SI Units and Conversion

Basic Units

Quantity	Unit	Symbol
length	meter	m
mass	kilogram	kg
time	second	s
current	ampere	A
temperature	degree Kelvin	° K
luminous intensity	candela	cd

Prefixes

Prefix	Symbol	Multiple
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}

Selected Derived Units

Quantity	Name	Symbol	Formula
acceleration	—	—	m/s^2
area	—	—	m^2
capacitance	farad	F	A–s/V
charge	coulomb	C	A–s
density	—	—	kg/m^3
electric field strength	volt/meter	V/m	—
energy	joule	J	N–m
force	newton	N	$kg–m/s^2$
frequency	hertz	Hz	1/s
inductance	henry	H	V–s/A
magnetic flux	weber	Wb	V–s
magnetic flux density	tesla	T	Wb/m^2
moment of a force	—	—	N–m
power	watt	W	J/s
pressure	pascal	Pa	N/m^2
resistance	ohm	Ω	V/A
velocity	—	—	m/s
voltage	volt	V	W/A
volume	—	—	m^3

Conversion Factors

To convert from	To	Multiply by
Acceleration		
g	$meters/s^2$	9.807
g	$feet/s^2$	32.16
$feet/s^2$	$meters/s^2$	3.048 E–01[1]
$inches/s^2$	$meters/s^2$	2.540 E–02[1]
Amplitude		
average	rms	1.111
peak	rms	0.707
peak-to-peak	rms	0.354
Angle/angular acceleration		
degree	radian	1.745 E–02
radian	degree	57.3
Hertz	radian/s	6.283
RPM	radian/s	1.047 E–01

Signal Analysis Reference

SI Units and Conversion

Conversion Factors		
To convert from	**To**	**Multiply by**
Area		
Inches ^{2}	meters^2	6.4516 E-04
feet^2	meters^2	9.290 E-02
yards^2	meters^2	8.361 E–01
acres	meters^2	4.047 E+03
acres	feet^2	43,560(1)
miles^2	kilometers^2	2.59
miles^2	acres	640(1)
Density		
lbm/in^3	kg/m^3	2.768 E+04
lbm/ft^3	kg/m^3	1.602 E+01
Energy		
BTU	joule	1.173 E 03
calorie	joule	4.187
erg	joule	1.000 E–07(1)
ft-lbf	joule	1.356
kw-h	joule	3.600 E+06(1)
Force		
dyne	newton	1.000 E–05(1)
kg force	newton	9.807
oz force	newton	2.708 E–01
lbf	newton	4.448
Length		
angstrom	meter	1.000 E–10(1)
micron	meter	1.000 E–06(1)
inch	meter	2.540 E–02(1)
inch	mil	1.000 E+03(1)
foot	meter	3.048 E–01(1)
yard	meter	9.144 E–01(1)
mile (US)	meter	1.609 E+03
mile (US)	kilometer	1.609
mile (naut)	meter	1.852 E+03(1)
light-year	meter	9.461 E+15

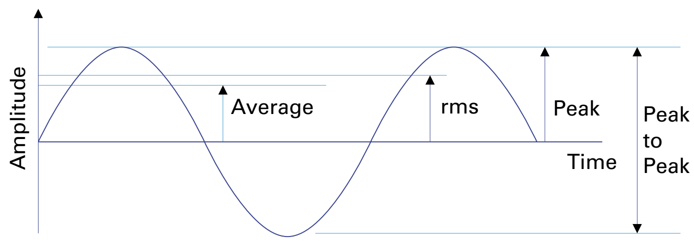
Conversion Factors		
To convert from	**To**	**Multiply by**
Mass		
ounce (mass)	gram	2.835 E+01
lbm	kg	4.536 E–01
kg	lbm	2.204
slug(lbf-s^2/ft)	kg	1.459 E+01
grain	gram	6.408 E–02
carat	gram	2.000 E–01(1)
stone (UK)	kilogram	6.35
stone (UK)	lbm	14
ton (2000 lb)	kilogram	9.072 E+02
Power		
ft-lbf/min	watt	2.260 E–02
ft-lbf/s	watt	1.356
hp (550 ft-lbf/s)	watt	7.457 E+02
hp (electric)	watt	7.460 E+02(1)
erg/s	watt	1.000 E–07(1)
cal/s	watt	4.184(1)
BTU/hr	watt	2.931 E–01
BTU/s	watt	1.173 E+03
Pressure/stress		
atmosphere	pascal	1.103 E+05
atmosphere	psi	14.7
bar	pascal	1.000 E+05(1)
bar	psi	14.5
dyne/cm2	pascal	1.000 E–01(1)
in of H_20 (4 °C)	pascal	2.491 E+02
mm of Hg (0 °C)	pascal	1.333 E+02
lbf/ft^2	pascal	4.788 E+01
psi	pascal	6.895 E+03
Torque		
dyne-cm	newton-meter	1.000 E–07(1)
oz(f)–in	newton–meter	7.062 E–03
lbf-in	newton-meter	1.130 E–01
lbf-ft	newton-meter	1.356

SI Units and Conversion

Conversion Factors		
To convert from	**To**	**Multiply by**
Velocity		
in/s	m/s	2.540 E–02[1]
ft/min	m/s	5.080 E–03[1]
ft/s	m/s	3.048 E–01[1]
knot	m/s	5.144 E–01
mph	m/s	4.4704 E–01[1]
mph	km/h	1.6093
g-seconds	in/s	386
Volume		
in^3	$meter^3$	1.639 E–05
in^3	liter	1.639 E–02
ft^3	$meter^3$	2.832 E–02
yd^3	$meter^3$	7.646 E–01
liter	$meter^3$	1.000 E–03[1]
liter	in^3	61.02
liter	quart	1.06
liter	gallon (US)	0.236
quart	$meter^3$	9.464 E–04
quart	liter	9.464 E–01
gallon (US)	$meter^3$	3.785 E–03
gallon (UK)	$meter^3$	4.546 E–03
once (US)	liter	2.957 E–02
once (UK)	liter	2.841 E–02

To convert from	To	Multiply by
average	rms	1.111
peak	rms	0.707
peak-to-peak	rms	0.354
rms	average	0.9
peak	average	0.637
peak-to-peak	average	0.318
rms	peak	1.414
average	peak	1.571
rms	peak-to-peak	2.828
average	peak-to-peak	3.142
crest factor = peak/rms		

Sinusoid Amplitude Relationships



Temperature Conversion			
Fahrenheit to Celsius	°C	=	(°F – 32)/1.8
Celsius to Fahrenheit	°F	=	1.8 °C + 32
Celsius to Kelvin	°K	=	°C + 273.15
Fahrenheit to Kelvin	°K	=	(°F + 459.67)/1.8
Rankine to Kelvin	°K	=	°R/1.8

Decibel Reference Levels(3)		
Quantity	**Formula**	**Reference Level**
Power (dBm)	10 log (P/P_0)	1 mW
Sound pressure		20 μPa (air)
Level (Lp)	20 log (p/p_0)	1 μPa (H_2O)
Voltage (dBV)	20 log (V/V_0)	1 Vrms

Signal Analysis Reference

Dynamic Signal Analyzer Reference

Window Function Selection

Signal Type	Window Function
Burst random noise	Uniform
Impact stimulus	Uniform or Force
Impact response	Uniform, Exponential or Force(5)
Impulse	Uniform
Periodic (sine, square, etc.)	Flat top
Pseudo-random noise	Uniform
Random noise	Hann
Transient	Uniform

(5) The decay rate of the exponential window can affect damping estimates.

Average Type Selection

Objective	Average Type
Stabilize spectrum	Stable (rms)
Improve statistical accuracy	Stable (rms)
Average changing signal	Exponential
Improve S/N ratio	Time
Hold peak values	Peak hold

Source Selection

Network	Source
Linear	Pseudo-random
	Chirp
	Burst chirp
	Swept sine
Nonlinear	Random
(least-squares estimate)	Burst random
Nonlinear	Chirp
(characterize at given level)	Burst chirp Swept sine

Burst sources provide leakage-free measurements, with some reduction in S/N ratio. To avoid leakage, burst length must be set so that response decays completely within the time record.

Line Spacing vs Span

Line Spacing (Hz)	800-Line Span (Hz)	400-Line Span (Hz)	256-Line Span (Hz)	Time Record (sec)
250	—	100,000	64,000	0.004
125	100,000	50,000	32,000	0.008
100	80,000	40,000	25,600	0.01
62.5	50,000	25,000	16,000	0.016
50	40,000	20,000	12,800	0.02
40	32,000	16,000	10,240	0.025
31.3	25,000	12,500	8,000	0.032
25	20,000	10,000	6,400	0.04
20	16,000	8,000	5,120	0.05
15.6	12,500	6,250	4,000	0.064
12.5	10,000	5,000	3,200	0.08
10	8,000	4,000	2,560	0.1
7.81	6,250	3,125	2,000	0.128
6.25	5,000	2,500	1,600	0.16
5	4,000	2,000	1,280	0.2
2.5	2,000	1,000	640	0.4
2	1,600	800	512	0.5
1	800	400	256	1
0.64	512	256	164	1.56
0.25	200	100	64	4
0.125	100	50	32	8
0.063	50	25	16	16
0.025	20	10	6	40
0.013	10	5	3	80
0.006	5	2.5	1.6	160
0.0025	2	1	0.6	400
0.0013	1	0.5	0.3	800

Dynamic Signal Analyzer Reference

Window Function Bandwidth Factors (Multiply by line spacing)

Window	3 dB BW	Eq Noise BW	Approx Shape Factor
Flat top, P401 (HP3561/62)	3.6	3.82	2.6
Flat top (HP3582)	3.6	3.67	2.6
Flat top, P301 (HP5420/23)	3.38	3.42	2.3
Hann	1.48	1.5	9
Uniform	1	1	716

Window Function Amplitude Accuracy For Line Spectra

Window	Accuracy (dB)	Accuracy (%)
Flat top	+0,–0.01 dB	+0,–0.12%
Hann	+0,–1.5 dB	+0,–16%
Uniform	+0,–4 dB	+0,–37%

Stable Average 90% Confidence Limits for Gaussian Noise Measurements

	Number of Averages				
	16	32	64	128	256
Upper limit dB	+2.0	+1.4	+1.0	+0.7	+0.5
Lower limit dB	–1.6	–1.2	–0.8	–0.6	–0.4

Selected Measurement Formulas

Measurement	Formula
Coherence function (Y)	$(G_{yx})^2/G_{xx}G_{yy}$
Auto power spectrum (G_{xx})	X(f)X*(f)
Cross-power spectrum (G_{yx})	Y(f)X*(f)
Transfer function (H1)	G_{yx}/G_{xx}
Transfer function (H2) (equivalent to H1/Coherence)	G_{yy}/G_{yx}

* Complex conjugate Fourier transform

The Coherence Function

$$\text{Coherence} = \frac{\text{Output power coherent with input}}{\text{Total output power}}$$

Low coherence at high-Q response peaks is usually the result of insufficient frequency resolution.[6] Other causes of low coherence are poor S/N ratio and nonlinearities.

6) Insufficient resolution results in bias error as a fraction of the actual value equal to –0.27(Br/Be)^1.7, where Br and Be are resolution BW and response peak BW.

Coherence Function 90% Confidence Limits

Measured Coherence	Number of Averages				
	16	32	64	128	256
0.4	0.15	0.23	0.28	0.32	0.34
	0.59	0.54	0.5	0.47	0.45
0.5	0.25	0.33	0.39	0.42	0.45
	0.67	0.63	0.59	0.57	0.55
0.6	0.36	0.45	0.5	0.53	0.55
	0.74	0.71	0.68	0.66	0.64
0.7	0.5	0.57	0.61	0.64	0.66
	0.81	0.78	0.76	0.75	0.73
0.8	0.65	0.7	0.74	0.76	0.77
	0.88	0.86	0.84	0.83	0.82
0.9	0.81	0.85	0.87	0.88	0.88
	0.94	0.93	0.92	0.92	0.91

Signal Analysis Reference

Acoustics

Acoustic Reference Levels

Quantity	Formula	Ref Level
SPL (L_p)	10 Log (p^2/p_0^2)	20 µPa (air)
		1 µPa (H_2O)
Velocity (L_v)	20 Log (v/v_0)	10 nm/s²
Power level (L_w)	10 Log (P/P_0)	1 pW
Intensity (L_I)	10 Log (I/I_0)	1 pW/m²

Sound Pressure from Sound Power

Transmission Environment	Lp
Free Field	L_w + log Q – 20 log r – 10.8 dB
Reflecting Plane	L_w + log Q – 20 log r – 7.8 dB
Reverberant Room	L_w – 10 log R + 6.2 dB

r = distance from source (m)
Q = directivity index of source
R = room constant (m^2)

Acoustic Intensity

$$I = \frac{Imaginary\left[G_{yx}(f)\right]}{4\pi\ \rho_0 \Delta r f} = \frac{Im\left[G_{yx}(f)\right]}{16.25 \Delta r f}$$

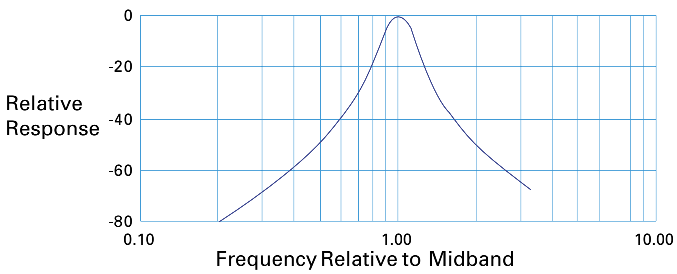
ρ_0 = fluid density = 1.293 kg/m^3 for air
Δr = microphone spacing (meters)
ff = requency

Acoustic Velocity

Medium	Approximate Velocity
Air (20 °C)	343 m/s
Aluminum	5150 m/s
Concrete	3600 m/s
Fresh water	1480 m/s
Glass	5300 m/s
Gypsum board	6800 m/s
Soft wood	3350 m/s
Steel	6000 m/s
Timber	4000 m/s

Wavelength = $\frac{\text{acoustic velocity frequency}}{\text{frequency}}$

1/3-Octave Filter Shape
ANSI S1.11-1986 Order 3



$$Ad = 10\log\left(1 = \left(4.5222944\left(f/f_{mid} - f_{mid}/f\right)\right)^6\right)$$

for Order 3, Type 1 — D 1/3 — Octave Filter,

where A_d = *nominal attenuation at frequency* f

f_{mid} = *exact frequency of* $1/3$ — *Octave Filter*

$$f_{mid} = (1000)\ 2^{(band\,\# - 30)/3}$$

Acoustics

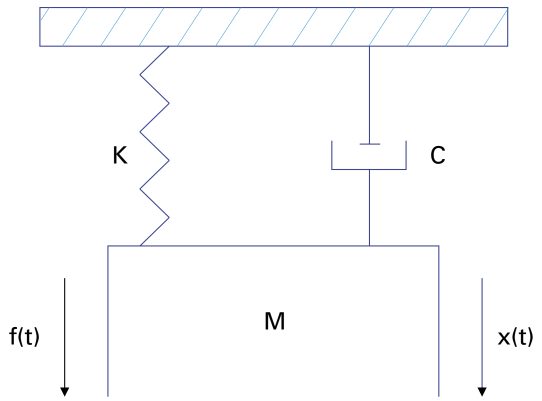
1/3 Octave Center Frequencies (ANSI S1.6 — 1984)			
Band No.	Nominal Center (Hz)	Exact Center (Hz)	Octave Center (Hz)
1	1.25	1.26	
2	1.6	1.58	
3	2	2	2
4	2.5	2.51	
5	3.15	3.16	
6	4	3.98	4
7	5	5.01	
8	6.3	6.31	
9	8	7.94	8
10	10	10	
11	12.5	12.59	
12	16	15.85	16
13	20	19.95	
14	25	25.12	
15	31.5	31.62	31.5
16	40	39.81	
17	50	50.12	
18	63	63.1	63
19	80	79.43	
20	100	100	
21	125	125.89	125
22	160	158.49	

1/3 Octave Center Frequencies (ANSI S1.6 — 1984)			
Band No.	Nominal Center (Hz)	Exact Center (Hz)	Octave Center (Hz)
23	200	199.53	
24	250	251.19	250
25	315	316.23	
26	400	398.11	
27	500	501.19	500
28	630	630.96	
29	800	794.33	
30	1,000	1,000.00	1,000
31	1,250	1,258.90	
32	1,600	1,584.90	
33	2,000	1,995.30	2,000
34	2,500	2,511.90	
35	3,150	3,162.30	
36	4,000	3,981.10	4,000
37	5,000	5,011.90	
38	6,300	6,309.60	
39	8,000	7,943.30	8,000
40	10,000	10,000.00	
41	12,500	12,589.30	
42	16,000	15,848.90	16,000
43	20,000	19,952.60	

Signal Analysis Reference

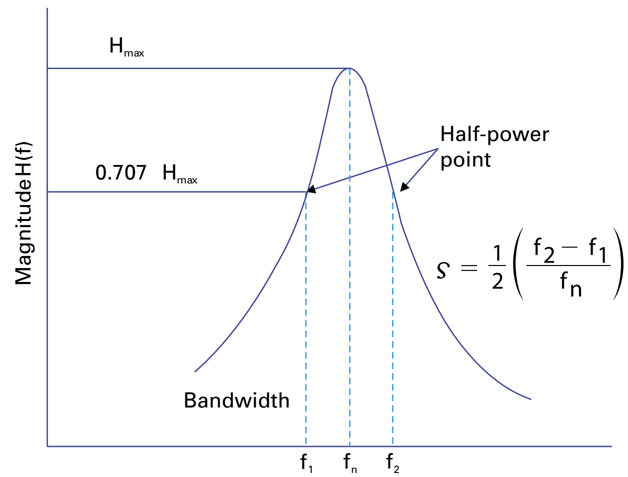
Modal Analysis

Fundamentals[7]



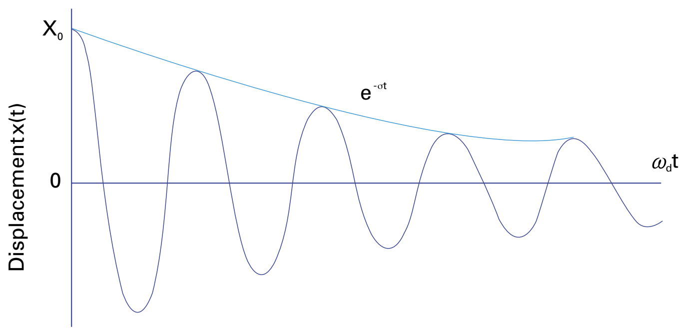
Quantity	*Units*	*Symbol*	*Formula*
natural circular frequency	rad/sec	ω_n	$\sqrt{K/M}$
natural circular frequency	rad/sec	ω_d	$\sqrt{1-\varsigma^2}\,\omega_n$
damping factor	–	ς	$\frac{C}{\sqrt{2\,KM}}$
period	$sec/cycle$	T	$1/f$
frequency	$cycles/sec$	f	$1/T = \omega/(2\pi)$

Damping Factor



Underdamped Oscillatory Motion $<\varsigma$

Impulse Response



Signal Analysis Reference

Rotating Machinery Vibration

Summary Troubleshooting Chart For Machinery Vibration

Frequency	Possible Cause
1 x running speed	Imbalance
	Misalignment
	Bent shaft
	Looseness
	Resonance
	Electrical
2 x running speed	Misalignment
	Bent shaft
Harmonics of running speed	Looseness
	Rubs
Subharmonics of running speed	Oil whirl
	Bearing cage
Non-integer multiples of running speed	RE bearings
	Gears
	Belts
	Blades/vanes
Powerline harmonics	Electrical

Blades and Vanes

Missing or cracked blades produce imbalance at running speed and harmonics around blade passing frequency (number of blades x running speed).

Electrical

Stationary defects (e.g., shorted stator) produce vibration at 2x power line. Rotating defects (e.g., broken rotor bar) produce 2x slip frequency sidebands around running speed. Components at running speed times the number of poles are normal in induction motors.

Gears

Gear defects produce large components at gear mesh frequency (number of teeth x gear running speed), although these components are present to some degree in normal operation. Sidebands around gear mesh frequency will usually appear at the running speed of the bad gear.

Imbalance

Characterized by a large component at running speed, although severe cases can result in harmonics. Also, steady phase that follows at transducer location (rigid rotors). Load variation, material buildup, and pump cavitation result in similar symptoms.

Misalignment

Characterized by large 2x running speed component and high levels of axial vibration.

Oil Whirl

A fault with fluid film bearings which typically appears at 0.43 to 0.48 times running speed.

Rolling Element Bearings

RE bearing defects produce frequency components determined by the formulas below. Inner and outer race defect frequencies can be approximated as 60% and 40% of the number of balls times running speed, respectively.

Defect	*Formula*
Outer race (BPFO)	$f = \frac{n}{2}\left(\frac{RPM}{60}\right)\left(1 - \frac{Bd}{Pd}\cos\varnothing\right)$
Inner race (BPFI)	$f = \frac{n}{2}\left(\frac{RPM}{60}\right)\left(1 + \frac{Bd}{Pd}\cos\varnothing\right)$
Ball defect (Ball Spin)	$f = \left(\frac{Pd}{2Bd}\right)\left(\frac{RPM}{60}\right)\left(1 - \left(\frac{Bd}{Pd}\right)^2\cos^2\varnothing\right)$
Fundamental train	$f = \frac{1}{2}\left(\frac{RPM}{60}\right)\left(1 - \frac{Bd}{Pd}\cos\varnothing\right)$

Where
Pd = Pitch diameter n = Number of balls
Bd = Ball diameter ϕ = Contact angle

The frequency components above will typically be accompanied by their harmonics and by running speed sidebands.

Parameter Conversion

It is often useful to convert accelerometer measurements to velocity or displacement. These conversions involve dividing by frequency or frequency squared, a common math function provided by most DSAs. A units conversion factor is sometimes also required. (For magnitude conversions in the formulas below, $j\omega = 2\pi * f$.)

Acceleration to Velocity(9)

To convert from	To	Multiply by
ft/s^2 rms	ft/s rms	$1/j\omega$
ft/s^2 rms	in/s rms	$12/j\omega$
ft/s^2 rms	in/s peak	$16.97/j\omega$
g rms	in/s rms	$386/j\omega$
g rms	in/s peak	$545.8/j\omega$
m/s^2 rms	mm/s rms	$1000/j\omega$
m/s^2 rms	mm/s peak	$1414/j\omega$
g rms	mm/s rms	$9806/j\omega$
g rms	mm/s peak	$13865.7/j\omega$

Signal Analysis Reference

Rotating Machinery Vibration

Acceleration to Displacement[9]

To convert from	To	Multiply by
ft/s² rms	in rms	$12/(j\omega)^2$
ft/s² rms	in p-p	$33.9/(j\omega)^2$
ft/s² rms	mil p-p	$33.9\ E{+}03/(j\omega)^2$
g rms	in rms	$386/(j\omega)^2$
g rms	in p-p	$1091.6/(j\omega)^2$
g rms	mil p-p	$1091.6\ E{+}03/(j\omega)^2$
m/s² rms	mm rms	$1000/(j\omega)^2$
m/s² rms	mm p-p	$2828/(j\omega)^2$
m/s² rms	micron p-p	$2828\ E{+}03/(j\omega)^2$

(9) Note that these factors apply to linear math operations on linear spectra, and should be squared for power spectra.

Glossary

Absorption coefficient. Fraction of incident sound energy absorbed or otherwise not reflected by a surface.

Acceleration. A vector quantity that specifies the time rate of change of velocity.

Accelerometer. A transducer whose output is directly proportional to acceleration. Typically uses piezoelectric crystals to produce output.

Aliasing. A phenomenon which can occur whenever a signal is not sampled at greater than twice the maximum frequency component. Causes high frequency signals to appear as low frequency components. Avoided by filtering out signals greater than 1/2 the sample rate.

Amplitude. The maximum value of a sinusoidal quantity.

Anechoic room. A room with highly absorbent walls that simulates a free field.

Angular frequency. Frequency multiplied by 2π (units of radians/second).

Angular mechanical impedance.* Impedance involving the ratio of torque to angular velocity. (See Impedance.)

Anti-aliasing filter. A low-pass filter designed to filter out frequencies greater than 1/2 the sample rate (typically 1/2.56 to allow for filter rolloff).

Anti-friction bearing. See "Rolling element bearing."

Antiresonance. For a system in forced oscillation, antiresonance exists at a point when any change, however small, in the frequency of the excitation causes an increase in the response at this point.

Asynchronous. For rotating machinery, frequency components not related to rotating speed.

Auto (power) spectrum. Defined as the Fourier transform of the input, times its complex conjugate. A spectrum whose magnitude represent power, and which has no phase.

Autocorrelation function.* The average of the product of the value of the signal at time t with the value at time $\tau+\beta$.

Averaging. In a DSA, digitally averaging several measurements to improve accuracy or S/N ratio, or to hold peak values.

Axial. For a rotating machine, the direction parallel to the shaft.

BPFO,BPFI. Ball pass outer and inner defect frequencies.

Balancing. A procedure for adjusting the radial mass distribution of a machine rotor so that the mass centerline approaches the rotor geometric centerline.

Glossary

Band-pass filter. A filter with a single transmission band extending from non-zero lower cutoff to finite upper cutoff frequencies.

Bandwidth. The spacing between frequencies at which a bandpass filter attenuates the signal by 3 dB.

Baseline spectrum. For rotating machinery, a vibration spectrum taken when a machine is new or in good working order; used as a reference for later analysis.

Bearing preload. The dimensionless quantity that is typically expressed as a number between zero and one, where a preload of zero indicates no bearing load upon the shaft, and one indicates the maximum preload.

Beats. Periodic variations that result from the superposition of two simple harmonic quantities of different frequencies f1 and f2. They involve the periodic increase and decrease of amplitude at the beat frequency (f1-f2).

Bias error. Low amplitude or incorrect phase reading that results from insufficient frequency resolution.

Blade passing frequency. For bladed machinery, the number of blades times shaft rotating speed.

Block size. The number of samples used in a DSA to compute the FFT (typically a power of 2, such as 2048 or 4096).

Bode Diagram. A plot of log gain and phase vs log frequency for a transfer function. For rotating machinery, a plot of linear 1x component amplitude and phase vs linear running speed.

Burst chirp. DSA swept-sine stimulus gated for completion within the time record. Used to obtain leakage-free measurements.

Burst random. DSA random noise stimulus gated for completion within the time record. Used to obtain leakage-free measurements.

Campbell diagram. A mathematically derived diagram used to check for coincidence of vibration sources (e.g., 1x imbalance) with rotor natural frequencies.

Cascade plot. See "Spectral map."

Cavitation. A condition in liquid handling machinery where low inlet pressure pockets lead to vaporization of the fluid.

Center frequency. For a bandpass filter, the center of the transmission band. For a DSA, the center of the measurement frequency span.

Charge amplifier. Amplifier used to convert accelerometer output impedance from high to low, reducing effects of cable capacitance on calibration. (Not required with IEPE accelerometer.)

Chirp. Sine sweep with duration matched to time record length. May be burst (gated) to allow response to decay to zero within the time record to reduce leakage.

Coherence function. Ratio of coherent output power to total output power.

Complex function. A function having real and imaginary components.

Compliance. The reciprocal of stiffness.

Constant bandwidth filter. Band-pass filter with bandwidth independent of center frequency (e.g., DSA filters).

Constant percentage bandwidth filter. Band-pass filter with bandwidth proportional to center frequency (e.g., 1/3-octave filters).

Correlation function. The average value of the product of two time functions.

Coulomb damping (dry friction damping). The dissipation of energy that occurs when a particle in a vibrating system is resisted by a force whose magnitude is a constant independent of displacement and velocity, and whose direction is opposite to the direction of the velocity of the particle.

Coupled modes. Modes of vibration which influence each other because of energy transfer between the modes.

Critical damping. The minimum viscous damping that will allow a displaced system to just return to its initial position without oscillation.

Critical machinery. Machines which are critical to a major part of the plant process.

Critical speed. Speed of a rotating system that corresponds to a resonant frequency of the system.

Critical speed map. A rectangular plot of bearing or support stiffness vs system natural frequency.

Cross-axis sensitivity. A measure of the off-axis response of velocity and acceleration transducers.

Damped natural frequency. The frequency at which a damped linear system will vibrate after a stimulus has been applied and removed.

Damping. The dissipation of energy with time or distance.

Damping ratio. See "Fraction of critical damping."

Decibel. A logarithmic representation of a ratio, expressed as 10 or 20 times the log of the ratio.

Signal Analysis Reference

Glossary

Degrees of freedom. The number of variables required to completely describe the state of a vibrating system.

Differentiation. In a DSA, multiplying the frequency spectrum by jw is equivalent to differentiating the corresponding time waveform.

Diffuse field.* A field in which the time average of the mean-square sound pressure is everywhere the same and the flow of energy in all directions is equally probable.

Digital filter. A filter which acts on data after it has been sampled and digitized. Used in DSAs for alias protection and zoom after internal resampling.

Displacement.* A vector quantity that specifies the change in position of a particle or body, and is usually measured from the mean or rest position.

Distortion.* An undesired change in waveform.

Driving point impedance.* The driving point impedance at a driving point of a transducer is the impedance based on the ratio of the applied sinusoidal potential difference, force, or pressure and the resultant current, velocity, or volume velocity, respectively, at this point. The output termination must be specified.

Dynamic range. The ratio of the largest to the smallest signals that can be measured at the same time. Typically expressed in dB.

Dynamic Signal Analyzer (DSA). Analyzer that uses digital signal processing and the FFT to produce frequency spectra and time histories.

Eccentricity. For a rotating machine shaft, the variation of the outer diameter of the surface relative to the true geometric centerline.

Eccentricity ratio. The vector difference between the bearing centerline and the average steady-state journal centerline.

Eddy current probe. Used to measure displacement in rotating machinery. An electric “eddy” current is generated on the surface of the shaft by the probe. The back EMF seen by the probe is modulated by the distance between the probe and the shaft, providing a signal whose modulation envelope is proportional to displacement.

Electrical runout. An error signal that occurs in eddy current displacementmeasurements when shaft surface conductivity varies.

Engineering units. With a DSA, refers to units that are calibrated by the user (e.g., g’s).

External sampling. Control of DSA sample rate with an external signal, typically a multiplied tachometer pulse. Normalizes the frequency axis to running speed, resulting in a stationary display with changing speed.

Fast Fourier Transform (FFT). Algorithm used in computers and DSAs to compute discrete frequency components from sampled time data.

Filter. Electronic circuit designed to pass or reject a specific frequency band.

Flat top window. DSA window function that provides the highest amplitude accuracy.

Flexible rotor. A rotor which operates close enough to (or beyond) its first bending mode for dynamic effects to influence rotor deformations.

Fluid-film bearing. A bearing which supports the shaft on a thin film of oil. The fluid film may be generated by journal rotation (hydrodynamic bearing), or by externally applied pressure (hydrostatic bearing).

Forced vibration. The oscillation of a system is forced if the response is imposed by the excitation. If the excitation is periodic and continuing, the oscillation is steady-state.

Fraction of critical damping. The ratio of the actual damping coefficient to the critical damping coefficient.

Free field. A field is a homogeneous, isotropic medium, free from boundaries. In practice it is a field in which the effects of theboundaries are negligible over the region of interest.

Free vibration. Vibration that occurs in the absence of forced vibration.

Fundamental mode of vibration.* The mode with the lowest natural frequency.

Gear mesh frequency. Computed as the number of teeth times running speed of the gear.

Hann window. DSA window function used to measue random noise.

Harmonic. A sinusoidal quantity that is an integral multiple of the frequency of a periodic quantity to which it is related.

Heavy spot. The angular location of the imbalance vector at a specific lateral location on a machine shaft.

High spot. Angular location on a machine shaft directly under the vibration transducer at the point of closest proximity. Can move with changes in shaft dynamics (e.g., with speed).

Glossary

High-pass filter. Filter with a transmission band starting at a lower cutoff frequency and extending to (theoretically) infinite frequency.

Hysteresis. Non-uniqueness in the relationship between two variables as a parameter increases or decreases. Also called deadBand.

IEPE accelerometer. Accelerometer with built-in signal conditioning electronics. Typically requires a 4 to 20 mA current source for power. (IEPE=integrated electronic piezoelectric)

Imbalance. Unequal radial weight distribution on a rotor system; shaft condition such that mass and shaft centerlines do not coincide.

Impact test. Response test where the broad frequency range produced by an impact is used as the stimulus.

Impedance. An impedance is the ratio of two complex quantities whose arguments increase linearly with time and whose real (or imaginary) parts represent a force-like and velocity-like quantity, respectively.

Influence coefficients. For rotating machinery, coefficients that describe the influence of system loading on system deflection. Insertion loss. Loss in dB that results from the insertion of an element in a network.

Integration. In a DSA, dividing the frequency spectrum by jw is equivalentto integrating the corresponding time waveform.

Jerk. Vector that describes the time rate of change of acceleration.

Journal. Specific portions of machine shaft surface from which rotor applied loads are transmitted to bearing supports.

Keyphasor. Trigger signal used in rotating machinery measurements, generated by a transducer observing a once-per-revolution event. (Keyphasor is a Bently, Nevada Co., USA trade name.)

Lateral vibration. Radial vibration.

Leakage. In DSAs, a result of finite time record length that leads to smearing of frequency components. Its effects are greatly reduced by selecting the correct window function.

Linear averaging. In a DSA, an average of linear spectra. The frequency domain equivalent of time averaging.

Linear resolution. See "Constant bandwidth filter."

Linear system. A system in which the response of each element is proportional to the excitation.

Lines. Term used to describe the analysis filters of a DSA (e.g., "400-line" analyzer).

Logarithmic decrement.* The natural log of the ratio of any two successive amplitudes of like sign, in the decay of a single-frequency oscillation.

Logarithmic resolution. See "Constant percentage bandwidth filter."

Longitudinal wave. Wave in which the direction of displacement at each point of the medium is normal to the wave front.

Low-pass filter. Filter whose transmission band runs from dc to an upper cutoff frequency. Mil. 1/1000th of an inch.

Mechanical impedance.* The impedance obtained from the ratio of force to velocity during simple harmonic motion.

Mechanical shock. Occurs when the position of a system is significantly changed in a relatively short time in a nonperiodic manner. It is characterized by suddenness and large displacements, and develops significant internal forces in the system.

Micron. One millionth of a meter.

Mobility. The reciprocal of impedance.

Mode of vibration. A characteristic pattern assumed by a vibrating system in which the motion of every particle is a simple harmonic with the same frequency. Two or more modes may exist concurrently in a multiple-degree-of-freedom system.

Modulation. The variation in the value of some parameter characterizing a periodic oscillation.

Narrowband random vibration. Random vibration having frequency components limited to a narrow band.

Natural frequency. The frequency of free vibration of a system. For a multiple degree-of-freedom system, the natural frequencies are the frequencies of the normal modes of vibration.

Nonlinear damping. Damping due to a damping force that is not proportional to velocity.

Normal mode of vibration. A mode of free vibration of the system. In general, any composite motion of the system is analyzable into a summation of its normal modes.

Nyquist criterion. Requirement that a sampled data system sample at greater than twice the highest frequency to be measured.

Octave. The interval between two frequencies with a ratio of 2 to 1.

Signal Analysis Reference

Glossary

Oil whip. Occurs when oil whirl frequency coincides with a shaft natural frequency.

Oil whirl. Unstable free vibration whereby a fluid-film bearing has insufficient unit loading. Shaft motion is usually circular in the direction of shaft rotation, at a rate of 40-49% of shaft speed.

Orders. Harmonics of the running speed of a rotating machine. Pseudo-random noise. A DSA stimulus whose period is matched to time record length, thus eliminating

Phon. The loudness level of a sound, numerically equal to the sound pressure level of a 1 kHz free progressive wave judged by listeners to be equally loud.

Piezoelectricity. Property exhibited by some asymmetrical crystalline materials which when subjected to strain in suitable directions develop electric polarization proportional to the strain.

Pink noise. Noise whose spectral density is inversely proportional to frequency.

Power spectral density. Mean-square value per unit bandwidth.

Quality factor (Q). A measure of the sharpness of resonance or frequency selectivity of a resonant vibratory system having a single degree of freedom. In a mechanical system, equal to 1/2 the reciprocal of the damping ratio.

Radial vibration. In a machine, vibration perpendicular to the shaft centerline.

Real time rate. For a DSA, the broadest frequency span at which data collection is continuous. Limited by FFT computation time.

Rectangular window. See Uniform window.

Relaxation time. Time taken by an exponentially decaying quantity to decrease in amplitude by a factor of 1/e=0.3679.

Resonance. Resonance of a system in forced vibration exists when any change, however small, in frequency causes a decrease in the response of the system.

Rigid rotor. A rotor which operates substantially below its first bending critical speed.

Rise time. Usually defined as the time for a step response to rise from 10% to 90% of its steady state value.

Rolling element bearing. Bearing whose low friction qualities derive from rolling elements (balls or rollers) with little lubrication.

Root mean square (rms). Square root of the arithmetic average of a set of squared instantaneous values.

Runout compensation. Electronic correction of a transducer output signal for the error resulting from slow roll runout.

S/N ratio. Signal-to-noise ratio.

Sabin. Sound absorption quality of a surface in terms of square meters of perfectly absorptive surface.

Self-induced vibration. Vibration resulting from conversion, within the system, of non-oscillatory excitation to oscillatory excitation.

Shake table. A device for subjecting a mechanical system to controlled and reproducible mechanical vibration. Shape factor. The ratio of 60 dB to 3 dB bandwidths of a filter.

Shear wave. A wave in an elastic medium which causes an element of the medium to change its shape without a change of volume.

Shock spectrum. A plot of the maximum acceleration experienced by a single-degree-of-freedom system as a function of its own natural frequency in response to an applied shock.

Signature. Term usually applied to the vibration frequency spectrum which is distinctive and special to a machine or component, system or subsystem at a specific point in time, under specific machine operating conditions, etc. Used for historical comparison of mechanical condition over the operating life of the machine.

Simple harmonic motion. Motion such that the displacement is a sinusoidal function of time.

Slow roll speed. Low rotating speed at which dynamic motion effects from forces such as imbalance are negligible.

Sone. A unit of loudness. The ratio of loudness to that of a 1 kHz tone 40 dB above a listener's threshold.

Sound intensity. The average rate of sound energy transmitted in the specified direction through a unit area normal to this direction at the point considered.

Sound power of a source. The total sound energy radiated by the source per unit time.

Sound pressure. The total instantaneous pressure in the presence of a sound wave minus the static pressure.

Spectral map. A three-dimensional plot of frequency spectra vs another variable (usually time or machine speed).

Standing wave. A periodic wave having a fixed distribution in space which is the result of interference of progressive waves of the same frequency and kind.

Glossary

Stiffness. The ratio of change of force (or torque) to the corresponding change in translational (or rotational) deflection of an elastic element.

Subharmonic. A sinusoidal quantity having a frequency that is an integral submultiple of the fundamental frequency of a periodic quantity to which it is related.

Time averaging. In a DSA, averaging of time records that results in reduction of the level of asynchronous components.

Time record. In a DSA, the block of time data that is converted to the frequency domain by the FFT (typically a power of 2, such as 2048 or 4096).

Torsional vibration. Amplitude modulation of torque measured in degrees peak-to-peak referenced to the axis of shaft rotation.

Transfer impedance. The impedance involving the ratio of force to velocity when force is measured at one point and velocity at the other (or at the same point in different directions).

Transient vibration. Temporarily sustained vibration of a mechanical system.

Transmissibility. The nondimensional ratio of the response amplitude of a system in steady-state forced vibration to the excitation amplitude.

Transverse wave. Wave in which the direction of displacement is parallel to the wave front.

Uniform window. DSA window function with uniform weighting.

Viscous damping. The dissipation of energy that occurs when a particle in a vibrating system is resisted by a force that has a magnitude proportional to the magnitude of the velocity of the particle and direction opposite to the direction of the particle. White noise. Noise whose spectral density is independent of frequency. Not necessarily random.