Mobius Institute Board of Certification
Category IV Exam Reference Equations

Vibration unit conversions [English]

$$mils_{pk-pk} = \frac{19098\ in/s_{pk}}{f_{cpm}}$$

$$in/s_{pk} = \frac{5217\ G_{rms}}{f_{cpm}}$$

$$mils_{pk-pk} = \frac{9.958x10^7 G_{rms}}{f_{cpm}^2}$$

$$G_{rms} = \frac{f_{cpm}\ in/s_{pk}}{5217}$$

$$in/s_{pk} = \frac{f_{cpm}\ mils_{pk-pk}}{19098}$$

$$G_{rms} = \frac{f_{cpm}^2\ mils_{pk}}{9.958x10^7}$$

Vibration unit conversions [Metric]

$$\mu m_{pk-pk} = \frac{27009\ mm/s_{rms}}{f_{cpm}}$$

$$mm/s_{rms} = \frac{93712\ G_{rms}}{f_{cpm}}$$

$$\mu m_{pk-pk} = \frac{2.53x10^9 G_{rms}}{f_{cpm}^2}$$

$$G_{rms} = \frac{f_{cpm}\ mm/s_{rms}}{93712}$$

$$mm/s_{rms} = \frac{f_{cpm}\ \mu m_{pk-pk}}{27009}$$

$$G_{rms} = \frac{f_{cpm}^2\ \mu m_{pk-pk}}{2.53x10^9}$$

$$1\ G_{rms} = 9.81 m/s^2{}_{rms}$$

$$f_{cpm} = 60\ f_{hz}$$

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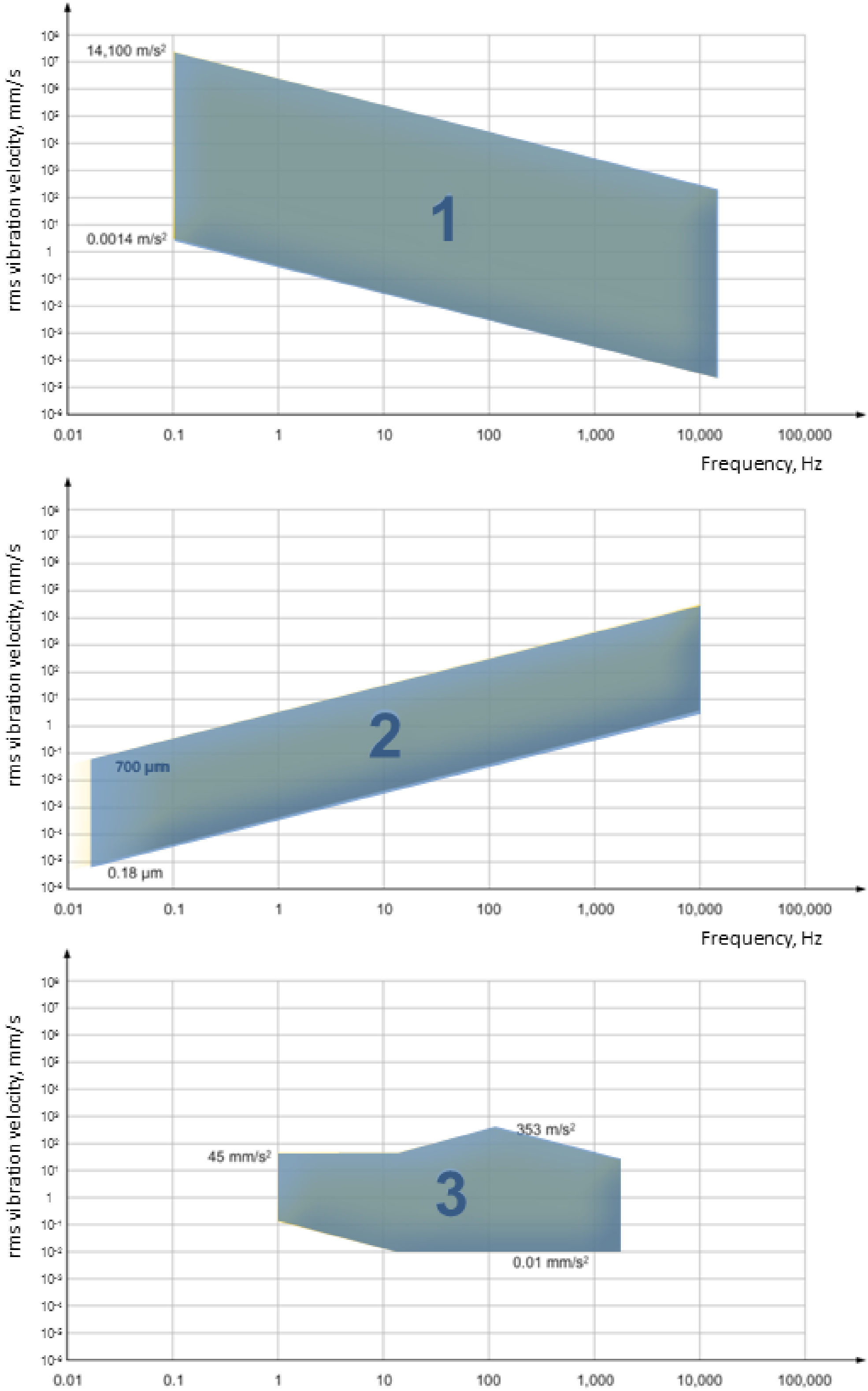
Transducer effective ranges:



1 Piezo-electric accelerometer
2 Eddy-current proximity probe
3 Electro-mechanical velocity transducer

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Unit conversions:

$$1\ oz = 28.3\ grams$$

$$1\ lb = 16\ oz$$

$$1\ N = 1\ kg\ \frac{m}{s^2}$$

$$1\ lb_f\ = 1lb_m x\ g = 386.1\ lb_m \frac{in}{s^2}$$

$$1\ lb_m\ = 1\frac{lb_f}{g} = 0.0026\ \frac{lb_m\ s^2}{in}$$

	newton	kilogram-force	pound-force
1 N	≡ 1 kg·m/s^2	≈ 0.10197 kp	≈ 0.22481 lb_F
1 kp	= 9.80665 N	≡ g_n·(1 kg)	≈ 2.2046 lb_F
1 lb_F	≈ 4.448222 N	≈ 0.45359 kp	≡ g_n·(1 lb_m)

$$1\ g = 386.1\frac{in}{s^2} = 9.81\frac{m}{s^2}$$

$$1\ in = 25.4\ mm$$

Vectors:

$$V_{add_x} = A\cos\alpha + B\cos\beta$$

$$V_{add_y} = A\sin\alpha + B\sin\beta$$

$$V_{add} = \sqrt{\left(V_{add_x}\right)^2 + \left(V_{add_y}\right)^2}$$

$$\phi_{add} = \tan^{-1}\frac{V_{add_y}}{V_{add_x}}$$

dB:

$$dB = 20\log\left(\frac{V_m}{V_r}\right)$$

$$\frac{dB_{octave}}{dB_{decade}} = \frac{log(2)}{log(10)} = 0.3$$

$$\frac{V_m}{V_r} = 10^{\frac{dB}{20}}$$

Signal process and data acquisition:

$$T = T_s x N = \frac{N}{F_s} = \frac{N}{2.56 x F_{max}} = \frac{LOR}{F_{max}}$$

T = Time required to collect the waveform
T_s = Time between each sample
N = Number of samples (1024, 2048, 4096, etc.)
F_s = Sampling rate = Samples per second
LOR = Lines Of Resolution (400, 800, 1600, etc.)
F_{max} = Frequency range

$$Effective\ resolution = \frac{F_{max}\ x\ Window\ factor\ x\ 2}{LOR}$$

$Window\ factor$ = 1.0 uniform, 1.5 Hanning, 3.5 flat top window

$$T = \frac{\#\ revs}{Speed} = \frac{\#\ events}{Forcing\ frequency}$$

T = Desired measurement time
$\#\ revs$ = Number of shaft revolutions in time waveform
$Speed$ = Shaft speed
$\#\ events$ = Machine event e.g. tooth mesh
$Forcing\ frequency$ = Frequency of event (e.g. gearmesh frequency)

Unbalance force:

$$U = m.r$$

$$F = m.r.\omega^2 = \frac{w}{g}.r.\omega^2$$

$$F = M.e.\omega^2 = \frac{W}{g}.e.\omega^2$$

$$\omega = 2\pi f = 2\pi \frac{RPM}{60}$$

$$F_{lbf} = m_{gr}.r_{in}\left(\frac{RPM}{4000}\right)^2$$

$$F_{lbf} = m_{oz}.r_{in}\left(\frac{RPM}{750}\right)^2$$

$$F_{lbf} = m_{lb}.r_{in}\left(\frac{RPM}{188}\right)^2$$

U = Unbalance (oz-in, gr-in, gr-mm)
F = Force (lbf or N)
m = Mass of balance weight (lbm or kg)
w = Weight of balance weight (lbf or N)
r = Radius of weight (in or m)
ω = Speed of rotation rad/s
f = Frequency Hz
e = Eccentricity of rotor
M = Mass of rotor (lbm or kg)
W = Weight of rotor (lbf or N)
g = 386.1 in/sec^2 or 9.81 m/s^2

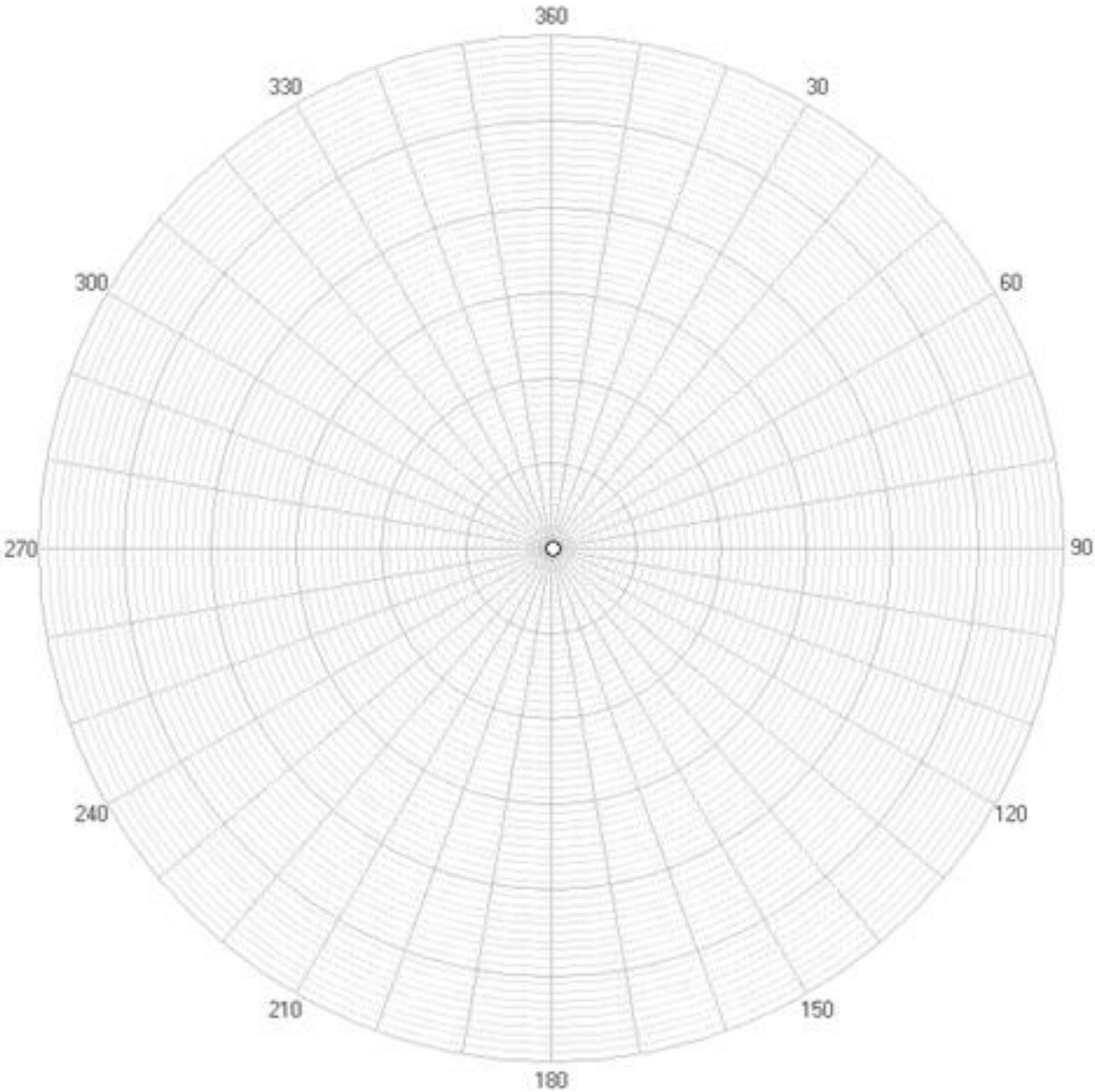
Calibration (trial) weights:

$$5\%\ cal.wt. = W_r\left(\frac{168}{RPM}\right)^2$$

$$10\%\ cal.wt. = W_r\left(\frac{238}{RPM}\right)^2$$

$$15\%\ cal.wt. = W_r\left(\frac{291}{RPM}\right)^2$$

W_r = Entire weight of rotor (lb)
cal. wt. = Calibration weight (oz-in)
RPM = Rated speed


360
30
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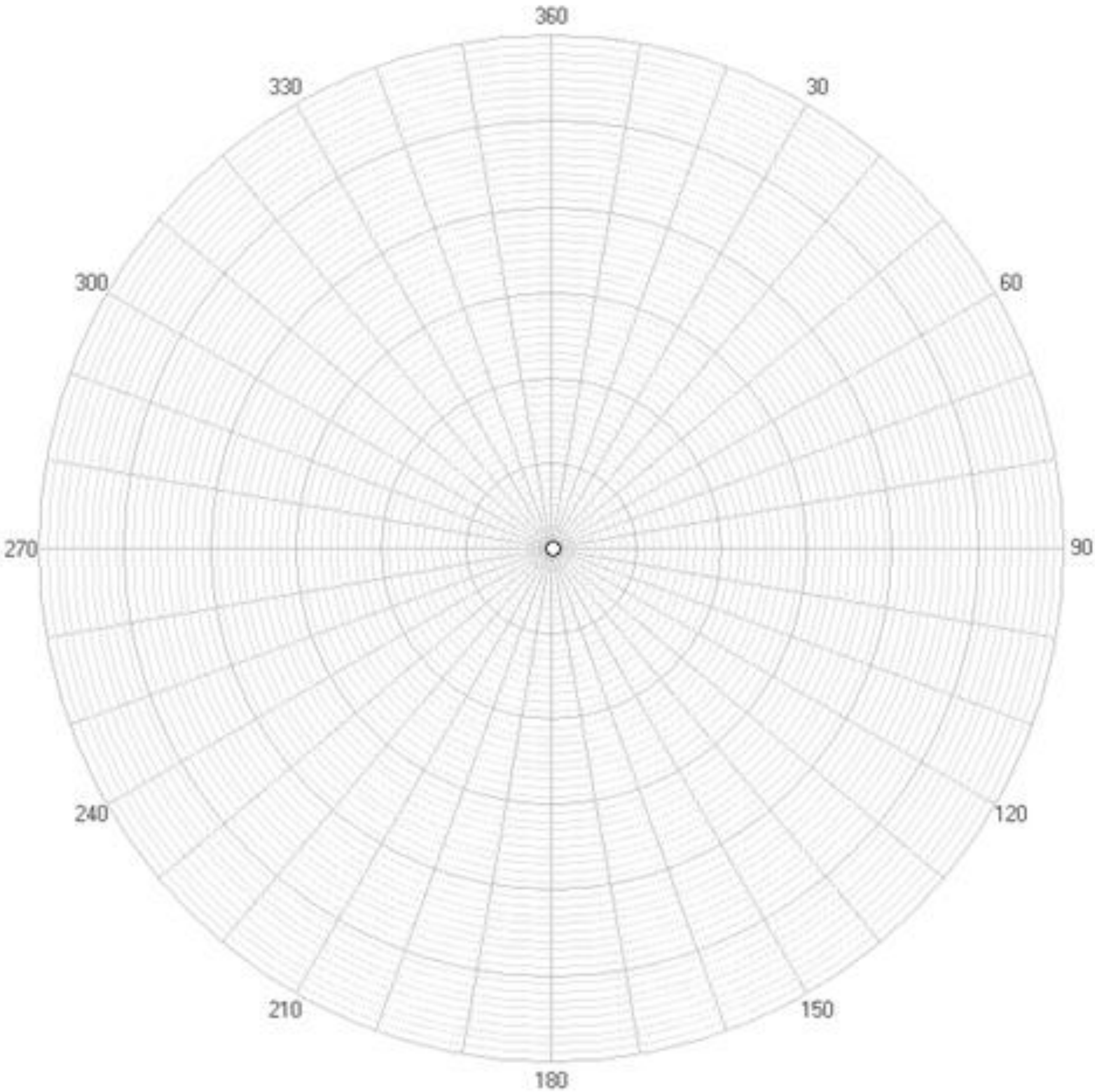

360
30
60
90
120
150
180
210
240
270
300
330

Force:

Spring force:

$$F = kx$$

Damping force:

$$F = c\dot{x}$$

Inertia force:

$$F = m\ddot{x}$$

F = Force (lbf or N)
k = Stiffness (lbf/in or N/m)
c = Damping (lbf sec/in or N sec/m)
m = Mass (lbm or kg)
x = Relative deflection (in or m)
$\dot{x}$ = Relative velocity (in/s or m/s)
$\ddot{x}$ = acceleration (in/sec^2 or m/sec^2)

$$1\ N = 1\ kg\ \frac{m}{s^2}$$

$$1\ lb_f = 1 lb_m x\ g = 386.1\ lb_m \frac{in}{s^2}$$

$$1\ lb_m = 1 \frac{lb_f}{g} x\ g = 0.0026\ \frac{lb_m\ s^2}{in}$$

Natural frequency:

$$\omega_n = \sqrt{\frac{k}{m}} = \sqrt{\frac{k\ g}{W}} = \sqrt{\frac{g}{\Delta}}$$

$$f_n = \frac{1}{2\pi}\omega_n$$

$$\zeta = \frac{C_v}{C_c}$$

$$C_c = 2m\omega_n$$

ω_n= Natural frequency
k = Stiffness (lbf/in or N/m)
m = Mass (lbm or kg)
W = Weight (lbf or N)
Δ = Deflection (in or m)
g = 386.1 in/sec^2 or 9.81 m/s^2
ζ = Damping ratio
C_v = Damping (lbf sec/in or N sec/m)
C_c = Critical damping

$$\omega_n = \sqrt{\frac{K_t}{J}}$$

K_t = Torsional spring stiffness (lbf-in/rad or N-m/rad)
J = Polar inertia (lbf-in-s^2 or N-m-s^2)

Stiffness:

$$k = \frac{W}{\Delta} = \frac{mg}{\Delta}$$

Series: $$\frac{1}{k_T} = \frac{1}{k_S} + \frac{1}{k_S}$$

Parallel: $$k_T = k_P + k_P$$

k_s = Springs in series (lbf/in or N/m)
k_p = Springs in parallel (lbf/in or N/m)
k_T = Total stiffness (lbf/in or N/m)

Unbalance response:

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

X = Rotor response (in or m)
ω_n= Natural frequency
ω = Shaft turning frequency
M = Mass of rotor (lbm or kg)
m = Unbalance mass (lbm or kg)
e = Eccentricity (radius) of mass

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

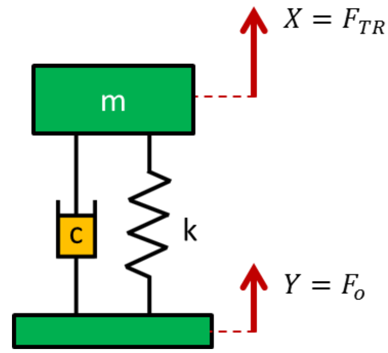
X = Rotor response (in or m)
ω_n= Natural frequency
ω = Shaft turning frequency
e = Eccentricity of rotor (in or m)

$$e = \frac{quality}{W} = \frac{oz\ in}{16W_{lbs}}$$

e = Eccentricity of rotor (in or m)
$quality$ = oz-in, gr-in, gr-mm
W = Weight of rotor
W_{lbs} = Weight of rotor (lbm)

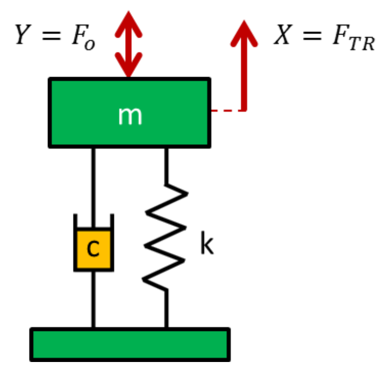
Transmissibility:

$$\frac{X}{Y} = \frac{F_{TR}}{F_o} = \frac{\sqrt{1 + \left[2\zeta \frac{\omega}{\omega_n}\right]^2}}{\sqrt{\left[1 - \left(\frac{\omega}{\omega_n}\right)^2\right]^2 + \left[2\zeta \frac{\omega}{\omega_n}\right]^2}}$$



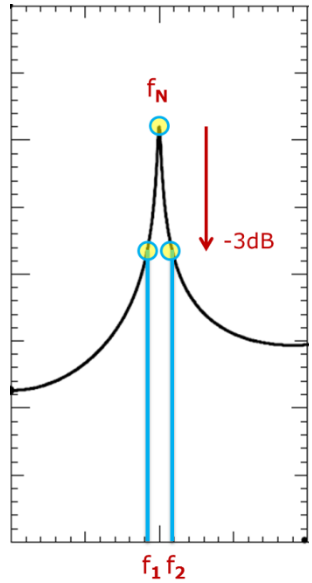
Force response:

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

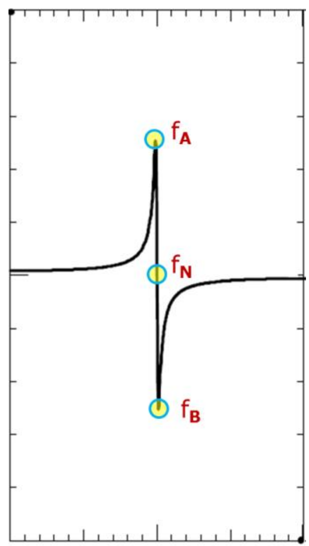


Amplification factor:

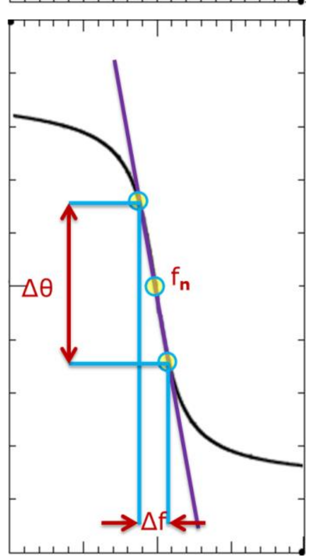
$$Q = \frac{f_N}{f_2 - f_1}$$



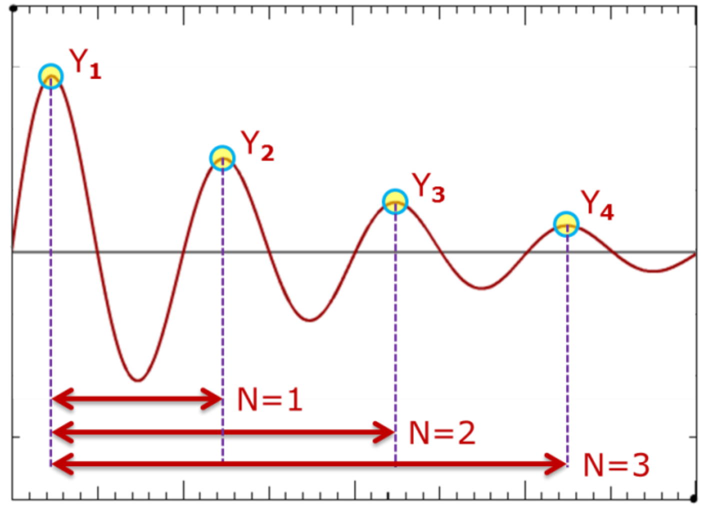
$$Q = \frac{{f_A}^2 + {f_B}^2}{{f_B}^2 - {f_A}^2}$$



$$Q = \frac{\pi\, f_n\, \Delta\theta}{360\, \Delta f}$$



Amplification factor:



$$\delta = \frac{1}{N} ln\left[\frac{Y_1}{Y_{N+1}}\right]$$

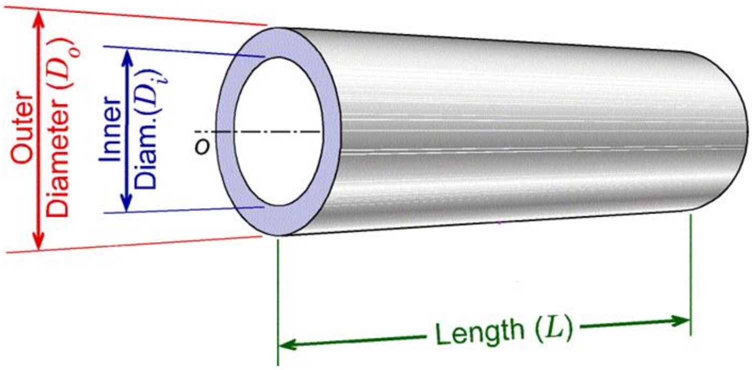
$$\zeta = \frac{1}{\sqrt{1+(\frac{2\pi}{\delta})^2}}$$

$$\zeta = \frac{\delta}{\sqrt{4\pi^2+\delta^2}}$$

$$\zeta = \frac{1}{2\,Q}$$

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

Polar inertia and stiffness:



$$W = \frac{\pi x L x \rho}{4}\left(D_o{}^2 - D_i{}^2\right)$$

W = Weight (lb)
L = Length (in)
ρ = Density (lb/in^3)
D_o = Outer diameter
D_i = Inner diameter

$$J_p = \frac{\pi x L x \rho}{32 x G}\left(D_o{}^4 - D_i{}^4\right)$$

J_p= Polar inertia (lb-in-s^2)

$$I_t = \frac{J_p}{2} + \frac{\pi x L^3 x \rho}{48 x G}\left(D_o{}^2 - D_i{}^2\right)$$

I_t= Transverse inertia (lb-in-s^2)

$$K_{ax} = \frac{\pi x E}{4 x L}\left(D_o{}^2 - D_i{}^2\right)$$

K_{ax} = Axial stiffness (lb/in)
E = Modulus of elasticity (lb/in^2)

$$K_{rad} = \frac{3 x \pi x E}{4 x L^3}\left(D_o{}^4 - D_i{}^4\right)$$

K_{rad} = Radial stiffness (lb/in)

$$K_{tor} = \frac{\pi x G_{shear}}{32 x L}\left(D_o{}^4 - D_i{}^4\right)$$

K_{tor} = Torsional stiff. (lb-in/rad)
G_{shear}= Shear modulus (lb/in^2)

Lift check multipliers for tilting pad bearings:

Load	3 Pad	4 Pad	5 Pad	6 Pad	7 Pad
LBP	0.667 x Lift	0.707 x Lift	0.894 x Lift	0.866 x Lift	0.948 x Lift
LOP	0.667 x Lift	Lift	0.894 x Lift	Lift	0.948 x Lift

LBP = Load Between Pads
LOP = Load On Pad

$$Bearing\ Diametric\ Clearance = Factor\ x\ Lift$$