Multilayer Piezoelectric Actuators User Manual

Rev. 1.1

JAN 2021

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1 INTRODUCTION

An actuator is an element that converts some form of input energy into mechanical output energy. A piezoelectric actuator is an electric-type actuator which converts electrical input energy into an output such as a displacement or generated force.

Recently, market demand in the field of mechatronics is new actuator performance such as nano controllability, high-speed response and low power consumption.

KEMET's multilayer piezoelectric actuator is a burned monolithic type multilayer piezoelectric actuator which was a world beating development by KEMET aimed at meeting the market demand using our unique multilayer ceramic technology.

We are confident that these actuators will prove beneficial to users as a key device for opening up the new world of mechatronics.

This manual is intended to facilitate the use of KEMET multilayer piezoelectric actuators.

2 CHARACTERISTICS OF PIEZOELECTRIC ACTUATORS

2.1 Conventional Actuators and Piezoelectric Actuators

2.1.1 Actuator Comparison[1]

Drive Source	Designation	Displacement Range	Displacement Accuracy	Generated Force	Response Speed
Pneumatic Drive Source	Pneumatic Motor	Rotation	-	5 kgm	10 sec
	Pneumatic Cylinder	100 mm	100 µm	10^{-2} kg/mm^2	10 sec
Hydraulic Drive Source	Hydraulic Motor	Rotation	-	10 kgm	1 sec
	Hydraulic Cylinder	1,000 mm	10 µm	10 kg/mm^2	1 sec
Electric Drive Source	AC Servo Motor	Rotation	-	3 kgm	100 msec
	DC Servo Motor	Rotation	-	20 kgm	10 msec
	Step Motor	1,000 mm	10 µm	30 kg	100 msec
	Voice Coil	1 mm	0.1 µm	30 kg	1 msec
	Piezoelectric Actuator	**0.05 mm**	**0.01 µm**	**3 kg/mm^2**	**0.01 msec**

Table 1 – Microdisplacement Controllability of Actuators

2.1.2 Characteristics of Piezoelectric Actuators, Compared to Conventional Actuators

- Large electromechanical energy conversion efficiency
- High-speed operation
- Small heat generation and electromagnetic noise
- Compact and light-weight
- High resolution control

[1] Uchino, Kenji: *Piezoelectric/Electrostrictive Actuator*, Morikita Syuppan Co., Ltd, 1986 (Japanese).

2.2 Classification of Piezoelectric Actuators

Conventionally used piezoelectric actuators are classified into bimorph piezoelectric actuators, which utilize a piezoelectric transverse effect, and stacked piezoelectric actuators, which utilize a piezoelectric longitudinal effect. Multilayer piezoelectric actuators are improved actuators of the stacked type.

Piezoelectric Transverse Effect — Bimorph Type

Piezoelectric Longitudinal Effect — Stacked Type

Multilayer Piezoelectric Actuators (KEMET's Burned Monolithic Type Actuators)

Although the bimorph piezoelectric actuator generates relatively large displacement with a low drive voltage, it has several disadvantages such as a small generated force, a slow response speed, and a large creep phenomenon, and poor energy conversion efficiency resulting from the utilization of the piezoelectric transverse effect.

The conventional stacked piezoelectric actuator has advantages such as a large generated force, a fast response speed, and high energy conversion efficiency, but disadvantageously requires a high drive voltage. This disadvantage is attributable to the fact that manufacturing and assembly limitations prevent a reduction in the thickness of each of the piezoelectric ceramic plates which form the actuator. Further, these limitations render the actuator bulky, which results in poor productivity.

2.3 Characteristics of KEMET's Multilayer Piezoelectric Actuators

KEMET's multilayer piezoelectric actuators could be implemented in the form of a new type of piezoelectric actuator, retaining the advantages of the conventional stacked piezoelectric actuator as a result of significant improvements in manufacturing processes and structure of the actuator. This has made it possible to respond to various customer demands for the piezoelectric actuators.

2.3.1 Structure

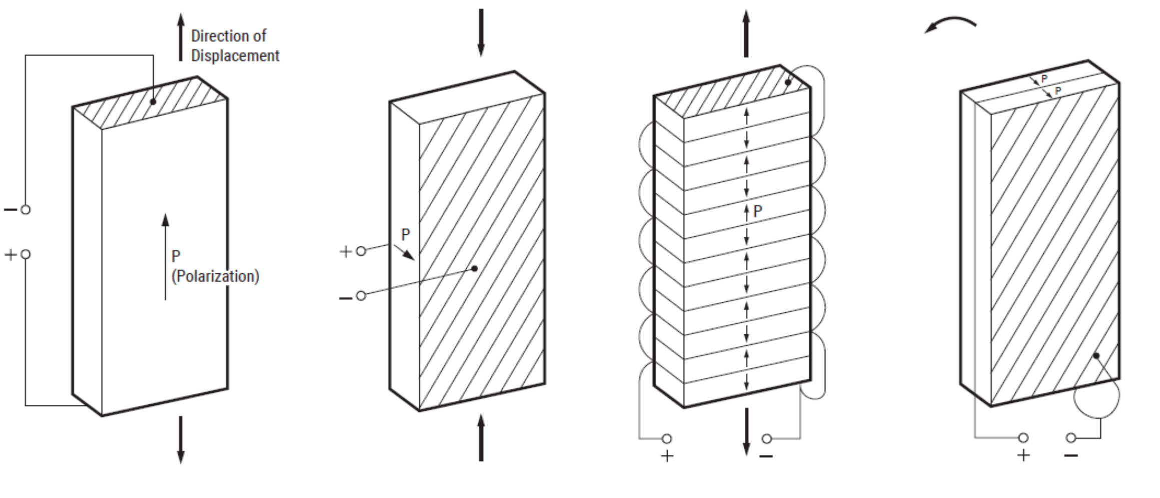


Figure 1 – Conventional Piezoelectric Actuator Element

Figure 2 shows the structure of a typical KEMET's multilayer piezoelectric actuator. Like the manufacture of a stacked ceramic capacitor, a thin ceramic sheet (a green sheet) is made by tape-casting, and ultra-thin internal electrodes, mainly containing an Ag-Pd alloy, are then patterned on the green sheet. A necessary number of the green sheets are stacked and burned. In this way, the thickness of one ceramic layer can be reduced to less than 110 µm, thereby resulting in a compact multilayer piezoelectric actuator which requires a low drive voltage. In the case of KEMET's AE****D16DF for example, with having a height of 20 mm, the number of stacked sheets is about 130.

Figure 3 shows a piezoelectric actuator element having a multilayer ceramic capacitor structure as a prototype of a stacked multilayer piezoelectric actuator element. Contrary to the stacked multilayer piezoelectric actuator, KEMET has adopted its own total electrode structure for the internal electrode, and stacked layers are insulated from each other by glass. A capacitor type piezoelectric actuator element includes expanding portions and non-expanding portions, and therefore stress concentrates on the edges of the internal electrodes. For this reason, the actuator element is apt to break as a result of repetitive actuation. On the other hand, the total electrode structure has no stress concentrations, which makes it possible to significantly improve the durability of the actuator element against repetitive actuation.

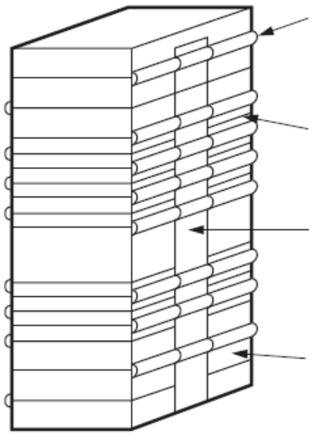


Figure 2 – KEMET's Multilayer Piezoelectric Actuator

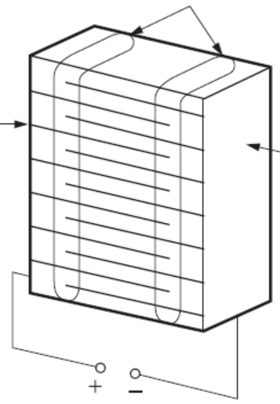


Figure 3 – Piezoelectric Actuator Element with Multilayer Ceramic Capacitor Structure

As mentioned above, as a result of the significant improvements in the manufacturing processes and structure of the piezoelectric actuator element, it has become possible to implement a new compact piezoelectric actuator having an improved productivity.

This piezoelectric actuator permits actuation at a low drive voltage, as well as retaining the advantages of the stacked multilayer piezoelectric actuator such as a large generated force, a high response speed, and a high energy conversion efficiency.

2.3.2 Piezoelectric Material

KEMET's multilayer piezoelectric actuator elements are manufactured from a piezoelectric ceramic material developed by KEMET. This ceramic material has large piezoelectric constants (strain/electric field: displacement/voltage), and material constants of the ceramic material are shown in Table 2.

The ceramic material is made of complex perovskite type composite oxides mainly composed of PZT ($PbZrO_3$-$PbTiO_3$).

Characteristics		Unit	Ceramic Material	
			N10	N17
Relative Dielectric Constant	$\varepsilon_{33}{}^{T}/\varepsilon_0$		5,440	4,363
	$\varepsilon_{33}{}^{T}/\varepsilon_0$		5,000	3,892
Frequency Constant	N1 (Radial)	Hz-m	2,040	1,918
	N2 (Lengthwise)		1,410	1,377
	N3 (Longitudinal)		1,370	1,340
	N4 (Thickness)		1,800	1,875
	N5 (Shear)		1,110	823
Electromechanical Coupling Constant	Kr (Radial)		0.62	0.64
	K31 (Lengthwise)		0.34	0.36
	K33 (Longitudinal)		0.68	0.67
	Kt (Thickness)		0.62	0.50
	K15 (Shear)		0.66	0.66
Elastic Constant	S11	$\times 10^{-12}$ m²/N	14.8	16.6
	S33		18.1	19.2
	Y11	$\times 10^{10}$ N/m²	6.8	6.0
	Y33		5.5	5.2
Piezoelectric Constant	d31	$\times 10^{-12}$ m/V	−328	−294
	d33		635	579
	d15		930	882
Poisson's Ratio	δ		0.34	0.35
Mechanical Quality Factor	Qm		70	63
Curie Temperature	Tc	°C	145	190
Density	D	$\times 10^{3}$ kg/m³	8.00	7.93
Thermal Conductivity		W / w · k	1~1.5	1~1.5

N10 = Used in AE, AER, ASB and AHB series. N17 = Used in ASL series.

Table 2 – Material Constant of Piezoelectric Ceramics

2.4 Operating Principles of Actuators

When considered at the crystal level, an actuator has the following properties.

A piezoelectric material possesses a perovskite crystalline structure. Lead zirconate titanate PbZr03-PbTi03 (abbreviated to PZT), which is the primary component of the piezoelectric material, is used as an example for explanation.

The crystalline structure of PZT becomes cubic (a cube) above a certain temperature known as the Curie temperature (Tc) (see Figure 4). In the cubic structure, three crystallographic axes have the same length (a = b = c), and all the angles between the crystallographic axes are 90° (α = β = γ = 90°). A positively charged Zr ion or Ti ion is centered on the lattice. The crystal is electrically balanced at this time, and therefore no electrical polarization arises in the crystal.

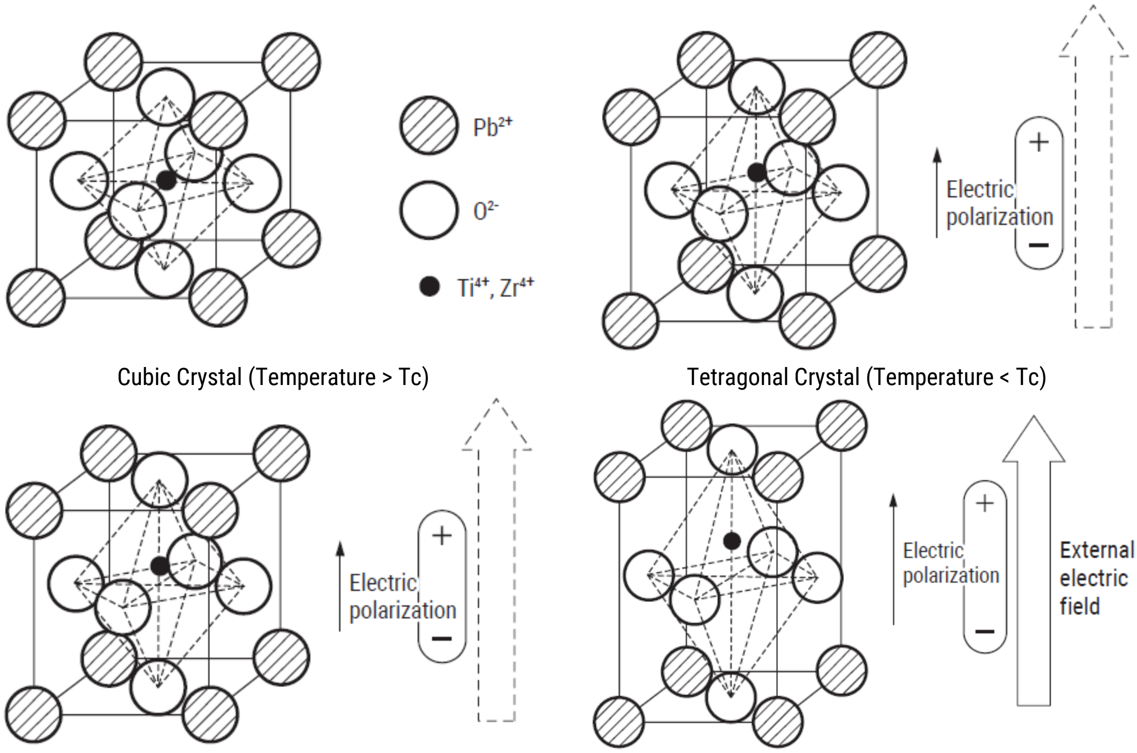
However, below the Curie temperature, the crystal structure becomes tetragonal (or assumes a rectangular-parallelepiped shape) or rhomboid. In the tetragonal structure, the c axis is longer than the other two axes (a = b ≠ c), and all the angles between the axes are 90°. On the other hand, in the rhomboid structure, the three axes have the same length (a = b = c), and the angles between the axes are not 90° (α = β = γ ≠ 90°).

A typical tetragonal structure will now be described. Below the Curie temperature, the positively charged Zr ion or Ti ion shift from the center. As a result of this, the c axis of the crystal becomes longer, and the resulting electrical imbalance brings about a dipole moment. The Zr ion or Ti ion has equivalent energy even when shifted to any position along the six axes in the crystal.

If an external electric field is applied to this tetragonal crystal, the Zr ion or Ti ion shift in the direction of the electric field. Even if the electric field is eliminated, the Zr ion or Ti ion do not return to their original positions and stay aligned in the direction of the electric field. As a result of this, the direction of the longer axis changes. This phenomenon is called 90° inversion. As a matter of course, 180° inversion may also occur. However, in this case, the direction of the long axis remains unchanged.

When an external electric field is applied to the crystal, the Zr ion or Ti ion are attracted to the negative side of the electric field, whereas O (oxygen) ions are attracted to the positive side, resulting in a longer crystal. Specifically, the application of the external electric field brings the displacement (expansion) of the crystalline lattice. Variations in the length of the crystal can be obtained as displacement in the form of voltage.

This is one of the principal factors with respect to the operating principles of the actuator.



Cubic Crystal (Temperature > Tc) | Tetragonal Crystal (Temperature < Tc)

Tetragonal Crystal Inverted 90° Resulting from the Application of an External Electric Field | Crystal Having an Expanded Crystalline Lattice Resulting from the Application of an External Electric Field

Figure 4 – Behavior of Actuator (Perovskite Crystalline Structure)

Below the Curie point, as viewed from a macroscopic viewpoint, that is, as considered at the crystal grain level, bounded areas (domains) where the Zr ion or Ti ion of the atoms are aligned in the same direction are generated (Figure 5). The domains have large Zr ion or Ti ion. The spontaneous polarization cancels each other out, and the Zr ion or Ti ion of the piezoelectric ceramic element as a whole is zero. Such a state is called a **nonpolarized state**.

If an electric field is applied to the nonpolarized piezoelectric ceramic element, the directions of the Zr ion or Ti ion of the domains are aligned in the direction close to the electric field as a result of the shift of the Zr ion or Ti ion. This phenomenon is called **polarization**. As a result of this, the length of the piezoelectric ceramic element becomes longer in the direction of the electric field.

Even if the electric field is eliminated, the length of the piezoelectric ceramic element does not return to its original length in the nonpolarized state as a result of the 90° inversion of the Zr ion or Ti ion. The variation in the length of the element is called **residual polarization**. The element is most stable in the nonpolarized state, from the viewpoint of energy. For this reason, the polarization is gradually lost if the element is stored for a long period of time, and the element finally returns to the nonpolarized state.

Some of the Zr ion or Ti ion which are inverted by 90° while the electric field is applied to the element become unstable, in terms of energy, as a result of the influence of the neighboring domains at the moment the electric field is eliminated, and they return to their original positions (their positions when the element was nonpolarized). In other words, when the electric field (a voltage) is applied to the piezoelectric ceramic element, the element becomes longer in the direction of the electric field. On the other hand, when the electric field (a voltage) is eliminated, the element returns to its original length. This variation in the length of the element is the displacement that can be obtained in the form of voltage. The variation in the length of the element is another element of the principal factors with respect to the operating principles of the actuator.

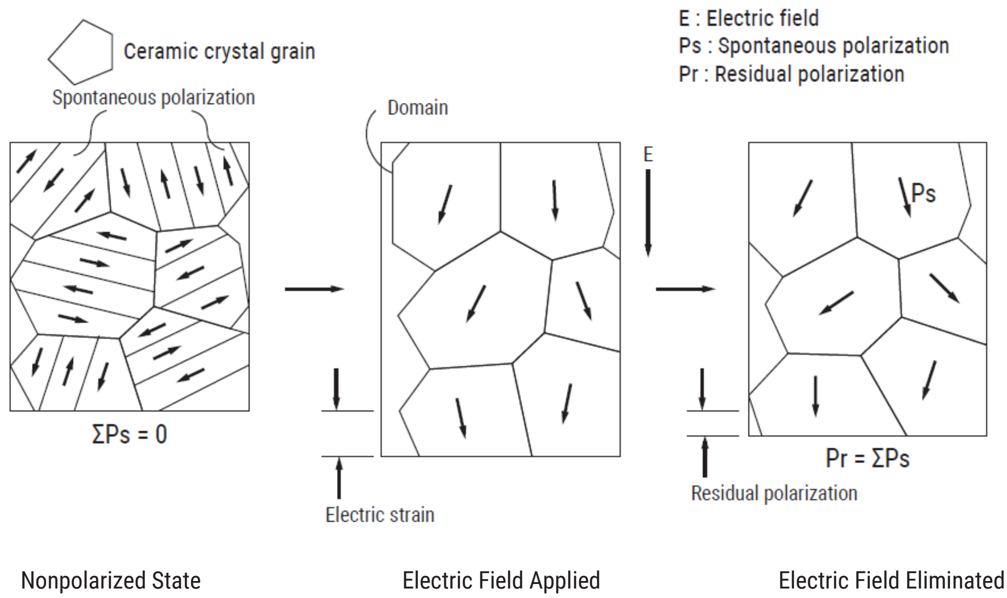


Figure 5 – Behavior of Actuator (Crystal Grain)

3 BASIC OPERATION OF ELEMENT

An element of KEMET's representative type (product name) was used as a test sample. For detailed information about relevant contents, please refer to KEMET's multilayer piezoelectric actuator lineup, detailed in Table 3 in Section 4 or in the datasheets of AE, AER, ASB, ASL or AHB series.

3.1 Drive Voltage and Displacement

Figure 6 illustrates the operation of a piezoelectric ceramic element. The piezoelectric ceramic element is a polycrystalline substance. In a nonpolarized state, a plurality of domains is randomly oriented in each of the crystal grains. In this state, the magnetic moments of the domains cancel each other out, and therefore the polarization of the element, as a whole, is zero.

When an electric field is applied to this piezoelectric ceramic element, the directions of polarization of the domains in the crystal grain are aligned in the direction of the electric field, and at the same time the length of the crystal grain becomes longer in the direction of the electric field. After the electric field has been eliminated, the crystal grain does not return to its original state but remains slightly polarized overall. The strain resulting from the polarization is called residual strain. The series of operations are called polarizing processing. After polarizing processing, the application and elimination of the electric field in the same direction cause the crystal grain to be switched between a state ③ and a state ⑤ shown in Figure 6. This switching action of the element is not linear but there is hysteresis.

Figure 6 is a plot for explaining the operation of the piezoelectric ceramic element. The above piezoelectric ceramic element is actuated in the order of ①→②→③→④→⑤→⑥→③→④→⑤. KEMET's multilayer piezoelectric actuators are polarized before shipment.

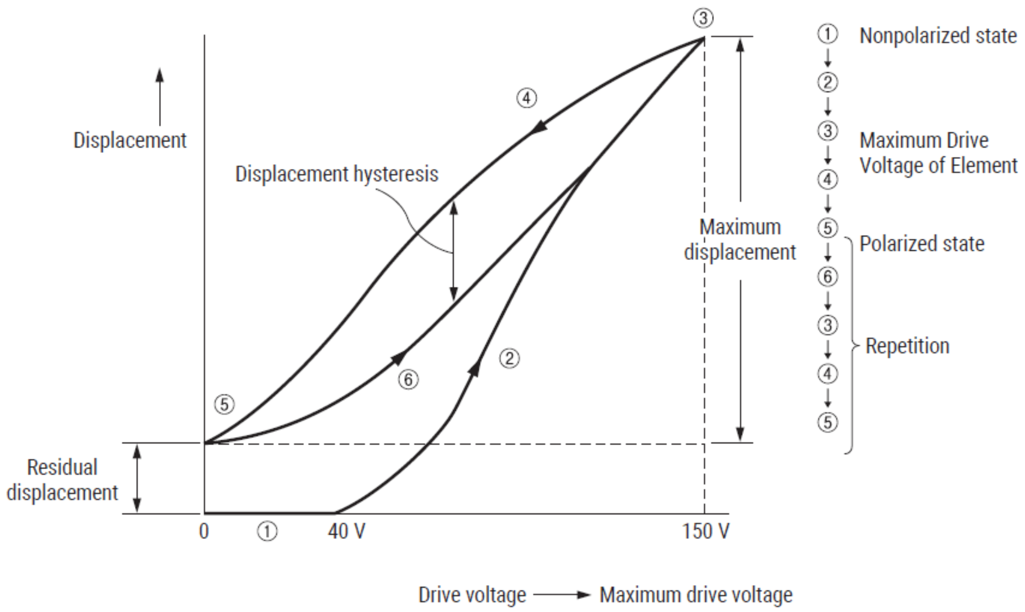
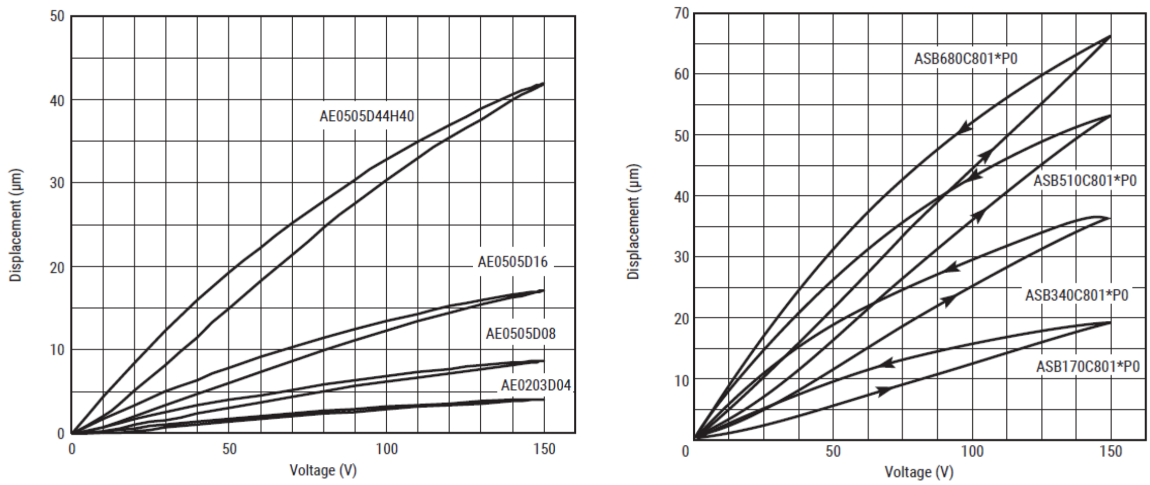


Figure 6 – Basic Operation Piezoelectric Ceramic Element

Figure 7 is a plot of voltage versus displacement of KEMET's multilayer piezoelectric actuators.



Drive Voltage and Displacement of AE Series

Drive Voltage and Displacement of ASB Series

Figure 7 – Drive Voltage and Displacement of Multilayer Piezoelectric Actuators

The relationship in between the drive voltage and the displacement is a butterfly curve as shown in Figure 8 when the positive and the negative voltages are alternately applied to the actuator element. However, in this case, repetition of polarization inversion causes in the piezo at around ±40 V and this may damage the piezo element. For this reason, please do not operate the actuator element with an AC voltage in order to prevent a drop in insulation resistance which may cause failures. KEMET has conducted tests using only a positive DC voltage.

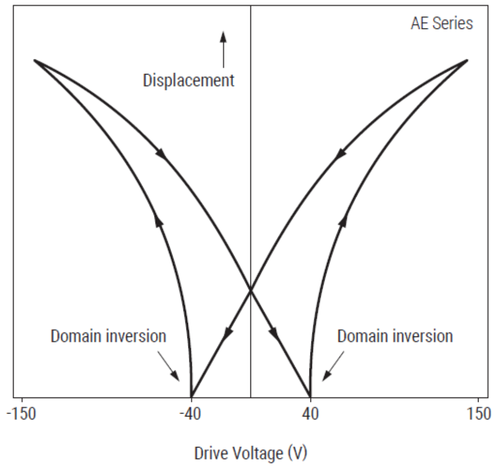


Figure 8 – Drive Voltage - Displacement Characteristics

3.2 Drive Voltage and Generated Force

Figure 9 shows the relationship between drive voltage and generated force. When the maximum drive voltage (150 volts for KEMET actuators) is applied to the polarized piezoelectric actuator without the application of external pressure, defined maximum displacement is obtained. The displacement decreases as the external pressure exerted on the actuator is progressively increased from this state. KEMET refers to stress at which the displacement becomes zero as maximum generated force.

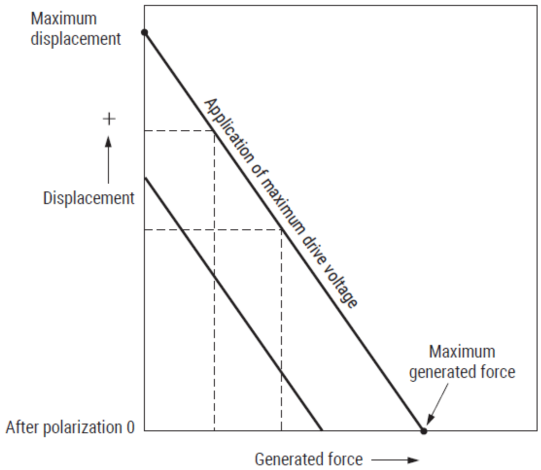


Figure 9 – Drive Voltage – Generated Force Characteristics

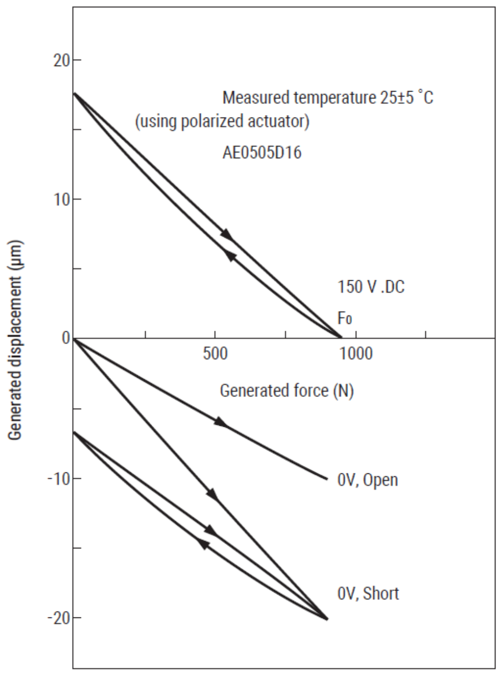


Figure 10 – Generated Force - Generated Displacement Characteristics

The behavior of a weighted piezoelectric actuator is described in Figure 10. When a weight (static load) is put on the polarized actuator without the application of a voltage, the actuator contracts under the weight. However, at this time, the manner of contraction becomes different between an open-circuit state and a short-circuit state. If the maximum drive voltage is applied to the weighted actuator with respect to the length of the further contracted actuator, the maximum displacement will be obtained. In this way, if the applied voltage is the same, the actuator provides approximately the same displacement irrespective of whether or not the actuator is weighted (under static load) (Figure 11).

Please be careful when calculating the reference point (zero point), because the overall length is different depending on each actuator. Moreover, it is possible to increase the weight (static load) applied to the actuator up to the load that causes the maximum generated force.

If a weak tensile force is added to a tensile force, the ceramic may break. For this reason, the use of the actuator under preload is effective in preventing mechanical breakage of the actuator. The optimum preload to be applied is about one-half of the maximum generated force.

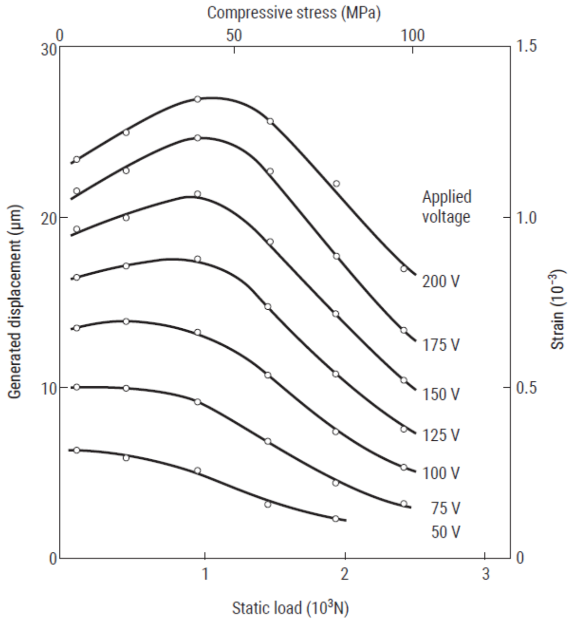


Figure 11 – Static Load-Generated Displacement Characteristics (5x5x20 mm Actuator Element)

The behavior of the displacement characteristic is different by the type of load used. Figures 12 and 13 shows displacement characteristic when the load is static load and spring load.

Static load: No load change when actuator moves.

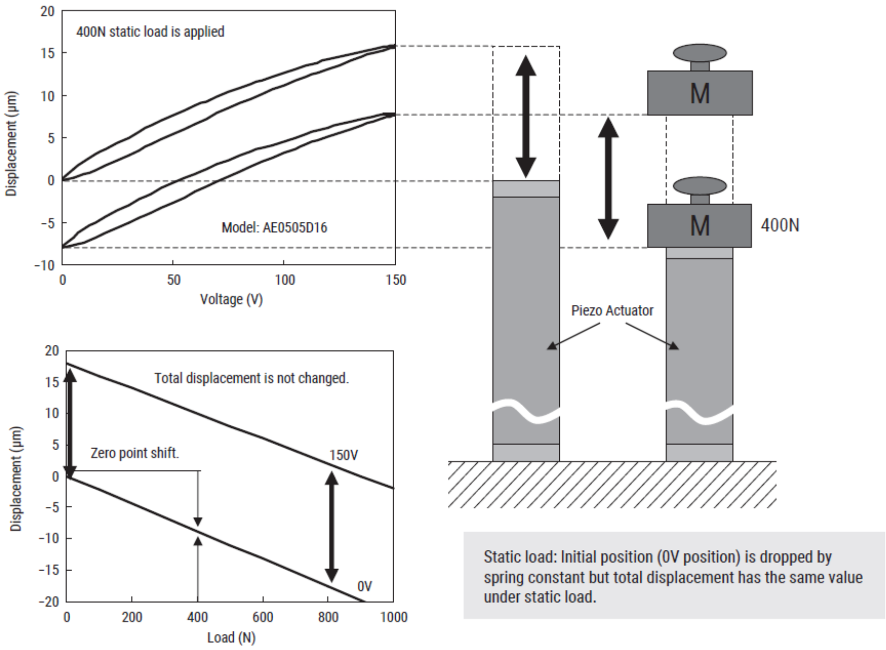


Figure 12 – Actuator Displacement under the Static Load

Fluctuating load: Load changes by spring reaction when actuator moves.

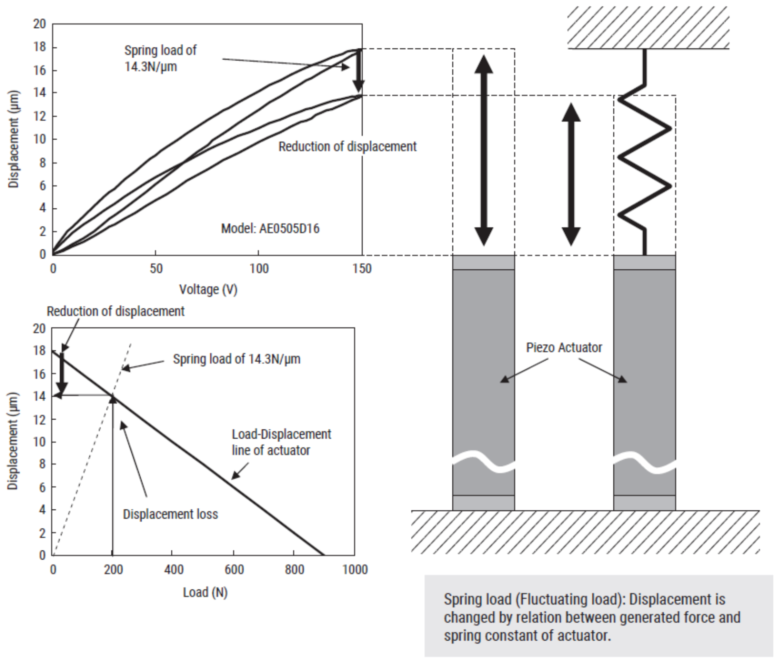
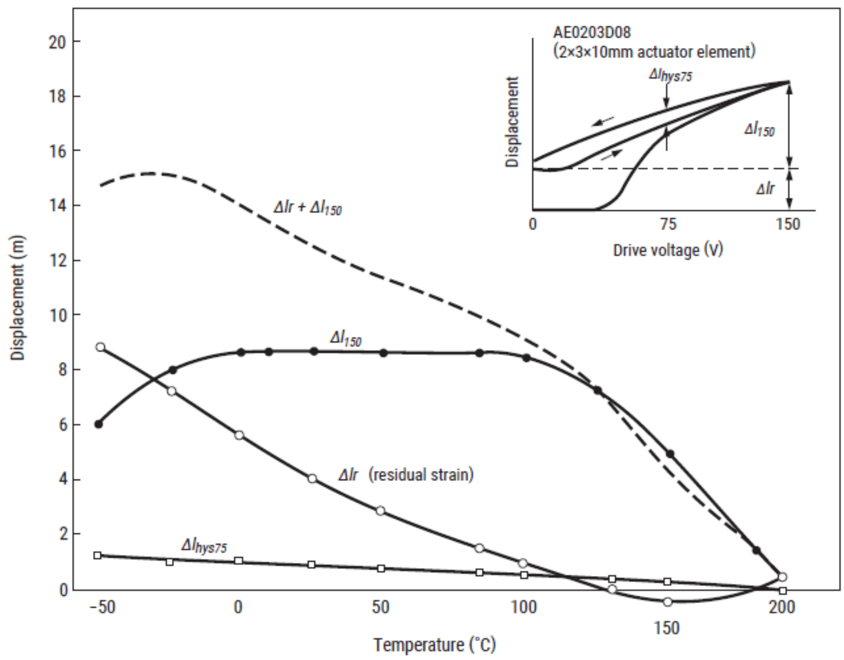


Figure 13 – Actuator Displacement under the Spring Load

3.3 Temperature Characteristics

The temperature characteristic of the displacement is shown below.

All AE and AER series have the same displacement behavior, but the metal cased actuator from ASB, ASL or AHB series has different displacement behavior over temperature because internal structures may differ from part to part.



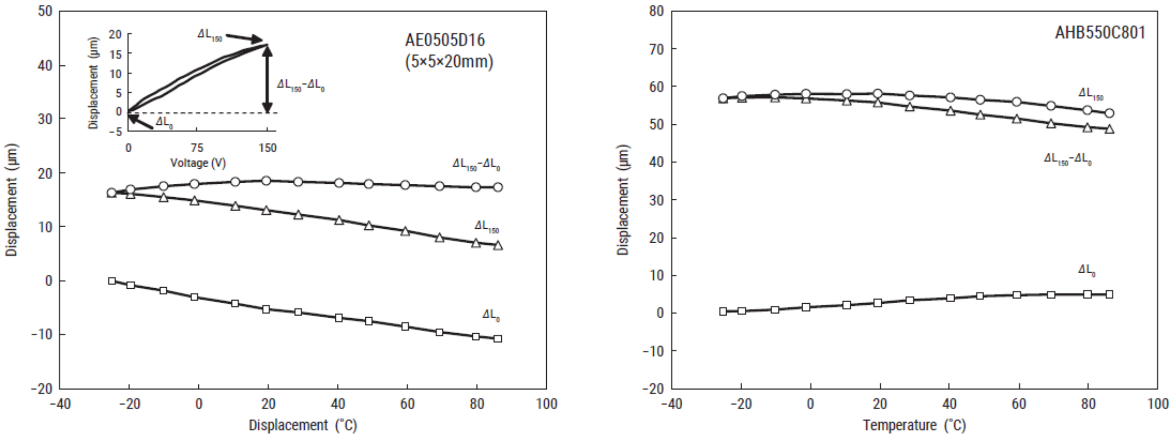


Figure 14 – Temperature-Displacement Characteristics

Followings are temperature characteristic for the insulation resistance and capacitance of the actuator. Both resin coated series and metal cased types have the same characteristics.

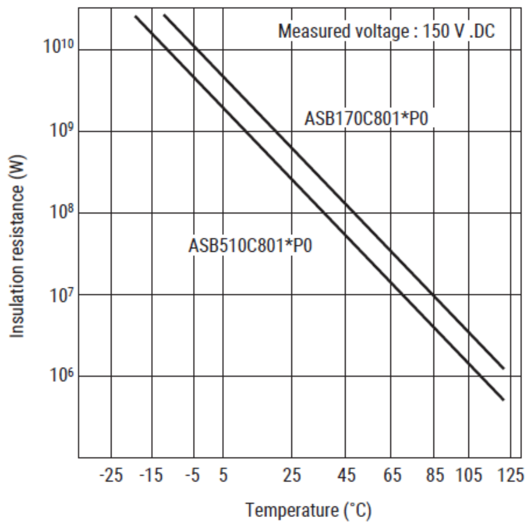


Figure 15 – Temperature-Insulation Resistance Characteristics

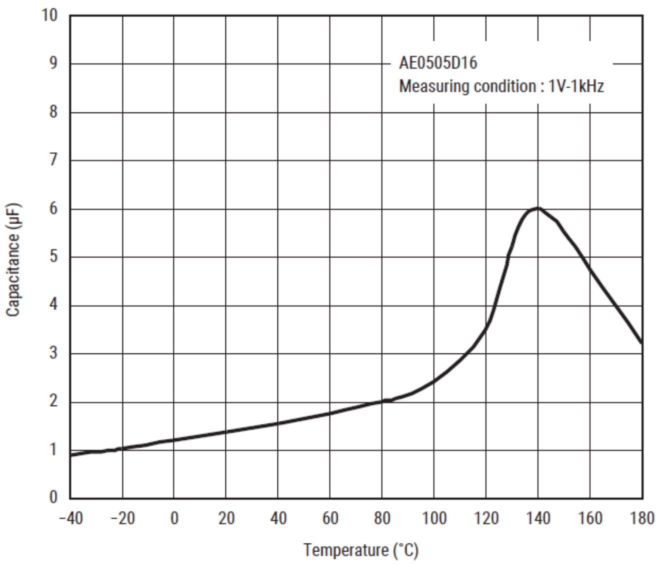


Figure 16 – Temperature-Capacitance Characteristics

3.4 Response Characteristics

KEMET's multilayer piezoelectric actuators can be driven up to about 1/3 of their self-resonance frequencies.

Abrupt rise and fall of the voltage applied to the actuator brings ringing in generated displacement, as shown in Figure 17, and a tensile force is exerted on the actuator element.

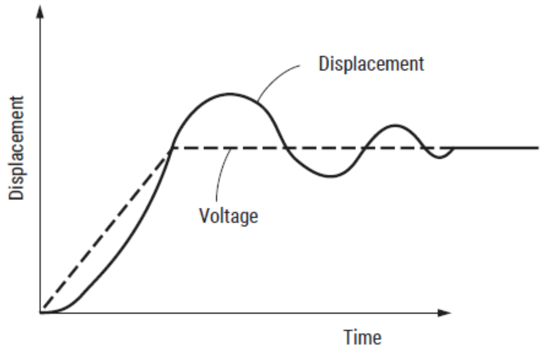


Figure 17 – Ringing

Ringing is a phenomenon in which an overshoot temporarily develops in the displacement of the actuator and eventually the actuator causes vibration and constriction when abrupt rising or falling of an applied voltage occurs.

Figure 19 shows actual measuring result of the ringing phenomenon.

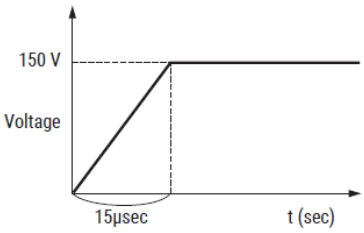
Intensive ringing may cause mechanical breakage of the actuator element. To prevent this, the rise or fall of the applied voltage should be kept within less than 1/3 of the resonance frequency of the actuator element.

The actuation of the piezoelectric actuator is similar to the injection of electric charges into a relative large capacitor. A large electric current is necessary to realize high-speed response of the actuator.

An estimate of a drive current is obtained in the same manner as in the case of a capacitor.

$Q = CV$ (C : capacitance, V : drive voltage)
$Q = It$ (I : drive current, t : rise time)
$\therefore I = \frac{CV}{t}$

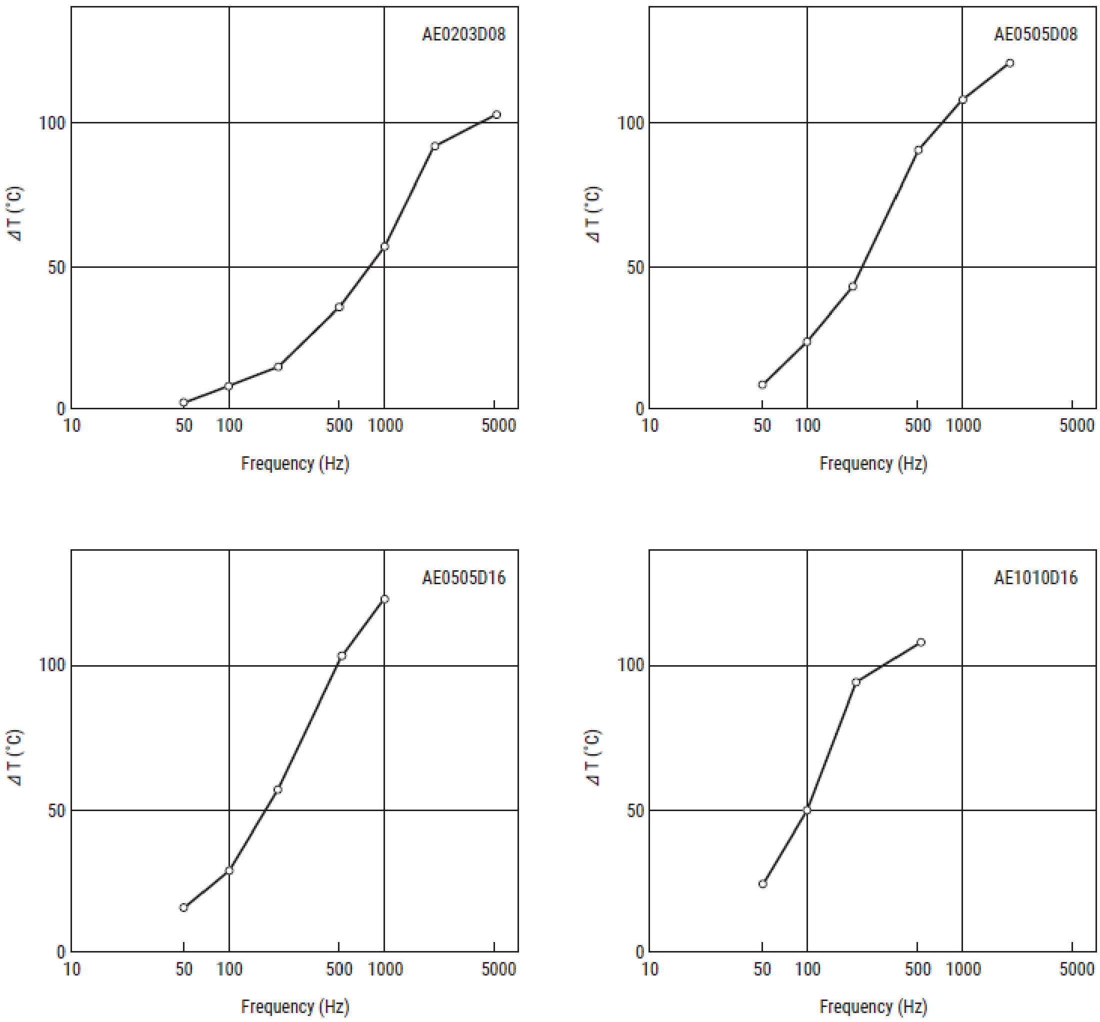
For example, if AE0203D08** (Cap = 0.18 μF) is actuated in the manner as shown in the following diagram, a current of about 1.8 (A) becomes necessary.



$$I = \frac{0.18 \times 150}{15} = 1.8 \ \text{(A)}$$

A much larger current may flow when the actuator element is actually driven, and therefore allowance should be made for current limitations of the power source.

If the actuator element is constantly operated at a high frequency, the actuator element generates heat, thereby resulting in higher temperature of the element. Figure 18 shows heat generation versus drive frequency characteristics of the AE series. If the temperature of the actuator element becomes high, the insulation resistance of the actuator element is degraded, which may cause failures. To keep the temperature of the actuator element within the operating temperature limit (less than 85˚C), either the drive frequency or the drive voltage should be reduced. Please note that the temperature of an actuator element varies because the heat radiation characteristics of the element are largely dependent on ambient conditions.



Test Method
Voltage: sine wave, V = 150 V
Temperature measurement: temperature after passage of 250 seconds or in an equilibrium state

Figure 18 – Drive Frequency and Element Temperature

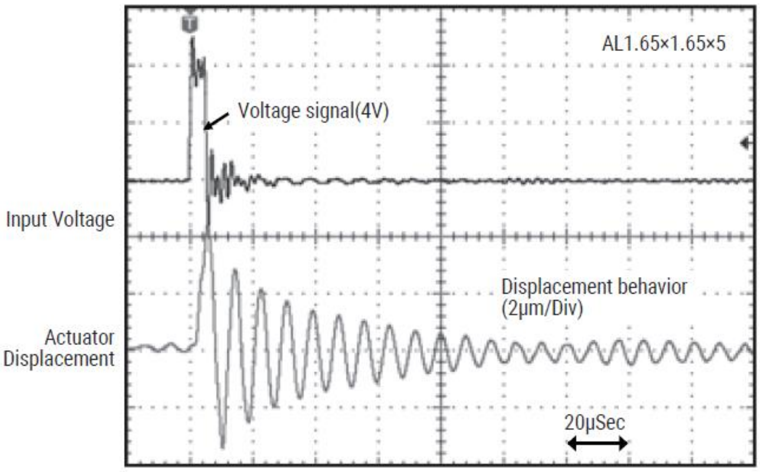


Figure 19 – Ringing of Piezo Displacement

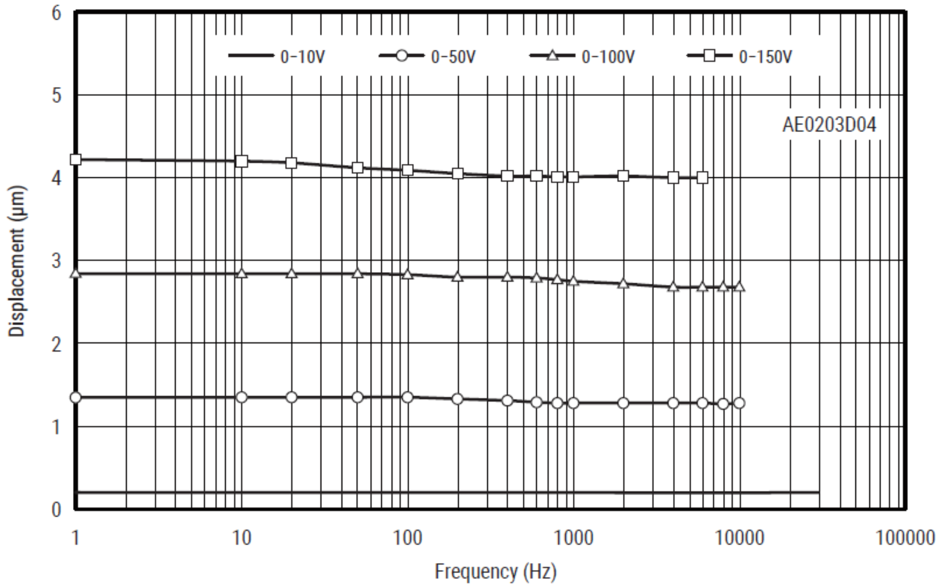


Figure 20 – Displacement Characteristic in High Frequency Drive

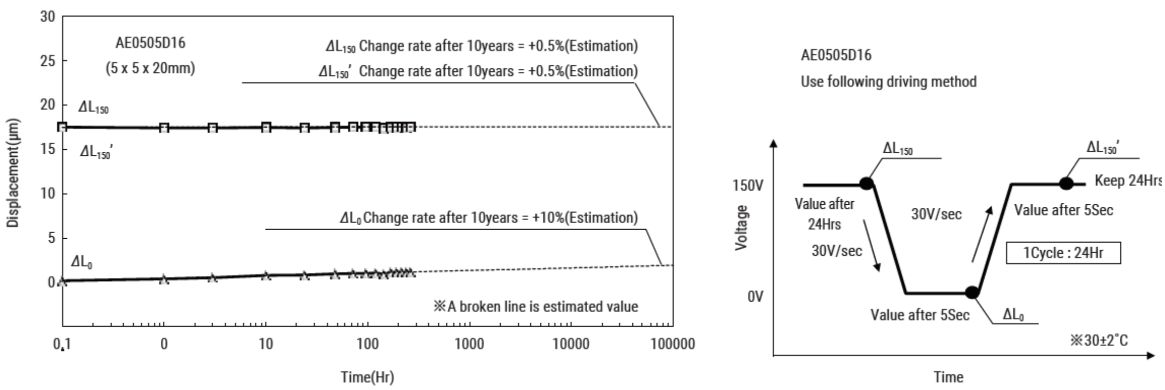


Figure 21 – Creep Characteristic of the Displacement at 150 VDC Operation (Long Term Drive)

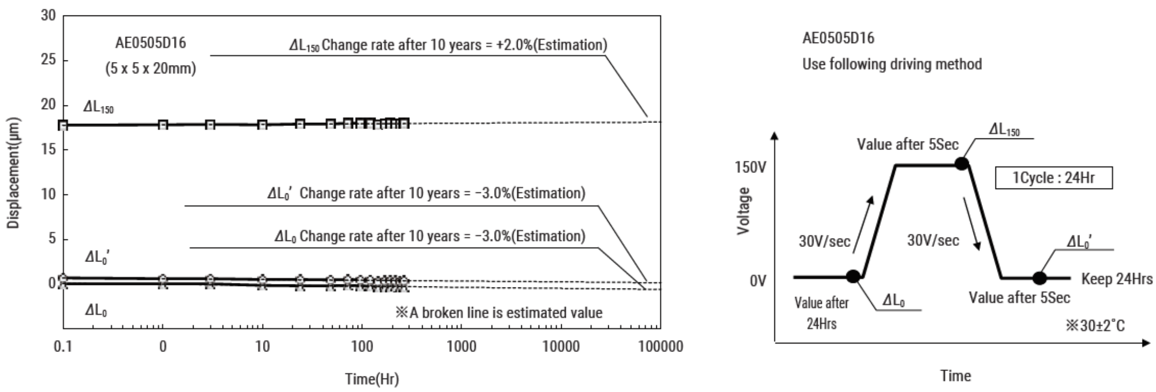


Figure 22 – Creep Characteristic of the Displacement at 0 VDC Operation (Long Term Drive)

3.5 Reliability

Majority of failure mode of multilayer piezoelectric actuators is the short circuit due to degraded insulation. Though the cause of degradation of insulation has not been clarified perfectly, it has been found that the failure rate varies greatly between static uses (DC voltage application) and dynamic uses (pulse voltage application). Like other electrical components, piezo actuators can be influenced by humidity as well as applied voltage and ambient temperature. KEMET has added the metal sealed type piezo actuators featuring high reliability by eliminating influence of the ambient atmosphere.

This section describes reliability guidelines for static and dynamic usages of the resin-coated and metal sealed types actuators.

Reliability of our multilayer piezoelectric actuators is represented by MTTF (mean time to failure) in case of static usage. Though the number of repetitions is considered to be used to represent the reliability in the case of dynamic usage, the accurate relationship between the indicator and cause **has not been determined because of various influential causes and the mutual action between them.** For the present, therefore, only the obtained data and our concept are described.

3.5.1 Reliability of the Resin-Coated Type AE and AER Series

DC Voltage Application

The acceleration factors have been obtained empirically for each of the drive voltage, ambient temperature and relative humidity based on many experimental results. The $MTTF_r$ in actual applications is estimated using equation (1) below with $MTTF_s$ observed under accelerated condition as the reference value.

$$MTTF_r = MTTF_s \times A_v \times A_h \times A_t \cdots (1)$$

$MTTF_r$: Estimated value

$MTTF_s$: Reference value (= 500 h)

A_v: Acceleration factor for drive voltage = $\left(\frac{150}{V_r}\right)^{3.2}$ — V_r: Actual voltage (V)

A_h: Acceleration factor for relative humidity = $\left(\frac{90}{H_r}\right)^{4.9}$ — H_r: Actual relative humidity (RH%)

A_t: Acceleration factor for ambient temperature = $1.5^{\frac{40-T_r}{10}}$ — T_r: Actual ambient temperature (°C)

As examples, the following calculation is made for use at 25°C, 60% RH and 100 V:

$$MTTF_r = 500 \times \left(\frac{150}{100}\right)^{3.2} \times \left(\frac{90}{60}\right)^{4.9} \times 1.5^{\frac{40-25}{10}}$$

$$= 500 \times 3.66 \times 7.29 \times 1.84$$

$$\approx 24{,}500 \text{ h (2.8 years)}$$

Pulse Voltage Application

When this element is driven by a pulse voltage, temperature rises as a result of heating due to dielectric loss of ceramics. Therefore, the element is not likely to be influenced by the humidity, thus extending the service life greatly. Since this effect is affected by the element shape, pulse waveform and frequency, it cannot be calculated by an equation as in the case of DC voltage application.

In KEMET's testing on the AE0203D08, there was no failure confirmed after 0-150 V rectangular pulse wave was applied with 500 Hz for 500 hours (equivalent to 900 million pulses were applied) .

Please pay attention to the physical damage due to ringing phenomenon caused by the fixed method of the element and the speed of the voltage rise.

Figures 23 and 24 show example of reliability test result by pulse operation.

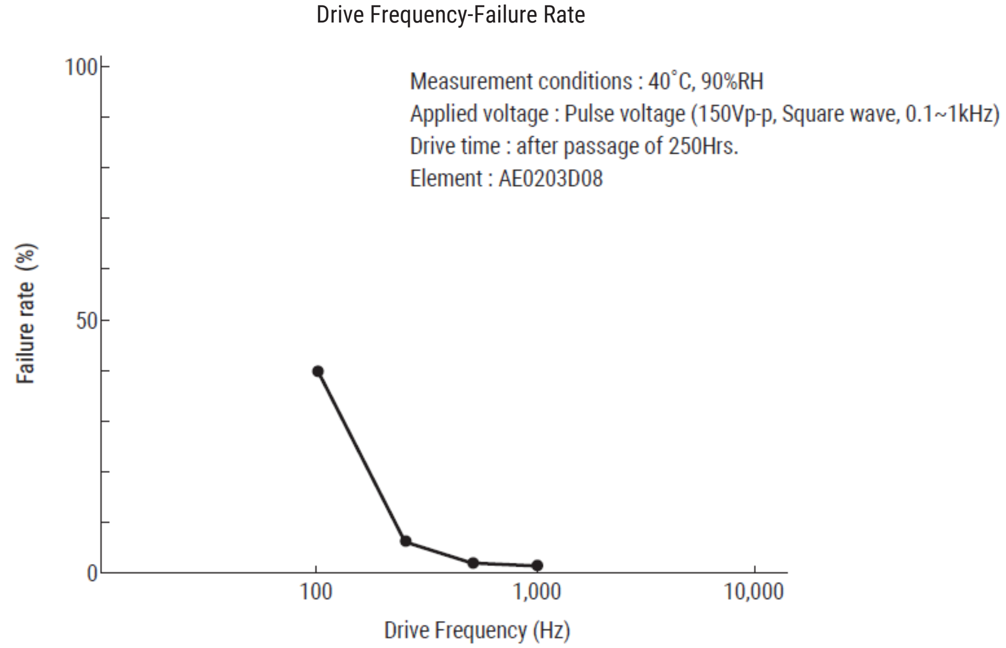
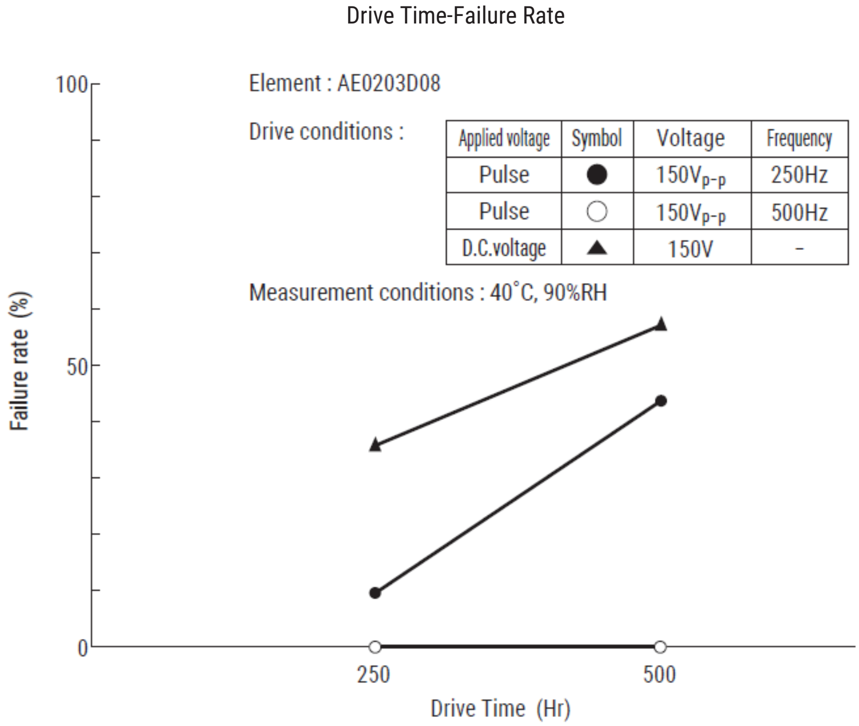


Figure 23 – Relationship Between Drive Frequency and Failure Rate under Humidity Resistance Load



Applied voltage	Symbol	Voltage	Frequency
Pulse	●	$150V_{p-p}$	250Hz
Pulse	○	$150V_{p-p}$	500Hz
D.C.voltage	▲	150V	-

Figure 24 - Relationship between Drive Time and Failure Rate

3.5.2 Reliability of the Metal Sealed Type ASB, ASL and AHB Series

DC Voltage Application

$MTTF_r$ of the metal sealed type under the actual operating conditions is calculated/estimated from the reference $MTTF_s$ and the acceleration factor as in the case of the resin-coated type. However, since the internal element is sealed from the atmosphere, it is not influenced by the atmospheric humidity. Therefore, equation (2) below is used.

$$MTTF_r = MTTF_s \times A_v \times A_t \cdot\cdot\cdot (2)$$

$MTTF_r$: Estimated value

$MTTF_s$: Reference value (= 36,000 h)

A_v: Acceleration factor for drive voltage = $\left(\frac{100}{V_r}\right)^2$ V_r: Actual operating voltage (V)

A_t: Acceleration factor for ambient temperature = $1.5^{\frac{85-T_r}{10}}$ T_r: Actual operating temperature (°C)

As examples, the following calculation is made for use at 25°C and 150 V:

$$MTTF_r = 36{,}000 \times \left(\frac{100}{150}\right)^2 \times 1.5^{\frac{85-25}{10}}$$

$$= 36{,}000 \times 0.44 \times 11.3$$

$$\approx 179{,}000 \text{ h (20.4 years)}$$

Pulse Voltage Application

Like the resin-coated type, it is extremely difficult to estimate reliability by using an equation in the metal sealed type because of the influence of the pulse waveform, frequency, etc. in addition to the voltage and ambient temperature.

In KEMET’s testing on the ASB170C801NP0, there was no failure confirmed up to 1,000 hours (equivalent to 100 million pulses were applied) under the conditions below.

Conditions for Evaluation

Temperature: 85 ±2˚C
Humidity: 90% to 95% RH
Load: 200 N to 500 N (20 kgf to 50 kgf)
Drive voltage waveform: rectangular wave, 30 Hz, 0 V to 100 V, duty ratio at 30%

Caution

The MTTF values and the acceleration equation are used only for reference, under the definite test conditions of KEMET.

Therefore, they are not guaranteed under wide-ranging drive conditions likely to be obtained if these products are used together with user's systems. Further, please remember that the degree of reliability varies depending on the size of the actuator.

4 MULTILAYER PIEZOELECTRIC ACTUATOR LINEUP

Series	Displacement Range at Maximum Voltage of 150 VDC	Generated Force Range	Overall Length Range	Notes
AE	4.6 – 42.0 µm	200 – 20,000 N	5 – 40 mm	• Resin coated type • General purpose
AER	9.1 – 13.2 µm	2,200 – 4,200 N	10.0 – 13.5 mm	• Resin coated type • Ring shape • General purpose
ASB	17.0 – 20.0 µm	200 – 800 N	24.4 – 38.4 mm	• Metal case type, 85°C • Easier installation with mounting attachment • High reliability
ASL	19.0 – 77.0 µm	800 N	24.4 – 98.4 mm	• Metal case type, 150°C • Easier installation with mounting attachment • High reliability
AHB	52.0 – 140.0 µm	800 – 3,600 N	44.4 – 125.4 mm	• Metal case type, 85°C high performance • Easier installation with mounting attachment • High reliability

Table 3 – Multilayer Piezoelectric Actuator Lineup

AE and AER series are resin coated products. Therefore, we recommend using metal case type, ASB, ASL or AHB series in high humidity condition.

For more detailed information on the KEMET Multilayer Piezoelectric Actuators, please refer also to the datasheets on https://search.kemet.com/component-edge/#/browsing?id=851.

5 HANDLING PRECAUTIONS

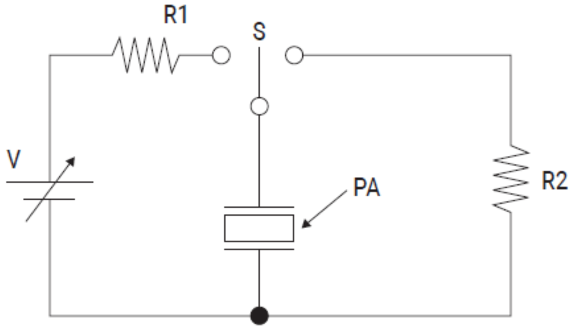
- ❖ Before using or designing a system using our products, read the precautions and specifications listed below.
- ❖ The main failures with multilayer piezoelectric actuators are deterioration of insulation resistance, short-circuit and open-circuit.

  Before using the products, systems should be designed carefully to ensure redundancy, prevention of the spread of fire, and prevention of faulty operation allowing occurrence of failures.
- ❖ Use the products after checking the working conditions and rated performance of each multilayer piezoelectric actuator series.

  Selection of AE or AER series (resin coated type) or ASB, ASL or AHB series (metal sealed type) should be based on the intended working temperature and humidity.

- Connect the red lead wire to the positive (+) terminal of the power supply.
- Avoid electric shocks since a high voltage is in use.
- Never apply excessive tension to a lead wire.
- Do not handle the product by picking up or moving the lead wire.
- Machining of the actuator element and replacement of the lead wire are prohibited.
- Do not handle the resin-coated type (AE and AER series) with bare hands.
- Do not wash resin-coated type (AE and AER series) with organic solvents.
- Do not disassemble the case of the metal sealed type (ASB, ASL and AHB series).
- Avoid excessive physical shock. Otherwise, the internal piezoelectric ceramic element may be damaged.

- If the actuator is exposed to high temperatures above 100°C or if used after long storage periods (more than three months), the device should be polarized by using the circuit configuration and conditions shown below.



Protective resistor R1 = 1 kΩ
Protective resistor R2 = 1 kΩ
Polarizing conditions: DC voltage application
0 V → 150 ±0.2 V (to be retained for 10 seconds) → 0 V

- Do not apply voltage exceeding maximum rating voltage, or rapid charging and discharging. These might lead to degradation of the reliability or mechanical fracture.
- Do not use the actuator in high concentrations of highly inflammable gas. Otherwise ignition may occur.
- Use the actuator so as not to cause bending, twisting or tension. Align the center axis of displacement of the actuator with the center axis of the mechanical load.
- When operated, the transient response time of the actuator should be less than 1/3 of the resonant frequency in order to prevent damage by ringing.
- Store actuators preferably in a dry atmosphere (desirably below 40% RH) at ordinary temperatures (-5˚C to +40˚C). Avoid condensation on the product's surface.
- Store actuators where there is no vibration.
- Handle products properly as industrial waste. When disposing, please contact your local waste disposal service and make sure the disposal methods meet all legal requirements.

5.1 Fixing Method

- Carefully prevent the piezo actuators from being bent, being twisted, or being applied tensile force.

	Reference Value	Remarks
Twisting Force	3×10^{-1} N・m or less	For an actuator which generates a force of 800 N (compression resistance).
Tension	50 N or less	

Table 4 – Guide for Tolerance of Twisting and Tension

- Install the actuator so that the center axis of generated displacement is aligned with the center axis of the load.

5.1.1 Resin-Coated Type

- Epoxy-based adhesives are recommended for bonding. Select adhesives that have high rigidity and allow minimum thickness so that the generation force and displacement cannot be deteriorated. Also do not form adhesives on the side of actuator.
- When thermosetting resin is used, perform polarizing treatment (see the caution section) after the adhesive is settled.
- The resin-coated type is weak to the tensile force due to its structure and may be broken when tensile forces are applied onto the device. Using the device in the state that constantly applies compression is effective against any mechanical damage. The pressure applied to this element should be kept at 20 to 50% of the force generated by this element (compression resistance).

- Install the element so that the axis of generated displacement is vertical to the mounting surface.

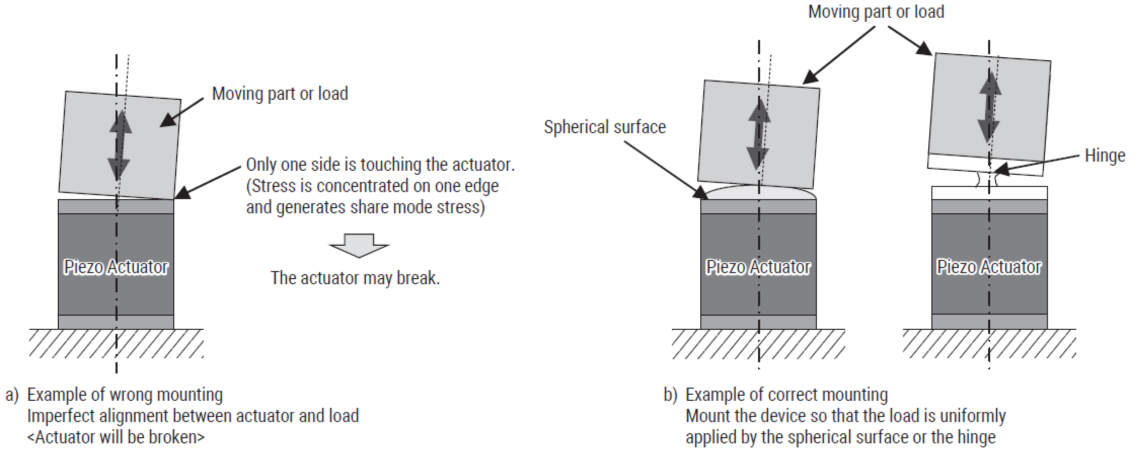


Figure 25 – Example of Actuator Mounting

5.1.2 Metal Sealed Type

- Select the mounting bracket (female thread type or flange type) according to the mounting method, and install the element utilizing the bracket.
- Fix the element securely so that the generated force and displacement cannot be deteriorated.
- Connect the driven item at the displacement generating end after securing the mounting portion so that it avoids unnecessary stress applied at the time of installation.
- Though this product is designed to apply a compressive force to the internal element by the metal case, avoid any usage that can cause bending, twisting, or tension force when the device is in use.

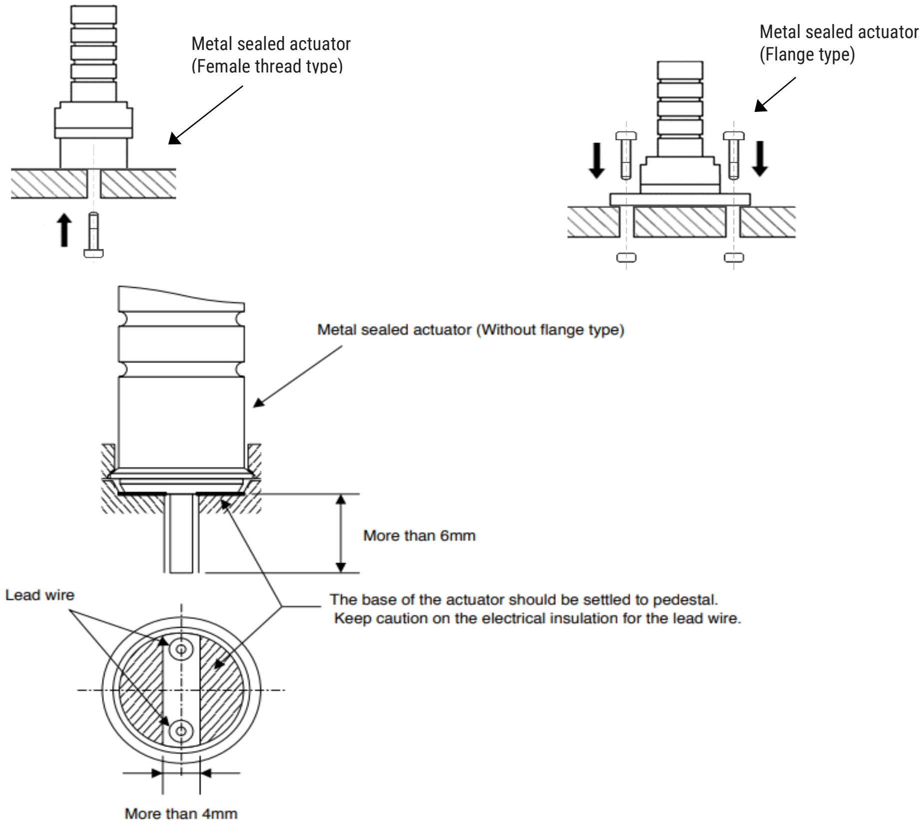


Figure 26 – Metal Sealed Type Fixing Methods

5.2 Driving Method

- Connect the red lead wire to the positive (+) terminal of the power supply. Also prevent reverse voltage application.
- Basically, the voltage controls the aimed displacement and generated force. In driving applications, however, it is necessary to take consideration of hysteresis, ringing, creep, and other similar phenomena.
- For pulse driving, it is also necessary to be aware of self-heat generation, charge/discharge current, and the power supply's impedance.

6 DRIVING POWER SUPPLY SYSTEM

6.1 Basic Configuration

When a voltage is applied to a multilayer piezoelectric actuator, the actuator generates displacement (expansion). The amount of displacement is approximately proportional to the applied voltage (refer to Section 3.1). Therefore, the displacement of the piezoelectric actuator becomes controllable if the applied voltage is controlled. To implement this, the following system configuration is basically required (Figure 27).

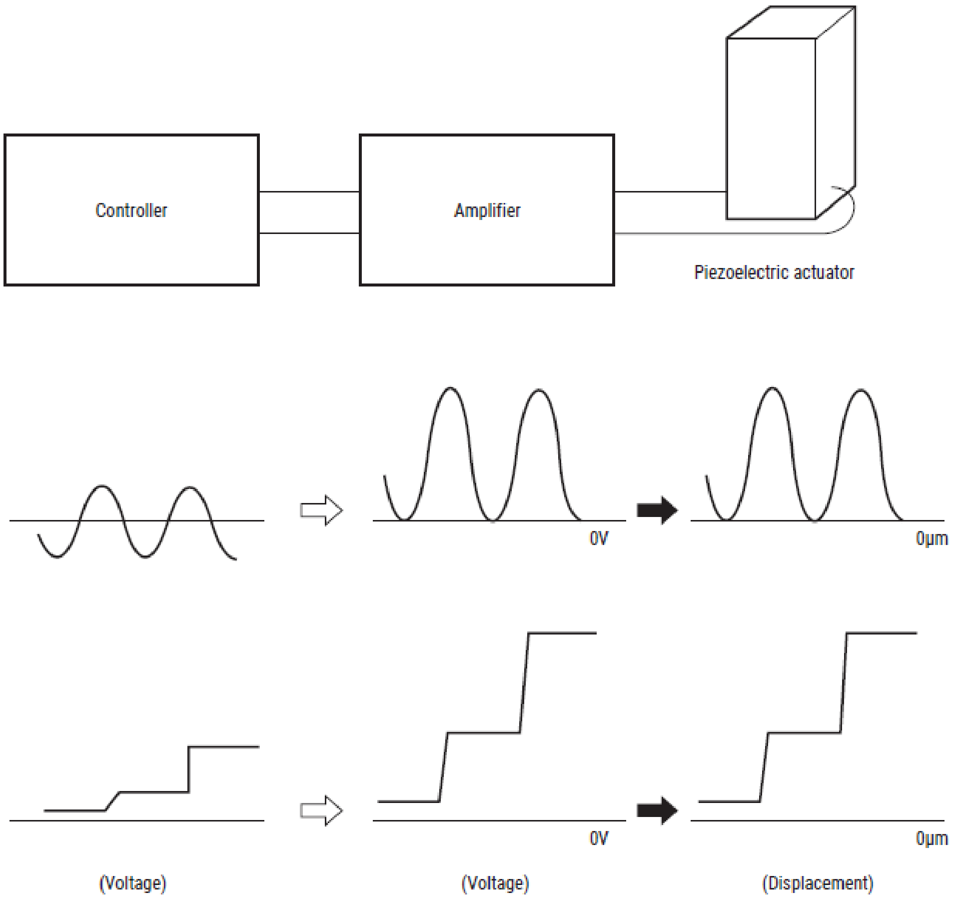


Figure 27 – Basic Configuration

Subsystem	Contents of Operation
Controller	Outputs a signal representing an up-and-down pattern of a voltage to be applied to a piezoelectric actuator.
Amplifier	Outputs a signal received from a controller after having amplified (converted) the signal to a voltage necessary to drive the actuator (the amplifier becomes unnecessary if the signal voltage output from the controller is sufficient to drive the actuator).

6.2 Feedback Control System

In high-precision positioning applications, it is possible to carry out more accurate control of displacement by adding corrections (feedback) to applied voltage.

Such a control system is called a feedback control system or a closed loop system (contrary to this, the system that does not require the addition of feedback is called an open-loop control system).

Figure 28 shows a representative example of configuration of the feedback control.

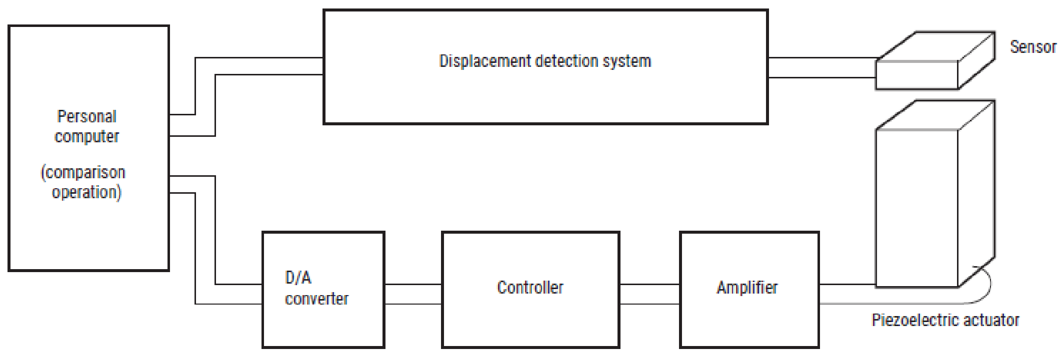


Figure 28 – Feedback Control (Representative Example)

A "displacement detection system" section (including a sensor) of the feedback control system may be implemented by another method other than the method of detecting the displacement of the piezoelectric actuator. Some examples of the feedback control system will now be described.

Purpose	Sensor
Gas flow control (opening and closing of a valve)	Flow sensor
Film thickness control for film forming (adjustment of gap between slits)	Thickness gauge
Optical shutter (opening and closing of shutter)	Photometer (illuminometer)

6.3 Selection of Each Subsystem of Power Supply

There are various configurations and methods for the system of the power supply depending on the driving method. Similarly, several alternatives are available for selection.

Precautions for selection and representative samples of alternatives will be described below.

6.3.1 Controller (for Generating a Step-Up and Step-Down Signal for Applied Voltage)

Representative Example 1 (method using a signal generator such as a function generator or a function synthesizer)

It is possible to generate a continuous pulse waveform (a repetitive waveform). A variety of generators, from a generator for generating a simple waveform such as a sine wave to a generator which permits the setting of an arbitrary waveform, are commercially available. Generators which allow the setting of a DC offset voltage are easy to use. These generators are suitable for effecting continuous driving using the same waveform.

Representative Example 2 (control using a computer)

A method of causing a digital-to-analogue converter, or the like, connected to a computer, to produce an output of a signal. Some controllers permit the setting of an output signal by means of a computer (a microcomputer or a personal computer) connected to the controller via a GP-IB interface. This type of controller in which the computer easily executes comparison operation is suitable for feedback control in high-precision positioning applications and driving methods in which displacement changes based not on regular iterative timing but irregular timing.

This type of controller may replace the signal generator (the function generator) depending on applications.

6.3.2 Amplifier

Setting precautions for representative items relating to the performance of an amplifier will be described below. An amplifier suitable for user's purpose should be selected after comprehensive study of the amplifier.

Voltage

KEMET's piezoelectric actuators operate at a maximum drive voltage of 150 V which is a much higher voltage than the ordinary controllers can generate. For this reason, if the actuator is driven up to the maximum drive voltage, that is, if the maximum displacement is necessary, an amplifier capable of outputting the control signal by amplifying it from 0 to 150 V becomes necessary.

If the actuator is operated at a voltage below the maximum voltage, it is only necessary for the amplifier to be able to output a voltage up to that required voltage.

If the actuator can be directly driven by means of a signal from the controller, the amplifier becomes unnecessary.

As previously mentioned in the precautions of the Section 3.1, do not apply a reverse voltage (a negative voltage) to the actuator, which may result in significantly reduced reliability.

To prevent the application of a negative voltage during pulse driving, it is easy to apply a DC bias to the drive voltage by adjusting the offset voltage of the controller or amplifier.

Current

As mentioned in Section 3.4, a required current depends on a required start-up speed. The piezoelectric actuator is assumed to be a capacitor in terms of an electrical circuit. Therefore, if high-speed start-up of the actuator is necessary, a large current also becomes necessary. A required current value should be calculated upon reference to Section 3.4. To ensure safety, an allowance of more than twice as much as a calculated current value should be made in setting an amplifier.

Frequency

An amplifier capable of responding to a drive frequency should be selected.

Output Impedance (output resistance)

If the actuator is driven at a particularly high speed, a larger current flows in the actuator. As a result of this, voltage drops arise in the drive voltage as a result of output resistance, which may make it difficult for the power supply to output a desired voltage.

6.3.3 Sensor for the Displacement

There are a variety of types of displacement sensor such as laser displacement sensors, differential transformer displacement sensors, eddy current displacement sensors, capacitance displacement sensors, and optical displacement sensors. Even similar types of displacement sensor have different performance capabilities.

Particularly when high-speed detection of displacement is required, the response of the sensor itself sometimes fails to follow the operation of the actuator. To prevent this, the study of the response characteristics of the displacement sensor should be sufficiently carried out before selecting the sensor.

Supplementary Note

If it is difficult for the user to obtain a power supply, please contact us so that we can recommend power supplies.

7 APPLICATIONS FOR MULTILAYER PIEZOELECTRIC ACTUATORS

Apparatus	Application Examples	Series [2]			Features [3]				
		Resin-Coated Type	Metal Sealed Type	Others	Compact	Quick Response	High Accuracy	Large Generated	High Frequency
Precision machinery Mechatronics	X-Y stage	○	⊙				⊙		
	Positioning machine	○	⊙		○	○	⊙	○	
	Ultrasonic scalpel								
	Part feeder			○		○		○	○
	Knitting machine			⊙	○	○			○
	Haptic display			⊙	○	○			
Semiconductor manufacturing system	Mass-flow controller		⊙			⊙	○		
	Stepper		⊙			⊙	○	⊙	
	Bonding machine	⊙			○	⊙	⊙		○
	Nano-printing machine		⊙						
	Active vibration control	⊙	○			⊙		⊙	
Valve	Pump		○	○		○		○	
	Control valve			○		○		○	
Household electrical appliance and audio equipment	Receiver (speaker)			⊙	○				
	Tweeter (speaker)	⊙			○			○	
	Bone conduction speaker	○		○	○				
Audiovisual equipment	Projector	○	○		○	○	○		
	Camera for image processor	⊙			⊙	○	○		
Printer	Inkjet printer	○	○			○		○	
	Inkjet drive source			⊙		○	○		○
	Wire dot drive source	○				○		○	⊙
Computer	HDD head tracking			⊙		⊙	○		
	Force feedback (haptic)			⊙	○	⊙			
Optical instrument	Positioning of lens or mirror (scanner)	⊙			○	⊙	⊙		
	Autofocus of microscope	⊙	○		○	○	⊙		
Communication	Optical fiber positioning	⊙				⊙	⊙		
Machine tool	Punching machine	⊙				⊙		⊙	
	Fine positioning of cutting tool	○	⊙		○	○	⊙		
	Dispenser	○			⊙		⊙		
	Vibration control	○				⊙	○	⊙	
Camera	Autofocus	⊙			○	⊙	○		
	Dust reduction			⊙	○	○			○
	Image stabilization	⊙			○	⊙	○		
Measuring equipment	Fine durometer	○			○		⊙		
	Position inspection equipment (HDD tester)	○	○		○	⊙	⊙		
	Hydraulic monitoring (stress)	⊙			○			○	
	Operation monitoring (vibration)	⊙			○		⊙		
Analytical instrument	Micro manipulator	⊙			⊙		⊙		
	Cell sorter	⊙			○	⊙			
	Vibration testing machine	○	○			○		⊙	
	Atomic force microscope	⊙	○		○		⊙		
	Endoscope	⊙			○	○	○		
Generator	Vibration generator	○		⊙	○				
	Light switch			⊙	○				

[2] Resin Coated-Type refers to AE and AER series, and their variations. Metal Sealed Type refers to ASB, ASL and AHB series, and their variations. Others refer to products capable to respond to full custom design. ○ indicates suitable, ⊙ indicates optimum.
[3] High Frequency: advantages obtained when the actuator is assumed to be a transducer (ultrasonic transducer). ○ indicates merit, ⊙ indicates larger merit.

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