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# 01 INTRODUCTION

**Choosing the right piezo technology can be challenging. We created this guide to ensure mechanical engineers can make an accurate comparison and an informed decision between the different piezo products and technologies out there.**

Selecting the right piezo product can be a challenge. There are a lot of options available, and actuator and stage manufacturers tend to use different terminology in their specs, making it hard to compare two models of a different brand.

Furthermore, different piezo technologies target specific performance needs. Factors such **as precision, speed, force, size, and operating conditions will dictate the best solution for your application.**

In most applications, piezo systems precisely position lightweight components-like lenses, sensors, or samples-in compact spaces. Regardless of the setup, all piezo systems operate on the same principle: applying voltage to generate precise mechanical movement.

The key differences between technologies lies in how they control and optimize this effect for speed, durability, noise levels, and system integration.

In order to be able to choose the product that suits you best, we have created this guide for selecting the perfect piezo actuator or stage for your project. It will explain the different versions and options available, help you to compare the right specs, and eventually guide you to the most suitable solution for your project.

This guide will also help you understand the core piezo terminologies as well as support you in your piezo technology selection process.



# 02 AVAILABLE PIEZO TECHNOLOGY OPTIONS

There are mainly three types of piezoelectric motors, all of which are based on piezoceramic (PZT ceramic).

The most common type is the **impact-driven stick-slip piezo motor**.

A second category consists of the **stepper type of piezo motors**, also called **walking piezo motor**, which are typically used for high-force applications.

The third type is the **ultrasonic or resonant piezo motor**.

All three types have their specific advantages and applications. When evaluating suppliers, it is vital to consider their technical expertise and reliability track record; these are key indicators for their ability to support your application over the long term.

Ultimately, understanding the fundamental differences between these technologies is essential for making the right selection.

Stick-slip piezo motors operate through a sequence of rapid and slow movements that create incremental motion through friction and inertia. They are widely used because of their relatively simple design and compact size, but they are generally slower and more susceptible to wear due to continuous frictional contact.

Walking piezo motors, on the other hand, use multiple piezo actuators that move in a coordinated stepping motion, enabling very high force output and nanometer-level positioning accuracy. These motors are often selected for applications where precision and holding force are critical.

Ultrasonic or resonant piezo motors function differently by generating high-frequency vibrations in the ultrasonic range.

These vibrations create a smooth elliptical motion at the contact surface, allowing continuous movement with very high precision and speed.

Compared to conventional stick-slip and walking technologies, **ultrasonic piezo motors typically offer quieter operation, lower wear, higher efficiency, and reduced power consumption**, making them particularly suitable for advanced compact and high-performance motion systems.

# 03 TERMINOLOGY

## The terms that really matter!

### 3.1 Sensor resolution

The term sensor resolution indicates the smallest motion detectable by the position sensor. This value is the lower limit for the stage/actuator resolution. Sensor resolution is also referred to as sensor sensitivity. It doesn't tell you anything about the motion specs, but only about the detection of the motion. Big difference.

#### Takeaway

*Don't be fooled! This is a sensor specification, not a system performance metric. It's an easy way to impress customers, but it doesn't reflect the actual precision your system will achieve.*

### 3.2 Sensor accuracy

The accuracy of a position sensor represents the absolute deviation with respect to a calibrated, metrologically traceable standard. Sensor accuracy does not necessarily relate to sensor resolution. Sensor inaccuracy is mostly caused by the imperfection of the sensor scale and by the alignment error of the sensor scale during assembly. The sensor accuracy error is, to a great extent, repetitive and can be compensated for by means of a lookup table.

#### Takeaway

*This is a tricky one and often misunderstood. You will typically find that these specs are much worse than the precision specs of an actuator or stage. But this shouldn't bother you too much, because the error is very repeatable, once the encoder is installed. Calibration of your system typically takes care of this. In 99% of the cases, this spec isn't very important.*

### 3.3 Stage/actuator resolution (= minimal step size)

Resolution is defined as the smallest, controlled mechanical displacement of a piezo positioning stage/actuator. The resolution is affected by the sensor resolution, mechanical influences (friction, compliance, contact point nonlinearities, etc.) and position control performance. This value is the lower limit for the stage/actuator repeatability. Other terms for stage/actuator resolution are minimal step size or minimal incremental motion (MIM).

Resolution and repeatability (see 3.4) together, define the practical precision achievable in a real-world system. For well-engineered piezo systems, you'll find specifications that deliver extreme control, extreme repeatability, extremely fast response time. This combination (precise positioning, consistency across movements, and rapid response) indicates a mature platform.

#### Takeaway

*Now things are getting interesting. When people talk about precision, this is the one they mean: the smallest step size an actuator or stage can take. In some cases, there can be quite some differences between the actuator/stage resolution and the encoder resolution. Together with stage/actuator repeatability, this is the most important parameter.*

### 3.4 Stage/actuator repeatability

Repeatability is defined as the range of positions attained when the stage/actuator is repeatedly commanded to one specific location under identical conditions. There are two types of repeatability.

1. **Unidirectional repeatability:** i.e., the ability of a stage/actuator to return to a given point, always coming from the same previously defined point. The value specified is the standard deviation of many moves to the same point.

2. **Bidirectional repeatability:** the ability of a stage/actuator to return to a given point coming from a random previous point. The value specified is the standard deviation of many moves from random directions to the same point. The values given on the Xeryon specifications refer to the bidirectional repeatability, unless specified differently.

Closed-loop control and system design play a major role in achieving consistent repeatability.

#### **Takeaway**

*As said above, a small minimal step size is nice. But you also want to be sure that when moving to a certain position at any moment or from any starting position, you always end up in the exact same position. Open-loop systems struggle with this because the step error is cumulative. However, there can also be huge differences between closed-loop systems, mainly due to the system control. Things get even worse when moving in two directions, because then the quality of the bearings starts to interfere as well. The longer the distance, the greater the effect. Therefore, this is the second most important spec to look at: bi-directional repeatability.*

## 3.6 Error motion of a rotation stage

According to the ANSI/ASME B89.3.4 standard, the error motion of a rotary stage's axis of rotation is defined as a change in position relative to the reference coordinate axes, of the surface of a perfect workpiece, as a function of rotation angle, with the workpiece centerline coincident with the axis of rotation. In other words, a rotary stage ideally has one degree of freedom, i.e., the rotation about the Z-axis.

However, as perfect rotary stages do not exist, any motion in the remaining five degrees of freedom is referred to as an axis-of-rotation error motion or simply error motion. Depending on the error direction, one can distinguish two radial contributions, one axial and two tilt or wobble contributions. Furthermore, the error motion of a rotary stage can be separated into a synchronous and asynchronous component. The error motion of a stage is often incorrectly referred to as stage runout. Synchronous error motion repeats consistently during every revolution and is typically caused by predictable mechanical imperfections, while asynchronous error motion occurs randomly and is often associated with vibrations, noise, or external disturbances affecting the system.

#### **Takeaway**

*When selecting a rotary stage, it is important to consider the error motion characteristics, as unwanted wobble or positioning deviations can significantly impact overall system accuracy and measurement reliability.*

## 3.5 Stage/actuator accuracy

The accuracy of a stage/actuator is directly related to the sensor accuracy. This is a result of the direct-drive principle of a stage/actuator and the small distance between the position sensor and mounting surface.

#### **Takeaway**

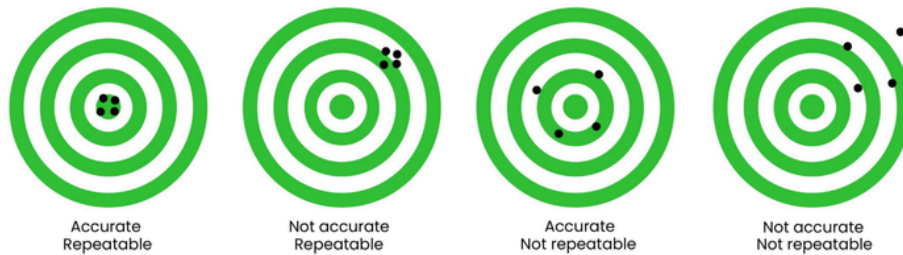
*Don't focus too much on this one. If you understand encoder accuracy, you also understand actuator/stage accuracy. Some manufacturers confuse actuator/stage accuracy with error motion. This is a separate spec, and a very important one (see 3.6)!*

## 3.7 Accuracy vs repeatability

Accuracy is how close a stage can position to the actual (true) value. Repeatability is a measure of the stage's ability to sequentially position to the same target value. It is important to understand that accuracy and repeatability are two different properties of a positioning system.

In a number of applications, the repeatability of a motion system is more important than the accuracy. Systematic errors can be taken into account and compensated, but the repeatability is the ultimate limit that is reached after all compensation.

Accuracy is also referred to as trueness. Other terms for repeatability are reproducibility or (slightly confusing) precision.



## 3.8 Error motion of a linear stage or actuator

The error motion of a linear stage/actuator is the undesired motion, as a function of the stage/actuator position, in all five degrees of freedom other than the direction of motion.

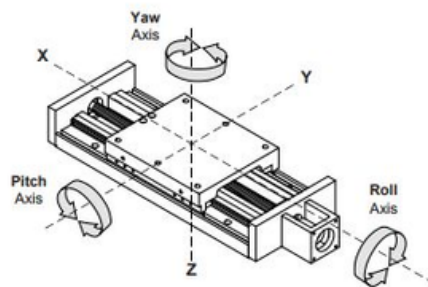
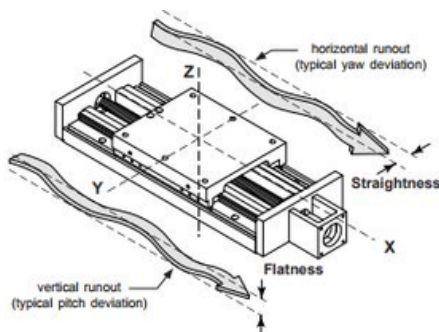
The error motion in the horizontal plane is referred to as straightness error, and the error in the vertical plane as flatness error. The angular error motion components in the different orthogonal directions are called pitch, roll and yaw. Another term for the error motion of a linear stage/actuator is the guiding error or travel error.

A quick word about actuators: Where a stage is designed to approach an error-less motion, even in the case of sideways forces, an actuator is designed to push and to pull. When there is some tolerance on the imperfect motion, an actuator can be used without any additional guiding of the payload.

But when you use an actuator, and you also need an error-free motion, you will need to add guides to the payload to keep it on track. So, remember: an actuator is for a push/pull motion, but a stage can also support the payload in other directions.

### Takeaway

*Same remark as with the rotary error motion: what's the point of having great precision when the actuator/stage has unwanted movements? The error motion specs of an actuator/stage are very important, as even small error motions can have a huge effect on your final results. In high-precision systems, even small guiding errors can propagate and affect overall system accuracy. Important for specific projects, but often not the decisive parameter.*



## 3.9 Travel speed

The maximum travel speed of the stage or actuator. Speed directly influences throughput and system efficiency in real-world applications. Different piezo technologies operate at vastly different speed ranges. Conventional inertia/stick-slip systems typically achieve approximately 2 to 3 millimeters per second, while advanced ultrasonic systems reach significantly higher velocities. This performance gap directly impacts your application's cycle time and overall productivity. Advanced ultrasonic piezo motors, such as Xeryon's ultrasonic motion technology, can achieve travel speeds of up to 1000 mm/s and travel ranges up to 300 mm. This demonstrates that modern piezo technology is no longer limited to only short travel distances and low-speed motion, as is often assumed with conventional piezo motors.

### Takeaway

*Not a difficult one but often overlooked. If you want to do a lot of measurements, the actuator/stage speed can have a huge impact on your throughput. For scanning measurements (measuring during movement), the speed stability is very important. If you are using long stages or actuators a high travel speed is a must to avoid long waiting times.*

## 3.10 Lifetime

Typical lifetimes of stick-slip piezo stages and actuators are about 20 - 30 km. When you do a lot of movements, this threshold is reached within a couple of months. In contrast, modern ultrasonic piezo systems such as Xeryon can achieve a life expectancy of > 1000 km. Long lifetime reduces maintenance requirements and improves system reliability over time.

Important to note is that the wear of the piezo ceramic generates ceramic dust particles. This is true for all types of piezo systems, but much less prominent in ultrasonic piezo. These can be harmful for your experiment or equipment.

### Takeaway

*Lifetime is often forgotten, but you don't want to buy new equipment too often or end up with ceramic dust in your setup. If you only move the stage or actuator sporadically this parameter is not very important.*

## 3.11 Sound and vibrations

Piezo products are vibration based. This is the core principle: The vibrations of the piezo element are converted into a net motion. If these vibrations are within the human audible spectrum (20 Hz to 20 kHz) the piezo motor will make a disturbing and audible noise.

A second issue with the vibration frequency of the piezo element is that it can generate resonance in its environment. Many small components have a resonance frequency in the 1-5 kHz spectrum and can start resonating when the piezo stage or actuator is activated. Ultrasonic piezo systems, such as Xeryon products, operate at 80-180 kHz. This is well beyond the human hearing range and far removed from typical environmental resonances (1-10 kHz). This eliminates both audible noise and unwanted vibration transfer to your setup.

### Takeaway

*Noise can be annoying for some applications. If you will be using the piezo motor all of the time, this is something to take into account. Resonance in your experiment can be a bigger issue than noise: be careful with low resonance frequencies!*

## 3.12 Driving force & holding force

**The driving force** explains the force with which the stage or actuator can push or pull in the direction of motion. It is important to make a distinction between horizontal and vertical movements.

In the horizontal direction in theory any payload can be moved, as long as the friction (and the inertia) allows it. The higher the mass of the payload, the lower the acceleration ( $F=m*a$ ). Because of the friction in the guidings, the top speed will also drop with heavy payloads.

In the vertical direction it is a different story: a stage or actuator can only lift a payload with a lower vertical force than the driving force of the motor. So, in theory, a 3N stage can lift a 300-gram payload. In reality, the lifting force is considerably less than this, because of loss of force during landing on the target position. Horizontally this is not an issue because gravity is perpendicular to the driving axis. This issue typically can be resolved by introducing

a mass compensating system, which compensates for the gravity of the payload. This can be done magnetically or mechanically (with springs or counterweights).

**The holding force** is the force you need to exert on the stage or actuator to move it when it is fixed on a position. A distinction needs to be made between active holding force and passive holding force. Active holding force means that the piezo motor is still active and when the stage/actuator is moved, the motor starts to counter-push. So, in this case the holding force equals the driving force. The passive holding force is relevant when the piezo motor isn't powered on anymore. In this case the holding force is generated by the friction between the piezo element and the ceramic driving strip of the stage or actuator. The piezo element is pushed against the strip with a certain force, giving the system a mechanical holding force when the power is off.

A distinctive feature of piezo systems is their inherent passive holding capability. Many piezo motors feature a self-locking effect, allowing them to hold position without continuous power consumption. This characteristic is particularly common in friction-driven piezo technologies such as stick-slip and ultrasonic piezo motors.

As a result, when powered off, the motor can maintain its position through friction with virtually zero energy consumption. This "power-off hold" capability is especially valuable in battery-operated devices and safety-critical applications where energy efficiency and fail-safe positioning are essential.

### Takeaway

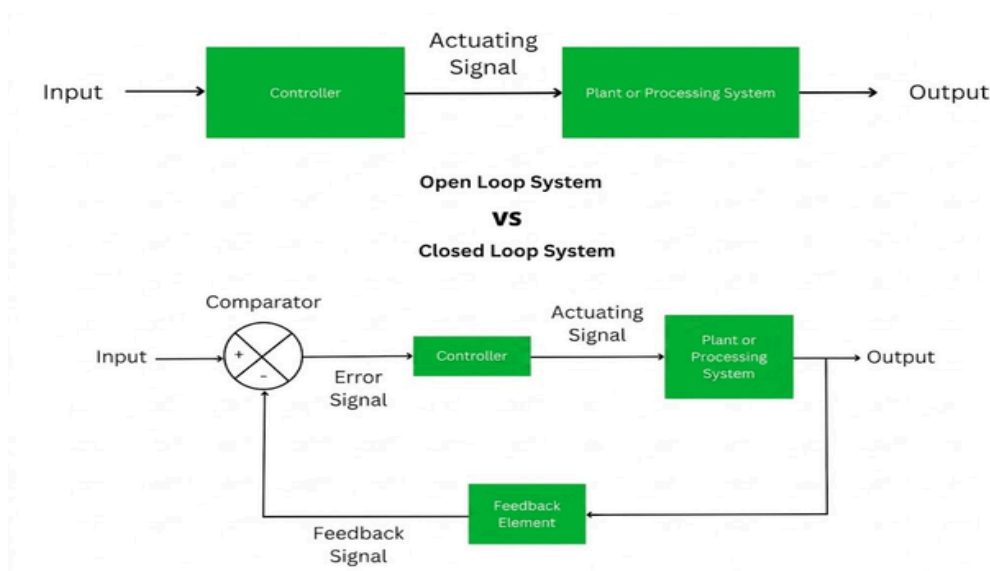
*Driving force is an important parameter when high accelerations are needed. When speed is not an issue, large masses can be moved with small piezo motors. If you are lifting a payload, much more attention needs to be given to the driving force as gravity comes into play. The passive holding force (when powered off) can be really important when you want to eliminate all kinds of vibrations and distortions from your setup or when you want to reduce power consumption.*

*Proper force sizing is critical for stable and predictable system performance.*

## 3.13 Open-loop vs. closed-loop

In position control, we often speak about open-loop or closed-loop control. In general, open-loop control in motion systems means that there is no position feedback of a moving object. Closed-loop control means that there is some kind of position information that is fed back to the motion controller of a system to help with positioning.

- **Open-loop piezo motors** are generally simpler, more compact, and cost-effective, making them suitable for applications where continuous position correction or ultra-high precision is not essential. However, without direct feedback, positioning accuracy may be affected by factors such as load variations, temperature drift, or external disturbances.
- **Closed-loop piezo motors** incorporate integrated feedback sensors that continuously monitor and correct the motor position. This enables higher positioning accuracy, improved repeatability, and greater long-term stability, particularly in demanding precision-motion applications. The main trade-off is increased system complexity and higher integration cost.

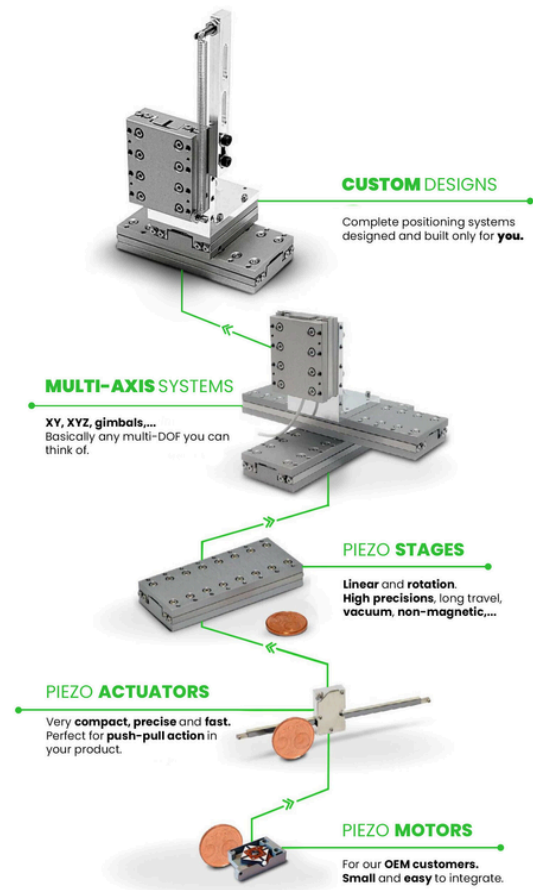


# 04 DIFFERENT LEVELS OF IMPLEMENTATION

Xeryon offers **flexible levels of implementation** to support different stages of product development and system integration.

Depending on your technical requirements, Xeryon solutions can be delivered as **individual components, complete motion modules, or fully integrated systems**. This allows customers to choose the right level of support - whether you are developing a prototype, integrating motion technology into an existing platform, or building a complete high-precision motion solution.

From early concept validation to **OEM-ready implementation**, Xeryon provides the flexibility needed to simplify integration, reduce development time, and achieve reliable motion performance in demanding applications.



## Discuss Your Motion Requirements With Us

— NO COST —

Send us your specs and our integration engineers will help you scope the right actuator, stage or motion module - from first sketch to scale.

[CONTACT US](#)



# 05 ABOUT XERYON



Xeryon supports clients across a wide range of applications and industries, providing motion solutions for:

- OEM integration**
- Scientific research applications**
- Manufacturing automation tool integration**

From high-performance environments such as MedTech devices, semiconductor manufacturing and metrology, to scientific fields such as materials science, imaging, and scientific research; Xeryon offers ultrasonic piezo products for any project imaginable.

Whether you need open-loop or closed-loop systems, actuators or stages, non-magnetic, vacuum-compatible, or vibration-proof components; Xeryon is your reliable partner for compact and precise motion solutions.


Different integration levels allow for maximum flexibility, depending on your specific application requirements.

Visit [www.xeryon.com](http://www.xeryon.com) to discover the right solution for your motion needs.


[Contact us](#) to discuss your project requirements or request a quote today!

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