ANTI-VIBRATION & SPRINGS

Anti-Vibration Mounts

Vibration Isolation

Vibration Isolation

Isolator Natural frequencies ***fn***

Undamped

$$fn = \frac{1}{2\pi}\sqrt{\frac{K}{M}}$$

Damped

$$fn = \frac{1}{2\pi}\sqrt{\frac{K\,(1-\zeta^2)}{M}}$$

ζ = Damping Ratio C/Cc

K = Spring Constant N/m

M = Supported Mass kg

For effective vibration isolation the isolator natural frequency ***fn*** should be less than 50% the lowest disturbing frequency ***fe***

Elastomeric rubber-metal isolators are used to prevent transmission of vibration from (active) or to (passive) supported equipment.

Rubber based anti vibration mounts offer good isolation of disturbing frequencies ***fe*** of 12Hz and above at reasonable cost.

To isolate frequencies below 12Hz low frequency isolators should be used.

Examples	**Natural Frequency *fn* Hz**	**Isolate above Disturbing Frequency *fe* Hz**
Air systems	1.5+	3+
Helical Coil spring systems	2.5+	5+
Compare Rubber Metal AV Mounts	6.0+	12+

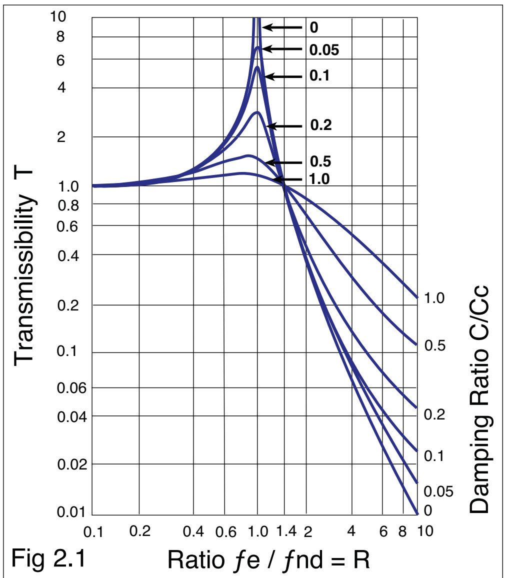

Fig 2.1

Vibration transmissibility

Vibration transmissibility **T** (i.e. % or fraction) of the vibration which the isolators transmit to the supported equipment (passive) or from the supported equipment (active) is calculated using the formula

$$\text{Transmissibility } T = \frac{1}{1-R^2}$$

Damped systems:

$$\text{Transmissibility } T = \sqrt{\frac{1+\frac{R^2}{Q^2}}{(1-R^2)^2+\frac{R^2}{Q^2}}}$$

$$R = \frac{fe}{fn} \qquad Q = \frac{1}{2\ C/Cc}$$

fe - disturbing frequency can be determined by measurement. The isolator natural frequency ***fnd*** is given by:

$$fnd = \frac{1}{2\pi}\sqrt{\frac{Ktd}{M}} \quad \text{Hz}$$

Ktd = Sum of Isolator Dynamic Spring Constants (K1+K2+K3...) N/m

M = Supported system mass kg

For natural rubber and coil spring isolators static and dynamic spring constants are the same.

Sources of vibration in rotating machines	
Source	**Disturbing Frequency fe Hz**
Primary out of balance	1 x rpm x 0.0167
Secondary out of balance	2 x rpm x 0.0167
Shaft misalignment	2 x rpm x 0.0167
Bent Shaft	1 & 2 x rpm x 0.0167
Gears(N=number of teeth)	N x rpm x 0.0167
Drive Belts (N=belt rpm)	N,2N,3N,4N x 0.0167
Aerodynamic or hydraulic forces	(N=blades on rotor) N x rpm x 0.0167
Electrical (N=synchronous frequency)	N x rpm x 0.0167

Significant problems occur when the disturbing frequency *fe* is near to or coincident with the natural frequency of the supporting structure (floor, foundation or subsoil).

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Damping Factor	frequency ratio R fe/fn							
C/Cc	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
0.05	20	66	80	87	91	93	94	95
0.10	19	64	79	85	89	91	93	94
0.15	17	62	76	83	87	90	91	93
0.20	16	59	74	81	85	87	89	91
0.30	12	52	67	75	80	83	85	87
	Percentage Isolation Efficiency							

Vibration Isolators Undamped

Force equation

$$M A + Kz = F(t)$$

M = Mass Kg
A = Acceleration m/s²
K = Spring Constant N/m
F = Applied force N
z = Deflection m
ω = $2\pi f$

			Units
Displacement response:	$Sr =$	$\frac{F}{K-M\omega^2}$	m
Velocity response:	$Vr =$	$\frac{F\omega}{K-M\omega^2}$	m/s
Acceleration response:	$Ar =$	$\frac{F\omega^2}{K-M\omega^2}$	m/s²
Force transmitted:	$Fr = KSr =$	$\frac{KF}{K-M\omega^2}$	N

Vibration Isolators with damping

Force equation

$$MA + CV + Kz = F(t)$$

Inertia force + damping force + spring force = applied force

M = Mass Kg
A = acceleration m/s²
V = Velocity m/s
C = Damping coefficient Ns/m
K = Spring Constant N/m
F = Applied force N
z = Deflection m
ζ = Damping ratio C/Cc
Cc = $2\sqrt{KM}$

Units

Displacement response: $Sr = \frac{F}{K\sqrt{(1+(2\zeta)^2)}}$ m

Velocity response: $Vr = \frac{F\sqrt{(K/M)*(1-\zeta^2)}}{K\sqrt{(1+(2\zeta)^2)}}$ m/s

Acceleration response: $Ar = \frac{F(1-\zeta^2)}{M\sqrt{(1+(2\zeta)^2)}}$ m/s²

Force transmitted: $Fr = KSr = \frac{F}{\sqrt{(1+(2\zeta)^2)}}$ N

Damping is expressed as a ratio C/Cc (ζ) which is a fractional measure of vibration energy absorbed by the isolator and not given back to the isolated equipment but dissipated into heat within the isolator.

Rubber metal anti vibration mountings are generally made using **NR** Natural Rubber which has low damping.

This is to

a) Provide efficient vibration isolation
b) Avoid excessive heat build up when isolating active vibration sources.

Where oil and other contamination is present the anti vibration mount must be designed so as to prevent the contaminants coming in contact with the rubber. Alternatively **NBR** (Nitrile) rubber isolators can be used, which have high oil and chemical resistance.

Phase lag (angle)

When a damped isolator is subject to an input vibration the reactive response lags behind the input which can be expressed as a phase lag (angle). The greater the phase lag, the greater the damping and dissipated energy.

Phase Lag between response and excitation is given by:

Phase lag (angle) $\varphi = \tan^{-1}(1/Q(\omega/\omega_0 - \omega_0/\omega))$

$$\omega_0 = \sqrt{\frac{K}{M}}$$

$$\omega = 2\pi fe$$

K = Isolator Spring Constant N/m
M = Supported Mass kg
fe = disturbing frequency Hz

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Damping is required where movement of the supported equipment
must be minimised especially at resonance. Damping is also required when shock is to be absorbed.

Isolators with	C/Cc	Product
No damping	0	Helical Springs
Low damping	0.01	NR Natural Rubbers
Moderate damping	0.05	CR Neoprene/ Chloroprene Rubbers
Good damping	0.1	NBR Nitrile Rubbers
High damping	0.2- 0.3	Helical spring with viscous damping

A = acceleration m/s^2
V = velocity m/s
D = displacement m
C = damping coefficient Ns/m
K = spring constant N/m
P = Peak vibration force N
f = frequency Hz

Relationships between vibration units

RMS = √ 2* (Peak)

$\omega = 2\pi f$

$A = \omega V$

$V = A/\omega = A/2\pi f$

$V = \omega D$

$D = V/\omega$

The above formula are valid for both vertical and horizontal vibrations.

Vertical Axis **Z**
Longitudinal Axis **Y**
Transverse Axis **X**

Distribution of Load on unsymmetrical supported mass

Total Load Lt

L.A	**Lt*((b-c)/b)*(d/a)**
L.B	**Lt*(c/b)*(d/a)**
L.C	**Lt*(c/b)*((a-d)/a)**
L.D	**Lt*((b-c)/b)*(((a-d)/a)**

It is important to aim for as near as possible the same static deflection for each isolator by selecting suitable sizes and stiffnesses to match loads at each point.

Static deflection at **A** mm = **L.A/K.A** etc.

K.A = Vertical Spring Constant of isolator at **A** N/mm
L.A = Static Load N at **A**

Vertical Natural Frequency

$$fnv = \frac{1}{2\pi}\sqrt{\frac{Kt*1000}{M}}$$

M= total equipment mass kg
K.T = K.A + K.B + K.C + K.D N/mm

When specifying Isolators it is important to ensure that the vertical and horizontal isolator natural frequencies are less than 50% of the lowest significant disturbing frequencies (determined by rotating speeds) or by measurement.

Natural frequencies and Coupled Modes

In most applications the vertical natural frequency of an isolation system is considered to be the most important. However the position of the isolators in relation to the equipment Centre of Gravity (C/g) should be taken into account.

Uncoupled Modes

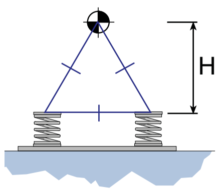
Isolators are in the same horizontal plane as the C/g. Vertical, horizontal and rotational modes are uncoupled.

Coupled Modes

Isolators below the C/g. The motion of the system is a combination of vertical, horizontal and rotational motion coupled with rocking about a lower or upper rocking centre.

Stability limit

The maximum distance H of isolators below the C/g is given by an equilateral triangle connecting isolators to each other and the C/g.



H = Maximum for stability

Determination of undamped Vertical Natural Frequency from static vertical deflection

$$fn = 15.76\sqrt{\frac{1}{\delta}}$$

δ = static deflection (mm)

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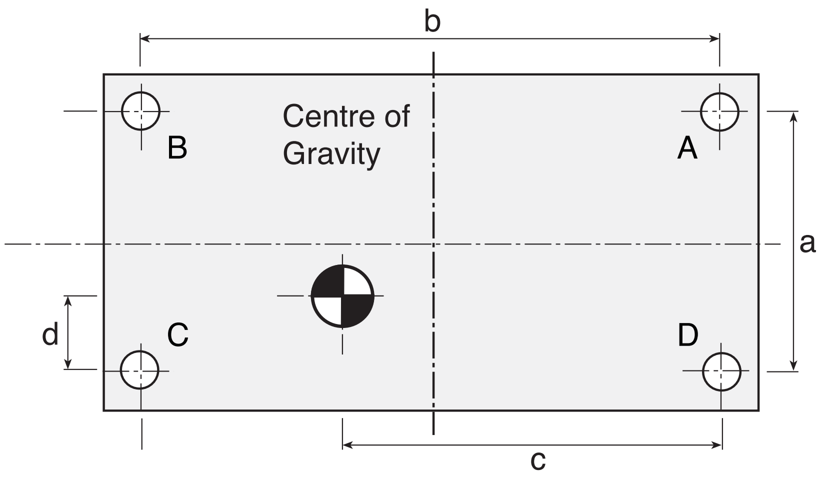
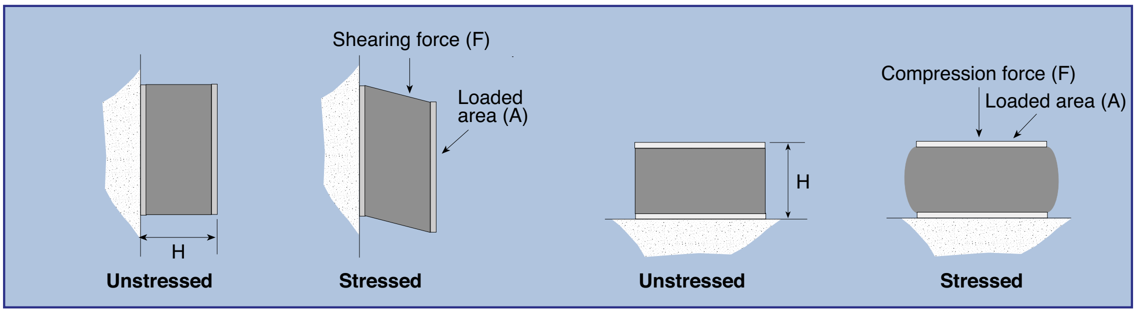


Rubber Metal Vibration Isolators



Features (NR Natural)

- Very high resilience
- Low damping for maximum vibration isolation efficiency.
- Very low creep.
- Low chemical and oil resistance

Typical Applications

- Low frequency anti vibration mountings
- Structural bearings

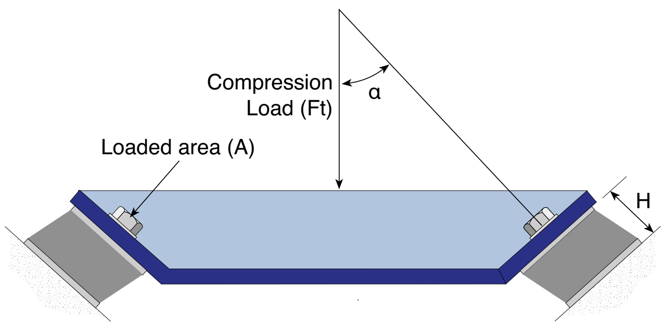
Optimium support design for Rubber Isolators

For maximum elastically supported stability, positioning rubber metal isolators at an angle to the vertical loads the rubber in a combination of shear and compression. Ideally the shear and compression deflection should be almost the same. To achieve this the angle should be 30°.

To calculate vertical deflection **δt** (mm):

$$\delta t = \frac{Ft*H}{2*A(G \sin^2\alpha + Ec \cos^2\alpha)}$$

G = Shear Modulus (N/mm²)
Ec = Compression Modulus (N/mm²)
H = Rubber height (mm)
A = Loaded rubber area (mm²)
Ft = Load (N)



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