Vibration Isolation in Optical Test Systems

In the world of precision motion control there is a continuous pursuit of higher performance, whether it's resolution, speed, stability, accuracy or step size. Even if a specified device appears on paper to be capable of achieving excellent results, the design of the mechanics and the platform stability play an integral role in achieving peak performance.

There is certainly an aspect of "art" in optical system design as these unique inventors look for new, innovative techniques to shape, bend, and manipulate light, either through the creation of new optical elements or by combining multiple elements. Equally important parts of the design are the mechanical elements that support, move, or control each component in the optical path. Each of these mechanical elements contributes to the stability (or instability) of the output beam and can be a hidden source of error if not properly designed or constructed.

Vibration Control

A common source of instability within a light beam path is vibration. Vibration control systems that include, typically, vibration isolators and optical tables, are intended to minimize the impact of environmental vibration. The optical table serves as a common base for the whole opto-mechanical assembly. Opto-mechanical components such as posts, rods, and mounts, as well as positioning stages, are made to anchor optical elements in place so that the optical paths will be undisturbed by environmental impacts such as vibration. The final result depends on the whole "structural loop," which encompasses support structures, motion control systems, and opto-mechanical elements.

Consider the innocuous optical post used by many to support optical mounts, sensors, and even motorized positioners. Typically these posts are machined from stainless steel or aluminum and serve as the foundation for many optical set-ups (Figure 1). When properly specified and installed they

Figure 1. Precision-ground, stainless steel optical posts for ultra-stable alignment and mounting of optical components.

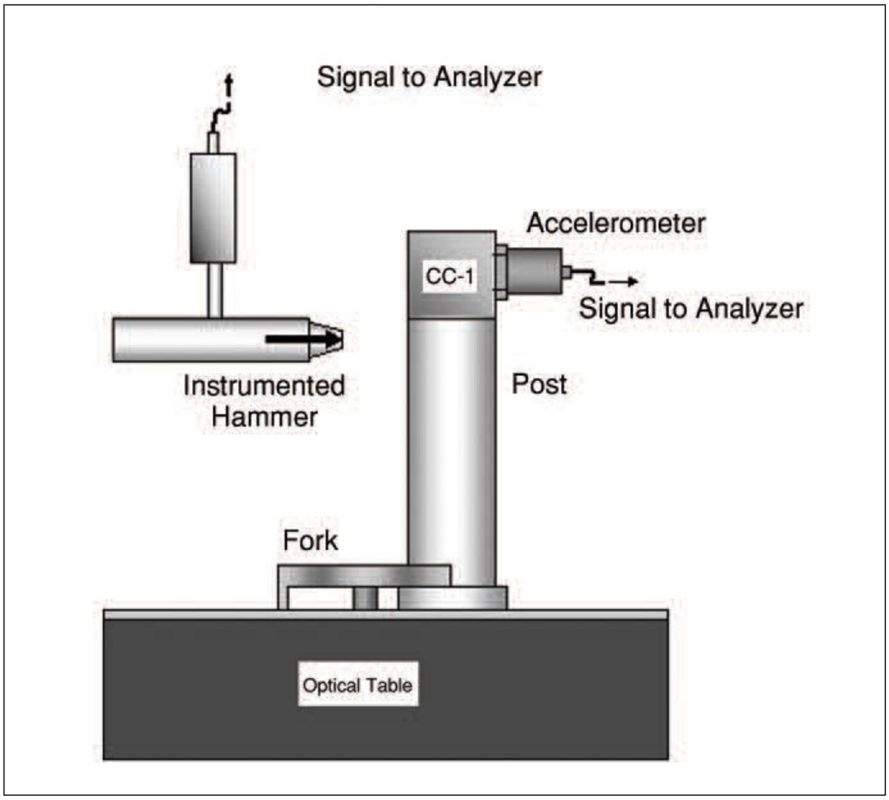

Figure 2. Test setup. Transfer-dynamic compliance estimates the ratio of the horizontal acceleration (recalculated into displacement) to the force applied near the top of the post, as a function of frequency.

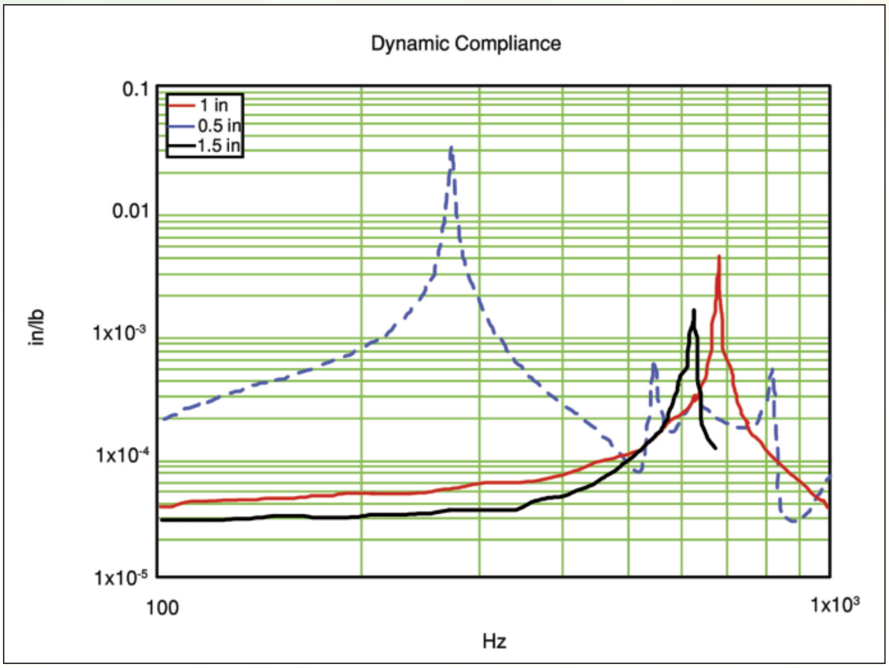

Figure 3. Graph of the Dynamic Compliance test results.

Diameter	0.5 in.	1.0 in.	1.5 in.
Frequency, Hz	272	680	622
Amplitude, milli-in./lb	33.1	4.3	1.6

Dynamic performance test data.

provide a rigid support to bring components to the proper beam height. However, when they are used incorrectly or installed improperly they can be a source of significant angst since the subtle vibration issues they may cause are typically blamed on the vibration control platform or motorized stage stability (i.e. proportional, integral, and differential (PID) problems or deadband hunting). To better understand this effect, testing was conducted on various diameter posts (0.5-in., 1.0-in., and 1.5-in.) of equal height (4-inches), to quantify the structural characteristics of each. Contact stiffness of the attachment was carefully controlled as it can be a significant factor affecting resonance vibration of the post.

Dynamic Performance

The dynamic performance of the posts was characterized by the dynamic compliance, which is the ratio of the displacement measured in horizontal direction at the top of the post, to the excitation force applied to the post, as a function of frequency. The dynamic compliance shows the natural frequencies and the level of damping of the assembly.

The test set-up shown in Figure 2 consisted of an accelerometer fastened to a Newport CC-1 construction cube via a threaded adapter, which was then fixed to the post by a screw and a washer. The total weight of the accelerometer, the cube, and the screw was 2.6 ounces. All testing was conducted on the surface of a Newport SmartTable® with dampers active to provide the most stable surface possible so that the post resonances could be clearly observed.

The test data presented in Figure 3 indicates that the 1-in. diameter and 1.5-in. diameter posts have comparable characteristics, whereas the 0.5-in. diameter post is much more compliant. Dynamic performance is considered better if the (lowest) natural frequency is higher and resonance amplitude is lower. The numerical results are summarized in the accompanying table.

The test results show that the 1-in. diameter and 1.5-in. diameter posts have comparable characteristics. The 1-in. post has somewhat higher frequency, but the 1.5-in. post has lower amplitude of resonance vibration. The lower frequency demonstrated by the 1.5-in. post can be explained by its larger mass coupled to the contact stiffness of the table surface. The 0.5-in. diameter post is much more flexible, with lower frequency of resonance vibration and higher amplitude. These results demonstrate the importance of product selection in opto-mechanical systems since the 0.5-in. post would exhibit more than 7x the displacement at a significantly lower frequency than the 1.0-in. diameter post. The frequency characteristics can also be very important since basic optical tables (4 ft. x 8 ft.) experience their primary resonant frequency at around 250 Hz - 275 Hz, thus increasing the risk of vibrations that can disturb optical setups. This risk is diminished by using highly-damped optical platforms or actively-damped SmartTables.

Optical Delay Lines

A common application where vibration platforms, optical components, and precision motion control must be carefully combined is the optical delay line (ODL). Optical delay lines are used to make minute changes in the total path length photons travel before reaching their destination. Common applications for delay lines include optical coherence tomography and pump-probe investigations such as two-dimensional infrared and transient-absorption spectroscopy. In these applications it is critical not only to be able to achieve very small incremental motions but also to maintain beam position along the total path of travel. In some applications data is taken in a "step-and-settle" process but other applications require data "on-the-fly," which requires more rigid components and careful attention to excitation frequencies of all components involved.

Newport manufactures an ODL kit (Figure 4) that allows users to select various levels of performance ranging from 100nm stages that provide 0.67 femtosecond (fs) delays, up to 1250nm stages that provide 8.33-fs delays. The ODL kit has been designed to provide the performance and stability required for critical applications. Notice in the Newport ODL the common use of 1.0-in. diameter posts and their minimal height since this provides the highest level of stability for optical mounts as shown in the testing results.

In the post testing results presented at the beginning of this article it was shown that the 0.5-in. diameter post exhibited

33.1 micro-in/lb displacement which translates to 0.840mm or 840μm motion when experiencing a 1-lb force. A 1-lb force is rather large for a typical optical experience but even at 1/1000th of that amount, it would translate to an 840nm movement, which would not allow users to achieve better than a 5.6-fs delay. Using a 1.0-in. diameter post in this same set-up would permit reaching a 0.72-fs delay. Although these displacement approximations represent a 4-in. post height, and shorter heights would enable better performance, consideration of the structural design factors that affect optical stability, including component resonance and stiffness, is critical in all applications that involve optical elements and precision motion control. These applications include micromachining, sensor characterization and calibration, laser imaging or optical material characterization.

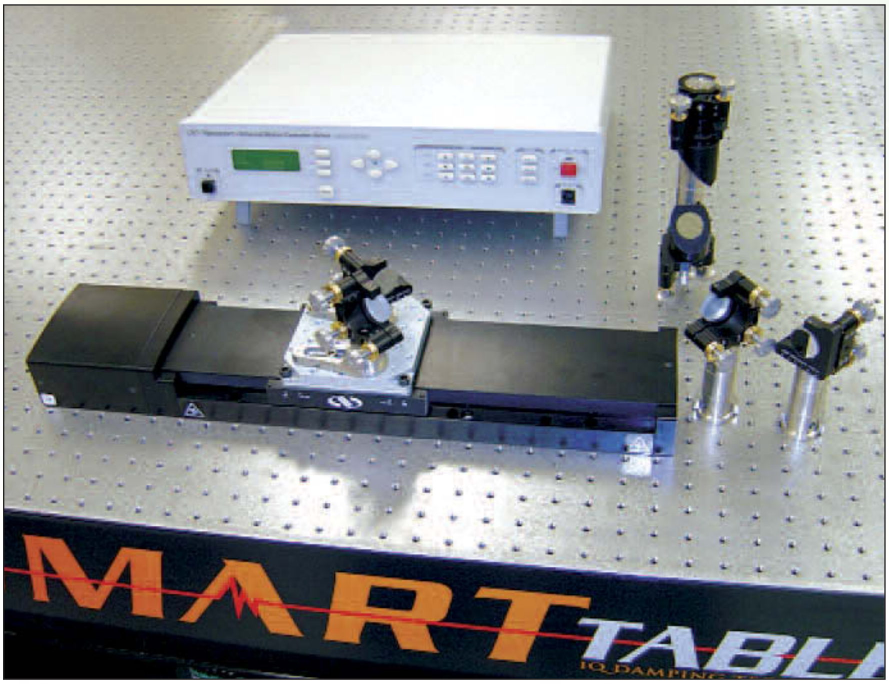

Figure 4. This Optical Delay Line Kit from Newport Corporation provides researchers and scientists with all the necessary components to create a high quality, free-space optical delay line assembly.

In sensitive applications, susceptibility to vibration and the realization of precision motion is not only a function of the optical platform, but also of the selection and installation of the optical components. It is a function of how all of these elements interact with the motorized positioners that is essential to achieving the desired step size of position sensitivity.

This article was written by Vyacheslav M. "Slava" Ryaboy Ph.D., D. Sc., Principal Mechanical Engineer, and James Fisher, Sr. Director, Newport Vibration Control Division (Irvine, CA). For more information, contact Dr. Ryaboy at vyacheslav.ryaboy@newport.com, Mr. Fisher at james.fisher@newport.com, or visit ***http://info.hotims.com/34458-200***.