

Figure 6: Available isolator types.

Vibration Isolation

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No matter how advanced the design, mechanical equipment will contribute to objectionable vibration and vibration-induced noise in buildings. Building owners' and tenants' increasing demand for a comfortable and productive workspace, and the increased presence of sensitive, high-tech equipment requires vibration control issues be considered. This article will examine if, why, or when vibration from HVAC&R equipment causes a problem in buildings, and some practical vibration isolation theory and installation guidelines.

What's the Buzz?

We all remember that age old idiom, "penny wise and pound foolish." A similar adaptation of this

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applies to vibration isolation of typical HVAC&R equipment and systems in buildings today. Attention to a relatively small, inexpensive vibration isolator during design and installation of equipment could prevent much more costly trouble later. It is not only higher in direct costs to retrofit an isolation system (as much as 10 times more), but the cost in downtime, consulting to diagnose a problem,

and customer bad will is many times more.

All mechanical equipment used in HVAC&R systems vibrate to some degree. The awareness of vibration problems have increased over recent years for a number of reasons:

- Economical, lightweight building construction has replaced the heavy construction of the past. These more flexible buildings are much more susceptible to transmit and resonate vibration.

- Valuable floor space results in mechanical systems located in smaller areas near occupants. The closer proximity to tenants means greater probability of complaint. Equipment located on flexible above-grade floors results in a greater risk of vibration transmission.

- The link between workplace comfort and individual productivity necessitates a noise and vibration-free environment. Classroom noise criteria also is becoming more stringent as studies show a link between learning and good room acoustics.

- The high-tech industry with

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high-precision production equipment has an extremely low tolerance for vibration, so losing millions of dollars in defective product caused by vibration is a concern

- Advanced diagnostic or microsurgery medical equipment requires a high-fidelity environment with low floor vibration.
- R&D facilities with precision lasers and electron microscopes require very low floor vibration to operate correctly.

Source-Path-Receiver

Vibration control can be broken in to three components: *source*, *path* and *receiver*.

The *source* is the machinery or system producing the vibration. Any type of equipment with rotating parts produces vibration. While HVAC equipment manufacturers are consistently improving their products, it is impractical and uneconomical to balance equipment beyond commercial tolerances. The amplitude of vibration that might be expected from typical new equipment maybe as low as 0.08 in./s (0.002 m/s) RMS velocity. Over the life of equipment, depending on the care and maintenance, the vibration may increase due to normal wear (bearing wear, belt misalignment, etc.) to 0.2 in./s to 0.6 in./s (0.005 to 0.015 m/s).

The pipe connected to the HVAC&R equipment also can be a source of vibration. Valves, pumps, pressure reducers, or a pipe geometry with a number of bends can produce turbulent flow, which can generate enough vibration to exceed occupancy tolerance. Vibration from duct is not as common as pipe, but abrupt changes in direction or rough transitions can cause flow pulsations that create a source vibration. *Figure 1* illustrates typical vibration sources.

The *path* is the medium through which the vibration is transferred. Most building components (floors, beams, columns, walls, etc.) will transmit vibration. Pipe and duct are also very good conduits of vibration. Lighter building construction, lightweight roofs, and larger column spans (30+ft [9 m]) can be more flexible and contribute to easier transmission. The close proximity of valuable commercial space to equipment decreases the path length, which increases the likelihood of complaints. *Figure 1* demonstrates typical paths.

The only sure way to cut off the path of objectionable vibration is with an isolation system. Note that a systems approach is necessary to achieve a successful installation. All paths must be cut off, since vibration will take the path of least resistance. If one piece of equipment is not isolated, or the connected pipe is not, then unwanted vibration may bleed through to the structure.

The *receiver* is the building occupant or equipment/

process that is affected by vibration. Complaints arising from transmitted vibration take the form of either a high level of vibration they perceive to be disturbing or alarming, or relatively small amounts of energy transmitted to building components (i.e. walls) that radiate as unacceptable noise. The more critical the occupant, the greater sensitivity to vibration or vibration induced noise: vibration control is more critical in a conference room or executive office than in a standard office; a hospital is typically more critical than an office building; a concert hall or performing arts center requires very low levels of vibration-induced noise; and classroom acoustics are increasingly important (especially in early primary education). In today's high-tech world, vibration in the building interferes with the proper operation of sensitive equipment and instruments.

Figure 2 compares acceptable occupant vibration levels with expected levels generated by HVAC&R equipment. The source level can be 10 to 1,000 times greater than acceptable receiver levels, depending on the equipment and type of occupancy. Since the source and the receiver cannot be changed, it is most practical to cut off the path with an isolation system as shown in *Figure 3*. An isolation system is the best inexpensive insurance against unwanted vibration.

How Vibration Isolation Works

Properly isolated equipment is designed to transmit negligible vibratory force and prevent the equipment from being considered a problem source. To be assured of proper isolation, it is necessary to apply the well established principles of vibration control.

Vibration isolator is defined as a resilient material placed between the equipment and the structure to create a low natural frequency support system for the equipment. Some common materials are elastomeric pads or mounts, helical steel springs, wire rope springs, and air springs. Often, materials are combined to create desired results. The spring

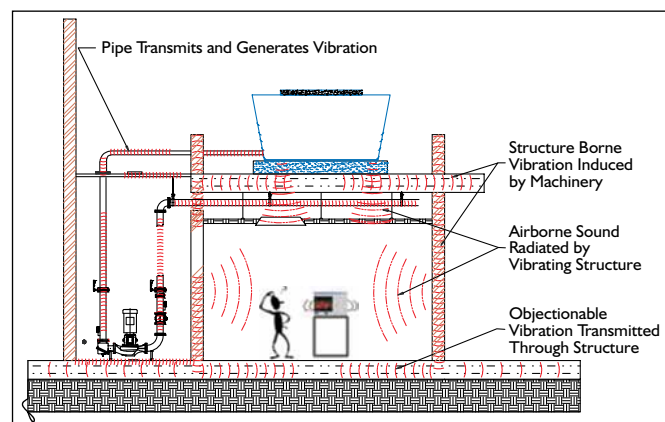


Figure 1: Typical vibration source, path and receiver.

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mass schematic in *Figure 4* is the simplified model used to represent equipment mounted on isolators.

Static deflection is how much the isolator (spring or elastomeric) deflects under the weight of the equipment. In general, larger static deflection gives better isolation.

Natural frequency, f_n , is the frequency at which a vibration isolator will naturally oscillate (bounce) when compressed and quickly released. See *Figure 4* for an equation that gives the natural frequency of a simple spring mass model in cycles per minute (cpm or rpm). Note that higher static deflection gives a lower natural frequency, which provides better isolation.

Disturbing frequency, f_d , is defined as the lowest frequency of vibration generated by the equipment. There are usually one or two dominant frequencies of vibration produced by equipment. For example, in a fan, the slower of the fan wheel or motor rpm will produce the frequency of dominant vibrations. There may be other higher-mode vibration frequencies present in equipment, depending on issues such as the rigidity of the equipment, its mass, the number of moving or rotating parts (blades, lobes, pistons, etc.) and many other properties. However, if we concentrate on proper isolation of the lowest disturbing frequency, we typically also isolate the higher frequencies. Therefore, the lowest operating equipment speed defines, for our purpose, the design disturbing frequency.

Amplitude, X^1 , is the magnitude of vibration. For the purposes of this discussion vibration amplitudes will be expressed in terms of velocity, X^1 (in./s or m/s RMS), as this is a common basis used in equipment vibration criteria and human response to vibration criteria. RMS (root mean square value of the vibration averaged over a sample time, equals about 71% of peak for cyclical vibration) gives a useful, nonzero, single number magnitude that gives an *effective* value of the vibration. It's the amplitude one might feel if they placed their hand on the equipment.

Damping, ε , acts as the brakes for equipment mounted on isolators and is an inherent property of most isolator materials. Damping reduces or stops motion by use of friction or viscous resistance. Friction damping occurs when the friction between sliding parts slows down movement between the parts, similar to brakes on a car. Viscous damping occurs with resistance to fluid or airflow. Shock absorbers on a car are an example of viscous damping. During normal equipment operation, damping tends to reduce the isolator efficiency as the breaking action transmits force to the structure. However, during incidental large movements (temporary imbalance, water hammer, temporary resonance, earthquake, etc.), the damping keeps movement from becoming too extreme, and out of control. *Figure 5* graphically demonstrates the

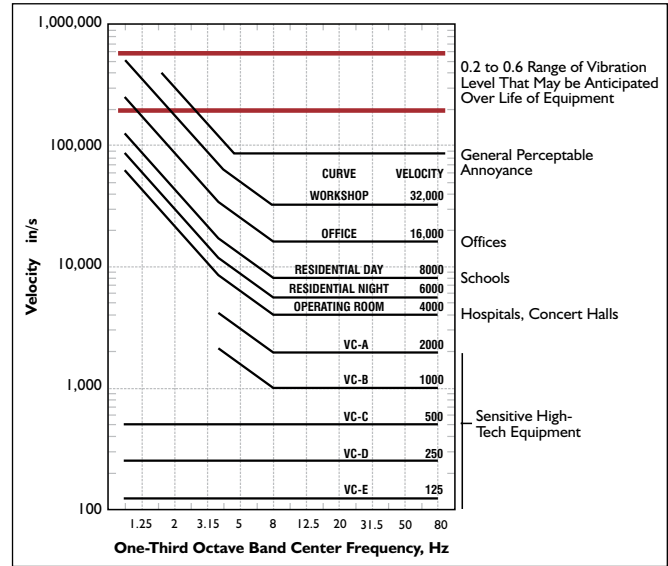


Figure 2: Comparison of equipment vibration levels to acceptable vibration levels in the occupied space.

effect of damping.

Percent transmissibility, T , is the percentage of the total force transmitted to the supporting structure through the isolators. Theoretical percent transmissibility can be calculated from the formula shown in *Figure 5* for damped and undamped isolators. A steel coil spring can be assumed an essentially undamped isolator. Many isolator materials such as elastomer-type isolators and pad-type isolators possess inherent damping, which should be considered when using this formula.

Isolation efficiency, E , is equal to 100% minus the percent transmissibility and indicates what percent of the vibratory forces will not be transmitted to the supporting structure.

Frequency or efficiency quotient, E_d , is equal to f_d/f_n . *Figure 5* shows the application of the frequency quotient. The higher the ratio of the disturbing frequency to the natural frequency of the isolators, the lower the percent transmissibility of the vibratory forces. Thus, it is sometimes referred to as an efficiency quotient. The higher this quotient, the higher the isolation efficiency. As a general rule, for minimum vibration isolation this ratio should be a minimum of 3. 5.

Resonant amplification is a phenomenon that occurs when the disturbing frequency matches the natural frequency of the isolators, i.e., $f_d = f_n$. Under this condition, the isolators dramatically amplify the vibratory forces.

Figure 5 is the graph of *transmissibility versus frequency quotient*. The effect of *resonance* and damping can be seen from the curve.

Practical Application and Implementation

Although the formulas used to estimate vibration

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isolation are fairly easy, the effort to wade through through the formulas for many pieces of the equipment in a typical building can be time consuming. To simplify this process, the vibration transmissibility chart in *Table 1*, can be used to quickly determine the static deflections required in an isolator to limit the transmission of vibration.

This table is only accurate for practically undamped isolators (e.g. steel springs, air springs). Elastomeric mounts and pads have damping and produce higher dynamic stiffness. This results in higher transmissibility. As a rough rule of thumb, double the required deflection given in the table for an elastomeric-type isolator. This factor may change as a result of dynamic characteristics of the elastomer (durometer, shape, formula, etc.) Contact the isolator supplier if more exact damping properties are needed.

Example

Assume, for example, that the wheel of a cooling tower fan rotates at 600 rpm (cpm), which is the lowest frequency of vibration (disturbing frequency). The cooling tower will be placed on steel spring isolators. To ensure negligible vibration enters the building, it is determined to keep the vibration transmissibility below 5%. Using the chart in *Table 1*, the intersection of the 600 rpm row and the 5% transmission column reveals that an isolator with a static deflection of 2.1 in. (53 mm) is needed to obtain the desired isolation. Industry - supplied spring isolators typically are available in static deflections of 1 in. (25 mm) increments. Field variances make it impractical to expect an exact deflection of 2.1 in. (53 mm). Therefore, round up the specified spring isolator to the next whole number. In this case, a 3 in. (76 mm) rated deflection spring will meet our requirement.

Note that if this tower were placed on pads at about 0.1 in. (2.5 mm) deflection, the vibration transmission is off the chart. The pad natural frequency F_n would

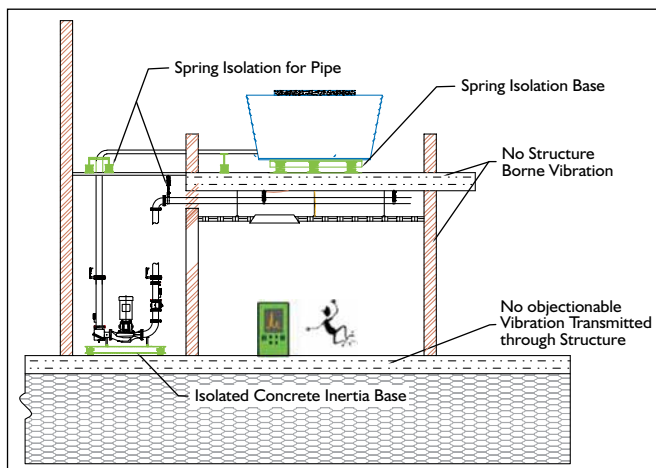


Figure 3: An isolation system helps provide a vibration-free environment.

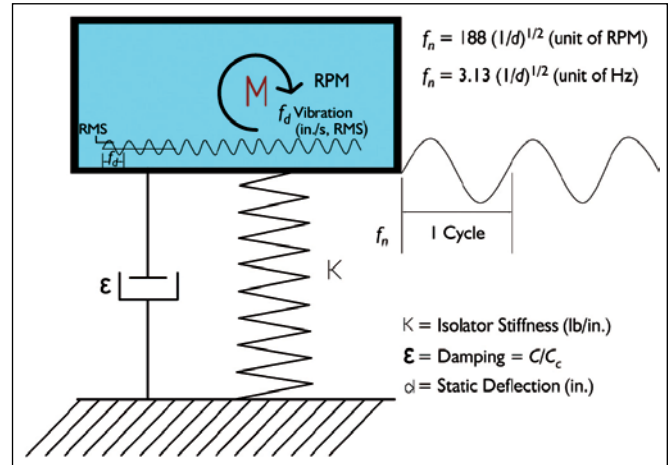


Figure 4: Spring-mass-damper model used to calculate properties of an isolation system.

be between 600 and 800 cpm, resulting in a resonant condition that would amplify the vibration. Therefore, indiscriminant use of isolation can make the problem worse. The vibration isolator must be correctly tuned to the disturbing frequency.

In addition to the static deflection, there are a few other important considerations when mounting equipment on vibration isolators in the field.

How much Isolation is Needed?

The first consideration is the criticalness of the installation. The more critical the installation, the more efficient the isolation must be. This is somewhat subjective, but some basic common sense usually can be applied to decide how critical an installation should be: equipment on grade, next to a warehouse would be noncritical; equipment in a general office building, but away from occupied areas could be considered an average sensitive installation; if equipment is directly above or adjacent to occupied rooms, it is usually considered sensitive; close proximity to classrooms, quiet environment tenants or conference rooms can create a more sensitive nature; and theaters, performing arts, high-tech installations,

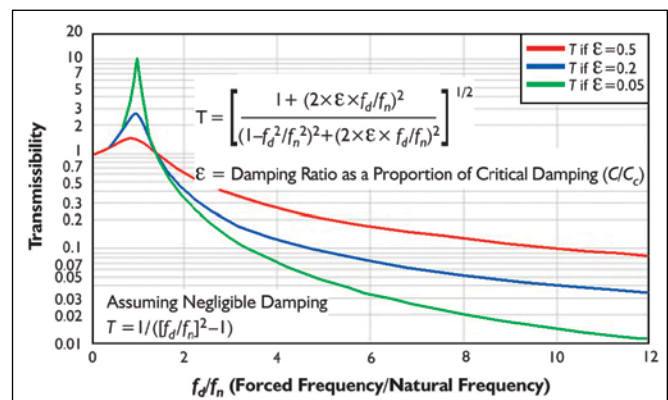


Figure 5: Transmissibility versus frequency or efficiency quotient.

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and hospitals usually would be considered critical installations with little tolerance for vibration or vibration-induced noise. As a general guide, select isolators with a maximum transmissibility of 3% for critical installations, 5% for sensitive installations and 10% for nonsensitive. If in doubt, it is usually a negligible cost to err on the conservative side.

Once the maximum allowable transmissibility has been decided, use *Table 1* to determine the minimum static deflection required to achieve the desired efficiency. The static deflection of the isolation system at the equipment operating weight is something that can be easily field verified. It is not practical for an installing contractor or inspector to try to verify the isolator natural frequency for isolated equipment. Therefore, the minimum static deflection becomes the key factor to specify to obtain the needed isolation.

Equipment Location and Substrate

Location, location, location. What is true in real estate is true in designing for low vibration transmission. The first and best option is to locate equipment as far away from occupied or sensitive areas as possible. If equipment must be located near occupied or sensitive areas, then try to place the equipment adjacent to areas such as bathrooms, storage areas, or hallways to create a buffer zone between the equipment and the more sensitive locations.

Next, consider the support structure. Rigid structure is needed beneath the isolated HVAC&R equipment to work properly. The stiffness is a function of the column spacing, the structural material used (wide flange, open web, prestressed or posttensioned concrete), and the construction. In general, heavier construction (concrete deck with heavy wide flange or concrete beams) is more rigid than light weight construction (open web joist, shallow concrete or wood deck). In some cases, especially lighter construction roofing, the floor can be flexible, and its natural frequency can be close to resonance with the vibration disturbing frequency. This requires greater isolation than with a stiff structure. To avoid problems, it is a good rule of thumb to use an isolator with a deflection of 10 times what the floor will deflect due to the equipment

| Equipment Speed (RPM) | Vibration Transmission – Percentage | | | | | | | | |
|-----------------------|--|------|------|------|------|------|------|------|------|
| | 0.50% | 1% | 2% | 3% | 5% | 10% | 15% | 25% | 40% |
| | Static Deflection Required for Isolator* | | | | | | | | |
| 3,600 | 0.55 | 0.27 | 0.14 | 0.09 | 0.06 | 0.03 | 0.02 | 0.01 | 0.01 |
| 2,400 | 1.2 | 0.62 | 0.31 | 0.21 | 0.13 | 0.07 | 0.05 | 0.03 | 0.02 |
| 1,800 | 2.2 | 1.1 | 0.56 | 0.37 | 0.23 | 0.12 | 0.08 | 0.05 | 0.04 |
| 1,600 | 2.8 | 1.4 | 0.7 | 0.47 | 0.29 | 0.15 | 0.11 | 0.07 | 0.05 |
| 1,400 | 3.6 | 1.8 | 0.92 | 0.62 | 0.38 | 0.2 | 0.14 | 0.09 | 0.06 |
| 1,200 | 4.9 | 2.5 | 1.3 | 0.84 | 0.52 | 0.27 | 0.19 | 0.12 | 0.09 |
| 1,100 | 5.9 | 2.9 | 1.5 | 1.0 | 0.61 | 0.32 | 0.22 | 0.15 | 0.1 |
| 1,000 | 7.1 | 3.6 | 1.8 | 1.2 | 0.74 | 0.39 | 0.27 | 0.18 | 0.12 |
| 900 | 8.8 | 4.4 | 2.2 | 1.5 | 0.92 | 0.48 | 0.34 | 0.22 | 0.15 |
| 800 | 11.1 | 5.6 | 2.8 | 1.9 | 1.2 | 0.61 | 0.42 | 0.28 | 0.19 |
| 700 | - | 7.3 | 3.7 | 2.5 | 1.5 | 0.79 | 0.55 | 0.36 | 0.25 |
| 600 | - | 9.9 | 5.0 | 3.4 | 2.1 | 1.1 | 0.75 | 0.49 | 0.34 |
| 550 | - | 11.8 | 6.0 | 4.0 | 2.5 | 1.3 | 0.9 | 0.59 | 0.41 |
| 400 | - | - | 11.3 | 7.6 | 4.6 | 2.4 | 1.7 | 1.1 | 0.77 |
| 350 | - | - | - | 9.9 | 6.1 | 3.2 | 2.2 | 1.4 | 1.0 |
| 300 | - | - | - | - | 8.3 | 4.3 | 3.0 | 2.0 | 1.4 |
| 250 | - | - | - | - | - | 6.2 | 4.3 | 2.8 | 2.0 |

*Table assumes negligible damping (open spring coil). Elastomeric type isolators will have inherent damping, resulting in higher transmissibility. Increase required static deflection by a factor of 2 (or as recommended by the isolator manufacturing) to account for damping

Table 1: Quick reference chart to determine isolator deflection required to limit vibration transmission.

weight. It is helpful to locate heavy equipment near columns or heavy-duty beams.

Available Isolator Types

Once the isolator deflection is resolved, it must be determined what type or style of isolator best suits the installation. There are a number of isolator styles that can be used. The different styles address practical installation issues encountered with various types of equipment. The following components are shown in *Figure 6*.

Open steel spring isolators provide high efficiencies, adjustability, and long maintenance-free life. These are the most common isolators used in the commercial industry. They are available in static deflections from 0.75 to 6.0 in. (19 to 152 mm), yielding natural frequencies from 4 to 1.3 Hz. Springs are an adjustable, free-standing, open-spring mounting. The springs are fastened to an integral cup/base plate or welded to the spring mounting base plate and compression plate for stability. The isolator is usually designed for a minimum k_x/k_y (horizontal-to-vertical spring rate) of approximately 1.0, and with a minimum outside diameter to operating height of 0.8 to ensure stability.

All steel springs should be used with elastomer pads or cup under the spring or base plate to provide anti-skid and a barrier to high-frequency noise that might pass directly

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through the steel spring. Every steel spring has a surge frequency at which vibration passes through without being isolated. If you thump a spring, it will resonate a ring tone (the surge frequency). This is a very high frequency that is not usually an issue. However, on the off chance that there exists vibration in the equipment that resonates with the surge frequency, the pad under the base plate effectively isolates it.

Restrained spring isolators use the open steel spring isolator type, and incorporate built-in restraints to prevent outdoor equipment from too much sway due to wind load. The restraint housing, which serves as a blocking device during equipment installation, also has restraint bolts to limit vertical movement resulting from large load variations as when equipment is filled or drained of water. This reduces strain on connections such as piping. The spring package is isolated from the housing by an elastomeric pad beneath the spring or base plate for high-frequency vibration absorption at the base of the spring. The spring assembly is typically removable with equipment in place. This enables changing springs out if needed without lifting the equipment or removing the housings. Restraints must have elastomeric grommets and adequate clearance to prevent shorting out the isolator. They are commonly available for loads from 15 to 25,000 lbs (67 to 111,200 N), and are customizable for virtually any load. These are the most common isolator types used for HVAC&R equipment such as cooling towers and chillers.

Housed telescoping isolator provides wind horizontal restraint and damping, but no vertical restraint.

Elastomer-type mountings provide 0.25 to 0.5 in. (6 to 13 mm) deflection, but inherent dampening in elastomers increases vibration transmission above theoretical. They are generally adequate for high frequencies and non-critical installations.

Elastomeric pads are generally used for very high-speed equipment or electrical (transformers, etc.) equipment and less critical installations. The typical static deflection is from 0.05 in. to 0.15 in. (1 mm to 4 mm). These materials are widely used as barriers against high-frequency noise transmission, and are also used as decouplers in floating floors.

Spring and elastomeric hangers are used for isolating suspended equipment pipe and duct. They consist of a steel box, coil spring, spring retainers and elastomeric element. To account for hangers that are out of plumb, the box may allow 30-degree rod misalignment.

Wire ropes are isolators made up of helical, stranded-wire rope held with metal retaining bars. This design provides excellent shock and vibration isolation in a multiple range of applications. These isolators offer specific response

characteristics based on the diameter of the wire rope, the number of strands, the cable loop length and the number of loops per section. The large dynamic displacement attenuates vibration, while the inherent damping provided by the sliding friction between the strands of the wire rope minimize post-shock noise and lower resonant peaks.

Air springs provide the ultimate in high efficiency and adjustability. They have long life, but they require a constant compressed air source and maintenance (such as a car tire). Air springs can be designed to provide natural frequencies from 4 Hz down to as low as 1.0 Hz. This isolation media allows a minimum height for extremely high efficiencies. They are not normally used in commercial installations as the expense and maintenance is considerably higher than other isolator types. They are used for extremely critical installations.

Base and Rail Requirements

Often equipment is not designed to be mounted on point-loaded isolators and may not have the rigidity to be direct mounted to isolators. If the equipment has a high center of gravity and a narrow foot-print, it may be susceptible to unstable rocking when direct-mounted to isolators. Some equipment can experience large unbalanced forces that require a solid mass support to stabilize and counteract the forces. In such circumstances, the equipment must be mounted on a properly designed base or rail, which is then mounted on the vibration isolator. The following are illustrated in *Figure 7*.

Rails may be used whenever equipment simply needs a level bearing surface to distribute the weight to the vibration isolator support. Made from channels, angles, wide flanges, and such, they are typically used on smaller fans, AHU, vent sets, packaged units, etc., that cannot be point loaded. Note, rails are not recommended for an installation that may be subject to earthquake or heavy wind loads, since the rails may tend to twist when subject to seismic or high wind loads.

Integral steel base is a welded steel frame that provides extra rigidity to maintain proper drive alignment for equipment such as belt-driven fans with separate motor mounts. The added strength and rigidity resists racking due to start-up torque. Steel bases also can be designed to withstand seismic and wind loading. Bases are generally made from wide flange, channel or angle, and can be provided with a motor slide rail for adjusting and tightening belt tension. Many equipment generic submittals show two wide flange rails supporting the equipment. This assumes the rails are rigidly attached or mounted to structure or grade. When the wide flange is mounted on springs, there is no longer a rigid attachment, and the rail is susceptible to twisting under wind or seismic loads. Thus, it is

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recommended to create a full base to resist these loads.

Concrete inertia bases provide the same advantages as a steel base, plus providing a solid base with extra mass as needed to provide maximum stability. A concrete inertia base provides:

- Increased rigidity for heavy and/or high horsepower equipment;
- A lower center of gravity and wider footprint to prevent rocking instability for tall, narrow equipment; and
- Increased mass to prevent high momentary or cyclical unbalanced forces from causing too much movement in the springs.

These types of bases are used with pumps, compressors, large fans (40 in. [1 m] wheel diameter or more), etc.

Roof curb isolation rail. Rooftop equipment often is mounted on a roof curb. For this, a continuous roof curb isolation rail is mounted on top of the roof curb. It consists of a top and bottom weatherproofed aluminum or formed metal rails for mounting between the equipment and roof curb. It provides a continuous air and water seal, which is protected from accidental puncture and direct sunlight by a weather shield. Rails incorporate spring isolators properly spaced and sized around the perimeter to maintain the specified deflection, and contain built-in seismic/wind restraints. Flexible connectors must be used between the isolated unit and the duct. Most suppliers offer options for flexible duct supports and sound barrier packages.

Integral isolation curb or pedestal. This type of rooftop support combines the equipment curb and isolation into one package, and is used as a structural spring isolation curb capable of resisting strong seismic and wind loading. The upper frame provides continuous support for the equipment. The lower frame accepts isolator point support and seismic/wind restraint. The upper frame must be designed with positive fastening provisions (welding or bolting) to anchor the rooftop unit to the curb in a manner that will not affect waterproofing. There is a continuous air seal between the upper floating member and the stationary bottom. A wood nailer is provided on the bottom portion for roofing/flashing. Spring locations have access ports with removable waterproof covers so isolators can be adjustable, removable and interchangeable. These type of curbs typically have a means to allow roof insulation and sound attenuating that act thermally outside and acoustically

inside. Flexible connectors must be used between the isolated unit and the duct. Most can be supplied with sound barrier packages and plenums.

Equipment Schedule

To ensure that the right isolation needed for the job is installed, it is essential that all the disciplines involved in the construction process know what is required. The design team, the mechanical engineer, the contractor, and the vendor must all be on the same page. The best way to accomplish this is via an equipment isolation schedule. Table 2 shows a portion of the suggested schedule from ASHRAE Handbook – HVAC Applications, Chapter 47, Table 48. The minimum deflections, listed in Table 48, recommended isolator type, and base type, are good recommendations for most HVAC equipment installations. The selections are based on typical concrete equipment room floors with typical floor stiffness. Projects of a more sensitive or critical nature or equipment, proximity to noise-sensitive areas may require more isolation than listed. In such circumstances, an acoustical professional is usually needed to design job specific isolation requirements.

Consider the following when using the table for isolator selection and applications:

- For equipment mounted on upper floors with longer column spans (30–40 ft [9–12 m]) or lightweight roof construction, use the far right column. This column may also be

used for equipment where isolation of the vibration is critical.

- Equipment located on upper floors with medium column spans (20–30 ft [6–9 m]) use the second column from the right. This column would also be used for equipment located anywhere in close proximity to sensitive areas.

- For upper floors that are stiff (10–20 ft [3–6 m] column spacing), use the second column from the left in the table. This may also be used for equipment on grade near noise sensitive areas.

- The first column is used for equipment located on grade in a nonsensitive location.

Pipe

Isolating piping is essential to completing the vibration isolation system. It also will accommodate thermal movement of the piping without imposing undue strain on the connections and equipment. Therefore, the following is suggested to provide a system that helps prevent vibration

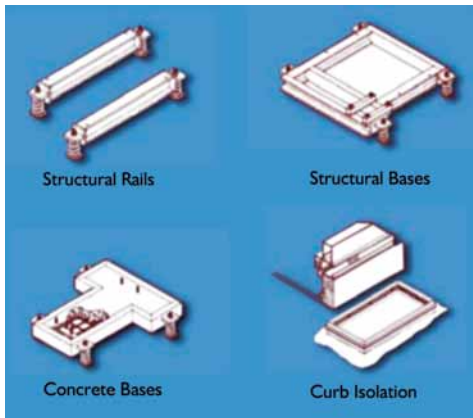


Figure 7: Support base options.

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| Equipment Type Horsepower and Other RPM | | | Equipment Location (Note 1) | | | | | | | | | | | | Reference Notes |
|---|---------------|-----------------|-----------------------------|---------------|-----------------|-------------|---------------|-----------------|-------------|---------------|-----------------|-------------|---------------|-----------------|-----------------|
| | | | Slab on Grade | | | Floor Span | | | | | | | | | |
| | | | Base Type | Isolator Type | Min. Defl., in. | Up to 20 ft | | | 20 to 30 ft | | | 30 to 40 ft | | | |
| 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. | Base Type | Isolator Type | Min. Defl., in. | |
| Refrigeration Machines and Chillers | | | | | | | | | | | | | | | |
| Reciprocating | All | All | A | 2 | 0.25 | A | 4 | 0.75 | A | 4 | 1.50 | A | 4 | 2.50 | 2,3,12 |
| Centrifugal, Screw | All | All | A | 1 | 0.25 | A | 4 | 0.75 | A | 4 | 1.50 | A | 4 | 1.50 | 2,3,4,12 |
| Open Centrifugal | All | All | C | 1 | 0.25 | C | 4 | 0.75 | C | 4 | 1.50 | C | 4 | 1.50 | 2,3,12 |
| Absorption | All | All | A | 1 | 0.25 | A | 4 | 0.75 | A | 4 | 1.50 | A | 4 | 1.50 | |

Table 2: Excerpt from the Selection Guide for Vibration Isolation (see 2007 ASHRAE Handbook—HVAC Applications, Chapter 47, Table 48 for complete schedule).

from leaking through the piping system.

Horizontal Pipe. Isolate all HVAC and plumbing pumped water, pumped condensate, glycol, refrigerant, and steam piping size 1¼ in. and larger within mechanical rooms. Outside equipment rooms this piping should be isolated for the greater of 50 ft or 100 ft (15 or 30 m) pipe diameters from rotating equipment. To avoid degrading the isolation for the equipment the first three support locations from equipment, provide isolation hangers or floor mounts with the same deflection as equipment isolators. All other piping within the equipment rooms should be isolated with a ¾ in. (19 mm) minimum deflection isolator. Any piping below or adjacent to a noise-sensitive area should also be isolated with a combination spring and rubber hanger. For installation purposes, the first two hangers adjacent to the equipment may be the positioning or precompressed type to prevent load transfer to the equipment flanges when the piping system is filled. The positioning hanger aids in installing large pipe, and therefore some use this type for all isolated pipe hangers for piping 8 in. (203 mm) and larger.

Flexible connectors at equipment provide piping flexibility to protect equipment from strain due to misalignment or thermal movement of piping. They can also help attenuate noise and vibration. Connectors are available in two common configurations for HVAC equipment: 1) The arched or expansion joint type, is a short-length connector with one or more large radius arches of an elastomer such as rubber, EDPM or PTFE (Figure 6). 2) The metal expansion joint types are convoluted stainless hose with stainless braids (Figure 6). The elastomeric arched joints provide for axial, lateral and rotational movement, and attenuate vibration-induced noise transmitted to the pipe wall. Metal hose provide lateral movement. Two hose can be installed in an L-, U-, or V-shape to obtain multidirectional movement. Metal hose is not as acoustically effective for sound isolation nor control of vibration-induced noise. They are commonly

used to provide for thermal movement, mechanical vibration, or differential movement experienced in earthquakes, and they can be used at temperatures and pressures beyond the ability of elastomeric type. Check the flex manufacturer’s literature for proper application and for chemical compatibility to insure the flex material is appropriate for the fluid or gas in the system.

Flex connectors should not be viewed as a substitute for pipe isolation hangers. When under pressure, they can become more rigid and control rods can become heavily loaded in tension, which can degrade the isolation. Since flex connectors do not completely attenuate vibration and do not control flow-induced noise, resilient hangers or supports should still be used.

Isolate *pipe risers* using isolators similar to those shown in Figure 6. This system eliminates the need for anchors or guides, and gives effective vibration isolation and acoustical break. In totally floating risers, springs are carefully engineered to accommodate the thermal movement, as well as, guide and support the pipe. This system also results in more consistent loads on the structure, as the springs allow the riser to float and move without a large change in load. Isolation of branch lines and riser take-offs must also be coordinated with the riser isolation to accommodate anticipated thermal displacement and to obtain a system without excessive stress.

All variable temperature vertical pipe risers 1¼ in. (32 mm) and larger should be considered for spring support using floor-mounted open steel springs or steel hangers. It is good practice to select a spring deflection that is a minimum of four times the anticipated deflection change with a ¾ in. (19 mm) minimum. Typically, risers 12 in. (305 mm) or less can be supported at intervals of every third floor of the building. Pipe risers 14 in. (356 mm) and over may require support at closer intervals.

Wall and floor penetrations often are overlooked as a vibration path. Significant acoustic energy can pass through a small opening in a wall or floor. Therefore, it is

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very important to seal openings with an acoustical barrier to prevent contact and decrease sound transmission. This can be done with an engineered sleeve, as shown in figure or, by filling the annular space with fibrous material and non-hardening caulk. Wall sleeves for take-offs from risers shall be sized for insulation O.D., plus two times the anticipated movement to prevent binding.

Duct

Similar to pipe, duct can experience vibration in the walls due to flow pulsations and turbulence caused by abrupt changes in direction or geometry. Although vibration is not as common a problem with duct, isolation hangers should be used in critical areas to ensure no vibration transmits through the hanger walls and into the building. It is good practice to isolate the first 50 ft (15 m) from AHU or fan discharge and where the duct is supported beneath or adjacent to a vibration sensitive area. This is especially recommended for large duct with a velocity of 25 fps or more. Spring or combination spring and rubber hangers are recommended.

Flexible canvas and elastomeric duct connections should also be used at fan and AHU discharge and intake. To prevent the flex from being overextended or becoming rigid, and thus defeating its purpose, a spring thrust restraint as shown in Figure 6 should be considered when the static pressure is more than 2 in. (51 mm).

Seismic Restraint Consideration

Although restraint of equipment against earthquake loads is not the main focus of this article, it is imperative that seismic restraint be mentioned briefly as it pertains to isolation. Check local building codes to determine if seismic restraint is required for equipment. Since the adoption of the IBC by most states, the requirement for seismic restraint has increased. Sixty to seventy-five percent of the U. S. is now subject to some degree of seismic restraint.

The design of equipment isolators must take into account special considerations if seismic restraint is required by the code. One common misconception is that the isolation system will isolate the earthquake from the equipment. In reality, an earthquake has peak ground accelerations close to the resonant frequencies of standard isolation systems. This places the earth-quake accelerations close to the peak in *Figure 5*. The result is amplified forces that have been known to make equipment leap across a mechanical room and through a wall. Therefore, the isolated systems must be tied down. To prevent the shorting out the isolators, restraints should be designed with about a ¼ in. (6.4 mm) gap so it is not engaged during normal operation. Hanging equipment pipe or duct is typically accomplished with restraint cables installed with slight

slack to eliminate any dead load during normal operation, and minimize any vibration transmission through the cable. For more complete information see ASHRAE's *A Practical Guide to Seismic Restraint* and *ASHRAE Handbook – HVAC Applications*, Chapter 53, Seismic and Wind Restraint. In addition, industry guides can be obtained from SMACNA and VISCMA.

Summary

As with all equipment, HVAC&R equipment produces vibration. As demonstrated in this paper, even the smoothest running equipment can produce vibration that is higher than the acceptable range for many occupants. Building components and pipe provide conduits that effectively transmit vibration throughout the building, which results in complaints about felt vibration or vibration induced noise. Fortunately, the path of the vibration can be readily cut off with a properly designed vibration isolation system. Following the basic isolation techniques presented in this paper is recommended to help achieve an acceptable vibration environment. An isolation system installed with the equipment can provide insurance against vibration induced complaints. Retrofitting after complaints develop is often far more expensive than an original installation – as “a penny of prevention is worth a pound of cure.”

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