KINETICS™

Control of Vibration, Shock, and Structure-Borne Noise

In many cases, buyers of production machinery give little thought to vibration and shock until after the equipment they have purchased is installed and running in their plants. At that point, if there is a problem with shaking floors and vibrating building members, they begin to search around for some way to eliminate it. Fortunately, even then it's not too late to do something about the problem.

But how much simpler - and more economical - it would be to check with a vibration and shock control specialist when machinery is first ordered. Methods used to control machine-generated shock and vibrations are relatively simple and easy to understand. The secret is isolation, which is easier to accomplish when equipment is being installed than after it is in place.

Vibration and shock are caused by different kinds of machinery actions. Vibration is a sustained reaction produced by rotating or reciprocating equipment, and usually occurs in the operating range from 300 to 7000 cycles/min. Rotating types of production machinery which may be prone to vibration include boring and drilling machines, lathes, air compressors, engine-driven equipment, etc.

Shock, on the other hand, is caused by reciprocating action in machines that operate at speeds up to about 600 strokes/min. Shock is inherent in machines such as presses, forges, shears, etc., and usually is the most severe of the two problems, because so much energy is put into the building structure with each stroke.

Vibration is a two-way problem. First, there is machine-induced vibration which must be prevented from transmitting into the supporting building structure.

Second, the building structure itself may vibrate due to any number of causes. This can be a problem when attempting to use a precision piece of equipment, such as inspection device, the accuracy of which would be impaired if building vibration were above a certain magnitude. In either case, the goal is to isolate the vibration by placing resilient materials between the machine and the building, or between the building and the precision equipment.

Key is material selection. Selection of the correct type of resilient material is the key to proper isolation to minimize the transmission of vibration. Parameters for selecting the correct material are straightforward and include: (1) deciding on the degree of isolation desired and (2) knowing the operating speed (disturbing frequency) of the vibration-producing machine. With these two factors, the natural frequency of the isolation material needed to do the job can be determined.

Actually, selection of a vibration isolating material with the desired natural frequency is as simple as looking on a chart. Companies such as Kinetics have developed selection guides for most kinds of production equipment. All the owner needs to know is the make of the machine and the model number in order to determine the recommended isolator.

However, some instances of vibration isolation may present special problems, so a basic understanding of the theories behind shock and vibration isolation is desirable. The degree of vibration isolation to be achieved is also referred to as isolation efficiency. Zero isolation efficiency, for example, means that with a machine producing a certain out-of-balance force, that same force would be transmitted to the building structure without reduction. An isolation efficiency of 50 percent means that the isolation material prevents 50 percent of the vibration from being transmitted to the building. Consider an example of material selection to achieve 95 percent reduction in the transmitted force of a pump operating at 1800 rpm. At 95 percent isolation efficiency, the vibration caused by the operation of the pump would hardly be noticeable.

Vibration Isolation. Effectiveness of isolators in providing vibration reduction is indicated by the transmissibility of the system. The graph (Fig. 1) illustrates a typical transmissibility curve for equipment which is subjected to vibration supported on isolators. When the system is excited at its natural frequency, the system will be in resonance; the excitation forces will be amplified rather than reduced. Therefore, it is mandatory to select the proper isolator so that natural frequencies of the structure will be excited as little as possible in service and not coincide with any critical frequencies of the equipment.

Referring to Fig. 1, it can be seen that when the ratio of the disturbing frequency f over the natural frequency fn is less than 1.4, the transmissibility is greater than 1, or the equipment experiences amplification of the input. Simply expressed when...

f/fn is less than 1.4, T is greater than or equal to 1.

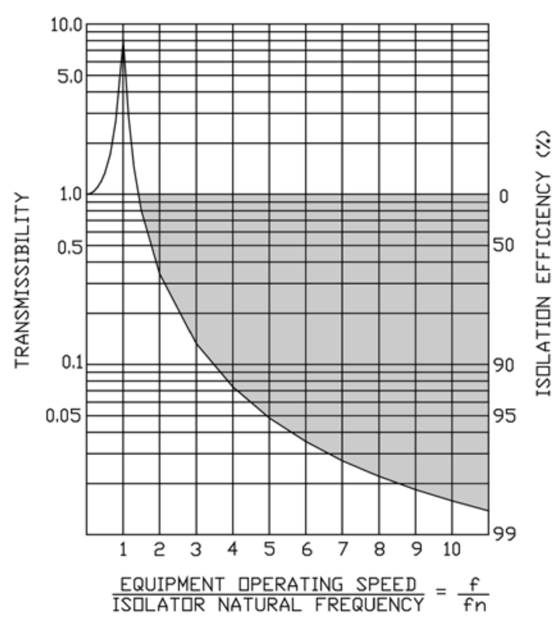
Theoretically, isolation begins when...

f/fn = 1.4, and this poiznt T = 1.

Also, it can be seen that when...

f/fn is greater than 1.4, T is less than 1.

the supported unit is said to be isolated.

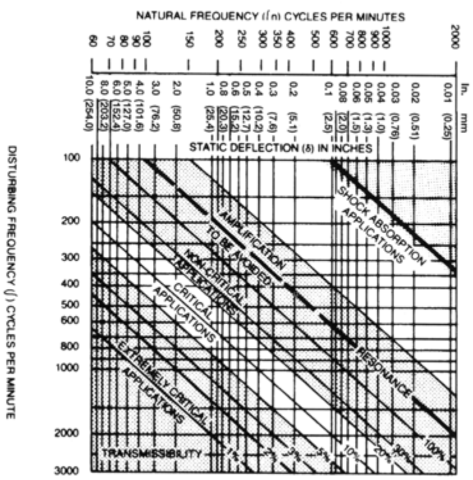


Typical transmissibility curve for an isolated system
Fig. 1

Manufacturers of vibration isolation materials publish the natural frequencies of their materials and vibration control devices. A selection can be made of spring isolators, air mounts, rubber material, fiberglass pads, or cork. Generally, the range of natural frequencies is 2 to 4 Hz for spring isolators, 4 to 10 Hz for rubber isolators, 5 to 15 Hz for fiberglass, 10 to 40 Hz for cork and 0.5 to 2.5 Hz for air mounts.

Using the chart in Fig. 1, it is also possible to determine the isolation efficiency of previously installed vibration control material. For example, a fan operating at 600 rpm is installed on a vibration isolator which has a natural frequency of 3 Hz, as shown in Fig. 4. The forcing frequency (600/60) is 10 Hz. Therefore, the ratio of forcing frequency to natural frequency (10/3) is 3.3. According to the chart, a ratio of 3.3 intersects the curve at approximately 90 percent efficiency. A good choice of isolating material was made.

Isolate, don't amplify! More often than not, however, selection of an isolation device or material is made in an arbitrary manner. Take the case of the same 600-rpm fan described above. On a previous occasion the maintenance person may have successfully stopped vibration on another piece of equipment by installing a set of rubber pads. He orders the same pads, which have a natural frequency of 9 Hz, from an industrial supply house and installs them under the fan's base. Much to his surprise, the vibration is worse.



Transmissibility for various disturbing frequencies
Fig. 2

By checking the chart in Fig. 1, it becomes obvious why the condition was made worse. With a forcing frequency of 10 Hz and a natural frequency of 9 Hz for the rubber pads, a ratio of (10/9) 1.1 develops. This ratio intersects the curve in the amplification range of the graph. Rather than isolate the vibration, the rubber pads have amplified it.

A situation worse than amplification is resonance. As can be seen on the chart in Fig. 1, the peak of the curve occurs at a ratio of one (1). That is when the natural frequency is exactly the same as the forcing frequency. In a resonant situation, a tremendous amount of force can be transmitted into the supporting building structure and vibration can be quite severe, causing equipment to bounce.

Span Between Supports Ft. (m)	Allowable Floor Deflection (1/306th of span) In. (mm)	Probable Deflection (20% of Allow.) In. (mm)	Probable Floor Natural Frequency (cpm)
10 (3.0)	0.33 (8)	0.066 (2)	720
20 (6.1)	0.67 (17)	0.134 (3)	560
30 (9.1)	1.00 (25)	0.200 (5)	400
40 (12.2)	1.33 (34)	0.266 (7)	360
60 (18.3)	2.00 (51)	0.400 (10)	300

Natural Frequency of concrete floor construction
Fig. 3

Supply Fan supported by Spring Isolators
Fig. 4

Spread shock impact. So far we have addressed situations here the ratio of the forcing frequency to the natural frequency is greater than one. This ratio comes about because of the higher operating speeds with which we are dealing. Since forcing frequency is derived from the vibration caused by rotating equipment operating at 250 rpm or greater, the resulting ratio will usually be greater than one. However, with machines that operate at slower speeds, such as presses, we have a situation where the ratio of forcing frequency to natural frequency is less than one. In these cases, the requirement is to dampen shock rather than isolate vibration.

Punch Press Isolated with fiberglass mounts
Fig. 5

Shock Isolation. The isolation of shock disturbances is considerably different from that of isolating steady-state vibration disturbance. The shock isolator is characterized as an energy storage device wherein the input energy such as from a punch press is instantaneously absorbed by the isolator. This energy is stored in the isolator and released to the building. Shock mounts change the sudden impact to a smaller,gradually applied force.

In shock mountings, the natural frequency or resonant frequency of the mountings is actually greater than the disturbing frequency, or strokes per minute, of the impact machines as illustrated in Fig. 2. This ratio is generally in the range of 1/6 or 1/7, and falls in the cross hatched area shown in the upper right hand corner of the chart.

For example, consider a punch press where the tool impacts a die set and transmits a shock into the building. If a resilient material is placed under the machine, as shown in Fig. 5, the effect is to spread out the time cycle of the impact. The building "sees" less force being transmitted. The same amount of energy is eventually transmitted into the building, but it is dissipated by the resilient material to the point that the shock input is diminished. Isolation efficiency is nil because energy is still being transmitted, but the transmission is over a longer time period and the desired effect is achieved.

If we have a press that operates at 100 strokes/min. (1.6 cycles/sec.) and place it on shock isolation pads which have a natural frequency of 40 cycles/sec. (a stiff material) we obtain a ratio of 0.04. The vibration has not been amplified by very much. Using the same 100 strokes/min. and a softer isolator with a natural frequency of, say, 10 cycles/sec., the resulting ratio is 0.2. The vibration has now been amplified a little more. Using a much softer isolator with a natural frequency of 3 cycles/sec., the ratio jumps to 0.5. The shock being transmitted into the building has almost doubled; it has been notably amplified.

The goal is to put the equipment on very stiff isolators in order to dampen the effect of shock. When going from 100 to 400 strokes/min, in order to maintain the desired low ratio (for example, 0.1) stiffer and stiffer isolators should be used. The upshot is that, with operating speeds below 175 strokes/min, softer isolators can be used; over 175 strokes/min, very stiff isolators are needed. At operating speeds over 250 to 300 strokes/min, the shock can be considered vibration, with isolation materials selected accordingly.

Support Structure Considerations. The theoretical isolation efficiency shown on the transmissibility curve is based on the deflection of the isolators located on a rigid floor. This type of rigidity does not exist for above-grade construction.The table in Fig. 3 shows the probable natural frequency of concrete floor construction. Vibration isolators must be selected to compensate for the floor deflection on any construction above grade.

Increasing the length of floor span for a building makes the structure more flexible and allows the structure to be easily set into motion. With the aid of the Kinetics Selection Guide, these problems can be avoided. The selection guide is based on isolator deflection rather than theoretical isolation efficiency.

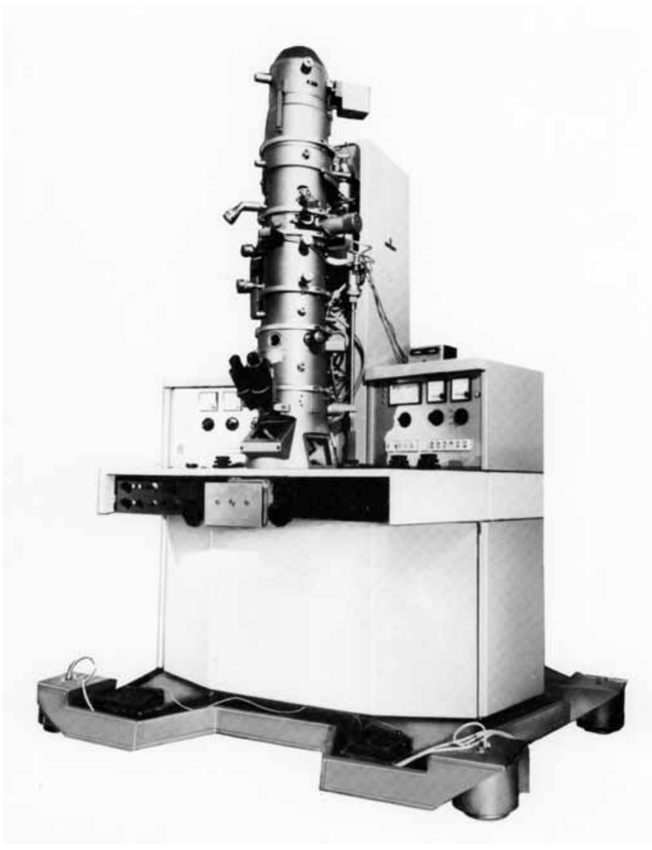
Another parameter in selecting the proper isolator is the weight distribution of the machine. If the machine has a large overhung load, special consideration must be given. The loading may be 1000 lbs. (454 kg) on two corners, 5,000 lbs. (2268 kg) on the third corner and only 200 lbs. (91 kg) on the fourth corner. Isolators must be selected accordingly and great care taken that the proper isolators were placed in the correct corners of the machine.

Isolating devices and materials. Negative isolation is a concern in many situations. For example, electron microscopes are used on line in foundries to determine the microstructure of castings, as Fig. 6 indicates.They are frequently used in the vicinity of forging hammers, furnaces, and shakeouts.

Because of vibration and shock generated by these operations, the microscopes may not be used during operating shifts, and usable only after the operations are shut down for the day, when there is minimum vibration in the plant structure. This makes it difficult to examine the grain structure of the metals on line immediately after a manufacturing operation. An air mount isolation system may be the answer to reducing this shock and vibration transmitted into the equipment. They are the softest isolators available, with a natural frequency of from 0.5 to 2.5 Hz. They are available with either a manual or automatic air leveling system to re-level the equipment with changes in loading. Air mounts are generally mounted in a housing to increase lateral stiffness. They have a load range from 250 to 40,000 lbs. (113 to 18144 kg) and the systems are designed specially for the equipment being supported.

Fiberglass is used extensively in industrial shock isolation, as shown in Fig. 7. It is, in effect, completely inert. Made of individually annealed glass fibers having a modulus of elasticity and permanency about the same as spring steel, it does not deteriorate with time, and it doesn't age. Neither cutting oils, mildew nor fungus will affect it. By proper selection, it can accommodate a wide load range - from about 1/2 psi to 500 psi (3.4 to 3447 kPa). Most large presses use fiberglass isolators. While rubber and cork deteriorate with exposure to ozone, oil, etc., fiberglass is not affected by these materials.

In manufacturing fiberglass pads, they are precompressed, stabilized and then coated with an elastomeric material to increase the damping. Fiberglass has been developed to have a constant natural frequency over a broad load range. It doesn't matter how it is loaded as long as it is within the load range. In the case of a mount designed for



Electron Microscope on an air mount isolation system
Fig. 6

2,500 lb. (1134 kg) loads, we can load it between 1,000 and 4,000 lbs. (454 and 1814 kg), and the performance will be the same. Rubber, springs or air mounts don't do that. Fiberglass is made in standard pad sizes or mounts and can be cut to specific shapes or sizes. Using fiberglass, a machine can be leveled by the use of shim plates or standard leveling type mounts.

Neoprene is generally oil-resistant and normally used as a vibration isolator and not for shock loads like shown in Fig. 8. The most prominent use is on equipment operating above 500 rpm. Neoprene is furnished in molded shapes or scored, ribbed pads. Because it is generally designed for shear loads, it has its most efficient isolation capability in a very narrow load range, and if not used within that range, difficulties can arise from the rapid change of its natural frequency. Used under forging hammers and presses, or other high-shock generating equipment, it must be reinforced to increase its load-carrying capacity and its natural frequency. It then operates as described previously, by damping shock input.

Spring isolators are available in many different forms, such as the example that Fig. 9 illustrates. Springs are generally used on equipment operating above 250 rpm, and are almost always used on rotating equipment such as compressors, generators, pumps, fans, etc. The housing limits lateral movement. Some isolators have adjustable snubbers, which permit damping control to overcome high initial torques. Available in standing sizes ranging from 35 lbs. to 15,000 lbs. (16 to 6804 kg) or higher if required. When a spring is overloaded it will become solid, providing no isolation. If it is under loaded, its effectiveness is reduced to some degree. Weight distribution is a requirement when using springs, to permit uniform deflection and performance.

Neoprene Isolators below an exhaust fan
Fig. 7

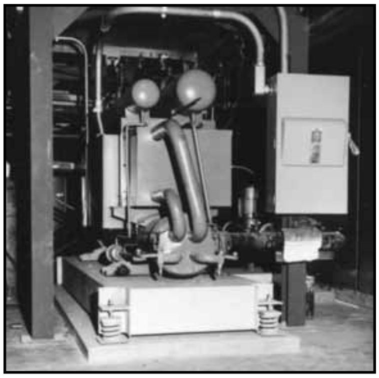
Springs are available with vertical restraints (anti-lift devices) as illustrated in Fig. 9.

Pendulum designs are available for supporting large masses and unbalanced forces, and as unrestrained stabile mounts.

A factor often overlooked is that of transmission of vibration through piping. If a machine is isolated through its supports, but has piping, conduit or ductwork that is anchored to the building, this will short-circuit the vibration isolation because the vibration will be transmitted through the piping system. In such cases, isolation hangers are needed.

Put it all together. When using isolation devices, it is important to know the operating speed of the equipment and the degree of isolation wanted. The natural frequency and loading characteristics of the isolators must be considered in order to determine how good a job will result. Otherwise, it is just a hit or miss approach and a problem will result. For most industrial applications, the approach is quite simple. For example, pads are usually well accepted for small industrial pieces of equipment.

Most manufacturers design their equipment so that the area of the foot loads the concrete floor at about 50 psi (344.7 kPa). Isolation pad materials are designed to operate efficiently between 50 and 200 psi (344.7 and 1379 kPa). Therefore, the simple thing to do is to determine the most efficient load range of the pad in pounds per square inch (kPa), and then cut the pad to size to attain this load. If the pad is cut to the same size as the foot of the equipment, proper loading will occur about 70 percent of the time.



Spring Isolators supporting a process chiller
Fig. 8

Most equipment can be mounted on pads or mounts without bolting to the floor. The cost of pads or mounts can range from $30 up; however, the cost of maintenance crew to set anchor bolts can be many times the cost of the isolation products. An isolation mount is designed to perform several functions, in the following order:

(1) Reduce vibration both to and from a piece of equipment.

(2) Help reduce structure borne noise.

(3) Decrease maintenance because vibration can cause bearing wear, etc.

(4) Improve quality of finished parts by reducing machine tool chatter.

(5) Increase productivity because less time is required to attain finished parts.

(6) Improve mobility of equipment, because anchor bolts can be eliminated on certain equipment.

Vertically restrained Spring Isolators used with a cooling tower
Fig. 9

Industrial Machinery Vibration and Shock Isolation Recommendations

	Spring Isolation Products													Bases or Rail Support Systems					Air Mounts & Special Systems		
	Model SM	Model FDS	Model FLS	Model FHS	Model PSS	Model SFH	Model L or N	Model KLM	Model SN	Model RD	Model NPD, NPS	Model KIP-SP	Model NDF	Model KIP	Model CIB-L	Model CIB-F	Model CIB-H	Model SFB	Model KAM	Special System Base Design	Noise Control Req'd
Air Conditioners	●	●		●		●					●	●			●	●					
Boring Machings	●						●	●	●		●		●				●			●	
Brakes							●	●	●		●	●	●							●	
Broaches (Small)							●	●	●		●		●				●				
Broaches (Large)									P		O			P						R	
Business Machines	●	●					●	●			●										
Centrifuges																				R	
Clickers	●								●		●	●	●								●
Coal Crushers & Pulverizers					P				O				O				R			●	●
Compressors:																					
(a) V, W, Radial	●	●		●					●		●				●	●	●				●
(b) Horiz Recip.					R												R			R	
Vert. Recip.					R												R			R	
(c) L-Shape Recip.					R												R			R	
(d) Centrifugal, Rotary, Screw Type	●	●												●			●			●	●
Cooling Towers			●	●							●						●	●			
Crushers					R						O						R			R	●
Die Casters							●	●	●		●		●								
Dynamometers	●	●		●	●						●				●	●	R			R	
Engines:																					
(a) High Speed	●	●	●	●	●						●			●			●			●	●
(b) Stationary	●	●	●	●	●						●			●			●			●	●
(c) Mobile, Marine																				R	●
Evaporative Condensers	●	●	●	●											●	●					
Fans:																					
(a) Centrifugal	●	●	●	●		●				●	●				●	●		●			
(b) Utility	●	●	●	●		●				●	●				●	●		●			
Furnaces-Boilers	●	●	●	●				●	●	●	●			●	●	●		●			
Gear Cutters							●	●	●		●	●	●								
Generator Sets:																					
(a) Stationary	●	●		●	●												●	●		●	●
(b) Marine	●										●		●							R	●
Grinders:																					
(a) Roll					P									O						R	
(b) Surface																				R	
(c) Others							●	●	●		●		●								
Hammers, Forging					P								●							R	●
Injection Molders							●	●	●		●		●								
Instruments	●	●												●					●	R	
Jig Borers							●	●	●		●		●	●						●	
Jolt Molders	●				●								●							R	●
Laundry Extractors																				R	
Lathes							●	●	●					●			●			R	
Microscopes (Electron & Others)																			●	R	
Milling Machines							●	●	●		●										
Mills, Ball or Rod									●											R	●
Pipe	●	●				●															
Precision Equip. (Granite Slabs, Interferometers, etc.)																			●	R	
Presses:																					
(a) Hydraulic	●						●	●	●					●						R	●
(b) Newspaper														●			●			R	●
(c) Printing							●		●					●			●			R	●
(d) Punch (See "SN" Section)							●	●	●		●		●	●						R	●
Pumps	●	●	●	●						●	●				●	●	●	●			
Roof Top Units	●	●	●	●																	
Shapers																				R	
Shears																				R	●
Textile Machinery																				R	●
Transformers	●	●		●			●	●		●	●			●	●	●					●
Vibrating Screens						●														R	●
Vibrating Test Machines														●						R	

The chart indicates recommended isolation for industrial machinery.
R indicates that an isolation system is required.
P indicates preferred isolator
O indicates optional isolator
● indicates alternative choices

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