Supporting Active Electro-Pneumatic Vibration Isolation Systems on Platforms Supported by STACIS^{tm} 'Hard-Mount' Piezoelectric Isolation Systems

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Abstract:

In locations with high levels of vibration, the internal pneumatic isolation systems in many semiconductor manufacturing tools can be inadequate, requiring the use of an additional isolation system – usually mounted underneath a sub-floor platform. This can be a problem it the tool's internal system uses 'active' vibration cancellation. These systems use linear motors (Lorentz force motors, sometimes called 'voice coil' motors) mounted between a supporting base frame and the isolated payload to improve the throughput and resolution of the tool. Sensors mounted to the payload can be used in a feedback loop to improve the dynamic response and vibration isolation performance of the system, and information from the system's stage motion controller can be used in a feed-forward path to reduce the payload reaction caused by stage motion. This paper demonstrates that such systems can be safely mounted on sub-floor platforms supported by 'hard-mount' STACIS^{tm} piezoelectric vibration isolation systems[1] without any adverse affect on the tool's internal isolation system. STACIS^{tm} is thus an exception to the "no active-on-active" rule of thumb which applies to other 'soft-mount' sub-floor active systems.

Introduction:

"No active-on-active" is a rule of thumb which states that no machine which incorporates active vibration isolation (internally) can be mounted on a platform which also uses active vibration control. The rule is incorrect, however, as it applies to only certain types of active vibration isolation systems.

The 'no acitve-on-active' rule exists because there is a potential for one of the active isolation systems to influence the other. There are two mechanisms for this. The first is that the coupling of the two mass-spring systems produces a new system with different (and more complex) 'normal mode' frequencies – the frequencies at which the system oscillates after a disturbance. This can alter the loop transfer functions in the control system, and can result in either unstable or non-optimized performance. This mechanism is not a coupling between the control loops in the two systems, but rather just a result of two systems *of comparable stiffnesses* being coupled. This can also result by placing a tool with an active pneumatic system on top of a *passive* pneumatic platform. The STACIS^{tm} active isolation system avoids this by having a stiffness which over 100 times higher than the typical pneumatic system.

The second mechanism is an actual coupling between the control system internal to the tool and the system in the supporting platform. Figure 1 illustrates two electro-pneumatic active isolation systems stacked on top of each other (simplified to one degree of freedom):

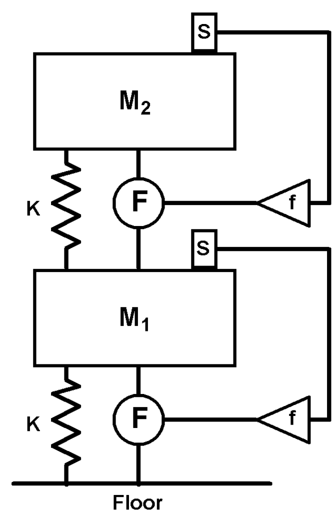

Figure 1

Each system supports a mass (M_1 & M_2) on a (pneumatic) spring (K). Here M_1 represents the sub-floor platform for the tool and the tool's frame. M_2 is

[1] US Patent Number 5,660,255

the internally isolated payload in the tool. The two masses are roughly equal, as are the Ks. Each active system has a sensor (s), a compensation system and amplifier (f), and a force actuator (F). The second mechanism involves the formation of an unstable or undesirable control loop involving both (nominally independent) systems. For example, a disturbance on M_2 generates a signal in the top sensor, which generates a force in the top actuator. But the top actuator also pushes against the low mass M_1. This causes a signal to be generated in the lower sensor, and a response in the lower actuator, which results in a force being transmitted to the M_2 via its support spring. A loop is thus formed. Such loops may or may not be stable, but they are always undesirable.

STACIS[tm] avoids these problems by significantly decoupling the two control loops, as shown in Figure 2 below:

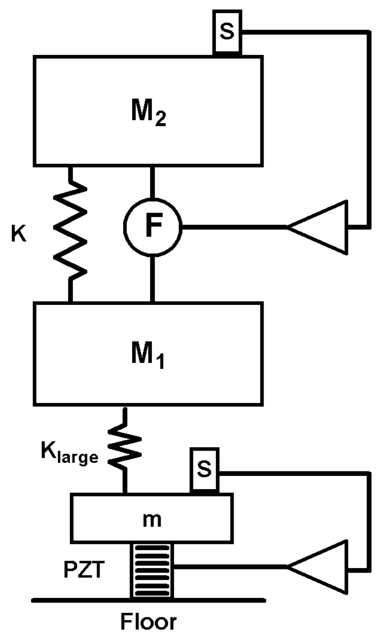

Figure 2

In this figure, M_1, M_2, and K represent the same elements as before, but the lower spring, sensor, and actuator are replaced by a STACIS[tm] piezoelectric isolation system. It consists of a sensor (s) mounted to a small mass (m) – typically only a few Kg in size. The sensor's output is filtered and drives a PZT stack which nulls the sensors output in a high-bandwidth servo (typically 200Hz). The mass M_1 is supported by a spring (K_{large}) which is over 100 times stiffer than the spring (K).

The tool's internal active isolation system is unaffected by the presence of the STACIS[tm] system. The normal modes of vibration for the mass M_2 are unchanged because the (series) stiffness is still dominated by K (K_{large}>>K). The results is that the loop transfer functions of the tool's control system are unchanged, and its performance unaffected. Intuitively, this makes sense: the resonant frequency of the tool and platform on the STACIS[tm] isolator (K_{large}) is approximately 20Hz – which is comparable to the lowest resonances in most frame structures, or even of many floor structures.

In addition, the STACIS[tm] isolation system is completely unaffected by the presence of the tool's active system. This is primarily because of the very high stiffness of the PZT stacks (typically several hundred million N/m). Any force transmitted to (m) through (K_{large}) results in virtually no motion of small mass. This breaks any potential 'active on active' feedback loops. This also gives STACIS[tm] a 'plug-and-play' characteristic – the system needs little or no adjustment in most installations.[2]

Test Results:

To demonstrate the ability of STACIS[tm] to support active pneumatic isolation systems, we set up an ElectroDamp[tm] II[3] system on top of a platform supported by STACIS[tm] isolators (see Figure 3 below).

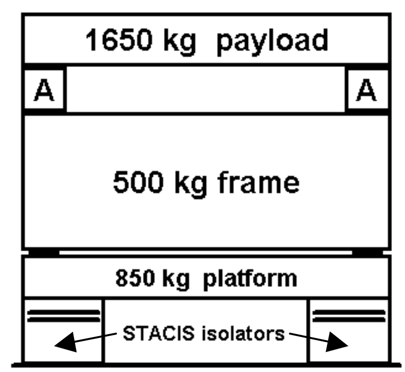

Figure 3

ElectroDamp[tm] II is a six degree of freedom, high performance active isolation system based on payload-mounted vibration sensors, high-force linear motors, and a DSP-based control system. It measures payload motion with the sensors and applies a compensating force to improve both

[2] Some installations on soft floors require minor gain adjustments to the STACIS[tm] loop gain.
[3] US Patent Number Re. 33,937

damping and vibration isolation (as shown in Figures 1&2). In addition, it can use information from stage motion controllers to apply multi-axis feedforward signals. It is used in semiconductor manufacturing equipment, and is typical of electro-pneumatic isolation systems. Figure 4 below is a photograph of the setup shown in Figure 3. Referring to Figure 4, the ElectroDamp™ active isolators are shown at (A). The entire system is approximately 1.5m square. The isolated payload (B) is a steel casting weighing 1650 kg. The frame (C) is of a welded steel construction, weighing approx. 500 kg and 1 meter

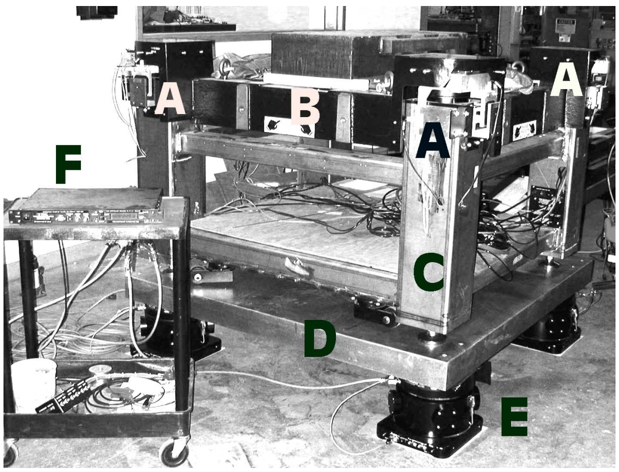

Figure 4

high. Beneath it is a standard TMC sub-floor platform (D) consisting of an epoxy-bonded lamination of steel plates and stiff damping layers in a stainless steel casing. It weights approximately 850 kg. Four medium-capacity STACIS™ isolators (E) support the entire system on a poured concrete floor. The STACIS™ DSP-based controller is shown at (F).

After the system was set up, both the STACIS™ and ElectroDamp™ systems were turned on. Neither system required any adjustment to be functional or to meet spec. The Auto-Tuning algorithm in the ElectroDamp™ system was then run to optimize the system, which is part of its standard installation procedure. The auto tuning ran with no problems, and made only minor gain adjustments (on the order of a few dB). This modest level of gain adjustment is typical of any installation.

To help understand just *how insensitive* the ElectroDamp™ is to the presence of the STACIS™ system, it is instructive to look at the *open loop transfer functions* in the ElectroDamp™ system. These are measured by 'breaking' the control system loop, injecting a test signal at the 'in' half of the break, and measuring the magnitude and phase of the response at the 'out' half of the break.

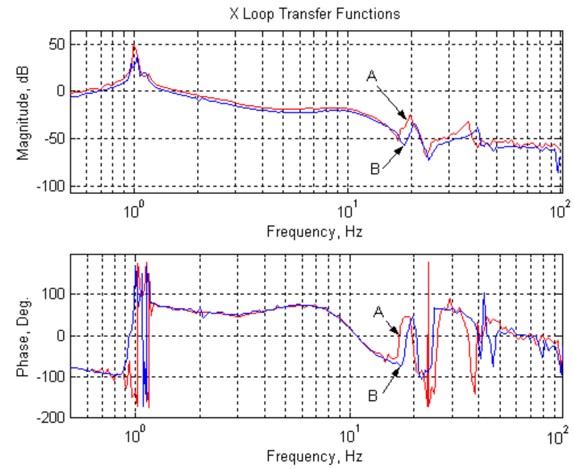

Figure 5

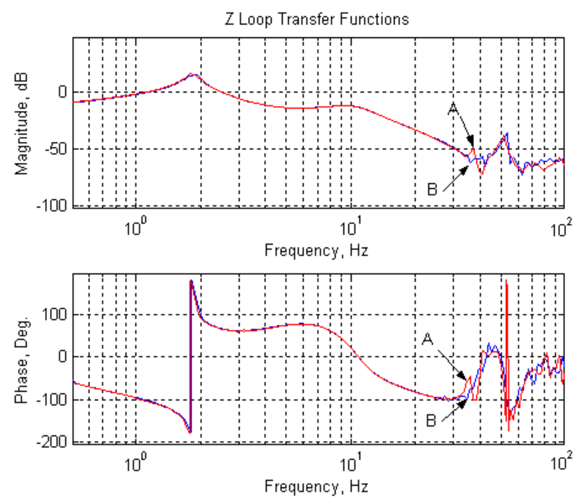

Figure 6

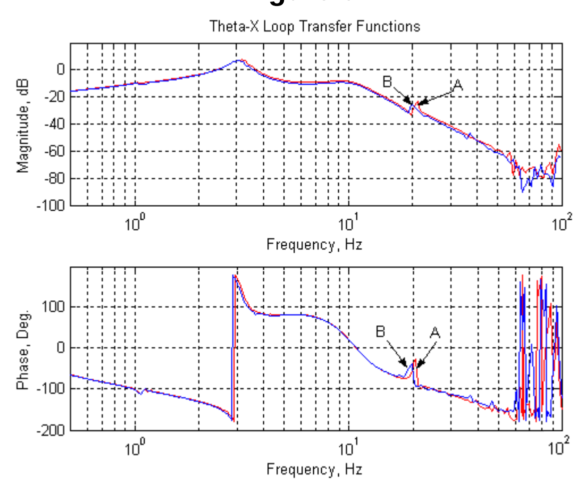

Figure 7

These curves are used by servo engineers to determine the stability and dynamic response of the system. Figures 5 through 7 show the open loop transfer functions for the X, Z, and Theta-X (rotation about the horizontal X-axis) degrees of freedom. In each plot, the curve marked (A) is the loop transfer function measured with the ElectroDamp™ frame placed directly on the concrete floor. The curves marked (B) are the loop transfer functions measured with the system placed on the STACIS™ platform as shown in Figures 3&4, with STACIS™ active (on).

In most regions, the (A) and (B) curves are so close that it is difficult to distinguish between them. *Most importantly, note that the magnitude and frequency of the primary mode of oscillation in each DOF was not changed by mounting the ElectroDamp™ system on the STACIS™ platform.* The resonances seen in the range from 20-50Hz are due to the welded frame and casting.

It is important to keep in mind what the loop transfer functions are measuring. A force is being applied to the payload by linear motors mounted to the base frame, and the vibration sensors on the payload are measuring the response to that force. What the curves demonstrate is that, *independent of the details of the control system, the frequency response is not affected by STACIS™*. In particular, *any* control system operating in the bandwidth from 0.5Hz to 100Hz will not see a change in its frequency response due to STACIS.

This argument applies equally well to systems which use feedforward to cancel payload reactions to stage motions: The force applied in the feedforward system will cause the same payload reaction independent of the presence of STACIS™. In principle, this a more stringent requirement than is necessary. In a properly designed feedforward system, the vector forces generated by stage accelerations are canceled by forces generated by the linear motors – if this cancellation is exact, then it doesn't matter what the payload dynamics are or what the frequency response is. No motion will result.

Benefits of the STACIS™ system:

STACIS™ enables the tool manufacturer to install equipment in environments that are otherwise too noisy for the tool. To demonstrate this, Figure 8 shows the vertical vibration transfer function for TMC's ElectroDamp™ system installed on a sub-floor platform mounted on STACIS (Figures 3&4). Instead of placing the STACIS system on the floor, however, we placed it on a second floor platform (weight 1730 kg) supported by high capacity STACIS™ isolators. This second system was used in the testing to provide a controlled floor excitation of approximately 1 micron amplitude.

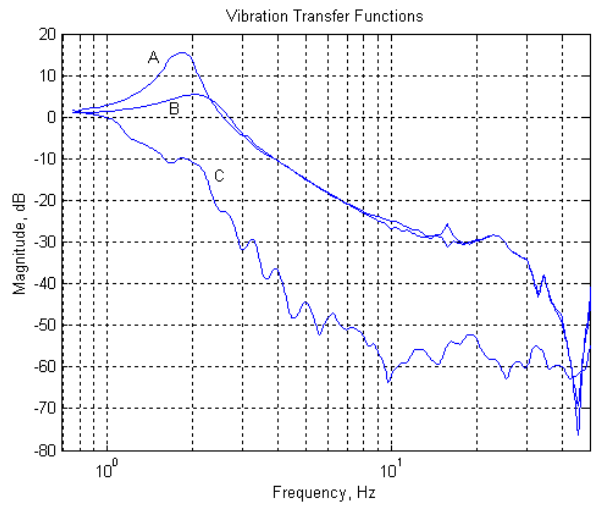

Figure 8

In the graph, curve (A) is the vibration transfer function for the system with both the ElectroDamp™ and STACIS™ systems turned off (passive pneumatic isolators only). Curve (B) is the vibration transfer function with ElectroDamp™ only[4], and (C) is with both active systems running. The sensors used in the measurements were Kinemetrics model SS-1 seismometers with 100x preamplifiers.

As can be seen by the measurement, the isolation at 10Hz is increased nearly 30dB by STACIS™, with a total attenuation of nearly 60dB (the noise in (C) is a result of the very low levels being measured – approximately 1nm). In the 2Hz range (where many buildings have high levels of noise), the system is providing 10dB of isolation – an order of magnitude better than an air isolator alone (curve (A)).

Conclusions:

These data show conclusively that 'soft mount' active isolation systems which use linear motors to enhance the performance of passive pneumatic isolation systems can be mounted on STACIS™ based platforms without affecting their performance.

The STACIS™ isolation system is also insensitive to active systems mounted on top of it because of the

[4] The gain in this ElectroDamp™ system is set to optimize settling time and payload positioning, not vibration isolation.

dynamics of its control loop being determined by the stiffness of the PZT actuators and supporting floor, both of which are several orders of magnitude stiffer than any of the elements in the active pneumatic system. K_{large}. also helps isolate the STACIS™ control system from forces generated on the payload.

STACIS™ gives tool makers and end users more flexibility in the installation of tools that use active systems. For example, many tools have floor vibration criteria for the installation site which must be met for the tool to meet its performance specification. If a site does not meet this specification, the tool must either be moved to a different site, or be placed on a sub-floor isolation system. STACIS™, unlike 'soft mount' isolation systems, can be used in these situations without any adverse effects to the tool.

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