New Technology Solves the Resolution/Speed Tradeoff

Scott Jordan, Nanopositioning Technologies, Polytec PI, Inc., Tustin, CA, USA

ABSTRACT

The relentless advance of areal densities (Figure 1) surpasses Moore’s Law (11) in the semiconductor industry. The semiconductor industry has driven electronics using CMOS technology, now at the 5 nm node and beyond. Each technologic advance is leading to higher-resolution processes. Yet, it has also driven the need for higher-resolution processes. But, as with any other process, the semiconductor industry is facing higher throughputs as well. Yet, despite the increasing demands, the semiconductor industry has been developing metrics (e.g., Figure 2) to support purchase decisions reflecting today's economics.

The performance of a positioning system is critical to the success of any semiconductor manufacturing process. This is especially true for the high-performance positioning systems used in the semiconductor industry. These systems must be able to meet the demanding requirements of the industry, such as high-speed, high-precision, and high-repeatability. The positioning systems used in the semiconductor industry are typically used in conjunction with other systems, such as lithography tools and wafer fab equipment. These systems must work together seamlessly to produce high-quality products.

Figure 1: IBM Areal Density Perspective 40 Years of Technology Progress. Source: http://www.research.ibm.com/technologies/semiconductor/50th-die/50th-die.html

Figure 2: Equipment Performance Metrics. Source: http://www.research.ibm.com/technologies/semiconductor/50th-die/50th-die.html

Figure 3: Equipment Performance Metrics. Source: http://www.research.ibm.com/technologies/semiconductor/50th-die/50th-die.html

Figure 4: Equipment Performance Metrics. Source: http://www.research.ibm.com/technologies/semiconductor/50th-die/50th-die.html

Figure 5: Equipment Performance Metrics. Source: http://www.research.ibm.com/technologies/semiconductor/50th-die/50th-die.html

Figure 6: Equipment Performance Metrics. Source: http://www.research.ibm.com/technologies/semiconductor/50th-die/50th-die.html

Figure 7: Equipment Performance Metrics. Source: http://www.research.ibm.com/technologies/semiconductor/50th-die/50th-die.html

BREAKING THE LAW

Obviously, motion-generated structural resonances increasingly impact throughput. Fortunately, engineers have several new throughput-enhancing tools available.

data tech
**LOOK-DOWN AIR BEARINGS**

Dover Instruments (Westboro, Massachusetts, USA) introduced high-stability spindles in 1994 incorporating novel look-down air bearings. These address the under-damped resonances of conventional air bearings. The look-down air bearing is highly stiff (high $f_{res}$) compared to conventional air bearings or even mechanical bearings and provides unparalleled in-position stability.

**INPUT SHAPING**

A patented [3], real-time feedforward technology called Input Shaping™ was developed based on research at the Massachusetts Institute of Technology and commercialized by Consentia, Inc. (New York, NY). It has been implemented in OMAX NanoAutomation™ products by PI (Walldorf, Germany). PI’s Mach™ Throughout Controller™ integrates this in its digital controllers (Figure 5).

Mach™ processes the command signal in real time to prevent excitation of resonances. It scales and times transitions in the command so motion-driven vibrations are cancelled. It uses a priori knowledge of resonances as quantified during installation, and does not use feedback. Unlike notch filtering, it is insensitive to

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**Table 1.**

<table>
<thead>
<tr>
<th>$f_{res}$ (Hz)</th>
<th>$(\omega_0 \text{ rad/s})$</th>
<th>$\zeta$</th>
<th>$s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>471.24</td>
<td>0.0005</td>
<td>4.244</td>
</tr>
<tr>
<td>0.001</td>
<td>2.122</td>
<td>0.005</td>
<td>0.426</td>
</tr>
<tr>
<td>0.01</td>
<td>0.212</td>
<td>0.05</td>
<td>0.042</td>
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<tr>
<td>0.06</td>
<td>0.051</td>
<td>0.1</td>
<td>0.021</td>
</tr>
<tr>
<td>250</td>
<td>1570.8</td>
<td>0.0001</td>
<td>6.366</td>
</tr>
<tr>
<td>0.0006</td>
<td>1.272</td>
<td>0.005</td>
<td>0.537</td>
</tr>
<tr>
<td>0.005</td>
<td>0.537</td>
<td>0.05</td>
<td>0.013</td>
</tr>
<tr>
<td>0.06</td>
<td>0.013</td>
<td>0.1</td>
<td>0.006</td>
</tr>
</tbody>
</table>

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**Table 2.**

<table>
<thead>
<tr>
<th>Today’s settling</th>
<th>$\zeta$</th>
<th>In 12 months of area density growth</th>
<th>% change</th>
<th>mV/mm</th>
<th>Zero vibration</th>
<th>% of time attenuation req’d</th>
<th>Pressure cycle time savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.400</td>
<td>0.0001</td>
<td>6.238</td>
<td>15.60</td>
<td>0.006</td>
<td>0.1</td>
<td>99.9</td>
<td></td>
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<tr>
<td>0.0005</td>
<td>1.572</td>
<td>9.333</td>
<td>3.93</td>
<td>0.4</td>
<td>99.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.001</td>
<td>0.988</td>
<td>2.47</td>
<td></td>
<td>0.6</td>
<td>99.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.005</td>
<td>0.622</td>
<td>3.30</td>
<td></td>
<td>1.2</td>
<td>98.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.01</td>
<td>0.463</td>
<td>1.16</td>
<td></td>
<td>1.3</td>
<td>98.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.05</td>
<td>0.417</td>
<td>1.04</td>
<td></td>
<td>1.4</td>
<td>98.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td>0.411</td>
<td>1.03</td>
<td></td>
<td>1.5</td>
<td>98.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
variations in frequency over a range > ±1%. It is effective against multiple resonances, resonances occurring outside the servo loop, and resonances exceeding system bandwidth. Its robustness makes the system attractive for OEM usage. In particular:

- It requires no changes to application setup, software, or servo parameters.
- It cannot degrade servo stability.
- It does not require specific configuration for specific motions.
- It is robust with changes in operating dynamics, such as unit-to-unit variations, or moderate changes in loading.

As a rule of thumb, Mach™ settles a system in about Fmax/2 after the pulse did last. Per Table 2, our example immediately benefits with virtually no residual vibration after only 6 ms (including 2 ms pulse duration) instead of the current >400 ms. After 1.2 months of cycle density progress, this application would require 6 ms to settle with Mach™ versus 800 ms without — a huge improvement. (The effectiveness of the Mach™ technology is essentially unrelated to the settling band.) Figure 1 shows real-world settling data from the Driver high-stability platform, revealing combined benefits of the lock-down antiaircraft and Mach™. The tool’s PZT stage (Figure 1) is very stiff for a high Fmax, resulting in <3 ms settling with 700 g load.

Mach™ also eliminates ringing during scanning, such as in pole-tip response (PTR) profiling, where use scans while the other scans. The motions cause recoil pulses to propagate through the structure. Resonant causes periodic image artifacts. This limits scan velocity and resolution.

Figure 2 (left) shows the resonant behavior of a scanning microscopy application, optics as visualized by a non-contact Polytec vibrometer. There is visible periodic scanning, and bands in the resulting image. Figure 2 (right) shows the optics’ behavior with Mach™ activated. The improvement in scan fidelity is obvious: cyclic inaccuracy is eliminated. The image improves dramatically (Figure 3, right) the central beam and the spot are at the right-hand revealed as a tisk of contrast and a phantom artifact.

ALTERNATIVES

Momentum compensation
This classical technique (or arm damping) acts on the reaction mass in opposition to the load. It benefits applications with low structural resonance frequencies. "Mach™ engineering" is required to work well.

The costly counter-actuation mechanism must be carefully matched to the load, and their cantilever must be collinear. Some residual vibration is unavoidable. This can be eliminated by parallel application of Mach™.

Signal prewashing
For applications with continuous, repetitive periodic inputs, a new pre-shaping technique [4] can reduce the "slosh", phase error and by-passes of the servo, improving the effective bandwidth and allowing more accurate tracking. It is implemented in object code based on an theoretical approach where the complex transfer function of the system is calculated, then mathematically transformed and applied in a feedforward manner to reduce the tracking error. It improves the
effective bandwidth by a factor of 16. It is more effective than classical phase-shifting approaches in reducing tracking error in multi-frequency applications. It can be combined with Mach\textsuperscript{TM} to address resonances outside the servo/feedback loop.

**Active Isolation systems**

Isolation structures have evolved to advanced systems controlled by DSPs and motion transducers. The controls strive for zero motion and are sometimes claimed to damp vibrations caused by onboard equipment. However, this is a feedback situation. By actuation, time is required to sense and act upon disturbances, and there is a threshold to the system’s sensitivity. (Mach\textsuperscript{TM} prevents vibrations rather than sensing them.) Some systems offer position feedback to help maintain levelness when large motion stages are slewed. The technique is no more effective than basic isolators for onboard motions on the submicron scale, or out of the XY plane.

**Motion controls with “active damping”**

Some DSP-based motion systems are available which claim active damping capabilities. The drawbacks noted above for the case of active isolators apply here as well.

**Postservo**

Postservo control, a technique developed in the 1950s, is a form of pole-zero cancellation that reduces residual vibration for the case of single resonance modes. However, it has achieved little acceptance because it is highly dependent on knowing the exact frequency and damping of the vibration to be cancelled. It is further limited because it is an analogue technique that requires exact timing. This can be problematic on digital control systems with a fixed update frequency. In contrast, Input Shaping\textsuperscript{TM} was developed to specifically address the short-
comings of Picocart. Input Shaping\textsuperscript{TM} produces exact solutions for digital control systems where multiple resources exist. The Input Shaping\textsuperscript{TM} solution is found in the real world where the measurements of the frequency may be imperfect or varies from unit to unit or from day to day.

**CONCLUSION**

Progress in the technology industries is illuminated by the staggering trends seen in small density growth and Moore's Law. But the profitability imperative makes this a major headache for the tool or process designer, as higher densities make for exponentially setting times. Recent mechanical and control advancements address this problem at its root by eliminating settling time by preventing the excitation of the resonant modes of the stage, load, fixtureing, frame and componentry.

**REFERENCES**


[3] The Mach\textsuperscript{TM} Throughput Coprocessor\textsuperscript{TM} is protected by one or more of the following US and foreign patents licensed by Convolv, Inc.: US 4,916,635; US 5,636,267; 04334357 (Europe); 06/152,924, and other Patents pending. Mach\textsuperscript{TM}, Throughput Coprocessor\textsuperscript{TM} and NanoAutomation\textsuperscript{TM} are trademarks of Polytec PI, Inc. Input Shaping\textsuperscript{TM} is a trademark of Convolv, Inc.


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**IF YOU HAVE ANY ENQUIRIES REGARDING THE CONTENT OF THIS ARTICLE, PLEASE CONTACT:**

Scott Jordan

**Nano-positioning Technologies**

Polytec PI, Inc.

1342 Bell Avenue, Suite 3 A

Tustin

CA 92780

USA

Tel: +1 (714) 850-1853

Fax: +1 (714) 850-1853

General E-mail: info@polytecpi.com

Scott Jordan personal: scott@usa.polytecpi.com

Web site: www.physikinstrumente.com

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**ABOUT THE AUTHOR**

Scott Jordan is President, Nano-positioning Technologies at Polytec PI, Inc. He has over twenty years of experience in the photronics, semiconductor and mass storage fields. His education spans physics (MS, physics, University of California, Irvine, 1980) and high-tech business development (MBA, Finance and New Venture Management, University of Southern California, 1984). His career has included a range of product development, marketing, research and general management roles. He has led several successful high-tech ventures to rapid growth through technical and market innovations and close partnerships with customers and suppliers. His invention of micro-optical automated alignment techniques represents a significant contribution to ultra-precision process automation. Another was CO2 development of six-degree-of-freedom production unit for lithography, and early work in lab-
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