Vibration Criteria for Healthcare Facility Floors

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Excessive structural vibrations in hospitals and other medical facilities can interfere with the performance of medical procedures, compromise the operation of sensitive equipment and have adverse effects on patient comfort. This article provides an overview of the vibration criteria for critical areas in healthcare facilities and brief discussions of related issues. The criteria covers operating rooms, patient rooms, areas above operating rooms and MRI systems.

Operating Rooms and Related Areas

Basis for Criteria. American National Standard Institute (ANSI) Standard S3.29-1983, "Guide to the Evaluation of Human Exposure to Vibration in Buildings" presents "base-response curve values" in relation to human perception and states that the base-response curve values correspond "to the approximate threshold of perception for the most sensitive humans" and approximately to one-half of the mean threshold of perception. This standard parallels International Standard ISO 2631-2:1989 (E), "Evaluation of Human Exposure to Whole-Body Vibration – Part 2: Continuous and Shock-Induced Vibration in Buildings (1 to 80 Hz)."

The frequency variations of two base-response-curve root-mean-square (rms) accelerations, in units of micro-g, are shown in Figure 1 (1 g = 9.8 m/s^2 = 386 in/sec^2). One corresponds to foot-to-head (or foot-to-buttock) vibration, and the other to vibrations in all axes (front-to-back and side-to-side, in addition to foot-to-head). The standard implies that the vibrations may be measured either in one-third-octave frequency bands or in bands of constant narrow width. Also shown in this figure are lines that represent constant velocities of 4,000, 2,000 and 1,000 micro-in per second. The acceleration A (in micro-g) at any frequency f (in Hz) and the velocity V (in micro-in per second) at that frequency are related according to $A = Vf/61.4$. At frequencies of 8 Hz and above, the two perception criteria curves are identical and correspond to a root-mean-square (rms) velocity of 4,000 µin/sec.

Operating Rooms. ANSI S3.29-1983 also suggests that the vibrations of operating room floors not exceed between 0.7 and 1.0 times the base-response curve values. But the ISO standard that parallels this ANSI standard suggests that vibrations in operating rooms merely not exceed the base response values.

Requiring that the vibrations of hospital floors not exceed the "all-axes" perception threshold of Figure 1 has become a widely accepted practice. This corresponds to limiting the rms vibration velocity to 4,000 micro-in per second = 0.1 mm/s = 100 µm/s at frequencies from 8 to 80 Hz, with somewhat greater velocities acceptable for frequencies below 8 Hz. However, there has been a tendency for building specifications not to state these frequency limitations, probably because the specification writers were not adequately informed. (In the Criteria Table of the widely used Steel Design Guide 11, "Floor Vibrations Due to Human Activity" (1997), the vibration criterion for operating rooms unfortunately appears in the wrong velocity category due to a copying error.)

For especially sensitive operating rooms, such as those for neurosurgery or microsurgery, a criterion amounting to one-fourth of the one for ordinary operating rooms – that is, 1,000 µin/sec = 25 µm/s – has been used widely. Unlike the criterion for ordinary operating rooms, this criterion is not related to tactile perception, but to the use of microscopes and sensitive equipment. The basis on which this 1,000 µin/sec limit was chosen is not clear, except that use of a "factor of safety" had been thought to be prudent.

Patient Rooms. If it is desired to constrain the vibrations of floors in rooms that are occupied by patients to the point where these vibrations are essentially imperceptible, as may be appropriate where patients are very sensitive to disturbances, then these vibrations should not exceed the limits presented above for operating rooms. Greater vibrations may be acceptable in rooms for less sensitive patients.

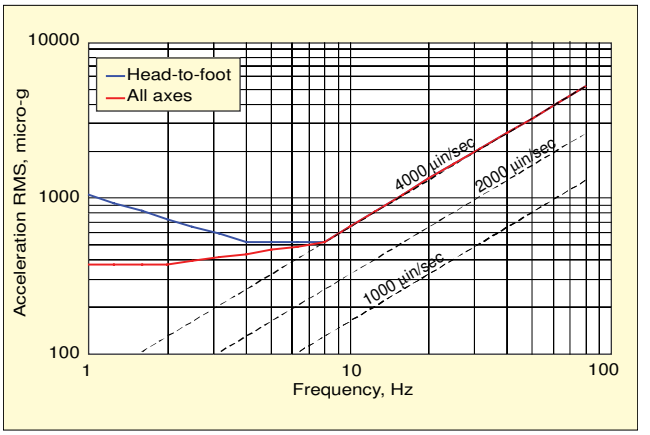

Figure 1. Perception criteria.

Areas above Operating Rooms. Where the structure of the ceiling of an operating room also is the structural floor of an area above the operating room, vibrations of the floor in this area may affect sensitive equipment that is supported from the operating room ceiling. Acceptability of these vibrations depends on the vibration sensitivity of the equipment and on the vibration transmission characteristics of the equipment's mounting arrangement. No generally acceptable criteria are available, but it likely is prudent to limit these vibrations to the magnitudes suggested above for sensitive operating rooms, which take some account of the use of equipment.

If no vibration-sensitive equipment is supported from the structural ceiling of an operating room, then no limits need to be placed on the vibrations of the floor above the operating room. Ceiling-mounted operating room equipment will not be disturbed by vibrations of the floor above the operating room if, for example, all such equipment is supported only from columns or from suitable structures that span between columns without making direct contact with the ceiling.

Application to Footfall-Induced Floor Vibrations. The aforementioned base-response curve values and related criteria are given in terms of rms magnitudes and apply for continuous vibrations. For impulsive vibrations, the ANSI standard indicates in effect that the peak value measured in a given frequency band should not exceed 1.4 times the value indicated in Figure 1 for that frequency band. It is not entirely clear how one should deal with other than impulsive transient vibrations. The ISO standard in effect admits this problem by stating that "the borderline between steady and transient vibrations is difficult to define." Although the average values one obtains for steady vibrations are essentially independent of the duration of the averaging one uses, the average values one obtains for vibrations that are not steady do depend on the averaging durations. The ANSI standard provides only the following guidance: "Averaging times for rms quantities should not appreciably exceed the event duration."

It appears that for ordinary operating rooms, the rms-footfall-induced vibrations should be limited to 4,000 µin/sec, and the peak footfall-induced vibrations should be limited to 5,600 µin/sec. For sensitive operating rooms, the corresponding limiting values are 1,000 and 1,400 µin/sec, respectively. These values apply for

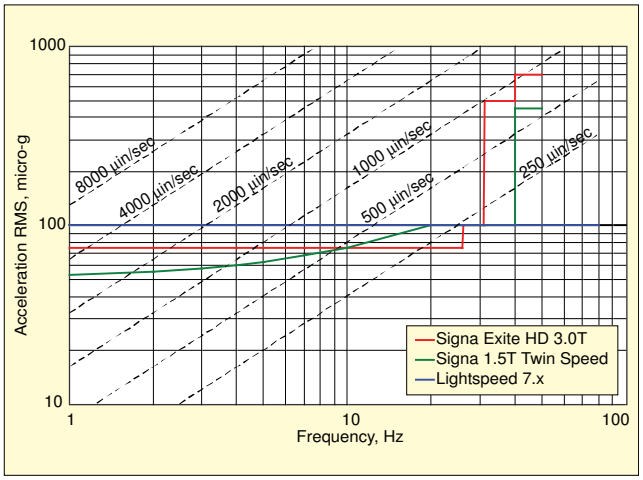

Figure 2. General Electric MRI criteria.

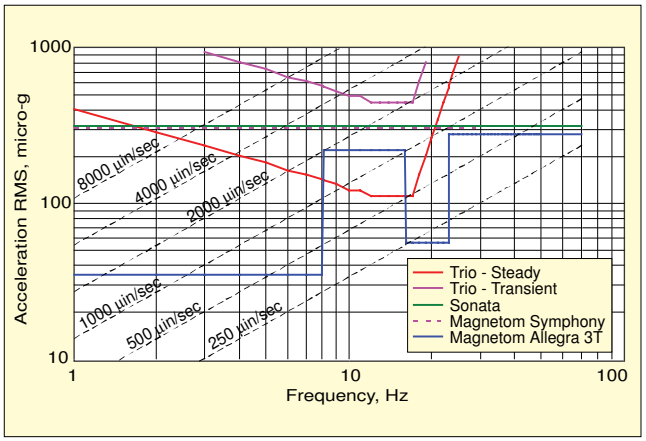

Figure 3. Siemens MRI criteria.

frequencies between 8 and 80 Hz; somewhat greater values are acceptable at frequencies below 8 Hz, as shown in Figure 1.

MRI Systems

The following paragraphs summarize criteria set forth for some MRI systems by their suppliers. Note that different criteria may apply to other models of systems from these same suppliers and that the criteria applicable to systems from other MRI suppliers may differ greatly from those cited here.

General Electric. General Electric's installation manuals typically specify limits on the steady-state vibrations "above the ambient baseline" to which the magnets may be subjected. The "ambient baseline" refers to the lower bounds of vibration spectra measured in absence of any overt disturbances and is relatively small in most practical situations. The ambient baseline conservatively may be taken as zero for design purposes.

The specified limits on the steady-state vibrations are shown in Figure 2 for three of GE's units. These limits may be taken to pertain to vibrations associated with steady operation of mechanical equipment or to continuing (relatively steady) rms vibrations induced by footfalls.

The GE specifications state that transient vibrations whose greatest zero-to-peak amplitude exceeds 500 micro-g must be subjected to frequency analysis, and the resulting frequency components must not exceed the limits of Figure 2. The specifications imply tacitly that transient disturbances (including those from footfall impacts that occur with some time separation between them) whose greatest zero-to-peak amplitude does not exceed 500 micro-g are acceptable.

Lines that correspond to rms velocities of 250, 500, 1,000, 2,000, 4,000 and 8,000 µin/sec are included in Figure 2 for the sake of comparison. The limits shown for the GE MRI systems in general are considerably more stringent than the nominal 4,000 µin/sec criterion for operating rooms.

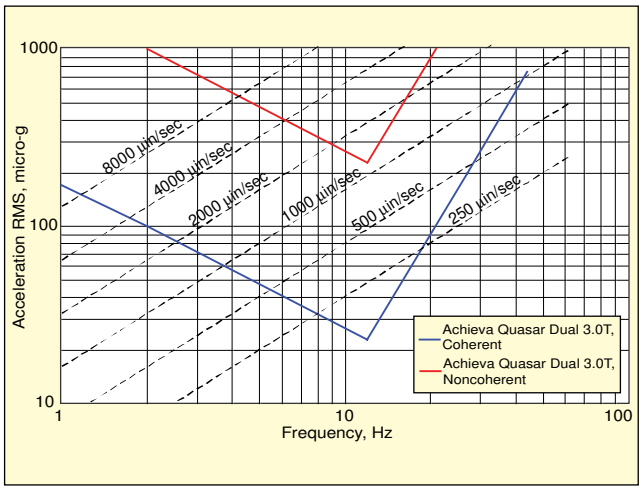

Figure 4. Philips MRI criteria.

Siemens. Figure 3 shows the acceleration limits for the Sonata, Magnetom Symphony, and Magnetom Allegra 3T units, taken from their installation manuals. It also shows steady and transient vibration criteria curves for the Trio system, based on data cited by Siemens for a recent proposed installation. Again, curves of constant velocity are shown for comparison.

For the Trio units, the acceptability of steady and intermittent footfall-induced vibrations may readily be evaluated by use of the indicated curves. The specifications for the other two units do not differentiate between steady and intermittent vibrations; all vibrations should be compared to the given criterion curves unless better information becomes available.

Philips. The vibration criteria for 'coherent' and 'noncoherent' vibrations set forth by Philips for its Achieva Quasar Dual 3.0T system are indicated in Figure 4. In this figure, the accelerations have been converted to rms values to facilitate comparison with the other criteria discussed above, although Philips actually specifies limits on the peak-to-peak values. For steady vibrations, the peak-to-peak value at any frequency is equal to $2\sqrt{2}$ times the corresponding rms value.

Philips defines coherent vibrations as those that have constant amplitudes and frequencies, such as those produced by rotating machinery, and defines noncoherent vibrations as consisting of pulses or transients, such as those caused by vehicular traffic and people walking. Philips' specifications state that that no more than one pulse or transient per minute is allowed. Presumably, this restriction applies only to transients that exceed the noncoherent criterion.

Application of Criteria

The criteria cited above pertain to vibrations from all sources, including external traffic, mechanical equipment and personnel activities. The vibrations due to walking typically need to be addressed early in the design process, because control of these vibrations requires appropriate consideration of the architectural layout and the structural design of the floors.

The most severe footfall-induced vibrations tend to occur at the fundamental natural frequency of the floor on which walking occurs. The vibrations at this frequency should not exceed the limits that apply at this frequency for the space usage and/or system of concern.

The approach delineated in Section 6 of the AISC Steel Design Guide 11 cited previously provides a means for estimating the expected relatively steady *peak* vibrations associated with a given walking condition. (The corresponding rms vibration values are equal to about 70% of the peak values.) Footfall-induced vibrations increase with increased walking speed. In most cases, walking in confined spaces, such as MRI rooms, is likely to occur at no greater than moderate speed, but foot traffic in nearby corridors may involve fast walking. SV

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