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Close Is Not Close Enough:

Micropositioners' Role In Nanopositioning

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When working at the nanoscale, every input has seismic impact on a researcher's ability to view, position, or manipulate the object of their attention. Whether the application is in single-molecule spectroscopy, optical trapping, super-resolution microscopy, or precision inspection, the journey from "infer" to "visualize" is rife with decisions that can undermine an experiment. Few of these decisions are more important than the equipment chosen to position and stabilize the experiment's subject.

Accordingly, the nanopositioners responsible for moving and holding firm such experiments are greatly scrutinized and carefully chosen. But, what of the position noise that must be addressed before a nanopositioner is considered? Even if a nanopositioner is noise-free, if it's sitting on something that isn't, the setup negates the nanopositioner's true power. Using microscopy cases as the primary example, this article examines how micropositioners affect movement and positioning capability, as well as overall task effectiveness — by creating, literally, a solid foundation for work at the nanoscale.

A Focus On Stability

Handling position noise is no mean task, as every element in an experimental setup — the optical table, the microscope, the lens — adds to oscillation, long-term drift, or other position noise. Thus, two key positional goals when constructing an experiment are minimizing vibration — a more immediate and short-term objective that ensures a high-resolution image — and stabilizing the work surface, over time, to the greatest extent possible. If it's moving at all, and you're trying to conduct an experiment over the course of several minutes or several hours, the very small sample on which you're focusing will leave the microscope's field of view.

Further, additional system elements often lead to greater thermal input or electromagnetic interference — all to the detriment of viewing resolution and precision. Nonetheless, experiment setups may need to employ specific viewing axes, or a range of motion along those axes, enabling researchers to scan the experiment surface and establish coarse positioning before focusing on a precise area or a series of specific areas. This requirement — coupled with the practice of using several measurement techniques on one experiment, on the same nanoscale area or particle, at the same time — places unique, stringent demands upon the necessary instrumentation's precision and stability.

The Importance Of Micropositioners

Despite the criticality of these system input decisions, the role of micropositioners — and their effect on overall success — in experimental setups can be overlooked or underestimated. Consider that a nanopositioning stage has nanometer-level precision, but its total range of motion is less than a millimeter. Since many applications require both nanometer-level precision and ranges of motion greater than a centimeter, a micropositioner often is required to coarsely position the nanopositioning stage. Since the micropositioner's positional noise level will add to the nanopositioner's noise, the micropositioner must operate with nanometer-level noise, despite not having nanometer-level precision.

Such accuracy is vital to modern experimentation, where the setup time required is immense and the chemistry involved is both complicated and time-consuming. As science has progressed and advances have taken place in lasers and camera techniques, researchers have required ever more complicated experiment setups, more stable equipment, faster equipment, and longer-range viewing capabilities.

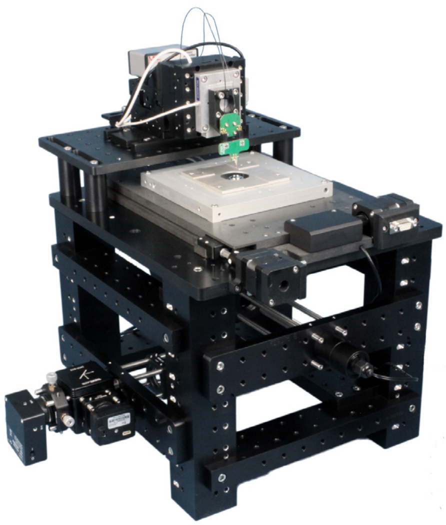
Additionally, one particle often serves as the basis for several experiments, so a single micropositioner typically must meet the range-of-motion, stability, and speed requirements to accommodate multiple experiments, over time, on the same object (e.g., the same cell or the same organelle inside of a cell).

Manual or Automated Stages?

To establish the micropositioner's necessary positional precision and to render it adaptable to a setup's movement needs, researchers must choose between manual stages and automated, programmable stages. Often, this decision comes down to cost: the ideal solution typically is an automated stage, but manual stages are less expensive. Weighed against the overall cost of an experiment — which can exceed several hundreds of thousands of dollars — and considering the devices' similar functionality, opting for manual over automated stages seems a prudent choice.

The most significant drawback with a manual stage is that the researcher must be physically near the setup, touching the apparatus. The individual's body adds heat and potentially causes movement within the setup. Conversely, when using an automated stage, the researcher is operating remotely, adjusting the stages from a computer, gaming-style pad, or joystick. Such precision control is particularly important in tasks involving automation and nanomanipulation.

Also, an automated, stepper motor-driven stage helps operators maintain a low metrology loop, rendering holding torque, acceleration, and deceleration more precisely manageable. Here, "metrology loop" refers to the path from one machine element to another, providing the machine's positioning reference while accounting for thermal expansion, force distortions, and misalignments. A system designed around this principle will help to dissipate heat in a manner that doesn't cause positional drift or minimizes drift in the system itself.



A combined single molecule fluorescence microscope and atomic force microscope (AFM). The AFM resolves features at the picometer scale and is dependent on highly stable, low noise micropositioners working in conjunction with closed loop nanopositioners.

Off-The-Shelf Or Custom?

Those creating experimental, nanoscale-level setups must consider whether an off-the-shelf (OTS) micropositioner will serve their needs or whether a custom setup will be necessary. In many cases, individuals and groups working at the leading edge of science are trying to do something nobody else has done before — meaning the appropriate equipment does not yet exist and must be custom-crafted.

Researchers seeking custom solutions should be prepared to work within the extended timeline required to create a custom solution versus providing or tweaking an established, OTS product. A custom micropositioner's design phase — comprising a lot of back-and-forth between the vendor and the customer to determine both what's possible and what's necessary — is the most critical part of the process, as well as the longest. Custom or OTS, the micropositioner is just one part of a larger experiment, and time spent perfecting fit on the first try is worth the return of a well-conceived setup.

This fit requirement applies to both the application's mechanical and digital aspects. To wit, the micropositioner must physically fit the overall system (e.g., its mounting) and its operating environment, as well as integrate with the accompanying components, including the nanopositioner, sample holders, and/or controller. Further, the micropositioner must be mechanically capable of precisely moving the mass of attached components.

It also must integrate seamlessly with software used in other setup components; while many vendors provide full-system solutions, researchers sometimes prefer — or applications sometimes require — that components from several different manufacturers be utilized. In such cases, micropositioner software must be compatible with the microscope and nanopositioner software, for example, or third-party software selected to drive the system.

Furthermore, the micropositioner must be robust enough to function properly and reliably in difficult operating environments. For example, a setup may be exposed to unavoidable thermal input or unexpected humidity. In the case of some live cell experiments, researchers may have to work in and endure certain temperatures and humidity conditions to keep their samples alive. Or, some setups call for the system to be enclosed inside ultra-high vacuum pressures or to withstand high magnetic fields while maintaining tight positional performance. Combinations of these hostile operating environments are not unheard of, either.

Think Big Before Going Small

Micropositioners are a vital and oft-overlooked element of experiments requiring nanoscale precision. While microscopy cases have been used here to illustrate this criticality, the considerations described apply to numerous applications, ranging from confocal and fluorescence imaging to nanomanipulation and particle tracking.

Cost, overall performance, and fit within a system comprise initial concerns when selecting a micropositioner. But, to make effective choices surrounding its use, one also must understand the impacts of using manual versus automated stages, system demands when operating in unique environments, and the limitations of OTS components.

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