-static discharge.	"W" or "M" shape or double step in sinusoid
Vibration Phase		Degradation - Does not rotate with transducer, possible 180 deg phase shift across coupling.
Vibration Orbit	Whirl/Whip - Forward Precession. Spikes in-line w/ probe (Prox Probe) - Shaft scratch. Randomly directed spikes (Prox Probe) - Electro-static discharge.	Pinched, peanut shaped, figure 8. Possible exterior loops.
Field / Operation Assessment	Bearing metal or return oil temperature change corroborates change in bearing loading or change in shaft C/L position. Increased return oil flow corroborates opening clearances. Whirl/whip may be initiated in response to changes in oil viscosity or pressure.	Expelled lubricant, dust, or debris inside coupling guard. Possible audible "clicking" from coupling.
Maintenance Assessment	Damaged babbitt or journal. Change in bearing Internal clearance. Change in Lift-Check dimension. Twist/Tilt condition. Journal damage due to abrasion, or electrical discharge/tracking. Failed bearing housing insulation test may explain electrical discharges.	Observe degraded or worn coupling, hardened or inadequate lubricant. Geared coupling sleeves don't slide off easily. Excessive hub runout, rim or face. Uneven coupling bolt torque.
PdM Assessment	Oil analysis may confirm bearing damage. Electric discharge test validates electro-static discharge. Parasitic magnetism test (rotor >2 gauss, housing >4 gauss) may indicate source of electric discharge damage.	Thermography may identify increased coupling temperature (dependent on coupling type).
Notes	Displacement thresholds: Internal Clearance ref ISO 20816-3, Annex C; Speed ref ISO 20816-3, Annex B; Load ref McHugh "Setting Vibration Criteria for Turbomachinery". Shaft C/L w/ low eccentricity ratio may yield higher vibration. Reduction in speed or load may quiet whirl or whip.	Coupling lock - Amplitude or phase change following start/stop cycle, load or speed change. Cannot rely on Vibe Analysis to identify coupling degradation.

Machine Vibration Matrix

Common Sources and Symptoms of Machine Related Vibration

	Component Related Vibration Sources		
	Degraded Pedestal	**Cracked Shaft**	**Runout / Eccentric Rotor**
Vibration Frequency Domain	**1X, or any forcing frequency** w/ possible harmonics.	1X and/or 2X	**1X**
Vibration Direction / Amplitude	**Anisotropic.** > 0.03 - 0.05 ips-p @ pedestal base. Machine foot vibration >30% of bearing vibration. **Possibly Isotropic?**... Location dependent, vertical machine?	**Isotropic.** Possibly high amplitude. Crack may propagate without vibration increase (Dependent on fracture plane).	**Isotropic** - If it causes unbalance. **Anisotropic** - If it causes interaction with bushing, wear ring, belt, etc.
Vibration Time Domain			
Vibration Phase	Pedestal "rocking" indicated by 180 deg phase difference between vert measurements on adjacent machine feet.	Phase may change (lag) w/ crack propagation	
Vibration Orbit		1X forward precession, w/ possible 2X internal loop.	
Field / Operation Assessment	**Caution! Observe safety protocols!** Any relative motion, sensed by touch at either grouted or jointed interfaces, is evidence of degradation. Observed gaps at structural interfaces.	Progressively decreasing rpm of critical speed on successive rollups may corroborate crack propagation.	
Maintenance Assessment	Observed damaged grout. Sole plate "Hammer test" - hollow or "drum" sound is evidence of grout voids or delaminating sole plate.	Visual inspection confirms crack.	Excessive runout… axial or radial.
PdM Assessment	Motion Amplification. Operating Deflection Shape (ODS).	NDE - Evidence of crack	
Notes	Simply retorquing embedded bolts is ineffective, must re-establish grout bonding. Consider epoxy fill of grouted base. Avoid attempt to correct alignment or softfoot if pedestal is degraded or soleplate delaminated.	Often diagnosed initially as unbalance with progressively changing phase as crack propagates. Fracture plane is perpendicular to stress, bending stress may go undetected prior to failure.	Visually observed runout sometimes interpreted as unbalance, but not necessarily true.

Machine Vibration Matrix

Common Sources and Symptoms of Machine Related Vibration

	Component Related Vibration Sources	
	Rotor Bow	**Belt/Sheave Wear**
Vibration Frequency Domain	**1X**	**1X** - Sheave runout (radial or axial). **1X or Belt Frequency** - Worn belts or sheaves. **1X and/or 2X** - Sheave misalignment, **Belt Freq Harmonics** - Worn or damaged belts.
Vibration Direction / Amplitude	**Isotropic** Possible high axial. High radial run-out and eccentricity at slow-roll speed.	**Any Direction**
Vibration Time Domain	Sinusoidal	
Vibration Phase	Stable. Rotates w/ transducer. Axial may be 180 deg out of phase across element	
Vibration Orbit	Circle / Open Ellipse	
Field / Operation Assessment	Commonly temperature related, causing *thermal* bow due to uneven heating, rub, or localized hot spot. Commonly result of failure to put shaft on turning gear following trip.	Belt Flop - Under-tensioned, or unevenly tensioned belts. Worn belts ride low in sheave w/ possible excessive belt dust. Squealing belts may not threaten serviceability.
Maintenance Assessment	Excessive radial runout. Generator shorted turns or blocked cooling passages. Induction motor broken rotor bars or shorted iron.	Excessive sheave runout, face or rim. Exposed belt cord. Bulge at belt splices. Cup shaped sheave race. Verify sheave pitch matches belt pitch.
PdM Assessment	May "self-balance" above critical speed, but remain difficult to roll-up through resonance.	Thermography - worn or slipping belts may result in Increased belt temperature.
Notes	Temporary bow will "roll-out" over time, following turning gear operation or extended slow-roll. Mild permanent bow will usually roll-out by operating at low speed or with steam for extended period. Possible "hand-baring" process may straighten a bowed shaft.	Belt squeal often mis-diagnosed as bearing squeal. Contrast belt noise from bearing noise by spraying DI water on belt/sheave interface. When replacing sheaves, always also replace belts.

Machine Vibration Matrix

Common Sources and Symptoms of Machine Related Vibration

	Machine Related Vibration Sources	
	Centrifugal Pump Condition	**Centrifugal Fan Condition**
Vibration Frequency Domain	**1X** - Opening wear-ring clearances, allowing higher rotor deflection and reduced damping. Impeller or fluid unbalance. **Vane pass** - Common... but possibly indicates flow outside Preferred Operating Range (POR), impeller/diffuser wear, improper gaps, may excite deep-cavity standing wave. **Sub-Synch** - Possible rotating stall. On deep-draft vert pumps possible opening bearing clearances. **Approx 0.35 - 0.48X** - Whirl @ impeller shroud or bearing. **Elevated noise floor, broadband haystacks** - Insufficient NPSH, cavitation, flow turbulence, air vortex sucked into pump suction, reversed impeller rotation (swapped motor leads?).	**1X** - Impeller unbalance. **Vane Pass** - Common. May coincide with fan wheel Fn. **0.6X to 0.75X** - Rotating stall. **0.5 to 2.0 Hz** - Surge. **Non synch** - Vortex Shedding at inlet damper.
Vibration Direction / Amplitude	**Any Direction**	**Any Direction** 1X ammplitude change after start/stop cycle - debris or water in impeller void.
Vibration Time Domain	Non-periodic impacts due to low-flow shuttling.	
Vibration Phase		1X Phase change after start/stop cycle - Debris or water in impeller void.
Vibration Orbit		
Field / Operation Assessment	Rotating stall may occur outside POR (70-120% BEP). Best Efficiency Point (BEP) confirmed by reviewing pump curve. Degrading pump curve performance indicates wear. Observed non-periodic axial shaft shuttling at low flow. Noise (rocks) - cavitation due to insufficient NPSH.	Stall may occur @ reduced flow. Surge @ unstable operating point. Surge evident by noise, flow, and amp fluctuation (0.5Hz - 2Hz). Vortex Shedding - Inlet damper throttled (<30%-50% open).
Maintenance Assessment	Visually examine for damaged/worn impeller, diffusers, wear rings. Visually examine for flowpath obstruction affecting flowrate. Impeller oxide layer may alter balance condition. Improper lift or gap dimensions. Paired ACBB (thrust brg) must be installed back-to-back; ref API 610-2021, para 6.10.1.8; may otherwise affect vibe.	Uneven buildup of contaminants, or uneven corrosion or erosion of impeller, may affect balance. Inspect for restriction, reducing flow. Damaged ducting possibly caused by stall.
PdM Assessment	Monitor pump curve performance.	Performance monitoring by tracking fan curve operating point. Dynamic pressure monitoring, and duct vibration, validates stall.
Notes	Diagnosis ref Olson, "Centrifugal Pump Vibration Diagnostics". Vibe Thresholds ref ISO 10816-7, HI 9.6.4., API 610-2021 6.9.4. Changing wear ring clearance may alter shaft stiffness (Lomakin effect), altering critical speed. Vane pass freq may excite standing wave or piping resonance, not likely to excite rotor resonance.	Diagnosis ref Sayer "Dynamic Testing of Centrifugal Fan Wheels" and ISO 13373-5. Vibe thresholds ref ISO 14694.

Machine Vibration Matrix

Common Sources and Symptoms of Machine Related Vibration

	Machine Related Vibration Sources	
	Induction Motor Condition	**Gear Unit Condition**
Vibration Frequency Domain	**2XLF** - Common (esp 2-pole mtrs), but possible uneven air gap, softfoot, stator frame distortion, top cover fit, loose termination. **2XLF w/ Mult Harms** - Loose stator core, stator winding fault. **1X & Harms w/ Pole Pass SBs** - Common w/ 2-pole motor?.. possible rotor fault or delaminating rotor core. **1X w/ Slip Freq S/Bs** - Eccentric rotor. **RBPF w/ 2XLF SBs** - Common, if multiple S/Bs possible loose rotor bars, reliability likely unaffected. **Stator Slot Pass w/ 1X S/Bs** - Loose stator coils. **6XLF / 12XLF** - VFD related.	**1X w/ multiple harmonics** - broken tooth (teeth). **1X and/or GM with 1X S/Bs** - eccentric gear or pitch line runout. **Gear mesh and harms w/ S/Bs-** misaligned or worn gears. **Gear Fn (Intermediate Freqs)-** Underloaded, possible early stage degradation.
Vibration Direction / Amplitude	**Any Direction**	**Any Direction** Detected at monitoring point closest to gear.
Vibration Time Domain		1X Impact - Broken gear tooth
Vibration Phase		
Vibration Orbit		
Field / Operation Assessment	Vibe or audible beat between 2XLF and 2X shaft speed is common for 2-pole motor, confirm contributing frequencies. Gradually changing 1X amplitude after start - faulted rotor bar heating? Speed modulation at pole-pass freq - faulted rotor bar? "Foghorn" sound at start - Loose stator weldments. 60Hz "buzz" during start w/o turning - improperly terminated. Rotor speed below nameplate rated speed, or stator temperature above nameplate insulation class rating - motor overloaded.	Audible pulsing at specific speed or load - torsional resonance.
Maintenance Assessment	Inspect for excessive softfoot. Measured uneven airgap (rotating or stationary eccentricity). Damaged stator bars/weldments. Evidence of contact between rotor and stator.	Broken gear teeth. Excessive or uneven gear wear. Misaligned gears or pitch line runout. Excessive backlash.
PdM Assessment	Electrical tests - PI, Surge, RIC, MCSA, ESA, Torque Signature Analysis. No reliable test for stator insulation embrittlement.	
Notes	Diagnosis ref IEEE Paper No. PCIC-99-20, ISO 13373-9. Vibe Thresholds ref ISO 20816-3, Uncoupled no load test thresholds ref NEMA MG 1-2006, Part 7. Rotor Fault diagnosis load dependent, recommend >80% rated load for accurate results.	Diagnosis ref "The Gear Analysis Handbook", Taylor; "Machine Analysis and Monitoring", Mitchell, pg. 214-232. Vibe thresholds ref ISO 20816-9. Common for gearbox vibe amplitude to vary substantially with load.

Machine Vibration Matrix

Common Sources and Symptoms of Machine Related Vibration

	Machine Related Vibration Sources	
	Steam Turbine Condition	**Generator Condition**
Vibration Frequency Domain	**1X** - Bowed rotor, change in balance condition due to material loss from rotating component, change in bearing elevation due to changes in exhaust backpressure or heat sink temperature. **Sub Synch** - Oil whirl at bearing or steam whirl.	**1X** - Abrupt change coincident with real or reactive load change or system disturbance?... possible Rotor Fault, which may be followed by additional gradual change lasting approx 20 min. **2XLF** - Common on frame, brg housings, end-windings, and stator core; acceptance thresholds are vendor specific.
Vibration Direction / Amplitude	**Any Direction**	**Any Direction**
Vibration Time Domain		
Vibration Phase	Progressively changing phase & amplitude over time - progressing shaft crack?	Phase shift following system disturbance - Possible retaining ring slippage.
Vibration Orbit		
Field / Operation Assessment	Progressively decreasing rpm of crit spds during successive rollups may indicate pedestal degradation or shaft crack. Evaluate any abnormal turb process parameter. Vibration changes may be result of transition between partial arc and full arc steam admission.	Large amplitude vibration increase at field breaker closure - possible rotor fault. H2 seal oil temp reduction may cause interaction between shaft and seal ring, resulting in long period amplitude and phase oscillation (Morton Effect).
Maintenance Assessment	Missing or damaged blade shrouds. Degradation of bearing support structure.	Pole drop test - Rotor Fault.
PdM Assessment	High eccentricity prior to rollup due to rotor bow, may be "rolled-out" after time on turning gear, admission of steam, or "hand-baring". Evaluate any Turbine Supervisory anomoly (e.g. thrust position, diff expansion, shaft centerline, casing expansion, etc.).	Flux probe may validate faulted rotor.
Notes	Diagnosis ref ISO 13373-4. Vibe Thresholds Stm Turb > 40MW ref ISO 20816-2,	Diagnosis >50 MVA generator reference ISO 13373-10 Vibe Thresholds > 40MW reference ISO 20816-2.