Sensors and Actuators A 161 (2010) 266–270

Contents lists available at ScienceDirect

Sensors and Actuators A: Physical

journal homepage: www.elsevier.com/locate/sna

Magnetic force memory effect using a magnetostrictive material and a shape memory piezoelectric actuator composite

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ARTICLE INFO

Article history:
Received 22 December 2009
Received in revised form 26 February 2010
Accepted 11 March 2010
Available online 18 March 2010

Keywords:
Magnetostrictive material
Shape memory piezoelectric actuator
Composite
Imprint electrical field

ABSTRACT

A magnetic force memory effect was realized by applying a pulse voltage to a composite structure comprising a magnetostrictive material and a shape memory piezoelectric actuator. The latter was produced by controlling the electrical imprint field, and the magnetostrictive material attached to the shape memory piezoelectric actuator maintained a certain permeability value. This composite structure was mounted into a magnetic circuit together with a permanent magnet. By applying a pulsed voltage to the actuator, the magnetic force from the permanent magnet was modified due to a change in the permeability. Following pulse operation, two distinct magnetic forces could be maintained without electrical input.

1. Introduction

Recently, we have proposed a shape memory piezoelectric actuator based on control of the imprint electrical field [1–6]. This actuator exhibited a shape memory effect when subjected to a pulsed voltage [1–5]. Usually, conventional piezoelectric actuators require a DC voltage to maintain certain positions and the polarization is not reversed. This is because even if the polarization is reversed, the piezoelectric displacement returns to its previous value. However, if the piezoelectric material has an imprint electrical field, it acquires a shape memory effect, and it can be operated with a pulse-shaped voltage to reverse the polarization.

Magnetic actuators, such as stepping motors, voice coil motors and solenoids are widely utilized in practical applications. However, there are difficulties in miniaturizing such actuators due to their complicated coil structure. Furthermore, the magnetic coils are operated under current flow, which results in Joule heating problems, and high response is restricted due to large inductive impedance. It is well known that Joule heating accounts for most of the energy loss in magnetic actuators.

In recent years, magnetostrictive materials that exhibit giant magnetostriction (over 1000 ppm) have been produced, such as Terfenol-D ($Tb_xDy_{1-x}Fe_2$), and various applications of these materials have been investigated [7,8]. A voltage controllable mechanism of magnetic force was proposed by using such a material in combination with a piezoelectric material and a permanent magnet [9,10]. In these studies, the shape change induced by the piezoelectric actuator is utilized to change the permeability of a magnetostrictive material. The permeability change results in a change in the magnetic flux density from a permanent magnet. This principle has been applied to realize voltage control of magnetic flux density in the absence of a coil; however, to maintain a certain magnetic flux density, a continuous voltage supply to the piezoelectric actuator is required.

We propose a composite structure that contains a shape memory piezoelectric actuator and a magnetostrictive material. The magnetic permeability of the magnetostrictive material is controllable by means of the strain present in the material. By using a magnetostrictive-shape memory piezoelectric actuator composite with a permanent magnet, the magnetic flux density can be controlled by a voltage applied to the shape memory piezoelectric actuator. Thereby, a coil-less structure based on voltage rather than current operation becomes possible. By attaching the shape memory piezoelectric actuator to a magnetostrictive material, the magnetic permeability can be controlled with a pulsed voltage and the memory effect can be maintained in the absence of an applied voltage. In a previous fundamental study, we have already confirmed this permeability memory effect using a similar composite [11]. In this composite, a piezoelectric plate actuator was used as the shape memory actuator; therefore its strain memory was quite small. In the previous experimental setup, it was difficult to evaluate the magnetic memory force because the magnetic circuit was closed. For this reason, the magnetic flux memory effect was examined using a Hall-effect sensor. However, by using the improved magnetic circuit structure, the magnetic force effect

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0924-4247/$ – see front matter © 2010 Published by Elsevier B.V.
doi:10.1016/j.sna.2010.03.025

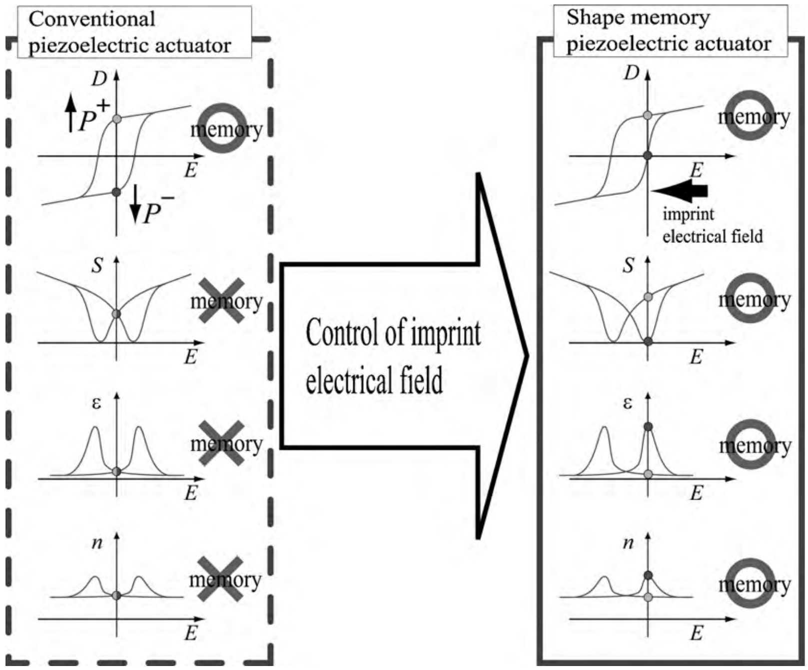

Fig. 1. Principle of memory effects induced by control of the imprint electrical field.

could be directly investigated in this study. In addition, using a multilayered piezoelectric actuator, a large memory effect could be realized. By combining this type of composite with a permanent magnet, it is expected that an innovative magnetic actuator with a magnetic memory effect can be developed for practical use.

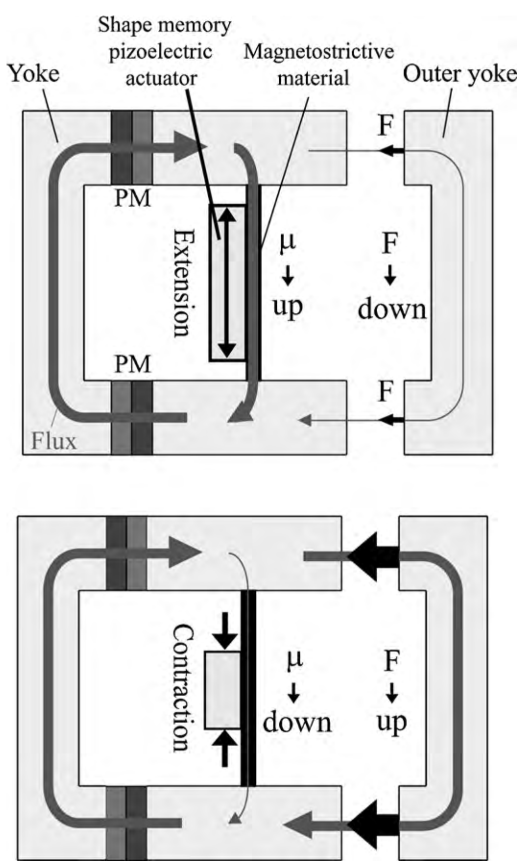

Fig. 2. (a) Extension and (b) contraction conditions of the composite model.

2. Principle

2.1. Shape memory piezoelectric actuator

We have already demonstrated a shape memory piezoelectric actuator operated by a pulse-shaped voltage [1–5]. This approach is far different from that used in conventional piezoelectric actuators. The purpose is to achieve an asymmetric piezoelectric strain curve by means of an imprint electrical field. Usually, the piezoelectric actuator has a completely symmetric butterfly curve, and has no memory effect even if the polarization is reversed. However, with an imprint electrical field, asymmetric butterfly piezoelectric curves were observed [4,5]. The imprint electrical field is an internal electrical field present in ferroelectric materials, and is a well-known phenomenon in ferroelectric thin films; however its detailed origin has yet to be clarified.

The principle of the memory effect is shown in Fig. 1. If an imprint electrical field exists, the *D–E* hysteresis characteristics of ferroelectric materials shift along the electrical field axis and become asymmetric. With an asymmetric butterfly curve, the shape memory piezoelectric actuator has two different stable strain values at 0 V, depending on the direction of polarization. This asymmetric feature affects not only the shape memory, but also the permittivity, optical properties, and so on.

Because the shape memory piezoelectric actuator has two stable states in the absence of electrical input, it does not require any voltage to maintain its state. To switch the state, a pulsed voltage is used to reverse the polarization. Following this, no electrical energy is consumed to maintain its state.

2.2. Magnetic flux density memory effect

The permeability of magnetostrictive materials can be controlled by their stress. In the proposed device, the magnetostrictive material is bonded to the shape memory piezoelectric actuator, and mechanical stress is induced by the piezoelectric shape memory. A permanent magnet was used as the source of the magnetic flux to the magnetostrictive material. In this study, the magnetic circuit to convert magnetic flux into