Applications of Piezoelectric Actuator

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Abstract

The piezoelectric actuator is a device that features high displacement accuracy, high response speed and high force generation. It has mainly been applied in support of industrial machinery that requires precise position control. Its application in the field of compact electronic equipment such as digital cameras and cellular phones is advancing rapidly.

Keywords

piezoelectric actuator, precision position control, compact electronic equipment

1. Introduction

An actuator is the generic name referring to devices that convert input energy into mechanical energy, and various actuators have been developed and put to practical use according to various types of input energy (**Fig. 1**). The electromagnetic, hydraulic and pneumatic actuators achieve displacement indirectly by moving a piston by electromagnetic force or pressure. On the other hand, the piezoelectric actuator achieves displacement by directly applying deformation of a solid, and thus features a higher displacement accuracy, larger generation force and higher response speed than other types of actuators. These advantages have resulted in the piezoelectric actuator being applied mainly in industrial equipment requiring precision position control, such as the ultrafine-movement stage of semiconductor exposure systems, precision positioning probes and probes for scanning tunnel microscopy (STM) and atomic force microscopy (AFM).

In addition, other advantages including the nonnecessity of a driving coil, ease of implementation of small devices, high energy conversion efficiency and low power consumption have recently led to application in consumer equipment such as digital cameras and cellular phone terminals.

In the following sections, we will describe the features of the piezoelectric actuator, changes in the fields of application and the future perspectives.

2. Features of the Piezoelectric Actuator

The piezoelectric ceramic material used in the piezoelectric actuator generates electrical energy when it is subjected to mechanical energy (piezoelectric effect) and generates mechanical energy when it is subjected to electrical energy (inverse piezoelectric effect) (**Fig. 2**).

The piezoelectric actuator is a device that makes use of the inverse piezoelectric effect. For example, when a voltage of about 1,000V is applied to a piezoelectric ceramic plate with a thickness of 1mm (1,000V/mm electrical field), a displacement of about 1μm is obtained due to the inverse piezoelectric

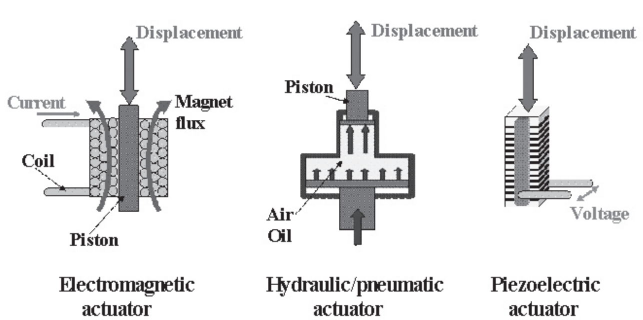


Fig. 1 Schemes of various actuators.

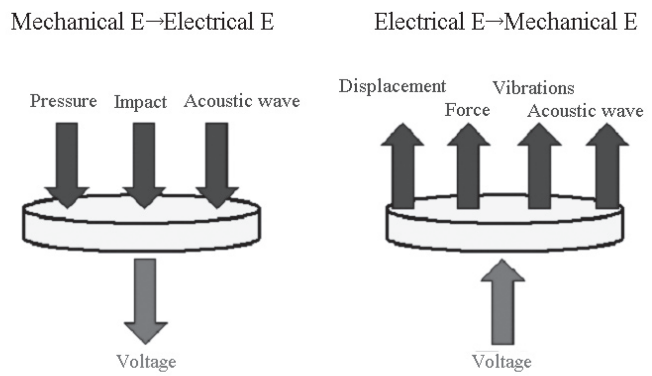


Fig. 2 Functions of piezoelectric ceramic.

effect. However, as this is in practice insufficient, because only a small displacement can be obtained with a high drive voltage, the piezoelectric actuators are structurally processed in order to obtain a larger displacement from a lower drive voltage and the process has thus been put to practical use.

In order to reduce the drive voltage of a piezoelectric actuator, it is necessary to reduce the thickness of the ceramic plate. For example, reducing the plate thickness to 0.5mm makes it possible to apply a 1,000V/mm electrical field with a 500V drive voltage, which results in a reduction in the drive voltage. **Fig. 3** shows the scheme of typical piezoelectric actuators.

Fig. 3(a) is an actuator called the bimorph piezoelectric actuator. It is fabricated by processing two piezoelectric ceramic plates to a thickness of some hundreds of μm and bonding them by inserting a metallic plate between them.

When an inverse voltage is applied to two piezoelectric plates, warp deformation is a consequence. This arrangement can offer a relatively large displacement but the force is not large. This device is implemented in a cantilever construction for use in positioning mechanisms, etc. and the drive voltage is usually some hundreds of volts.

Fig. 3(b) is an actuator called the multilayer piezoelectric actuator (hereinafter referred to as the "multilayer actuator"). It is fabricated by multilayer ceramic films of 100μm thickness, each of which is formed by the green sheet process and electrode films of a few micrometers thickness, which are then sintered together, the resulting structure being similar to a ceramic capacitor.

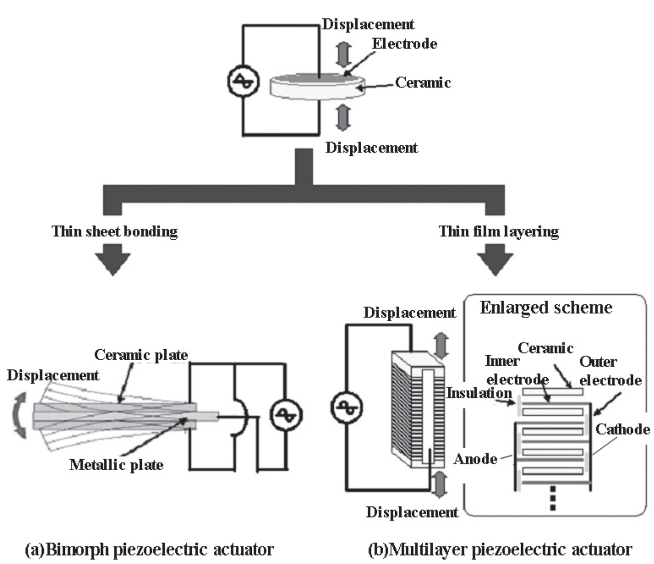


Fig. 3 Typical example of piezoelectric actuators.

The multilayer actuator features higher displacement accuracy, larger generated force and higher response speed because of the lower drive voltage due to the reduction in the ceramic plate thickness per layer and of the possibility of utilizing the distortion and rigidity of the ceramic material without adopting means such as a metallic rim.

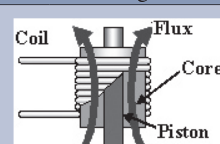
3. Applications of the Piezoelectric Actuator

The field of applications of piezoelectric actuators is comparable to that of electromagnetic actuators. **Table** shows the comparison of electromagnetic and piezoelectric actuators based on their principles. The piezoelectric actuator has disadvantages compared to the electromagnetic actuator in terms of its displacement amount. However, it is advantageous from other aspects, including that of its displacement accuracy, generated force and response speed and energy efficiency as well as from the aspect of ease of proportional control and absence of electromagnetic noise.

At NEC TOKIN, we succeeded in the practical implementation of the multilayer actuator in 1985. **Photo 1** shows the multilayer actuators that were released by us at that time.

The product line includes the AE Series and the ASB Series.

Table Comparison of actuator characteristics.

	Electromagnetic		Piezoelectric	
				
Drive system	Indirect drive by electromagnetic force		Solid deformation by inverse piezoelectric effect	
Displacement amount	○		×	1/10 to 1/100
Force generation	×		○	Utilization of solid rigidity
Displacement accuracy	×	＞0.1mm	○	0.01mm to 0.1mm
Response speed	×	＞1msec.	○	0.1 to 1 msec.
Energy efficiency	×	Coil winding loss	○	No coil
Noise	×	Piston sliding reciprocation noise	○	No piston
Proportional control	×	ON/OFF control	○	Voltage-proportional
Drive voltage	○		×	Hundreds of V/mm

○: Advantageous ×: Disadvantageous

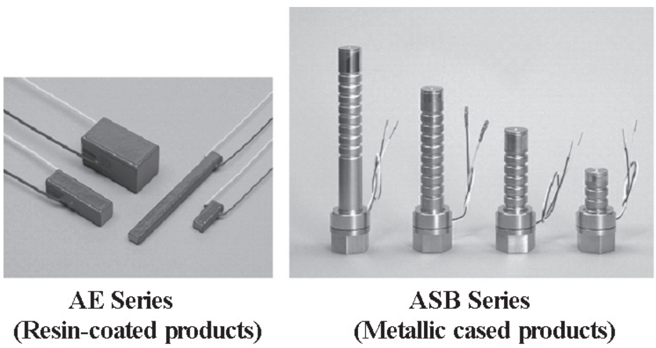


Photo 1 Multilayer actuators from NEC TOKIN.

The AE Series has a multilayer actuator, which is coated with resin and fabricated using the high-performance piezoelectric material NEPEC as a unique full-face electrode structure, in which electric field and stress are almost non-existent. The ASB series with which a multilayer actuator is sealed with inactive gas in a metal casing that has a bellows like structure. The metallic cased ASB Series presents excellent endurance against environmental variations in humidity, etc., and it is evaluated highly in the field of industrial equipment.

The multilayer actuator was incorporated in the mass-flow controller for use in semiconductor fabrication systems that require ultra-precise flow control (**Fig. 4**). This was the first case in which the multilayer actuator was put to practical use in an industrial application.

The use of the piezoelectric actuator for driving the flow-control diaphragm has made it possible to control the flow more precisely and more rapidly than with the traditional electromagnetic valve.

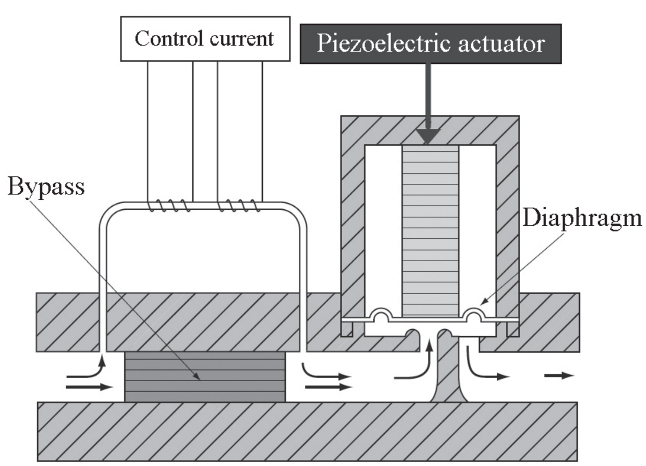


Fig. 4 Outline of the mass-flow controller.

Subsequently, applications in the semiconductor fabrication systems field have expanded, including application in the precision position control stage of an exposure system in the 1990's (**Fig. 5**). The coarse movement of this precision stage is performed with a DC servo meter and fine movement is performed with a piezoelectric actuator, and the same method has been applied in various systems.

In the late 1990's, the piezoelectric actuator was applied for the optical axis alignment of optical fiber (**Fig. 6**). The alignment system installs a piezoelectric actuator with a hole in the center and aligns the optical axis of the optical fiber inserted from either end. It makes use of the displacement accuracy at the nanometric level of the piezoelectric actuator and can be regarded as one of the applications that utilizes the piezoelectric actuator's characteristics most effectively.

As described above, the piezoelectric actuator has mainly

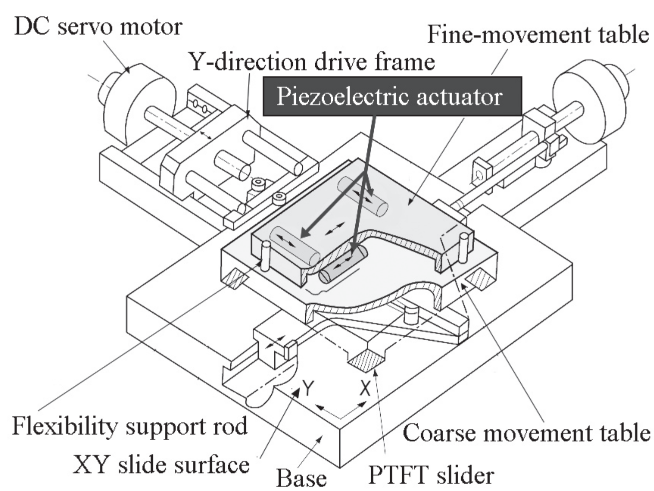


Fig. 5 Outline of the precision stage.

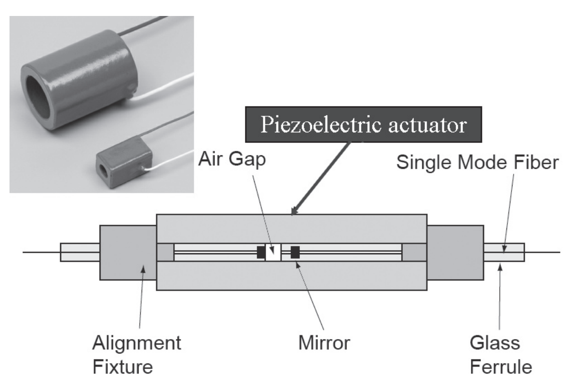


Fig. 6 Optical fiber axis alignment mechanism.

been applied in the field of industrial machinery, but its applications in the digital equipment field, particularly in video equipment, has been advancing rapidly since 2000. One of its typical applications is for the CCD (Charge Coupled Device) drive.

Color video cameras often feature improvements in the resolution of the CCD using the "pixel deviation" technique, which shifts the CCD by half a pixel in the horizontal direction in order to increase the apparent pixels and improve the resolution. Since each CCD pixel usually has a size of 5 to 7μm, the deviation distance is about half of this, or 2.5 to 3.5μm. A piezoelectric actuator has also been applied to process the deviation mechanically. The versatility demonstrated by the application of this device has been attracting the attention of engineers because of its enabled positional control accuracy and its high response speed in tracking the camera's shooting. The pixel deviation technique is also used for large-screen LCD projectors as well as in video cameras.

The CCD drive technique is also being applied to help produce more compact electronic equipment such as digital cameras.

As the number of pixels has increased, the number of digital cameras introducing the hand-blurring correction technique has also increased. Low-priced digital cameras often correct hand blurring by an electronic process, but high-class digital cameras, which are subject to requirements for high-definition images need to correct hand blurring by an optical means. The high response speed of the piezoelectric actuator is indispensable for executing the optical correction processing instantaneously by achieving the correct definition for a good picture. **Fig. 7** schematically shows the hand blurring correction system of a digital camera. This system cancels hand blurring by moving the CCD in the XY directions according to the hand blurring signal detected by a gyro sensor, etc., and a piezoelectric actuator is used in driving the CCD.

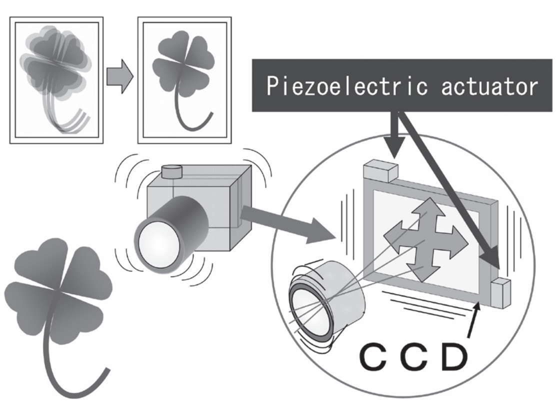


Fig. 7 The concept of hand-blurring correction of digital cameras.

Unlike professional cameras and large-screen projectors, the application of the piezoelectric actuator in compact electronic equipment such as digital cameras needs to solve some problems.

One of these is the fact that the displacement amount of the piezoelectric actuator is as small as only about 0.1% of its overall length.

This problem is solved basically by using a displacement enlargement mechanism that applies the principle of the lever. In general, a large displacement enlargement mechanism with high rigidity is used to extract the force generated by the piezoelectric actuator at maximum. Nevertheless, this does not cause a serious problem with equipment that features a space margin such as large industrial machines, professional cameras and large-screen projectors. However, compact electronic equipment with limitations in space are not able to use such a large-sized displacement magnification mechanism. In the early 2000's, however, a displacement enlargement mechanism with a compact size and simple construction was developed by emphasizing the high response speed and high displacement enlargement ratio. The problem of the application of the piezoelectric actuator has thus been solved and its application in compact electronic equipment has since then been advancing rapidly.

Another problem is the high drive voltage of the piezoelectric actuator. The bimorph and multiplayer actuators are some of the designs for solving this problem. However, past multiplayer actuators needed drive voltages of some tens to a hundred volts. Since compact electronic equipment such as digital cameras is basically driven by a battery, the drive voltage may be as small as no more than 5V.

To solve this problem, we have attempted to reduce the thickness of the multilayer arrangement and have developed an actuator that can be driven with a voltage of no more than 5V. In addition, we have also challenged reduction of the actuator sizes and have eventually developed the world's smallest multilayer piezoelectric actuator, or 0.3 × 0.3 × 1.2mm, in 2004 (**Photo 2**).

The piezoelectric actuator size reduction technology of NEC TOKIN has contributed significantly to improvements in the performance of compact electronic equipment.

It is also becoming the key device for supporting the increase in the pixels of cellular phones featuring cameras, in a similar manner to that of digital cameras. The camera lens drive system combining a compact actuator and a compact

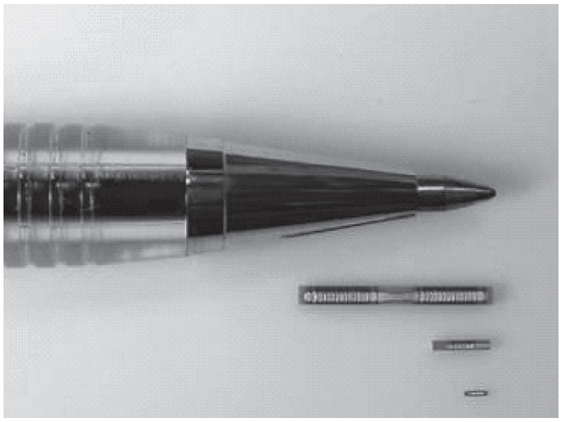


Photo 2 The world's smallest multilayer piezoelectric actuator.

displacement enlargement mechanism is now entering the phase of practical implementation.

Since cellular phones are restricted by space and subjected to higher power consumption requirements than digital cameras, it is said that the electromagnetic motor is limited due to the necessity of a driving coil.

From this viewpoint, it is expected that the application of piezoelectric actuators will expand more in the future due to the non-necessity of a driving coil and its capabilities in space and power saving.

4. Conclusion

As described above, the piezoelectric actuator is extending its field of application from industrial machinery to compact electronic equipment such as digital cameras and cellular phones. In addition, research institutions including universities expect it to make a contribution to nanotechnology, for example as the drive source of micro robots such as inch worms, precision position control in MEMS technology and probes for biotechnological purposes.

At NEC TOKIN, we plan to supply actuators of various sizes and to thus contribute to technical innovations in the manufacturing industry in various areas. These will include industrial machinery, digital home appliances and nanotechnology products, which are based on our experience in the world's first practical implementation of multi-layering.

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