Vibration Control Design of High Technology Facilities

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High technology equipment such as that used for the production of advanced integrated circuits, for precision metrology, and for microbiological or optical research, requires environments with extremely limited vibrations. Ground motions, personnel activities, and the extensive support machinery typically present in high technology facilities may produce unacceptably severe vibrations, unless mitigation of these vibrations is taken into account in the facility design. This article is intended to present pertinent facility design criteria and to summarize approaches to achieving the desired vibration environments.

The first of the following sections discusses the development of simple, practical facility criteria from equipment specifications and presents a suggested set of general criteria. Subsequent sections present an overview of approaches and means for dealing with vibrations generated by sources outside and within a facility.

Vibration Criteria

A completely vibration-free environment is as unachievable as are such other idealized abstractions as immovable objects, irresistible forces or perfect vacua. Fortunately, in practice it generally suffices to provide an environment that is adequately vibration free – that is, an environment that does not exceed suitably selected vibration limits. Establishment of appropriate limits is crucial to the successful design of a sensitive facility; limits that are insufficiently stringent lead to degradation in the performance of sensitive equipment, whereas limits that are too stringent lead to excessive complexity and increased costs.

For a given sensitive facility – be it a plant area for the manufacture of integrated circuits, a microbiology research laboratory, an optical calibration facility, or a metrology laboratory – it is logical to select the limit of permissible vibration to correspond to the most severe vibration environment under which all critical items of vibration-sensitive equipment can operate satisfactorily. This approach to development of an appropriate vibration criterion is relatively straightforward, at least in concept, if all equipment items to be placed in the facility are fully identified and if the acceptable vibration limits for all items are known. In this case, one simply needs to require that the environmental vibration in each given frequency band does not exceed the greatest vibration magnitude that is acceptable for the equipment with the most stringent limitation in that band. (Of course, different equipment items may determine the criterion values in different bands. Also different criteria may apply in different locations of a given facility.)

In practice, however, development of facility vibration criteria involves some complications. The equipment to be installed in a facility may not be fully defined at the time the facility is being designed – and new equipment with initially undetermined sensitivities is likely in the future to replace or supplement the originally installed equipment. Furthermore, acceptable vibration limits for many sensitive items of equipment are not known adequately. Although most equipment manufacturers provide some sort of specification that sets limits on the environmental vibrations of the areas where this equipment is to be installed, many of these specifications tend to be overconservative and many are inadequately defined in that they do not indicate the frequency ranges in which they apply or the frequency bandwidths in which measurements are to be made.

Criteria for Sensitive Equipment. For the purpose of developing practically useful facility vibration criteria, we have reviewed numerous specifications provided by equipment manufacturers and also have carried out measurements on a number of equipment items of various types. We have found that specifications which are based on frequency dependent tests may conveniently be bounded by curves of constant velocity. Figures 1 to 3 show manufacturer's environmental vibration specifications for three different types of sensitive equipment, together with lines of constant velocity which essentially represent lower bounds to the data. Availability of these lines permits one to state a conservative environmental vibration criterion for a given equipment item in terms of a single number – the vibration velocity corresponding to the aforementioned bound on the data.

It is clear, however, that applicability of a given vibration velocity criterion must be limited to a restricted frequency range. One may expect that the operation of mechanical or optical devices in general is affected by internal deflections or relative displacements – and not by overall (absolute) motions. Because support motions at frequencies that are considerably below a device's fundamental natural frequency can produce only comparatively small relative displacements, a device's performance is likely to be relatively unaffected by support motions at low frequencies. In other words, at frequencies below a certain value, the device can be permitted to be exposed to greater support motions. At high frequencies, the device's structure is likely to provide some isolation of its sensitive internal components; also, at these frequencies, conventional vibration isolation means can be used to greatly attenuate the motions transmitted from the supporting structure to the device. Thus, considerably greater support motions are generally acceptable at high frequencies than in the mid-frequency range.[1-3]

The foregoing considerations have led to the development of the general criterion curve shown in Figure 4. A constant vibrational velocity value applies between 8 and 80 Hz. Below 8 Hz, two alternatives are indicated which depend on the fundamental natural frequency of sensitive equipment: (1) for equipment items that do not incorporate pneumatically isolated systems, the velocity criterion increases by a factor of 2 from 8 Hz to 4 Hz and does not extend below 4 Hz; (2) for equipment with pneumatically isolated systems, the velocity criterion remains constant and extends down to 1 Hz. Below and above the frequency range indicated in Figure 4, no generally applicable data are available, but much greater vibrational velocities than indicated by the curve may be permissible at these frequencies. The velocity value that applies between 8 and 80 Hz may be used conveniently to designate a given criterion curve.

Although most manufacturers' specifications were developed from tests involving single-frequency or narrow band excitation, we have chosen to state the criteria in terms of one third octave frequency bands. For situations in which a device is subject to excitation at a single frequency or at a few widely separated discrete frequencies – as often is the case where the

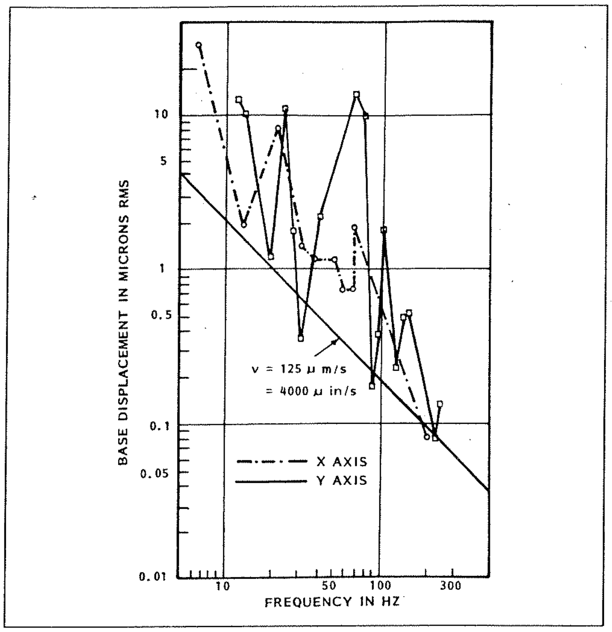


Figure 1. Vibrational base displacements of Perkin-Elmer Micralign Model 341 resulting in 0.1 micron image motion. Solid curve corresponds to vertical, dotted curve to horizontal base vibration. Line represents constant velocity which is approximate lower bound to data. (Data from Perkin-Elmer document MLD 00254 "Micralign Sensitivity to Floor Vibration and Acoustic Disturbances.")

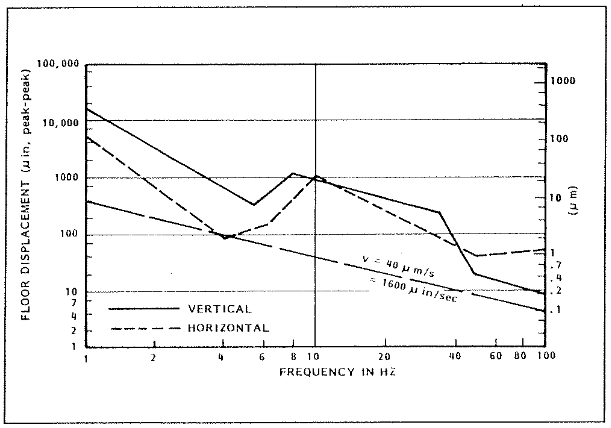


Figure 2. Allowable floor vibration for Mann Type 4800 DSW Wafer Stepper, with standard isolation table, as specified by manufacturer on basis of vibration tests. Solid curve corresponds to horizontal, dashed curve to vertical floor vibration. Line represents constant velocity which is lower bound to curves. (Floor vibration specifications from GCA Corporation Technical Note "Floor Vibration Environment for the Mann Type 4800 DSW Wafer Stepper".)

dominant vibrations in a building are due to various items of rotating machinery – one obtains practically the same vibration in a one third octave band that encompasses a dominant narrow band as one obtains in the narrow band; in this case, the bandwidth in terms of which the criterion is stated in essence does not matter. However, use of a criterion that is stated in terms of narrow bands does not account for the fact that broadband excitation or closely spaced single-frequency components may have an interactive effect on a sensitive component. We have chosen criteria in terms of one third octave bands because one third octave bands represent a reasonable approximation to the modal response bandwidths of realistic components, provide a good compromise between too much detail and too little resolution of data, and permit data to be analyzed by means of readily available instrumentation.

The criterion curve of Figure 4 that extends down to 4 Hz has the same shape as the criterion curves adopted by the International Standards Organization (ISO) and the American National Standards Institute for characterization of floor vibrations in a building in relation to human comfort. Although the curve of Figure 4 applies to sensitive equipment and was developed on the basis of equipment data, which is unrelated to human comfort considerations, the somewhat coincidental similarity of the two criteria permits one to compare them readily.

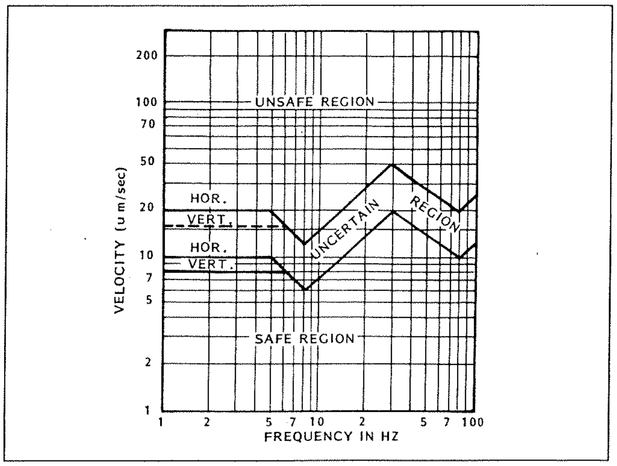


Figure 3. Allowable floor vibrations for Philips Electron Beam Pattern Generator Beamwriter EBPG-4, as specified by manufacturer (from installation conditions manual 4822-874-80301). Lower bound to dividing line between safe and uncertain operating regions is 6 μm/sec = 240 in/sec.

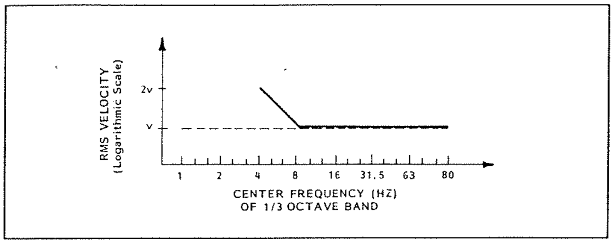


Figure 4. General criterion curve, to be used with values of Table 1. Solid curve pertains to equipment without pneumatically isolated systems, dashed curve to equipment with low-frequency pneumatic isolation.

Facility Criteria. Table 1 lists velocity criterion values (corresponding to the aforementioned 8 to 80 Hz region) that have been found suitable for facilities housing various classes of sensitive equipment, together with some values suggested by the International Standards Organization and the American National Standards Institute[4,5] for several different building space usages. It is important to note that the listed criterion values were developed on the basis of available data;[2,3] although these criteria are generally conservative and have led to numerous successful facility designs, it is possible that they may not be adequate for some particularly sensitive new items of equipment.

In selecting a vibration criterion for a facility, one needs to consider the extent to which occasional disturbances may be acceptable. For example, the blurring of an image in an optical microscope resulting from occasional heavy foot traffic in a nearby corridor may annoy the microscope's user a little, but is likely to have little effect on the progress of research in the laboratory, whereas even a brief disturbance of a manufacturing process may lead to serious production losses. Clearly, one would be inclined to prescribe stringent criteria in situations where disturbances have more severe consequences, e.g., where disturbances occur continuously and where continuous undisturbed equipment operation is essential, whereas one might relax the criterion for areas in which disturbances occur only occasionally and can be tolerated. Where the effect of vibration on productivity is known, the permissible vibration exposure may be specified in terms of exceedance statistics –

e.g., in terms of the L_n vibration levels (the levels exceeded n% of the time) analogous to those commonly used for characterization of environmental noise.

Categories of Vibration Sources

The major sources of vibrations of concern in relation to high technology facilities fall into three categories: external sources, internal activities and service machinery. Figure 5 illustrates schematically how vibrations from such sources propagate to sensitive areas.

External sources include ambient vibrations at the site (sometimes called micro-tremors), nearby road and rail traffic (including underground and elevated roads and rail systems), construction activities (including blasting), and machinery operating in the vicinity (either outdoors or in nearby buildings).

Internal activities include personnel walking (footfalls) and service activities (e.g., repair and construction), in-plant vehicles (such as forklifts and carts), and production work (e.g., actuation of production machines or other tools).

Service machinery includes all mechanical and electrical equipment that either is part of the building's system or that is installed by the building's users. It includes air-conditioning and distribution fans, chillers, cooling towers, furnaces, and all pumps, compressors and vacuum pumps, as well as elevators and mechanically actuated doors and loading platforms.

Externally Generated Vibrations

Site Selection. It stands to reason that vibration-sensitive facilities should be sited where ambient ground vibrations are acceptably small. Thus, such facilities should be located in areas where there exists no significant nearby road or rail traffic and in whose vicinity there is expected no continuing construction activity or other heavy machinery operation. At a given building site, it generally is advantageous to locate vibration-sensitive activities as far from external vibration sources as possible.

Table 1. Vibration criteria.

Facility Equipment or Use	Vibration Velocity* (μin/sec)	(μm/sec)
Ordinary workshops	32,000	800
Offices	16,000	400
Residences**; Computer systems	8,000	200
Operating rooms; Surgery; Bench microscopes at up to 100× magnification; Laboratory robots	4,000	100
Bench microscopes at up to 400× magnification; Optical and other precision balances; Coordinate measuring machines; Metrology laboratories; Optical comparators; Microelectronics manufacturing equipment – Class A***	2,000	50
Micro-surgery, eye-surgery, neuro-surgery; Bench microscopes at magnification greater than 400×; Optical equipment on isolation tables; Microelectronics manufacturing equipment – Class B***	1,000	25
Electron microscopes at up to 30,000× magnification; Microtomes; Magnetic resonance imagers; Microelectronics manufacturing equipment – Class C***	500	12
Electron microscopes at greater than 30,000× magnifiication; Mass spectrometers; Cell implant equipment; Microelectronics manufacturing equipment – Class D***	250	6
Microelectronics manufacturing equipment – Class E***; Unisolated laser and optical research systems	130	3

* Value of V for Figure 4

** Criterion given by solid curve of Figure 4 corresponds to a standard mean whole-body threshold of perception (Ref. 4)

*** Class A: Inspection, probe test, and other manufacturing support equipment.

Class B: Aligners, steppers and other critical equipment for photolithography with line widths of 3 microns or more.

Class C: Aligners, steppers and other critical equipment for photolithography with line widths of 1 micron.

Class D: Aligners, steppers and other critical equipment for photolithography with line widths of 1/2 micron; includes electron-beam systems.

Class E: Aligners, steppers and other critical equipment for photolithography with line widths of 1/4 micron; includes electron-beam systems.

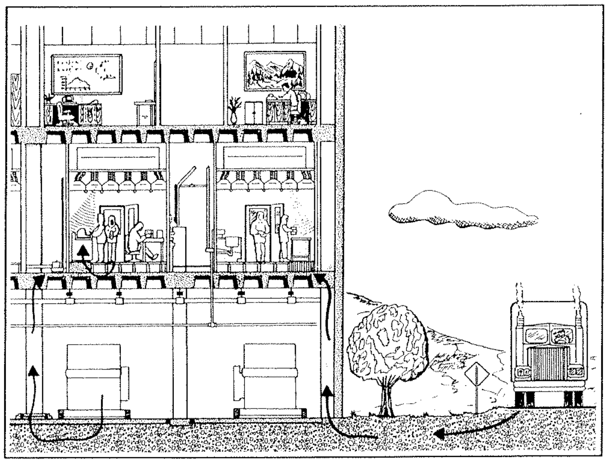


Figure 5. Propagation of vibrations from typical major sources to sensitive areas.

A site vibration survey generally is advisable for evaluation of the suitability of a given site for a given facility and for the selection of favorable locations at a given site. Such a survey may need to consider the weather-related variations in the vibration-transmission properties of the ground (which properties may depend on moisture content, temperature and the height of the water table, among other things), local geological nonuniformities (e.g., variations in depth of bedrock), the types of foundations to be used, and the daily variations in traffic.[6]

Reduction of Vibration from Traffic. In some instances, one may be able by design to reduce the vibrations generated by an external source. For example, it is well-known that the most severe vibrations associated with road traffic result from heavy vehicles moving rapidly along roads with surface irregularities. Thus, one may reduce vibrations at a site by keeping heavy trucks away from sensitive facilities, limiting the permissible speeds, and smoothing the road surface. Certainly, "speed bumps," potholes, misaligned slabs and expansion joints (in bridges) should not be permitted near vibration-sensitive facilities. Similarly, if the related costs are acceptable, one may consider replacing jointed rail by continuously welded rail in railroad tracks passing near sensitive facilities, and/or placing such rail on thick ballast beds or on resilient rail support systems.[7]

In some situations, schedule control may be most cost-effective. For example, one might confine the use of critical electron microscopes to nighttime, when nearby construction activities have ceased and road traffic is minimal. Alternatively, one might consider installing a vibration monitoring system that senses approaching trains and halts the operation of sensitive equipment during train passages.

Propagating Vibrations. We are aware of no practical means for shielding facilities from vibrations that propagate along the ground. Berms, heavy walls, and other structures above the ground have very little effect on ground vibrational waves at the frequencies of primary concern here. The same is true of trenches, sheet piling, slurry walls and similar underground structures or geotechnical means (e.g., grout injection) of practical size, largely because the wavelengths at the frequencies of concern tend to be great (of the order of 100 ft) and discontinuities that extend over only a fraction of a wavelength fundamentally can provide little attenuation.[8,9]

Foundation Design and Isolation. Some vibration control benefits can be obtained from appropriate foundation design

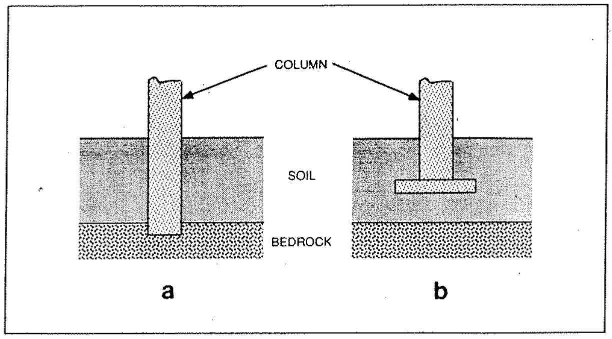


Figure 6. Support of building on quieter stratum: (a) column to bedrock; (b) spread footing on soil.

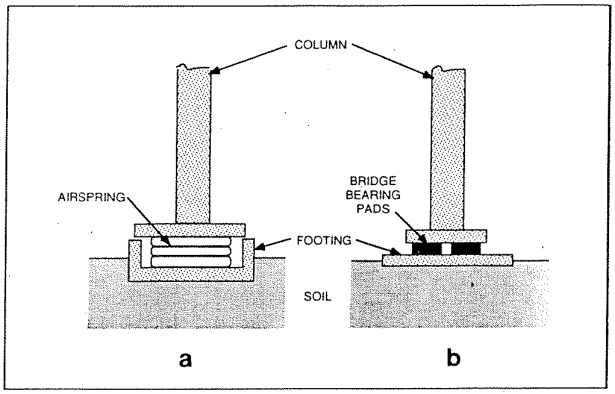


Figure 7. Resiliently supported columns: (a) air springs;[10] *(b) bridge bearing pads. Note: lateral restraints, which may be required for stability, are not shown.*

and from isolating key parts of a facility from soil vibrations. In situations where the ambient vibrations of the bedrock are of relatively small magnitude, compared to those of the surface soil, one may base the building foundations on the bedrock and avoid their coupling to the surface soil (see Figure 6). On the other hand, where the surface soil vibrates less than bedrock, mat foundations or spread footings are preferable from the vibration standpoint. Which of these situations exists depends on the soil conditions and on the locations and types of the predominant external vibration sources.

In some instances, one may also be able to design "tuned" footings that reduce the vibration intrusion in certain frequency ranges. The footing and adjacent soil together act like a spring that supports a portion of the building's mass, so that this arrangement acts somewhat like a classical spring-mass system. At frequencies that lie considerably above the system's natural frequency, only a small fraction of the ground vibration amplitude is transmitted to the mass – i.e., to the building structure. One may "tune" the footings (generally by adjusting their footprint areas and shapes)[8] so that the desired attenuation is obtained in the frequency ranges of interest – or at least to avoid resonances at frequencies at which relatively severe ground vibrations are present. In designing such tuned footings, one generally needs to consider the frequency distribution of the ground vibrations in three orthogonal directions and one needs to account for the different footing stiffnesses and building components that relate to motions in the different directions.

Where footing design cannot provide sufficient attenuation, selected parts of the building may be isolated from ground vibrations by supporting their columns or footings on resilient elements such as neoprene bridge-bearing pads or "air mounts" (pneumatic springs), as sketched in Figure 7. The selection of these elements depends on the frequency ranges that are of primary concern. Here again, these resilient elements and the mass they support act like a mass-spring system, which attenuates vibrations above its resonance frequency, but amplifies vibrations near that frequency. Such a specially designed system has the advantage that it can be made very resilient, with a resonant frequency below the range of concern, and with the potential for providing considerable attenuation of intruding groundborne vibrations. It has the disadvantages of considerable construction complexity and attendant costs, as well as the potential for increasing vibrations resulting from internal activities.

Figure 7 illustrates schematically how building columns may be supported on air springs or bridge bearing pads, but does not show the lateral restraint that must be provided at the column bases to ensure stability of the structure, particularly with regard to earthquakes. Placement of air springs in a pocket that is open on one side permits removal and replacement of the air springs in the event that becomes necessary. One would merely need to deflate the air spring, permitting the column footing to rest on the lips of the support; one could then slide the air spring out, replace it, and inflate the replaced air spring until the column footing is again supported only on the spring.[10]

Reduction of intruding vibrations in selected frequency ranges may also be achieved by mounting resiliently supported masses to the foundations, so as to produce in essence a "tuned absorber" system. One arrangement which has been employed successfully in buildings in Japan in a different context[11] is illustrated in Figure 8. It uses concrete slabs in the basement as absorber masses and relies on resilience of the soil under these masses for the spring action, resulting in classical spring-mass systems. At their natural frequencies, these systems act to impede the motion of the springs' support points, which here correspond to a plane below the soil surface

Internally Generated Vibrations

Walking The problem of vibrations caused by footfalls (walking personnel) needs to be addressed early in the facility design process, because it generally requires a structural or architectural solution. Footfall-induced vibrations tend to be of major importance for above-grade floors, but usually are less significant for slabs on grade.

An above-grade floor may be visualized as acting somewhat like a massive trampoline. Footfall impacts on a floor set the floor structure into motion, subjecting any equipment resting on it to corresponding vibrations. Footfalls near the center of a bay tend to cause the greatest vibrations, and the vibrations always tend to be most severe at mid-bay and least severe near columns. Thus, footfall-induced vibrations and their effects may be reduced by confining heavily travelled areas (e.g., corridors) to regions near column lines, placing sensitive equipment near columns, and keeping as much distance as possible between heavily travelled areas and sensitive equipment.

It is also well-known that rapid walking causes more severe footfall impacts than slower walking and that several people walking in step can cause very severe vibrations. The probability of obtaining such conditions may be reduced by avoiding layouts with long straight corridors that permit rapid walking and by instituting administrative measures (e.g., posting signs and educating personnel to walk slowly).

However, the most reliable solutions to the footfall-induced vibration problem usually are structural, consisting of: (1) making the floor structures stiff enough so that the footfall-induced vibrations associated with expected foot traffic remain within acceptable limits, and/or (2) separating the structures on which people walk from those that support the sensitive equipment.

Analysis[12] has shown that the vibrational velocity induced in a structural bay by a person walking in or near that bay for most practical bay structures is essentially inversely proportional to the product kf, where f denotes the fundamental natural frequency of the bay and k represents the bay's stiffness at its midpoint (that is, the vertical force applied at the midpoint that results in a vertical unit deflection at that point). Since the natural frequency f also increases with increasing stiffness k, the bay stiffness is the dominant parameter; thus, effective control of footfall-induced vibrations by structural design in essence consists of providing a sufficiently stiff structure. Floor structures with high stiffnesses can generally be obtained most readily by use of small column spacings; otherwise, considerably deeper than usual floor girders, joists and slabs may need to be employed. In the design of an optimized building structure, one needs to take into account the distribution of the vibrations; the value of kf to be used for design purposes should be chosen on the basis of considering the locations of sensitive equipment and of the areas where foot traffic occurs.

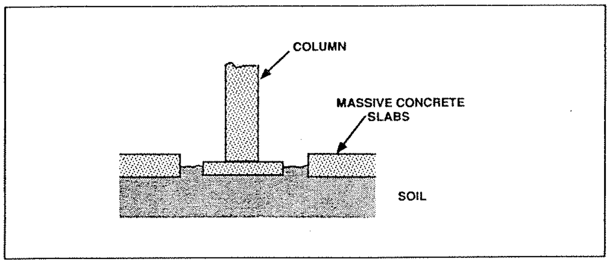


Figure 8. Concrete masses on soil, which may be designed to act as dynamic absorbers.

It often is convenient to separate areas exposed to foot traffic from adjacent areas that house sensitive equipment by providing a separation between these areas and, ideally, designing the structure so that these areas do not share a common support (girder or column line). The separation should consist of a physical joint, which may include resilient supports and seals. In some situations it may be useful instead to provide "bridges" on which people can walk, where these bridges (which may be at the level of a raised floor) are constructed so that they are supported only at the columns, without making contact with the floors on which sensitive equipment is supported.

In-Plant Vehicles. The aforementioned concepts for controlling footfall-induced vibrations also are useful for limiting vibrations due to in-plant vehicles. In addition, because a vehicle entering on a floor slab or leaving a slab in effect produces a suddenly applied load, it is desirable to reduce the suddeness of load application – e.g., by using joints with long interlacing fingers or by having joints arranged so that only one wheel of a vehicle at a time crosses the joint. It is also useful to use soft pneumatic tires on all vehicles and to keep the surfaces traversed by the vehicles smooth and free of surface discontinuities.

Production Machines and Activities. The effects of vibrations resulting from production-related machines and activities that may cause disturbances (such as machine adjustments or the installation of gas cylinders) can be reduced by keeping these as far from sensitive equipment areas as possible, by locating these machines and activities in areas where the supporting structures are relatively stiff (e.g., near columns), and by supporting machines on resilient vibration-isolating systems. In general, the same vibration control concepts that are discussed in the following paragraphs in relation to service machinery apply here also.

Machinery Vibration

Machinery Selection. It is useful where possible to select alternative mechanical and electrical equipment types that inherently are relatively free of vibration. For example, rotating compressors tend to produce considerably less severe vibrations than reciprocating compressors, because their inertia forces are better balanced; for the same reason, multicylinder (particularly opposed-piston) engines and compressors are preferable to single-cylinder machines. Similarly, it is advisable to choose the better balanced of two otherwise similar machine models, and one may do well to opt for the purchase of equipment with the best economically feasible field-balance specifications; however, we have found that ultrafine balance usually is unnecessary.

Machinery Placement. It is advisable generally to keep as much distance between vibration-sensitive equipment and vibration-producing machinery as possible, to support vibration-producing machinery on stiff structural components, and to provide this machinery with efficient vibration isolation systems. Machinery isolation usually involves the use of well-known approaches and readily available technology; however, special care generally is required to avoid bridging of the isolation via piping and conduits. Good planning and facility layout usually goes a long way toward minimizing the rerouting of pipes and ducts and their special isolation that may otherwise be required for vibration control.

Machinery Isolation. Figure 9 illustrates three approaches to reducing the transmission of vibrations generated by heavy equipment located at grade to the adjacent soil (and thus to the building). Where the building rests on footings that do not communicate directly with bedrock, it is useful to let the machinery act on the bedrock via suitable columns or piers that do not make direct contact with the soil. The other approaches involve relatively straightforward isolation of a machinery base from the building floor slab or ground. Two alternatives to the conventional use of steel coil springs are illustrated in Figure 9b and 9c, an arrangement in which a layer of fill serves as the resilient isolation element, and a system that employs air springs in a pocket arrangement (for easy replacement) to provide very effective isolation.

It should be noted that a simple cut in a concrete slab that rests on soil (or a gap between two structural components, both of which rest on soil) provides no significant reduction in the transmitted vibrations. The dynamic properties of concrete and of soil are sufficiently alike so that the vibration in the frequency ranges of general concern are transmitted around the gap via the soil with very little attenuation.

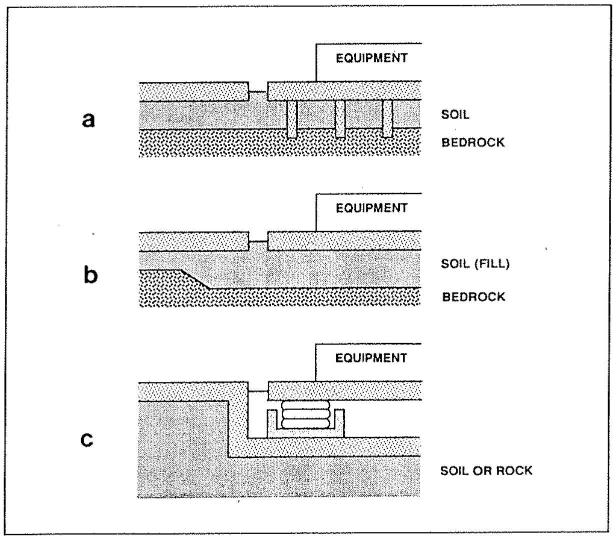
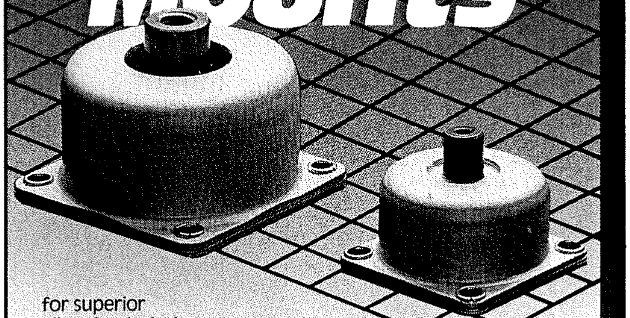
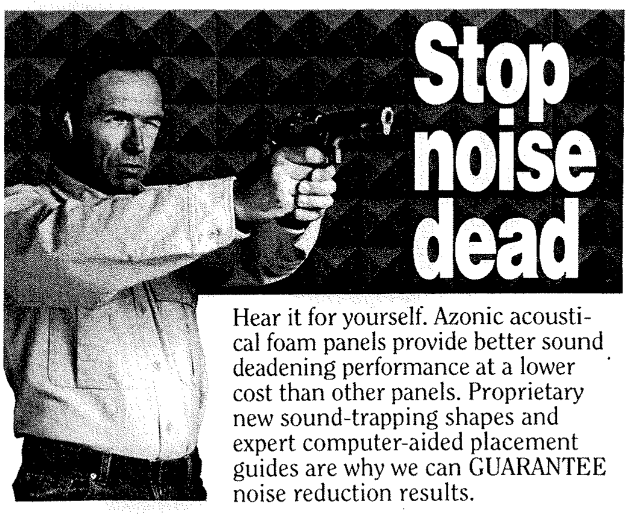
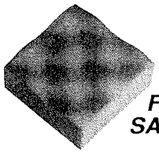


Figure 9. Isolation between equipment and soil: (a) sleeved columns to bedrock; (b) tuned bed of fill; (c) air spring system in trench.

In high technology facilities, as in any complex dynamic system, careful attention needs to be paid to a large number of details, in order to ensure that the desired vibration performance is indeed obtained. All potential vibration transmission paths that may "short circuit" machinery isolation systems or structural breaks need to be considered and eventually treated. This includes piping, ducts, conduits that may bridge the isolation systems or gaps, as well as such auxiliary structures as partitions and pipe racks.







Isolation of Sensitive Equipment

It is generally advisable to locate vibration-sensitive items in areas where vibrations due to external sources and internal activities are comparatively benign. Such areas typically include on-grade locations that are away from external traffic and not too close to mechanical equipment (e.g., elevator machinery or pumps, furnaces and air handlers which may be in mechanical equipment rooms). Favorable locations on upper floors typically are areas near columns and major girders, as far as possible from heavily travelled corridors. Confining placement of sensitive equipment to such favorable locations or to limited, specially designed areas can result in significant structural savings.

Supporting vibration-sensitive equipment on raised "computer" floors is generally undesirable, because vibrations produced by people walking on such floors can be transmitted relatively readily to the equipment. It is preferable to support the equipment from the structural floor via separate pedestals or via separate, braced sections of raised flooring that do not make direct contact with the portions of the flooring on which people can walk. Bracing of raised floors designed specifically for vibration control (sometimes including bolting of floor tiles) has been found to be considerably more effective for the protection of equipment from small amplitude disturbances than has the bracing commonly used for code compliance in seismically active areas.

Many items of sensitive equipment include extremely resilient internal isolation of their critical components, and some can be ordered with special "isolation tables" or "isolation cradles." For this reason, supporting such an item on an additional isolation system typically provides little benefit, unless this isolation system incorporates extremely flexible elements. Two-stage isolation, involving a heavy base on soft springs under an equipment item incorporating resiliently supported elements, may be useful on occasion; however, very soft springs and large masses are usually required to provide significant isolation in the frequency ranges of concern.

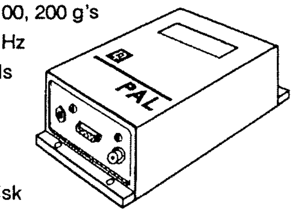
In some instances, one may need to protect sensitive equipment located at grade from ground vibrations. In such cases, in view of the predominance of disturbances at relatively high frequencies, conventional isolation arrangements or those shown in Figure 9b and 9c merit consideration.

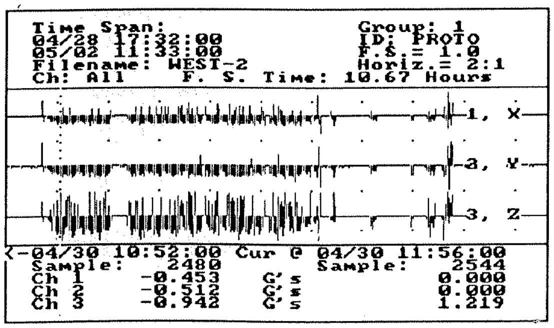
Noise Considerations

Some types of high technology equipment, notably electron microscopes and several items of microelectronics production equipment as well as optics research equipment, exhibit considerable sensitivity to airborne noise, other air pressure fluctuations, and air turbulence such as associated with ventilation air flows and with pulsations, e.g., those produced by the sudden opening or closing of doors in pressurized areas. In facilities that involve "clean room" installations which require large amounts of air, audible noise tends to be a significant problem from both equipment performance and personnel comfort standpoints.

Noise sensitivity data are available for only a very limited number of equipment items. Experience has shown the noise sensitivity of microelectronics production equipment typically is greatest at frequencies in the 20 to 250 Hz range and that satisfaction of a noise criterion of PNC-55 provides a noise environment that is satisfactory for most equipment as well as for personnel. Exceedance of PNC-55 at frequencies above 250 Hz usually has relatively little adverse effect on equipment but results in increased annoyance of personnel. Optical equipment, which may be affected by fluctuations in the air density in the optical path, may require considerably more stringent limitations on the airborne noise in its surroundings.

In some situations, the pressure fluctuations associated with low-frequency sound, with air flows, or with pulsations also may constitute a significant source of vibration of the floors





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 Ch 1      -0.453   G's            0.000
 Ch 2      -0.512   G's            0.000
 Ch 3      -0.942   G's            1.219
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that support sensitive equipment. This is the case particularly for facilities that require large air flows and that are located on the upper floors of buildings with large spans and relatively flexible floors. Because air handling systems and other machinery are sources of both noise and vibration, it usually is cost-effective to address noise control considerations simultaneously with vibration control.

Conclusions

Cost-efficient design of a high technology facility from a vibration standpoint generally requires collaboration of a vibration control specialist with the facility's user and architect (to develop favorable layouts), with geotechnical and structural engineers (to arrive at desirable footings and structural configurations), with mechanical engineers (to obtain adequate vibration isolation and noise control for air handling and other service equipment and the related piping and ducts), and often with process and other equipment specialists. Involvement of a vibration control engineer beginning with the early design stages usually is most beneficial, because in the early stages there often exist opportunities to make design choices which are beneficial from a vibration standpoint, but which imply little or no increased cost.

Good design from the start is important, but even the best design is useless unless it is implemented properly. For this reason, it is advisable during the entire design and construction process to monitor the myriad details that may affect vibration by careful review of relevant design, construction and shop drawings and by repeated field inspection in the course of construction. Ideally, vibration measurements should also be performed after the facility is completed, so that conformance with vibration specifications can be verified and any residual problems can be identified and resolved.

Like most engineering projects, vibration control design of high technology facilities requires little esoteric science and no black magic – only proper application of available data and generally well-known principles, together with careful attention to details. It is our hope that the overview of the important vibration considerations and of the available arsenal of vibration control approaches presented in this article will serve as a useful guide.

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