

MACHINERY FAULT DIAGNOSIS

Unbalance

Unbalance is the condition when the geometric centerline of a rotor does not coincide with the mass centerline.

A pure unbalance will generate a signal at the rotor speed 1X vibration signal predominant at the radial direction.

STATIC UNBALANCE

The static unbalance is seen when the machine is not in operation, the rotor will turn to the unbalance mass as at the lowest position. The static unbalance produces a vibration signal at 1X, radial predominant and in phase signals in both shaft extremes.

MOMENT UNBALANCE

Moment unbalance is caused by two identical unbalance masses located at 180° in the transverse area of the shaft.

Moment unbalance may be statically balanced. When rotating dynamic unbalance produces a vibration signal at 1X, radial predominant and in opposite phase signals in both shaft extremes.

DYNAMIC UNBALANCE

In practice, dynamic unbalance is the most common form of unbalance found. When rotating the dynamic unbalance produces a vibration signal at 1X, radial predominant and the phase will depend on the mass distribution along the axis.

DOCUMENTATION OF BALANCING

Frequency spectra before/after balancing, and balancing diagram.

WHERE IS TO BE MEASURED?

The measurement locations with the highest 1X vibration level are dependent on the rotor structure and the location of the unbalance.

Misalignment

Misalignment is the condition when the geometric centerline of two coupled shafts are not co-linear along the rotation axis of both shafts at operating condition. A 1X and 2X vibration signal predominant in the axial direction is generally the indicator of a misalignment between two coupled shafts.

ANGULAR MISALIGNMENT

Angular misalignment is seen when the shaft centerlines coincide at one point along the projected axis of both shafts. The spectrum shows high axial vibration at 1X plus some 2X and 3X with 180° phase difference across the coupling in the axial direction.

PARALLEL MISALIGNMENT

Parallel misalignment is produced when the centerlines are parallel but offset. The spectrum shows high radial vibration at 2X and a lower 1X with 180° phase difference across the coupling in the radial direction. These signals may be also visible in the axial direction at a lower amplitude and 180° phase difference across the coupling in the axial direction.

ALIGNMENT TOLERANCE TABLE

Short "flexible" couplings	Alignment Tolerance (Inches)		
	RPM	acceptable	excellent
Offset	750	0.0074	0.0035
	1500	0.0035	0.0023
	3000	0.0023	0.0011
	6000	0.0011	0.0007
Angularity (gap difference at coupling edge per 3.9 inches diameter)	750	0.0051	0.0035
	1500	0.0027	0.0019
	3000	0.0015	0.0011
	6000	0.0011	0.0007
Spacer shafts and membrane (disk) couplings (one 3.9 inches spacer length)	750	0.0098	0.0059
	1500	0.0047	0.0027
	3000	0.0027	0.0015
	6000	0.0011	0.0007
Angularity (mrad)	750	2.5	1.5
	1500	1.2	0.7
	3000	0.7	0.4
	6000	0.3	0.2
Soft foot	any	0.0023	

The suggested alignment tolerances shown above are general values based upon experience and should not be exceeded. They are to be used only if existing in-house standards or the manufacturer of the machine or coupling prescribe no other values.

Shaft Bending

A shaft bending is produced either by an axial asymmetry of the shaft or by external forces on the shaft producing the deformation. A bent shaft causes axial opposed forces on the bearings identified in the vibration spectrum as 1X in the axial, vibration, 2X and radial readings can also be visible.

Structural Looseness

Rotating looseness occur by an excessive clearance between rotor and bearing.

Structural looseness may produce a 1X signal in the radial direction predominant in the horizontal reading. Measurements should be made on the both, feet and bases in order to see a change in the amplitude and phase. A decrease in amplitude and 180° phase difference will confirm this problem.

Blades & Vanes

A blade or vane generates a signal frequency called blade pass frequency $f_{bpf} = \frac{v}{\pi \cdot d}$.

Identify and trend BPF, an increase and harmonics may be a symptom of a problem like blade-diffuser or vane or gap differences.

Vibration Limits - ISO 10816-3

Mechanical vibration - Evaluation of machine vibration by measurements on non-rotating parts.

Machine type	Group 1		Group 2	
	flexible	rigid	flexible	rigid
Foundation				
Velocity v_{rms} (inches/s)	0.45	0.28	0.35	0.22
600-6000 rpm	C	D	C	D
120-60000 rpm	B	C	B	C
120-6000 rpm	A	B	A	B
120-6000 rpm	A	B	A	B
120-6000 rpm	A	B	A	B

Fluid

There are two basic moving fluid problems diagnosed with vibration analysis:

- Turbulence
- Cavitation

Assessment of vibrations in piping systems according to VDI 3842.

Fan Categories and Vibration Limits according to ISO 14694

Category	1	2	3	4	5	6	7	8	9
Velocity v_{rms} (inches/s)	0.35	0.25	0.18	0.13	0.10	0.07	0.05	0.04	0.03
Frequency (rpm)	600	1200	2400	4800	9600	19200	38400	76800	153600

Belt Drive

Belt transmission a common drive system in industry consisting of:

- Driver Pulley
- Driven Pulley
- Belt

The dynamic relationship is: $\frac{v}{l} = \frac{3.1416 \cdot v_{rpm}}{l}$

BELT DRIVE FAULTS

Belt Worn

High 1X of the eccentric pulley visible in the spectrum, predominant in the radial direction. Easy to confuse with unbalance, but 2X generally dominates the spectrum.

Eccentric Pulleys

The geometric center doesn't coincide with the rotating center of the pulley. High 1X of the eccentric pulley visible in the spectrum, predominant in the radial direction. Easy to confuse with unbalance, but 2X generally dominates the spectrum.

Pulley Misalignment

1X of driver or driven pulley visible and predominant in the axial reading.

Belt Resonance

If the belt natural frequency coincides with either the driver or driven 1X, this frequency may be visible in the spectrum.

Rotating Looseness

Rotating looseness occur by an excessive clearance between rotor and bearing.

Rolling element bearing

Journal bearing

Permissible overall vibration velocity v in inches/s (rms) - according to ISO 20816-8

Component	Foundation	Frame	Cylinder (overall)	Cylinder (rod)	Roller (rod)	Roller (overall)
Vibration velocity (rms)	0.16	0.10	0.07	0.05	0.04	0.03
Frequency (rpm)	600	1200	2400	4800	9600	19200

Assessment of vibrations in piping systems according to VDI 3842

Vibration velocity (inches/s rms) vs Frequency (rpm)

Permissible evaluation velocity in inches/s - according to VDI 3834

Component	Main bearing	Overhaul	Condition	Roller/bearing
Velocity v_{rms} (inches/s)	0.16	0.10	0.07	0.05
Frequency (rpm)	600	1200	2400	4800

Resonance

Resonance is a condition caused when forcing frequency coincides with (or is close to) the natural frequency of the machine's structure. The result will be a high vibration.

1st form of natural flexure, 2nd form of natural flexure, 3rd form of natural flexure.

Shaft 1: 2nd and 3rd critical speeds cause a resonance state when operation is near these critical speeds.

Resonance can be confused with other common problems in machinery. Resonance requires some additional tests to be diagnosed.

Resonance step-up: Phase jump at 180°.

Amplitude at rotation frequency f_r by residual unbalance on rigid rotor.

Strong increase in amplitude of the rotation frequency that at the point of resonance, step-up dependent on the excitation (unbalanced condition) and damping.

RUN UP OR COAST DOWN TEST

Performed when the machine is turned on or turned off.

Series of spectra at different vibration signals tracking may reveal a resonance.

The use of tachometer is optional and the data collector must support this kind of test.

RESONANCE DIAGNOSING TESTS

Bump test

Excitation - force pulse

Response - component vibration

Frequency response, vertical

Frequency response, horizontal

Natural frequency, vertical

Natural frequency, horizontal

DIN ISO 13373-3:2015

Large Bearings, Small bearings

Frequency range for RPM and DP acceleration measurements is 600rpm - 60000rpm

Bearing in good condition, Bearing condition to be considered, Bad bearing condition.

DIN ISO 10816-7

Pump type	Category 1		Category 2	
	< 200 kW	> 200 kW	< 200 kW	> 200 kW
Velocity v_{rms}	0.3	0.37	0.3	0.37
600-6000 rpm	C	D	C	D
120-6000 rpm	B	C	B	C
120-6000 rpm	A	B	A	B

Journal Bearings

Journal bearings provide a very low friction surface to support and guide a rotor through a cylinder that surrounds the shaft and is filled with a lubricant preventing metal to metal contact.

High vibration damping due to the oil film:

- High frequencies signals may not be transmitted
- Displacement sensor and continuous monitoring recommended

Clearance problems (rotating mechanical losses)

Rolling Element Bearings

WEAR

Lifetime exceeded, Bearing overload, Incorrect assembly, Manufacturing error, Insufficient lubrication.

Outer race damage: 1 - Outer race damage, 2 - Inner race damage, 3 - Rolling element damage, 4 - Cage damage.

Inner race damage: 1 - Inner race damage, 2 - Rolling element damage, 3 - Cage damage.

Rolling element damage: 1 - Rolling element damage, 2 - Rolling element damage, 3 - Rolling element damage, 4 - Rolling element damage.

Cage damage: 1 - Cage damage, 2 - Cage damage, 3 - Cage damage, 4 - Cage damage.

RACE DAMAGE

1 - Outer race damage, 2 - Inner race damage, 3 - Rolling element damage, 4 - Cage damage.

Outer race damage: 1 - Outer race damage, 2 - Inner race damage, 3 - Rolling element damage, 4 - Cage damage.

Inner race damage: 1 - Inner race damage, 2 - Rolling element damage, 3 - Cage damage.

Rolling element damage: 1 - Rolling element damage, 2 - Rolling element damage, 3 - Rolling element damage, 4 - Rolling element damage.

Cage damage: 1 - Cage damage, 2 - Cage damage, 3 - Cage damage, 4 - Cage damage.

LUBRICATION PROBLEMS

Major fluctuation in level of shock pulses and damage frequencies.

Subsequent small temperature increase.

Large temperature increase after lubrication.

Insufficient lubricant, Over-lubricating, Maintenance error, Defective grease regulator, Grease nipple blocked.

BEARING RINGS DEFORMED

Incorrect installation, Wrong bearing size, Fault manufacturing error, Bearing housing over-torque.

Bearing forces on floating bearing: 1 - Bearing forces on floating bearing, 2 - Bearing forces on floating bearing, 3 - Bearing forces on floating bearing, 4 - Bearing forces on floating bearing.

Source vibration: 1 - Source vibration, 2 - Source vibration, 3 - Source vibration, 4 - Source vibration.

ELECTROMAGNETIC FORCES VIBRATIONS

Twice line frequency vibration: $2 \cdot f_l$

Bar rotating frequency: f_{br}

Synchronous frequency: $f_s = \frac{2 \cdot f_l}{p}$

Slip frequency: $f_{sl} = f_l - f_s$

Pole pass frequency: $f_{pp} = \frac{2 \cdot f_l}{p}$

Stator eccentricity, Loose stator windings, Eccentric rotor, Rotor problems, Loose connections, Loose Rotor Bars, Loose rotor.

STATOR ECCENTRICITY

Loose iron, Stator lamination saturation, Soft foot.

1X and 2X signals, without sidebands, Radial predominant, High resolution should be used when analyzing two poles machines.

ECCENTRIC ROTOR

Rotor offset, Misalignment, Poor base.

1X, 2X and 2X signals with sidebands at f_r , Radial predominant, High resolution should be used when analyzing two poles machines.

ROTOR PROBLEMS

1. Rotor thermal bow

2. Broken or cracked rotor bars

3. Loose rotor bar

4. Loose connections

Unbalanced rotor bar current, Unbalance rotor conditions, Observable after some operation time.

1X and harmonics with sidebands at f_r , f_{sl} can be higher, 1X and 2X can appear.

2f excessive signal with sidebands at 3/2f, Electrical phase problem, Correction must be done immediately.