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High-precision positioning using a self-sensing piezoelectric actuator control with a differential detection method

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ABSTRACT

We present a self-sensing control method for piezoelectric actuators, which enables high-resolution positioning without an external positioning sensor. One of the present authors previously proposed a self-sensing piezoelectric actuator control system (Kawamata et al. (2008) [1] and Ishikiriyama and Morita (2010) [2]). In the previous studies, a linear relationship between piezoelectric displacement and permittivity change was discovered, and this linear relationship was applied for positioning control. To detect permittivity changes, a high frequency voltage signal (permittivity detection voltage), in addition to the driving voltage signal, was applied to the actuator. The permittivity change was monitored as the amplitude of the current at the same frequency as the permittivity detection voltage. From this current amplitude, the permittivity change was easily calculated in real time. However, the positioning resolution was insufficient compared to that of traditional external positioning sensors, such as a strain gage sensor.

In this study, we improved the positioning resolution by introducing a differential current measurement using two piezoelectric elements, one on each side of a bimorph actuator. The phase of the detected current signal was taken into consideration using a lock-in amplifier. In other words, the conductivity-related current and the permittivity-related current were measured separately. With these improvements, the permittivity change related to the piezoelectric displacement could be measured precisely, and self-sensing feedback control with a positioning error of less than 0.4 μm over a movement range of 80 μm was demonstrated.

1. Introduction

Conventionally, in order to eliminate the hysteresis of a piezoelectric actuator control system, positioning sensors such as strain gauges or laser interferometers have been indispensable. Unfortunately, such sensors increase manufacturing costs and system complexity. To overcome these problems, we proposed a self-sensing actuator control system based on the linear relationship between piezoelectric displacement and permittivity change [1,2]. We previously demonstrated this principle, but the positioning resolution was limited. In this study, we introduce a differential current measurement to enable more accurate measurement of the permittivity change and more precise control of the actuator.

2. Measuring the permittivity change of a piezoelectric actuator

A self-sensing method was previously proposed for the control of piezoelectric actuators, based on the linear relationship between displacement and electric charge [3,4,5]. However, the method was not appropriate for a slowly moving actuator because charge error accumulates during the integration of the current signal, and the charge signal is difficult to measure precisely due to floating capacitance. Furthermore, the charge–displacement relationship becomes non-linear when polarization inversion occurs.

On the other hand, permittivity monitoring does not require integration, and a linear relationship could be maintained over the polarization inversion range. Because the relationship between voltage and permittivity is that of a butterfly-curve, it is similar to the relationship between voltage and displacement (Fig. 1). We observed a linear relationship between displacement and permittivity, and successfully controlled a piezoelectric actuator using permittivity feedback. This linear relationship was experimentally observed over a wide displacement range. The fundamental physics behind this behavior is currently under investigation but we believe that a domain structure change strongly affects both the

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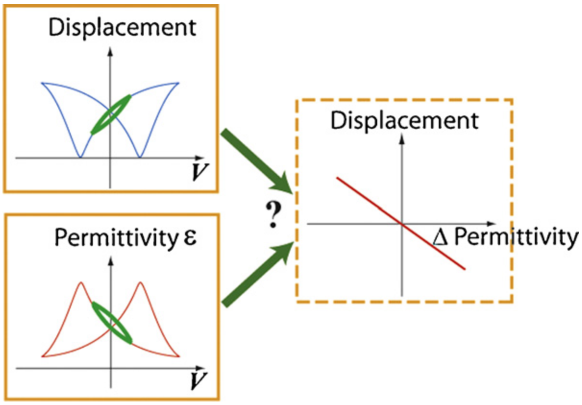

Fig. 1. Relationship between applied voltage, displacement, and permittivity.

piezoelectric displacement and the permittivity. Therefore, domain structure information can be obtained from the observed permittivity change, and this information is related to the piezoelectric displacement.

Fig. 2 shows a schematic diagram of the real-time permittivity change monitoring system. We used soft-PZT bimorph actuators for the experiment, but this material can be replaced with any ferroelectric material, and stacked actuators could be used instead of the bimorph actuators. The driving voltage for the actuator (low frequency, high voltage) and the permittivity detection voltage (fixed high frequency, fixed low voltage) were added together and applied to the piezoelectric actuator. The actual displacement of the actuator was measured with a laser interferometer. The frequency of the permittivity detection voltage was much higher than the mechanical resonance frequency of the actuator, so that it did not affect the actuator movement. On the contrary, the electrical property (permittivity) of piezoelectric material is affected by the permittivity detection voltage.

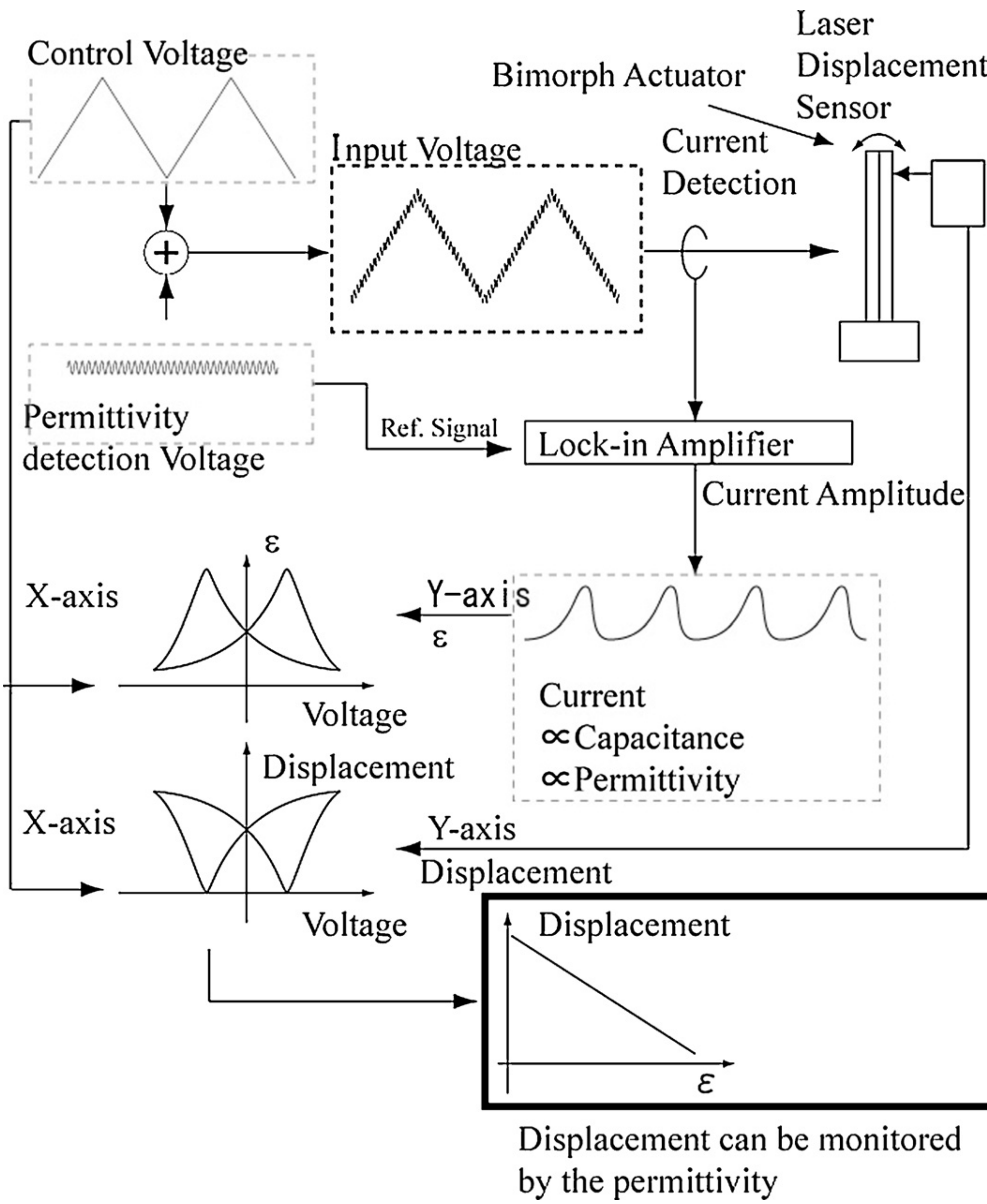

Fig. 2. Schematic diagram of real-time permittivity change measurement.