



Characterization of a C-morph Monolithic Actuator

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ABSTRACT

A piezoelectric monolithic actuator was studied. It is a piezoelectric hollow cylinder coated with electrodes on both inner and outer surface. This actuator is called cylinder morph (C-morph) in this paper due to the similarity in configuration and function as that of the conventional series bimorph. Compared with bimorph, higher resonant frequency and blocking force are available using the cylinder morph. It also reduces the interface problem in the bimorph actuator due to the monolithic structure and accordingly increases the reliability of the actuator. Both the longitudinal and bending displacement as a function of voltage in the static case were studied. It is found that in the lower electric field, the displacement varies linearly. In higher field, the displacement forms the butterfly shape. However, the bending deformation remains wider linear range than that of the longitudinal deformation. The resonant properties were also investigated. The displacement or vibration velocity depends on the frequency and driving voltage simultaneously. To obtain the maximum displacement or vibration velocity, the voltage and frequency should match well.

Keywords: Actuator, C-morph, Displacement.

1. INTRODUCTION

Unimorph, bimorph and multimorph are three typical bending actuators. They are usually constructed by bonding piezoelectric plates with elastic layers. These actuators normally exhibit large bending displacement. However, the generative force and resonant frequency are low. Further more, the bonding layer may degrade the performance and reduce the reliability of the actuator [1]. To improve the performance, the actuators with monolithic structure, such as rainbow [2], FGM monomorph [3], have been proposed. However, those proposals are mainly focused on the improvement of the reliability of the actuator. Zhu [4] also proposed an in-plane multilayer bending actuator. It exhibits advantages of large displacement, blocking

force and higher resonant frequency. This paper introduces another type of bending actuator—piezoelectric cylinder morph (C-morph). It's a piezoelectric hollow cylinder, coated with electrode on both inner and outer surface. The outer surface is usually sectioned into several parts based on the applications. This actuator generates displacement not only in the transverse direction, but also in the longitudinal direction. Varying the configuration of the actuator, such as the roundness of cross section, the displacement, resonant frequency, and blocking force can be adjusted in a wide range. The monolithic structure also increases the reliability of the actuator. The purpose of this paper is to characterize the actuator both in static and dynamic states.

2. MATERIALS AND METHODS

Commercial C-morph actuator from BPO Boston Piezo-Optics Inc. (O.D. 3.2 mm, I.D. 2.4 mm and length 10 mm; $d_{31} = 1.34 \times 10^{-10}$ m/V) was applied. A system, consisting of RT6000HVS ferroelectric tester, MTI2000 fonic sensor, FG300 function generator, PZD2000 high voltage amplifier and DL1640L oscilloscope, was set up for the purpose of characterization. Among them, fonic sensor was used for displacement measurement; ferroelectric tester and the left equipments for static and dynamic driving and data acquisition, respectively. In the longitudinal characterization, the voltage was applied on the inner and outer surface of the actuator. In the bending characterization, the actuator was supported at 2 nodal positions (0.23L from the end [5]). The displacement at the free ends was measured both in static and dynamic state. In the static measurement, the applied frequency is 2.5 Hz. In the dynamic measurement, the measurement was performed near the resonance.

3. RESULTS AND DISCUSSION

Figure 1 shows the static longitudinal displacement of the C-morph actuator. As an electric field is applied across the wall thickness direction, a displacement in the axial direction will be produced. The displacement is proportional to d_{31} , applied electric field and length of the actuator. From Figure 1, it can be seen that in the low field condition, the displacement varies linearly with the applied voltage. As the field increases, the hysteresis becomes large and finally the hysteresis loop turns to the typical butterfly shape. This is due to the domain reorientation caused by the variation of the applied electric field.

Figure 2 shows the static bending displacement of the actuator. As seen from Figure 2 (b), the bending deformation remains linearity in a wider range compared with that of the longitudinal case. When the voltage reaches 1.5 kV (3.75 kV/mm, Figure 1), the longitudinal deformation has changed to the butterfly shape. However, the bending deformation still keeps linearity under the same

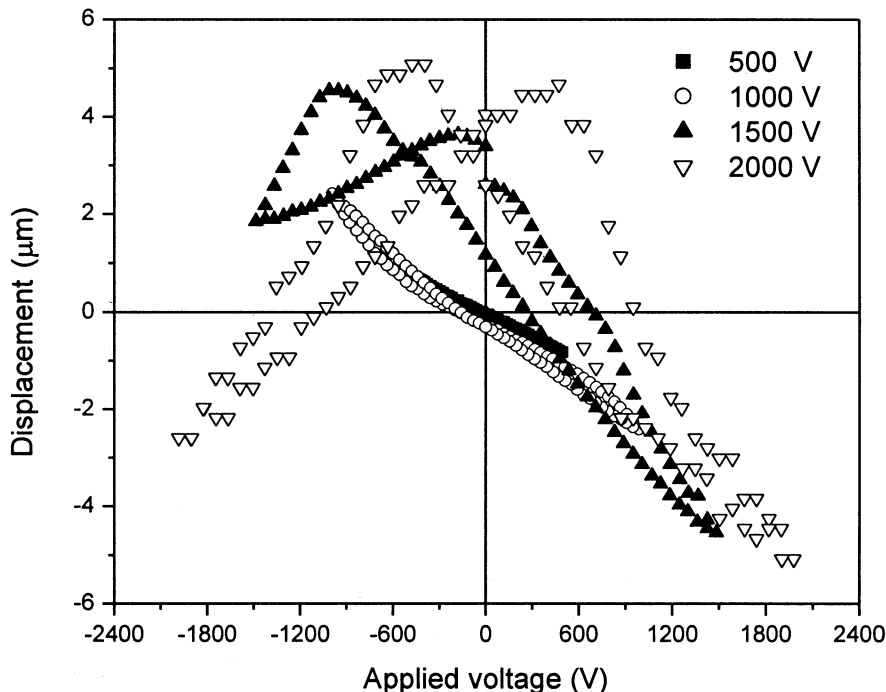


Figure 1. Static longitudinal displacement of the C-morph actuator.

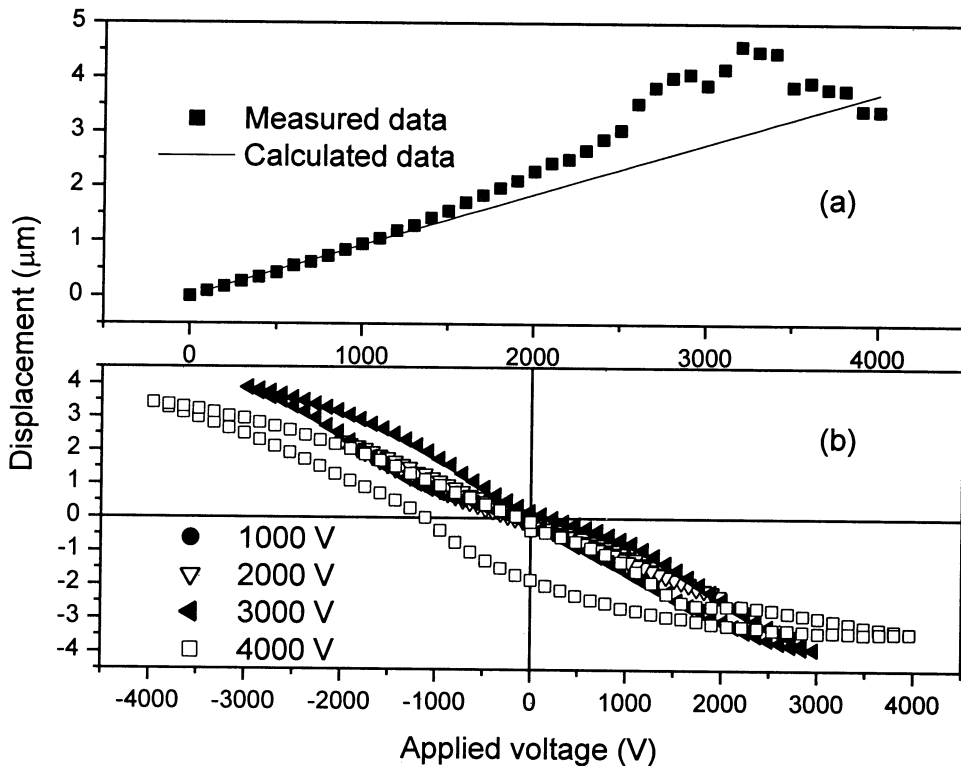


Figure 2. Static bending displacement of the C-morph actuator.

condition. This may be due to the difference in domain states, parallel or anti-parallel to the field, in the two cases, respectively. Figure 2 (a) shows the maximum displacement achieved in each hysteresis loop in Figure 2 (b). It can be seen that the displacement increases linearly first, then deviates from the linearity, and finally drops as field increases. The drop of the displacement is due to the domain reorientation. In the linear range, the displacement can be estimated using the following equation [5]

$$\zeta = -\frac{4d_{31}V \cos \beta l(L-l)}{\pi(r_o^2 + r_i^2) \ln(r_o/r_i)} \quad 0 < \beta < \frac{\pi}{2} \quad (1)$$

where ζ is the displacement, l is the supported points, V is the applied voltage, β is a constant (here is 45°), r_o and r_i are the outer and inner radius, respectively. From Figure 2 (a), it can be seen that the measured data and calculated data coincide well in the linear range.

Figure 3 shows the dynamic displacement and velocity of the actuator as a function of voltage and frequency. The vibration velocity

increases monotonously in the studied range as seen in Figure 3 (a). The displacement is both frequency and voltage dependent as seen in Figure 3 (b) and (c). It reaches maximum at the resonant frequency. However, the resonance frequency shifts to the lower frequency range as the voltage increases due to the higher losses. Figure 3 (c) highlights the effect of the applied frequencies. It can be found that, even the same order of voltages are applied, the displacements are quite different at different frequencies. The amplitude of the displacement obtained at a higher voltage may not be higher than that obtained at a lower voltage. So it can be concluded that to obtain a higher displacement or vibration velocity, the applied voltage and frequency must match well.

4. CONCLUSION

(1) The bending displacement remains a wider linear range than that of the longitudinal displacement due to the difference in domain state. The bending displacement in the linear

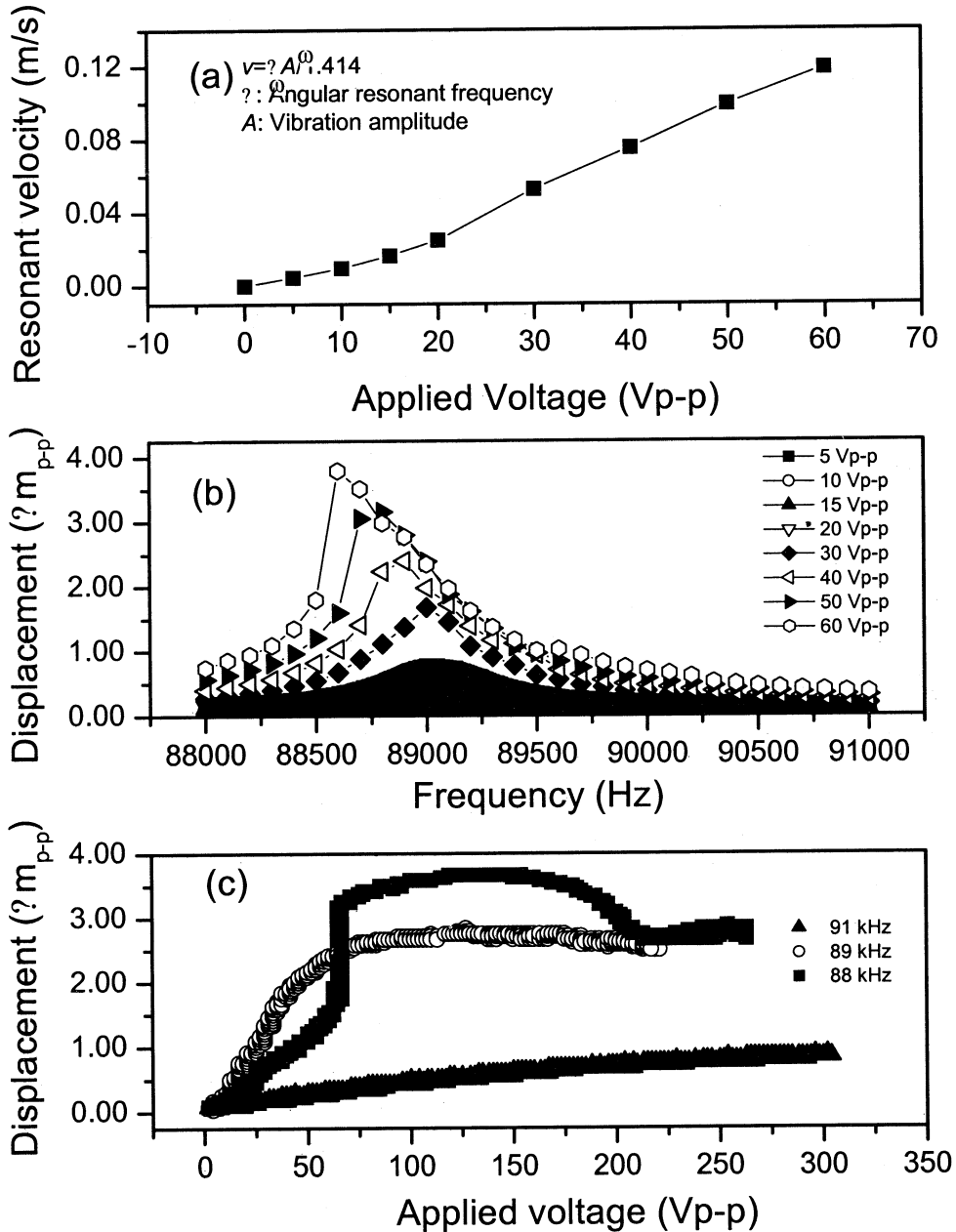


Figure 3. Dynamic displacement and velocity of the C-morph actuator.

range can be estimated using the established equation.

(2) Both frequency and voltage affect the dynamic displacement and vibration velocity. They should match well to obtain the maximum displacement and velocity.

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