V22 Version

CoreMorrow
Piezo Nano Motion

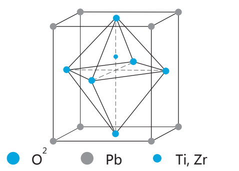
Piezo Nano Motion

- Piezo Technology -

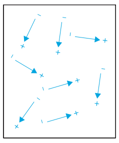
Harbin Core Tomorrow Science & Technology Co.,Ltd.

Properties of Piezoelectric Stack

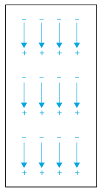
Piezoelectric ceramics are functional materials that can convert electrical energy into displacement. When the piezoelectric crystal deforms under the action of external force, a charge proportional to the external force can be generated on the crystal surface. This phenomenon of polarized charge on the crystal surface due to the action of mechanical force is called the positive piezoelectric effect. At the same time, when apply a electric field to the piezoelectric crystal, the crystal will deform due to the electric field. The magnitude of the deformation is proportional to the strength of the external electric field. This phenomenon of the piezoelectric crystal being deformed due to the action of the electric field is called the inverse piezoelectric effect.



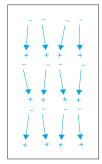
Below the Curie temperature, the crystal unit deforms spontaneously with four corners polarization.



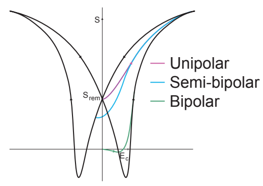
(1) Unpolarized ceramics



(2) During polarization



(3) After polarization



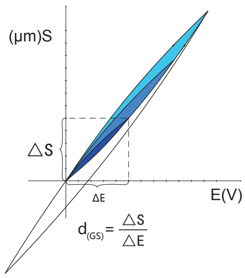
The curves of piezoelectric ceramics in the polarization direction and different voltage amplitudes

The upper right picture shows the displacement curve of piezoelectric ceramics driven by unipolar, semi-bipolar and bipolar voltages.

▸ Hysteresis

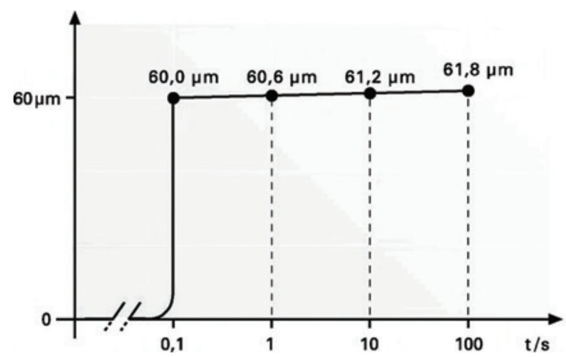
There is a displacement difference between the piezoelectric ceramic rising and falling voltage and displacement curve. Under the same voltage value, the displacement value on the rising curve and the falling curve has a significant displacement difference, and this displacement difference will change with the change of the voltage variation range. The smaller the driving voltage, the smaller the displacement difference will be. The hysteresis of piezoelectric ceramics is generally about 10%~15% of the displacement value under a given voltage. The slope between the switching points of the local hysteresis curve is defined as the piezoelectric large-signal deformation coefficientd$_{(GS)}$:

$$d_{(GS)} = \frac{\triangle S}{\triangle E} \ (\mu m/V)$$



▸ Creep

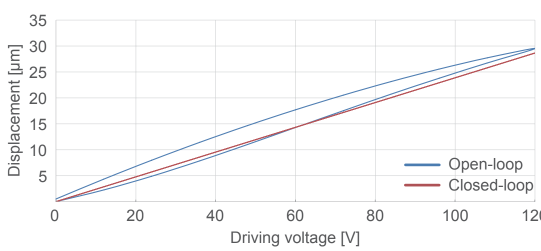
Creep means that the voltage value applied to the piezoelectric ceramic does not change, the displacement value is not stable at a fixed value, but slowly changes with time, and will reach a stable value after a certain period of time, as shown in the below figure. Generally, the creep within 10s is about 1%~2% of the elongation.



Remarks: Selecting closed-loop piezoelectric actuators can remove hysteresis and creep characteristics.

▸ Linearity and Nonlinearity

The hysteresis and creep of PZT can be effectively eliminated through closed-loop control. You can choose Coremorrow's closed-loop actuators and servo controller products.



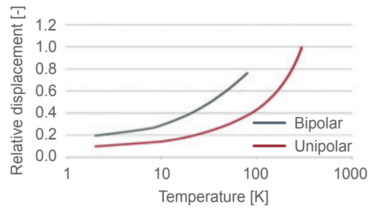
Eliminate hysteresis and creep through closed-loop control

E00/E01 Closed-Loop Controllers

▶ Temperature Characteristic

Temperature change is a very important factor that affects the nano-positioning accuracy of piezoelectric ceramics. The performance of piezoelectric ceramics will change significantly with temperature changes. The operating temperature of stacked co-fired piezoelectric ceramics is -25°C~+80°C. If use it above 100°C, the performance of ceramics will greatly decrease. The displacement of the piezoelectric ceramics will be affected to a certain extent if the temperature increases, depending on the difference in temperature from the Curie temperature. If the ceramic is heated to the Curie temperature, depolarization will occur, and the piezoelectric effect will disappear, and it will not be restored. When the temperature decreases compared to room temperature, the piezoelectric effect decreases. When the low temperature is less than 260K, the loss is about 0.4% per K. In the environment of liquid nitrogen, the elongation of the ceramic is about 10% of that in the room temperature environment.

The axial thermal expansion coefficient: about -5ppm/°C for low voltage PZT, +2ppm/°C for high voltage .



Compared with the room temperature environment, the displacement corresponding to different voltages in the low temperature environment is relatively reduced.

▶ Preload and Load Capacity

The tensile strength of piezoelectric ceramics is very low, about 5MPa, so it is recommended to add a certain preload force during installation and use. Based on the experience, 7MPa can compensate for the tensile force generated by high dynamics. If it is a constant force, it is better not to exceed 15MPa. The preload force is generally one-tenth of the maximum load of the actuator. For ceramics with a small height, the lateral force produces a shearing force, and a relatively high ceramic produces a bending force. During use, it is necessary to avoid these two forces from causing damage to the ceramic. Preloaded force limitation: when ceramics are subjected to a pressure greater than tens of MPa, mechanical depolarization begins to occur, which can be re-polarized through a large voltage signal, but the effective energy is lost, which will be detrimental to the service life of the component. Preloaded force will also generate tension, so when a high load acting on the ceramic exceeds the PZT's tensile strength, it will reduce the service life or damage the ceramic.

▶ Stiffness

The stiffness of piezoelectric ceramics is an important parameter for calculating blocking force, resonant frequency and other operating conditions. The stiffness of piezoelectric ceramics can be up to several hundred Newtons/micron. Calculated as follows:

$$K_{AStack} = \frac{E * A}{l}$$

K_{AStack} : The stiffness of piezoelectric ceramics

E : Effective modulus of elasticity

l : Length of piezoceramic

A : Cross-sectional area of piezoelectric ceramics

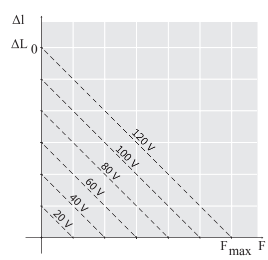
The stiffness of the piezoelectric benders is very low, which is several orders of magnitude lower than that of ordinary stacked ceramics.

▶ The Relationship between Displacement and Blocking Force

Displacemen ΔL_0: The displacement produced by piezoelectric ceramics. This value is measured under no-load conditions, that is, there is no resistance during the deformation process of piezoelectric ceramics. After applying voltage to the ceramic, the corresponding displacement is measured. Blocking force F_{max}: the maximum blocking force produced by piezoelectric ceramics. This value is the measured output force of piezoelectric ceramics under the maximum driving voltage and at the same time the displacement is 0, that is, the force that resists a large-stiffness load.

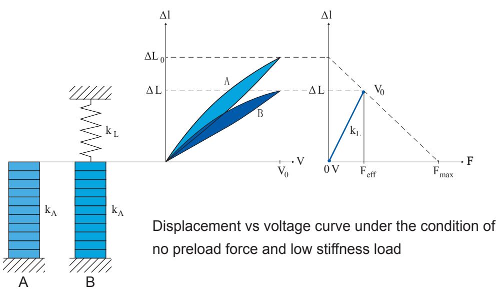
$$k_A = \frac{F_{max}}{\Delta L_0}$$

Suppose that piezo is fixed between two walls and the maximum voltage is applied to piezo. Due to the high stiffness of the two walls, piezo cannot be extended and the displacement is zero. At this time, the output force is the maximum blocking force. But in fact, any object will exhibit a certain modulus of elasticity. When the stiffness of the external mechanical structure is zero, the maximum voltage is applied to piezo, and piezo produces the maximum displacement. At this time, the blocking force is zero. The relationship between blocking force and displacement is shown on the right.



As long as there is stiffness in the external connection mechanical structure, there must be loss of displacement of the ceramic. The magnitude of the displacement loss depends on the stiffness of the external mechanical structure. The greater the stiffness of the external mechanical structure, the greater the loss of displacement. When the stiffness is the same as the stiffness of the ceramic, the displacement and blocking force are half of the maximum displacement and the maximum blocking force, and the ceramic energy efficiency is maximized.

The figure below shows the relationship diagram of the displacement of piezoelectric ceramics under different load.



Displacement vs voltage curve under the condition of no preload force and low stiffness load

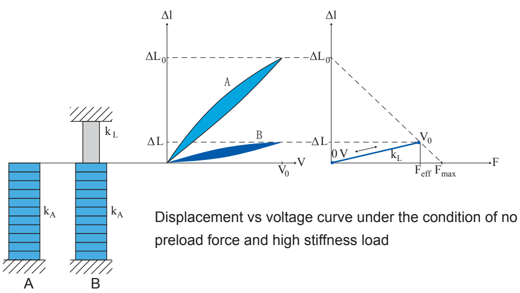
Under the condition of no preload force and low stiffness load:

$$\Delta L \approx \Delta L_0 \left(\frac{k_A}{k_A + k_L}\right)$$

ΔL: Displacement — ΔL_0: Nominal displacement

k_A: Piezoelectric ceramic stiffness — k_L: Stiffness of the load

When subjected to a variable force, the displacement of the piezoelectric ceramics will have a certain loss. The specific loss depends on the stiffness of the external mechanical spring.



Displacement vs voltage curve under the condition of no preload force and high stiffness load

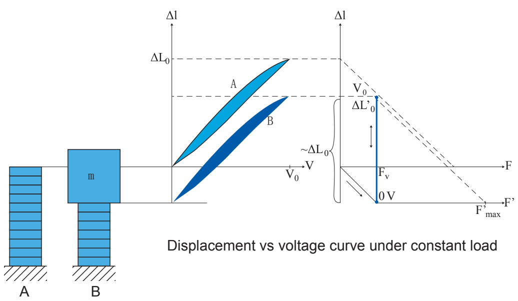
Under the condition of no preload force and high stiffness load:

$$F_{\text{eff}} \approx F_{\max} \left(\frac{k_L}{k_A + k_L}\right)$$

F_{eff}: Effective blocking force — $F_{\max}$: Maximum blocking force

k_L: Stiffness of the load — k_A: Stiffness of piezoelectric ceramic

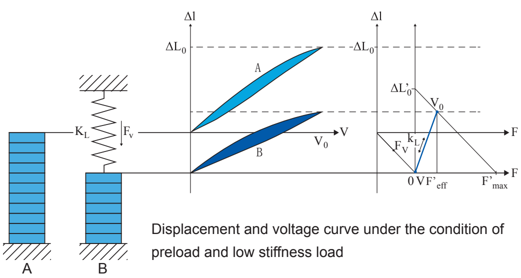
When it is necessary to produce greater blocking force, the stiffness of the load is greater than the stiffness of the ceramic.



Displacement vs voltage curve under constant load

Under constant load conditions:

When the load is a constant force, the piezoelectric ceramic will be compressed (the amount of compression depends on the stiffness of the ceramic and the magnitude of the load force), a nominal voltage is applied, and the piezoelectric ceramic will extend the nominal displacement on the basis of being compressed.



Displacement and voltage curve under the condition of preload and low stiffness load

Under the condition of preload force and low stiffness load:

For a low-stiffness load, the preloaded force of piezoelectric ceramic like a heavy object will cause the ceramic to be compressed, and the stiffness of the load will cause the ceramic to lose part of the displacement. Therefore, the stiffness of the load must be an order of magnitude smaller than that of the ceramic.

▸ Resonant Frequency

The resonance frequency of piezoelectric ceramics reflects the response time of ceramics and cannot be used as a frequency for ceramics. The resonant frequency is usually measured under a small driving signal when both ends are not fixed. When one end is fixed, the resonant frequency can be calculated by the formula on the right:

$$f_0' = f_0 \sqrt{\frac{m_{eff}}{m_{eff}'}}$$

f_0': Loaded resonant frequency, Hz

f_0: Unloaded resonant frequency, Hz

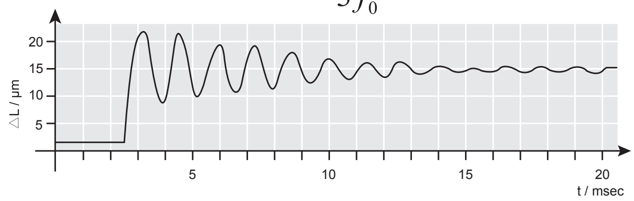
m_{eff}: Effective mass of piezoelectric ceramic, kg

m_{eff}': Effective mass of load and piezoelectric ceramic, kg

▸ Response Time

Due to its high response frequency, piezoelectric ceramics rapidly expand and contract with changes in driving voltage. Therefore, piezoelectric ceramics are widely used in valve and shutter technology. The fastest response time of piezoelectric ceramics depends on its resonant frequency. Generally, the corresponding displacement is reached within 1/3 of the resonance time of the piezoelectric ceramic.

$$T_{\min} \approx \frac{1}{3 f_0}$$



▸ Dynamic Force

In dynamic applications, the push and pull force of piezoelectric ceramics exist at the same time, and the push force is far greater than the tension, and the tension has a great influence on piezoelectric ceramics. When piezoelectric ceramics are used in dynamic applications, the two forces alternately appear. Even if there is no external load, dynamic forces must still be considered. Therefore, it is necessary to choose ceramics with preload in dynamic applications.

When the piezoelectric ceramic is used at the frequency Fdyn of the sinusoidal signal, the dynamic force estimation formula is:

$$F_{\mathrm{dyn}} \approx \pm 4\pi^2 m_{eff} \frac{\Delta L}{2} f^2$$

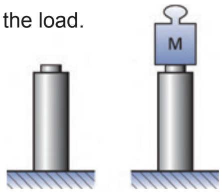
F_{dyn} : Blocking force, N

m_{eff} : Effective mass, kg

f : Operating frequency, Hz

ΔL : Peak-to-peak displacement, m

The effective mass m_{eff} is equal to 1/3 of the mass of the ceramic itself plus the weight of the load.



$m_{eff} \approx m/3$ $m_{eff} \approx m/3 + M$

Constant load is fixed on the moving end

▸ Resolution

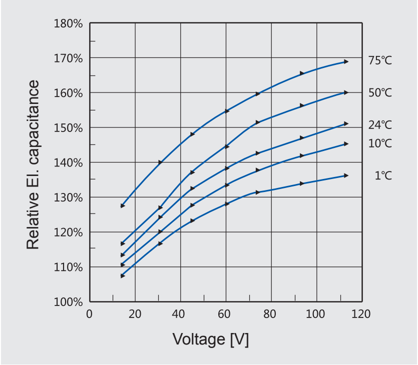
Piezoelectric ceramics have a very high resolution. The resolution of piezoelectric ceramics measured by the laser interferometer is 0.01nm, and the resolution that piezoelectric ceramics can show depends on the minimum output signal of the driving power supply. CoreMorrow E00/E01 piezoelectric controller can reach a resolution of one hundred thousandth of the full amplitude.

▸ Vacuum Compatibility

The piezoelectric effect is compatible with vacuum environments. For vacuum and ultrahigh-vacuum applications, a vacuum compatible version can be selected.

▸ Driving

Our company has many types of piezoelectric ceramics with operating voltage ranging from 60V to 1000V. Operating below the resonance frequency, the performance of the piezoelectric ceramic is equivalent to a capacitor, and the displacement depends on the amount of charge stored in the piezoelectric ceramic. The capacitance depends on the cross-sectional area, thickness, and piezoelectric material. The capacitance value in the parameter table is measured under very small voltage, low frequency, 20°C, and no load. It will change with changes in voltage amplitude, temperature and mechanical load. When the temperature rises to 80°C, the capacitance increases by about 70% compared with room temperature and small signal.



Piezoelectric ceramics can be regarded as capacitors under small signals, which can be calculated by the following formula.

$$C = \mathrm{n}\,\varepsilon_{33}^{T} \frac{A}{h_L}$$

$$\mathrm{n} \approx l / h_L$$

$$C = l\varepsilon_{33}^{T} \frac{A}{h_L^2}$$

C : El.capacitance, C

n : Number of piezoelectric ceramic layer

ε_{33}^{T} : Dielectric constant, As/Vm

A : Cross-sectional area of piezo, m^2

l : Length of piezo, m

h_L : Thickness of piezo, m

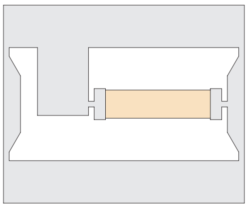
▸ Curie Temperature

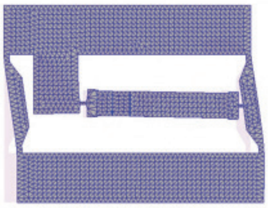
When the temperature of piezoelectric ceramic reaches the Curie temperature point, the piezoelectric ceramic will be depolarized. Therefore, in the process of using piezoelectric ceramics, keep it far below the Curie temperature. Generally, the Curie temperature of low-voltage piezoelectric ceramics is about 150~360°C, and that of high-voltage ceramics is about 215~340°C.

Piezo Technology

▸ Flexure Hinge Mechanism

1. Generally, the impact of rebound and friction of flexible hinges is negligible, but it is quite important in nano-positioning requirements and cannot be ignored. The nanopositioning stage adopts the elastic deformation of the flexible hinge mechanism and the mechanical amplification mechanism. The following figure shows the application of flexible hinges in piezoelectric mechanisms to achieve high resolution and large displacement. The magnifying mechanism and elastic load mechanism can achieve ultra-low tilt to ensure straightness.





2.The main materials of piezo stages are aluminum alloy, stainless steel, etc.

1) Our main aluminum alloy is lightweight and high-strength super-duralumin. It is suitable for high dynamic and lightweight applications;

2) Our main steel is pre-hardened steel with a higher yield point. Since the Young's modulus of this material is 3 times that of aluminum alloy, high-rigidity piezoelectric platforms of different volumes can be produced;

3) In addition to conventional materials, materials with lower thermal expansion rates are also used. Because of their low thermal expansion rate, they are especially used to reduce the effects of temperature changes.

In addition to the above materials, other materials and surface treatments can also be customized.

▸ Integrated Sensor

SGS Resistive Sensor

The displacement is detected by the change in resistance after the deformation of the SGS sensor.

Function

Correct the hysteresis and creep of the piezoelectric element in the process of elongation and contraction.

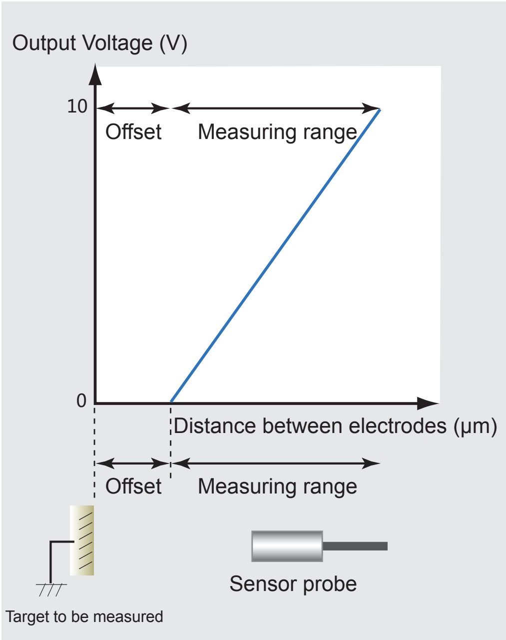
Capacitive Sensor

The capacitive sensor is composed of two parallel electrode plates. The two electrode plates are respectively on the measuring terminal and the measured target, and the change of the capacitance between the two electrode plates is converted into displacement. The sensor has the characteristics of high resolution, high reproducibility and high stability.

Function

When the distance between the sensor probe and the measured target is a certain distance, the sensor output is zero. The distance is called "offset". Set the measurement range according to the offset distance. The offset is usually equivalent to 5~10% of the measurement range. The selectable measurement range varies according to the outer diameter of the measuring probe. The displacement resolution of the sensor is calculated by the following formula:

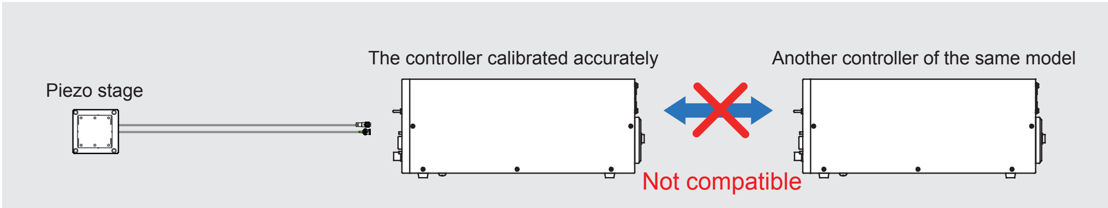
Resolution = Measurement Range/Output Voltage Width × Noise Level



▸ Servo Control

The sensor and the controller need to be calibrated, so the sensor and the controller must be used in one-to-one correspondence, and the wrong connection may cause damage.

For multi-axis piezo actuator, the corresponding axis must be connected with the output channel that has been calibrated with it, so be sure to pay attention to the corresponding connection.



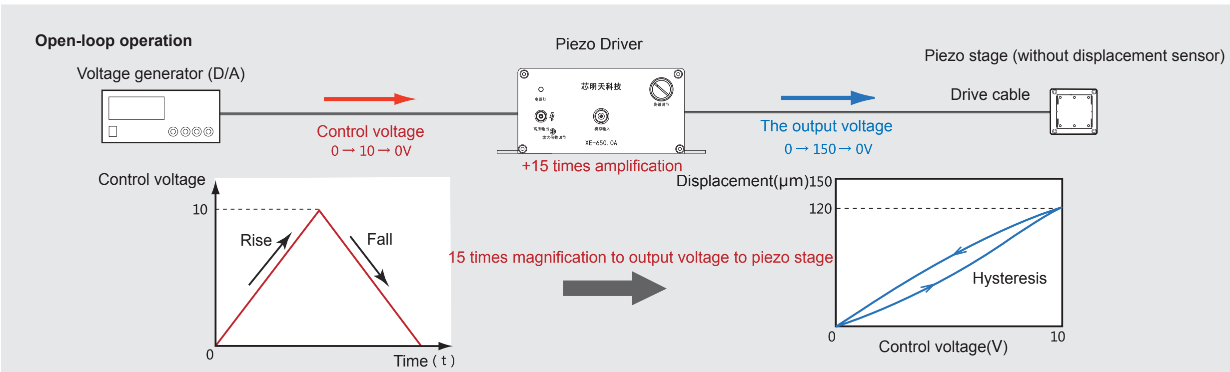
Open-loop operation output magnification is 15 times, inputting 0~10V analog signal, that is, applying 0~150V driving voltage to the nanopositioning stage, and the creep, hysteresis, and nonlinear characteristics of the piezoelectric element will cause the positioning to be not too accurate. In closed-loop operation, the piezoelectric controller can always detect the position signal in the nanopositioning stage, compensate and correct, so the 0~10V command signal and 0 to maximum displacement always maintain linearity.

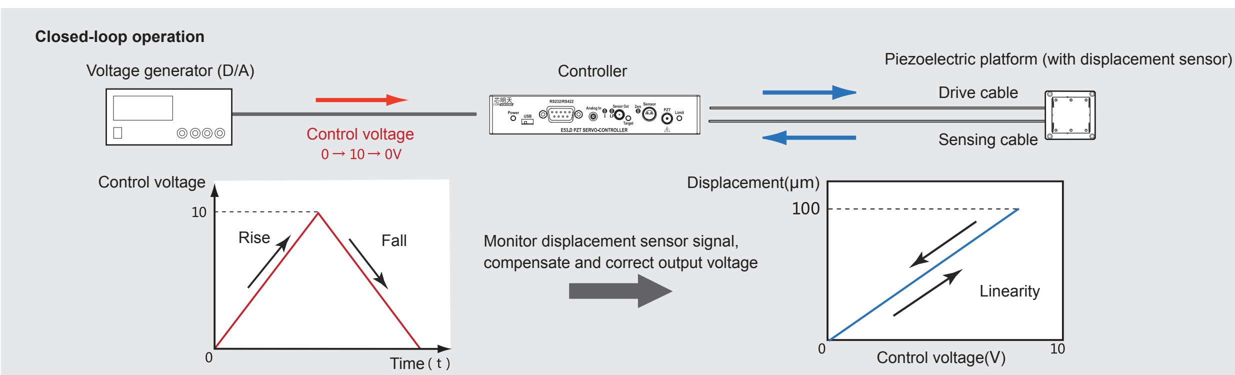
Example: The following describes that the analog signal voltage is linearly applied to the piezoelectric nanopositioning stage in open-loop and closed-loop operation. The following analog input values are in the order of 0V→10V→0V

Stroke range: 120μm, open loop

100μm, closed loop

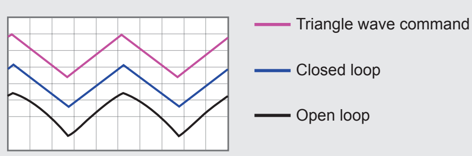
Input control voltage: 0V→10V→0V





※ The movement of the platform when input the triangular wave voltage

Comparison of open-loop and closed-loop motion of piezoelectric platform



Challenge the Limits of Nano Motion and Control Technology...

Harbin Core Tomorrow Science & Technology Co., Ltd.
Tel：+86-451-86268790 +86-18944636468
Fax：0451-86267847
Postcode：150086
Email：info@coremorrow.com
Web：www.coremorrow.com
Address：Building I2, No.191 Xuefu Road, Nangang District, Harbin

Wechat CTO