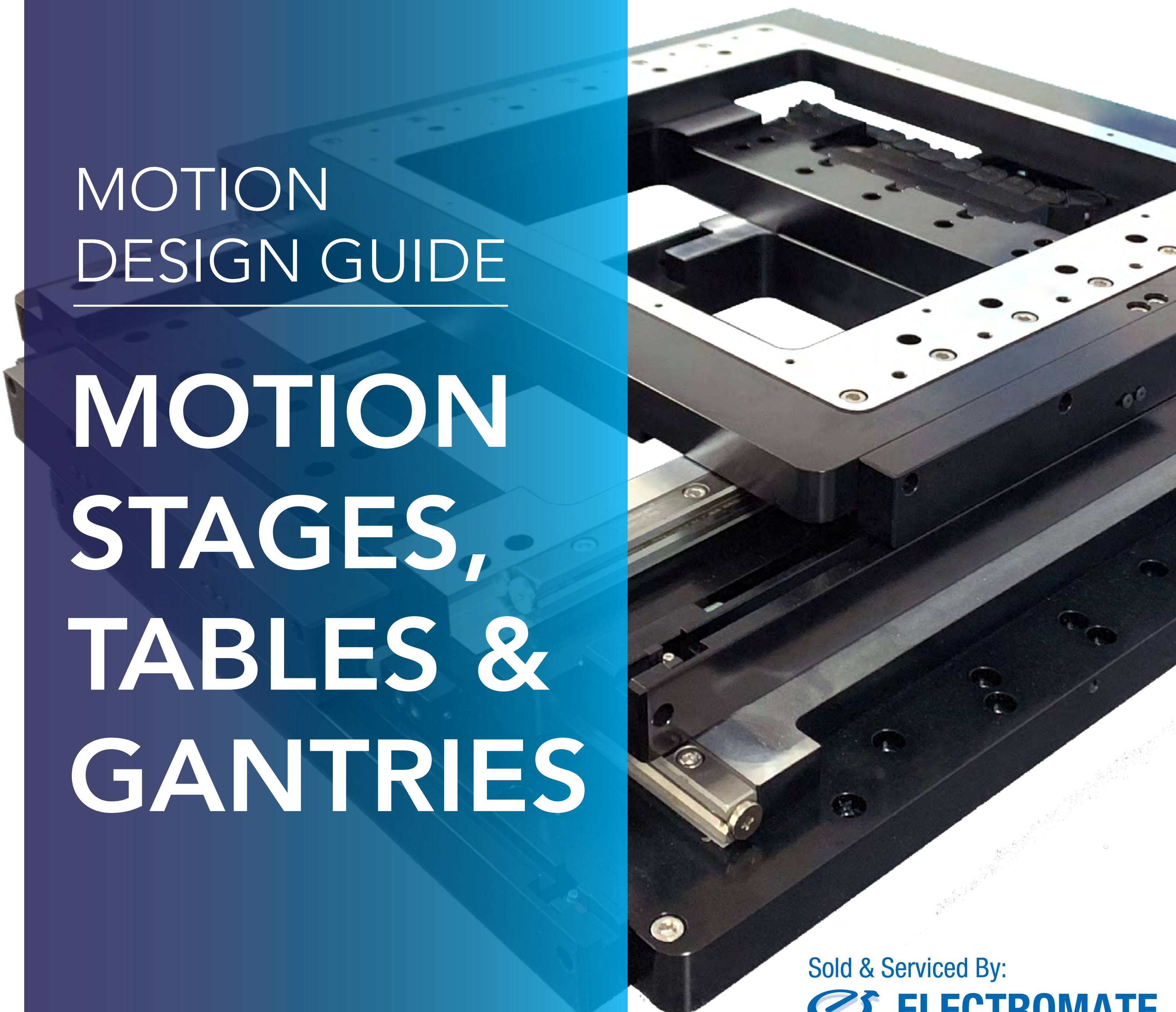
MOTION DESIGN GUIDE

MOTION STAGES, TABLES & GANTRIES



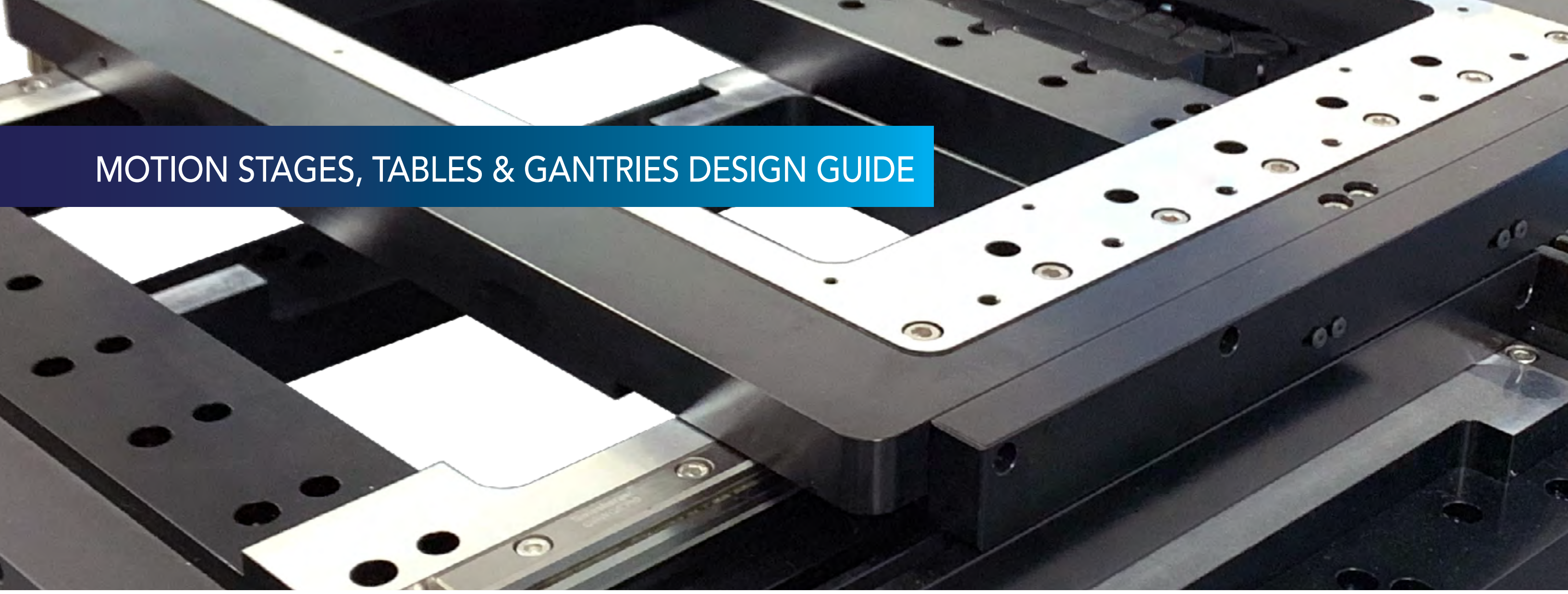
Sold & Serviced By:
ELECTROMATE
Toll Free Phone (877) SERVO98
www.electromate.com
sales@electromate.com

SPONSORED BY:

Akribis
where precision matters
AKRIBIS-SYS.COM

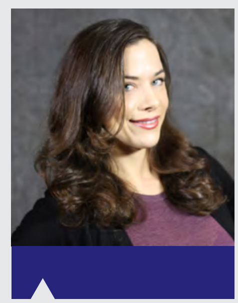
BROUGHT TO YOU BY:

MOTION CONTROL TIPS
A Design World Resource
WWW.MOTIONCONTROLTIPS.COM



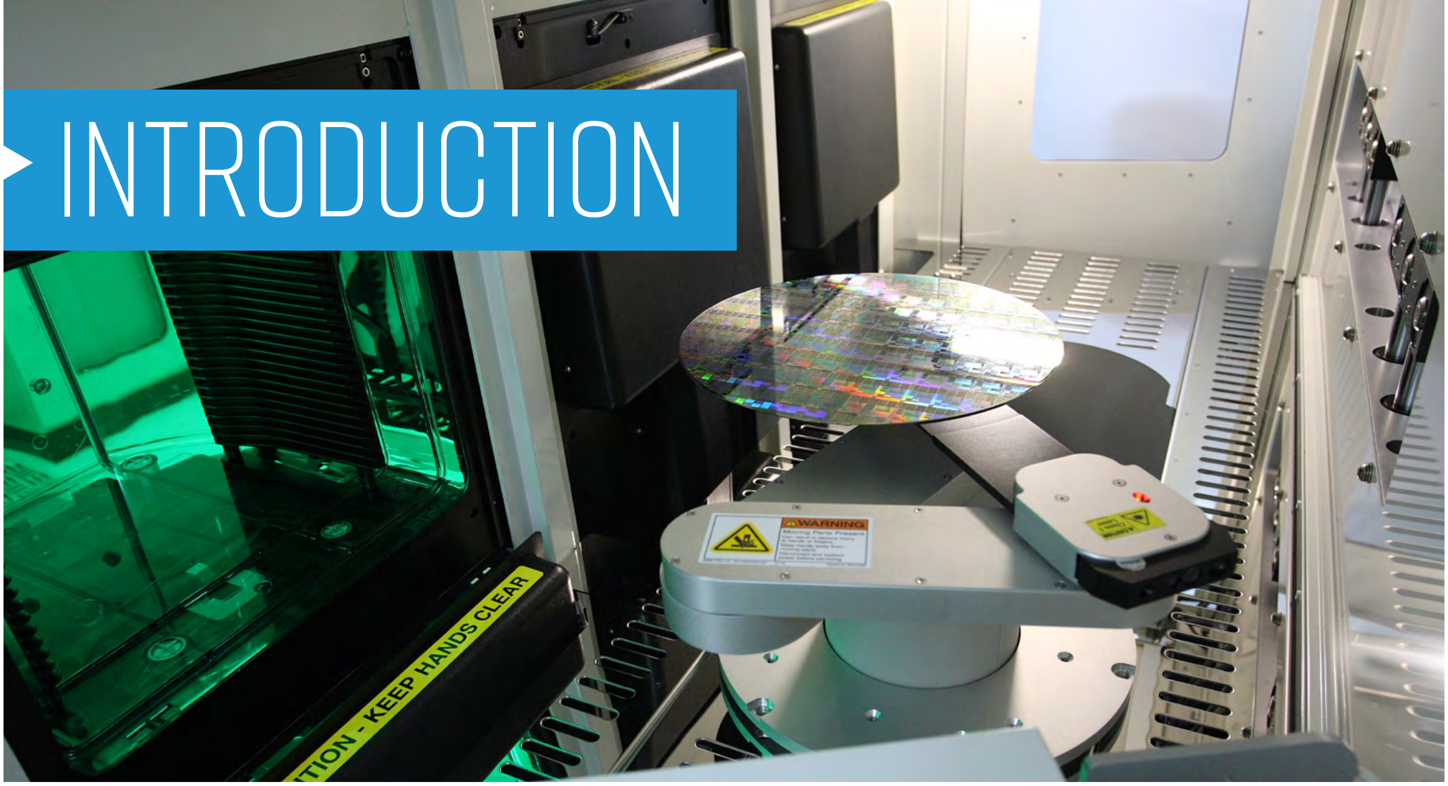
In this exclusive Design Guide, the editors of Design World review the functions and variations of motion stages for precision automation as well as their connectivity and configuration requirements.

TABLE OF CONTENTS



LISA EITEL
Executive editor

INTRODUCTION



Semiconductor wafer manufacture image: Shuo Wang

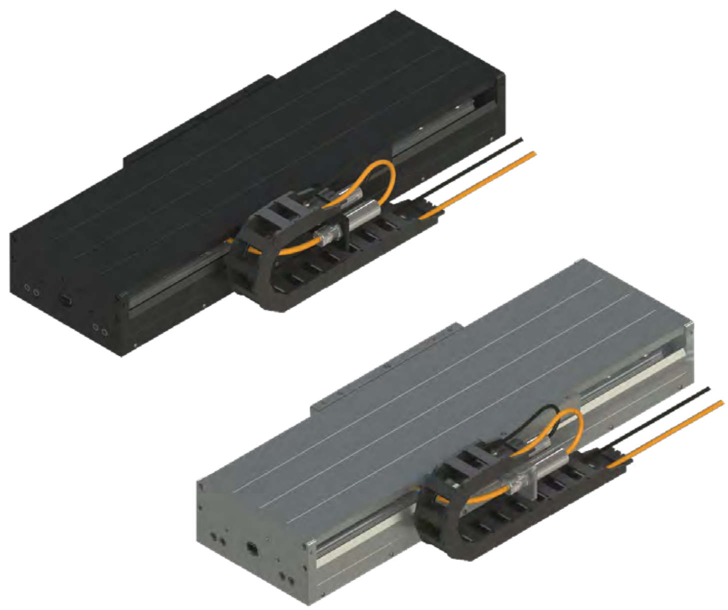
There are many ways to build linear systems for motion in the X, Y, and/or Z directions — also called Cartesian coordinates. Industry terms for these systems depend on how the axes are assembled, where the load is positioned, and (to some extent) the type of use for which the system was designed. In many industrial applications, Cartesian and gantry-style robots are prevalent … but in precision applications, XY tables are often the better choice due to their compact rigid structure and very high travel and positioning accuracies.

Cartesian systems: Cartesian systems consist of two or three axes — X-Y or X-Z or X-Y-Z. They often incorporate an end effector with a rotational component for orienting the load or workpiece, but they always provide linear motion in at least two of the three Cartesian coordinates.

Cartesian systems can include two axes (X and Y) or three axes (X, Y, and Z), and the load is usually cantilevered from the outermost axis (Y or Z). For example, in an X-Y gantry the load is mounted to the Y axis ... either to the axis end or at a distance from it … creating a moment arm on the Y axis. This can effectively reduce the payload a given Cartesian arrangement can bear ... particularly when the outermost axis has a very long stroke and induces large moment on the lower supporting axes.

Cartesian systems are used in a wide range of applications with maximum strokes on each axis typically one meter or less. The most common include pick-and-place, dispensing, and assembly applications.

Gantry systems: To address the issue of outer axes causing a moment load on the inner axes, gantry systems use two X axes, and in some cases, two Y and two Z axes. Gantries almost always have three axes — X, Y and Z. The load on a gantry system is located within the gantry's footprint and the gantry is mounted over the working area. However, for parts that cannot be handled from above, gantries can be configured to work from below.



DGH linear modules from Akribis Systems are high-performance dual-guide linear stages with no cogging effect. They have a safety-centric design with high load capacity to max velocity ratio. Improved rigidity enhances safe performance. DGH linear modules easily integrate for multi-axis assembly with repeatability to ±0.5 µm. Effective strokes are 100 to 1,200 mm with encoder resolution to 2.44 nm with 13-bit interpolation. Longer strokes are available upon request; the modules are suitable for high-speed high-accuracy applications.

(continued)

INTRODUCTION

Gantry systems are used in applications with long strokes (greater than one meter) and can transport very heavy payloads that are not suitable for a cantilevered design. One of the most common uses for gantry systems is overhead transport, such as moving large automotive components from one station to another in an assembly operation.

The economical Akribis DGC dual-guide linear stage provides a more compact, high-density structure at an excellent price-performance ratio. Its design aims to reduce parts and therefore make the unit more economical and easier installation. Despite this, repeatability is still achieved to ±3 µm. The linear-motor stage can travel up to 2m/sec. Effective stroke from 100 mm to 1,400 mm with encoder resolution up to 0.05 µm. Longer stroke available upon request.

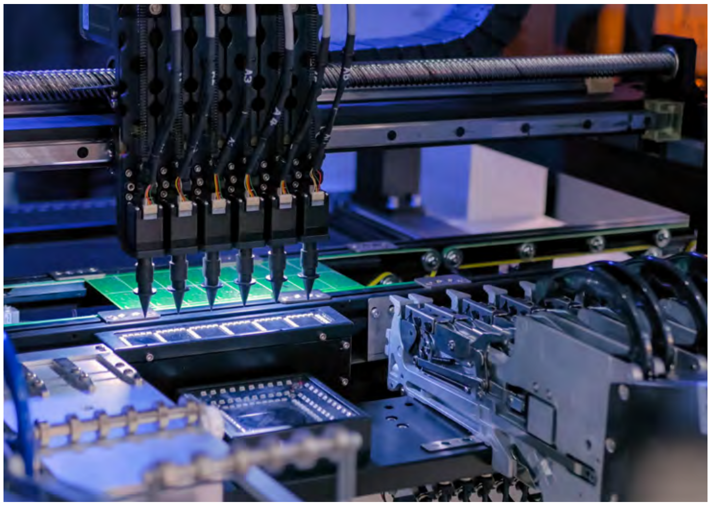
XY tables: These are similar to XY Cartesian systems in that they have two axes (X and Y) mounted on top of each other ... and typically have strokes of one meter or less. But the key difference between XY Cartesian systems and XY tables lies in how the load is positioned. Instead of being cantilevered as in a Cartesian system, the load on an XY table is almost always centered on the Y axis with no significant moment created on the Y axis by the load.

> *A COMMON XY TABLE DESIGN USES CROSSED ROLLER SLIDES AND A BALLSCREW DRIVE FOR VERY HIGH TRAVEL AND POSITIONING ACCURACIES.*

This is where the principle of *how the system is used* helps distinguish between the various types of multi-axis systems. XY tables generally work only within their own footprint, meaning the load does not extend beyond the Y axis. This makes them best suited for applications where a load needs to be positioned in the horizontal plane (X-Y). A typical example is a semiconductor wafer being positioned for inspection, or a part being positioned for a machining operation to take place. Designs called open-frame or open aperture have a clear opening through the center of the table. This allows them to be used in applications where light or objects need to pass through, such as back-lit inspection applications and insertion processes.

> *OPEN FRAME XY TABLES HAVE A CLEAR OPENING IN THE CENTER OF THE TABLE.*

Because XY tables are primarily used for very high precision applications, the guideway of choice is crossed roller slides, which provide extremely smooth and flat travel. Drive mechanisms are typically ballscrew or linear motor, although very fine pitch lead screws are also common.



This machinery manufactures surface-mount devices (SMDs) that accept semiconductor components on their PCB surfaces. Such operations require precision linear drives.

STAGES AND ROTARY TABLES USED IN ALL INDUSTRIES

Positioning stages and rotary tables are leading the migration to integrated designs in motion applications. Just consider how fiber optic, test and measurement, and semiconductor applications such as assembly setups all use precision stages and tables to boost throughput and quality. More specifically, the manufacture of flat-panel displays has spurred ever-larger motion-stage formats with linear-motor actuation and air-bearing load carrying. Elsewhere, belt-driven stages satisfy the need for long strokes but avoid ballscrew support challenges and the cost of linear motors.

Another growth industry using positioning stages is additive manufacturing. Here, ever-improving materials and layup techniques demand new stages at all performance levels. Many basic maker-

(continued)

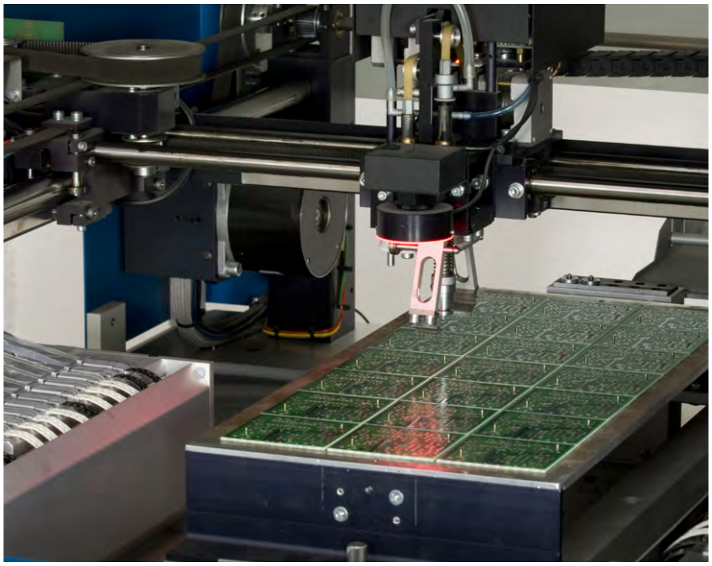
INTRODUCTION

level machines use stages with synchronous belt-driven axes. More demanding applications (such as research and prototyping, medical, and small-batch manufacturing) commonly use positioning stages with motor-driven ballscrews to coordinate motion. In the same way, medical and life-research applications make use of ultra-precision stages that deliver performance motion profiles impossible a decade ago. Here, piezomotors, miniature linear supports and coarse-and-fine tandem actuators are increasingly common options.

Pre-engineered positioning stages dominate packaging, as this industry often forces integrators to satisfy design schedules that bar design and set up of multi-axis functions in house. Likewise, the machine-tool industry is making more use of custom-built positioning stages—in laser-cutting and similar machines, for example. These and the stages for CNC applications are increasingly customized to specific motion tasks. That helps them deliver on dynamic parameters at lower cost and without the hassle of reformatting or retrofitting stock setups. Enabling this newer approach are proliferating software tools that let OEMs and end users manipulate initial design iterations within virtual environments that have accurate models of real-world stage components.

Assembly is different. Here, semi-custom Cartesian stages excel for pick-and-place and inspection via machine vision. More typical in these setups are traditional rotary motors paired with rotary-to-linear devices (ballscrews, for example) and controllers that compensate for system dynamics to get accuracy to a few micrometers or better.

Automotive applications widely vary. For example, the large scale of sheet metal and body-assembly tasks present unique challenges that, in some cases, only overhead stages (or those with rack-and-pinion sets) satisfy. At the opposite end of the spectrum, stages that carry inspection instrumentation to detect part features on a nanometer scale often take the form of direct-drive axis assemblies driven by a precision controller that even corrects for environmental fluctuations.



Many multi-axis linear arrangements use a variety of linear drive types.

With a central 288 x 288-mm opening and ironless linear motors, the Akribis AFXS open frame stage has an innovative hollow structure design that can be accessed either from the top or bottom of the stage. XY-axis adopts a cross-roller guide with repeatability up to ±0.75 μm and velocity up to 0.2 m/sec. Currently, it only has an effective stroke at 200x200mm with encoder resolution up to 0.05 μm. Longer strokes or a different combination of strokes are available upon request. Suitable for application of detection of sapphire, wafer etc.

EVALUATING THE ACCURACY OF STAGES

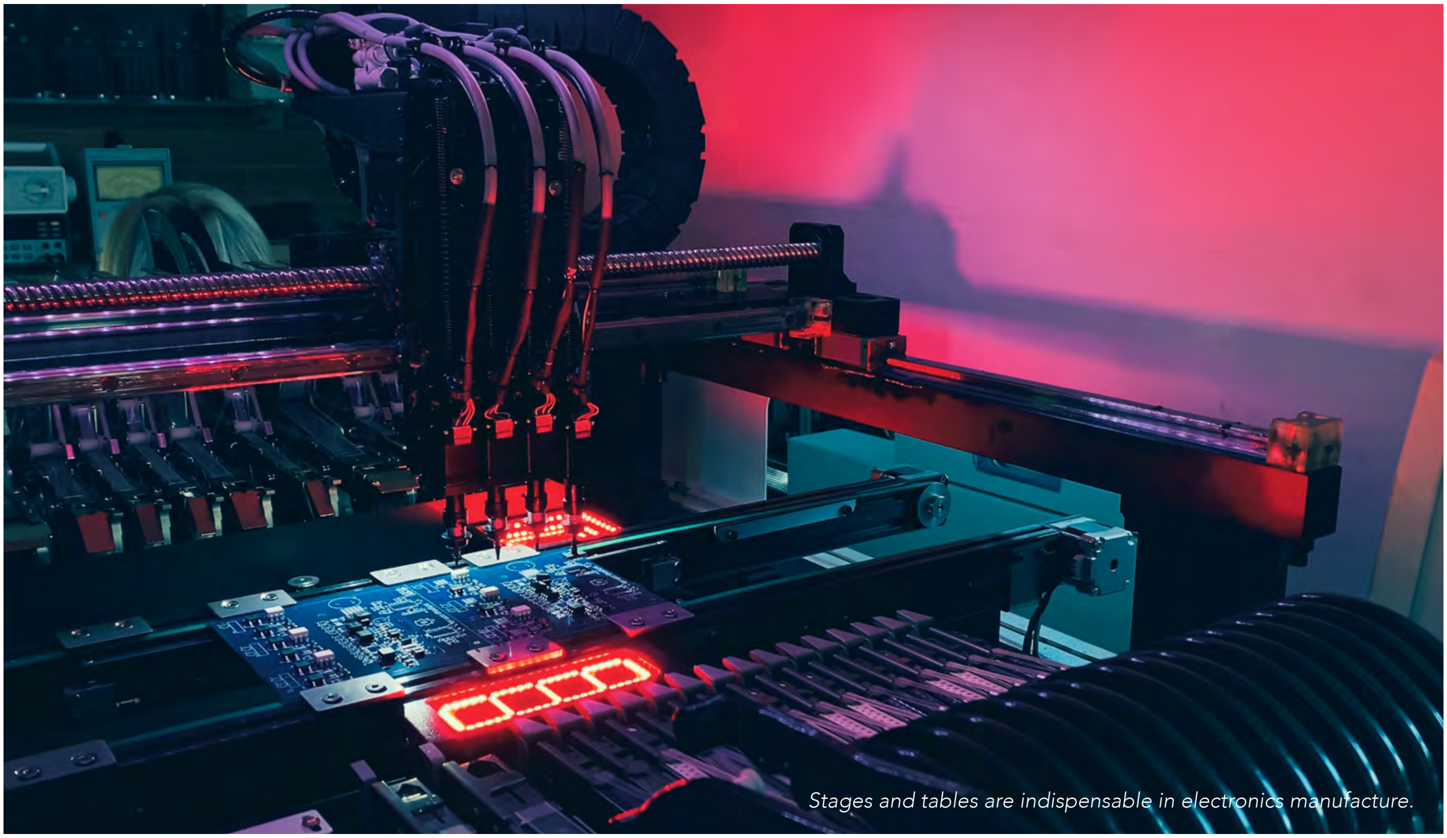
When evaluating the accuracy of a linear motion system, the area of focus is often the positioning accuracy and repeatability of the drive mechanism. But there are many factors that contribute to the accuracy (or inaccuracy) of a linear system, including linear errors, angular errors, and Abbé errors. Of these three types, Abbé errors are probably the most difficult to measure, quantify, and prevent, but they can be the most significant cause of undesirable results in machining, measuring, and high-precision positioning applications.

Abbé errors begin as angular errors: Abbé errors are caused by the combination of angular errors in the motion system and the offset between the point of interest — for tooling or the transport of load — and the origin of the error such as the linear-axis screw or guideway. Angular errors — commonly called roll, pitch, and yaw — are unwanted motions due to the rotation of a linear system around its three axes.

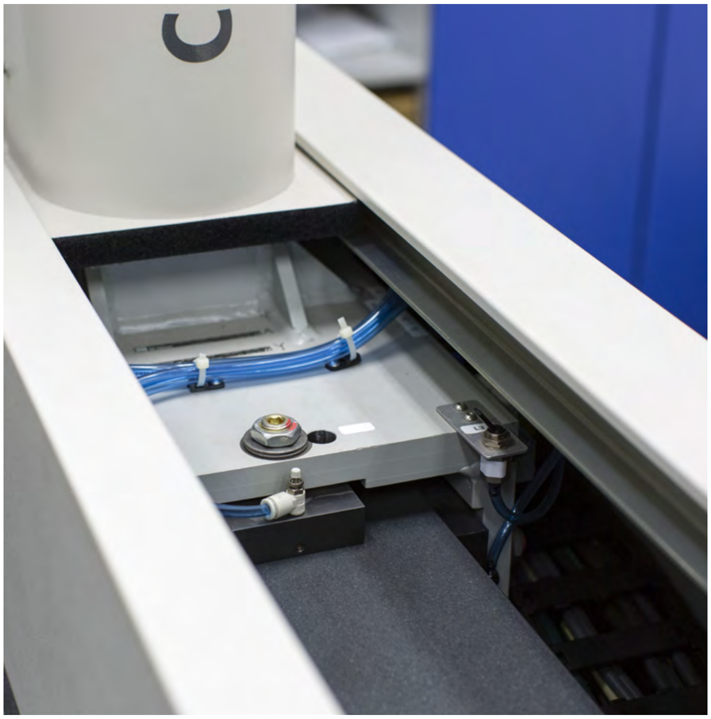
If a system is moving horizontally along the X axis, as shown below, pitch is defined as rotation around the Y axis, yaw is rotation around the Z axis, and roll is rotation around the X axis.

Errors in roll, pitch, and yaw typically result from inaccuracies in the guide system, but mounting surfaces and methods can also be sources of angular errors.

INTRODUCTION



Stages and tables are indispensable in electronics manufacture.



Granite tables and four-sided air bearings ensure stable motion for precise measurements in this metrology arrangement.

For example, mounting surfaces that are not precisely machined, components that are not sufficiently fastened, or even varying rates of thermal expansion between the system and its mounting surface can all contribute to angular errors greater than those inherent in the linear guides themselves.

Note that crossed-roller linear bearings are particularly sensitive to mounting errors. Their rigidity and accuracy make them less forgiving than other options of mounting inaccuracies. That's why many linear-bearing manufacturers recommend only mounting crossed-roller variations to honed surfaces expected to exhibit no more than a few micrometers of deflection.

Abbé errors are especially problematic because they amplify what, in most cases, are very small angular errors, increasing in magnitude as the distance from the error-causing component (called the Abbé offset) increases. Abbé offset h dictates the amount of Abbé error δ as expressed $\delta = h \cdot \tan\theta$.

For overhung loads, the farther the load is from the cause of the angular error the higher the Abbé error will be. The cause of the angular error is typically the guideway or a point on the mounting surface. What's more, Abbé errors for multi-axis configurations are even more complex because they're compounded by the presence of angular errors in each axis.

(continued)

INTRODUCTION

The best methods for minimizing Abbé errors are to use high-precision guides and to ensure that mounting surfaces are sufficiently machined — so they don't introduce additional inaccuracies to the system. Reducing the Abbé offset by moving the load as close as possible to the center of the system will also minimize Abbé errors.

Abbé errors are most accurately measured with a laser interferometer or other optical device that is completely independent of the system. But laser interferometers aren't practical for most setups, so linear encoders are used in many applications where Abbé error is a concern. In this case, the most accurate measurements of Abbé error are achieved when the encoder read head is mounted on the point of interest such as the tooling or the load.

XY tables are less susceptible to Abbé errors than other types of multi-axis systems such as Cartesian robots. That's primarily because they minimize the amount of cantilevered travel and typically operate with the load located at the center of the Y axis carriage.

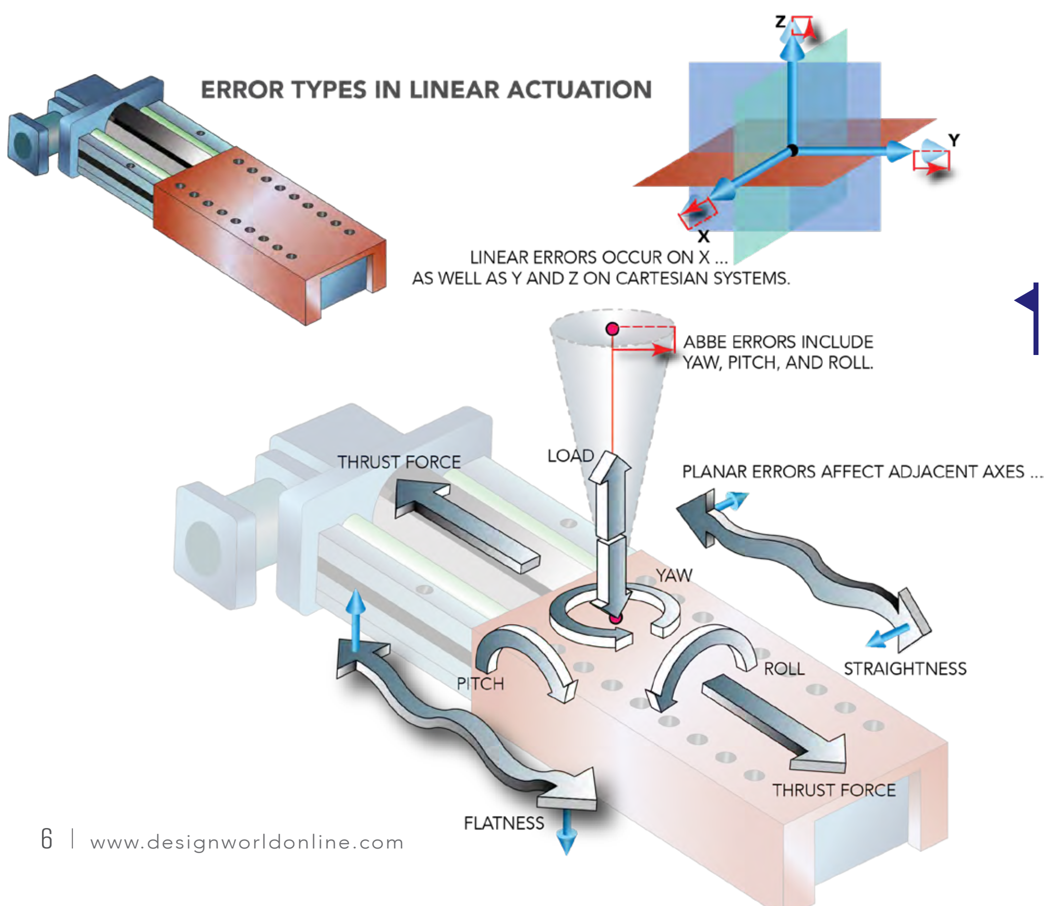
MORE ON PLANAR ERRORS AND LINEAR-MOTION ACCURACY

In an ideal world, a linear motion system would exhibit perfectly flat, straight motion and reach the intended position with zero error every time. But even the highest precision linear guides and drives (screws, rack and pinions, belts, linear motors) have some errors due to machining tolerances, handling, mounting, and even the manner in which they're applied.

> *ANGULAR ERRORS ARE THOSE THAT INVOLVE ROTATION AROUND AN AXIS. THESE ERRORS CAN WREAK HAVOC ON MACHINING, MEASURING, AND ASSEMBLY APPLICATIONS, ESPECIALLY WHEN THEY'RE MULTIPLIED BY THE DISTANCE BETWEEN THE ORIGIN OF THE ERROR AND THE POINT OF INTEREST.*

There are three types of errors found in linear motion systems — linear errors, angular errors, and planar errors — and each type has a different effect on the system and the application. To avoid paying for high-precision components where they're not needed or ending up with a system that doesn't meet the application requirements, it's important to understand the differences between these three types of linear motion errors and their causes.

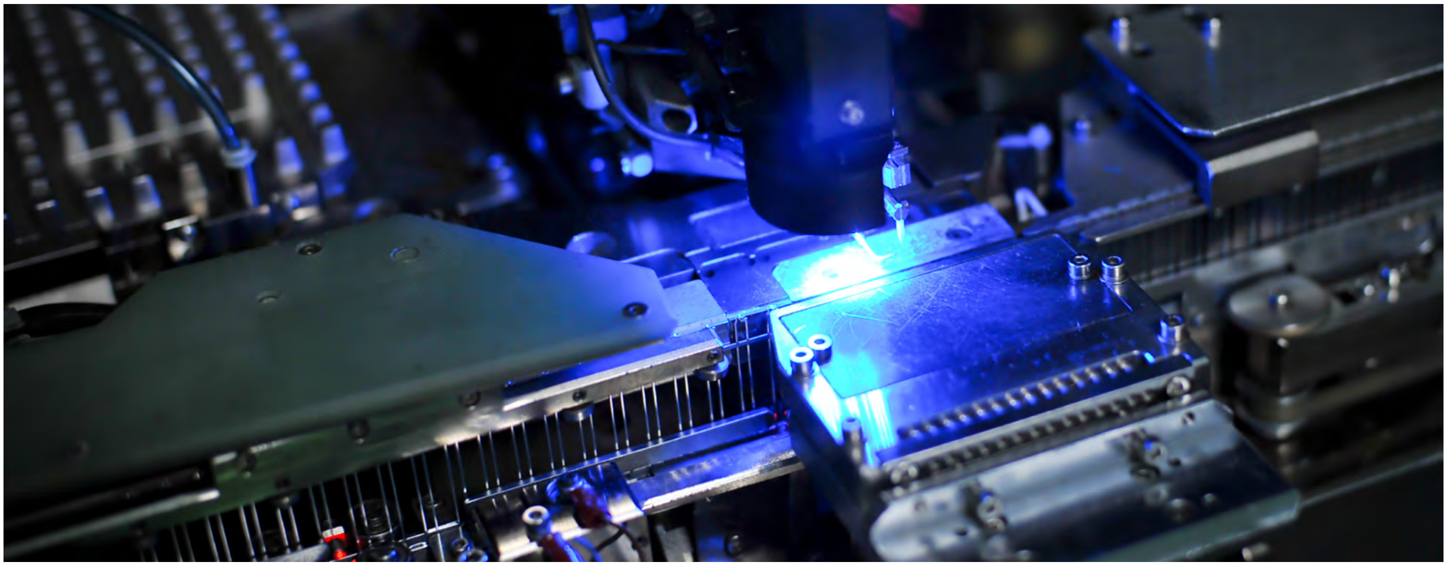
Linear errors in linear systems: Linear errors include positioning accuracy and repeatability. These errors are sometimes referred to as positioning errors because they specify the system's ability to reach the desired position. In the context of linear systems, the term "accuracy" typically refers to positioning accuracy, which is the deviation between the target position and the position the system achieved. Repeatability refers to how well a system returns to the same position over multiple attempts. The main contributor



Angular errors include roll (rotation about the X axis) and pitch (rotation about the Y axis) and yaw (rotation about the Z axis).

(continued)

INTRODUCTION



Linear systems in LED manufacture require the highest precision.

to linear errors is the drive mechanism (screw, rack and pinion, or linear motor, for example), but the system's tuning can also affect its ability to reach the target position accurately and repeatably.

Angular errors in linear systems: As mentioned earlier, angular errors are errors in which the point of interest rotates around an axis. These are typically referred to as roll, pitch, and yaw errors, denoting rotation around the X, Y, or Z axis, respectively. If the point of interest is the center of the table, or slide, angular errors may not have a significant effect on the application. But when the point of interest is some distance away from the table or slide, Abbé errors, which are angular errors amplified by distance, can produce undesirable results, especially in machining, measuring, and assembly applications. The primary causes of angular errors, and by extension, Abbé errors, are inaccuracies in the linear guides and poorly machined mounting surfaces.

> *SYSTEM TUNING ISSUES CAN DEGRADE THE ABILITY OF RACK-AND-PINION, SCREW, AND BELT DRIVES TO ACCURATELY REACH TARGET POSITIONS. DRIVES BASED ON LINEAR MOTORS ARE HARDLY IMPACTED BY SUCH ISSUES.*

Planar errors in linear systems: Planar errors — often called straightness and flatness issues — occur during the system's travel, but rather than rotation around an axis, planar errors are deviations from an ideal, straight reference plane. Straightness defines the extent of motion along the Y axis as the system travels along the X axis. Similarly, flatness defines the extent of motion along the Z axis as the system travels along the X axis.

> *PLANAR ERRORS ARE DEVIATIONS IN TRAVEL IN THE HORIZONTAL PLANE (STRAIGHTNESS) AND IN THE VERTICAL PLANE (FLATNESS).*

Note here that the point of reference is the axis of travel (typically the X axis), so there are only two types of planar errors, involving motion along the remaining two axes.

Planar errors are detrimental to applications such as dispensing, machining, or measuring, where the system's behavior during motion is critical. In multi-axis systems, planar errors in one axis affect the adjacent axis (or axes) especially when the axes are stacked such as in X-Y tables, planar tables, and some Cartesian systems.

Further reading:

Racking in gantry systems and how can it be avoided

Types of motion possible with multi-axis linear systems

Three important design considerations for Cartesian robots

Planar stages and gantries

Difference between vertical lift stages and Z-axis actuators

Seventh-axis (RTU) systems and where they're used

How linear stages are different from other motion systems

CROSSED-ROLLER BEARINGS COMPLEMENT LINEAR STAGES

Crossed-roller linear guides often complement linear-stage builds and other precision motion systems. They are based on a non-recirculating linear bearing design in which cylindrical roller bearing elements are oriented in a crisscross pattern. Because the rollers don't recirculate, these guides provide high load capacity and good stiffness … with smoother motion than recirculating-bearing counterparts. That's because the rollers don't suffer from the pulsations that recirculating bearings experience as the balls (or rollers) enter and exit the load zone.

Lack of impacts due to recirculating elements also reduces noise generation, making crossed-roller slides noticeably quieter than linear bearings with recirculating elements. One caveat is that crossed-roller linear bearings are limited travel — typically to one meter.

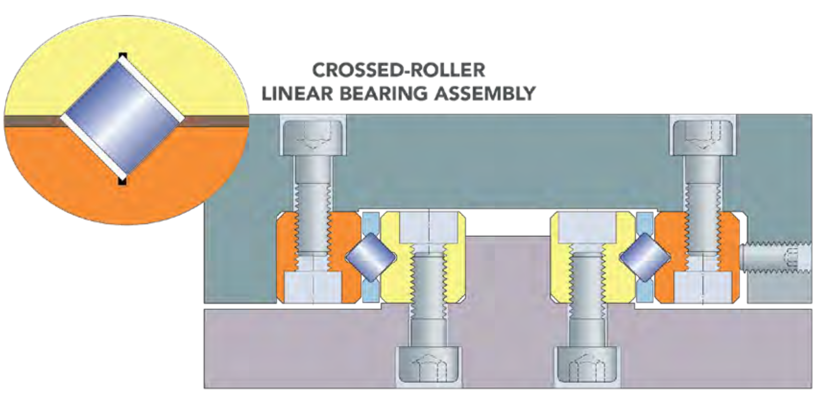
At their core, crossed-roller linear bearings support and allow the low-friction movement of loads on arrays of cylindrical roller bearings.

The rollers (also called roller bearings or rolling elements) are often made of hardened bearing steel of 55 to 65 HRC or stainless steel if the linear bearing is to operate in a corrosive setting.

The rollers alternate between two 90° offset orientations. Because of these opposing roller directions, crossed-roller linear bearings can carry loads upward, downward, and from both sides.

This Akribis XRL cross-roller-guided linear stage is compact and designed to be stiff — ensuring excellent straightness and flatness as well as high load capacities. The smooth movement is achieved by operating with low friction, high precision, quick response, and a short settling time.

XRL stage repeatability is to ±0.5 μm. Effective strokes are 35 to 210 mm (with longer strokes available upon request) and encoder resolution to 0.05 μm.



Shown here is a cross section of a crossed-roller linear bearing assembly.

(continued)

CROSSED-ROLLER BEARINGS COMPLEMENT LINEAR STAGES

Crossed-roller linear-bearing assemblies contain the rollers between solid twin bars or rails (usually made of through-hardened tool steel or stainless steel) cut with ground V-shaped grooves to serve as raceways. Some linear-bearing designs destined for corrosive environments feature electrolytically applied chrome coatings on these rails to extend design life and boost wear resistance.

Usually a third element called a cage (or bearing retainer or just retainer) keeps the rollers well-spaced … and prevents excess friction in the form of skidding or roller-to-roller contact.

Cages made of hard plastic PEEK, polyacetal (or poly-oxy-methylene) or composite engineered plastic (sometimes with fiberglass reinforcement) let rollers space more tightly together. That in turn lets more rollers fit into the crossed-roller guide assembly for a given stroke length … and increases load capacity.

In contrast, cages made of aluminum, brass, steel, or other metal take more space and reduce the guide roller count for a given length but are often the only suitable choice for harsh environments or applications operating in cleanrooms or vacuums. That's because composites are sensitive to contamination and can foul controlled environments with outgassing.

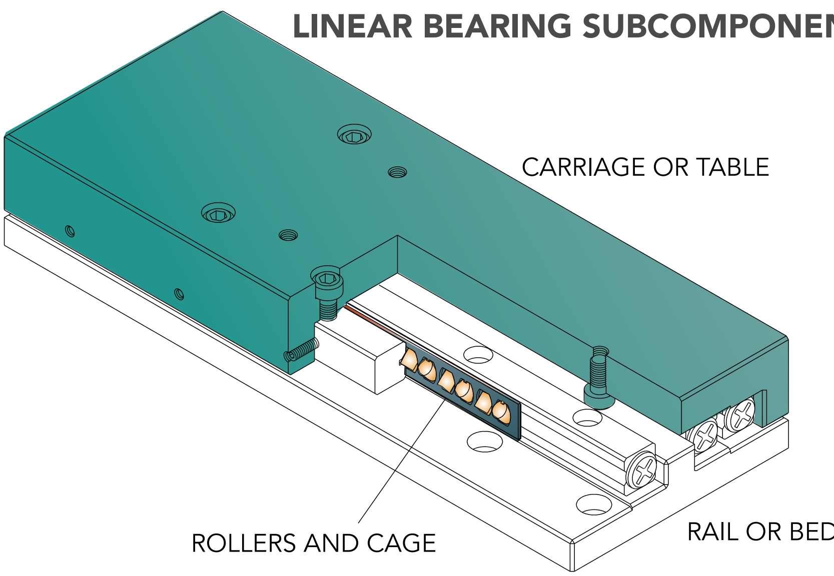
Sometimes linear bearings contain the roller-filled cage with steel or chromed end pieces. However, a fourth element called an anti-creep mechanism (usually a studded wheel or gear) is usually necessary. That's because while cages solve one problem, they can create another.

More specifically, crossed-roller guide cages are indispensable but can exhibit cage creep.

Because the cage floats between the guide assembly's two bar guides, during operation it can drift from its correct position … especially when operating on vertical axes or when the axis makes many partial strokes. Vibrations and shock loading can also induce cage creep.

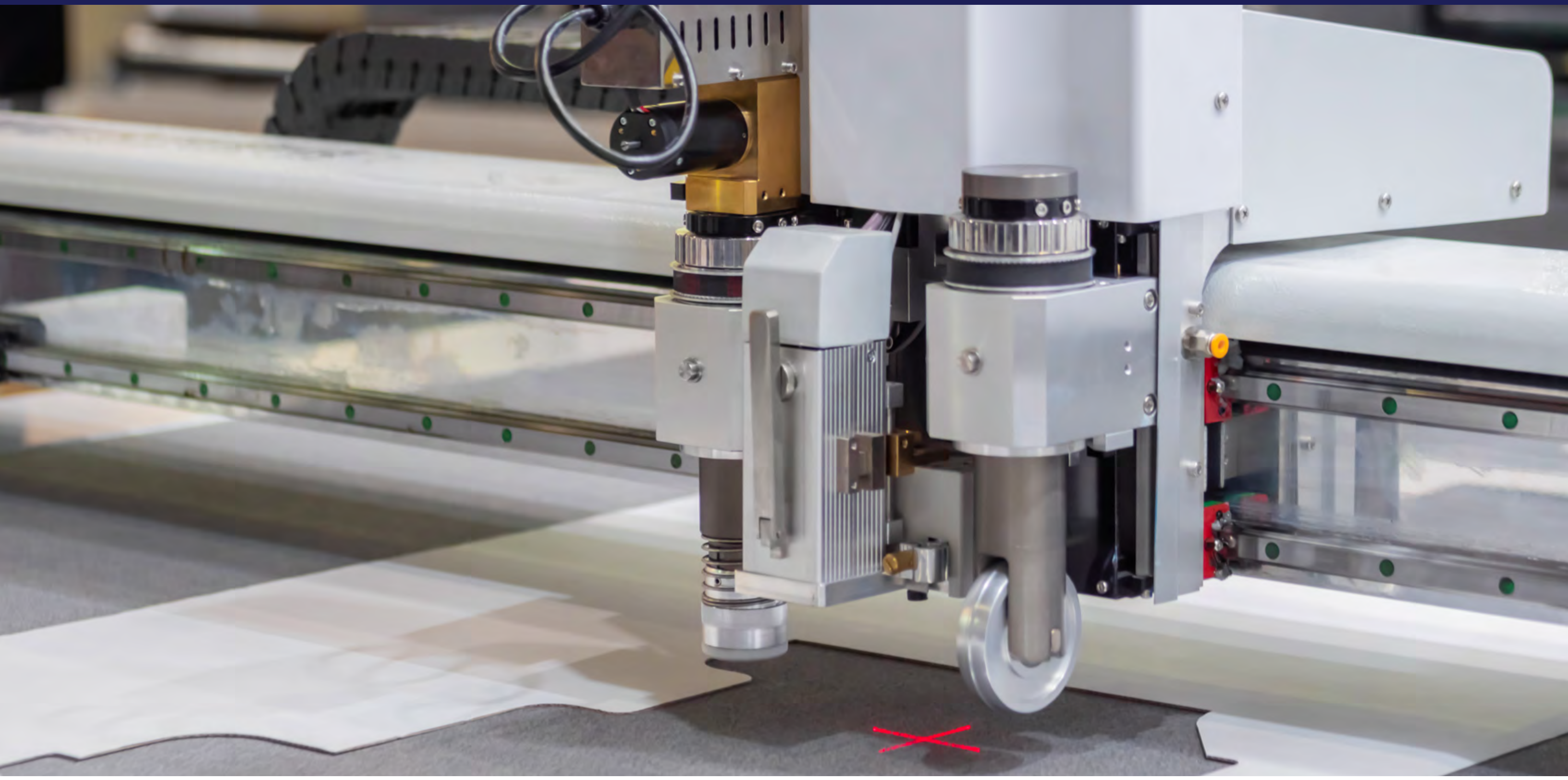
A cage that's misaligned from center effectively reduces stroke length … because the cage strikes end stops before the completion of a full stroke. That in turn forces the cage back to its centered position — potentially damaging the slide halves and inducing the very roller skidding or sliding the cage is supposed to prevent.

CROSSED-ROLLER LINEAR BEARING SUBCOMPONENTS



Shown here are the basic elements of a crossed-roller linear bearing.

LINEAR MOTORS
IN THE CONTEXT OF LINEAR ACTUATION



Flatbed cutter gantry image: Aleksey Popov

Linear motion systems — consisting of a base or housing, a guide system, and a driving mechanism — are available in a wide variety of designs and configurations to suit almost any application.

Design known as ***linear stages*** are widely recognized as the most precise category of linear motion systems. Any system called linear stage is generally expected to provide high positioning accuracy and repeatability as well as low angular and planar errors. To achieve this level of performance, there are several principles that manufacturers generally follow in terms of construction and the type of components used in the stage design.

Unlike other linear motion systems (which commonly use an aluminum extrusion or plate as the base) a linear stage begins with a precision-ground base. Stages designed for the highest levels of flatness, straightness, and rigidity often use a base made of steel or granite, although aluminum is used in some designs. Steel and granite have lower coefficients of thermal expansion than aluminum, so they exhibit better dimensional stability in environments with extreme or varying temperatures.

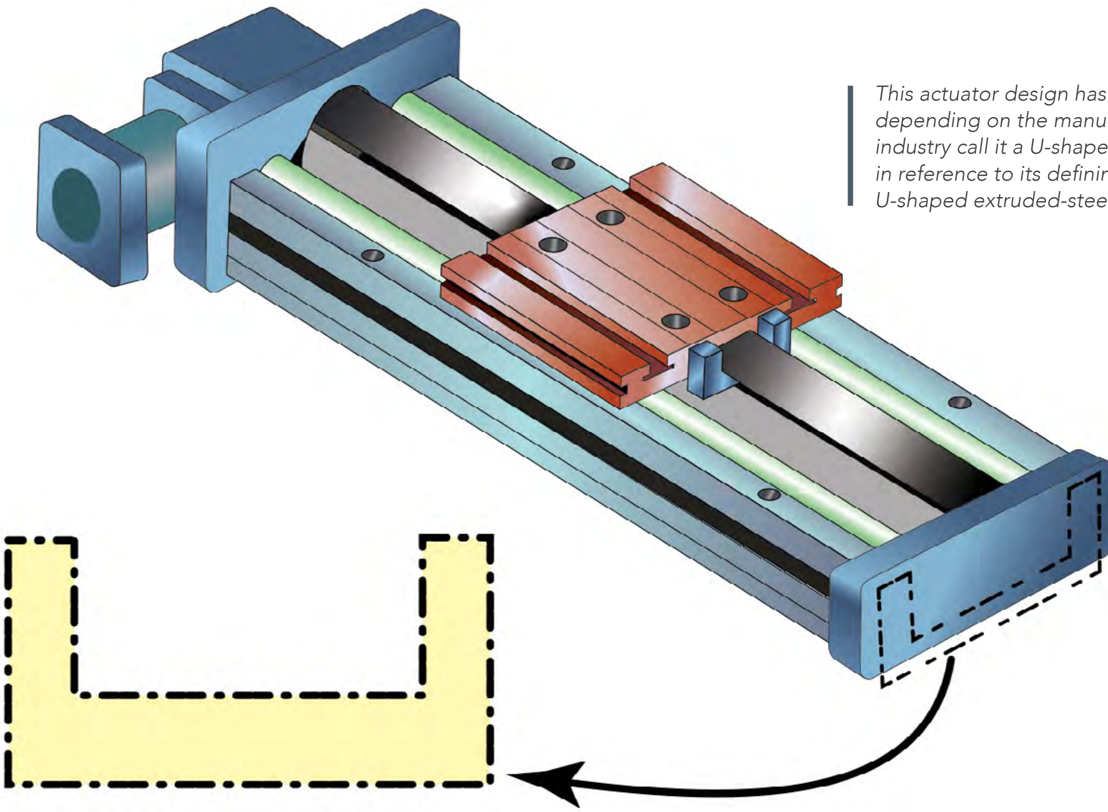
The linear guide system also contributes to the straightness and flatness of travel, so the guide mechanisms of choice for linear stages are high-precision profiled rails, crossed roller slides, or air bearings. These guide systems also provide very stiff support to reduce angular errors that can lead to Abbé errors when there's an offset between the origin of the error (the guide) and the point of interest (tooling point or load position).

While many types of linear motion systems use high-precision drive mechanisms, linear stages overwhelmingly use one of two technologies — high-accuracy ballscrews or linear motors. Linear motors typically provide the highest level of positioning accuracy and repeatability because they eliminate the compliance and backlash inherent in a mechanical drivetrain and coupling between the drive and the motor. For the special case of sub-micron positioning tasks, piezo actuators or voice coil motors are typically the drive mechanisms of choice for their highly accurate and repeatable motion.

Although the term linear stage implies a single-axis motion system, stages can be combined to form multi-axis systems such as XY stages, planar stages, and gantry stages.

SPONSORED BY:
AKRIBIS-SYS.COM

COMPARING LINEAR STAGES AND U-FRAME ACTUATORS



This actuator design has various names depending on the manufacturer. Some in industry call it a U-shaped linear actuator in reference to its defining feature — a U-shaped extruded-steel profile.

Although there are no industry standards that define linear actuators and linear stages, generally accepted terminology indicates that:

A linear actuator is typically constructed with an aluminum extrusion or base.

A linear stage is typically built on a flat machined steel or granite base.

This distinction implies that linear actuators can provide longer strokes and use a variety of drive mechanisms (belt, screw, rack and pinion) while stages generally have higher rigidity and use high-precision linear guides and drive mechanisms (typically a ballscrew or linear motor) for excellent travel and positioning accuracies.

But one actuator design — the U-shaped linear actuator — defies these specifications ... using an extruded steel base to provide rigidity and travel accuracy specifications that rival some linear stages.

The use of a steel (rather than aluminum) profile makes the U-shaped design extremely rigid and allows manufacturers to offer a linear actuator with the high travel and positioning accuracies typically found in more precise (and more expensive) linear stages.

The steel base can also be machined to provide a reference edge for precise alignment with other machine components ... or with other actuators in a multi-axis system.

With their very high rigidity, U-shaped linear actuators can be better suited than other designs to applications where the actuator is supported only on one end. These include two and three-axis Cartesian systems, for example.

In U-shaped actuators, the linear guide system is integrated ... and there is no guide rail. Instead, the raceways that would normally be found on the guide rail are ground into the inside of the base. The carriage or table is analogous to a linear bearing block turned inside-out, with the balls riding on the outside.

This leaves the center portion of the carriage available to accommodate the ballscrew nut. This construction principle makes the entire actuator extremely compact, with a width-to-height ratio of approximately 2:1.

For example, a U-shaped actuator with a width of 60 mm is only 33 mm high. The most common cross-sections (width x height) are 40 x 20 mm, 50 x 26 mm, 60 x 33 mm, and 86 x 46 mm … although other sizes are offered as well.

(continued)

COMPARING LINEAR STAGES AND U-FRAME ACTUATORS

To be clear: Despite their compact dimensions, U-shaped linear actuators have excellent load and moment capacities. This is because the raceways are spaced relatively far apart … so the geometry of the carriage is similar to that of a bearing block much larger than the actuator could accommodate in its standard form. Some manufacturers offer U-shaped linear actuators made from extruded aluminum profiles, with steel inserts for the linear guide raceways.

Aluminum versions lack the rigidity of steel designs, but they offer a very compact profile. In addition, they are often dimensionally interchangeable with steel versions where an application might benefit from a lower-cost option.

The use of a steel (rather than aluminum) profile makes the U-shaped design extremely rigid and allows manufacturers to offer a linear actuator with the high travel and positioning accuracies typically found in more precise (and more expensive) linear stages.

While steel versions of U-shaped linear actuators use ballscrew drives almost exclusively, aluminum designs are more likely to be offered with both ballscrew and leadscrew drive options.

Originally developed for high-precision applications such as semiconductor wafer handling and medical diagnostic dispensing (for which space constraints don't allow a typical linear stage) U-shaped linear actuators are now used in various industries and applications. These include plasma welding, automated assembly, and optical inspection.

One of the driving factors behind the widespread adoption of U-shaped actuators is that they are the only linear actuator design with dimensional interchangeability between manufacturers.

However, due to differing guideway and ballscrew designs, technical specifications (such as load capacity, speed, or rigidity) can vary between manufacturers and product lines — even for products with the same cross-sectional size and mounting dimensions.

The Akribis DGL linear stage is Akribis' best-selling dual-guide linear stage. With no cogging effect, it also has an excellent force-size ratio has been designed for high precision and precise homing in this linear motor stage (Repeatability up to ±1 μm). The linear motor stage can travel up to 5m/sec with accelerations up to 10 ***g****. Effective stroke from 100 mm to 1,200 mm with encoder resolution up to 0.05μm. Longer strokes are available upon request. Akribis DGL dual-guide linear stages are suitable for point-to-point motion control and scanning applications.*

ALTERNATIVE WAYS TO GET

DOFs FROM XY GANTRIES

This Akribis precision gantry has a granite base for maximum stability. A T-drive version has a single motor and encoder; an H-drive version has dual motors and encoders in a gantry configuration. For a smooth consistent motion with a short settling time and high throughput, the motor force is aligned with the bridge's center of gravity. Repeatability of this gantry stage is up to ±3 μm. Standard strokes are 200 x 200 mm to 800 x 800 mm (with other strokes available) and encoder resolution is to 0.05 μm. This gantry is suitable for dispensing, micro packaging, and precision detection applications — as well as Pick and place, AOI, and electronics applications.

Repeatability and accuracy are core to all motion systems — especially XY gantries. On gantries, controls make axes run through predefined trajectories. Traditional XY gantry setups include an upper Y-axis gantry member sitting on twin X1 and X2 support axes. The latter axes include motor, screw, and bearing separated by a finite distance orthogonal to stroke.

Due to manufacturing limitations of linear guides, there are deflections, ballscrew lead errors, and misalignments that cause X1 and X2 position errors — in large part because of imperfect orthogonality. So as the loaded Y-axis sweeps the XY plane, it also introduces X-axis position errors.

How to address this problem or propagating error? Usually engineers add 2D position-error mapping to the controls or suspend the Y axis from flexible members called flexures … and then independently control the X1 and X2 axes to maintain orthogonality. This reduces system bandwidth and allows angle adjustment or no more than 1° or so.

Myriad other applications are intentionally built with a large theta angle for an X-Y-theta axis setup to allow work-tool alignment to non-orthogonally located objects and patterns.

Some manufacturers design and make such XY gantries to cover large areas with a theta angle to 20° or more. Often, the kinematic setup gives OEMs large ranges of motion from independent X1 and X2 parallel axes. Plus it lets controls hold orthogonality in the XY plane or intentionally increase theta of the Y axis about X1 and X2 and even rotate Y around a virtually programmed point.

In some cases, the gantry has two pivot points on X1 and X2 to let the Y cross-axis rotate around each X axis and then displace linearly about each. Current iterations of such gantries use motor-driven ballscrew actuators (more specifically, run off a brushless servo motor that includes an encoder) but the design in future iterations may leverage the integration of linear servo motors for applications that need direct-drive accuracy. These gantries also traverse a larger working area than delta robots (which can also be costly and bulky).

OPTIONAL Z-AXIS FOR APPLICATIONS NEEDING DOF

Some stage and gantry suppliers also incorporate a multi-axis controller into the gantry to independently steer both X1 and X2 positions and theta (as X1-X2 control). Independently controlling the X1 and X2 axes means they can make strokes to any number of programmable distances — and that in turn enables Y-axis rotation around programmable pivot points.

Some gantries of this design to deliver XY travel of 800 x 800 mm with 20° of Y rotation. Theta angle control is to 1 arc-sec of resolution with repeatability to 3 arc-sec. Larger versions are available upon request. The gantries already operate in myriad reticle alignment, semiconductor wafer, and flat-panel manufacturing applications.

MONOLITHIC XY TABLES

Automated vision inspection stage image: Sorapol Ujjin

XY tables are constructed from two linear axes — typically driven by linear motors, ballscrews, or lead screws — that are mounted perpendicular to each other in either a stacked or a monolithic design.

Stacked XY tables consist of two complete, separate axes mounted together, much the same way they are configured in a basic XY Cartesian system. With a stacked design, there are few restrictions on the type and configuration of each axis. For example, the bottom (X) axis could be linear motor driven while the top (Y) axis is ballscrew driven. This flexibility, along with simple manufacturing and assembly, make stacked tables a popular design.

> *MONOLITHIC TABLES ARE ALSO CALLED INTEGRAL TABLES, COMPOUND ARCHITECTURE TABLES, AND THREE-PIECE TABLES.*

Monolithic XY tables consist of two axes that have been integrated together. Instead of two independent axes mounted to each other, this design integrates the top (moving part) of the X axis and the bottom (stationary part) of the Y axis into one single structure that serves both axes. This connecting structure is called a monolithic center.

> *SOME XY TABLES ARE CONSTRUCTED WITH A MONOLITHIC CENTER, MEANING THE TOP OF THE X AXIS AND THE BOTTOM OF THE Y AXIS HAVE BEEN INTEGRATED INTO A SINGLE PART. THIS IMPROVES STIFFNESS AND REDUCES OVERALL HEIGHT.*

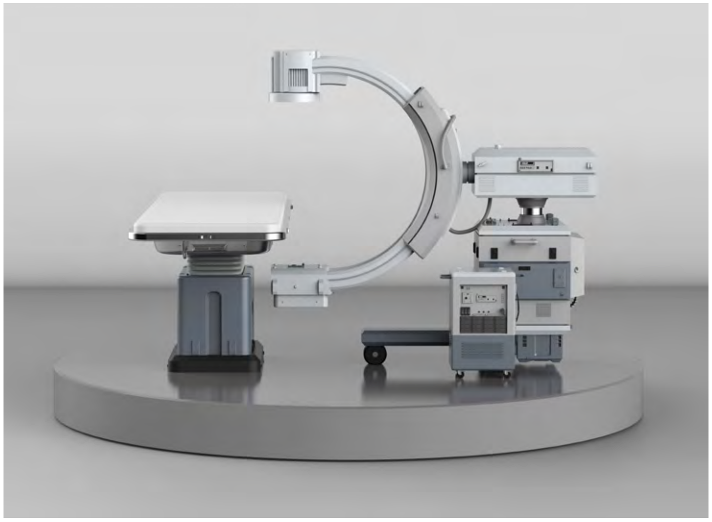
The most noticeable benefit of monolithic XY tables is a more compact design. By taking an assembly that is typically made of four parts (X axis base, X axis carriage, Y axis base, and Y axis carriage) and making it with just three parts (X axis base, monolithic center, and Y axis carriage) the assembly's overall height is significantly reduced.

But the monolithic design has other benefits as well. First, the use of a common structure connecting the two axes allows better control of orthogonality between the axes. This is critical in applications such as microscopy, inspection, and micromachining, where not only are the independent X and Y positions important, but so is the position of the axes relative to each other.

Monolithic XY tables also provide better rigidity than stacked designs, for the simple reason that fewer attachment points mean fewer points where deflection can occur. Another benefit of monolithic tables is that they allow the motors for both the X and Y axes to be attached to the center section and move with the X axis. This lowers the moved mass and inertia of the Y axis, and results in less moment loading on the X axis.

The term monolithic, when applied to a single linear axis, can also refer to a construction method in which the bearing raceways are machined into the platform, or body, of the table. This design does away with the traditional rail, shaft, or guide that would be mounted to the platform, which further reduces components and mechanical connection points, resulting in even higher stiffness and rigidity of the overall system. It also eliminates the potential influences of thermal expansion on linear bearing preload.

GONIOMETER STAGES AND WHERE THEY ARE USED



X-ray imaging goniometer application: Kittipong Jirasukhanont

The term ***goniometer*** can refer to a type of device that measures angles or to a device that rotates objects to a precise angular position. The former type, for measuring angles, is widely used in physical therapy to measure the range of motion of joints, such as the wrist or knee. This type of goniometer also has applications in science, for measuring the angles between crystal faces or for positioning samples and detectors for X-ray diffraction.

The latter type for rotating an object around a fixed axis is similar to a linear stage … but instead of providing linear motion in the X, Y, or Z axis a goniometer stage produces partial rotation around a fixed point or axis above the stage. Rotation angles can range from as little as a few arc-seconds to 90° in some cases.

Common industrial uses for goniometer stages include micromachining applications and the alignment of mirrors for inspection systems. In laboratory applications, they're often used for directing lasers and aligning mirrors or lenses in microscopy equipment, such as transmission electron and scanning electron microscopes.

> *CURVED CROSSED-ROLLER GUIDES ARE OFTEN CALLED GONIO WAYS; THEY'RE OFTEN USED IN GONIOMETER STAGES.*

Like linear stages, goniometer stages come in a wide variety of designs … but every design incorporates a low-friction guide and a high-precision drive mechanism. The guide mechanism can be a curved dovetail bearing, a curved crossed roller guide, or even an air bearing. In some designs, bearing races are machined directly into the stage to form the equivalent of a partial, single-row rotary bearing that supports and guides the load.

The drive mechanism can be a:

- High-ratio worm gear
- Ballscrew or lead screw (typically with an anti-backlash nut) or
- Direct-drive motor.

Because goniometers are often used for very fine positioning, worm gear versions use very high ratios — in the range of 300:1 — and can be driven by hand with a micrometer or with a stepper or servo motor. Similarly, ball and lead screw versions use very small leads, and these are often driven by servo or stepper motors. Goniometer stages with crossed roller guides and piezo motors can provide ultra-high resolution for small ranges of motion to meet the needs of micro- or nano-positioning applications.

> *SOME LARGE GONIOMETER STAGES USE CURVED PROFILED RAIL GUIDES AND A PRECISION DIRECT-DRIVE SERVOMOTORS TO PROVIDE ±45° (90° TOTAL) ROTATION.*

One of the benefits of such a wide variety of designs is that goniometer stages can be used in a broad range of applications — including cleanrooms and vacuum environments.

Most goniometer stages are designed to allow stacking of multiple stages, providing orthogonal rotation around a common point. In many cases, manufacturers of goniometer stages also manufacture linear stages and have made it easy to integrate the two types from a mounting and control standpoint … presenting designers with a pre-engineered solution that provides both linear and rotational movement. For example, a pre-engineered three-axis X-Y-Z stage might provide linear positioning of two stacked goniometers complemented by curved crossed roller guides for a five-axis motion solution.

PUTTING CARTESIAN ROBOTS IN CONTEXT

CNC cutting linear-motor application image: Nordroden

We've touched on Cartesian robots several times in this Design Guide, but let's take a step back and define exactly what makes a robot a Cartesian robot as opposed to another robot or multi-axis system.

First, a Cartesian system is one that moves in three, orthogonal axes — X, Y, and Z — according to the Cartesian coordinates. (Although it should be noted that a rotary axis — in the form of an end effector or end of arm tooling — is sometimes included on the outermost axis of a Cartesian robot.)

What makes a Cartesian robot a robot is that the axes perform coordinated motion, through a common motion controller. The axes of a Cartesian robot are made from some form of linear actuator — either purchased as a pre-assembled system from a manufacturer or custom-built by the OEM or end user from linear guide and drive components. Simple, right?

The ISO 8373:2012 standard defines an industrial robot as:

An automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications.

But not every linear system that works in the X-Y or X-Y-Z axes is a Cartesian robot. One notable exception is a type of robot that employs two base (X) axes in parallel. This configuration — 2X-Y or 2X-Y-Z, for example — moves the robot out of the Cartesian category and into the category of gantry robots.

The primary difference between gantry and Cartesian robots is that a Cartesian robot uses one linear actuator on each axis, whereas a gantry robot is always constructed with two base (X) axes, with the second (Y) axis spanning them. This configuration prevents the second axis from being cantilevered (more on that below) and allows gantries to have much longer stroke lengths — and in many cases, larger payloads — than Cartesian robots.

The second type of multi-axis linear system that does not fall under the definition of Cartesian robot is the XY table. The difference between Cartesian robots and XY tables lies in the mounting and loading arrangement. In a Cartesian robot, the second or third (Y or Z) axis is cantilevered, being supported at only one end by the axis below it. In addition, the load on the outer axis is generally cantilevered from that axis.

This arrangement creates not only a moment load on the outer axis, due to the applied load, but also a significant moment load on the supporting axis, due to the combined effect of the applied load along with the outer axis. The mounting and loading arrangement limits the load-carrying capability of Cartesian robots and is a primary factor in determining the maximum stroke length for the outer (cantilevered) axis.

(continued)

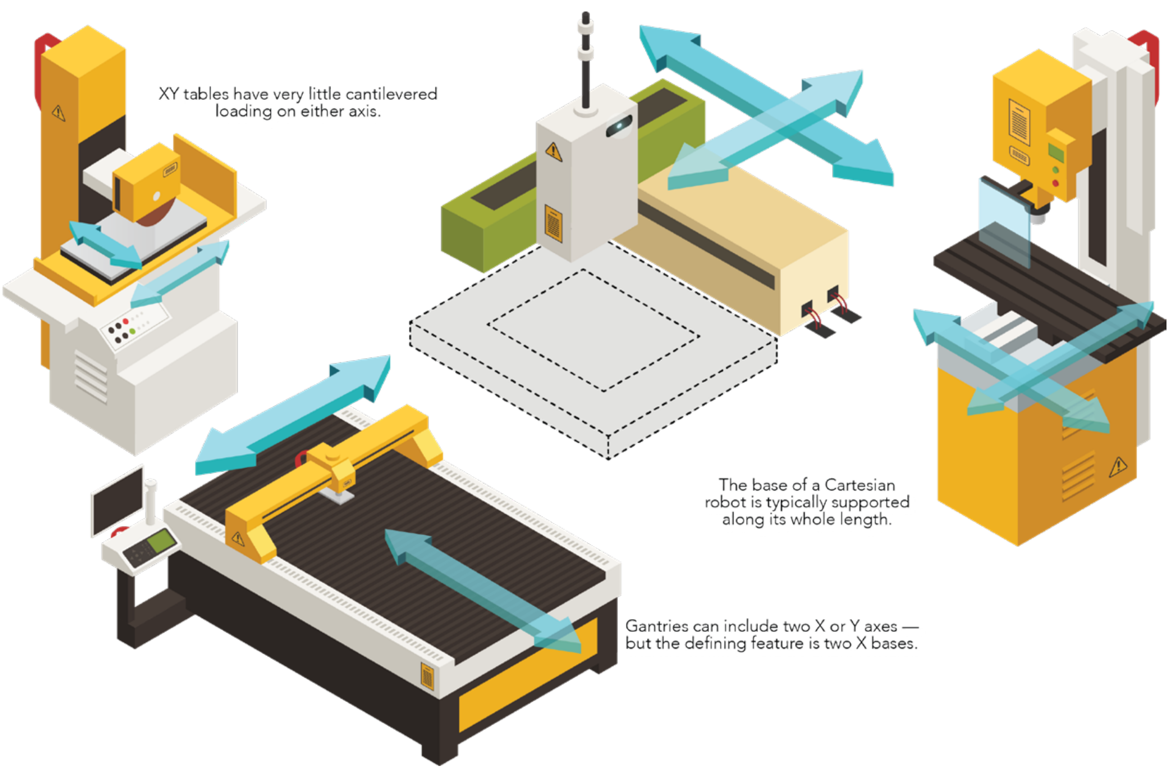
PUTTING CARTESIAN ROBOTS IN CONTEXT

In contrast, XY tables consist of two axes centered on top of each other, often with similar stroke lengths. In addition, the load is generally centered on the Y axis. This axis configuration and load positioning results in very little cantilevered loading on either axis (and often no cantilevered loading on the Y axis).

Cartesian robots overlap SCARA and six-axis (articulated) robots in some technical specifications and can be applied in some of the same applications, but Cartesian robots have several benefits over SCARA and 6-axis types. First, Cartesian designs provide a rectangular work envelope in which a significant percentage of the robot's footprint is used as active work area. SCARA and six-axis types, on the other hand, have circular or oval work envelopes that often result in a lot of dead (unused) space, especially when the required travel, or reach, is very long.

Cartesian robots can be constructed from virtually any type of linear actuator with any variety of drive mechanisms — belt, ball or lead screw, pneumatic actuator, or linear motor. (Note that rack and pinion drives are also possible but are more commonly used in gantry systems with very long strokes.) This means they can, and often do, have better positioning accuracy and repeatability than SCARA and 6-axis types. Cartesian robots also have an ease-of-use advantage in terms of programming because their kinematics are simpler (three Cartesian axes, rather than multiple rotational axes).

In the recent past, preassembled Cartesian robots were rare, with most units being custom-built by an OEM, a robot integrator, or even the end user. But now, many linear actuator manufacturers also provide pre-configured, pre-assembled Cartesian systems, with myriad options to fit common travel, payload, speed, and precision requirements. And manufacturers of traditional 6-axis and SCARA robots are getting in on the action as well — recognizing that for many industrial automation and assembly applications, Cartesian robots offer a better tradeoff between load capacity and footprint than SCARA and six-axis designs.



The base (X) axis of a Cartesian robot is generally supported along its entire length, but the Y or Z axis is cantilevered. A gantry configuration can include two Y and/or two Z axes, for additional load capacity and stiffness, but the defining feature of a gantry robot is its two base (X) axes. Unlike Cartesian systems, which have significant cantilevered loads, XY tables have very little cantilevered loading on either axis.

PRIMER ON GIMBALS

Gimbals are also called gimbal mounts because they're often used for mounting optics or sensors. Image source: Akiyoko74

In simple terms, a gimbal is a pivoting platform that allows an object to rotate around one or more axes. They're often found in photography and videography applications to stabilize cameras, as well as in navigation systems for ships. In these applications, two or more gimbals are mounted together with orthogonal axes (axes mounted 90° to each other) and the supported object remains stationary while the gimbals rotate around it to counter any rolling, pitching, or yawing motions that occur.

In industrial applications, gimbals are typically classified as a type of rotary stage and are also called ***gimbal mounts*** because they're commonly used for mounting mirrors, sensors, or other direction-sensitive equipment. Gimbal axes are driven with servo, stepper, or even piezo or voice-coil motors. For precise positioning, they operate in a closed-loop system with a feedback device — typically a high-resolution rotary encoder — on each axis.

Gimbal movements are based on the horizontal coordinates of azimuth and elevation, with some multi-axis gimbal stages also including a third axis whose movement is called roll. Azimuth and elevation are most easily visualized by thinking of an object's position relative to the horizon, as shown below.

Drone gimbal image: Draftmode

Azimuth is the position around the horizon, measured from a reference point such as true north or true south. Azimuth movements occur around the Z (vertical) axis. Elevation is the object's distance above or below the horizon (also called altitude in astronomy and aerospace applications). Elevation movements occur around the Y axis.

Roll movements occur around the X axis as it rotates with the Y and Z axes.

To demonstrate, this video from OES Motion Control shows a three-axis gimbal system with movements in azimuth, elevation, and roll directions.

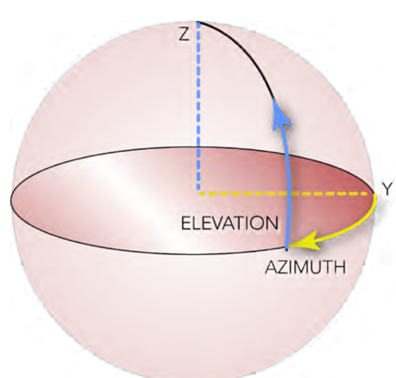
Note that some manufacturers and reference guides refer to the three axes of a gimbal stage as yaw (rather than azimuth), pitch (rather than elevation), and roll.

Gimbals can be gear-driven or direct-driven and often use radial crossed roller bearings to support the load. Rotation can be specified within a required range for each axis — for example, ±90° azimuth and ± 45° elevation and ± 90° roll. When full rotation (360°) is required on any axis, a slip ring can be used to transmit power and data, eliminating complex systems for managing cables as the axis rotates.

Gear-driven gimbals most often use worm gears with servo or stepper motors. A benefit of gear-driven designs is that the gear helps to mute and dampen the effects of the motor hunting for position due to overshoot or undershoot. Gear-driven designs also have higher load capacities than direct-drive gimbals, but gears introduce backlash to the system, which reduces bi-directional repeatability. This backlash, or play, also makes it difficult for the gimbal to execute quick movements, especially when changing travel direction.

Direct-drive gimbals that use rotary torque motors benefit from fewer mechanical connections in the drivetrain and therefore less backlash. Although they have lower load capacities, they're better suited for dynamic movements and rapid changes in the direction of rotation.

Gimbals are common in aerospace and military applications, especially for tracking and communication devices. In industrial settings, two- and three-axis gimbal stages are used for sensor calibration and alignment and for precise angular positioning of optics and lasers.



Azimuth movements occur around the Z (vertical) axis, and elevation movements occur around the Y axis.

MORE ON **VERTICAL LIFT STAGES**

In many applications that require vertical motion, a Z-axis actuator combines with one or two horizontal axes in a Cartesian or gantry-style arrangement. In such multi-axis configurations, the moved load is mounted to the Z axis via a bracket — creating a moment load that affects the Z axis as well as the horizontal (X and Y) axes. This cantilevered load can induce deflection in the supporting linear guides, actuator housings, and brackets … in addition to unacceptable settling times and oscillations in highly dynamic applications.

Therefore, applications that require vertical motion with high rigidity and minimal deflection sometimes use a vertical lift stage rather than a traditional Z axis actuator.

A vertical lift stage uses a flat horizontal table to support a load as it moves vertically to eliminate cantilevered loads that can cause deflection. In fact, there are several design variations of vertical lift stages. However, any stage demanding extremely smooth and accurate travel (and high positioning accuracy) typically consists of a table connected to crossed-roller slides in a wedge arrangement.

A ball or leadscrew drives the table in the lateral direction, and the wedge arrangement of the crossed-roller slides transforms the horizontal motion from the screw into vertical motion of the table. This design provides very accurate travel and positioning accuracy … but is typically limited to stroke lengths of 25 mm or less. Another common design for vertical lift stages uses:

- a vertical linear guide at each corner (or in some cases, six linear guides evenly spaced around the table area) and
- a vertical ball or lead screw located in the center.

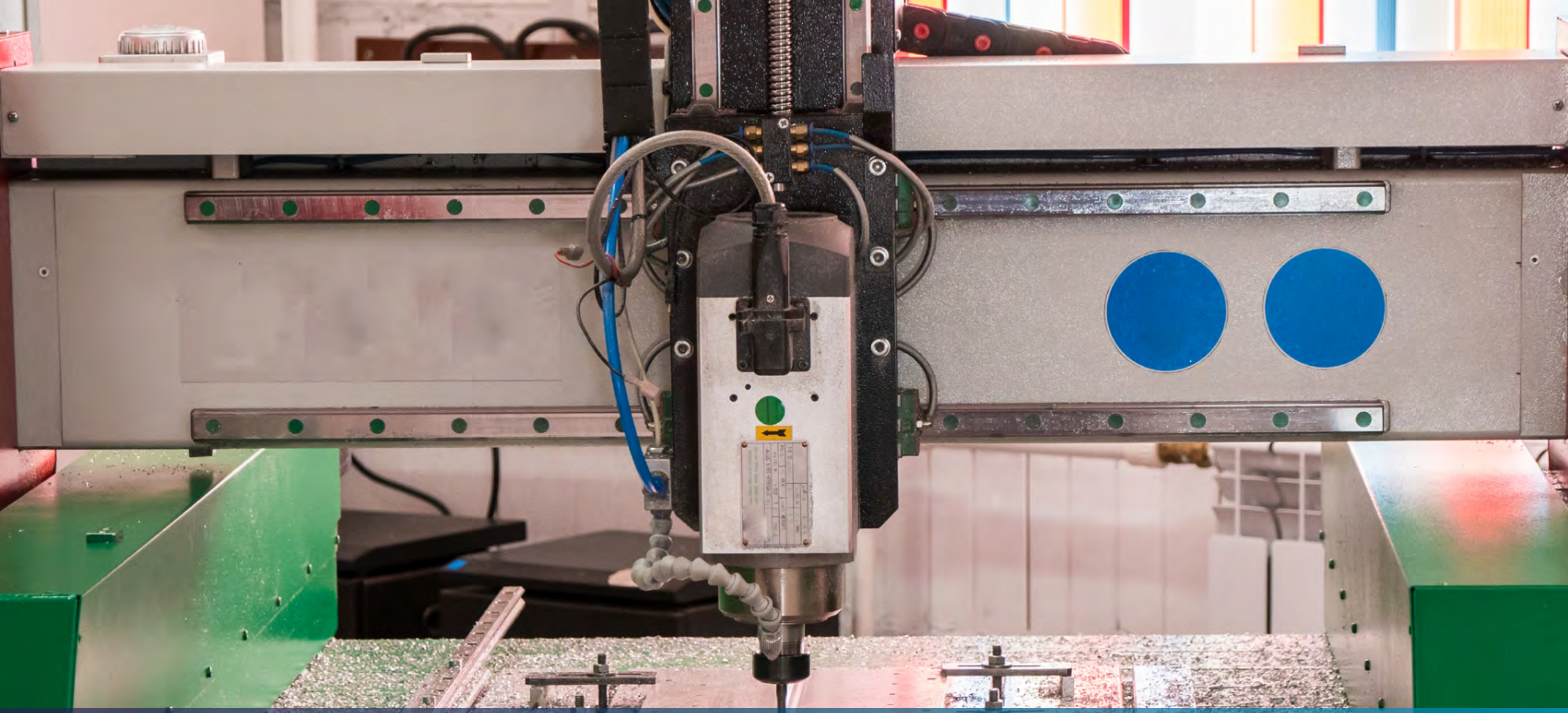
The guides are typically round shafts with recirculating linear bushings because the latter provide very smooth motion and have a lower tendency to bind when a design needs four (or more) guides in tandem. That's because linear-motion guides based on recirculating-ball linear bushings can accommodate for misalignment.

The benefit of this vertical lift stage design is the ability to carry larger and heavier payloads while maintaining smooth, precise motion and good parallelism between the table and base during motion. Available stroke lengths are also longer than for the screw-driven wedge design — up to several hundred millimeters in some cases.

Note that both types of vertical lift described above are termed stages because they're designed for extremely accurate travel and positioning in the Z direction … much like XY stages that use high precision linear guides and ball or leadscrew drives. However, in the screw-driven wedge design the table surface is typically machined to a very tight flatness tolerance, so it more closely fits the traditional definition of a stage than does the screw-driven linear guide version.

Of course, vertical lifts used in material handling and people-moving applications are vastly different than the vertical motion systems covered here and elsewhere in this Design Guide … and to be clear are often called vertical platform lifts or (where applicable) scissor lifts.

The vertical lift on this automated Rockwell hardness tester is an isolated axis.



THE BASICS OF SPLIT BRIDGE SYSTEMS

In a split bridge system, one axis is not connected to the others, but works in conjunction with them. Split-bridge system image: Konstantin Shishkin

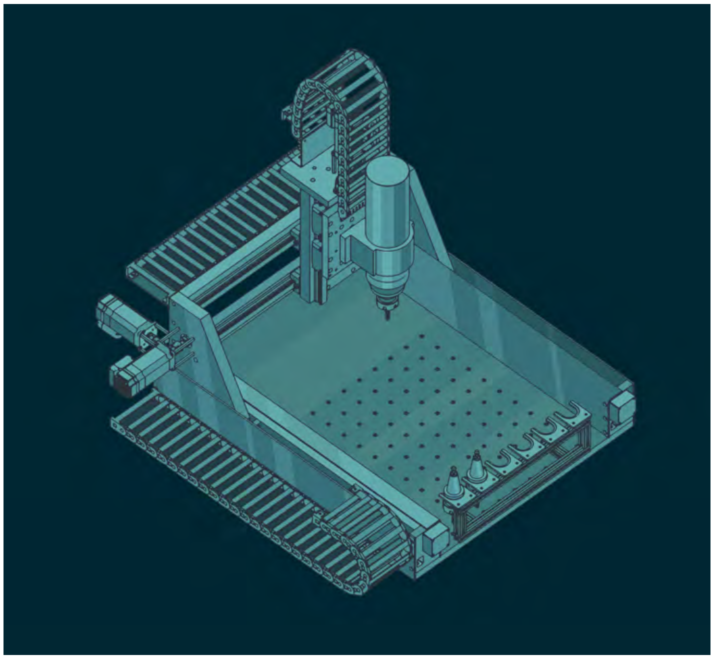
Multi-axis linear systems come in a variety of designs, with Cartesian, gantry, and XY tables being some of the most common types. While these designs simplify construction and can provide space savings, they also introduce "stacking" errors — the compounding of errors from each axis, which manifests at the work piece or tool point. Mounting axes to one another also creates cantilevered loads and Abbé errors — angular errors that are amplified as the point of interest (work piece or tool point) moves farther from the source of the error. But one multi-axis configuration — the split bridge system — provides a solution for high-precision tasks that require multiple axes of motion while minimizing stacking errors.

Split bridge systems provide two, three, or more axes of motion using a cross or bridge axis that spans the base and supports at least one of the axes. While this setup is similar to a traditional gantry, there are some notable differences.

To start, a traditional gantry system uses two X or base axes with a Y axis that spans across them and — in most applications — a Z (vertical) axis mounted to the Y axis. The gantry design provides very long travel lengths with good load capacity and high rigidity because roll moments on the X axis are eliminated, and yaw moments can be minimized.

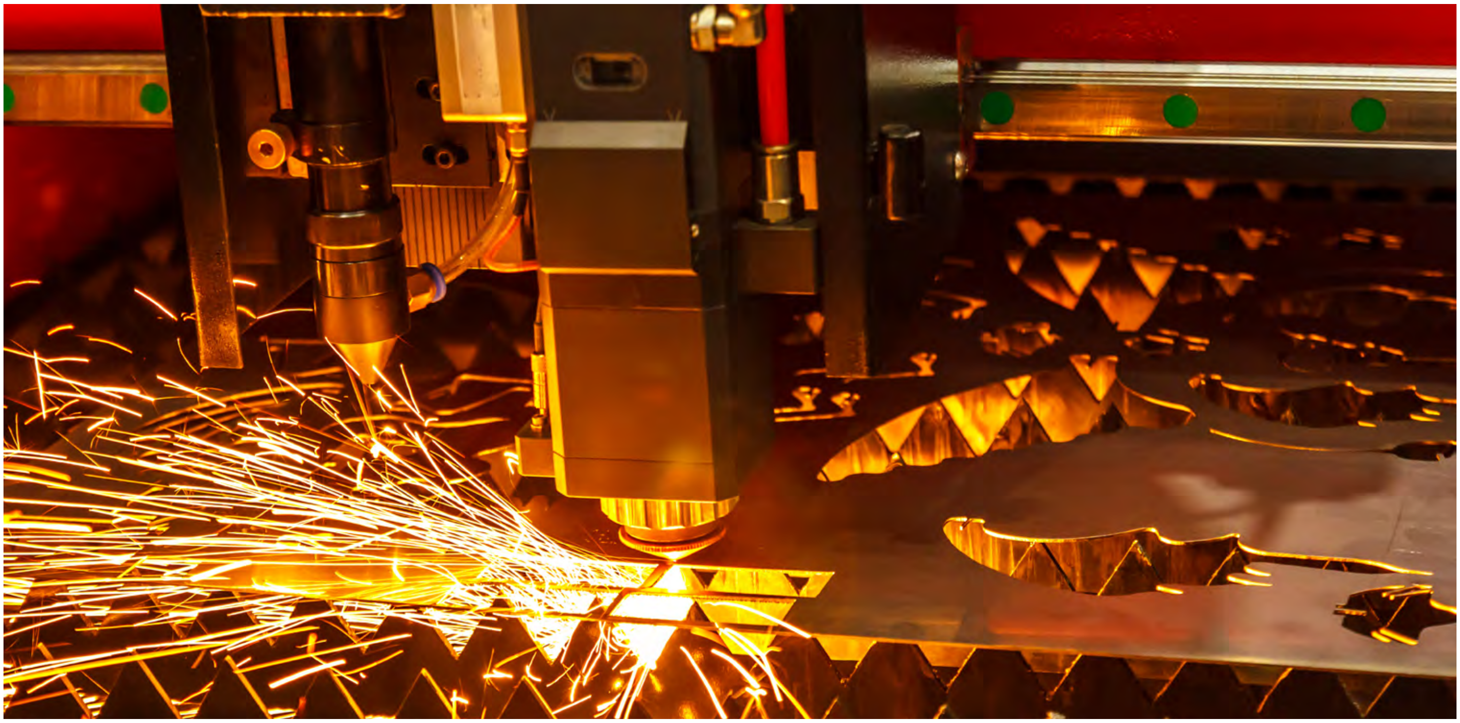
But if the parallel X axes on a gantry aren't synchronized, then racking or skewing of the axes can occur — which will produce errors in the Y and Z axis positions.

A split bridge system avoids these issues by using a static member or fixed bridge to span the base axis or axes. The base



Gantry systems use two parallel X axes with a Y axis that spans them and – in many cases – a Z axis mounted to the Y axis. This design allows for long travel lengths, but often introduces errors in the Y and Z axis motions.

THE BASICS OF SPLIT BRIDGE SYSTEMS

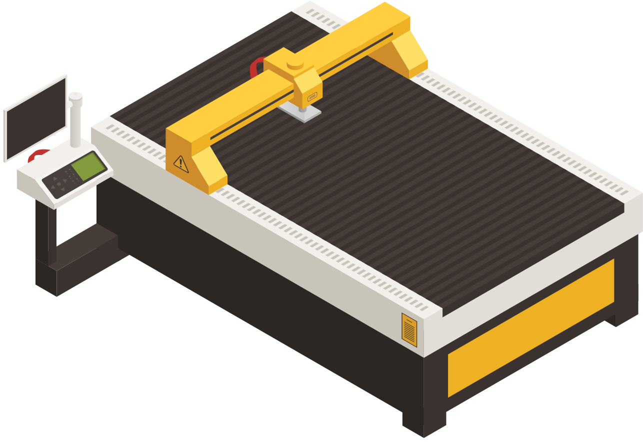


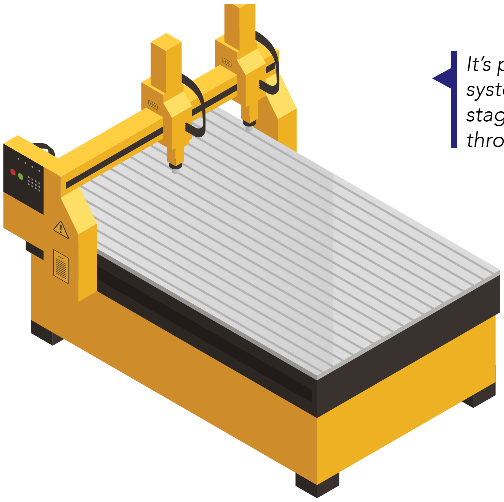
This split bridge system for laser cutting includes an XY stage (which moves the cutting tool) and an independent Z axis which moves the laser head.

axes — whether a single axis, an XY table, or a two-axis planar gantry — are mounted to a machined surface (typically steel or granite, although machined aluminum is sometimes used) for flatness and rigidity.

The Z or vertical axis is mounted to the bridge, independent of the base axes. In some cases both Y and Z axes are mounted to the bridge, making them both independent of the X axis. The axes mounted to the bridge are typically high-precision stages, like the base axes, although more traditional linear systems can also be used, depending on the application requirements.

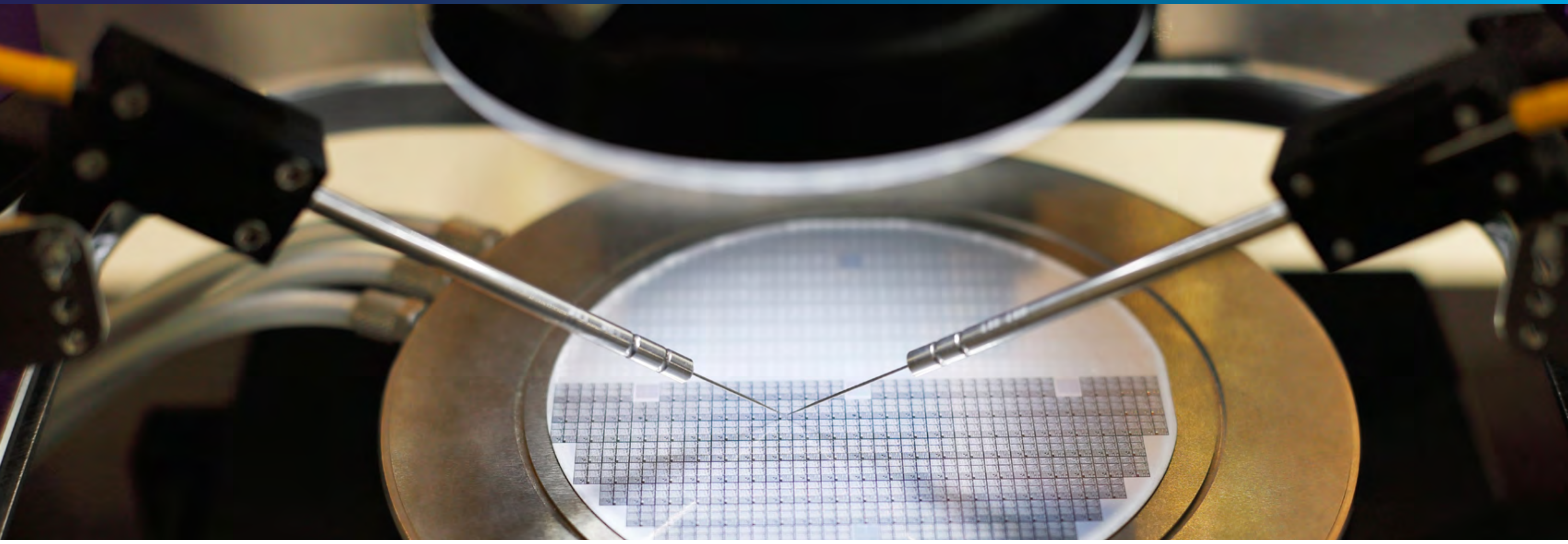
One of the primary reasons for using a split bridge system is so a part or sample can be moved into a very precise position with the base axes, and then a process such as scanning, probing, or drilling can be done by the axis (or axes) mounted on the bridge.





It's possible for split bridge systems to use multiple Z axis stages on the bridge for higher throughput.

SATISFYING THE DEMANDS OF NANOPOSITIONING



Probe testing of semiconductor wafers requires motion designs capable of nanopositioning. Image via Dreamstime

Recent decades have seen the unabated spread of automation continues into applications that just a decade or two ago were considered exotic, prohibitive, or downright impossible. Nowhere are the resulting technologies more specialized than those for new nanopositioning and miniature linear-motion designs — where a proliferating array of tiny motors, mechanical components, and especially electronics have enabled nanopositioning and miniature machine designs for specialty workcells, handtools, and mobile robotics.

These builds often rely on components pre-integrated into subsystems such as:

- Miniaturized slotless and coreless motors sporting thumbnail-sized drives and encoders within housings are often no larger than a pencil
- Frameless motors that don't come with their own housing, but rely on the OEM's component frame for protection and support
- Linear actuators that tightly integrate shape-memory alloys
- Linear stages with linear rails pre-engineered into the build by the supplier
- Piezo-based hexapods, stages, and other designs sans the unavoidable bulk of copper-wire-based electromechanical actuation

Other examples of pre-integration for compactness abound. No matter how they're built into systems though, nearly all motion components come in diminutive versions that were unimaginable even a decade ago.

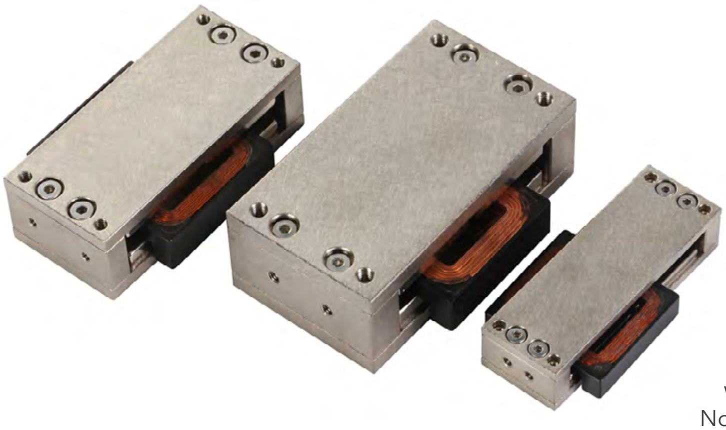
MARKETS FOR PRECISION MINIATURE MOTION

Semiconductor manufacture continues to spur many of scaled-down machine designs, along with demand for pocket-sized consumer home products and small appliances with motion functions.

Consider the challenging applications of semiconductor manufacturing — including backend wafer inspection. Some

Shown here are AVM direct-drive zero cogging voice-coil motors from Akribis Systems.

SATISFYING THE DEMANDS OF NANOPOSITIONING



Akribis AVA planar voice-coil motors deliver limitless resolution — with this aspect of its output dependent only on the feedback device.

operations require motion stages capable of strokes of a few hundred millimeters even while maintaining X and Y-direction accuracy of 1 µm. The extra wrinkle is that some such operations (because of the need for high throughput) must process wafers quite quickly — demanding stage speeds of a couple m/sec along with accelerations to 2 g sans significant vibration in the focal Z axis. No wonder the stage kinematics and heat dissipation capabilities as well as its motion-controller sophistication are all so critical.

In fact, the manufacture of microelectronics and silicon photonics (ICs employing light along nano-optical structures for driving and fast and efficient data transmission) has grown thanks in part to the kinematics and controls advances for ultra-high-precision motion stages.

Most of these ultra-high-precision motion stages are pre-integrated, as such systems do two things: They free researchers and manufacturers in demanding fields to focus on core competencies, and they outperform serial-kinematic Cartesian-type robots (often built by end users' stacking linear stages into XYZ systems). Such Cartesian-type stages typically require additional degrees of freedom — which are often had through still more (bulky and error accumulating) addition of goniometers and rotational yaw, pitch, and roll stages. In contrast, Stewart (hexapod) platforms deliver motion dictated by the controller and not the mechanical bearings and power-transmission linkages. A user-definable rotational center along with lower inertia and higher stiffness are just a few benefits.

> *“ALONG WITH INSPECTION, TEST AND MEASUREMENT, AND METROLOGICAL EQUIPMENT, AEROSPACE TOO CONTINUES TO REQUIRE PINT-SIZED DESIGNS FOR MAXIMAL EFFICIENCY AND FUNCTIONALITY.”*

Another option in some instances are ultra-precision motion stages with clever kinematics for well-placed centers of gravity and optimized system dynamics.

Case in point: To address the issue of outer axes causing a moment load on the inner axes, certain gantry systems use two X axes or (in some cases) two Y and two Z axes. Gantries almost always have three axes … X, Y, and Z. The load on a gantry system is located within the gantry's footprint and the gantry is mounted over the working area. However, for parts that cannot be handled from above, gantries can be configured to work from below.

Perhaps the next-biggest driver of miniature motion designs (after the semiconductor industry) is the medical-device industry … a trend likely to grow as COVID demands creative new approaches to medical manufacturing, distribution, and treatment —

Due to its compact internal structure, this AMS miniature stage from Akribis is classified as a low-profile direct-drive stage. A unique selling point of this product is its stackable configuration. Each stage is designed with repeatability up to ±0.3 µm. Currently, it only has an effective stroke at 15 mm with encoder resolution up to 0.05 µm. Longer stroke available upon request. Suitable for high-precision positioning applications with auto-focus and auto-alignment requirements.

(continued)

SATISFYING THE DEMANDS OF NANOPOSITIONING

including more emphasis on automated status-monitoring systems, distributed laboratory operations, and home healthcare.

The medical-device industry necessitates an array of miniature motion designs. Complicating matters is how FDA requirements on medical-device makers and their suppliers continue to include actuator and motor manufacturers in regulatory scrutiny, so controls on design processes continue to tighten — usually as reverification of production lines and test equipment. Overseas competition, medical-device taxes, and withering Medicare reimbursements are also forcing lower costs for devices and the motors for these applications.

A concurrent trend in medical devices — from medical robots to handpieces to implantables — is that they're ever smaller and more compact. So medical continues to adopt technologies from consumer electronics and the small motor-driven designs they enable.

Case in point: Bean-sized mechatronic hexapods employing piezomotors under closed-loop control are indispensable in lens-focusing functions of consumer and smartphone-grade cameras and UAVs. In fact, the six-DOF technology delivers enough precision to drive handheld surgical tools, biometric identification, and in-vitro diagnostics. Some dc motors with diameters of just a few millimeters now have enough power density and reliability to satisfy technical and regulatory requirements for implantable pumps to treat an array of conditions.

The piezoelectric micromotors in these hexapods are complemented by miniature bearing assemblies, motor mounts, flexures, spring preloads, and miniature drive electronics to cancel hand-tremor movements during the use of microsurgical tools.

Elsewhere, miniature motion designs automate processes that surgeons still do manually. Consider an implant procedure in which a doctor must physically turn a knob to locate and move a device inserted into a patient's body. Now, automated motion systems integrating tiny gearmotor, leadscrew, and nut can execute such tasks more precisely. Of course, such tools must be extremely small and sterile and (because they're single use) must be inexpensive.

Another application example demanding increased power density and miniaturization is brushless dc cannulated gearmotors — those with gearbox-motor combinations that (among other things) allow for inline driving of Kirschner wires and pins in orthopedic surgery. Demand for cannulated gearmotors is rising as orthopedic-drill designers are looking to decrease their designs' overall size.

Where applications require tight integration (as for handheld or mobile designs) shrinking semiconductor sizes have let miniature-component suppliers integrate ever-smaller drives and controls into smaller and smaller motors for top reliability and cost effectiveness.

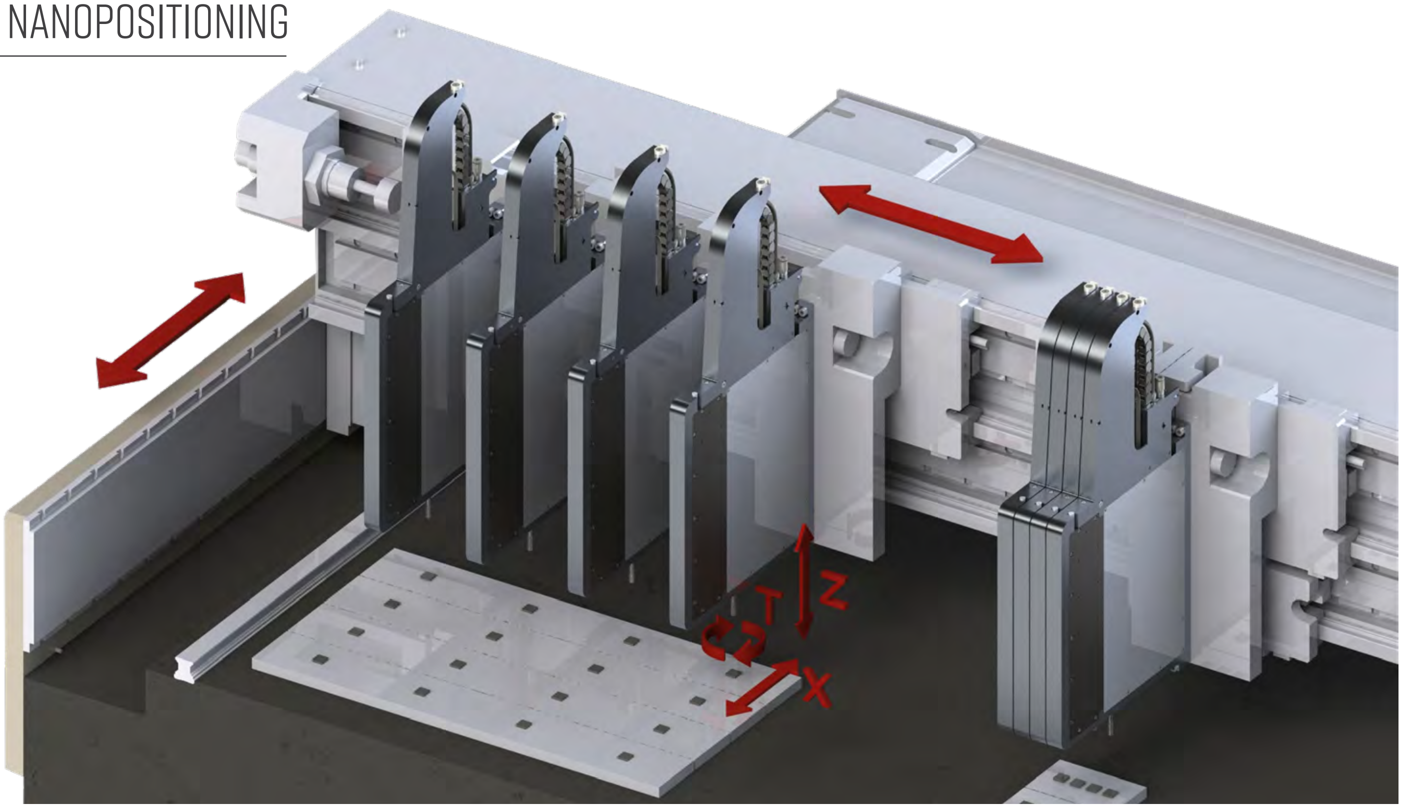
Designed for pick-and-place machines, the APK picker from Akribis is one of the world's smallest three-axis high precision high UPH pick-and-place modules on the market. 15 mm thick, the APK delivers high speed and Z-axis acceleration up to 2 g.

A rotary axis has a hollow shaft for vacuum feedthroughs. During pick-and-place motion (shaft contact) it can maintain force control to within ±3 g.

Z-axis strokes are 25 to 100 mm with repeatability to ±3 μm for the linear axis and ±70 arc-sec for the rotary axis.

(continued)

SATISFYING THE DEMANDS OF NANOPOSITIONING



Stacking multiple Akribis APK pickers is possible with minimal head-to-head pitch placement … so more parts can be picked and placed. In fact, the APK is the only three-axis picker of its type on the market. APK ZT two-axis and APK Z single-axis pickers offer more peak force than competitor products.

While the machines and devices get smaller, in many cases they must also be increasingly precise. Consider the interest in making more inpatient procedures into outpatient procedures. To this end, surgeons are now using robots or motor-assist tools to boost accuracy. Even risky forms of eye and brain surgery now rely on motor-driven automation to let doctors treat diseased areas in the body while avoiding healthy tissue.

The medical industry is also prompting electric-motor innovation for smaller and less costly designs. For example, motor-driven tools in operating rooms must draw low voltage and be quiet. Here, traditional peristaltic pumps can be noisy, especially when they're in a bank or driven by brush motors. Some manufacturers have addressed the problem with alternative dc-motor designs paired with quiet planetary gearing. Another example is portable oxygen concentrators that demand long life because they run off batteries. Miniature motion designs in these are increasingly efficient and power dense as well.

MORE ON LINEAR-MOTION SOLUTIONS FOR MINIATURE APPLICATIONS

When we talk about linear motion, we typically discuss applications where the travel distance is at least a few hundred millimeters, and the required positioning is in the range of a few tenths of a millimeter. For these requirements, guides and drives with recirculating bearings are a good fit. Case in point: the lead deviation for a common class-5 ballscrew is 26 microns per 300 mm of travel. But when the application calls for positioning in the nanometer range — one-billionth of a meter — engineers must look beyond mechanical rolling and recirculating elements to get the required resolution.

The three most common linear motion solutions for nanopositioning are piezo actuators, voice coil actuators, and linear motor stages. The drive mechanism in each of these solutions is completely free of mechanical rolling or sliding elements, and they can be paired with air bearings for high positioning accuracy and resolution.

(continued)

SATISFYING THE DEMANDS OF NANOPOSITIONING

Piezo actuators: Also called piezo motors, these take advantage of the reverse piezoelectric effect to produce motion and force. There are many styles of piezo actuators, but two common ones for nanopositioning are linear stepper and linear ultrasonic. Linear stepper piezo motors use several piezo elements mounted in a row that act as pairs of legs. When an electrical charge is applied, one pair of legs grips a longitudinal rod via friction and moves it forward as the legs extend and bend. When this pair of legs releases, the next pair takes over. By running at extremely high frequencies, some linear stepper piezo motors produce continuous linear motion with strokes up to 150 mm and with picometer-level resolution.

Linear ultrasonic piezo motors are based on a piezoelectric plate. When an electrical charge is applied to the plate, it becomes excited at its resonance frequency, causing it to oscillate. These oscillations produce ultrasonic waves in the plate. A coupling (or pusher) is attached to the plate and preloaded against a longitudinal rod — also called a runner. The ultrasonic waves cause the plate to expand and contract in an elliptical manner, enabling the coupling to advance the rod forward and produce linear motion. Linear ultrasonic piezo motors can achieve resolution of 50 to 80 nm, with maximum travel comparable to that of linear stepper motors — 100 to 150 mm.

Voice coil actuators: Another solution for nanopositioning applications are voice coil actuators. Like linear motors, voice coil actuators use a permanent magnet field and a coil winding. When current is applied to the coil, a force is generated (known as the Lorentz force). The magnitude of the force is determined by the product of the current and the magnetic flux. This force causes the moving part (which can be either the magnet or the coil) to travel, with guidance provided by either air bearings or crossed roller slides. Voice coil actuators can achieve resolution down to 10 nm, with strokes typically up to 30 mm, although some are available with strokes up to 100 mm.

Solenoids are another solution for nanopositioning applications. However, they are simply on-off devices sans ability to control the stroke, speed, or force. Solenoids are typically used for opening and closing valves and for driving microliter or nanoliter pumps.

Linear motor stages: When nanometer resolution is required over longer strokes, linear motor stages with air bearings are typically the best choice. While piezo and voice coil actuators have limited travel capabilities, linear motors can be designed for travel up to several meters. The use of air bearings as the guide system makes a linear motor stage completely non-contact, with no mechanical transmission elements or friction to affect the motion and positioning accuracy. In fact, linear motor stages with air bearings can achieve single-nanometer resolution.

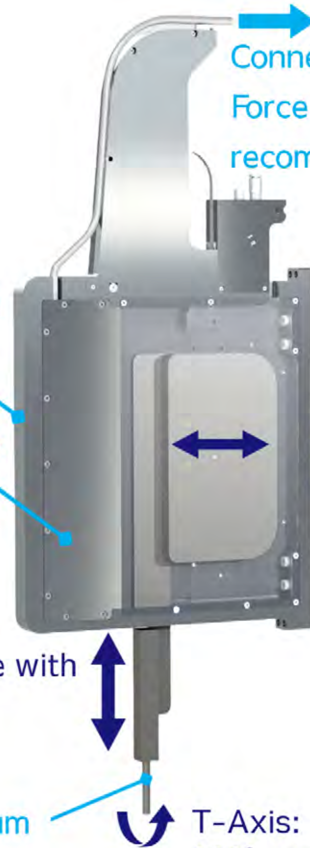
The downside of linear motor stages for nanopositioning applications is their footprint, which is much larger than that of piezo or voice coil actuators. While they can be challenging to integrate into small devices, they are a good fit for applications needing a relatively long stroke and high resolution, such as medical imaging.

This MBV direct-drive linear mechanism from Akribis is built around a voice-coil motor. It's suitable for the quick short strokes of punching operations. The design is compact with a built-in spring as the counterweight for high-speed movement in the vertical direction. Superior precision and trajectory control are possible when operating at high frequency — all sans cogging and backlash. In addition to being highly responsive, this linear component delivers repeatability to ±2.5 μm. Effective stroke is 6 to 8 mm with encoder resolution to 0.2 μm. Longer strokes are available.

Akribis
where precision matters

APK PICKER SERIES

WORLD'S SMALLEST 3-AXIS HIGH PRECISION PICKER FOR PICK-AND-PLACE APPLICATION



AWARDED "MADE IN SINGAPORE AWARDS 2021"

DIRECT DRIVE MOTOR

MULTIPLE PICKERS' HEAD ALIGNMENT

MINIMAL HEAD-TO-HEAD PITCH PLACEMENT

LONG PICKING STROKE