

Tabletop Design

There are two basic goals in designing an optical tabletop. The natural resonances of the table should be as high as possible, since the excited vibration amplitude decreases sharply with increased frequency ($1/mf^2$), and the table should be well damped to further decrease the amplitude of the low-frequency resonances. Both of these goals must be accomplished without making the table overly massive and heavy. Increasing the resonant frequency is achieved by maximizing the stiffness-to-mass ratio; decreasing the resonant amplitude is achieved by enhancing the natural damping of the tabletop.

TABLETOP VIBRATIONS

A typical rectangular tabletop is capable of several types (modes) of low-frequency vibration, as shown in figure 9.14: bending along the long axis of the tabletop, bending along the short axis of the tabletop, and torsional bending.

Each of these independent modes has a characteristic resonant frequency, which gives rise to a corresponding peak in the compliance curve. To avoid any resonant effects from induced floor or tabletop vibrations, the first bending and twisting peaks (shown in figure 9.15) should occur at as high a frequency as possible. The peak associated with the short bending mode usually occurs at a much higher frequency and therefore can be ignored.

Each mode has a series of higher-frequency harmonics (overtones) associated with it. Each successive harmonic has more nodes (null amplitude points) and antinodes (points of maximum amplitude) and a higher resonant frequency than the previous. Because different vibrational modes have their nodes and antinodes at different places on the table, and because it is possible to have several modes oscillating simultaneously, the resultant compliance is a complex function which varies greatly over a table's surface. Furthermore, deflections under time-varying loads (dynamic operation) can be much higher than when under static loading. The nodes and antinodes for the first bending and torsional modes on a typical optical table are shown in figure 9.16.

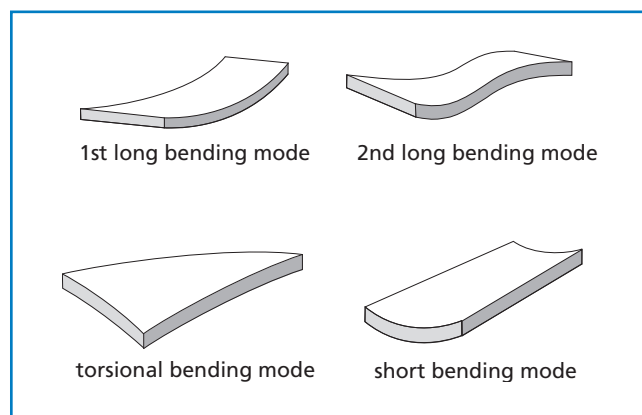


Figure 9.14 Vibrational modes of an optical tabletop

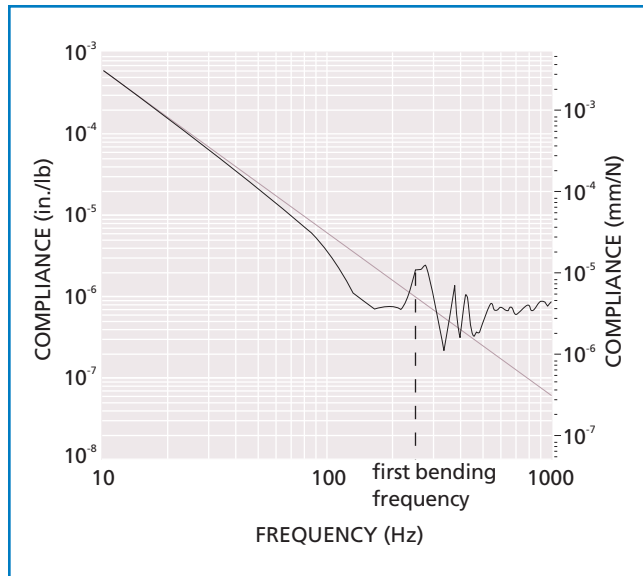


Figure 9.15 First bending-mode peak

TABLETOP MATERIALS

There are three basic requirements for an optical tabletop:

- It must have good static and dynamic stiffness (see figure 9.17).
- Its first resonance must be higher than 100 Hz.
- It must be well damped.

For many years, scientists performed delicate optical experiments on home-built tables. Tabletops have been constructed from granite, concrete, wood, and steel. Also, many elaborate composite structures have been used in attempts to improve performance while keeping weight at a realistic level. Each technique has disadvantages. Granite and concrete slabs tend to absorb water vapor and deform accordingly. In fact, due to residual chemical changes, concrete changes shape slightly for many years. Steel has a high density and tends to ring at several vibrational frequencies, with very little natural damping. In many ways, wood is a surprisingly good choice for an optical table; however, it has a tendency to warp with time, particularly in the presence of moisture.

Clearly, the best material for optical table construction should be a composite, a matrix of materials that combine the stiffness of pure metal, the damping of rubber, and the low density of a material like wood. It is now accepted generally, that the best combination of materials for optical table construction is a metal honeycomb sandwich. The top and bottom layers are steel or aluminum, and the large core is a low-density metal honeycomb, usually steel. The plates provide the stiffness or rigidity, and the honeycomb is a material which combines excellent dynamic stiffness with very low density. The honeycomb also exhibits fairly good natural damping; however, in cases where ultimate performance is required, additional damping is needed.

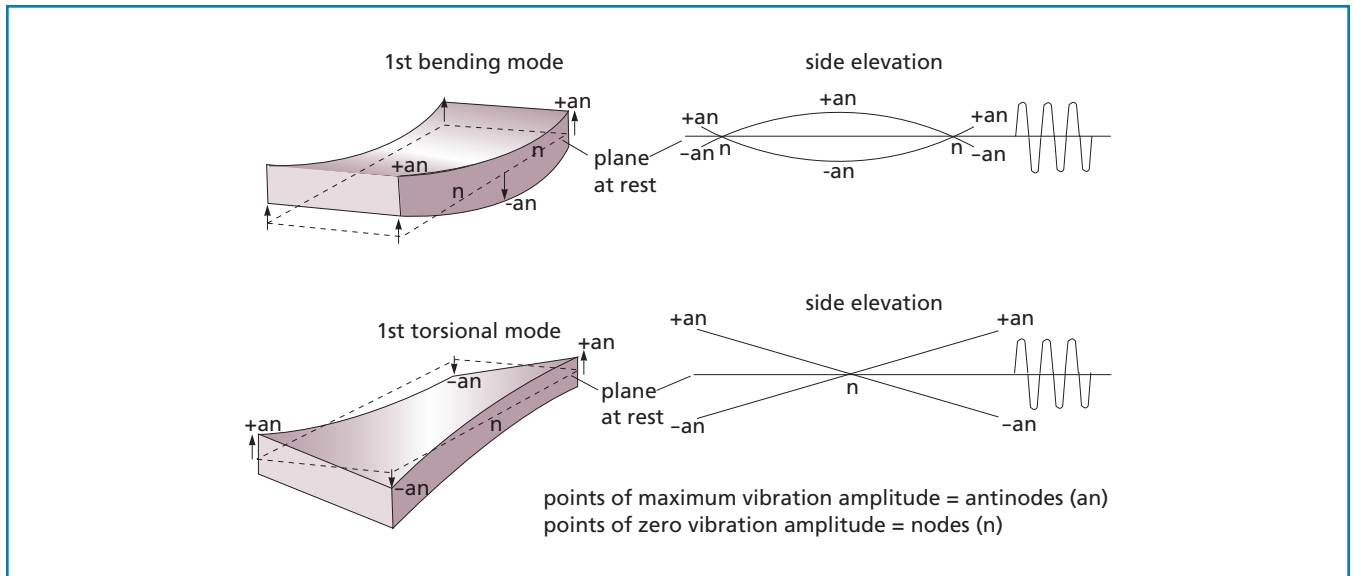


Figure 9.16 Vibrational nodes

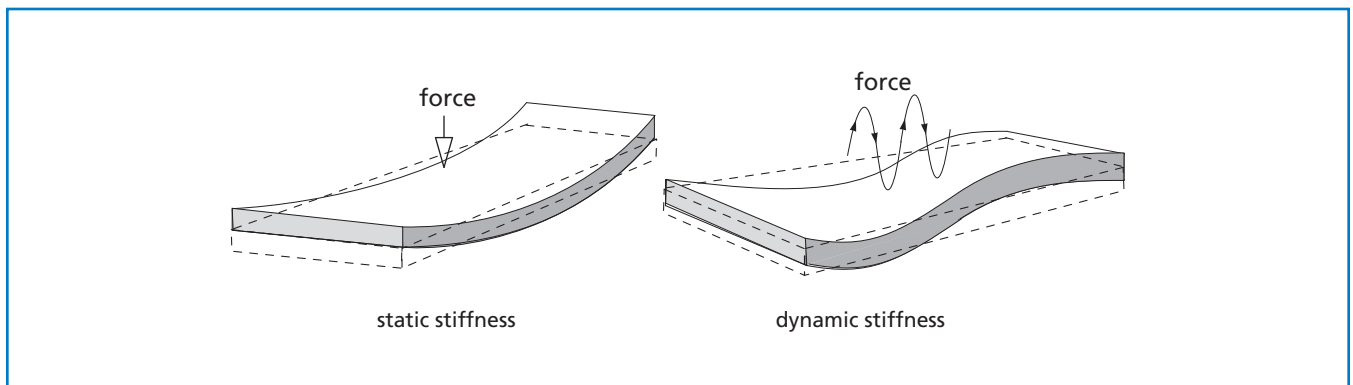


Figure 9.17 Static and dynamic stiffness

Stiffness of Hollow versus Solid Structures

Consider a solid bar of a homogeneous material such as steel (figure 9.18). If this bar is bent, then one edge is stretched and the other is compressed. The core of the bar is affected much less by this deformation. Consequently, the major contributions to the restoring force arise from the edges of the bar, and a hollow bar would be almost as resistant to this bending deformation as a solid bar. Therefore, the strength of a structure is dependent not only on the material of the structural elements, but also on their shape and position. This is an important concept in optical table design.

Now consider the case of a simple I beam. Under load, the top flange is under tension and the bottom flange is under compression, but at the "neutral axis" the stress is zero.

The flanges carry the bending stresses and the web resists the shear forces. The farther apart the flanges are, the lower the deflection for a given load, i.e. the higher the stiffness.

STEEL AND HONEYCOMB SANDWICH

An optical table requires the rigidity of steel, yet a solid steel table would be ridiculously massive and would ring badly. As previously discussed, the important vibrations of an optical table are those occurring at lower frequencies (bending and torsional vibrations). These all involve vertical displacements of various portions of the table, which may be in phase and out of phase.

A hollow steel table would be very rigid for its mass because the sides and the top and bottom skins would act as an extended I beam. However,

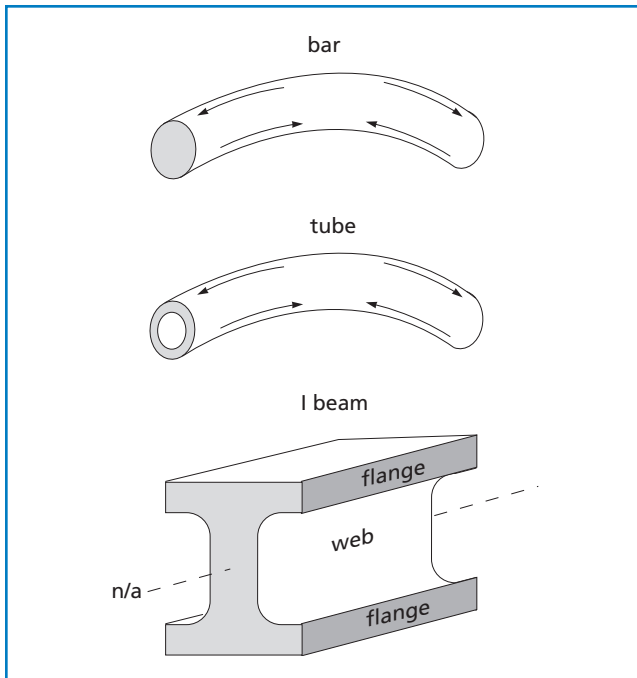


Figure 9.18 Tubes and I-beams have a large stiffness-to-mass ratio

it would tend to ring owing to the absence of damping and would also sag in the middle under heavy load conditions.

Consequently, optical tables should not be hollow, but should be filled with a material that combines rigidity and damping with reasonable stiffness in the vertical direction. The most successful materials for this purpose are honeycomb materials made from steel, aluminum, phenolic, graphite, Kevlar, or even wood pulp.

Honeycomb Theory

Consider bending a thin sheet of material such as paper. The sheet is very resistant to deformation within the plane of the sheet, as shown in figure 9.19. Now suppose the tabletop is filled with many linked sheets all lying vertically. If the sheets are all parallel, the table is much more resistant to deformation in one bending direction than the other. In one case the initial motion is parallel to the sheets, and in the other it is perpendicular to them.

Suppose now that the sheets are linked and arranged at 90 degrees to one another. In the case of a rectangular top, the sheets could be arranged so that the core is very resistant to the two bending (strong) vibrations. However, there is a plane at 45 degrees to both the strong planes. The effectiveness of the core in resisting a vibration in this plane will be reduced by $\cos\theta$ where θ equals 45 degrees. Any vibration, such as torsion, which involves vibration in or close to this plane will not be resisted.

Clearly, it is advantageous to have the sheets in the structure at intermediate angles. For both theoretical and practical fabrication reasons, the best honeycomb is a hexagonal or sinusoidal cellular structure. When this is incorporated into a tabletop, the worst case would be a vibration at 30 degrees to the two strong planes.

All CVI Melles Griot standard tables consist of a sandwich structure: thick steel top and bottom plates with a metal honeycomb core. CVI Melles Griot honeycomb is fabricated from strips of precision crimped steel which are then bonded together with a high tensile strength epoxy adhesive. The structure is shown in figure 9.20.

Bonding Materials

In any sandwich structure, the ultimate performance depends on more than the quality of the materials used in the sandwich components, in this case thick steel outer plates and the metal honeycomb core. It also depends on the bonding materials used to bind the elements together to produce an integral composite structure. CVI Melles Griot uses a hot pressing method and a modified structural epoxy adhesive to bond the honeycomb to the steel plates. This aerospace-grade adhesive possesses high tensile strength as well as extremely high shear and peel strengths. The bonds are cured for 18 hours under vacuum to ensure that the adhesive reaches its ultimate properties.

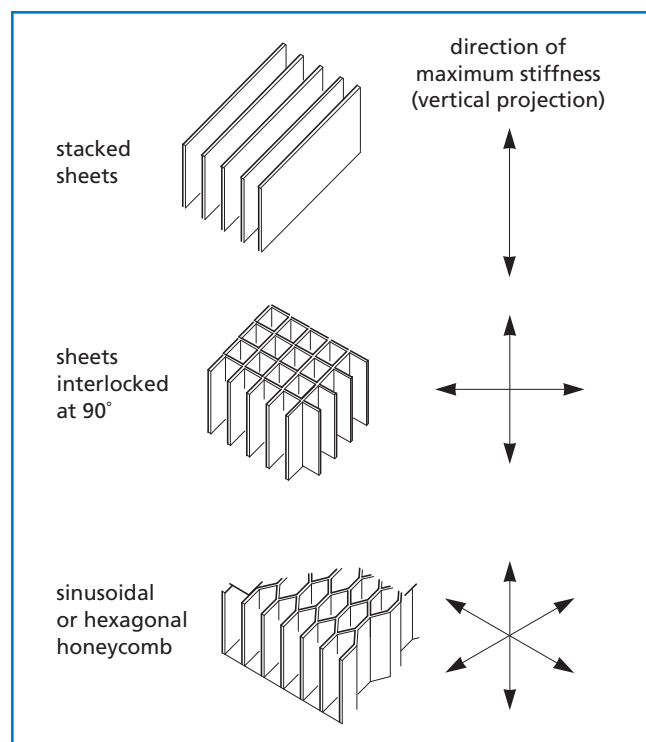


Figure 9.19 Planes of stiffness

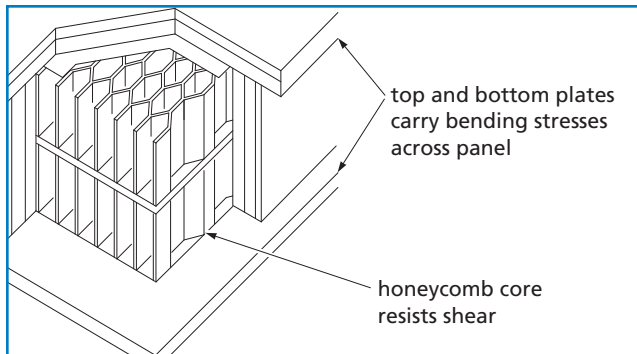


Figure 9.20 Construction of a honeycomb panel

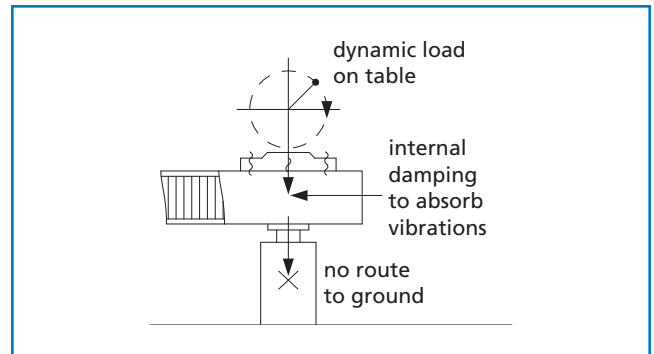


Figure 9.21 Damping and vibration isolation

DAMPING TECHNIQUES

Damping refers to any process that causes an oscillation in a solid body to decay to zero. Damping is a resonant effect, inasmuch as it significantly affects, the compliance function at or near resonance.

In theory, a resonating structure without damping has an infinitely high compliance peak at its natural frequency. Damping systems suppress these peaks by converting the energy of vibration into heat, which causes the amplitude of the disturbance to decay rapidly to zero.

As previously stated, the equipment mounted on the tabletop can be a major source of vibration (e.g., an out-of-balance laser-beam chopper blade). Once a table is mounted on its pneumatic isolators it is floating in a free condition, and any vibrations induced on the top cannot find a route to the ground. Therefore, these vibrations must be damped by the table's own internal damping (see figure 9.21).

The damping of an optical table arises from several sources. The materials themselves have some natural damping, particularly in the case of the metal honeycomb. Producing a table with state-of-the-art performance, suitable for the most demanding applications, requires additional damping. Some manufacturers use dashpot dampers for this purpose. These oil-filled dashpots are placed at positions in the table where the amplitude of the excited vibration is the greatest, usually at the corners. The dashpot, used in this way, acts as a tuned damper. The natural frequency of the paddle moving within the damper is chosen to match the largest compliance peak for the particular table. Other resonance peaks are not greatly affected. Oil-filled dashpots, however, can leak if the tabletop is tilted excessively or stored on its side.

In CVI Melles Griot tables, the damping method involves positioning dry dampers at strategic points in the core of the table. These dampers are specially shaped pieces of inhomogeneous material which act as though they contain a spectrum of masses, separated by a continuous spectrum of distances in an elastomeric polymer. The effect is dramatic, greatly reducing the height of the low-frequency resonance compliance peaks, sometimes by more than an order of magnitude.

CVI MELLES GRIOT OPTICAL TABLETOP CONSTRUCTION

CVI Melles Griot optical tabletops provide an ultrastable environment for optical research and product development.

Minimum Relative Tabletop Motion

CVI Melles Griot StableTop™ optical tables, shown in figure 9.22, incorporate a triple-plate double-honeycomb design, which provides unsurpassed stiffness and excellent dynamic rigidity. The top layer consists of a stainless steel top plate and a secondary steel plate, separated by a unique plated-steel honeycomb-like structure. The second layer includes the main steel honeycomb structure and the stainless steel bottom plate. The main honeycomb core is fabricated from strips of precision-formed plated steel, which is bonded together with a high tensile strength epoxy adhesive. The thinner, honeycomb-like top structure is made from cylindrical-shaped steel cups, which enhance the overall stiffness of the tabletop and provide improved support of the top plate.

Low Dynamic Deflection

A tabletop with state-of-the-art performance suitable for the most demanding applications requires enhanced damping. CVI Melles Griot tables use a unique damping method to reduce the amplitude of tabletop resonances. Strategic positioning of tuned and broadband dampers ensures superior performance by reducing the compliance curve resonance peak, which further reduces relative tabletop motion.

Excellent Surface Flatness

Tabletop flatness is critically important during many experimental setups. Lack of local flatness requires readjustment of components for height variations across the tabletop and can cause component wobble. CVI Melles Griot tabletops provide unsurpassed flatness due to high-precision magnetic stainless-steel plates which are specially handled to maintain superior flatness throughout the manufacturing process. A

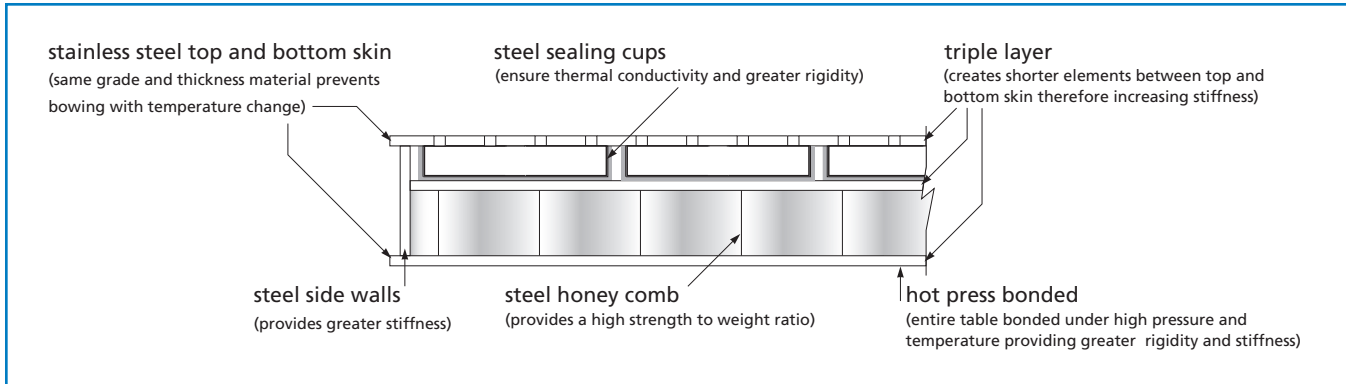


Figure 9.22 CVI Melles Griot tabletop with triple-plate, double honeycomb core construction

unique thermal bonding process ensures that stress is not induced during manufacture, thereby retaining the flatness of the top plate.

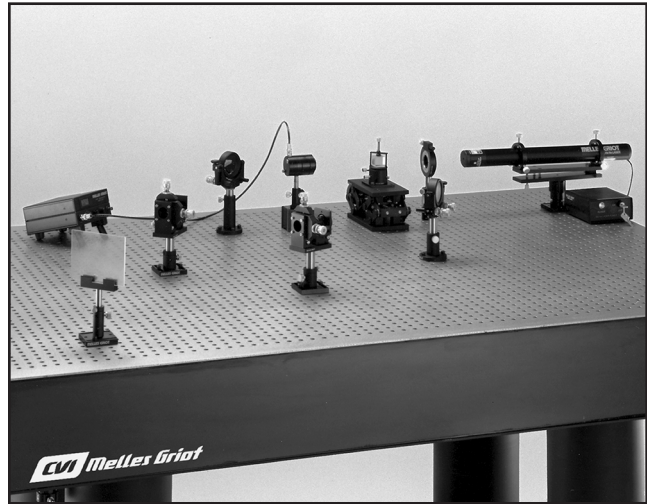
Athermalized Design

The top and bottom plates of CVI Melles Griot tabletops, made of magnetic stainless steel, have identical thermal and mechanical characteristic. This unique athermalized design eliminates any thermal bowing effects caused by temperature variations.

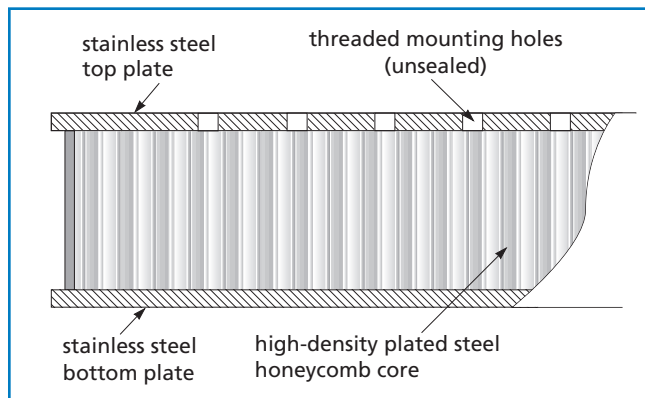
EVALUATING TABLETOP PERFORMANCE

The performance of an optical table is quantified by its compliance. At CVI Melles Griot, the compliance of our tables is measured with a dynamic signal analyzer. The test setup is shown in figure 9.23.

An impulse hammer is used to apply a measured force to the top surface of the table; transducers attached to the surface sense the resultant vibrations. The signals from the transducers are interpreted by the analyzer and used to produce a frequency response spectrum—a compliance curve. During the development phase of an optical table, compliance curves are recorded at many points on the tabletop; however, compliance is always greatest at the corners. The compliance curves and data published by CVI Melles Griot are recorded at the corner of the table and, therefore, represent the worst-case data.



A typical setup on an optical table



Schematic of a two layer breadboard

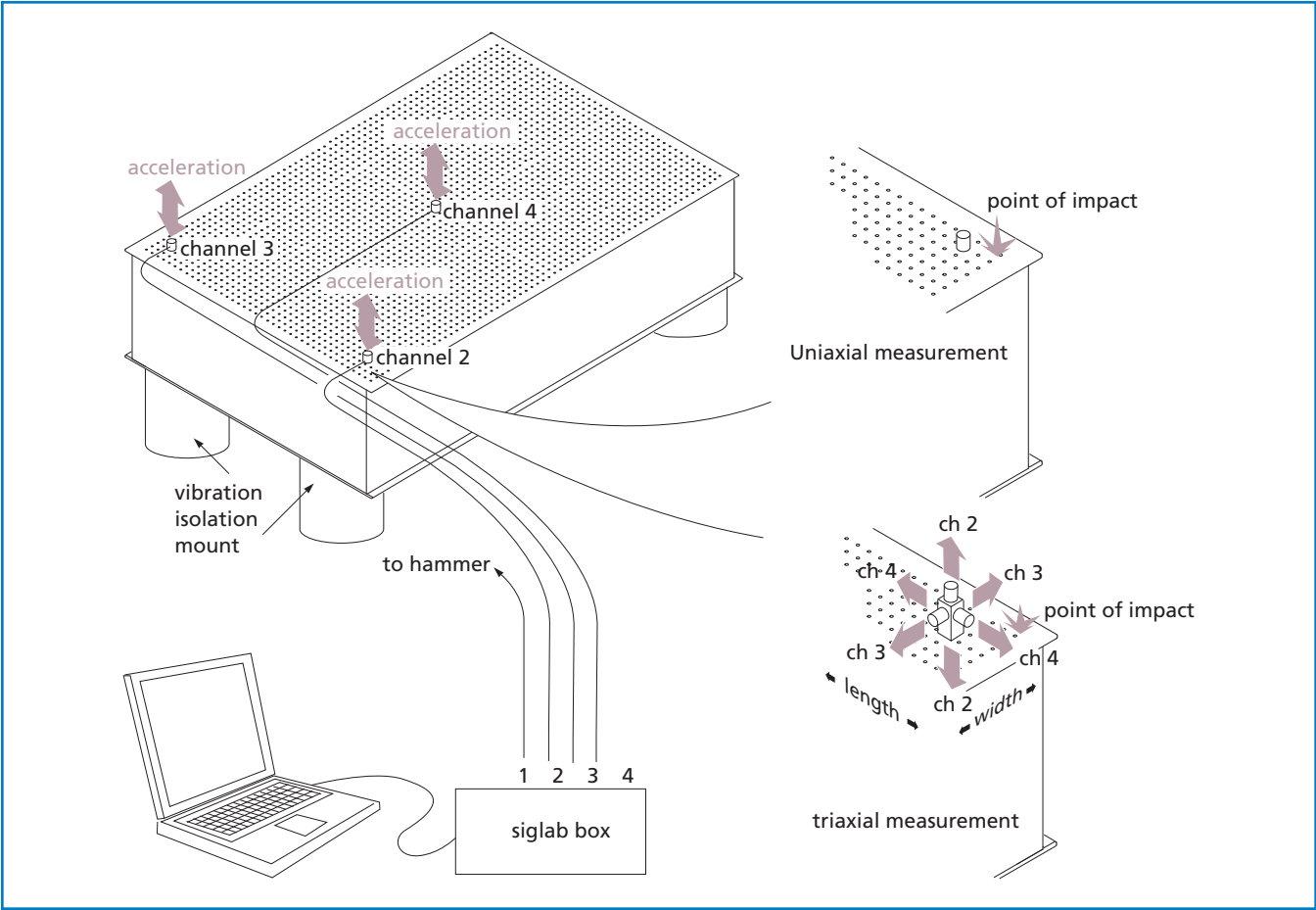


Figure 9.23 Evaluating the performance of an optical tabletop