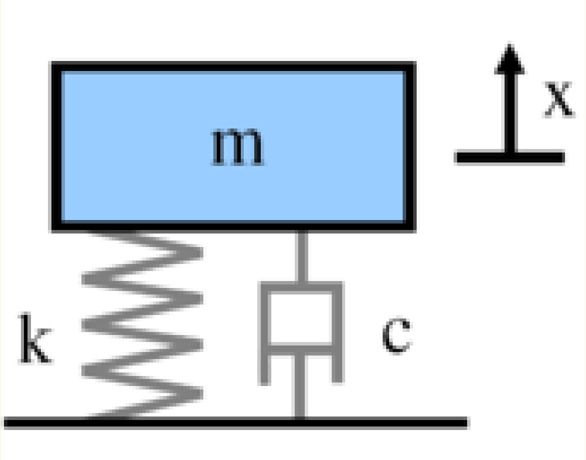
MEBS6008 Environmental Services II

http://www.hku.hk/mech/msc-courses/MEBS6008/index.html



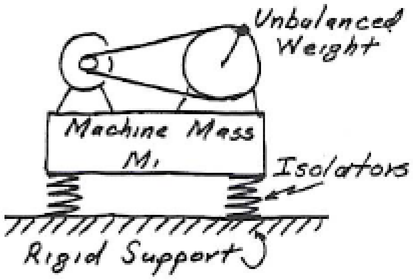
Acoustic Treatment – Vibration Control

Department of Mechanical Engineering
The University of Hong Kong

Content

- Fundamental of Vibration
- Vibration isolation
- Single Degree of Freedom Model
- Modes of Vibration
- Transmissibility and Isolation Efficiency
- Two Degree of Freedom Model
- Selection Guide for Vibration Isolator
- Vibration Control in Practice

Fundamental of Vibration



A rigidly mounted machine transmits its internal vibratory forces directly to the supporting structure.

Vibration isolators is resilient mountings

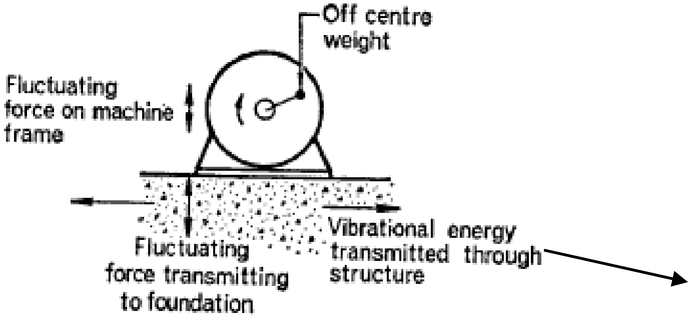
By inserting isolators between the machine and supporting structure, the magnitude of transmitted vibration can be reduced (%).

Vibration isolators can also be used to protect sensitive equipment from disturbing vibrations.

Vibration energy from mechanical equipment → transmitted to the building structure → radiated as structure-borne noise.

Vibration isolation

Any residual, out-of-balance force in the rotating parts as a weight located eccentrically.



eventually appear as noise energy

The weight rotates → each part of the machine structure subjected to a cyclic force from inertia of the rotating off-centre height

Vertical component of the force is concerned →acting alternately upwards and downwards, at a frequency equal to the shaft rotational frequency.

Other case of cyclic force example: Combustion loads in reciprocating engines

Single Degree of Freedom Model

Only motion along the vertical axis is considered , damping is disregarded

Valid only when the stiffness of the supporting structure >> the stiffness of the vibration isolator.
(mechanical equipment on G/F or basement locations)

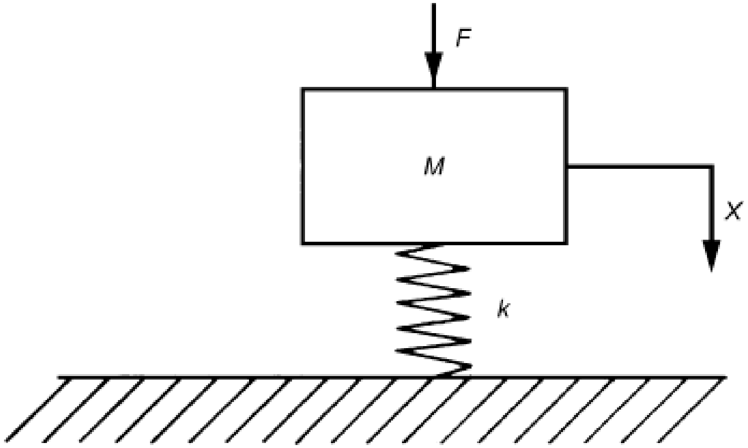
Natural frequency of the isolator : deflect the spring a little more + suddenly release it → the machine oscillate vertically about its rest position at natural frequency.

The natural frequency f_n of the system is

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

where k is the stiffness of vibration isolator (force per unit deflection)

M is mass of the equipment supported by isolator.



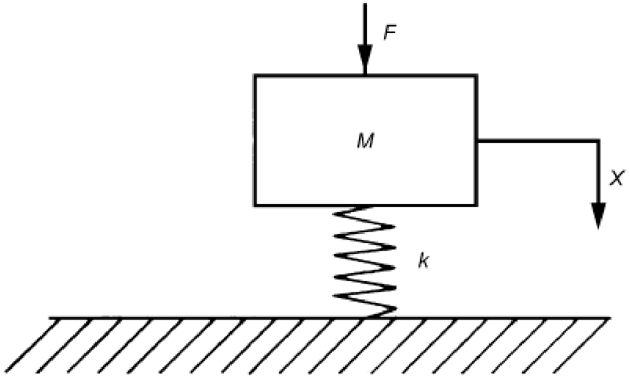
Single-Degree-of-Freedom System

Single Degree of Freedom Model

This model is the one upon which most manufacturers of vibration isolation hardware base their catalog information.

It is valid only when the stiffness of the supporting structure is large with respect to the stiffness of the vibration isolator.

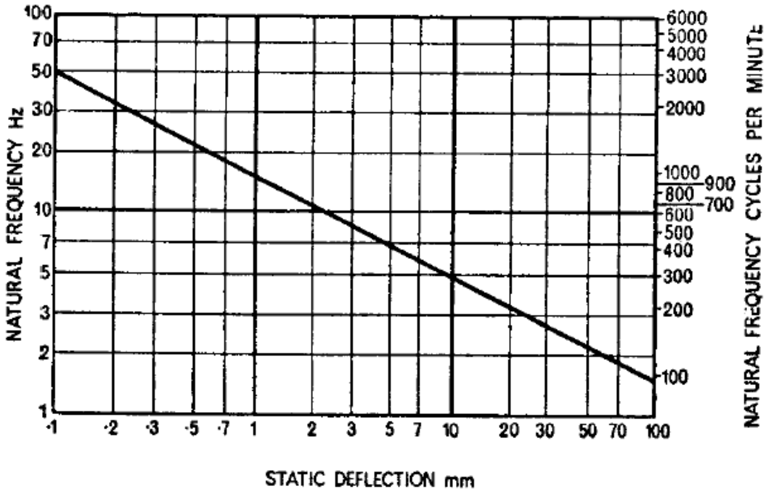
This condition is usually satisfied for mechanical equipment in on-grade or basement locations.



Single-Degree-of-Freedom System

Single Degree of Freedom Model

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{M}} \xrightarrow[\text{(try yourself, noting the unit of g)}]{\text{This equation simplifies to}} f_n = \frac{15.8}{\sqrt{\delta_{st}}}$$



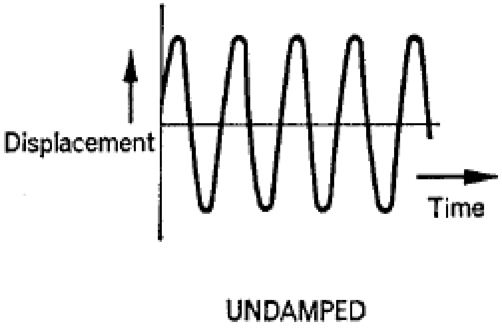
where δ_{st} is the isolator static deflection in mm, $k/M = g/\delta_{st}$.

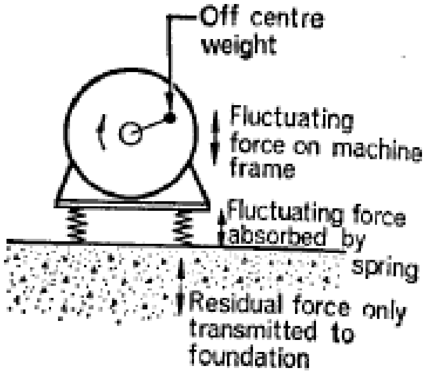
Static deflection = incremental distance the isolator spring compressed under equipment weight.

Isolator static deflection & supporting load → achieve the appropriate system natural frequency

Modes of Vibration - Undamped

Use the steel spring as vibration isolator.





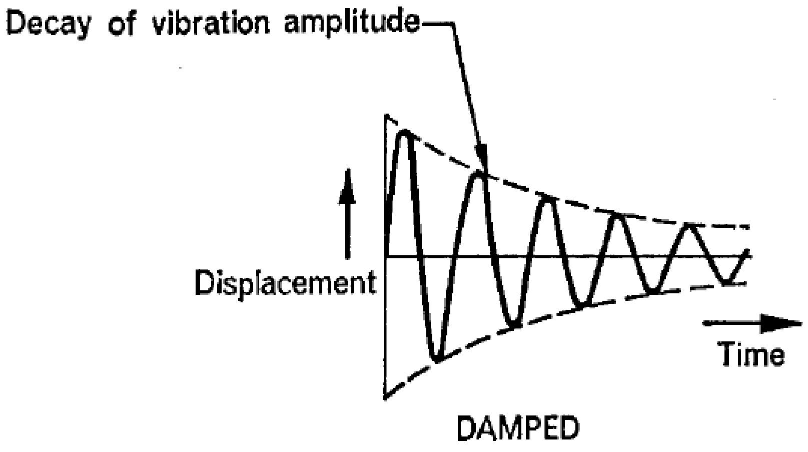
The machine settles under its own weight

The machine deflects the spring by a certain amount → static deflection of the isolator

Static deflection determines the eventual performance of the spring as an isolator when the machine is running.

Static deflection depends **only** upon static stiffness of the spring , weight of the machine.

Modes of Vibration - Damped Vibration



Damped Vibration
Real isolators have a certain degree of internal damping

Energy is progressively removed from the system

Amplitude of vibration steadily reduces
Large amount of damping→ movement of the mass back to its rest position after initial deflection will be very sluggish

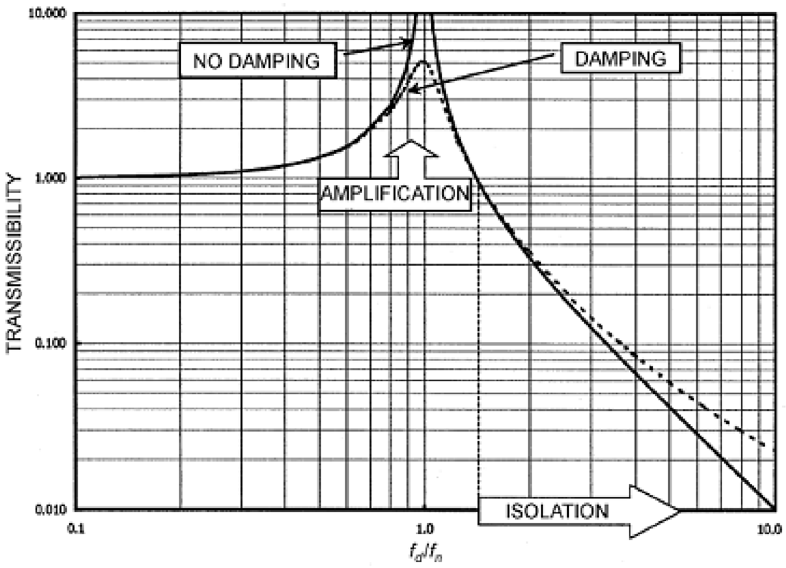
Neither overshoot nor oscillate

Critical damping
Amount of damping just sufficient for mass to return to its mean position in min. time without overshoot

Transmissibility and Isolation Efficiency

$$\text{Transmissibility} = \frac{\text{Force transmitted to the foundation}}{\text{Force applied by the machine}}$$

Transmissibility T is inversely proportional to the square of the ratio of the disturbing frequency f_d to the system natural frequency f_n, or



Vibration Transmissibility T as a Function of f_d/f_n

$$T = \left| \frac{1}{1 - (f_d/f_n)^2} \right|$$

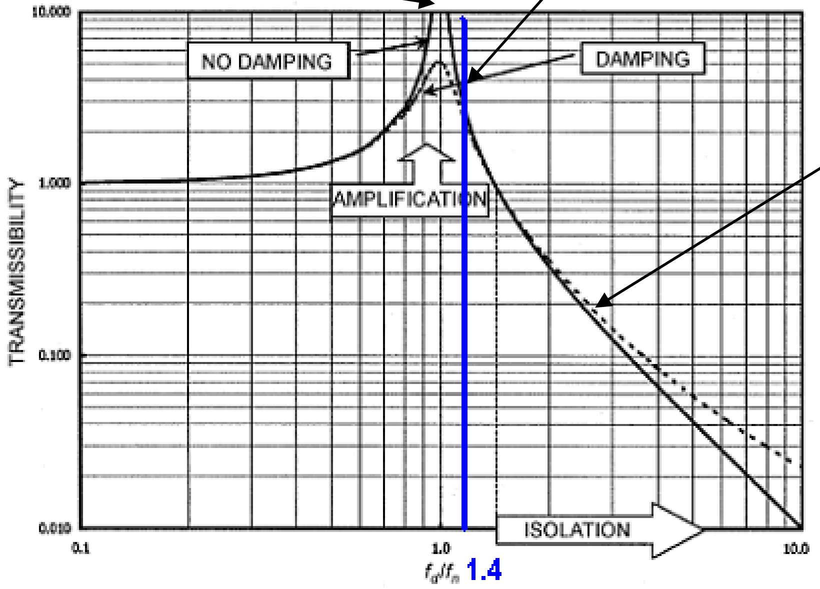
Transmissibility and Isolation Efficiency

Vibration isolation begin after $f_d / f_n > 1.4$.

At $f_d = f_n$, **resonance** occurs (the denominator of Equation equals zero)

At resonance
→theoretically infinite transmission of vibration.

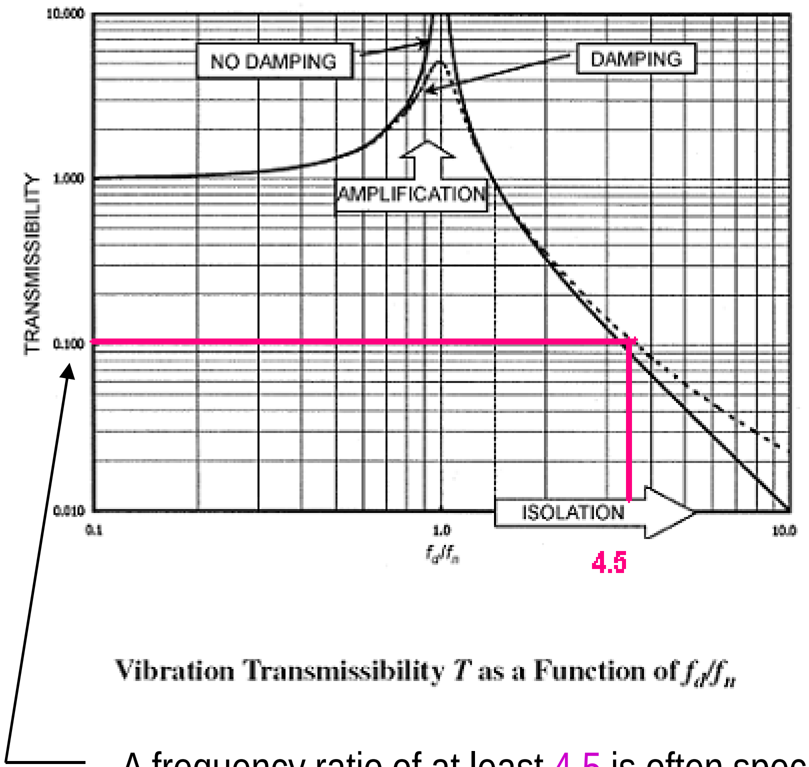
In practice, some limit on the transmission at resonance exists due to some inherent damping.



Vibration Transmissibility T as a Function of f_d/f_n

Vibration transmissibility rapidly decreases.

Transmissibility and Isolation Efficiency



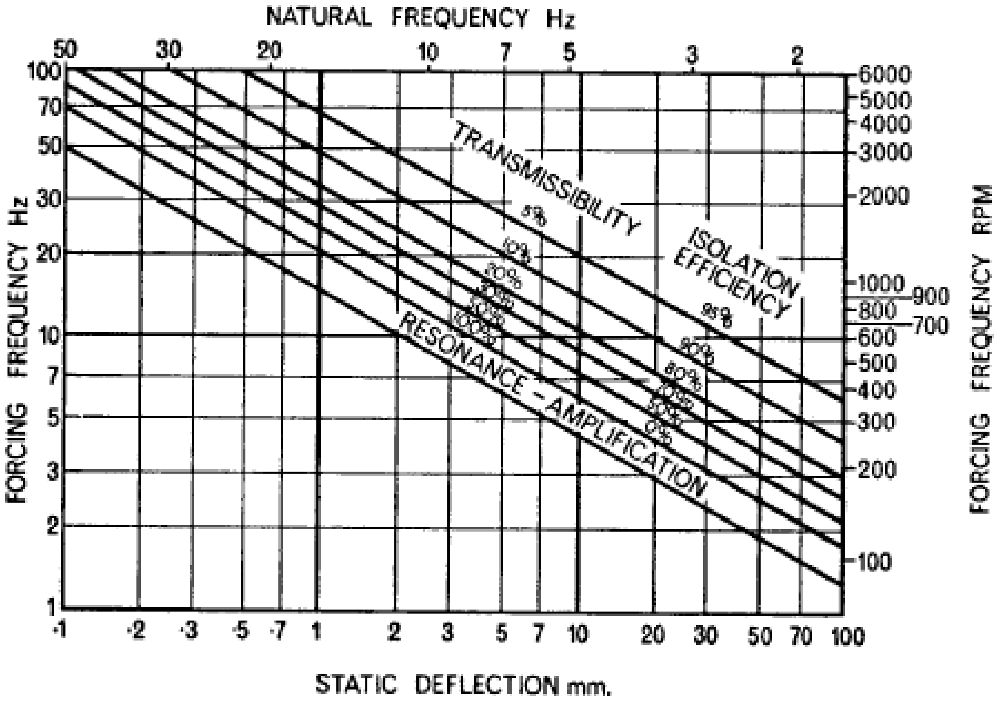
Vibration Transmissibility T as a Function of f_d/f_n

A frequency ratio of at least 4.5 is often specified, which corresponds to an isolation efficiency of about 90%, or 10% transmissibility.

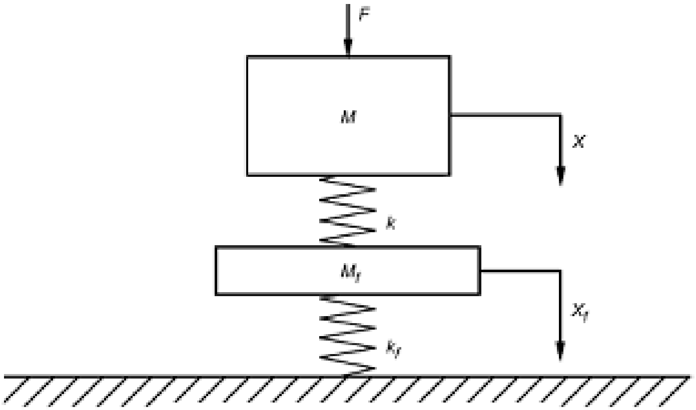
Higher ratios may be specified, but in practice this is difficult to achieve.

Nonlinear characteristics cause typical isolators to depart from the theoretical curve.

Transmissibility and Isolation Efficiency



Two Degree of Freedom Model



Two-Degree-of-Freedom System

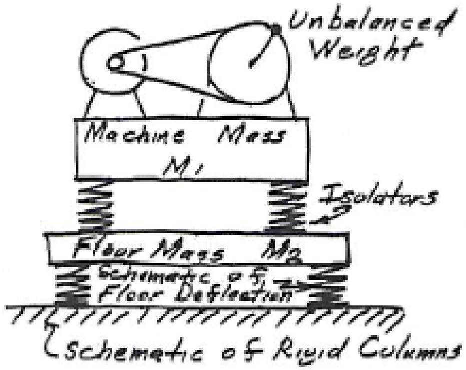
M and M_f represent effective masses of vibrating equipment and supporting floor, respectively; k and k_f are corresponding stiffness of isolator and floor system.

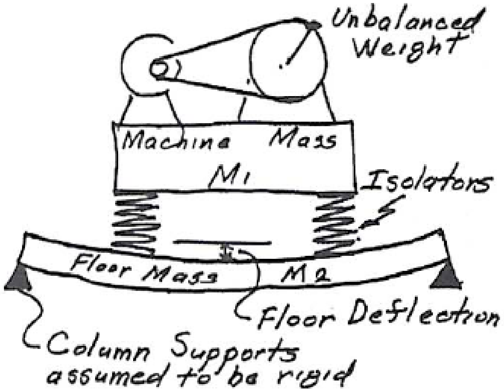
When heavy mechanical equipment is installed on a structural floor(especially roof), the stiffness of the supporting structure may NOT be >> the stiffness of the vibration isolator.

Significantly “softer” vibration isolators are usually required in this case.

Two-degree-of-freedom model for the design of vibration isolation in upper-floor locations.

Two Degree of Freedom Model





The precise behavior of this system with respect to vibration isolation is difficult to determine.

The objective is to minimize the motion of the supporting floor M_f in response to the exciting force F.

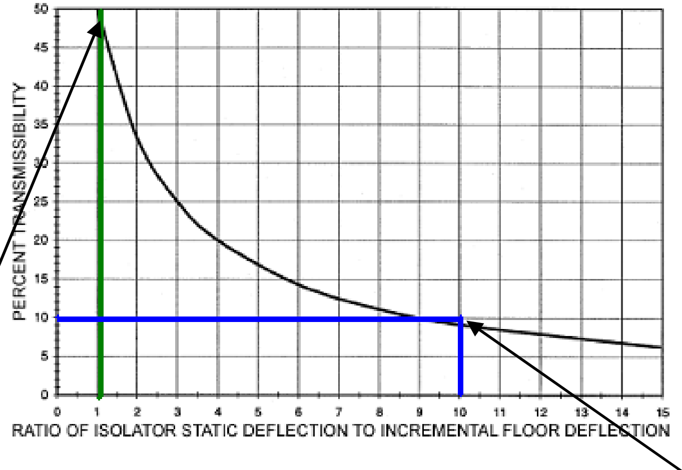
Evaluating the interaction between two system natural frequencies and the frequency of the exciting force→ complicated

Fraction of vibratory force transmitted across an isolator to the building structure (transmissibility) depends in part the isolator stiffness comparing with that of supporting floor.

Two Degree of Freedom Model

Ratio = isolator static deflection / incremental floor deflection

To optimize isolation efficiency → static deflection of the loaded isolator>> incremental static deflection of the floor under added equipment weight.



Floor deflection → excessive vibration is attributable to upper floor or rooftop mechanical installations.

Static deflection of the vibration isolator is = incremental deflection of the supporting floor under the added weight of the equipment →50% of the vibratory force

Ideally, this ratio should be on the order of 10:1 to approach an isolation efficiency of about 90%.

Two Degree of Freedom Model

Selection of vibration isolators on the basis of the single-degree-of-freedom model →neglected floor stiffness→ inadequate

Steps to choose vibration isolators with consideration of floor stiffness

Asking structural engineer to estimate the incremental static deflection of the floor due to the added weight of the equipment at the point of loading

Choose an isolator that will provide a static deflection of 8 to 10 times that of the estimated incremental floor deflection.

Consider also building spans, equipment operating speeds, equipment power, damping and other factors

Remarks

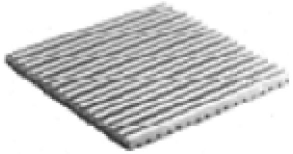
The type of equipment, proximity to noise-sensitive areas, and the type of building construction may alter these choices.

Selection Guide for Vibration Isolator

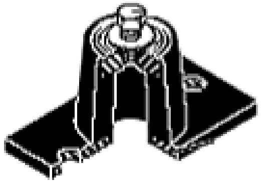
Equipment Type	Shaft Power, kW and Other	Rpm	Equipment Location											
			Slab on Grade			Up to 6 m Floor Span			6- to 9 m Floor Span			9- to 12 m Floor Span		
			Base Type	Iso-lator Type	Min. Defl., in.	Base Type	Iso-lator Type	Min. Defl., in.	Base Type	Iso-lator Type	Min. Defl., in.	Base Type	Iso-lator Type	Min. Defl., in.
Refrigeration Machines and Chillers														
Bare compressors	All	All	A	2	0.25	C	3	0.75	C	3	1.75	C	4	2.50
Reciprocating	All	All	A	2	0.25	A	4	0.75	A	3	1.75	A	4	2.50
Centrifugal	All	All	A	1	0.25	A	4	0.75	A	3	1.75	A	3	1.75
Open centrifugal	All	All	C	1	0.25	C	4	0.75	C	3	1.75	C	3	1.75
Absorption	All	All	A	1	0.25	A	4	0.75	A	3	1.75	A	3	1.75

Base Types:
A. No base, isolators attached directly to equipment
B. Structural steel rails or base
C. Concrete inertia base
D. Curb-mounted base

Isolator Types:
1. Pad, rubber, or glass fiber
2. Rubber floor isolator or hanger
3. Spring floor isolator or hanger
4. Restrained spring isolator
5. Thrust restraint

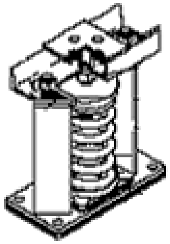


Type 1 Rubber Pad

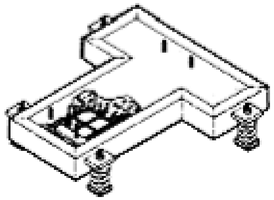


Type 2 Rubber Mount

Type 3 Spring Isolator

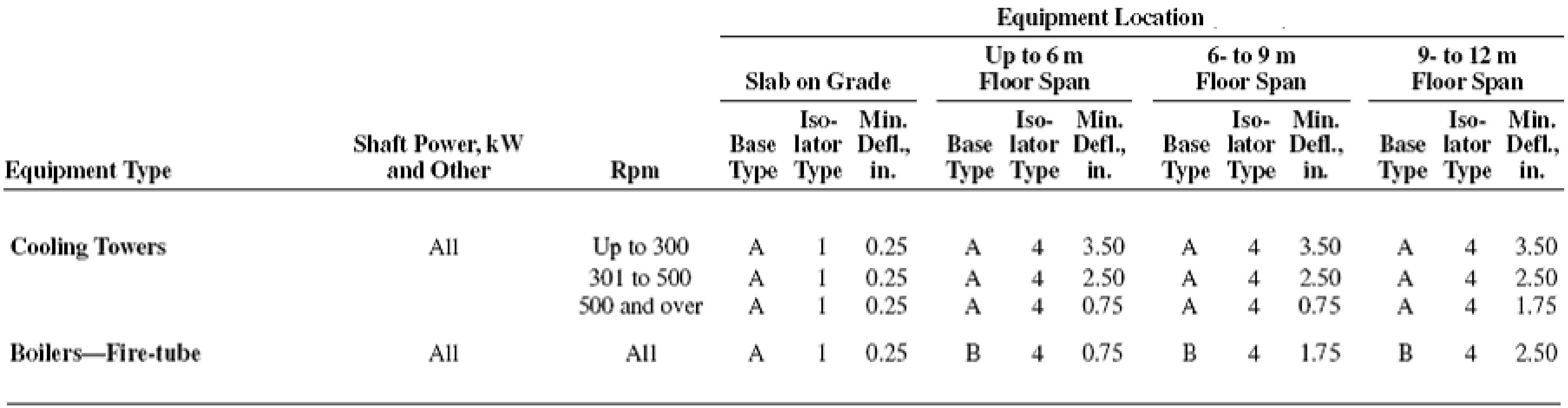


Type 4 Restraine Spring Isolator



CONCRETE BASES (Type C)

Selection Guide for Vibration Isolator



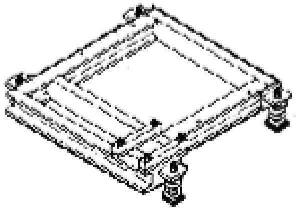
			Equipment Location											
			Slab on Grade			Up to 6 m Floor Span			6- to 9 m Floor Span			9- to 12 m Floor Span		
Equipment Type	Shaft Power, kW and Other	Rpm	Base Type	Isolator Type	Min. Defl., in.	Base Type	Isolator Type	Min. Defl., in.	Base Type	Isolator Type	Min. Defl., in.	Base Type	Isolator Type	Min. Defl., in.
Cooling Towers	All	Up to 300	A	1	0.25	A	4	3.50	A	4	3.50	A	4	3.50
		301 to 500	A	1	0.25	A	4	2.50	A	4	2.50	A	4	2.50
		500 and over	A	1	0.25	A	4	0.75	A	4	0.75	A	4	1.75
Boilers—Fire-tube	All	All	A	1	0.25	B	4	0.75	B	4	1.75	B	4	2.50

Base Types:

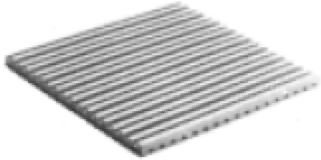
A. No base, isolators attached directly to equipment
B. Structural steel rails or base
C. Concrete inertia base
D. Curb-mounted base

Isolator Types:

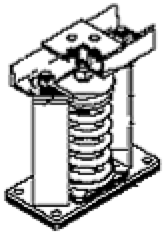
1. Pad, rubber, or glass fiber
2. Rubber floor isolator or hanger
3. Spring floor isolator or hanger
4. Restrained spring isolator
5. Thrust restraint



STRUCTURAL BASES (Type B)

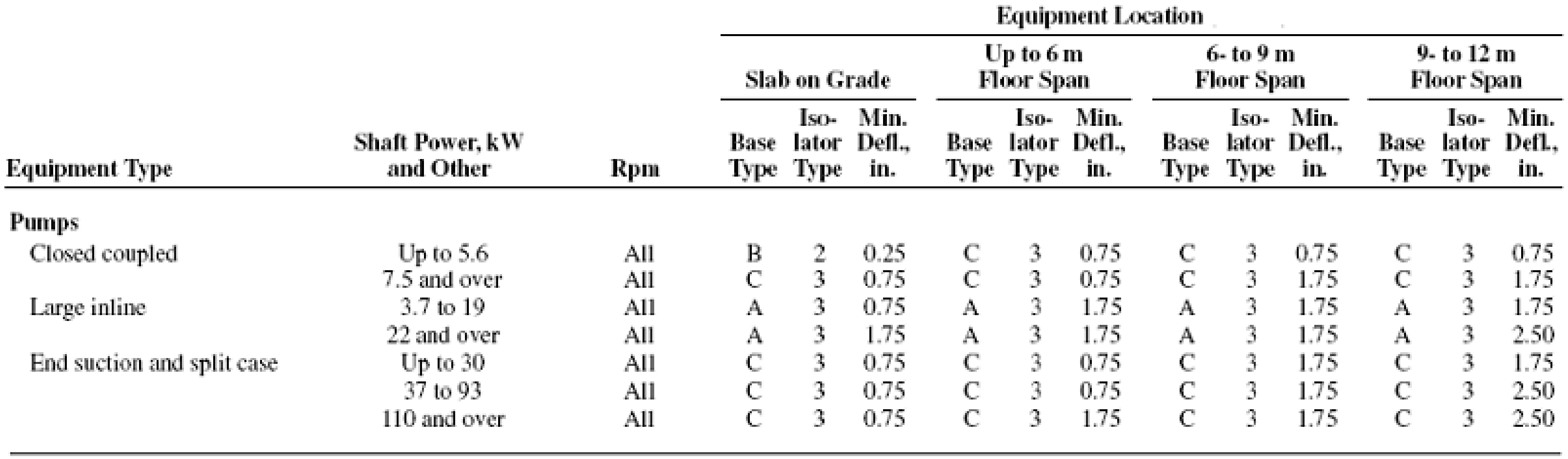


Type 1 Rubber Pad



Type 4 Restrained Spring Isolator

Selection Guide for Vibration Isolator



			Equipment Location											
			Slab on Grade			Up to 6 m Floor Span			6- to 9 m Floor Span			9- to 12 m Floor Span		
Equipment Type	Shaft Power, kW and Other	Rpm	Base Type	Iso-lator Type	Min. Defl., in.	Base Type	Iso-lator Type	Min. Defl., in.	Base Type	Iso-lator Type	Min. Defl., in.	Base Type	Iso-lator Type	Min. Defl., in.
Pumps														
Closed coupled	Up to 5.6	All	B	2	0.25	C	3	0.75	C	3	0.75	C	3	0.75
	7.5 and over	All	C	3	0.75	C	3	0.75	C	3	1.75	C	3	1.75
Large inline	3.7 to 19	All	A	3	0.75	A	3	1.75	A	3	1.75	A	3	1.75
	22 and over	All	A	3	1.75	A	3	1.75	A	3	1.75	A	3	2.50
End suction and split case	Up to 30	All	C	3	0.75	C	3	0.75	C	3	1.75	C	3	1.75
	37 to 93	All	C	3	0.75	C	3	0.75	C	3	1.75	C	3	2.50
	110 and over	All	C	3	0.75	C	3	1.75	C	3	1.75	C	3	2.50

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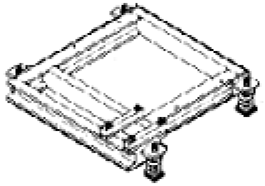
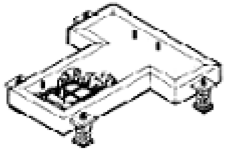
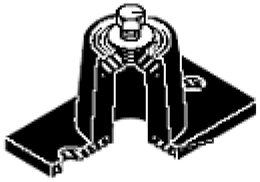


STRUCTURAL BASES (Type B)



CONCRETE BASES (Type C)



Type 2 Rubber Mount

Type 3 Spring Isolator

Selection Guide for Vibration Isolator

			Equipment Location											
			Slab on Grade			Up to 6 m Floor Span			6- to 9 m Floor Span			9- to 12 m Floor Span		
Equipment Type	Shaft Power, kW and Other	Rpm	Base Type	Iso-lator Type	Min. Defl., in.	Base Type	Iso-lator Type	Min. Defl., in.	Base Type	Iso-lator Type	Min. Defl., in.	Base Type	Iso-lator Type	Min. Defl., in.
Axial Fans, Fan Heads, Cabinet Fans, and Fan Sections														
Up to 560 mm dia.	All	All	A	2	0.25	A	3	0.75	A	3	0.75	C	3	0.75
610 mm dia. and over	Up to 500 Pa s.p.	Up to 300	B	3	2.50	C	3	3.50	C	3	3.50	C	3	3.50
		300 to 500	B	3	0.75	B	3	1.75	C	3	2.50	C	3	2.50
		501 and over	B	3	0.75	B	3	1.75	B	3	1.75	B	3	1.75
Centrifugal Fans														
Up to 560 mm dia.	All	All	B	2	0.25	B	3	0.75	B	3	0.75	C	3	1.75
610 mm dia. and over	Up to 30	Up to 300	B	3	2.50	B	3	3.50	B	3	3.50	B	3	3.50
		300 to 500	B	3	1.75	B	3	1.75	B	3	2.50	B	3	2.50
		501 and over	B	3	0.75	B	3	0.75	B	3	0.75	B	3	1.75

Base Types:

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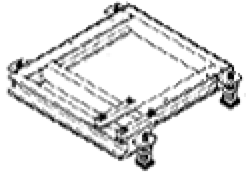
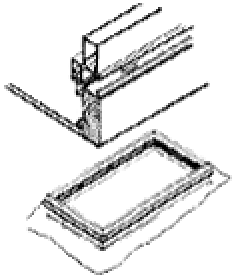
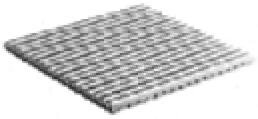


STRUCTURAL BASES (Type B)

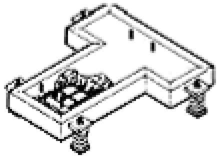


CURB ISOLATION (Type D)

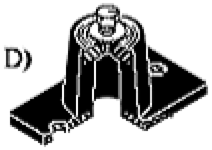


Type 1 Rubber Pad

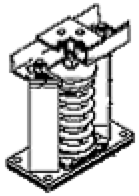
Type 3 Spring Isolator



CONCRETE BASES (Type C)

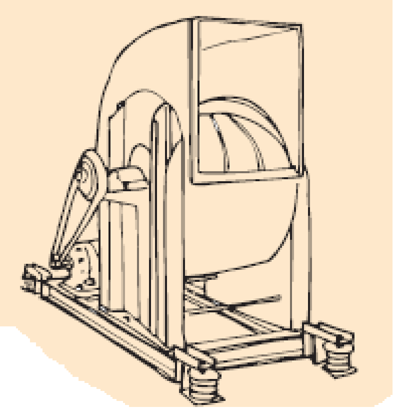


Type 2 Rubber Mount



Type 4 Restrained Spring Isolator

Vibration Control in Practice



Fans and Air-Handling Equipment

Fan with wheel diameter < or = 560 mm and operate at speeds < or = 300 rpm NOT generate large vibratory forces.

For fans operating under 300 rpm, select isolator deflection so that the isolator natural frequency is 40% or less of the fan speed (for example, fan speed at 275 rpm, an isolator natural frequency of 110 rpm (1.8 Hz) or lower is required (0.4 × 275 = 110 rpm).

Vibration Control in Practice

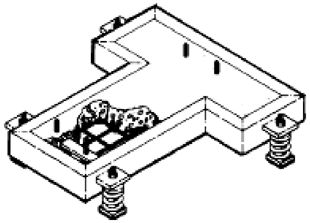
Pumps

Concrete bases (Type C) should be designed for a thickness of one tenth the longest dimension with minimum thickness as follows:

For up to 20 kW, 150 mm;

For 30 to 55 kW, 200 mm;

For 75 kW and higher, 300 mm.

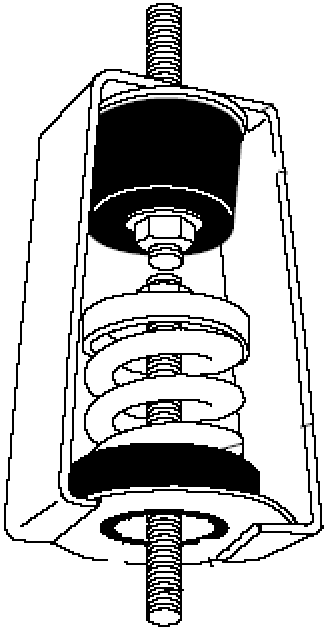


CONCRETE BASES (Type C)

Pumps over 55 kW and multistage pumps may exhibit excessive motion at start-up → supplemental restraining devices can be installed if necessary.

Vibration Control in Practice

Resilient Pipe Hangers and Supports



Resilient pipe hangers and supports are necessary to prevent vibration and noise transmission from the piping to the building structure and to provide flexibility in the piping.

Isolation hangers should be used for all piping in equipment rooms.

The first three hangers from the equipment : the same deflection as the equipment isolators (a max. limitation of 50 mm deflection)

Remaining hangers : spring or combination spring and rubber with 20 mm deflection.

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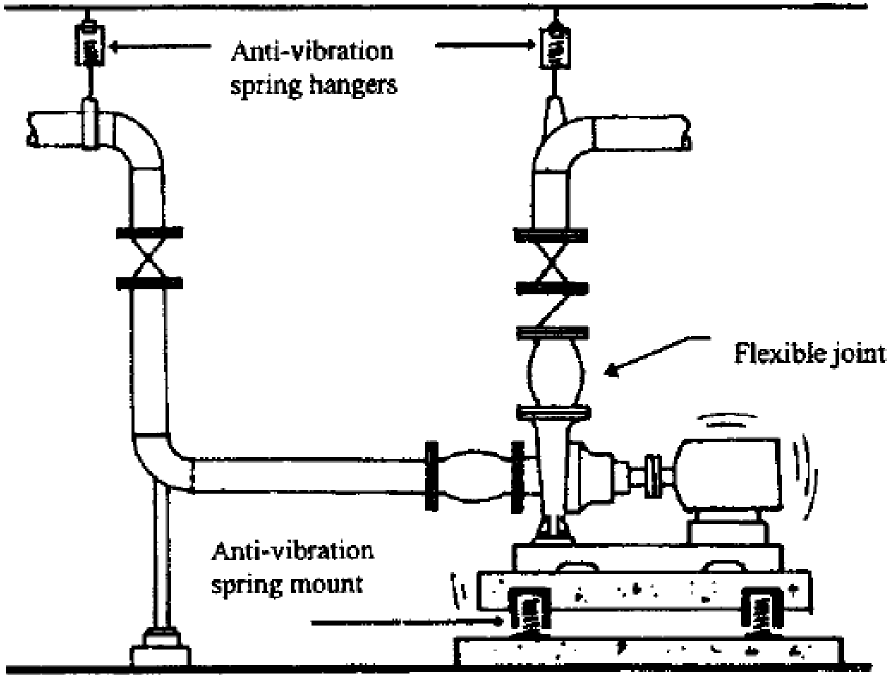
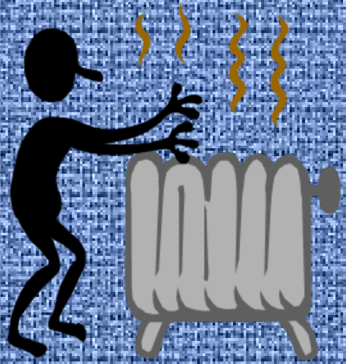


Vibration isolation for pumping system



Question and Answer