# Sources of Vibration

Consider a laboratory in a location where a number of energy sources exist simultaneously. The experiment is being performed on a supported steel plate. A mechanical beam chopper has been placed on this plate, accompanied by an oscilloscope with a line-synchronous cooling fan, and a vacuum pump rests on the floor. The steel plate will be undamped and, if excited mechanically or acoustically, will "ring" for long periods of time. The chopper, scope, and pump will provide mechanical excitation because there is a direct mechanical link with no isolation. It is also highly likely that the pump will radiate acoustic energy and that the cooling fan will generate variations in local air density, thereby changing the path length of any interferometer. However, this is by no means the whole story. Some other potential sources frequently identified in laboratory installations are shown in figure 9.1. Therefore, it is common in laboratories to find an ambient noise spectrum where the inputs are most likely to be structural and acoustic. The accompanying table lists some of the most common sources of noise (acoustic and structural energy).

Typically the frequency content will range from 4 to 100 Hz and peak around 40 Hz. Further properties of the inputs are that they can be multiaxial, random, and periodic. It can be seen from this list that a laboratory needs to be carefully selected and managed efficiently as a "quiet room." Structural inputs are most likely to dominate, simply because the energy coupling efficiency between mechanically connected objects is high compared to acoustic excitation and because structural sources are direct displacement inputs.

### Common Vibrational Sources

| Source | Frequency (Hz) | Amplitude (in.) |
|---|---|---|
| Air Compressors | 4–20 | $10^{-2}$ |
| Handling Equipment | 5–40 | $10^{-3}$ |
| Pumps | 5–25 | $10^{-3}$ |
| Building Services | 7–40 | $10^{-4}$ |
| Foot Traffic | 0.55–6 | $10^{-5}$ |
| Acoustics | 100–10,000 | $10^{-2}$ to $10^{-4}$ |
| Air Currents | Labs can vary depending on class | Not applicable |
| Punch Presses | Up to 20 | $10^{-2}$ to $10^{-5}$ |
| Transformers | 50–400 | $10^{-4}$ to $10^{-5}$ |
| Elevators | Up to 40 | $10^{-3}$ to $10^{-5}$ |
| Building Motion | 46/height in meters, horizontal | $10^{-1}$ |
| Building Pressure Waves | 1–5 | $10^{-5}$ |
| Railroads | 5–20 | ±0.15g |
| Highway Traffic | 5–100 | ±0.001g |

Thermal disturbances from air conditioning systems and cooling fans also can cause relative motion between components owing to material expansion and contraction as a function of temperature fluctuations. Most air conditioning systems will typically only maintain temperatures to within one degree per hour. Additionally, some experimental techniques will be

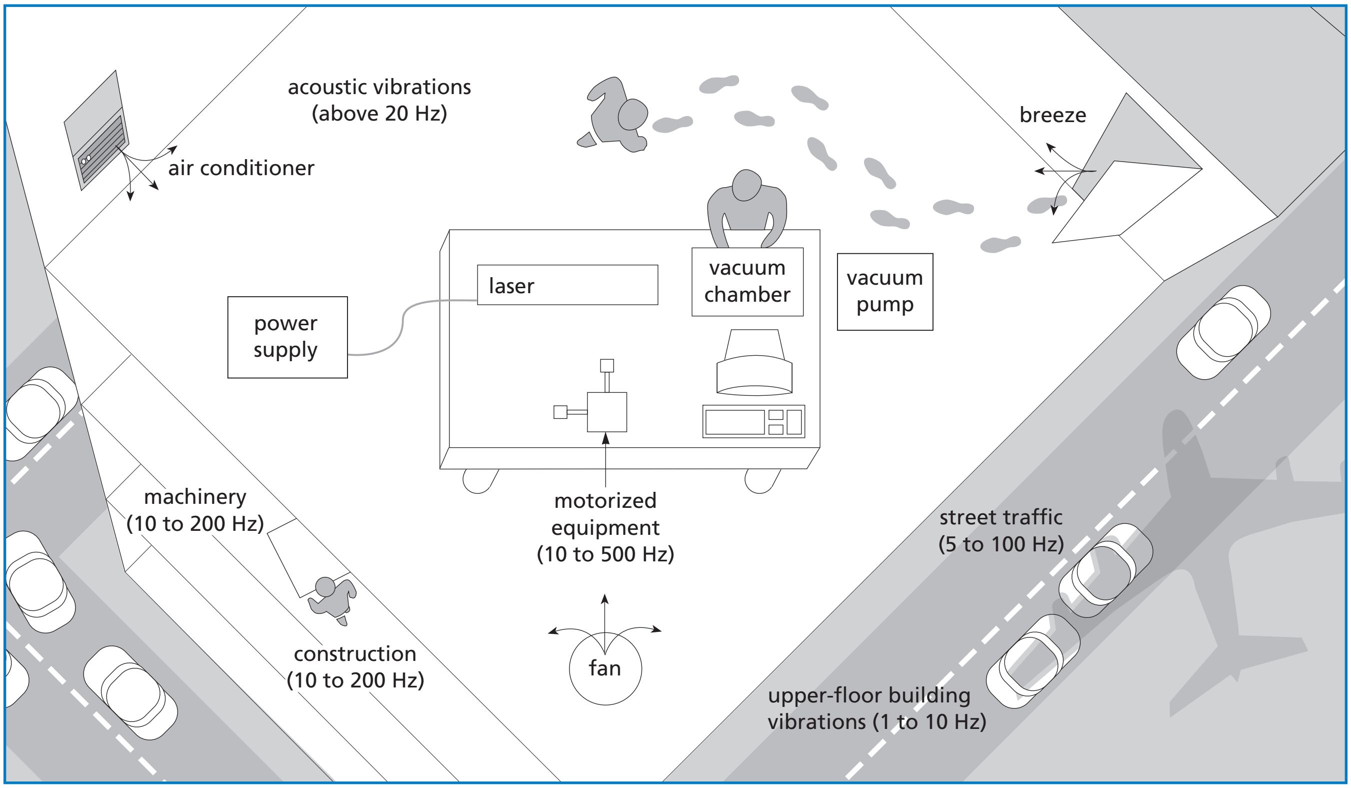

Figure 9.1 **Common environmental sources of noise**

sensitive to virtual movements as a consequence of changes to the refractive index of air and its density, both of which have a temperature dependency.

If the above energy sources are not considered fully, it is possible that sensitive electro-mechanical equipment can experience structural damage and reduced signal-to-noise ratios. Optical equipment can experience low-frequency jitter, resulting in blurred images, reduced resolution, and the appearance of line thickening.

## VIBRATION CRITERIA

When determining the isolation from ambient vibration required for a specific facility, a common misconception is that the most expensive equipment will account for all eventualities. However as we have seen, without due care and attention to the planning of the whole laboratory, the potential performance of the platform can be seriously compromised.

To this end it is useful to first identify some vibration criteria, in terms of maximum permissible levels for the measurements to be made without significantly degrading the signal-to-noise ratio of the measurements. This is not difficult because most manufacturers of analytical equipment will specify limits in velocity and acceleration amplitudes with respect to frequency.

If specific data are not available, generic criteria can be used. Colin Gordon & Associates have widely published criteria backed by many years of research and experience, which can be used as a means of setting targets for the maximum permissible vibration levels on the working surface. These generic criteria are summarized in figure 9.2 and described in the table.

With a clear understanding of the potential noise sources and vibration criteria needed for high-quality results, it is now possible to construct a vibration-isolation system and control regime. If it is not possible to remove noise sources from the laboratory and its local environment, the system should attenuate all dynamic inputs in the range of from 4 to 100 Hz and simultaneously minimize the duration of any impulsive disturbance by providing a level of damping to the working surface. Thermally induced sources must also be minimized and, where necessary, the area above the working surface should be enclosed to negate air currents.

## ASSESSING THE ENVIRONMENT AND APPLICATION

Laboratory environments are continuously subjected to ambient vertical vibrations in the region of from 4 to 40 Hz. In the wind, tall buildings may sway up to a meter with a horizontal frequency of from 1 to 10 Hz. Vibrations caused by equipment and machinery often have a somewhat higher frequency, but usually they are below 200 Hz. Vibrations, both natural and manmade—always with us— produce relative motions of components that may be imperceptible to the casual observer and yet are often disastrous to a wide range of precision experiments.

Before choosing a vibration-isolation system it is important to determine both the severity of the environment and the sensitivity of the application. The sensitivity of the experiment primarily relates to the selection of the tabletop; the severity of the environment primarily relates to the

### Application and Interpretation of Criterion Curves

| Criterion Curve | rms Amplitude ($\mu$m/sec)* | Detail Size ($\mu$m) | Description of Use |
|---|---|---|---|
| Workshop (ISO) | 800 | N/A | Distinctly discernible vibration. Appropriate to workshops and nonsensitive areas |
| Office (ISO) | 400 | N/A | Discernible vibration. Appropriate to offices and nonsensitive areas |
| Residential Day (ISO) | 200 | 75 | Barely discernible vibration. Probably adequate for computer equipment, probe test equipment and low-power (to 20 × ) microscopes |
| Operating Theatre (ISO) | 100 | 25 | Vibration not discernible. Suitable in most instances for microscopes to 100 × |
| VC-A | 50 | 8 | Adequate for most optical microscopes to 400 × , microbalances, optical balances, proximity and projection aligners |
| VC-B | 25 | 3 | Appropriate for optical microscopes to 1000 × inspection and lithography equipment (including steppers) to 3 micron line widths |
| VC-C | 12.5 | 1 | A good standard for lithography and inspection equipment to 1 $\mu$m detail size |
| VC-D | 6 | 0.3 | Suitable for the most demanding equipment, including electron microscopes (TEMs and SEMs) and E-beam systems. |
| VC-E | 3 | 0.1 | A difficult criterion to achieve in most instances. Assumed to be adequate for long-path laser-based interferometers and other systems requiring extraordinary dynamic stability |

**Data courtesy of Colin Gordon Associates*

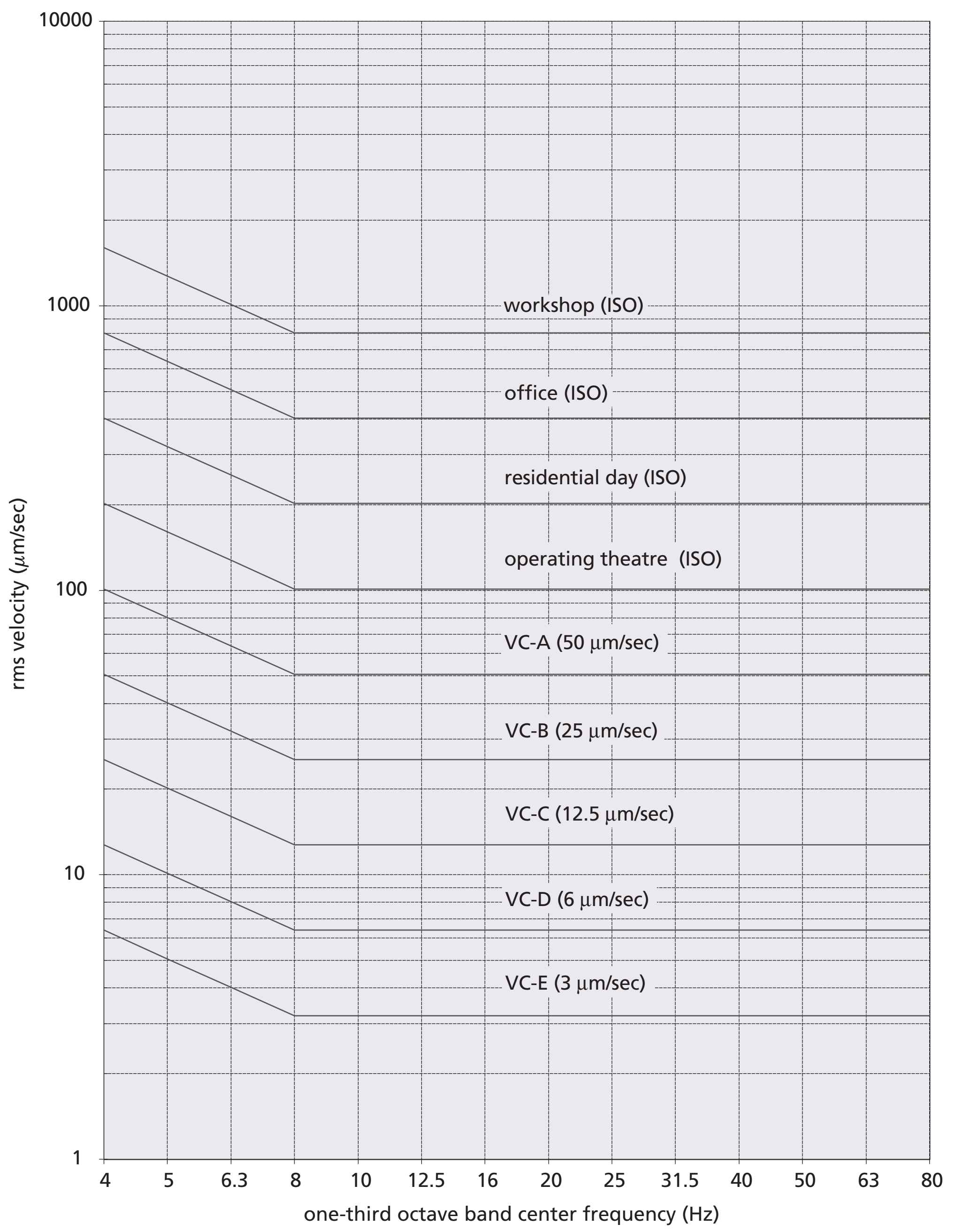

Figure 9.2 **Generic vibration criterion**

selection of the isolation system. After both aspects have been considered separately, the overall requirements can be reviewed together to ensure that the tabletop is compatible with the mounting system.

## A SIMPLE GRAPHICAL MODEL

The following examples show typical experiments and their environmental situations. They provide simple guidelines for selecting the most appropriate vibration-isolation equipment. In each case, two arrow gauges are used to characterize the overall requirement: one represents the sensitivity of the experiment, and the other represents the severity of the environment, as shown in figure 9.3. Both arrows range from a low of 0 to a high of 10. For the experiment gauge, 10 represents an exceedingly vibration-sensitive application, such as long-exposure holography, whereas 0 represents an application where only a large working surface is required. For the environment gauge, 10 represents a site in a high, steel-frame building in a heavily trafficked area, whereas 0 represents a remote basement location with no passing traffic. Using this model, considerations of the experiment in its intended environment can be interpreted graphically as the relative position of the two gauges. The following examples illustrate the use of these gauges.

Case A, shown in figure 9.4, is typical of a less-demanding experiment conducted in an environmentally sound location. Case B, shown in the same figure, typifies a highly sensitive experiment conducted in the most demanding location. However, in reality, it is more common to experience the situations shown in cases C and D.

Case C (figure 9.5) is typical of a delicate interferometer located in a basement and mounted on a seismic block, hence incurring negligible environmental disturbances.

Case D (figure 9.6) represents a relatively insensitive experiment located on the fourth floor of a building. This experiment needs considerably better environmental isolation than the previous case.

Figure 9.3 **Simple arrow gauges representing environmental and experimental conditions**

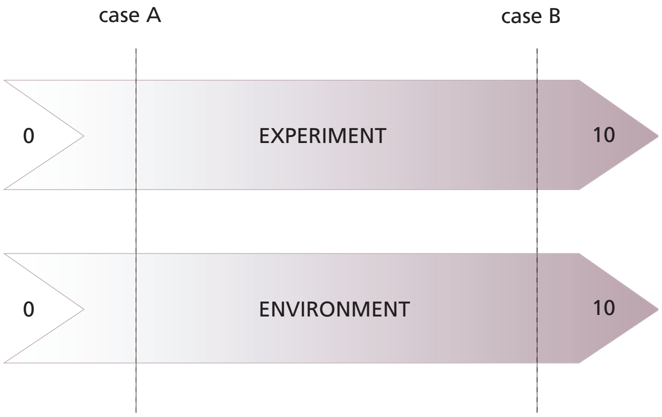

Figure 9.4 **Cases A (low sensitivity/low severity) and B (high sensitivity/high severity)**

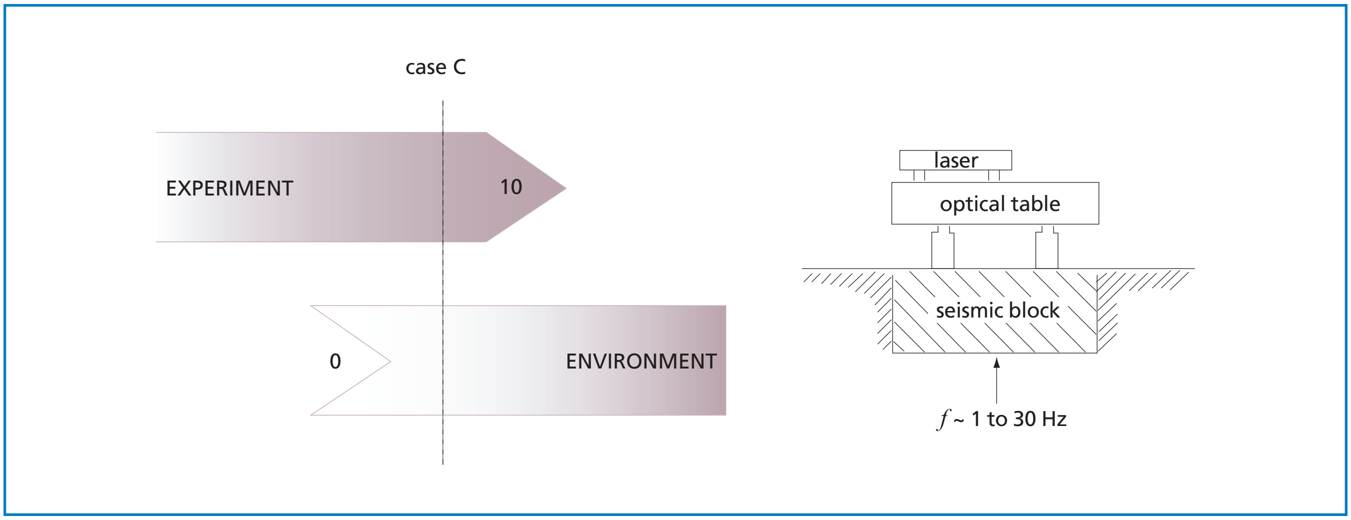

Figure 9.5 **Case C (high sensitivity/low severity)**

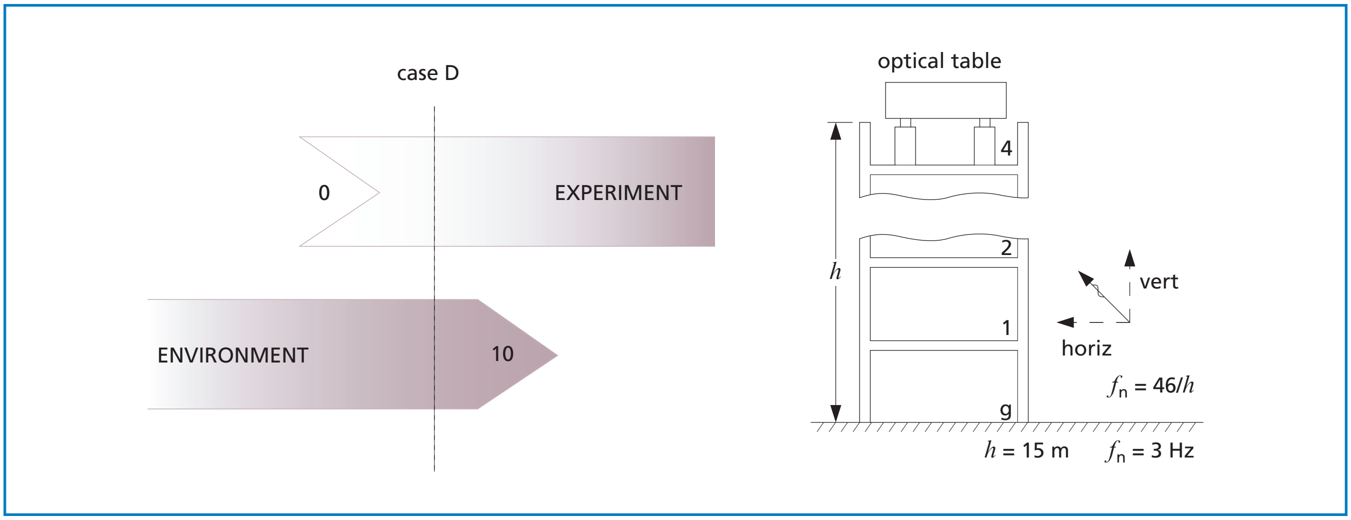

Figure 9.6 **Case D (medium sensitivity/medium severity)**