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MAGNETIC FLUX MEMORY EFFECT USING A MAGNETOSTRICTIVE MATERIAL-SHAPE MEMORY PIEZOELECTRIC ACTUATOR COMPOSITE

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Abstract: We propose a coil-free magnetic flux memory effect using a magnetostrictive-shape memory piezoelectric actuator composite. A shape memory piezoelectric actuator can be fabricated by controlling the electrical imprint field, and the shape memory effect maintains a certain permeability of the magnetostrictive materials. To demonstrate magnetic force memory, the magnetic circuit that converted magnetic flux into magnetic force was fabricated. This magnetic force effect could be operated with a pulsed voltage to the shape memory piezoelectric actuator, so that no energy was consumed to maintain a certain magnetic effect.

Key words: magnetostrictive material, shape memory piezoelectric actuator, composite, imprint electrical field

1. INTRODUCTION

Ferroelectric materials are utilized for various applications, because of their multifunctional properties, such as piezoelectricity, large permittivity, nonvolatile charge and electro-optical functions. We have already proposed to control the imprint electrical field in order to realize a memory effect of these properties [1-6], and demonstrated a shape memory piezoelectric actuator [1-5]. Conventional piezoelectric actuators are driven with a DC voltage to maintain certain positions. However, using by imprint electrical field control, a piezoelectric actuator can be operated with a pulse-shaped voltage, so that the piezoelectric actuators can obtain a memory effect.

On the other hands, different from the piezoelectric actuators, magnetic actuators realize a long stroke with a relative large output force. Magnetic actuators, such as stepping motors, voice coil motors and solenoids are widely utilized in practical applications. However, there are difficulties in miniaturizing magnetic actuators, due to their complicated coil structure. Furthermore, the magnetic coils are operated with current flow, which results in Joule heating problems, and high response is restricted due to large impedance as inductance. It is well known that the Joule heating is most of the loss of energy for magnetic actuators.

In recent years, magnetostrictive materials that have giant magnetostriction (over 1000 ppm) have been produced, such as Terfenol-D ($Tb_xDy_{1-x}Fe_2$), and various application have been investigated [7-8]. A voltage controllable mechanism was proposed by using this material with a piezoelectric material and a permanent magnet [9-10]. In these studies, the shape change induced by the piezoelectric actuator is utilized for the permeability change of a magnetostrictive material. The permeability change results in a magnetic flux density from permanent magnet. This principle has been applied to realize voltage control for a magnetic flux density without coil; however, to maintain a certain magnetic flux density, continuous voltage supply is required.

In this study, the shape memory piezoelectric actuator and the magnetostrictive material were attached to form a composite structure. The magnetic permeability of the magnetostrictive material is controllable depending on its strain condition. By using a magnetostrictive-shape memory piezoelectric actuator composite with a permanent magnet, the magnetic flux density can be controlled by voltage applied on the shape memory piezoelectric actuator. Thereby, a coil-less structure and voltage operation instead of current operation becomes possible. The innovative aspect of this study is to apply a shape memory piezoelectric actuator to the system. By attaching the shape memory piezoelectric to a magnetostrictive material, the magnetic permeability can be operated with a pulsed voltage and the memory effect can be maintained without voltage input. The combination of this composite with a permanent magnet is expected as an innovative magnetic actuator with a magnetic memory effect.

2. PRINCIPLE

2.1 Shape memory piezoelectric actuator

We have already demonstrated a shape memory piezoelectric actuator which is operated by a pulse shaped voltage reversing its polarization [1-5]. This approach was quite different from that of conventional piezoelectric actuators. The shape memory piezoelectric actuator was realized with the control of the imprint electrical field. The piezoelectric actuator has a completely symmetric butterfly curve, due to the perfect reversal of its polarization, and therefore, it does not have a memory effect. However, with an imprint electrical field, asymmetric butterfly piezoelectric curves were observed [4-5]. The imprint electrical field is an internal electrical field of ferroelectric materials, and is a well-known phenomenon in the field of ferroelectric thin films, however its detail origin has yet to be clarified.

The principle of the memory effect is shown in Fig.1 with and without imprint electrical field. The D-E hysteresis characteristics of ferroelectric materials shift to the direction of the electrical field axis and become asymmetric with the imprint electrical field. This asymmetric feature is used for memory effects, not only for the polarization, but also for the piezoelectric strain, permittivity, optical properties, and so on. With an asymmetric butterfly curve, the shape memory piezoelectric actuator has two different stable points of strain at the point of 0 volts, depending on its direction of polarization.

Because the shape memory piezoelectric actuator has two stable states without electrical input, it does not require any voltages to maintain the state. To switch the state, a pulsed voltage is required to reverses the polarization of the shape memory piezoelectric actuator. After this operation, no electrical energy is consumed to maintain its state.

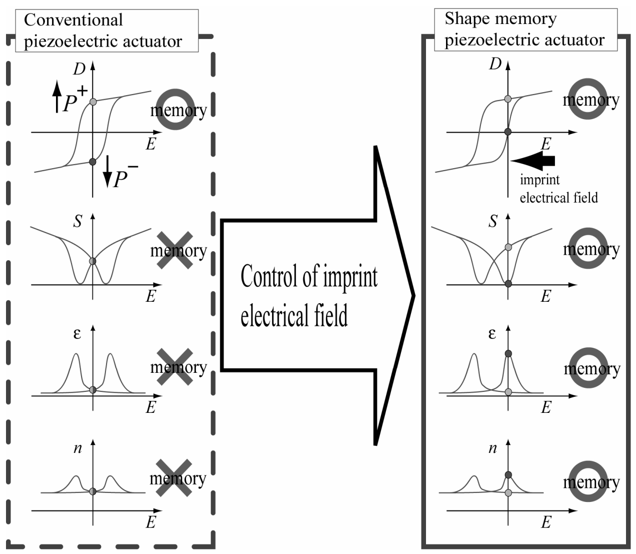

Fig. 1: Principle of the memory effect induced by control of the imprint electrical field.

2.2 Magnetic flux density memory effect

Magnetostrictive materials are functional materials with controllable magnetic permeability by its strain. In the proposed device, the magnetostrictive material is adhered to the shape memory piezoelectric actuator, and the mechanical strain is induced by the piezoelectric shape memory. With the addition of a permanent magnet, the magnetic flux density can be controlled as a function of the permeability of the magnetostrictive material. In this study, the magnetic circuit to convert magnetic flux into magnetic force was fabricated as shown in Fig. 2(a), (b).

In this system, the magnetostrictive material can be controlled by voltage applied on the shape memory piezoelectric actuator. The magnetic flux from permanent magnet flows on two flux paths of magnetostrictive material and outer yoke. When the plus voltage is applied, the magnetostrictive material expands driven by the shape memory piezoelectric actuator as shown in Fig. 2(a). In this condition, the permeability of magnetostrictive material becomes large due to its strain. Therefore, the large amount of the magnetic flux from permanent magnet goes to the magnetostrictive material. As a result, the magnetic force to attract outer yoke becomes small. To the contrary, when the minus voltage is applied, the magnetostrictive material contracts and magnetic force becomes large (Fig. 2(b)). Using this principle, these two conditions are changed by the plus and minus pulse voltage. Without the electrical power, two different magnetic forces can be maintained.

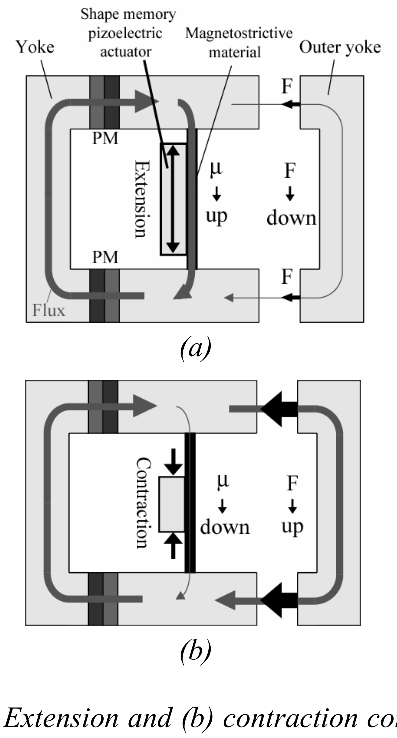

Fig. 2: (a) Extension and (b) contraction conditions of the composite model.

3. EXPERIMENTAL SETUP

3.1 Fabrication process of the magnetostrictive-shape memory piezoelectric composite

A multilayered lead zirconate titanate (PZT) actuator (Nihon Ceratec Co., Ltd., PAC133J) was used for the experiments. The dimensions of the piezoelectric actuator were 3×3×10 mm, and the thickness of each PZT layer was 0.065 mm.

To apply the memory effect, an imprint electrical field was induced to the actuator with a 350 DC voltage to the driving electrode at 180 °C for 3 h in an electric oven (Yamato Co., Ltd., DKN302). The shape memory piezoelectric actuator and the Terfenol-D magnetostrictive material (Etrema Products Inc., $Tb_{0.3}Dy_{0.7}Fe_{1.92}$, 1×5×15 mm) were attached using an epoxide-based adhesive to form a composite structure (Fig. 3).

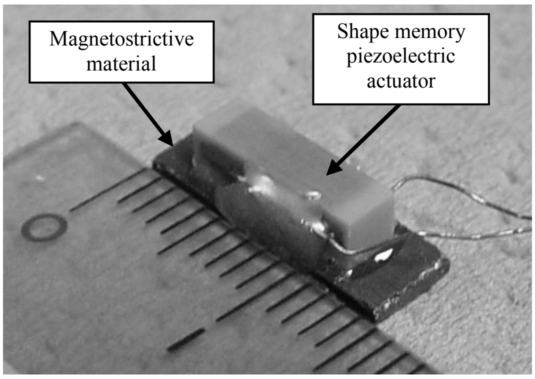

Fig. 3: A magnetostrictive-shape memory piezoelectric actuator composite.

3.2 The magnetic circuit that converts magnetic flux into magnetic force

Fig. 4 shows the magnetic circuit, which was composed of a permanent magnet (Nd-B-Fe, 0.24 T), silicon steel (Yoke), and the composite. The magnetic force was measured using a load cell (Kyowa, LTS-1kA). The operating voltage was applied from a function generator (NF Co., Ltd., WF1946) through a voltage amplifier (NF Co., Ltd., 4010). Strain gauge was attached to the shape memory piezoelectric actuator for detecting piezoelectric strain in the longitudinal direction.

4. EXPERIMENTS AND THIR RESULTS

4.1 Relationship between piezoelectric strain and magnetic force

A triangular voltage of 200 Vpp at 1 Hz was applied to the shape memory piezoelectric actuator. The piezoelectric butterfly curve and change in magnetic force change are shown in Fig. 5. The

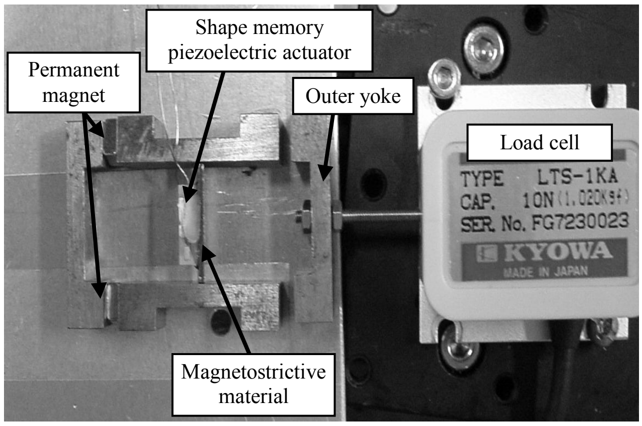

Fig. 4: Experimental setup.

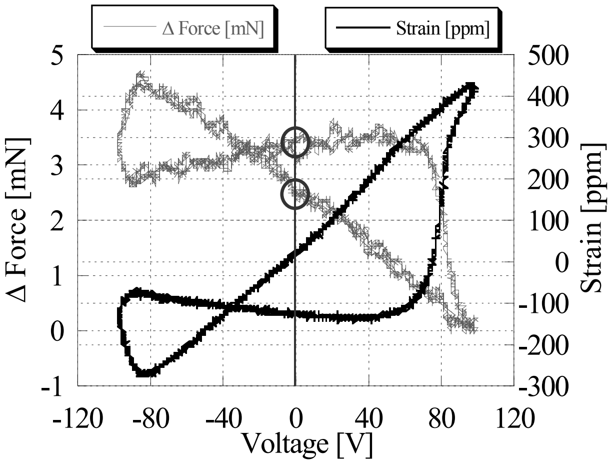

Fig. 5: Relationship between piezoelectric strain and the variation in Δ Force with voltage applied

piezoelectric strain showed an asymmetric curve, and the magnetic force had two distinct values at 0 V. The memory value of the strain was confirmed as 120 ppm, and that for the magnetic force was 1 mN.

4.2 Magnetic force memory effect by pulse voltage operation

The magnetic force memory was controlled using the pulse voltage. Plus and minus pulse voltages of 100 V (pulse width: 100 ms) at 0.25 Hz were alternately applied to the shape memory piezoelectric actuator. The magnetic force results are shown in Fig. 6. The shape memory composite indicated two distinct stable values depending on the polarization direction. When the pulse voltage was applied, the shape memory piezoelectric actuator was obtained by 120 ppm strain (Fig. 6). The magnetic flux density was operated using the change in the permeability of the magnetostrictive material. The memory value of the magnetic force was 1 mN, as shown in Fig. 6 This value corresponds to the value of the asymmetric

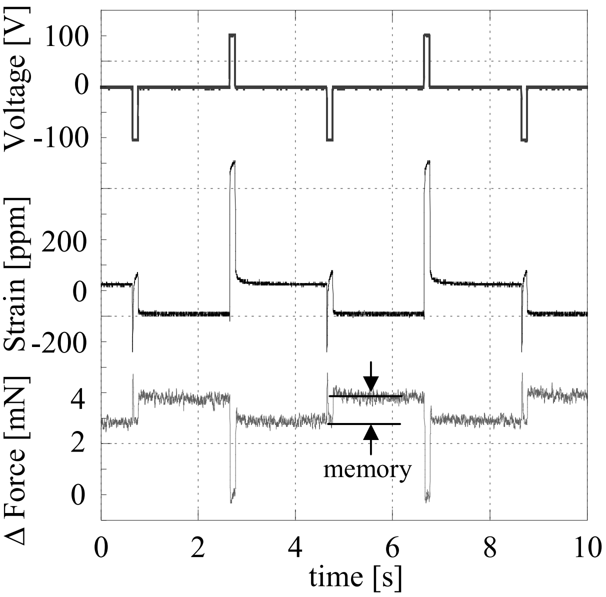

Fig. 6: Change in the piezoelectric strain and the magnetic force driven using a pulsed voltage.

butterfly curve at 0 V, as shown in Fig. 5. From these experiments, the expected memory effect was confirmed, and at 0 V, the magnetic force memory maintained a stable value.

5. CONCLUSION

A composite of a shape memory piezoelectric actuator and a magnetostrictive material was proposed to obtain a magnetic permeability memory effect. The memory effect realized a magnetic force using this system. It was successfully operated under a pulsed voltage. In contrast to conventional magnetic devices, the principle of the proposed device enables operation with a pulsed voltage, eliminating Joule heating problems. The simple coil-less structure is one of the advantages for miniaturization. Optimization of the magnetic circuit is ongoing, with an aim to maintain a larger magnetic force memory for practical applications.

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