MAD CITY LABS INC.

Confirming Picometer Performance Of Nanopositioning Systems

MAD CITY LABS IS THE ONLY NANOPOSITIONING COMPANY SHOWING REAL-WORLD EXPERIMENTAL VERIFICATION OF <50-PM CLOSED-LOOP STEP-RESOLUTION.

By Shannon Ghorbani, Mad City Labs, Inc.

When evaluating nanopositioners and their performance, interpreting published specifications from multiple vendors always is challenging. Differences in definitions or units of measurement can make it difficult to make an apples-to-apples comparison. Additionally, a technical specification is only a starting point. For most users, interpreting each specification and how it will affect their real-world application is more critical.

Which Specifications Matter To Your Application?

Comparisons between different companies' products always include technical datasheets. Users are often confronted with a confusing array of specifications, compounded by the fact that no "standard" set of parameters exists to enable easy comparison between vendors. Even the same parameters may have varying definitions or measurement units under different vendors. So, how can a user confirm those specifications are accurate or relevant? Are they achievable in a real-world setting, or only in unrealistic environmental or setup conditions? Understanding the story behind the specifications is key to making good choices for the application.

Determining a specification's importance within a given application begins with understanding the circumstances under which that specification was recorded, as well as the metric by which it is gauged. Among the specifications often quoted for nanopositioners — including resolution, accuracy, and repeatability — closed-loop resolution stands out as uniquely verifiable using a number of different methods. Conversely, consider how the specification of "resolution" is defined by any given vendor. Some vendors talk about their instrumentation resolution in terms of position noise or step resolution, without highlighting whether they are RMS values or peak-to-peak values.

When considering the example of closed-loop resolution — with a specification at the sub-nanometer or picometer level — it is important to understand the conditions in which any measurement was taken, as well as the method of measurement. Few users have access to "ideal" lab space (i.e., acoustically and thermally isolated with strict testing controls). Thus, measurement test conditions are relevant since they provide insight into how the specification may change in the user's application environment.

Vendors may use different units of measurement and present the data however they wish. Our advice to customers is to look beyond the numbers and understand the definition and context. Earlier, we described how resolution values can be described as RMS values or peak-to-peak values. This seemingly minor distinction makes a big difference! At Mad City Labs, we encourage customers to discuss specifications in the context of their application. Customers should expect transparency and have confidence in the specifications provided.

Proving Performance

Showing measurable proof that specifications are achievable represents the gold standard for instrumentation buyers. The methodology by which specifications are determined is as important as the number on the datasheet; this is particularly true for high resolution measurements below 0.5 nm. For closed-loop nanopositioners, verifying motion requires the use of other displacement measurement devices. Three techniques generally are used: tracking the position sensor of the device under test (DUT), confirming movement using a displacement laser interferometer, and testing with an atomic force microscope (AFM).

Position Sensor — One way to verify motion is to monitor the integrated position sensor tracking the nanopositioner's movement. Presumably, if the sensor indicates the stage is moving, it is moving (for examples of this approach, see "Additional Resources" below).

Interferometer — Interferometry is often used as a standard measurement technique. However, for measurements at or below nanometer resolution, displacement measuring interferometers typically rely on interpolation of a signal period, which is hundreds of nanometers, to derive small position changes. Interpolation introduces small errors whose cumulative effect becomes increasingly significant the more you interpolate, as is necessary to reach the sub-nanometer scale. Interpolation, coupled with the interferometer's inherent drift (via lasers and the metrology loop itself), renders interferometers suboptimal for confirming positioning resolution at the sub-nanometer scale.

Atomic Force Microscopy — AFMs provide a different avenue to verify nanopositioner performance with better precision and more reliable results at the sub-nanometer scale. AFMs, whose accuracy has been tested using standard physical samples (<1-nm height features) can verify displacement performance of nanopositioners

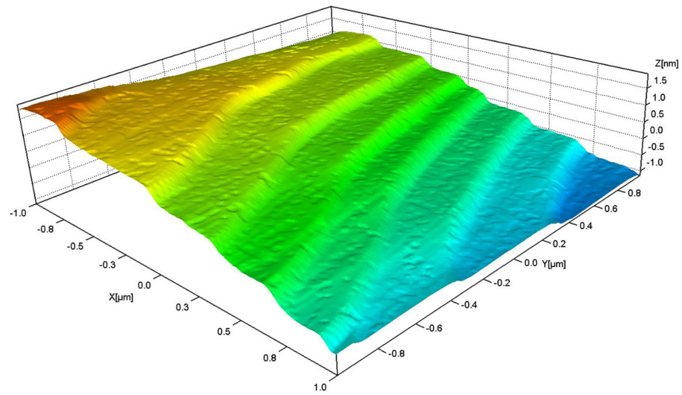

Fig 1: *Data showing individual atomic steps of Si(111). The steps should measure, on average, a step-to-step height of 312 pm. This physical sample measurement ensures the calibrated AFM is itself capable of reliably taking accurate measurements at the sub-nanometer scale.*

down to the 10-picometer (pm) level. AFMs use the force interaction between an oscillation sharp tip (usually silicon or tungsten) and a sample surface to measure the topography of a physical sample.[1]

To confirm accuracy of the testing instrumentation, a calibrated AFM is used to measure a known sample: for example, atomic steps in silicon (Si) or silicon carbide (SiC), whose atomic spacing are well known from crystallography and can be confirmed

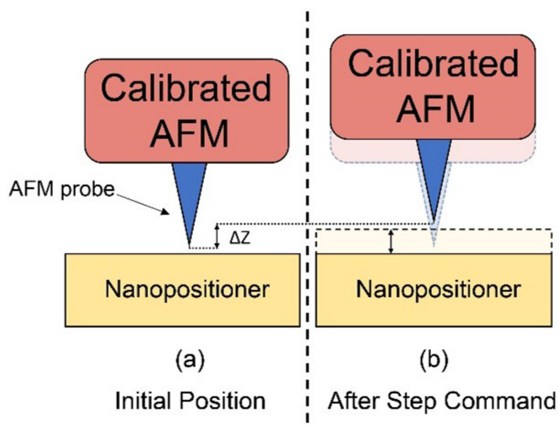

Fig 2: *Schematic of a calibrated AFM measuring a nanopositioner's height. The initial height position is measured by the AFM in (a). When the Z-position of the nanopositioner is commanded to move by ΔZ in (b), the probe of the calibrated AFM also changes in height.*

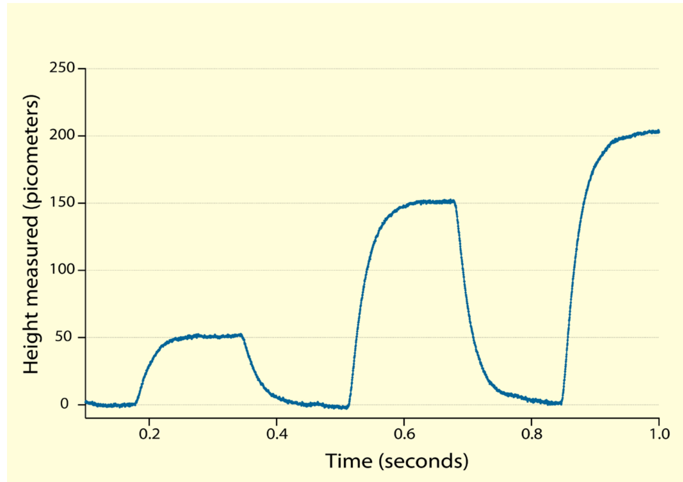

Fig 3: *The AFM measured height position of the nanopositioner Z-axis (model Nano-LPQ) after known step commands. The step sizes commanded are (left to right) 50 pm, 150 pm, and 200 pm, commanded via 20bit USB while in closed-loop mode. Data shown is an average of several iterations of the same sequence of step commands.*

via other means (e.g., X-ray diffraction). If the heights are accurate as measured by the AFM (i.e., within expected uncertainties), the calibrated AFM is confirmed to be accurate at the sub-nanometer scale.

Therefore, it is possible to confirm the performance of a nanopositioner by performing a simple AFM experiment: command the nanopositioner to execute a specific step size. When the AFM perceives motion from the nanopositioner, the AFM effectively gauges that movement as a change in height of the sample, which the AFM measures and records. For example, if the nanopositioner is instructed to move 50 pm, and the AFM shows the stage moved 50 pm, the former's precision is confirmed.

Fig. 3 shows the results of such a measurement. A closed-loop nanopositioner (Nano-LPQ) was commanded to move in 3 separate steps — 50-pm, 150-pm, and 200-pm steps — externally measured by a calibrated AFM. The AFM measurement confirms closed-loop resolution of 50 picometers on a system with 50 microns range of motion. Incidentally, it also demonstrates that the AFM measures the position noise of the nanopositioner to be substantially less than the resolved steps. This performance is unmatched by any other commercial nanopositioner.

Final Thoughts

For Mad City Labs, the most important part of AFM testing is that we perform it in closed-loop mode. Our PicoQ sensor technology is low enough noise such that the position measured by the inter-

[1] https://www.photonicsonline.com/doc/building-a-do-it-yourself-atomic-force-microscope-0001

nal sensors (PicoQ) matches the external metrology system (the AFM), confirming ultimate closed-loop, step-resolution capability.

Mad City Labs is the only nanopositioning company showing real-world experimental verification of <50-pm closed-loop step-resolution. No other nanopositioning company tests its products using AFMs in this manner, using a well-known physical standard that is easily obtainable by anybody. We offer transparency that the specifications we list are, in fact, achievable and verifiable.

Ultimately, that conversation is invaluable for our customers. Each potential user should have the opportunity to confirm instrumentation performance for themselves. Tell us what is important about your application, and we can help you determine which specs matter, and whether the desired performance is achievable.

To learn more about leveraging AFMs to confirm nanopositioner performance, or to discuss <1-nm resolution experimentation further with our experts, contact the author and visit http://www madcitylabs.com/.

Additional Resources

- *https://www.photonicsonline.com/doc/extreme-metrology-big-science-requires-a-nano-perspective-0001*
- *https://www.photonicsonline.com/doc/understand-noise-at-the-sub-nanometer-scale-0001*
- *https://www.photonicsonline.com/doc/precision-motion-and-how-to-achieve-it-0001*

About The Author

Shannon Ghorbani is a member of the Technical Sales team at Mad City Labs. He obtained a B.S. in Physics and Astronomy from the University of Wisconsin – Madison. Shannon has been a part of the Mad City Labs team for over 14 years, focusing on wide-ranging applications of extreme metrology, scanning probe microscopy, optical microscopy, and more. He may be contacted at shannon@madcitylabs.com.

About Mad City Labs

Mad City Labs designs and manufactures a complete product line of high-precision piezo nanopositioners, micropositioners, atomic force microscopes, and single molecule microscopes. We provide innovative instrument solutions from the micro- to pico-scale for leading industrial partners and academic researchers. Visit www.madcitylabs.com or email mclgen@madcitylabs.com for more information.

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