Tabletop Isolator Design

True seismic mounting of an optical tabletop requires a mounting system which addresses two issues.

- Ambient building vibrations occur at low frequencies; therefore the mounting system must have very low vertical and horizontal resonant frequencies in order to function as a seismic isolator.
- These motions must be damped in order to suppress the resonant peaks.

The aim of vibration-isolation supports is to reduce motion and vibration from the building and surrounding environment, and to isolate these vibrations from the tabletop surface. Such vibrations may result from building seismic activity, nearby machinery, or pedestrian traffic. Isolation from these vibrations is achieved by using a mounting system with a very low resonant frequency, for example, soft-spring pneumatic systems.

AIR-SPRING VERTICAL ISOLATION

The simplest, most successful optical table supports are legs containing air springs, which have been successfully employed in solving vibration-isolation problems for over 50 years. Typically, an air spring is a flexible diaphragm on top of a rigid cylinder of compressed air as shown in figure 9.28. A heavy object can be placed on the air spring, and, as the object vibrates or as the floor vibrates with respect to the stationary object, the air is alternately compressed and allowed to expand.

Air springs differ from their conventional mechanical counterparts because they have a very low spring constant compared to their small range of travel. A mechanical spring with a low spring constant usually exhibits a large-amplitude vibration because of the small restoring force. In an air spring, the relationship between restoring force and deflection varies with the shape and material of the air spring envelope. The resonant frequency of an air spring isolator is given by

$$f_n = \sqrt{\frac{rAg}{V}} \qquad (9.11)$$

where r is the specific heat ratio for the gas (air) in the spring, A is the piston area, g is the acceleration caused by gravity, and V is the volume of the air bag (or cylinder).

From the above equation, we can conclude that the stiffness of the spring (and hence the natural frequency of a mass supported on the spring) is dependent upon the height of the spring (volume of air), but it is independent of the load. Consequently, if the load is changed but the pressure is adjusted to maintain a constant height, then the resonant frequency remains constant. This is highly desirable for optical tables.

The simplest table support system has several legs (usually four, depending on table size). Each leg consists of a stiff rubber bag of compressed air, and the weight of the table rests on a metal disc on top of the bag. When the isolators are unpressurized, the table rests on the top of the outer casing of the leg. Pressurizing the air spring floats the table, thus providing seismic mounting. With four air springs involved, there are several vertical vibrational modes (i.e. resonant vibrations) of the table on the support system. These are the various in- and out-of-phase combinations of vibrations of the individual isolator legs. These motions include vertical motion, pitching and rolling. Their resonant frequencies are shifted only slightly relative to that of an individual isolator with a quarter of the table weight on it.

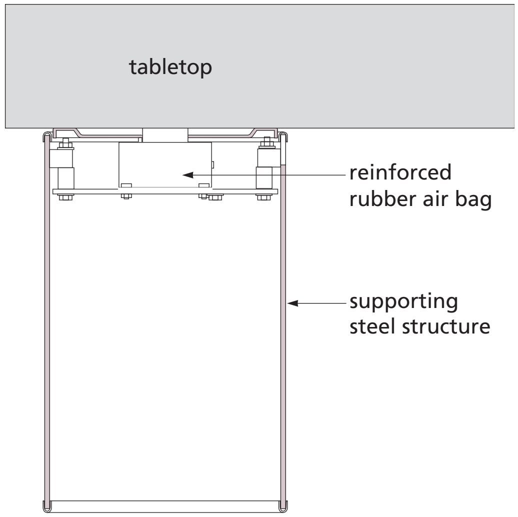

Figure 9.28 **A simple air spring**

CHOOSING AN ISOLATION SYSTEM

The simple air spring design described previously is more than adequate for use in lower vibration environments, or for less sensitive experiments, and it is a vast improvement on rigid support systems such as steel legs. However, three issues are not directly addressed: enhanced damping, horizontal vibrations, and load leveling.

Enhanced Damping: With the simple air spring, damping is limited to that provided by viscoelastic deformation of the walls of the air bag. As a result, the vibration peak at the resonant frequency can be quite large.

Horizontal Isolation: Horizontal vibration may make the table rock on its legs. The horizontal resonant frequency depends upon the nature and shape of the linkage between the table and the air bags, but is typically in the 3- to 5-Hz range. Because ambient horizontal vibrations tend to occur at lower frequencies than vertical floor vibrations (1 to 20 Hz versus 10 to 50 Hz), they are more difficult to isolate. However, with the exception of upper-floor locations in tall buildings, horizontal floor motions are generally much smaller then vertical vibrations.

Load Leveling: With the simple air spring, there is no provision for self-leveling and automatic height adjustment. When large loads are placed on the tabletop it will be lowered slightly, and if the load is not placed centrally, the tabletop will no longer be level.

Ground Floor Locations

In a ground floor situation, predominately vertical floor borne vibrations in the 4 to 50 Hz range are likely to be encountered. These are readily attenuated using a passive isolation system.

CVI Melles Griot Pump & Go™ passive isolators, shown in figure 9.29, are ideal for removing floor vibrations in the critical 10- to 50-Hz f.requency range. They provide simple, effective vibration isolation with excellent horizontal and vertical stability without any air consumption. Each isolator consists of a cylindrical reinforced rubber air mount in the top of a cylindrical steel leg. An integral part of the air mount is a steel plate on which the bottom of the optical table rests. The pressure of the isolator can be adjusted by admitting or releasing air through a standard Schraeder valve on the side of each isolator.

The passive air mount design is ideal for most general optical table uses, providing low-frequency isolation coupled with excellent stability in both vertical and horizontal directions. The thick wall construction ensures maximum safety and overload protection with an economical design. This passive air mount continues to support and isolate even with no air pressure. It provides low transmissibility at resonance, particularly when compared to conventional rubber or neoprene isolators. The transmissibility above 10 Hz is below 0.3 and results in low values of relative tabletop motion for the assembled system.

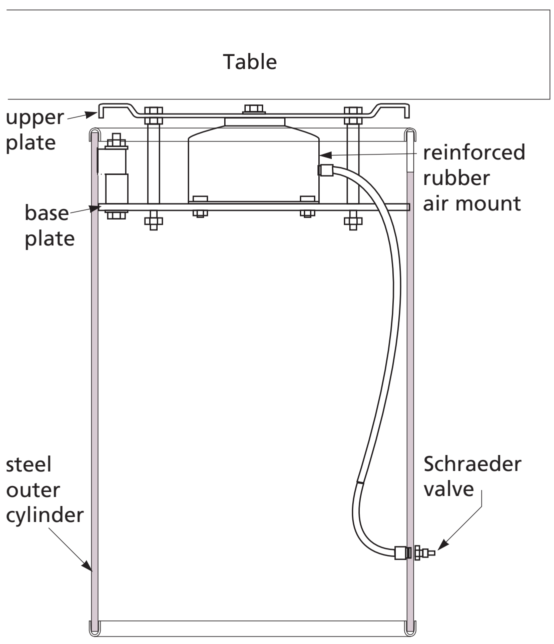

Figure 9.29 **Construction of Pump and Go™ isolator**

Upper-Floor Locations

If an experiment is conducted on an upper floor, the building may sway, causing both vertical and horizontal vibrations. CVI Melles Griot SuperDamp™ self-leveling isolators, shown in figure 9.30, are large-diameter free-standing systems that provide maximum stability and safety, without cumbersome tie bars. The low vertical and horizontal transmissibility of these isolators results in the least possible relative tabletop motion. The proprietary design uses no liquids that could leak or degrade over time.

Vertical damping is achieved by the use of a dual chamber, damped pneumatic spring. The table is supported by the air pressure in these chambers. A piston, clamped to the bottom of the table, is sealed to the upper chamber with a rolling rubber diaphragm, allowing virtually friction-free motion between piston and chamber. Floor or tabletop motion forces air to flow from one chamber to the other through a high-resistance damper.

This restriction of airflow damps oscillatory motion between the floor and table, dramatically reducing settling time. The volume ratio of the chambers has been optimized to maximize damping performance for our complete range of tabletops while preserving a low resonant frequency.

As stated previously in the discussion on seismic mounting in the vertical direction, isolation of an optical table from low-frequency ambient vibrations is best achieved by having a soft coupling between the floor and tabletop, so that the resonant frequency is lower than most of

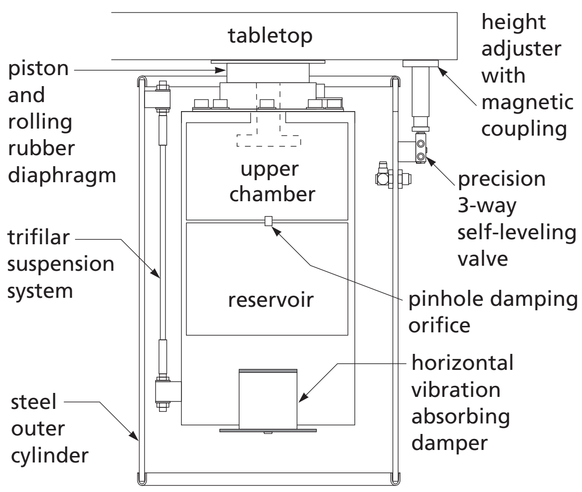

Figure 9.30 **Construction of SuperDamp™ isolator**

the ambient vibrations. It is also desirable for the transmissibility of the mounting system to be independent of loading.

A simple method of mounting a tabletop so that it can execute horizontal motion with a low resonant frequency is to suspend the table, rather like a pendulum. Furthermore, the resonant frequency of a pendulum is independent of the mass suspended from it and is given by

$$f_n = \sqrt{\frac{g}{l}} \qquad (9.12)$$

where g is the acceleration caused by gravity and l is the length of the pendulum. CVI Melles Griot SuperDamp™ isolators damp horizontal vibrations by supporting the pneumatic vertical isolator on a trifilar suspension system. This innovative pendulum design uses gravity to provide the restoring force after horizontal disturbances. Horizontal oscillations at the system's resonant frequency are damped by linking the base of the vertical isolator to the outer cylinder with an oil-free vibration-absorbing damper.

To allow for changes in load distribution, SuperDamp isolators also feature a self-leveling system which incorporates precision threeway valves that do not compromise vertical isolation when the system is at rest. Because these valves are actuated by tabletop movement, the system returns to its original level position within ±0.25 mm (0.01 in.) after disturbances. The valves also compensate automatically for any changes in tabletop load distribution.

Additionally, this system allows the table height to be adjusted over a range of 26 mm (1.5 in.) and can be used to compensate for an uneven floor. These isolators require a constant supply of air. When the air supply is removed, the tabletop rests securely on top of the legs with the isolation system disabled. Three isolator heights are available to create a working table height of 910 mm (36 in.). Nonstandard heights are available upon request.

Less-Sensitive Applications

Many environments and applications do not warrant vibration isolation. In such cases, it is necessary only to have a nonisolating support structure with two basic features: an economical support structure strong enough to support an optical tabletop under heavy loading and a manual leveling adjustment on each support to compensate for uneven floors. CVI Melles Griot offers free-standing non-isolating supports each with three adjustment screws to level or adjust the table height.

INSTABILITY AND OSCILLATION

Systems with a high center of gravity (CG) can experience stability problems when supported on pneumatic isolators, particularly when the tabletop is narrow and/or thick. A high CG, combined with narrow isolator spacing, can cause static instability, and the table tends to rock slowly backwards and forwards about an axis midway between the two isolators. Furthermore, a dynamic instability can be experienced in the leveling system, causing the table to rock quickly from side to side.

Static Instability

Most table systems have a center of gravity which is above the height of the diaphragms, and narrow spaced isolators located at either end of the table. Any disturbance of the tabletop causes the CG to move away from the centerline between the isolators, and the weight of the table and equipment assists this sideways motion, causing the table to tilt further.

This tilting action is resisted by the stiffness of the isolators: stiffer isolators mean more stability. However, as we concluded previously, it is the softer isolators that are more effective in removing vibration. A trade-off must therefore be made between isolation and stability.

It is generally accepted that in order to avoid static instability and oscillation caused by excessive rocking, the CG, including that of the table, should be within the pyramid shown in figure 9.31.

The base of this pyramid is defined by connecting the center point of each isolator, and the height is equal to half the shortest distance between isolators. Static instability is not dependent on the air pressure in the system or (for active systems) the adjustment of the leveling valves. The only solution is either to lower the CG (moving equipment below the table surface by use of accessory shelves) or to increase the isolator spacing.

Dynamic Instability

In an active isolation system, table height is controlled by leveling valves, which let in or exhaust air as required. If the in-let or exhaust rate is too fast, then oscillation occurs. This oscillation can be removed by reducing the airflow to and from the isolators.

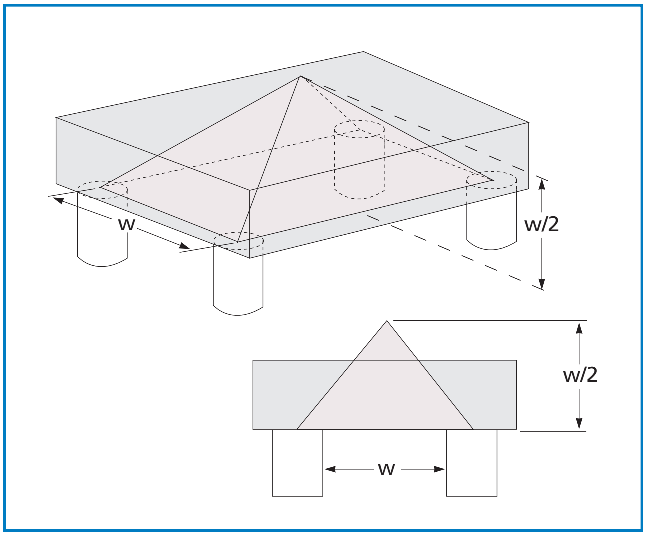

Figure 9.31 **Stability diagram for a tabletop**