Pacific Vibration Matrix

Symptoms of Commonly Occurring Causes of Machine Vibration

	Imbalance	Resonance	Looseness / Impacting
Vibration Amplitude / Direction	High Radial. Distributed all directions radial. Couple Imbalance - Possible high axial.	Structural - High in direction of resonance mode. Shaft - High radial. Substantial amplitude changes with speed changes.	High or increasing. Anisotropic. Amplitude difference across loose interfaces.
Vibration Frequency Domain	Dominant 1X	Most Commonly excited by 1X of rotor speed. Possibly excited by 2X,3X. 2XLF or RBPF (motor), or vane pass (fan or pump). Any freq in the presence of impacting or rub.	1X w/ multiple harmonics. Roller coaster pattern across tops of harmonics in spectra. Half orders in presence of resonant frequencies or severe condition.
Vibration Time Domain	Sinusoidal	Sinusoidal in the direction of greatest response.	Not sinusoidal. Sharp peaks or truncation
Vibration Phase	Stable. Rotates w/ transducer.	Substantial phase changes w/ speed change.	Unstable. Phase difference across structural joints.
Vibration Orbit	Circle / Open Ellipse. Normally forward precession. Possibly reverse if overhung due to gyroscopoic effect.	Elongated ellipse along axis of resonant response. Normally forward precession (reverse precession w/ split critical)	
Operating Characteristics / Parameters	Rigid Shaft: Force $\propto$ Speed Squared	Substantial amplitude changes with speed changes.	"Nibbling" at joints.
Maintenance History / Inspection	Newly installed rotating element. Residual Imbalance > ISO-21940 recommendations	High balance sensitivity. Condition veritied w/ impact test. Commonly recommend quieting resonance before attempting balance correction.	Fretting evidence. Bluing shows insufficient contact. Denting or peening at loose contact surfaces.
Corroborating PdM Technnologies		Verified with impact test or modal analysis. Shaft impact test for sleeve brg machine perfomed @ cstdwn.	Oil analysis shows wear if looseness occurring within lubrication boundary.
Notes	References: Rigid rotors ISO 21940-11 Flexible rotors ISO 21940-12	May detune resonance by varying mass or stiffness. May be quieted by damping or dynamic absorber. Torsional resonance generates high radial in gearbox, but may otherwise go undetected.	

Pacific Vibration Matrix

Symptoms of Commonly Occurring Causes of Machine Vibration

	Shaft Misalignment	Coupling Degradation	Rub
Vibration Amplitude / Direction	Changing axial or radial. Anisotropic. Presence may increase or decrease vibe amplitude.	Changing axial or radial. Anisotropic. Presence may increase or decrease vibe amplitude. Vibration may change following start/stop, load or speed change.	High. Any direction. Shaft rub may create long period amplitude oscillation (Period from a few minutes to several hours).
Vibration Frequency Domain	1X, possible 2X or multiple harmonics (dependent on coupling type).	1X, possible 2X or multiple harmonics (dependent on coupling type)	Several possible freqs… 1x, harmonics, non-synch, sub-synch, broad-banded. Possibly excite natural freqs.
Vibration Time Domain	"W" or "M" shape or double step in sinusoid	Double step in sinusoid. "W" or "M" pattern.	Non-sinusoidal. Truncation.
Vibration Phase	Stable. Does not rotate with transducer. Possible 180 deg phase displacement across coupling… axial or radial.	Does not rotate w/ accel. Possible 180 deg disp across coupling… axial or radial. Phase may shift following start/stop, load or speed change.	Unstable. 1X may create circular pattern on polar plot… progressing against shaft rotation over time.
Vibration Orbit	Pinched, peanut shaped, figure 8. Reverse precession harmonics (exterior loops).	Pinched, peanut shaped, figure 8. Possible reverse precession harmonics or exterior loops.	Truncation, exterior loops. Full annular rub may result in reverse precession.
Operating Characteristics / Parameters	Increased bearing housing or coupling temperature (dependent on coupling type).	Grease expelled inside coupling guard. Increased bearing housing or coupling temperature.	
Maintenance History / Inspection	Newly Installed or aligned. Allowable misalignment 1800 rpm: <1.8 mils/in 3600rpm: <1.5 mils/in	Observe worn coupling or hardened lubricant. Mis-directed lubricant spray. Excessive hub runout, rim or face.	NDE evidence at contact point
Corroborating PdM Technnologies	Thermography identifies increased bearing housing or coupling temperature (dependant on coupling type).	Thermography identifies increased bearing housing or coupling temperature (dependant on coupling type).	Thermography - Evidence of high temperature at contact point.
Notes	May require "on-line to running" alignment survey.	Amplitude or phase change following start/stop cycle - torsional binding. Cannot rely on Vibe Analysis to predict failure.	Rub may "wipe away" interference …restoring normal vibration. May create "chaotic" sypmtoms. Morton Effect - similar symptoms for oil lubricated interface.

Pacific Vibration Matrix

Symptoms of Commonly Occurring Causes of Machine Vibration

	Degraded Pedestal	Bent Shaft	Cracked Shaft
Vibration Amplitude / Direction	High or increasing. Anisotropic. > 0.03 - 0.05 ips-p at pedestal base.	High radial or axial.	High…any direction. Increases with crack propogation.
Vibration Frequency Domain	1X, or any forcing frerquency w/ possible harmonics.	1X	1X or 2X
Vibration Time Domain		Sinusoidal	
Vibration Phase	"Rocking" indicated by 180 deg phase difference betweeen vert measurements on adjacent machine feet.	Stable 1X. Rotates w/ transducer. Axial 180 deg out of phase across element	Phase may change (lag) w/ crack propagation
Vibration Orbit		Circle / Open Ellipse	1X forward precession, 2X internal loop.
Operating Characteristics / Parameters	"Nibbling" at pedestal interfaces.		
Maintenance History / Inspection	Observed damaged grout. Hammer test.	Excessive face and/or rim runout.	Verified by NDE exam
Corroborating PdM Technnologies			NDE - Evidence of crack
Notes	Simply retorquing embedded bolts is ineffective. Must re-establish grout bonding. Possible epoxy refill. Rigid Mounting definition: NEMA MG 1-2006, para 7.6.3.		Commonly diagnosed initially as imbalance.

Pacific Vibration Matrix

Symptoms of Commonly Occurring Causes of Machine Vibration

	Rolling Element Bearing Degradation	Rolling Elem Bearing Poor Fit / Distortion
Vibration Amplitude / Direction	Increasing amplitude, radial or axial. Early stage evident closest to energy source.	Cocked Outer Ring - high axial. Pinched outer ring or distorted inner ring, high radial.
Vibration Frequency Domain	Stage 1 Fatigue Degradation / or Underlubrication >5K Hz – HFD or Spike Energy – Excites casing transducer Nat Freq Stage 2 Fatigue Degradation 0.5K – 10K Hz Acceleration – Defect freqs in demod spectra. Elevated noise floor. Stage 3 Fatigue Degradation <1K Hz Defect Freqs in velocity spectra – sidebands and/or harmonics. Replace Now! Stage 4 Fatigue Degradation Increasing 1X and defect freq velocities, Reduction in high freq acceleration	Cocked Outer Ring - 1X. Pinched Outer Ring - 1X or 2X of BPFO.
Vibration Time Domain	Consider Replacement: Ball Bearing True-Peak >8g-p Roller Bearing True-Peak >12g-p	
Vibration Phase		Cocked outer ring - axial phase rotates with transducer.
Vibration Orbit		
Operating Characteristics / Parameters	Audible squeal may corroborate ball-sliding, under-lube, early degradation, or false brinelling. Ball-sliding common with under-loaded bearing, possibly corrected with wavy-washer.	Elevated housing temps due to pre-load.
Maintenance History / Inspection	Observe damaged ball paths due to fatigue failure, false brinelling, contamination, or fluting. Confirm damage cause via ISO 15243.	Poorly fitted inner ring (<80% contact), may result in bore fretting.
Corroborating PdM Technnologies	High Fe in oil may confirm bearing damage. Inadequate grease lubrication - possible elevated noise floor or BSFs. Black oil possibly due to poor oil delivery or ball sliding.	Thermography - Elevated housing temps due to pre-load.
Notes	Ref L10 for expected service life due to fatigue degradation. False-brinelling freqs appear similar to fatigue degradation. High oil Fe w/o defect freqs, possible ring fretting. Ball-sliding: Haystacking at housing Nat Freqs w/ BPFO sidebands.	Inner ring fretting may cascade quickly to failure; causing heat, expanding ring, squeezing bearing clearance, and loss of oil film.

Pacific Vibration Matrix

Symptoms of Commonly Occurring Causes of Machine Vibration

	Sleeve Bearing Degradation / Condition	Belt/Sheave Wear
Vibration Amplitude / Direction	Increased Radial.	Increasing along direction of belt
Vibration Frequency Domain	1X isotropoic - Excessive clearance, incorrect preload dimensions, change in shaft centerline position. 1X anisotropoic - Internal misalignment. Sub-harmonics on long vert shaft - open internal clearances, whirl, or whip. Whirl: Approx 0.44X. Whip: Sub-synch locked on shaft resonance.	1X or Belt Frequency. Multiple belt freq harmonics in spectra. Observe decrease in 1X frequency if belt is slippiing.
Vibration Time Domain	Random spikes in time domain - Electro-static discharge.	
Vibration Phase		
Vibration Orbit	Whirl/Whip - Forward Precession. Random spikes - elecrto-static discharge. Spikes in-line w/ probe - shaft scratch.	
Operating Characteristics / Parameters	Bearing metal or return oil temp change. Increased return oil flow. Whirl/whip may be initiated due to changes in oil viscosity or pressure.	Observe Belt riding low in sheave. Belt elevated temperature. Excessive belt dust.
Maintenance History / Inspection	Damaged babbitt or journal. Change in bearing Internal clearance. Journal damage due to abrasion, or electrical discharge/tracking.	Exposed belt cord. Cup shaped sheave race. Verify sheave pitch matches belt pitch.
Corroborating PdM Technnologies	Oil analysis may confirm bearing damage.	Thermography - Increased belt temperature
Notes	Shaft C/L w/ low eccentricity ratio may yield higher vibration. Acceptable R/C vibration thresholds ref ISO 10816-7. Whirl/whip may require design modification for correction, reference Sommerfeld variables. Electric discharge possibly result of parasitic magnetism (rotor >2 gause, housing >4 gause).	Belt related noise can be distinguished from bearing noise by spraying water on belt/sheave interface.

Pacific Vibration Matrix

Symptoms of Commonly Occurring Causes of Machine Vibration

	Eccentric Rotor/Sheave	Thermal Variability	External Force
Vibration Amplitude / Direction	High…any direction	Changing…any direction. Vibration change occurs during warm-up following cold start.	Random direction & amplitude.
Vibration Frequency Domain	1X	1X and/or 2X	Non-synchronous. Frequency peaks generated by adjacent machinery.
Vibration Time Domain			Possibly same as adjacent machinery.
Vibration Phase	Stable	Phase may vary during warm-up	
Vibration Orbit			
Operating Characteristics / Parameters		Vibration change occurs with change in machine or process fluid temperature	
Maintenance History / Inspection	Excessive runout… axial or radial.		
Corroborating PdM Technnologies			
Notes	Compromise balance may decrease vibration in one direction, but increase vibration in the other directions.	May be caused by localized rotor heating, creating compressive forces causing rotor bow. Allow thermal effects to find equilibrium prior to collecting balance data.	Assess likely external sources and compare frequencies.

Pacific Vibration Matrix

Symptoms of Commonly Occurring Causes of Machine Vibration

	Centrifugal Fan Condition	Centrifugal Pump Condition
Vibration Amplitude / Direction		
Vibration Frequency Domain	Vane pass - Common. 0.6X to 0.75X - Rotating stall. 0.5 to 2.0 Hz - Surge. Non synch - Vortex Shedding (possible inlet damper throttled).	1X - Impeller or fluid imbalance. Vane pass - Flow outside BEP, improper gaps. May excite resonance. 0.1X - 0.3X - Diffuser stall. 0.6X - 0.9X - Impeller stall or suction recirculation. Elevated noise floor - Insufficient NPSH. Approx 0.44X - Whirl @ bearing or impeller shroud. High subsynch - Possible Whip @ bearing or impeller shroud.
Vibration Time Domain		Non-periodic impacts due to low-flow shuttling.
Vibration Phase	1X Amp & Phase change after start/stop cycle - debris or water accumulated in hollow impeller blade.	
Vibration Orbit		Vane pass harmonics.
Operating Characteristics / Parameters	Stall occurs w/ reduced flow or inlet disturbance. Surge @ unstable opertng point. Vortex Sheding - Inlet damper throttled (30-50%).	Operation away from BEP confirmed by reviewing pump curve. Preferred operating range 70-120% BEP. Observed non-periodic axial shaft shuttling at low flow. Degrading performance indicates wear or excessive clearances. Noise (rocks) with insufficient NPSH.
Maintenance History / Inspection		Visually confirm damaged/worn impeller, wear rings, or dffusers. Confirm improper lift or gap dimensions.
Corroborating PdM Technnologies	Dynamic pressure monitoring. Duct vibration survey. Perf monitoring by tracking fan curve operating point.	Performance monitoring. Changing pump curve characteristics.
Notes	Fan imipeller modes may become excited. Fan design normally specifies several diameters of straight ducting at inlet and outlet of fan.	Vibration generally increases as flow is throttled <BEP. Wear ring clearance may alter shaft stiffness and damping (Lomakin effect). ACBB Face-to-face configuration allows axial movement that may affect C-Dimension.

Pacific Vibration Matrix

Symptoms of Commonly Occurring Causes of Machine Vibration

	Induction Motor Condition	Gear Degradation
Vibration Amplitude / Direction		Observed at monitoiring point closest to gear.
Vibration Frequency Domain	1X harmonics w/ pole pass SBs - rotor fault. RBPF w/ 2XLF SBs - Common but possible rotor fault? 2XLF - Possible uneven air gap / softfoot / loose terminations. 2XLF w/ harmonics - possible loose stator windings. (verified by inspection, corrected by re-wedging). 6XLF / 12XLF - VFD related. Slot pass w/ 1X SBs - Loose stator coils?	1X w/ multiple harmonics - broken tooth (teeth).. 1X and/or GM with 1X S/Bs - eccentric gear or pitch line runout. Gear mesh w/ harmonics - misaligned or worn gears, backlash.
Vibration Time Domain		1X Impact - Broken gear tooth
Vibration Phase		
Vibration Orbit		
Operating Characteristics / Parameters	Audible beat at polepass interval - faulted rotor. Gradaully changing 1X after start - faulted rotor bar heating. Common audible 2-pole motor beat between 2XLF and 2X shaft speed. "Foghorn" sound at start - Loose stator weldments. 60Hz "buzz" w/o turning - improperly terminated.	Audible pulsing at specific speed or load - Torsional Resonance.
Maintenance History / Inspection	Softfoot. Measured uneven airgap (rotating or stationary eccentricity). Inspect damaged stator bars/weldments. Inspect evidence of contact between rotor and stator. Circulating currents confirmed by failed bearing insulation test.	Broken gear teeth. Excessive or uneven gear wear. Misaligned gears. Excessive backlash.
Corroborating PdM Technnologies	Electrical tests - PI, Surge, RIC, MCSA, Torque Signature Analysis. No reliable test for stator insulation embrittlement.	Oil Analysis - Wear evidence in oil.
Notes	2XLF and RBPF w/ 2XLF SBs common, difficult to set action threshold, may not warrant corrective maintenance. Rotor Fault diagnosis load dependent, requires >80% rated load. Corroborate pole-pass SBs by PP in demod specra. VFD Drive: Motor faults appear as S/Bs around carrier freq.	Early-stage degradation evident in demodulated data. Common for gearbox vibration amplitude to vary substantially with load.