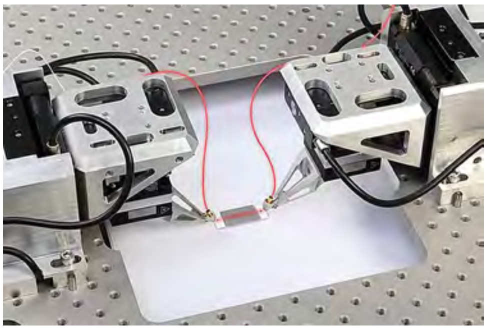
HOW TO SELECT A NANOPOSITIONER SOLUTION?

Emmanuel Pascal[1,*], Scott Jordan[2]
[1] PI FRANCE, 380 avenue Archimède, bât D, 13100 Aix en Provence, France
[2] PI USA, Head Office, 16 Albert Street, Auburn, MA 01501, USA
***e.pascal@pi.ws**



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Many recent innovations have been enabled by high precision positioning devices operating at a nanometer level or below. Developments in this field have been very fast over the last years supported by applications in material sciences, genomics, photonics, defense, biophysics, and semiconductors creating challenges for the scientists and engineers in need of precise and yet robust positioning systems. The critical point is: how should you select your nano positioning solution?

NANOPOSITIONING SYSTEM: A NEW DEFINITION?

By its original definition, a nanopositioning device is a mechanism capable of repeatedly delivering motion in increments as small as one nanometer. Lately, demands from industry and research have pushed requirements to the picometer range. While electroceramics such as piezo materials with flexure guides remain the gold standard for breaking the resolution nanometer barrier, there are several other solutions available today providing repeatable single-digit nanometer step resolution including linear motors, voice-coil drives, and frictionless guides such as air bearings and magnetic bearings.

Emmanuel Pascal: Country Director, PI France
Scott Jordan: Head of Photonics Market Segment, PI Group

Dynamic issues dominate many applications and can be addressed by novel approaches that benefit real-time/high-dynamic applications. They present new opportunities for optimizing process economics.

Rapid testing and packaging of the latest silicon photonics (SiPh) devices — starting at the wafer level — is the perfect example. In these applications, optical elements and probes must be brought into perfect coupling with devices in various stages of manufacture from wafer to final package. With thousands of optical elements on a single wafer, coupling time becomes the most critical cost factor in testing. The same applies to all further process steps up to assembly and packaging, where active and passive optical elements (e.g., LEDs, laser diodes, photodiodes and optical fibers and waveguides) must be precisely positioned

Figure 1. A double-sided test and alignment system for silicon photonics wafers based on hexapods and piezo nanopositioning stages to combine the fastest alignment speeds with the highest flexibility.

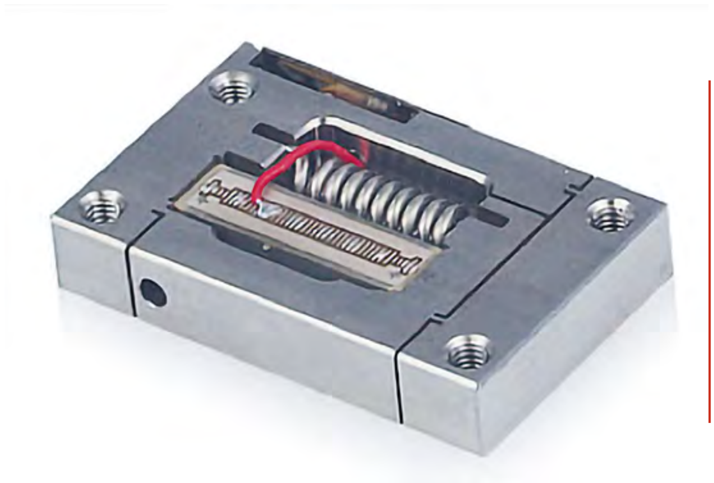

Figure 2. A motion amplified, flexure-guided actuator based on a multilayer piezo stack. Piezo flexure drives can last 100 billion cycles!

relative to each other, typically with accuracies in the sub micrometer range. Here, too, the time required for coupling optimization is decisive for cost-effectiveness. What makes these applications even more challenging is the frequent requirement to optimize positioning in up to all six degrees of freedom. This requires intelligent, precisely coordinated motion control in order not to destroy the result once achieved in one axis by movements in another axis. Complex algorithms that enable parallel, *i.e.*, simultaneous, optimization in multiple degrees of freedom are the solution here. This creates a new paradigm for the definition of a nanopositioning system. We are not talking anymore about a single piezo flexure stage but sophisticated and yet robust systems, built application specific, that can work from lab to fab environment.

NANO POSITIONING: NO FRICTION PLEASE

As a rule of thumb, the lower the mechanical friction in a motion system, the higher the positioning performance. Three frictionless guiding technologies are often used in nanopositioning applications: flexures, air bearings, and magnetic bearings.

Flexures guides are highly stable and stiff, but with travels limited to the millimeter region. For motion ranges from a few to hundreds of millimeters, air bearings offer a solution. An air-bearing stage is a linear or rotary positioner constrained on a cushion of air, using preload mechanisms, virtually eliminating mechanical contact and thus wear, friction, bearing noise, and hysteresis effects. Air-bearing nano-positioning stages are used in numerous high precision motion applications, such • • •

PIEZO ACTUATORS ON MARS!

All-ceramic-encapsulated, cofired piezo actuators were introduced many years ago pushing performance and reliability to new limits to respond to the industrial requirements.

These actuators improve greatly the reliability of devices based on this technology, especially when used in challenging environments.

In fact, NASA/JPL engineers ran these actuators through harsh life tests including 100 billion expansion/contraction cycles before selecting them for the Mars Rover's science lab!

as metrology, flat panel display inspection, large-area photonics test etc. The non-contact design also makes these stages work well in cleanroom applications.

SHORT TRAVEL PIEZO POSITIONERS

When talking about nanopositioning actuators with precision in the nm range and travel ranges of up to a few millimeters, piezo actuators combined with flexure designs are the historical solution. Flexure guides are frictionless and can be extremely small and robust at relatively low cost.

Piezoelectric technologies play a foundational role in positioning applications with nanometer resolution requirements. The benefits of piezo-based devices include:

- Unlimited resolution: positioning increments well below 1nm are possible and fit applications ranging from semiconductor to super resolution microscopy
- Fast response (microsecond time constants)
- Maintenance-free, solid-state construction that reduces wear and tear
- High efficiency: energy is absorbed only to perform movement
- Inherent vacuum-compatibility
- Non-magnetic and magnetic-insensitive construction
- High throughput and dynamic accuracy

Figure 3. Example of Voice Coil Miniature Linear Stage with Air Bearings.

LONG-TRAVEL PIEZO TECHNOLOGIES

By combining lateral actuation and longitudinal actuation of piezo actuators, it is possible to create the basic element of a **piezo walking drive**. A digital controller sequences their operation, providing high-force, long travel step-mode actuation plus picometer resolution fine high-bandwidth actuation. Forces can be generated to 800N and resolution down to 50pm are achievable. This unique combination of class-leading characteristics is proving to be an enabling technology for a wide variety of applications.

Figure 4. High-load walking drives combine piezo clamping and shear actuators in order to move a rod.

Another use of piezo ceramics technology is in **ultrasonic piezo motors**. These are composed of monolithic slabs of piezo ceramics; standing waves are driven in the substrate at frequencies of tens to hundreds of kilohertz. A hardened contact-point attached at a resonant node-point is thereby made to oscillate in a quasi-elliptical fashion; when preloaded against a runner, this confers linear or rotary motion. These piezo motors achieve up to 500mm/sec or 720 degrees/sec over virtually unlimited travel ranges while providing high precision and fast start/stop dynamics. A key benefit of this class of motor is the in-position stability.

CLOSED LOOP OPERATION: SELECTING THE RIGHT SENSOR/ CONTROLLER SOLUTION

Achieving nanometer precision requires further technologies. The stage's internal metrology system must also be capable of measuring motion at the nanometer scale. The characteristics to consider when selecting a stage metrology system are linearity, resolution, stability and bandwidth. Other factors include the ability to measure the moving platform directly and contact *vs.* noncontact measurements. Three types of sensors are mostly used in nanopositioning applications: linear encoders (for longer travels), and capacitive and strain sensors (for short travels).

Linear encoders are familiar devices for measuring long displacements up to hundreds of millimeters. While resolution in the nanometer range is common, accuracy is typically limited to 1 µm per 100 mm. However, this can be improved significantly with modern controllers. Incremental encoders measure changes in position and must be initially referenced to a home switch on power up; absolute encoders do not require this step but tend to be costlier. For short travel nanopositioning devices, cost-effective strain gauges (incl. piezoresistive sensors) use elements whose electrical characteristics

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change with strain. These devices are usually attached to the piezo ceramics itself or to a structural element of the stage. Special care must be taken when designing them into a mechanism. If there are elastic or frictional elements in the path between the point of motion and the point of measurement, errors will result. Physically small sensors (such as piezoresistive sensors) measure a highly spatially localized strain, from which the overall mechanism position can be inferred. And these sensors cannot be configured to compensate for orthogonal (parasitic) errors in multi-axis configurations — only parallel metrology of the actual moving platform can provide this valuable capability. Capacitive sensors have emerged as the preferred solution for the most demanding nanopositioning applications requiring short travel ranges. They are absolute, extremely accurate and ultrahigh-resolution devices for determining absolute position over ranges of hundreds of microns or even millimeters. The device's positioning motions vary the distance between two nano-machined capacitor plates, providing a sensitive and drift-free positional feedback signal.

ACTIVE OPTIC MOUNTS: TRAVELLING IN SPACE

Beyond linear single or multi-axes configurations, piezoelectric devices are very suitable to create tip/tilt platforms. With the integration of actuators with resolutions well below 1nm, these systems routinely offer angular resolutions surpassing 1/100 arcsec. Compact piezo- and voice-coil-actuated active optic mounts are available with multiple degrees of optical deflection. Two-axis, parallel-kinematic piezo mounts offer advantageous gimbal-style actuation with coplanar rotational axes. Compared to galvos and voice-coil systems, piezo-driven active optic mounts are typically more compact, fieldless, faster, inherently stiffer, and more predictable when power is cut. They are of great interest in the innovative field of Free Space Optical Communications (FSOC), where thousands of satellites form a high-speed, low-latency global information network. For these applications, robustness, long life and environmental insensitivity are prized.

INTERFACING

A wide variety of interfaces is available today, RS-232 to Ethernet, SPI, and USB, plus a host of specialty interfaces are among them. The choice depends on your environment, and all have pros and cons. Since motion controllers communicate via short messages, latency is often much more important to overall throughput than bulk transfer speed. USB and Ethernet are very common, with the latter supporting remote and distributed communications at the cost of variable latencies when the common TCP/IP communications protocol ●●●

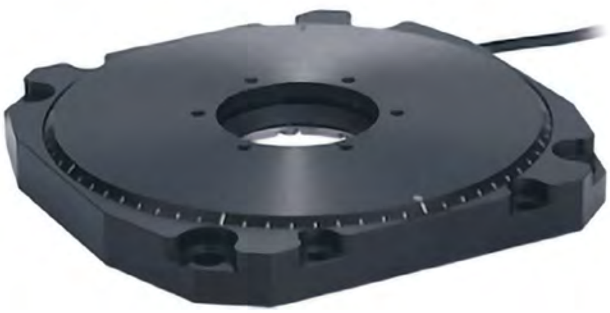

Figure 5. Example of Voice Coil Miniature Linear Stage with Air Bearings.

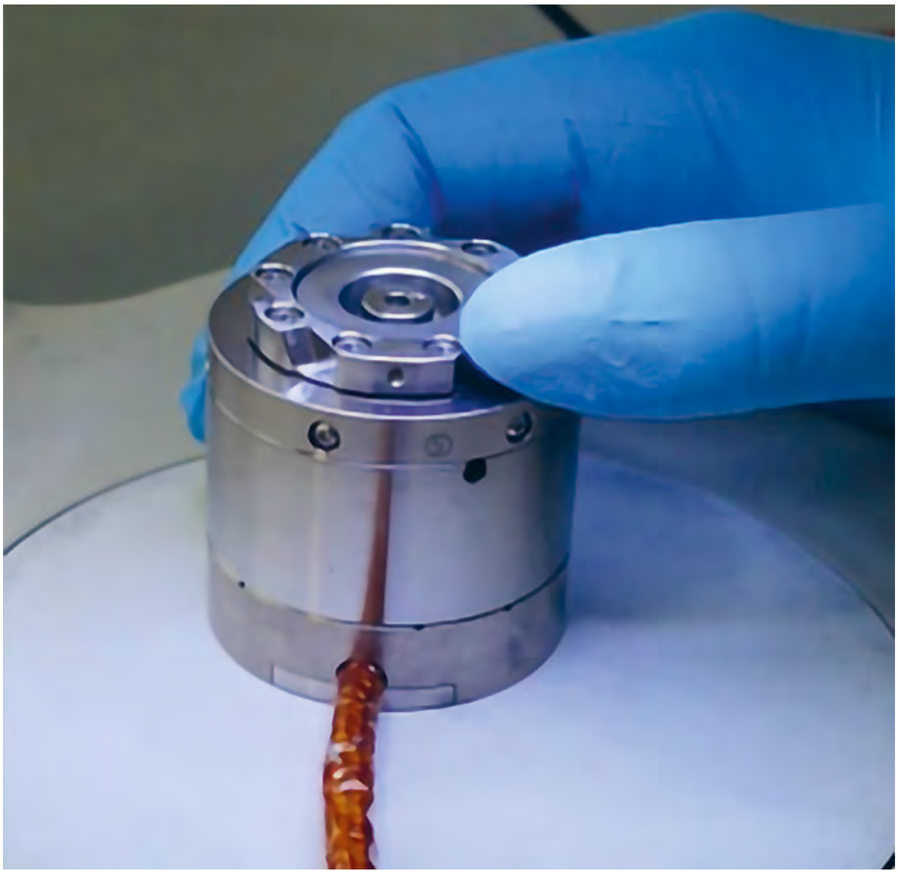

Figure 6. A tip/tilt beam steering platform, used in the Solar Orbiter space probe. In principle various sizes of mirror can be installed and optical deflections to several degrees are achievable.

is used. By comparison, EtherCAT is a deterministic, open protocol that leverages the ubiquity and speed of Ethernet hardware, allowing flexible construction of sophisticated and scalable systems. Although analog interfacing may sound obsolete, it has essentially zero latency and infinite speed and is easily coordinated with data acquisition, triggering and other real-time processes. Good implementations of a digital interface with a precision DAC generally add internal waveform generation and synchronization capabilities; the highest-performance implementations are of course fully fledged DSP architectures which eliminate the analog servo-circuitry entirely. A particularly common application of nanopositioners to photonics is in automated alignment. Recent advanced controllers for piezo nanopositioners, hexapods and stage stacks embed automated alignment routines including parallel gradient search methods for the most rapid optical alignments. Advanced controllers for sophisticated automation tasks in industrial environments are now available on the market with nanoscale capabilities. They can drive linear or brushless motors, are based on a real time architecture and serve applications such as laser material processing, photolithography, fine inspection or any application where tight synchronization is required. They can generate controlled trajectories—for example from a 3D CAD file—and offer advanced correction capabilities to achieve the best results.

CONCLUSION

It is nowadays possible to build advanced instrumentation with nanoscale performances with various technologies. Beyond the fundamentals of product capability, quality, global support, and applications savvy, choosing a vendor represents a choice of partners. There are tangible benefits of working with a supplier whose experience crosses many fields and many drive technologies. Such a supplier is able to share best-practices from other arenas. This multicompetences ability can help you drive innovation in your application, delivering a competitive advantage through a holistic approach. ●

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