

Vibration Isolation

Isolator Natural frequencies f_n

Undamped

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

Damped

$$f_n = \frac{1}{2\pi} \sqrt{\frac{K(1-\xi^2)}{M}}$$

ξ = Damping Ratio C/C_c

K = Spring Constant N/m

M = Supported Mass kg

For effective vibration isolation the isolator natural frequency f_n should be less than 50% the lowest disturbing frequency f_e

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

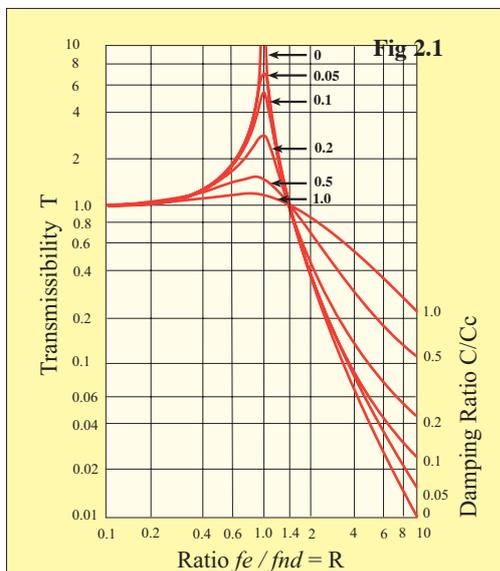
Rubber based anti vibration mounts offer good isolation of disturbing frequencies f_e of 12 Hz and above at reasonable cost.

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

Examples

Natural Frequency f_n Hz	Isolate above Disturbing Frequency f_e Hz
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Air systems	1.5+	3+
Helical Coil spring systems	2.5+	5+
Compare		
Rubber Metal AV Mounts	6.0+	12+



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:

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

$$R = \frac{f_e}{f_n} \quad Q = \frac{1}{2 C/C_c}$$

f_e - disturbing frequency can be determined by measurement. The isolator natural frequency f_n is given by:

$$f_n = \frac{1}{2\pi} \sqrt{\frac{K_{td}}{M}} \quad \text{Hz}$$

K_{td} = Sum of Isolator Dynamic Spring Constants ($K_1 + K_2 + K_3 \dots$) 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 f_e 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 f_e is near to or coincident with the natural frequency of the supporting structure (floor, foundation or subsoil).

Damping Factor C/Cc	frequency ratio R f_e/f_n							
	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

$$\omega = 2\pi f$$

			Units
Displacement response:	$S_r =$	$\frac{F}{K-M \omega^2}$	m
Velocity response	$V_r =$	$\frac{F \omega}{K-M \omega^2}$	m/s
Acceleration response	$A_r =$	$\frac{F \omega^2}{K-M \omega^2}$	m/s ²
Force transmitted	$F_r = K S_r =$	$\frac{K F}{K-M \omega^2}$	N

Vibration Isolators Damped

Force equation

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

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

$$C_c = 2\sqrt{KM}$$

			Units
Displacement response:	$S_r =$	$\frac{F}{K\sqrt{(1+(2\zeta)^2)}}$	m
Velocity response	$V_r =$	$\frac{F \sqrt{(K/M)*(1-\zeta^2)}}{K\sqrt{(1+(2\zeta)^2)}}$	m/s
Acceleration response	$A_r =$	$\frac{F(1-\zeta^2)}{M\sqrt{(1+(2\zeta)^2)}}$	m/s ²
Force transmitted	$F_r = K S_r =$	$\frac{F}{\sqrt{(1+(2\zeta)^2)}}$	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

- Provide efficient vibration isolation
- 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:

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

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

$$\omega = 2\pi f_e$$

K = Isolator Spring Constant N/m

M = Supported Mass kg

f_e = disturbing frequency Hz

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

Against receipt of full information free advice and proposals will be given for the use of all Farrat products.
A charge may be made where a detailed site survey is required involving vibration measurements.

Natural frequencies and Coupled Modes

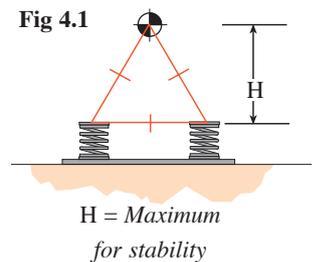
In most applications the vertical natural frequency of an isolation system is considered to be the most important. However the position of the isolators in relation to the equipment Centre of Gravity (C/g) should be taken into account.

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.



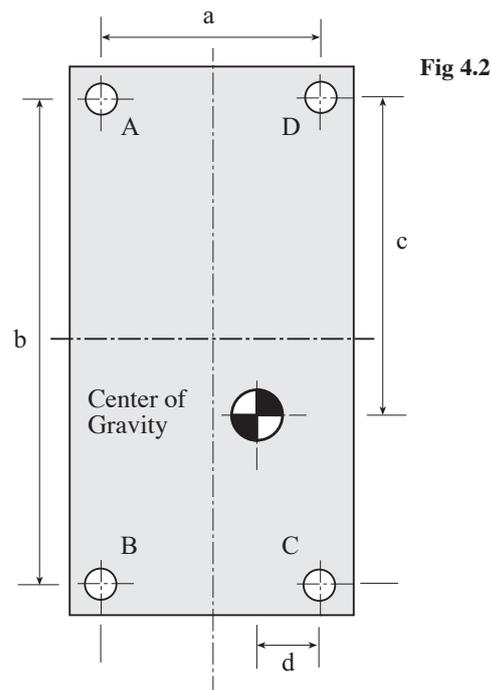
Stability limit

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.

Determination of undamped Vertical Natural Frequency from static vertical deflection

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

δ = static deflection (mm)



- A = acceleration m/s²
- 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 = $\sqrt{2}$ * (Peak)
- $\omega = 2\pi f$
- A = ωV
- V = $A/\omega = A/2\pi f$
- V = ωD
- D = V/ω

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.

Fig 4.1

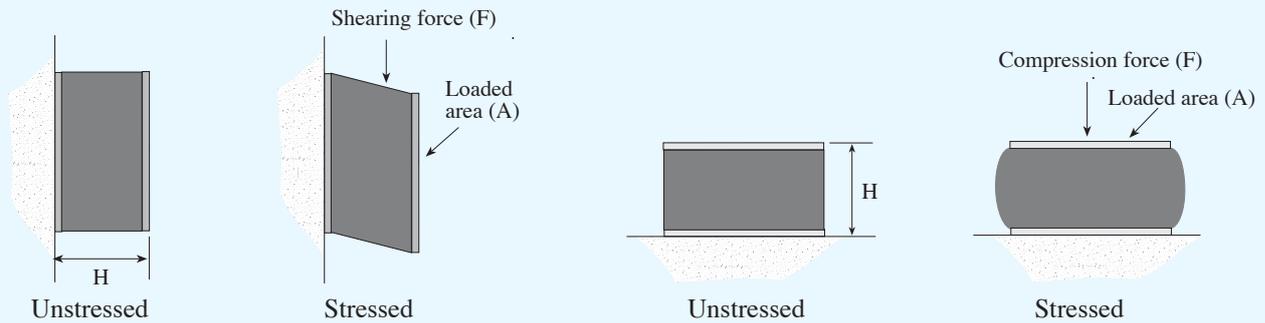


Fig 5.1

Unstressed

Stressed

Unstressed

Stressed

Rubber Metal Vibration Isolators

Rubber is produced in Natural, Synthetic or Thermoplastic forms

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

Synthetic rubbers

Synthetic rubbers come in many formulations depending on application requirements.

Commonly used for anti vibration mountings requiring damping and or good oil and chemical resistance.

NBR Nitrile.

Moderate resilience
Damping ratio $C/C_c = \xi = ca 0.10$
Low creep
High oil and chemical resistance

Typical Applications

Anti vibration mountings in hydraulic and other chemical environments.
Shock absorption pads
Anti vibration pads for plant and machinery

CR Chloroprene / Neoprene

High resilience
Damping ratio $C/C_c = \xi = ca 0.05$
Low creep
Moderate oil and chemical resistance
Fire retardant properties

Typical Applications

Acoustic damping pads
Floating floors
Structural bearings
Anti vibration pads
Sensitive equipment isolation

Optimum support design for Rubber Isolators

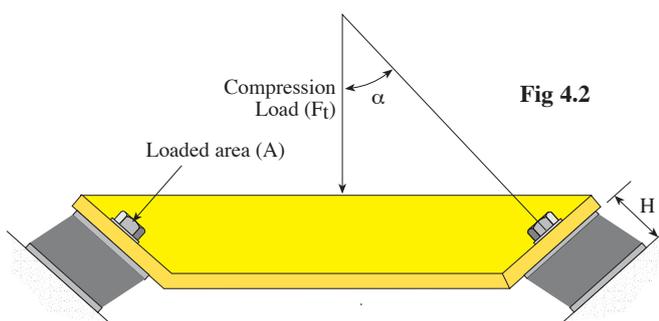


Fig 4.2

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):

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

G = Shear Modulus (N/mm²)

E_c = Compression Modulus (N/mm²)

H = Rubber height (mm)

A = Loaded rubber area (mm²)

F_t = Load (N)

The information contained in this brochure is intended to be a guide only. We suggest product samples be tested and approved based on your intended applications. We reserve the right to alter specifications or withdraw products with or without prior notice.