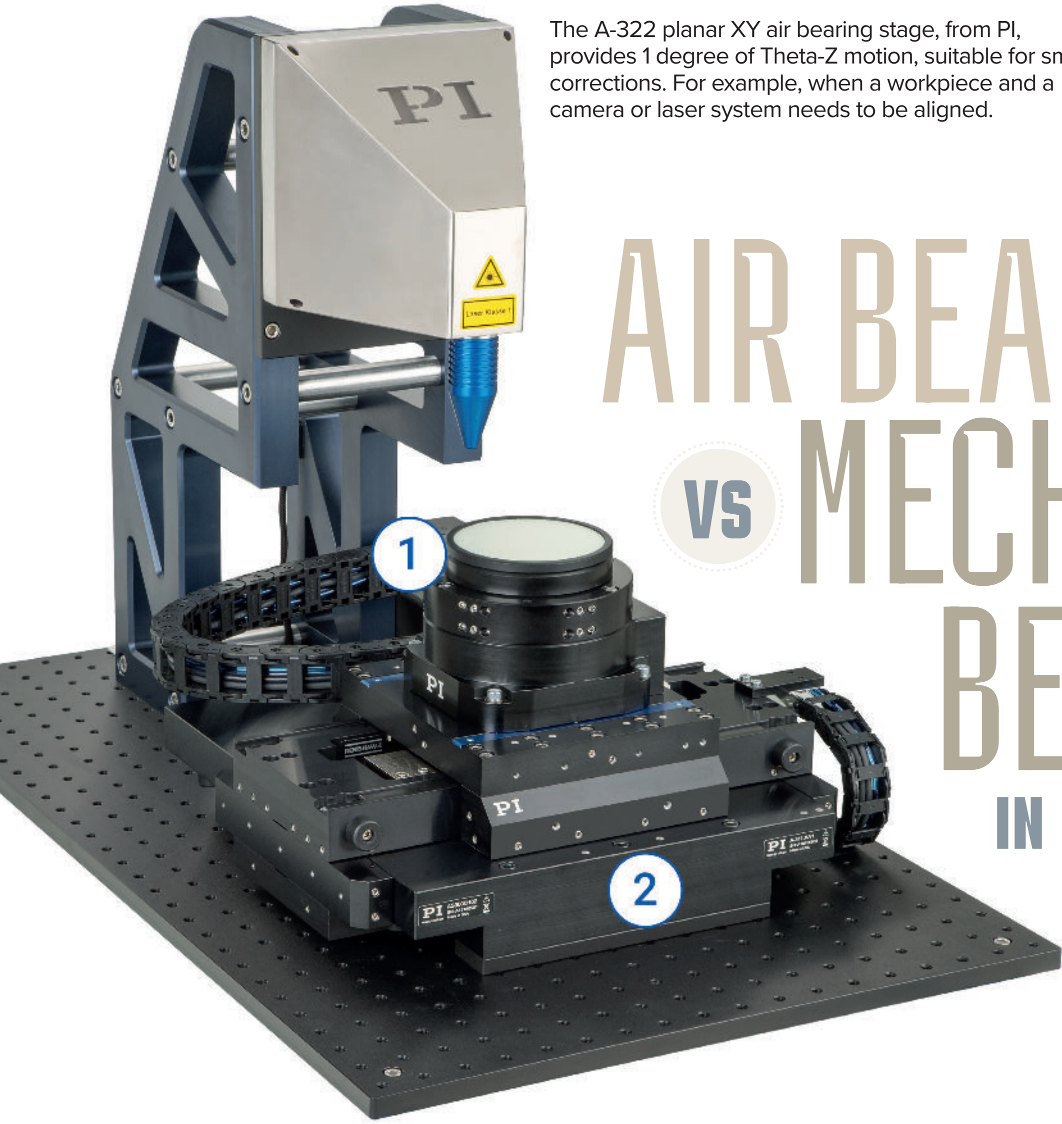

The A-322 planar XY air bearing stage, from PI, provides 1 degree of Theta-Z motion, suitable for small corrections. For example, when a workpiece and a camera or laser system needs to be aligned.

AIR BEARINGS VS MECHANICAL BEARINGS IN MOTION SYSTEMS

STEFAN VORNDRAN
VP MARKETING
PHYSIK INSTRUMENTE L.P. (PI)

While traditional mechanical bearings and guidance systems are suitable for most motion applications, they have many drawbacks, especially when it comes to high-performance motion control. In applications where lifetime, minimal vibrations, optimal precision, repeatability, or geometric performance are essential, air-bearing guided mechanics can provide superior performance and deserve a closer look.

AIR bearings and air bearing motion stages use a cushion of air to eliminate mechanical contact, thereby effectively mitigating common problems associated with traditional bearings such as friction, wear, vibration, hysteresis effects, and particle generation. These factors indicate that air-bearing stages may be the best choice for high precision, 24/7 test automation, and metrology applications.

Air bearing surfaces are usually hard coated and meticulously ground to achieve exceptional tolerances. High bearing stiffness is achieved by frictionless magnetic or vacuum preloading. The surface averaging effect helps provide better geometric performance, such as straightness and flatness because the large area of the bearing, together with the precision ground surfaces, can deal much better with small imperfections than ball bearings or roller bearings.

The effect can be compared to the difference between a hovercraft and a conventional truck riding over a pot-hole-covered highway. That averaging effect is also comparable to the smoothness of a magnetic levitation train versus a conventional train running on steel wheels. With the absence of wear, and no need for lubrication and maintenance, air bearings offer considerable benefits in high-speed motion applications and precise positioning, particularly in high throughput 24/7 automation scenarios that demand high uptime and reliability.

Air bearing advantages for precision motion and positioning applications

1. Unlimited lifetime, maintenance-free, clean room compatible: Since air bearings work without mechanical contact between components, they do not deteriorate and thus do not require periodic inspections, maintenance, or relubrication cycles. Also, unlike cross-roller bearings, there is no risk of cage migration, especially when small repetitive motion cycles are executed. Due to the absence of friction and lubricants, these systems also fulfill the requirements for clean room applications.

2. Motion with excellent geometric performance and extremely small straightness, flatness and eccentricity errors: Air bearings provide high accuracy because of the high-precision manufacturing process of their components. Due to the surface averaging effect, linear air bearings feature flat and straight travel (0.75µm over 500mm) with minimal roll, pitch, and yaw errors (10µrad), and rotary air bearings are also superior in terms of eccentricity, wobble, and tip/tilt. This makes them highly suitable for manufacturing and measurement processes such as optical inspection, providing excellent repeatability of the same procedure.

3. True-planar multi-axis motion: Planar XY stages and XY-theta stages cannot be designed with traditional mechanical bearings. Here, individual axes are usually stacked on top of one another. In some instances, XY stages are combined into a single assembly and falsely called planar stages. However, the X and Y axis do not use the same reference plane. The approach of building a multi-axis motion system by stacking individual axes is simple but has several drawbacks. As the upper axis moves to the extremes, it will generate torque loads on the lower axis, leading to geometric errors.

In air-bearing designs, fully planar XY and XY-Theta positioning systems are feasible, where all degrees of freedom reference to the same base plane and are fully supported over the full travel range.

4. Motion with constant velocity, vibration-free, and high dynamic range: The fluid film in air bearings can readily accommodate high velocity, and some air bearings can even improve efficiency at high speed, due to aerodynamic lift effects. Certain processes and experiments, such as semiconductor wafer scanning, 3D tomography, and inertial sensor testing, demand constant motion at precisely controlled speeds, where mechanical bearing rumble would introduce unwanted errors.

5. Long travel ranges of 1m and more feasible: Air bearings are not limited to short travel ranges, in contrast to another well-known frictionless positioning technology, often used in nanopositioning applications — piezo flexure-guided mechanisms can provide sub-nanometer precision, high scanning speeds and share many of the advantages of air bearings, however their travel ranges are limited to micrometer and the lower millimeter range.

6. High accuracy, frictionless motion: In linear motion applications, precise positioning of a moving carriage within a few nanometers is achievable by using a non-contact, direct-drive motor and high-resolution optical encoder combined with an air bearing. For rotational applications, angular resolutions to tenths of arc-seconds are achievable. Here, slotless torque motors are used as the driving force.

Air bearings are often preferred in many inspection, metrology, and manufacturing applications due to their minimal hysteresis effect or reversal error, resulting from a lack of mechanical contact and friction. Eliminating friction makes it possible to minimize hysteresis and improve repeatability and accuracy significantly.

Another technology to be considered in precision positioning, with similar performance to air bearings, is called magnetic levitation. Here, magnetic fields replace the function of air as a supporting medium, but control electronics are significantly more complex because all 6 degrees of freedom must be monitored and controlled all the time.

7. Rotary motion with minimal eccentricity and wobble: Rotary air bearings are highly effective in providing precise rotary motion due to their high stiffness and surface averaging effect. In air bearing rotary stages, wobble or tilt errors typically occur within the range of 0.1 to 1 arc-second — significantly smaller than with mechanical bearing-based rotary stages.

8. Cost-efficiency. Air bearing mechanisms can also use air pressure to provide actuation in addition to guidance. This design eliminates additional electric motors, reducing complexity, size, and cost. In general, absence of wear and tear and the need for maintenance is a great advantage reducing operating cost and improving ROI. This may be the most important factor when designing high-throughput automation equipment with 24/7 operation and stringent uptime requirements for years to come. DW

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The F-142 compact photonics alignment system provides multi-axis motion with high speed and nanometer resolution. It is based on miniaturized air bearing stages with direct drive motors and automatic gravity force compensation on the Z-axis. PI